USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

TO INCREASE SHIP ENERGY EFFICIENCY
(CO₂ PROBLEMATIC)

Bachelor´s degree final project
("TFG" Trabajo final del Grado)

Realized by:
Tomas Novotny

Tutor:
Marcel.ia Castells Sanabra

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Acknowlegdments

First of all I would like to express my sincere gratitude to my tutor and advisor Prof. Marcel.la Castells Sanabra who supported me throughout the writing process of this thesis and whose doors were always opened for consultation.

I would never have been able to finish my thesis without unconditional support of my family, especially my parents, grandparents and aunt who encouraged me with their best wishes and provided to me necessary background which allowed me to get duly concentrated on the topic of present work.

Finally I would like to give my special thanks to all of my friends who cheered me up and stood by me in the good and bad.
Summary

Objective of present thesis is to identify global impact of maritime industry on the environmental problematic and solutions provided by government and private sector to reduce the same. This document is divided in three main sections which describe the CO$_2$\(^1\) and global warming problematic, provide overview of current regulations adopted by different entities with focus on IMO\(^2\) energy efficiency project and finally describe energy efficiency solutions from shipbuilders and shipping companies. Additionally author tries to map global awareness of environmental issue within industry and its consciousness about steps needed to be taken to improve ecological footprint of the modern shipping.

A method used to achieve above proposed objectives was investigation based on internet resources mainly from trustworthy web pages of institutions, governments, entities, intern universities sites and similar sources to guarantee quality of the information and its undeniable content. The reason why I preferred to the use web sources instead of books its evident. Web content provides updated information hence considerable time saving is obtained and it is assured that the newest data about the issue are available at any moment.

During my research I discovered, and it was a nice surprise, that the state of knowledge of environmental problematic is on high level. Organizations like IMO and European Union (EU) are aware about seriousness of the issue and all efforts to reduce impact on global warming from maritime industry are reinforced by laws and regulations which gives no choice to operators but follow them if they would like to continue with their activities in the future. Among all I would like to highlight amendment of MARPOL\(^3\) and inclusion of annex VI regarding air pollution from ships and adoption of energy efficiency design index which every new ship built from 2013 on needs to comply and progressive increase of their energy efficiency is contemplated within different phases of this regulation.

On the other hand private sector did not stay apart and engineers from all over the world concentrate their efforts to help to shipping companies to reach criteria established by authorities. These efforts are focused especially on investigation regarding use of alternative means of propulsion. As we will see further in the text some of these projects provide with really futuristic solutions using only renewable energies and providing 100% green ships. Others combining conventional engine, with alternative means of propulsion providing additional thrust or satisfying energy needs for essential consumers of the ship. The second solution seems to me more realistic at this stage for different reasons. On one hand because such ships already exist and they are in active use. On the other hand because financial crisis slowed down investigations in all sectors hence many of innovative solutions are in stand-by waiting for recuperation of world’s economy. Other important factors to have in mind are low prices of fuel and least but not last our dependency on crude oil industry supported by numerous lobbies of this sector.

\(^{1}\) Carbon dioxide.
\(^{2}\) International Maritime Organization .
Despite these efforts of lobbyists, nowadays LNG\textsuperscript{4} fuel starts to be very popular in maritime industry and it is possible that it will be an intermediate step between traditional and alternative way of propulsion. Some examples of ships using LNG fuel will be provided in chapter 4 regarding energetically efficient ships.

Detailed information about all above mentioned concepts can be found further in the text and I hope this will serve as a solid base to every person who would like to understand more the environmental problematic related to shipping industry today and its possible evolution in the future.

\textsuperscript{4} Liquefied natural gas.
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INTRODUCTION

As it always happened in the past, big changes are the fruit of necessity. In the modern world the international cargo shipping is the unthinkable part of our globalized society. Thousands of tons of different goods are transported by ships from country to country, continent to continent.

Maritime business is so far the most profitable way of shipping invented ever, but it is still very dependent on the oil industry and its price fixing which means very representative costs in operations of the vessel. Maybe it’s time to think of alternative way of propulsion to reduce this dependency, reduce costs to shipping companies and consequently make the shipping industry more environmental friendly as the price of the fuel is not the only concern of current maritime industry.

European Union included maritime industry in the "white paper on transport 2011\(^5\)" and it is estimated substantial increment of shipping until 2050. This will bring along associated negative impact on contribution of maritime industry on so called global warming due to an increment of CO\(_2\) and other GHG\(^6\) emissions. That’s why IMO and EU insist on shipping companies to treat this issue and new regulations were implemented in order to obtain tangible results of their efforts.

Improvements were made in traditional diesel engines to reduce its consumption and also alternative ways of propulsion were implemented. For example we can mention CODED\(^7\) engines or those using LNG as a principal fuel instead of traditional fuel oil. The last one seems to be a solution and many companies invest their money to refit their vessels with LNG engines which are more ecological and the price of this fuel is more affordable. The question is what the increasing demand of LNG will do with prices of this type of fuel in the future?

That’s why other engineers thought about different solution and it seems to be very obvious. Which is the energy we can retrieve from the nature without causing any harm to it and moreover it’s free of charge? The wind power. Since ancient Mesopotamia vessels were propelled with oars and sails and so it was until industrial revolution when mechanical engines were invented.

Dimensions of commercial vessels changed since that time so now the challenge is to find how to combine modern technology with traditional way of sailing to create green energy able to move huge modern vessels and satisfy the needs of maritime industry in terms of cost and time effectiveness.

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\(^5\) European Commission’s roadmap of 40 concrete initiatives to build a competitive transport system within EU. Among others it includes recommendations to use waterborne transport (sea or inland waterways)for routes over 300 km.

\(^6\) Green House Gases.

\(^7\) Combined diesel electric -diesel mechanical.
I will centre my work in problematic of pollution by CO₂ and other GHG gases proceeding from operation of ships. Existing regulations will be reviewed and finally projects centred in hybrid vessels propulsion will be analyzed. Purpose of this part of my thesis is to compare advantages and disadvantages and viability of proposed solution in the modern shipping. This solution will be supported by real case calculation and it will be demonstrated how the use of alternative means of propulsion should help to companies to reach IMO pollution limits established for modern ships.
Chapter 1: CO$_2$ EMISSIONS, GLOBAL WARMING AND MARITIME TRANSPORT

1.1. Environmental issue

Environment could be defined as a ensemble of abiotic (elements without life) and biotic (living organisms) elements integrated in the Biosphere of the Earth. Humans, inhabitants of the planet Earth are included in the second group and since the beginning of our existence, we were able to modify significantly our environment with our actions. When our knowledge and resources were limited this direct influence was significant only at the local scale. Due to a mental capacity of "homo sapiens", the human being, it was possible to escape from the environmental limitations applicable to the rest of species and to modify the environment, step by step, to our needs. Fast progress is registered since the middle age which was culminated in the 19th century by the Industrial revolution which brought discovery of fossil fuels. Since that time significant change of the environment has started to increase exponentially. Scientific investigations revealed that CO$_2$ emissions were nearly constant during ages (280 ppm), but in the last century this value increased to 396 ppm\textsuperscript{8} due to disproportionate use of fossil fuels. It is thought that this fact is responsible for the global warming due to the process known as Green House Effect. Carbon dioxide, CO$_2$, impede dissipation of the radiation of IR\textsuperscript{9} waves to the space as they rebound back from the GHG layer and returns to the surface of the Earth warming the same. This effect is responsible of the global warming of the Earth. As per IPCC study\textsuperscript{10}, the increase of global temperature was 0,6$^\circ$ C in last 100 years (1,5$^\circ$ C above pre-industrial levels), but it is estimated that it will increase from 1 to 6$^\circ$ C within the 21\textsuperscript{st} century. Environmental impact of this increase could bring some side effects like melting of Ice in Polar regions and subsequently increase of the sea level, which may cause significant changes in ocean and air currents, traduced in the change of the global climate as known today. Direct impact on the vegetation, harvest, potable water among others will be inevitable.

Even that the global warming is the indisputable fact, Scientifics are not unanimous in the interpretation of its causes. Some of them reject theories of the global warming due to human activity and instead they believe that the fluctuation of the temperature it is a normal process already seen in the past cycles of the Earth. Others do accept existence of this "normal fluctuation", but also they believe that human actions has decisive impact on acceleration of the same and they see need to regulate emissions in order to slower down global warming of the Earth.

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\textsuperscript{8} United States Environmental Protection Agency (EPA), Causes of Climate Change (2013 data) and United Nations Conference on Trade and Development (UNCTAD), Review of Maritime Transport 2009.

\textsuperscript{9} Infra red.

\textsuperscript{10} Intergovernmental panel on climate change (IPCC) 5\textsuperscript{th} assessment report, Climate Change 2014, Synthesis Report, Summary for Policymakers.
1.2. Green house effect gases

1.2.1. Classification and regulation and certification

In following paragraph some basic concepts regarding already mentioned GHG will be reviewed, especially their classification, regulation and their effect on global warning.

Additionally to CO\(_2\), not regulated within shipping industry, we include among GHG gases those defined in already mentioned Annex VI of MARPOL.

<table>
<thead>
<tr>
<th>Basic GHG classification:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not regulated</td>
<td>CO(_2)(^{11})</td>
</tr>
<tr>
<td>Regulated Annex VI</td>
<td>NO(_x)(^{12})</td>
</tr>
<tr>
<td></td>
<td>SO(_x)(^{13})</td>
</tr>
<tr>
<td></td>
<td>VOC’s(^{14})</td>
</tr>
<tr>
<td></td>
<td>Ozone depleting substances - CFC(^{15})</td>
</tr>
<tr>
<td></td>
<td>- HCFC(^{16})</td>
</tr>
</tbody>
</table>

In this annex requirements referring to above mentioned gases can be found and emission limits are established as follows:

- **requirements for SO\(_x\):** Emissions of sulphur oxides is probably the biggest concern within maritime industry due to high level of sulphur in fuel oils used on board of ships. So far Baltic sea, North Sea, North American Atlantic Ocean area and the United States Caribbean Sea\(^{17}\) were declared as a SO\(_x\) emission control area (ECA). This means an area where special mandatory rules applies in order to prevent, reduce and control of air pollution caused by ships. Others areas may be included in the future in accordance with IMO procedures. Limits of sulphur content in fuel oil are established as follows:

  Outside SO\(_x\) emission control area: \(< 4.5\%\) of Sulphur in any fuel oil used on board
  
  Within SO\(_x\) emission control area: \(< 1.5\%\) of Sulphur in any fuel oil used on board or exhaust gas cleaning system reduce total emissions to \(6\ g\ SO_x/kWh\) or less

---

\(^{11}\) Produced by combustion of hydrocarbons in presence of oxygen \(HC+O_2 \rightarrow CO_2 + H_2O + \text{heat} \).

\(^{12}\) NO\(_x\) means Nitrogen oxides (combination of NO\(_2\) and NO\(_3\)).

\(^{13}\) SO\(_x\) means Sulphur oxides (combination of SO\(_2\) and SO\(_3\)).

\(^{14}\) Volatile organic compounds. (Methane exhausted from LNG ships).

\(^{15}\) Chlorofluorocarbons - their use is currently prohibited on new ships.

\(^{16}\) Hydro-chlorofluorocarbons - permitted until 1\(^{st}\) of January 2020.

\(^{17}\) Sea areas defined in MARPOL Annex I.
- **requirements for NO$_x$:** Emissions of nitrogen oxides from diesel engines are permitted within limits, specified in NO$_x$ technical code as follows:

17.0 g/kWh when $n$ is less than 130 rpm  
45.0 $n^{(0.2)}$ g/kWh when $n$ is 130 or more but less than 2000 rpm  
9.8 g/kWh when $n$ is 2000 rpm or more

Where $n$ = rated engine speed (crankshaft revolutions per minute)

- **requirements for the Ozone depleting substances:** Emissions of these substances are prohibited, except in emergency to save the ship or human life at sea. New installations containing such gases are prohibited on new ships except HCFC ones which are permitted until 1$^{st}$ of January 2020.

- **requirements for VOC:** This part applies especially to ports and terminals. Technical information regarding the same is provided by MSC$^{18}$ Circular 585 related to “Standards for Vapour Emission Control Systems.” Tankers which may be subjected to vapour emission control system shall be equipped with vapour collection system approved under authority of the Government as detailed within the circular.

Ships compliant with requirements of Annex VI of MARPOL convention will receive International Air Pollution Prevention Certificate$^{19}$ issued by the Administration.

Additionally those ships equipped with diesel engines compliant with NO$_x$ technical code shall receive an Engine International Air Pollution Certificate$^{20}$.

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$^{18}$ IMO’ s Maritime Safety Committee.  
$^{19}$ IAPP certificate.  
$^{20}$ EIAPP certificate.
1.2.2. GHG impact on global warming

Once classified GHG and established their emission limits by the regulation, it’s time to summarize their impact on the global warming and describe how the greenhouse effect occurs.

Approximately half of the solar radiation is absorbed by the Earth’s surface and warms it. Other half is reflected back to atmosphere. So far, so good, but the problem occurs when we take close look out on the IR radiation from the Sun. It is absorbed and afterwards emitted from the Earth’s surface. Part of this radiation is returned back to the space, but the most of it is absorbed and re-emitted by GHG molecule and clouds in all directions. This is the principle cause of the warming of the Earth’s surface and lower part of the Atmosphere. Finally below figure illustrates the whole process.

![Green House Effect model](source)

Figure 1: Simplified Green House Effect model
Source: IMO Course on Energy Efficient Ship Operation

The impact caused depends on the radiation power of the transmitter. More radiation power means more warming. Within GHG gases, the CO\textsubscript{2} has the lowest power of radiation, but due to its great level of emissions it has mayor effect then others. Values of radiation power of each GHG are detailed as follows:

**Radiation Power values:**
- CO\textsubscript{2} = 1. Reference value
- NO\textsubscript{x}, SO\textsubscript{x} = 6.000-8.000 times more than CO\textsubscript{2}
- VOC’s/CFC/HCFC - 10.000-19.000 times more than CO\textsubscript{2}

As we seen in previous paragraph the most of these gases are regulated by IMO and Administrations of Member States in accordance with MARPOL Annex VI. It may seems odd that the gas with the most emissions level, CO\textsubscript{2}, is the one least covered by current regulation applying to shipping sector. It is due to relative low contribution of maritime industry to emission of the same, but increasing ship operations can change this scenario within next years. That’s why I will centre next chapter exclusively to CO\textsubscript{2} problematic omitting rest of Green Houses Gases duly regulated by Administrations.
1.3. Kyoto Protocol
Currently UNFCCC’s “Kyoto Protocol” is the key document for stop of the climate change and reduction of emissions of CO$_2$ on the level as in 1990. Scientists calculated that this level is the highest one that the Earth can assume. Based on this protocol, International emission trading was established in order to help to signatory parties to comply with established criteria. Due to low emissions of CO$_2$ from ships, maritime industry is not included in the Protocol and responsibility for the reduction of these emissions was transferred directly to International Maritime Organization (IMO).

1.4. Maritime transport and CO$_2$ emissions
As per secretary of International Chamber of Shipping (ICS) information provided at Climate Summit of United Nations held on 23rd of September 2014 in New York, CO$_2$ emissions proceeding from maritime transport has decreased 22.8% (From 3.5% in 2007 to 2.7% in 2012). Its numbers roughly coincide with information provided by IMO in the Third IMO GHG Study from 2014.

In comparison with other transports, CO$_2$ emissions from international maritime transport represented in 2008, 7-8% of the global emissions as per following graphics:

**Figures 2-4: CO$_2$ emissions per type of transportation**

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22 International Chamber of Shipping, ICS Press release and ICS Report regarding “Shipping, world trade and the reduction of CO2 emissions.”

23 Organisation for Economic Co-operation and Development (OECD).
Other method used to compare emissions between different type of transport is to measure CO₂ emissions in grams per tonne and kilometre (or nautical mile). This system is commonly used to compare environmental cost and social benefit.

<table>
<thead>
<tr>
<th>Mode</th>
<th>CO₂ (gr/tonne-km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing 747-400</td>
<td>552</td>
</tr>
<tr>
<td>Heavy truck</td>
<td>50</td>
</tr>
<tr>
<td>Rail-diesel</td>
<td>17</td>
</tr>
<tr>
<td>Rail-electric</td>
<td>18</td>
</tr>
<tr>
<td>S-type container vessel (11,000 TEU)</td>
<td>8.35</td>
</tr>
</tbody>
</table>

Figure 5: CO₂ gr/tonne-km per type of transport
Source: Maersk Line, Maersk Sustainability Report 2013

It can be observed that maritime transport has the lowest emissions of CO₂ in grams per tonne and kilometre due to its big cargo capacity in comparison with other mode of transportation.

Following graphics resume methodology used for both types of statistics and factors that has an influence in the calculation in each method.

Figure 6: CO₂ Statistics Methods
Source: MARTRANS

As seen in above scheme both statistics methods are complementary. One use total bunkering of ships per year to calculate total CO₂ emissions. Other is based on tonnes of goods transported per kilometre. In the second method, a part of the cargo capacity and cargo utilization (in %), the significant factor is speed. Reduction of average speed due to fuel prices and excess of tonnage contributed significantly to reduction of CO₂ emissions of the international maritime transport. IMO study²⁴ revealed that 12% reduction of average speed

²⁴ IMO, Third IMO GHG Study 2014.
contributed to 27% daily consumption savings (almost one third). Some companies have implemented "Slow steaming," operation which consist in sailing at lower speed than the ship was designed for. This method was used for the first time in 2007 due to increase of fuel prices on international markets. For example, the major container company Maersk line has implemented slow steaming speed of 18 knots in their normal operations between 2009 and 2010. In some cases super slow steaming speed of 14-16 knots is adopted, especially on the long routes between Europe and Asia.

IMO expects different scenarios of possible consumptions and emission levels in 2050. Expects 50-250% increase of maritime transportation in relation to 2012 level. This means considerable increase of emissions which can be compensated with mayor use of LNG as a fuel. In order to evaluate effect of this increase and to find formula to reduce impact of the same, UN issued document on Maritime Transport in 2009\textsuperscript{25} presented on the UN Conference on Trade and Development (UNCTAD) at Geneva, Switzerland. This issue of the annual document, which analyse actual state of the world maritime fleet and evolution of the international commerce, propose the group of technical and operational measures to promote potential of ship’s energy efficiency and reduction of environmental emissions as suggested in below figure.

\begin{table}[h]
\begin{center}
\begin{tabular}{|c|c|}
\hline
Strategy & Potential efficiency gains \\
\hline
Efficiency of scale & <4 per cent \\
Design for reduced ballast operation & <7 per cent \\
Lightweight construction & <7 per cent \\
Optimum hull dimensions & <9 per cent \\
Air lubrication & <15 per cent \\
Bulbous bow & <20 per cent \\
Diesel electric drives & 5-30 per cent \\
Waste heat recovery & <10 per cent \\
Counter-rotating propellers & <12 per cent \\
Propeller efficiency monitoring & <5 per cent \\
Efficient propeller speed modulation & <5 per cent \\
Wind power: Flettner rotor & <30 per cent \\
Wind power: kites and sails & <20 per cent \\
Solar power & <4 per cent \\
Automation & <10 per cent \\
Fuel additives & <2 per cent \\
Port turnaround time & <10 per cent \\
Propeller surface maintenance & <10 per cent \\
Hull coating & <5 per cent \\
Ship speed reduction & <23 per cent \\
Voyage planning and weather routing & <10 per cent \\
Overall energy awareness & <10 per cent \\
\hline
\end{tabular}
\end{center}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{potential楦.jpg}
\caption{Potential increase of Energy efficiency per use of diverse technical and operational methods.}
\label{fig:potential_increase}
\end{figure}

\textsuperscript{25} UNCTAD, Review of maritime transport 2009.
1.5. SOLUTIONS PROVIDED BY IMO

Carbon dioxide (CO\textsubscript{2}) emissions from merchant ships are not regulated by any law at the moment. Despite the fact that maritime transport is excluded from "Kyoto protocol", IMO and maritime sector are conscious about the seriousness of this issue and they assumed to reduce emissions of CO\textsubscript{2} effectively in accordance with possibilities of the industry.

IMO’s responsibility in matter of reduction of GHG emissions resulted in approval of Assembly resolution A.963 (23) "IMO POLICIES AND PRACTICES RELATED TO THE REDUCTION OF GREENHOUSE GAS EMISSIONS FROM SHIPS” in which urge to MEPC\textsuperscript{26} to elaborate mechanism or mechanisms to limit or reduce given emissions, to establish levels of reference and elaborate methodology able to describe energy efficiency of the ship in form of index of emission of GHG.

In accordance with above mentioned request from Assembly, MEPC issues Resolution MEPC.203(62) from 15\textsuperscript{th} of July 2011 which emends MARPOL Convention and in its Annex VI Chapter 4 regarding "Regulation on energy efficiency for ships" includes methodology for calculation of above mentioned index. This means the first compulsory resolution involved in reduction of GHG in maritime transport. There are in total 2 indexes; the first, compulsory for new ships (EEDI)\textsuperscript{27} and the second for existing ships (EEOI\textsuperscript{28}) applicable on voluntary basis. Both index will be reviewed with more detail further in this document.

At 63\textsuperscript{rd} session of MEPC held between 27\textsuperscript{th} of February and 2\textsuperscript{nd} of March 2012 the Committee adopted guidelines in order to assure uniform implementation of compulsory measures relative to increase of ship’s energy efficiency required in resolution MEPC.203 (62).

Adopted guidelines were as follows:

- MEPC.245 (66) 2014 Guidelines on method of calculation of the attained energy efficiency design index (EEDI) for new ships.
- MEPC.261 (68) 2014 guidelines on survey and certification of the Energy Efficiency Design Index (EEDI) as amended.
- MEPC.233 (65) 2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI) for cruise passenger ships having non-conventional propulsion.
- MEPC.231 (65) 2013 Guidelines for calculation of reference lines for use with the EEDI.
- MEPC.213 (63) 2012 Guidelines for the development of a ship energy efficiency management plan (SEEMP).

(Note: Above list represents amended version of these guidelines as on August 2016)

\textsuperscript{26}IMO’s Marine Environmental Protection Committee.
\textsuperscript{27}Energy efficiency design index.
\textsuperscript{28}Energy efficiency operational indicator.
Regarding the method for EEDI calculation there is not established in the guideline any particular technology which should be used in order to achieve requested EEDI compliant with the resolution. It gives to maritime industry and engineers free space for creativity and invention to find out more suitable solution for convenient cost.

Importance of the issue and concern of international maritime community regarding CO₂ emissions invites to cooperation between all member states as we can understand from MAPOL Annex VI Rule 23 regarding Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships which request to all administrations promote and provide, as appropriate, support directly or through the Organization to States, especially developing States, that request technical assistance.

Furthermore amendment of Annex VI of MARPOL regarding application of EEDI was issued through MEPC 251 (66) and application extended to LNG carriers, Ro-pax (cargo and passenger) ships, cruise ships having non-conventional propulsion when delivered on and after 1st of September 2019. Exemption is granted to ships without mechanical propulsion and for cargo ships having ice-breaking capability.

Above mentioned resolutions and guidelines applies only to "new ships" as defined in resolution MEPC.203 (62). For "existing ships" defined in the same resolution apply MEPC.1/Circ.684 from 17th August 2009 "Guideline for voluntary use of the ship energy efficiency operational indicator (EEOI)" based on voluntary application.

Other instrument to reduce GHG emissions proposed by IMO is called Market Based Measure²⁹ with two main proposals:

1) providing an economic incentive for the maritime industry to reduce its fuel consumption by investing in more fuel efficient ships and technologies and to operate ships in a more energy efficient-manner (in-sector reductions); and

2) offsetting in other sectors of growing ship emissions (out-of-sector reductions).

²⁹ IMO, Market Based Measures (MBM).
Proposals of MBM realized by the Organization\(^{30}\) are as follows:

1. **Creation of International Fund for GHG emissions from ships (GHG Fund) (Cyprus, Denmark, the Marshall Islands, Nigeria and IPTA (MEPC 60/4/8)):** Establishes a global reduction target for international shipping, set by either UNFCCC or IMO. Emissions above the target line would be offset largely by purchasing approved emission reduction credits. The offsetting activities would be financed by a contribution paid by ships on every tonne of bunker fuel purchased.

2. **Leveraged Incentive Scheme (LIS) (Japan (MEPC 60/4/37)):** GHG Fund contributions are collected on marine bunker. Part thereof is refunded to ships meeting or exceeding agreed efficiency benchmarks and labelled as “good performance ships”.

3. **Port State Levy (Jamaica (MEPC 60/4/40)):** Levies a uniform emissions charge on all vessels calling at their respective ports based on the amount of fuel consumed by the respective vessel on its voyage to that port (not bunker suppliers).

4. **Ship Efficiency and Credit Trading (SECT) (United Sates (MEPC 60/4/12)):** Subjects all ships to mandatory energy efficiency standards. As one means of complying with the standard, an efficiency-credit trading programme would be established. These standards would become more stringent over time.

5. **Vessel Efficiency System (VES) (World Shipping Council (MEPC 60/4/39)):** Establishes mandatory efficiency standards for new and existing ships. Each vessel would be judged against a requirement to improve its efficiency by X% below the average efficiency (baseline) for the specific vessel class and size. Standards would be tiered over time with increasing stringency. Existing ships failing to meet the required standard through technical modifications would be subject to a fee applied to each tonne of fuel consumed.

6. **Global Emission Trading System (ETS) for international shipping (Norway (MEPC 61/4/22)):** Sets a sector-wide cap on net emissions from international shipping. A number of allowances (Ship Emission Units) corresponding to the cap would be released into the market each year via a global auctioning process. The units could then be traded.

7. **Global Emissions Trading System (ETS) for international shipping (United Kingdom (MEPC 60/4/26)):** Differs from the Norwegian ETS proposal in two aspects: the method of allocating emissions allowances (national instead of global auctioning) and the approach for setting the emissions cap (set with a long term declining trajectory).

8. **Emissions Trading System (ETS) for International Shipping (France (MEPC 60/4/41)):** Sets out additional details on auction design under a shipping ETS. In all other aspects the proposal is similar to the Norwegian ETS proposal.

9. **Market-Based Instruments: a penalty on trade and development (Bahamas (MEPC 60/4/10)):** Insists that the imposition of any costs should be proportionate to the contribution by international shipping to global CO\(_2\) emissions.

10. **Rebate Mechanism (RM) for a market-based instrument for international shipping (IUCN (MEPC 60/4/55)):** Compensate developing countries for the financial impact of a MBM. It could be applied to any maritime MBM which generates revenue.

---

\(^{30}\) Organization means International Maritime Organization.
From above mentioned proposals it seems to me that many of these are beneficiary only for countries with strong economies as they allow them to contaminate more by purchasing emission credits and also trade with them afterwards. From my point of view these measures does not contribute to reduction of emissions at all and in worse scenarios emissions could even increase.

Solutions promoting reduction of emissions by refunding compliant companies and charging additional fees to non-compliant ones are linked to investments in technologies and investigation. For many developing countries these measure would be outside their possibilities.

These concerns were discussed on 63rd MEPC session. Participants agreed on the need to undertake an impact assessment of the MBM proposals with focus on possible impacts on consumers and industries in developing countries, in general, and in particular, least developed countries, small islands developing States and remotely located developing countries with long trading distances, and considered in detail the methodology and criteria it should be based on.\textsuperscript{31}

On the next MEPC session its participants agreed to postpone discussions on MBM’s for a future sessions. As on August 2016 the same was not re-initiated and seems to be suspended until further notice.

Graphic resume regarding emission reduction activities provided by the Organization may be resumed as per below figure.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{IMO_frame.png}
\caption{IMO EE regulatory framework}
\end{figure}

Source: IMO Course on Energy Efficient Ship Operation

\textsuperscript{31} As stated on IMO’s web page in section related to Market Based Measures.
From above figure it’s understood that at current stage the priority is given to energy efficiency solutions promoted by regulations adopted by different MEPC session as described above in the text. That’s why I will dedicate the next chapter entirely to description of these regulations and I will provide examples of their application in a real life.

As seen from the next figure\textsuperscript{32} it took a long time before these regulations were adopted, but we are just at the beginning of the path. Continuous improvement of these and discussion about additional energy efficiency measures such as data collection\textsuperscript{33} or MBM’s will be without doubt main topics of future MEPC meetings.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig9.png}
\caption{IMO EE regulatory activities timeline}
\label{fig:fig9}
\end{figure}

\textit{Source: IMO Course on Energy Efficient Ship Operation}

\textsuperscript{32} Note: Energy efficiency regulations (EEDI and SEEMP) for news ships which entered in force on 1\textsuperscript{st} of January 2013 through amendments of Annex VI Chapter 4 of MARPOL are missing in the timeline.

\textsuperscript{33} Need of annual mandatory requirement to report consumption data of each fuel of ships of 5.000 GT or more to Flag state was approved in Draft amendments to Marpol Annex VI at the 69\textsuperscript{th} MEPC session in London held from 18 to 22 of April 2016. This requirement will be put forward to adoption at the 70th MEPC session in October 2016.
CHAPTER 2: IMO ENERGY EFFICIENCY REGULATIONS

In this chapter will be reviewed both voluntary and compulsory regulations and different guidelines on improvement of energy efficiency of ships, defined the scope of these, explained basic concepts and methods of calculation of different measures. Finally we will provide with two examples of calculation of EEDI for different kind of ships as proposed by IMO´s training programme in order to divulgate and promote energy efficiency regulations within the sector.

2.1. Energy efficiency design index EEDI

Based on Annex VI Chapter 4 of MARPOL and its Regulations on ship´s energy efficiency adopted by MEPC in resolution MEPC.203 (62) and its further amendments. Apply to all ships with GT > 400 with exemptions stated in Regulation 19.

The attained EEDI shall be calculated for:
- each new ship (contract signed or keel laid on or after 1/1/2013; delivered on or later 1/7/2015)
- each new ship which has undergone a major conversion; and
- each new or existing ship which has undergone a major conversion, that is so extensive that the ship is regarded by the Administration as a newly constructed ship

2.1.1. Attained energy efficiency design index (Attained EEDI)

Attained EEDI shall be specified for each ship and accompanied by the EEDI technical file taking in account Guidelines issued by IMO, in particular Resolution MEPC.245 (66) mentioned in chapter 1.5. It shall be verified by Administration or any organization duly authorized by the same (normally Classification Society).

Equation for Attained EEDI as per MEPC.245 (66)

- measure of ship´s energy efficiency (g/T . Nm)

(relation between environmental cost and social benefit)

\[
\text{EEDI} = \sum_{i=1}^{k} \left( \prod_{j=1}^{n} f_j \cdot f_i \cdot \text{Capacity} \cdot f_{\text{m}} \cdot V_{\text{m}} \right)
\]

Equation 1: EEDI calculation
Source: IMO, MEPC.245 (66):

Where:
P_{\text{ME}} - Power of the main engine (in kW) - 75 % of the rated installed power/
for ships using LNG fuel following equation shall be applied: \( P_{\text{ME}} = 0.83 \times \left( \frac{\text{MPPmotor}}{\eta_i} \right) \),
where: \( \text{MPPmotor} \) means rated output of motor specified in the certified document
\( \eta_i \) means product of electrical efficiency of generator, transformer, convertor and motor (weighted average).
C_{\text{FME}} - non-dimensional conversion factor between fuel consumption of the main engine measured in g and CO\textsubscript{2} emission also measured in g based on carbon content.
SFC_{\text{ME}} - Specific Fuel Consumption of the main engine.
P_{\text{AE}} - Required auxiliary engine power to supply maximum sea load (kW)
C_{\text{FAE}} - non-dimensional conversion factor between fuel consumption of auxiliary engines measured in g and CO\textsubscript{2} emission also measured in g based on carbon content.
SFC_{AE} - Specific Fuel Consumption of auxiliary engines
f_i - ; Capacity factor
P_{PTI} - shaft motor power
f_{eff} - ; Availability factor of innovative energy efficiency technology
P_{AEeff} - auxiliary power reduction due to innovative electrical energy measured at P_{ME(i)}
P_{eff} - output of innovative mechanical energy efficient technology
f_c - ; Cubic capacity correction factor (chemical tankers, gas carriers)
f_{ropax} - ; Cubic capacity correction factor (roro passenger ships)
f_j - ; Correction factor for ship specific design elements (ice-class ships, shuttle tankers, general cargo)
f_{roro} - ; Correction factor for ship specific design elements in ro-ro cargo and passenger ships
Capacity - DWT - bulk, gas, LNG, roro, car, ropax, general, refrigerated carriers or combination
- GT - for passenger and cruise ships
- 70% of DWT - for container ships
f_w - weather factor
V_{ref} - Ship’s speed

Further information about calculation and values for each factor should be found in above mentioned resolution.

On the web page of BIMCO\textsuperscript{34} we can find web based tools in order to verify if Attained EEDI for the ships complies with Required EEDI (we will define this concept in next chapter).

\textbf{BIMCO EEDI CALCULATOR}

\textsuperscript{34} The Baltic and international maritime council. The largest international shipping association of ship owners, operators, brokers and agents with more than 2.200 members in 2016 from more than 120 countries.
Figure 10 shows how the reference line and Required EEDI progressively decrease its value. Each of 4 implementation phases is related to date of construction of the new ship as specified in above image. Ship energy efficiency management plan should be focused to comply with this desired reduction of EEDI value.

2.1.2. Required EEDI

As defined by Regulation 21 of MARPOL’s Annex VI, Chapter 4, required EEDI shall be always above attained EEDI as shown in above figure in order to comply with the legal requirement;

\[
\text{Attained EDDI} \leq \text{Required EEDI};
\]

and it is calculated by following formula:

\[
\text{Required EEDI} = \frac{1 - \frac{X}{100}}{X} \times \text{Reference line}
\]

Equation 2: Required EEDI
Source IMO, MEPC.245 (66)

Where \(X\) is a reduction factor; percentage reduction in required EEDI relative to Reference line.

Following figures provide with numeric data which shall be applied in the required EEDI formula depending on the type and size of the vessel for which is the index calculated.
### USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

**Figure 11:** Reduction factor \( X \) (in %) for the EEDI relative to the EEDI Reference line

Source: Resolution MEPC 203(62)

**Figure 12:** Reduction factor

Source: *IMO Course on Energy Efficient Ship Operation*

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Size</th>
<th>Phase 0 1 Jan 2013 – 31 Dec 2014</th>
<th>Phase 1 1 Jan 2015 – 31 Dec 2019</th>
<th>Phase 2 1 Jan 2020 – 31 Dec 2024</th>
<th>Phase 3 1 Jan 2025 and onwards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk carrier</td>
<td>20,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>10,000 – 20,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-20*</td>
<td>0-30*</td>
</tr>
<tr>
<td>Gas carrier</td>
<td>10,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2,000 – 10,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-20*</td>
<td>0-30*</td>
</tr>
<tr>
<td>Tanker</td>
<td>20,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>4,000 – 20,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-20*</td>
<td>0-30*</td>
</tr>
<tr>
<td>Container ship</td>
<td>15,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>10,000 – 15,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-20*</td>
<td>0-30*</td>
</tr>
<tr>
<td>General Cargo ships</td>
<td>15,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3,000 – 15,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-15*</td>
<td>0-30*</td>
</tr>
<tr>
<td>Refrigerated cargo carrier</td>
<td>5,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3,000 – 5,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-15*</td>
<td>0-30*</td>
</tr>
<tr>
<td>Combination carrier</td>
<td>20,000 DWT and above</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>4,000 – 20,000 DWT</td>
<td>n/a</td>
<td>0-10*</td>
<td>0-20*</td>
<td>0-30*</td>
</tr>
</tbody>
</table>

* Reduction factor to be linearly interpolated between the two values dependent upon vessel size. The lower value of the reduction factor is to be applied to the smaller ship size.

n/a means that no required EEDI applies.

**Figure 11**: Reduction factor \( X \) (in %) for the EEDI relative to the EEDI Reference line

Source: Resolution MEPC 203(62)

- Reduction factor is the % reduction in Required EEDI relative to Reference Line.

- Cut off levels:
  - Bulk Carriers: 10,000 DWT
  - Gas carriers: 2,000 DWT
  - Tankers: 4,000 DWT
  - Container ship: 10,000 DWT
  - Gen./ref.Cargo: 3,000 DWT

**Figure 12**: Reduction factor

Source: *IMO Course on Energy Efficient Ship Operation*
USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

**EEDI Reference line for specific ship** = \( a \times b^c \)

<table>
<thead>
<tr>
<th>Ship type defined in regulation 2</th>
<th>a</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.25 Bulk carrier</td>
<td>961.79</td>
<td>DWT of the ship</td>
<td>0.477</td>
</tr>
<tr>
<td>2.26 Gas carrier</td>
<td>1120.00</td>
<td>DWT of the ship</td>
<td>0.456</td>
</tr>
<tr>
<td>2.27 Tanker</td>
<td>1218.80</td>
<td>DWT of the ship</td>
<td>0.488</td>
</tr>
<tr>
<td>2.28 Container ship</td>
<td>174.22</td>
<td>DWT of the ship</td>
<td>0.201</td>
</tr>
<tr>
<td>2.29 General cargo ship</td>
<td>107.48</td>
<td>DWT of the ship</td>
<td>0.216</td>
</tr>
<tr>
<td>2.30 Refrigerated cargo carrier</td>
<td>227.01</td>
<td>DWT of the ship</td>
<td>0.244</td>
</tr>
<tr>
<td>2.31 Combination carrier</td>
<td>1219.00</td>
<td>DWT of the ship</td>
<td>0.488</td>
</tr>
</tbody>
</table>

Figure 13: Parameters for determination of reference values for the different ship types
Source: Resolution MEPC 203(62)

From above figures we can conclude that EEDI index is not specified for all kind of new ships and depending on the size of the same it does not affect them equally. Small ships are excluded as defined by cut-off levels for each type of the vessel. The purpose of this index is gradual reduction of CO\(_2\) emissions per tonne and nautical mile developed in 4 phases (Phase 0-4). In the final stage the reduction shall represent at least 30% of the emissions as the Attained EEDI is always below the required EEDI which is the upper limit of permitted emissions for the new ships.

**2.1.3. Guidelines on ship minimum power**

By no means energy efficiency measures should jeopardize ship’s safety and manoeuvrability and "Interim Guidelines for determining minimum propulsion power to maintain manoeuvrability of the ship in adverse conditions" (MEPC.262 (68) and amendments) has to be taken in account.

This Guideline provides to Administration or duly recognized organization’s verification that ships complies simultaneously with EEDI and Minimum power requirements to maintain manoeuvrability in adverse conditions

**Adverse condition means:**
Significant wave height \( h_s = 5.5 \text{ m} \);
Peak wave period \( T_p = 7-15 \text{ s} \);
Mean wind speed \( V_w = 19 \text{ m/s} \) (approximately 37 knots, Bft 8 Gale Force)

**Applicable to:** Bulk carriers, Tankers and Combination carriers

**Assessment Method:**
**Level 1; Minimum Power lines assessment**
Minimum Power Line Value
MCR (kW) = \( a \times \text{DWT} + b \)

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Carriers</td>
<td>0.0687</td>
<td>2924.4</td>
</tr>
<tr>
<td>Tankers</td>
<td>0.0689</td>
<td>3253.0</td>
</tr>
<tr>
<td>Combination Carriers</td>
<td>see tankers above</td>
<td></td>
</tr>
</tbody>
</table>

Figure 14: a and b parameters for Minimum power line value calculation. Source: MEPC.232 (65)

---

35 New ship as defined in Regulation 2 of MEPC.203 (62) for the phase 0. Same principle will apply for following phases.
Level 2; Simplified Assessment

This assessment does not need further calculation and it is based on the experience from the particular ship. It shall define required advance speed in head winds and waves to ensure course-keeping in all wave and wind directions and assessment whether the installed power is sufficient to comply with above conditions.

2.1.4. Guidelines on innovative EE Technologies

MEPC.1/Circ 815 regarding "2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of attained EEDI" provides with technologies which use shall be reflected in attained EEDI equation, especially in its part related to Innovative energy efficiency techniques for Power Generation and Propulsion.

Such technologies are categorized in three different groups (A, B & C) depending on their effects to the EEDI formula. Additionally group B and C are divided in 2 sub-categories (B-1, B2 & C-1, C2) as shown in following figure.

<table>
<thead>
<tr>
<th>Innovative Energy Efficiency Technologies</th>
<th>Reduction of Main Engine Power</th>
<th>Reduction of Auxiliary Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>Category B-1</td>
<td>Category B-2</td>
</tr>
<tr>
<td>Cannot be separated from overall performance of the vessel</td>
<td>Can be treated separately from the overall performance of the vessel</td>
<td>Effective at all time</td>
</tr>
<tr>
<td>$f_{\text{eff}} = 1$</td>
<td>$f_{\text{eff}} &lt; 1$</td>
<td>$f_{\text{eff}} = 1$</td>
</tr>
</tbody>
</table>

- low friction coating
- bare optimization
- rudder resistance
- propeller design
- hull air lubrication system (air cavity via air injection to reduce ship resistance) (can be switched off)
- wind assistance (sails, Flügger-Rotors, kites)
- waste heat recovery system (exhaust gas heat recovery and conversion to electric power)
- photovoltaic cells

Following lines provide with resumed description of each category

Category A:
Technologies that shift the power curve, which results in change of combination of $P_p$ and $V_{\text{ref}}$. They cannot be separated from overall performance equation and emission reduction is achieved by use of following techniques.

Example of A category techniques:
Use of low friction coating, propeller design, bare optimization, reducing rudder resistance or any other technology with similar effect on affected part of the overall performance equation.

---

$P_p$ is the propulsion power and is defined as $P_{\text{ME}}$. When shaft generator is installed $P_p$ is equal to the sum of propulsion power form main engine ($P_{\text{ME}}$) and power from the shaft motor ($P_{\text{PTIshaft}}$).
**Category B:**

Technologies that reduce propulsion power $P_p$ at $V_{ref}$, but do not generate electricity. The saved energy is counted as $P_{eff}$. They can be sub-divided in two sub-categories depending on their effect on availability factor of innovative energy efficiency technology ($f_{eff}$).

- **B-1:** Used at any time during operation. $f_{eff} = 1$
- **B-2:** Full use only under limited conditions $f_{eff} < 1$

**Example of B-1 category technique:**

Use of hull air lubrication technique where ship frictional resistance is reduced by covering ship surface with air bubbles injected from fore part of the ship’s bottom using bubble blowers. This technique can be used at any time.

**Example of category B-2 technique:**

Use of the wind assistance for propulsion. Their use is limited to favourable wind conditions. Details of such examples will be provided in Chapter 4 regarding projects of energetically efficient ships.

**Category C:**

Technologies that generates electricity. Saved energy is counted as auxiliary power reduction due to innovative electrical energy ($P_{AEeff}$). Furthermore this category is subdivided in two, depending on time availability of each technology.

- **C-1:** Used at any time during operation. $f_{eff} = 1$
- **C-2:** Full use only under limited conditions $f_{eff} <$

**Example of C-1 category technique:**

Use of waste heat recovery where electricity is generated by recovering heat from exhaust system and so it reduce powers need from auxiliary engines. This technique can be used at any time.
Example of C-2 category technique:

Use of solar energy where photovoltaic (PV) generation system provides part of electric power either for propelling the ship or for onboard power needs. PV power generation system consist of PV Modules and other electric systems. PV module consist of combining solar cells. (Crystalline silicon terrestrial PV, Thin-film terrestrial PV...). Use of this technique is limited to favourable solar conditions.

Summary of effect of different categories on attained EEDI equation is provided by below figure. As we can observe effects on emission reduction provided by category A cannot be attributed to the part of equation related to innovative energy efficiency techniques for power generation and propulsion, as explained previously, and they only affect the part of the equation related to overall performance.

Equation 3: Use of EE Technologies and their effects on EEDI formula

Source: IMO Course on Energy Efficient Ship Operation
### 2.1.5. Surveys and certification

Circular MEPC.1/Circ.855 and resolutions MEPC.254 (67), as amended by MEPC.261 (68) related to "2014 Guidelines on survey and certification of the EEDI" defines that those ships mentioned in Chapter 4 shall be subjected to following surveys and certifications.

- **An initial survey** - for a new ship

- **General or partial survey** - after a major conversion (attained EEDI to be recalculated) (major conversion regarded as a new construction initial survey shall be decided by Administration)

- **Existence of SEEMP on board** - for existing ships at the first intermediate or renewal survey after 1st of January 2013

![Figure 19: Basic flow of survey and certification](Source: MEPC.1/Circ.855)

In the whole process from design to delivery of the new ship there are two principal persons called "Submitter" and "Verifier" defined as follows:

"Verifier" as defined in MEPC.1/Circ.855 means Administration or authorized organization, such as classification society, which conducts the process of survey and certification of the EEDI in accordance with regulations stated in MARPOL Annex VI and in above mentioned circular.

"Submitter" is not defined in the text, but as understood from above circular it includes ship owners, shipbuilders, manufacturers or any other party interested in the construction of determined ship.
Certification and surveys are realized in different stages as described below:

**Certification and survey process**

1. **Preliminary verification of the attained EEDI at design stage**
   
   In this part basic model and tank test are realized and EEDI technical file based on these is elaborated. The submitter also provides with any other relevant background data to the verifier who witness above mentioned test and is responsible to issue pre-verification report once verified that the technical file provided by the submitter is correct. When the satisfactory report is issued, proper construction of the ship may be started.

   Note: Power curves are used for the preliminary verification based on a result of tank test. Tank test may be omitted if they already exist for the same type of ship or sea trials will be carried under EEDI conditions (in presence of the verifier).

2. **Final verification of the attained EEDI at sea trials**
   
   In this part of the process sea trials are realized by the submitter in order to confirm results of EEDI technical file elaborated in previous stage. The verifier on board of the ship confirms that sea trial conditions and the performance of the vessel are in accordance with this file and/or with the regulation.

   Prior to these trials verifier should receive information regarding test procedure to be used for the speed trial, final displacement tables and the measured light weight, NO\textsubscript{x} technical file and any other relevant information.

   Sea trials attended by both submitter and verifier includes testing of

   - propulsion and Power supply system
   - particulars of the engine and other relevant items described in EEDI Technical File
   - Ship speed
   - Shaft Power and RPM of the main engine

   under determined sea conditions and trim and draft of the vessel.

   The submitter should compare power curves obtained as a result of the sea trial and estimated power curves calculated at design stage. In case of differences attained EEDI should be recalculated and provided to the verifier for revision.
3. Certification and delivery of the ship for sea service

If there are no further discrepancies within revised EEDI technical file, the verifier issues certificates of compliance and the ship can be delivered for sea service. Issued certificates are:

1) **International Air Pollution Prevention Certificate (IAPP)**\(^{37}\) issued to any ship of 400 GT or more engaged in voyages to ports or terminals under jurisdiction of other parties. Certificates are issued by Administration or other recognized organization (such as Class Societies) and certifies ship’s compliance with annex VI of MARPOL

IAPP is valid maximum 5 years

2) **International Energy Efficiency Certificate (IEEC)**\(^{38}\) issued to any ship of 400 GT or more engaged in voyages to ports or terminals under jurisdiction of other parties. Certificates are issued by Administration or other recognized organization (such as Class Societies) and certifies ship’s compliance with energy efficiency requirements if applicable.

IEEC is valid throughout the life of the ship

Port state control inspections shall be limited to verifying existence of valid IEEC on board in case of new ships as defined in resolution MEPC.203 (62). Valid IEEC certificate needs to be provided with records of construction containing following information:

- Particulars of the ship
- Description of thee propulsion system
- Attained EEDI calculation
- Required EEDI calculation
- SEEMP
- EEDI Technical File
- Endorsement that provided data are correct.

\(^{37}\) Further information about form of IAPP Certificate available in MARPOL Annex VI.

\(^{38}\) Further information about form of EIAPP Certificate available in MARPOL Annex VI.
2.2. Energy efficiency operational indicator EEOI

In accordance with MEPC.1/Circ.684 Circular regarding "Guidelines for voluntary use of the ship EEIO", this indicator is an example of transparent and recognized approach to voluntary energy efficiency system with respect to CO\textsubscript{2} emissions compatible with other company environmental system.

Main objectives of EEOI can be defined as follows:

- voluntary compliance with IMO’s energy efficiency politics on CO\textsubscript{2} emissions
- measure performance and trends of the ship or fleet with respect to CO\textsubscript{2} emissions
- use this operation index to reduce emissions of GHG in order to decrease impact of global maritime industry to the climate change.

Guidelines regarding EEOI have as a main objective to provide assessment on implementation and method for calculation of the given index. It is similar to EEDI, but not compulsory.

As defined in above mentioned circular, EEOI should be defined as follows:

... in its most simple form the Energy Efficiency Operational Indicator is defined as the ratio of mass of CO\textsubscript{2} (M) emitted per unit of transport work: Indicator = M CO\textsubscript{2}/transport work.

To establish EEOI indicator following information needs to be provided:

- define the period for which the indicator will be calculated included ballast condition voyages (voyages realized in order to guarantee safety of the ship or to save human life at sea shall be excluded)
- define source of data for the calculation
- achieve data
- converse these in appropriate format
- calculate EEOI

Same as EEDI, this indicator includes fuel consumption (FC) at sea or in the port for one or period of voyages including consumptions of the main engines, auxiliary engines, incinerators etc.
Data collection

To establish uniform data collection method as suggested by the guideline, at least following data need to be provided:

- **D**: (Actual) Distance sailed in nautical miles

- **C<sub>F</sub>**: Fuel type used as per fuel mass to CO₂ mass conversion factor

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>Reference</th>
<th>Carbon content</th>
<th>C&lt;sub&gt;F&lt;/sub&gt; (t-CO₂/t-Fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Diesel/Gas Oil</td>
<td>ISO 8217 Grades DMY through DMC</td>
<td>0.875</td>
<td>3.206000</td>
</tr>
<tr>
<td>2. Light Fuel Oil (LFO)</td>
<td>ISO 8217 Grades RMA through RMD</td>
<td>0.86</td>
<td>3.151040</td>
</tr>
<tr>
<td>3. Heavy Fuel Oil (HFO)</td>
<td>ISO 8217 Grades RME through RMK</td>
<td>0.85</td>
<td>3.114400</td>
</tr>
<tr>
<td>4. Liquified Petroleum Gas</td>
<td>Propane</td>
<td>0.819</td>
<td>3.000000</td>
</tr>
<tr>
<td>(LPG)</td>
<td>Butane</td>
<td>0.827</td>
<td>3.030000</td>
</tr>
<tr>
<td>5. Liquified Natural Gas</td>
<td>Liquefied Natural Gas (LNG)</td>
<td>0.75</td>
<td>2.750000</td>
</tr>
</tbody>
</table>

Figure 20: C<sub>F</sub> Fuel conversion factors
Source: MEPC.1/Circ. 684

- Cargo mass carried or Work done expressed as follows:
  - **TEU**: Number of TEUs transported for "solely" container ships. Total mass in metric tonnes can be used instead if combination of containers and other cargoes is transported. Full container TEU of 10 T and empty container of 2 T shall be applied in calculation.
  - **GT/Number of passengers**: For Ro-Ro/Ro-pax ships
  - **Car units/Lane metres**: For car carriers or car ferries
  - **T**: metric tonnes For the rest of the ships

Monitoring and Verification

To obtain relevant information all monitoring and measure procedures should be documented and maintained. There are some elements to be considered when establishing the same:

- operations with impact on the performance
- data sources and measurements and their conversion to specific format
- frequency and responsible persons for those measurements
- quality control procedures for verification process

The objective of the verification and validation process is the self-evaluation same as in SEEMP. In other words acquired data shall be used to improve energy efficiency of the ship.

To avoid burdens on ship personnel, as far as practicable, analysis of acquired data should be realised by on shore staff based on information from Log book, Engine book, Oil record book and other documents if relevant.
In order to obtain significant data, from the statistics point of view, period of data recompilation from each ship shall be constant and large enough to achieve relevant rolling average indicator. This means data collection for 1 year or for 6-10 voyages.

**Resume:**
The methodology used to obtain EEOI has to provide information leading to reduction of ship’s emissions with respect to CO$_2$ and should contain principles of continuous (continual) improvement using PDCA$^{39}$ techniques.

Indicator should provide information regarding current performance and trend of the same over time.

Based on EEOI data internal targets and performance criteria should be set.

$^{39}$ PDCA stands for Plan, Do, Check, Act. See Chapter 2.3 Ship energy efficiency management plan, figure 22.
USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

EEOI Calculation

Appendix of the circular MEPC.1/Circ.684 provides furthermore with guidelines for calculation of EEIO based on operational data. These data shall be acquired as described in previous section. For calculation purpose the guideline provides with two equations which should be used depending on period of data collection.

1) EEOI for a single voyage

This formula applies to calculation of EEOI for every single voyage.

\[
EEOI = \sum_{j} \frac{FC_{ij} \times C_{F_j}}{m_{cargo} \times D_i}
\]

Equation 4:
Source: MEPC.1/Circ.684

Result of the same is stored for data collection used as a database for calculations of EEOI for number of voyages or period.

2) EEOI for a number of voyages or period

Following equation is basically used for calculation of rolling average EEOI. This means for a suitable period of time such as one year or for determined number of voyages.

\[
\text{Average EEOI} = \frac{\sum_{i} \sum_{j} (FC_{ij} \times C_{F_j})}{\sum_{i} (m_{cargo,i} \times D_i)}
\]

Equation 5:
Source: MEPC.1/Circ.684

Where:
• \( j \) is the fuel type;
• \( i \) is the voyage number;
• \( FC_{ij} \) is the mass of consumed fuel \( j \) at voyage \( i \);
• \( C_{F_j} \) is the fuel mass to CO\(_2\) mass conversion factor for fuel \( j \);
• \( m_{cargo,i} \) is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships at voyage \( i \); and
• \( D_i \) is the distance in nautical miles corresponding to the cargo carried or work done at voyage \( i \).

Units of EEOI will depends on the data source of Cargo mass carried or Work done as explained previously in this chapter.

Commonly used EEOI units are:
- CO\(_2\)/ Tonne and Nautical mile
- CO\(_2\)/ TEU and Nautical mile
- CO\(_2\)/ Passenger and Nautical mile
Example of Average EEOI calculation based on the data reporting sheet

<table>
<thead>
<tr>
<th>Voyage or day (i)</th>
<th>Fuel consumption (FC) at sea and in port in tonnes</th>
<th>Voyage or time period data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel type (HFO)</td>
<td>Fuel type (LFO)</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

\[
EEOI = \frac{100 \times 3.114 + 23 \times 3.151}{(25,000 \times 300) + (0 \times 300) + (25,000 \times 750) + (15,000 \times 150)} = 13.47 \times 10^{-6}
\]

unit: tonnes CO₂(tons • nautical miles)

Figure 21: EEOI calculation example
Source: MEPC.1/Circ .684
2.3. Ship energy efficiency management plan SEEMP

Each ship shall keep on board specific Ship Energy Efficiency Management Plan which may form part of ship’s Safety Management System (SMS) and shall be developed in accordance with MEPC.213 (63) "Guidelines for the Development of a SEEMP". It needs to be elaborated in order to obtain International Energy Efficiency Certificate (IEEC) issued to new ship on initial survey or for existing ships at the first intermediate or renewal survey after 1st of January 2013.

Main purpose of this document is to establish mechanism to improve energy efficiency of ship’s operations.

Additionally SEEMP should help to comply with objectives of ISO 14001:2004 Environmental Management (if implemented). The document is based on the system of continual improvement model PDCA with small modifications in the name of each stage which are as follows:

Stage 1: Planning (plan)

The most important stage where current status of ship’s energy efficiency is described and expected improvements are determined.

In this part Energy Efficiency Measures (EEM’s) are identified. The best measures depends basically on type of the ship, cargoes, routes and many other factors. There are specific measures for the ship or company, but the improvement of the energy efficiency depends also on number of stakeholders involved in the operation of the ship and company.

Example of EEM’s:
- Specific Measures for each ship
- Specific Measures for the company
- Human Resources measures (training of on-shore/off-shore personnel, importance of human factor in a planning and in an implementation phase)
- Goal Setting (voluntary and not subjected to external inspection but highly recommended)

The coordination between all parts is essential so sufficient time and special attention needs to be paid to this part of the SEEMP.

Figures 22 & 23: PDCA (up right) and SEM Stakeholders (left down)
Source: IMO Course on Energy Efficient Ship Operation
Stage 2: Implementation (do)
Create a system of implementation of selected measures and mark responsible persons to follow up. Implementation period (start and end dates) should be indicated and records of the implementation of each measure kept for self-evaluation. If any measure cannot be implemented, reasons of the same should be recorded for evaluation stage.

Sometimes implementation forms part of planning. Both stages should be considered complementary.

Stage 3: Monitoring (check)
This stage also should be completed in planning phase and it determines procedures for data collecting and responsible person for the same. This stage should be as far as possible carried out by shore staff in order to do not increase burden’s on ship’s staff.

Stage 4: Self-evaluation and improvement (act)
Final stage of PDCA cycle where a feedback shall be provided for the next improvement cycle. The main purpose is evaluate effectiveness of adopted measures and to identify any other possible improvements.

GUIDANCE ON THE BEST PRACTICES FOR FUEL-EFFICIENT OPERATIONS OF SHIPS
Chapter 5 of the MEPC.213 (63) provides with guidance relative to increase of fuel efficiency of the ship during operations by measures defined in the planning phase of the SEEMP (stage: plan). Examples of such measures are provided as follows:

- **Voyage planning** - optimal route (Resolution A.893 (21)).
- **Weather Routing** - system which improves voyage planning. Commercially available system for many specific trade routes and for all type of ships.
- **Just in Time** - Adapt speed to estimated Berth availability in the next port of call (ETA Pilot).
- **Speed optimization** - minimum consumption for tonne and nautical mile. (does not mean the minimum speed, but the speed for which the consumption is optimum in relation to the time of the voyage).
- **Optimized shaft power** -constant revolutions (RPM) can be more effective then adjusting speed through engine power (automatic controls depending on ETA for the next port of call).
- **Optimum trim** - minimum resistance for any given draft. Design or safety factors may limit full use of this practice.
- **Optimum ballast** - to meet optimum trim, steering and ballast condition - depends on efficient cargo planning.
- **Optimum propeller and propeller inflow consideration** - normally determined in design and construction stage, modifications can be considered. Use of fins or nozzles could increase power efficiency and hence reduce fuel consumption.
- **Optimum use of rudder and heading control system (autopilot)** - good use of autopilot reduce course deviation (off track - reduce distance sailed), provide smaller and less frequent corrections which leads to fuel savings.
- **Hull Maintenance** - Use of new technology - coating systems to decrease hull resistance, regular docking and cleaning based on ship performance. Propeller cleaning and polishing (or coating) may increase fuel efficiency.
- **Other measures** - Waste heat recovery (available for some ships), Improved Fleet management and Cargo Handling, Computer Software for fuel consumption calculation, Use of renewable energy sources such as wind, solar or cell technology, use of onshore power in ports (when available).

Next figure shows an example of the SEEMP as suggested in relevant guidelines. As observed the plan does not provide only with examples of measures to be used to increase operational efficiency of the ship, but also contemplates setting of measurable goals, monitoring and evaluation of adopted measures.

![Sample of onboard SEEMP](image)

Source: MEPC.213 (63)

Following figure (right) summarize the whole process from shipbuilding to ship operation for new and existing ships as described in previous sections.

![EE processes](image)

Source: IMO Course on Energy Efficient Ship Operation
2.4. EEDI CALCULATION (REAL CASE STUDY) - IMO GUIDELINES

In order to provide better guidance on EEDI Calculation and make it accessible to general public, IMO with cooperation of World Maritime University (WMU) developed new educational programme called "Train the trainer"\(^{40}\). It is a free web based course focused on ship’s energy efficiency and GHG emission primarily targeted at developing countries. The main purpose is to provide with material to lecturers who themselves would provide training courses all over the world and make shipping industry more conscious about seriousness of the CO\(_2\) problematic.

A part of theoretical information related to MARPOL Annex VI, IMO energy efficiency measures for ships updated with relevant details from the Third IMO GHG Study 2014 this online course provide with EEDI Calculator for training purposes. I have used the same to simulate real calculation using proposed examples of ships.

2.4.1. Calculator scope and limitations

Before proceed with calculation it needs to be highlighted that used calculator is limited to six types of ships only (as defined in MARPOL Annex VI, Regulation 2) as follows:

**Scope:**
1. Tanker
2. Bulk Carrier
3. Container
4. General Cargo
5. LNG Carrier
6. Cruise passenger ship

**Limitations:**

Ship propulsion is limited to one main engine, propeller shaft, shaft generator or shaft motor where applicable.

Auxiliary power calculation does not have in account cases where ship’s electric power tables are required.

Only dual fuel engines are included in the scope, not pure gas engines.

Pure diesel electric propulsion can be calculated if proceed.

\(^{40}\) IMO, Train the Trainer (TTT) Course on Energy Efficient Ship Operation.
2.4.2. Equations used in calculator

Below equations were already explained in theoretical part of this thesis and they are attached as a reminder of these formulas.

### Used Formulas

#### Attained EEDI Formula

\[
\left( \prod_{j=1}^{n} f_j \right) \left( \sum_{i=1}^{n_{ME}} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)} \right) + \left( \prod_{j=1}^{n} f_j \cdot f_{PTI} \right) \left( \sum_{i=1}^{n_{PT}} P_{PTi} \cdot C_{PAE(i)} \cdot SFC_{PAE(i)} \right) - \left( \sum_{i=1}^{n_{PT}} f_{PTi} \cdot P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)} \right)
\]

\[f_j \cdot f_{PT} \cdot f_{PTI} \cdot \text{Capacity} \cdot f_w \cdot V_{ref}\]

**NOTE:** The above colour coded parts of formula are represented in relevant sheets of the same tab colours.

#### Required EEDI Formula

\[
\text{Required EEDI} = (1 - X/100) \times (a \times \text{DWT}^e)
\]

Equation 6: Main formulas for EEDI Attained and Required calculation

Source: *IMO Course on Energy Efficient Ship Operation*

2.4.3. Basic data required for calculation

In order to use this excel based EEDI calculator it is necessary to collect data. Some of these has only information purpose, others are applied in the equation and they are essentials to obtain proper results of EEDI calculations.

**EEDI Calculator data:**

- Ship Type
- Ship particulars and tonnage
- Ship reference speed and capacity
- Main engine characteristic
- Auxiliary engine characteristic
- Shaft generator data or Power take out (if applicable)
- Shaft power or Power take in (if applicable)
- Fuel type used and specific fuel consumption for main or auxiliary power
- Innovative systems used to generate main propulsion power
- Innovative systems used to generate electrical power
2.4.4. Test case 1: Conventional containership (Built 2014 - Phase 0)

Following example was calculated using EEDI Technical file for use with EEDI Calculator provided by IMO and the company EnEmSol as a part of web based course on energy efficiency.

2.4.4.1. Ship technical specification

**Ship Type:** Container (as defined by MARPOL Annex VI, Reg. II)

**Ship particulars and Tonnage**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall (LOA)</td>
<td>255.0 m</td>
</tr>
<tr>
<td>Length between perpendiculars (LPP)</td>
<td>245.0 m</td>
</tr>
<tr>
<td>Moulded breadth</td>
<td>031.5 m</td>
</tr>
<tr>
<td>Moulded depth</td>
<td>015.0 m</td>
</tr>
<tr>
<td>Summer load line moulded draft</td>
<td>011.0 m</td>
</tr>
<tr>
<td>Deadweight at summer LL moulded draft</td>
<td>49.500.0 tons</td>
</tr>
</tbody>
</table>

**Ship reference speed and capacity**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship reference speed ($V_{ref}$)</td>
<td>24.3 knots</td>
</tr>
<tr>
<td>Ship reference capacity (Attained EEDI)</td>
<td>34.650.0 tons (70% of DWT at summer LL draft)</td>
</tr>
<tr>
<td>Ship reference capacity (Required EEDI)</td>
<td>49.500.0 tons</td>
</tr>
</tbody>
</table>

**Main Engine characteristics (ME)**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sets</td>
<td>1,000 Unit(s)</td>
</tr>
<tr>
<td>Maximum continuous rating (MCR)</td>
<td>37,000,000 kW (@ 85 rpm)</td>
</tr>
<tr>
<td>Power ME ($P_{ME} = 75%$ of MCR)</td>
<td>27,750,000 kW</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>Diesel Oil (D.O.)</td>
</tr>
<tr>
<td>Carbon factor of D.O ($CF_{ME}$)</td>
<td>3,206 g CO$_2$/g fuel</td>
</tr>
<tr>
<td>Specific fuel consumption ($SFC_{ME}$)</td>
<td>165,000 g/kWh (@ 75% of MCR)</td>
</tr>
</tbody>
</table>

**Auxiliary Engine Characteristics**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sets</td>
<td>3,000 Unit(s)</td>
</tr>
<tr>
<td>Maximum continuous rating (MCR)</td>
<td>900,000 kW (@ 900 rpm)</td>
</tr>
<tr>
<td>50% of MCR</td>
<td>450,000 kW</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>Diesel Oil (D.O.)</td>
</tr>
<tr>
<td>Carbon factor of D.O ($CF_{AE}$)</td>
<td>3,206 g CO$_2$/g fuel</td>
</tr>
<tr>
<td>Specific fuel consumption ($SFC_{AE}$)</td>
<td>220,000 g/kWh (@ 75% of MCR)</td>
</tr>
</tbody>
</table>

---

41 LOA means total length of the vessel.
42 LPP means length measures between the fore and aft perpendiculars.
43 Moulded breadth means horizontal distance inside of the moulds.
44 Moulded depth means vertical distance inside of the moulds.
45 Summer load line moulded draft means distance from the bottom of the keel to surface of the water at summer load line mark.
46 Deadweight means weight of the vessel and its contents such as cargo, bunkers, equipment, provisions and stores at summer load line moulded draft.
47 $V_{ref}$ means speed in deep water at 70\% of Summer DWT and 75\% of Maximum continuous rating MCR.
SCHEME OF PROPULSION AND ELECTRIC POWER SUPPLY

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Figure 26: Propulsion and electricity power supply schema
Source: IMO Course on Energy Efficient Ship Operation

Energy saving equipments
Not available

2.4.4.2. Calculation of attained EEDI

a) CO₂ emissions term for Main Engine/Main propulsion motor

\[
\left( \prod_{j=1}^{n} \left( \frac{1}{f_j} \right)^{n_{ME}} \cdot C_{ME(i)} \cdot SFC_{ME(i)} \right)
\]

Equation 7: Main Engine and Shaft Gen. Formula
Source: IMO Course on Energy Efficient Ship Operation

Correction factor for specific design elements \((f_i) = 1 \rightarrow \) No specific design elements

\[(1) \times (27.750 \text{ kW} \times 3,206 \text{ g CO}_2/\text{g fuel} \times 165 \text{ g/kWh} = 14,679,472,5 \text{ g CO}_2/\text{h}\]

b) CO₂ emissions term for Auxiliary power Requirements

Required Auxiliary Engine Power \(P_{AE}\) (in accordance with MEPC R.245 (66) depending on Maximum Continuous Rating of the Main Engine

**Specific formula for container ships**

\[P_{AE} = 0,025 \times (\text{MCR}_{ME} + \frac{P_{PTI}}{0,75}) + 250 = 0,025 \times (37,000 \text{ kW}) + 250 = 1.175 \text{ kW}\]

\[\left( P_{AE} \cdot C_{AE} \cdot SFC_{AE} \right)\]  
Equation 8: Auxiliary Power Formula
Source: IMO Course on Energy Efficient Ship Operation

\[1.175 \text{ kW} \times 3,206 \times 220 \text{ g CO}_2/\text{g fuel} \times 220 \text{ g/kWh} = 828,751 \text{ g CO}_2/\text{h}\]

---

48 Following typos in the figure 26: Accomodatio=Accommodation, Switchboar=Switchboard.
49 PPTI(i) not available as shaft motor is not installed.
c) CO₂ emissions term for Shaft Motor

\[ \prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{n_{PI}} P_{PI(i)} \]

Equation 9: Shaft Motor Formula

Source: IMO Course on Energy Efficient Ship Operation

Not available - shaft motor not installed; value = 0 g CO₂/h

d) CO₂ emissions term for innovative technologies for main power

\[ \left( \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME} \right) \]

Equation 10: Innovative technologies main power formula

Source: IMO Course on Energy Efficient Ship Operation

Not available - no innovative technologies used; value = 0 g CO₂/h

e) CO₂ emissions term for innovative technologies for auxiliary power

\[ \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{Aeff(i)} \cdot C_{FAE} \cdot SFC_{AE} \]

Equation 11: Innovative technologies aux. power formula

Source: IMO Course on Energy Efficient Ship Operation

Not available - no innovative technologies used; value = 0 g CO₂/h

f) Correction factors

- \( f_j \) Correction factor for specific design elements
  No specific design elements \( \rightarrow f_j = 1 \)

- \( f_c \) Cubic capacity factor
  Not available for container ships \( \rightarrow f_c = 1 \)

- \( f_i \) Capacity factor for ship design
  No specific design elements \( \rightarrow f_i = 1 \)

- \( f_l \) Factor for general cargo ships equipped with cranes or other cargo gears
  Not available for container ship \( \rightarrow f_l = 1 \)

- \( f_w \) Weather factor\(^{50}\)
  Specific formula for container ships
  \[ f_w = 0,0208 \times \ln(\text{Ref. Capacity}) + 0,633 = 0,0208 \times \ln(34.650) + 0,633 = 0,898 \approx 0,90 \]
  \( f_w = 0,90 \) for EEDI Attained calculation
  \( f_w = 1,00 \) (for EEDI Required calculation) - constant value

\(^{50}\) For further details check MEPC Circ.1/796 Guidelines for fw attained EEDI.
g) Attained EEDI Calculation

\[
\frac{1}{f_i} \left( \prod_{j=1}^{n} \left( \sum_{k=1}^{m} \frac{P_{c,d}(j) \cdot C_{n,m}(j) \cdot SFC_{d,m}(j)}{\sum_{k=1}^{m} \frac{P_{c,d}(j) \cdot C_{m,n}(j) \cdot SFC_{d,m}(j)}} \right) + \left( \prod_{j=1}^{n} f_i \cdot \sum_{k=1}^{m} \frac{P_{c,d}(j) \cdot C_{m,n}(j) \cdot SFC_{d,m}(j)}{\sum_{k=1}^{m} \frac{P_{c,d}(j) \cdot C_{m,n}(j) \cdot SFC_{d,m}(j)}} \right) \right) - \left( \prod_{j=1}^{n} f_i \cdot \sum_{k=1}^{m} \frac{P_{c,d}(j) \cdot C_{m,n}(j) \cdot SFC_{d,m}(j)}{\sum_{k=1}^{m} \frac{P_{c,d}(j) \cdot C_{m,n}(j) \cdot SFC_{d,m}(j)}} \right)
\]

Equation 12: Attained EEDI Calculation (global formula)
Source: IMO Course on Energy Efficient Ship Operation

Attained EEDI \((f_w = 1)\)

\[
\frac{1}{1 \times 1 \times 34.650 \text{ tons} \times 1 \times 24.3 \text{ nautical miles} \times \text{hour (knots)}} \times 14.679.472.5 \frac{\text{g CO}_2}{\text{h}} + 828.751 \frac{\text{g CO}_2}{\text{h}} + 0 \frac{\text{g CO}_2}{\text{h}} = \frac{18.42 \text{ g CO}_2}{\text{ton x Nm}}
\]

Attained EEDI Weather \((f_w = 0.90)\)

\[
\frac{1}{1 \times 1 \times 34.650 \text{ tons} \times 0.90 \times 24.3 \text{ nautical miles} \times \text{hour (knots)}} \times 14.679.472.5 \frac{\text{g CO}_2}{\text{h}} + 828.751 \frac{\text{g CO}_2}{\text{h}} + 0 \frac{\text{g CO}_2}{\text{h}} = \frac{20.46 \text{ g CO}_2}{\text{ton x Nm}}
\]
2.4.4.3. Calculation of required EEDI

Required EEDI = (1-X/100) x (a* <DWT> - c)

Where X is a reduction factor (in percentage) as defined by Regulation 21 of MARPOL’s Annex VI, Chapter 4 (see chart Nº 2)

And a and b are parameters for determination of reference line for different type of ships (for further details refer to Chart Nº3)

Required EEDI = (100-0/100) x (174,22*49.500 tons<sup>-0.201</sup>) = 19,84 g CO<sub>2</sub>/ton x Nm

2.4.4.4. Conclusion of calculation and compliance

Regulatory compliance: Attained EEDI Accepted as 18,42 < 19,84 g CO<sub>2</sub>/ton x Nm
Attained EEDI is 7,16% less than Required EEDI.

From above mentioned calculation is evident that our container ship complies within the first phase (Phase 0) of implementation of EEDI only in case when weather factor is not used. Furthermore if there is a delay in delivery and the same will be realized in 2015 (Phase 1) where 10% of reduction applies the compliance will be not granted and more energy efficient technologies will need to be implemented.
2.4.5. Test case 2: LNG Carrier with diesel-fuel/electric propulsion (LNG with DFDE) (Built 2014 - Phase 0)

Following example was calculated using EEDI Technical file for use with EEDI Calculator provided by IMO and EnEmSol as a part of web based course on energy efficiency.

2.4.5.1. Ship technical specification

Ship Type: LNG carrier (as defined by MARPOL Annex VI, Reg. II)

Ship particulars and Tonnage
Length overall (LOA): n/a m
Length between perpendiculars (LPP): n/a m
Moulded breadth: n/a m
Moulded depth: n/a m
Summer load line moulded draft: n/a m
Deadweight at summer LL moulded draft: 75,000,0 tons

Ship reference speed and capacity
Ship reference speed \(V_{\text{ref}}\)^{51} 18,5 knots
Ship reference capacity (Attained EEDI) 75,000,0 tons
Ship reference capacity (Required EEDI) 75,000,0 tons

For LNG Carriers with DFDE Propulsion ship reference capacity for both attained and required EEDI is 100% of deadweight tonnage.

Main Engine characteristics (ME)
Main engine not available

Auxiliary Engines Characteristics
a) Main Power Generation System
Number of sets 3,000 Unit(s)
Maximum continuous rating (MCR) 10,000,000 kW (each)
Fuel Type LNG
Carbon factor of D.O \(\text{CF}_{\text{AE}}\) 2,866 g \(\text{CO}_2\)/g fuel
Specific fuel consumption \(\text{SFC}_{\text{AE}}\) 161,600 g/kWh (@ 75% of MCR)

---

^{51} \(V_{\text{ref}}\) means speed in deep water at summer load line DWT and 83% of MCR of the shaft electric motor.
USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

b) Pilot Mode
Number of sets: 1,000 Unit(s)
MCR: 6,400,000 kW
Fuel type: Heavy Fuel Oil
Carbon factor of D.O ($CF_{AE}$): 3,144 g CO₂/g fuel
Specific fuel consumption ($SFC_{AE}$): 6,000 g/kWh

c) Total Auxiliary Engines
Number of sets: 4,000 Unit(s)
MCR: 36,400,000 kW
Fuel type: Dual fuel with LNG
Carbon factor of D.O ($CF_{AE}$): 2,866 g CO₂/g fuel (effective weighted avg.)
Specific fuel consumption ($SFC_{AE}$): 161,700 g/kWh (effective weighted average)

Shaft power
Number of sets: 1,000 Unit(s)
MCR (66% of 36.400kW): 24,000,000 kW
Electric chain efficiency from generator: 91.300 %
Shaft motor efficiency $\eta_{PTI}$: 83.000 %

SCHEME OF PROPULSION AND ELECTRIC POWER SUPPLY

Figure 27: Scheme
Source: IMO Course on Energy Efficient Ship Operation

Energy saving equipments
Not available
2.4.5.2. Calculation of attained EEDI

All formulas used were already mentioned in previous example$^{52}$

a) $CO_2$ emissions term for Main Engine/Main propulsion motor

\[
P_{ME} = \left( \frac{n}{\prod_{i=1}^{n} \beta_i} \cdot \sum_{i=1}^{n} \frac{P_{ME(i)} \cdot C_{ME(i)} \cdot SFC_{ME(i)}}{i} \right)\]

$P_{ME}$ of Diesel Electric Propulsion:

Specific formula for LNG Carriers with DFDE propulsion

\[
P_{ME} = 0.83 \times \frac{MPP_{motor}}{0.913} = 0.83 \times \frac{24,000 \text{ kW}}{0.913} = 21,818, 182 \text{ kW} \approx 21,818 \text{ kW}
\]

$MPP_{motor}$ is 66% of total MCR of engines on average: 66% of 36,400 kW = 24,000 kW

Correction factor for specific design elements ($f_j$) = 1 → No specific design elements

\[
(1) \times (21,818 \text{ kW} \times 2,866 \text{ g CO}_2/\text{g fuel} \times 161,7 \text{ g/kWh} = 10111,163,74 \text{ g CO}_2/\text{h}
\]

b) $CO_2$ emissions term for Auxiliary power Requirements

Required Auxiliary Engine Power $P_{AE}$ (in accordance with MEPC R.245 (66) depending on Maximum Continuous Rating of the Maine Propulsion Power ($MPP_{motor}$)

Specific formula for LNG Carriers with DFDE propulsion

\[
P_{AE} = 0.025 \times (MPP_{motor} + \frac{P_{PTI}^{F3}}{0.75}) + 250 + 0.02 \times P_{ME} =
\]

Where term:

\[
0.025 \times (MPP_{motor} + \frac{P_{PTI}}{0.75}) \text{ means Required Auxiliary Engine Power}
\]

and term:

\[
0.02 \times P_{ME} \text{ means Power needed for NG compressors (DF)}:
\]

\[
P_{AE} = (0.025 \times (24,000 \text{ kW}) + 250) + (0.02 \times 21,818 \text{ kW}) = 850 \text{ kW} + 436 \text{ kW} = 1286 \text{ kW}
\]

\[
(P_{AE} \cdot C_{AE} \cdot SFC_{AE} *)
\]

\[
1.286 \text{ kW} \times 2,866 \text{ g CO}_2/\text{g fuel} \times 161,7 \text{ g/kWh} = 595,973,81 \text{ g CO}_2/\text{h}
\]

Equation are the same as in previous chapter - to avoid confusion numbering of these repeated will not be provided in this section.

$^{53}$ PPTI(i) not available - excluded when shaft motor is propulsion motor.
c) CO₂ emissions term for Shaft Motor

\[
\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{n_{PTI}} P_{PTI(i)}
\]

Not available - shaft motor as a principal propulsion motor is excluded; **value = 0 g CO₂/h**

d) CO₂ emissions term for innovative technologies for main power

\[
\left( \sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME} \right)
\]

Not available - no innovative technologies used; **value = 0 g CO₂/h**

e) CO₂ emissions term for innovative technologies for auxiliary power

\[
\sum_{i=1}^{n_{eff}} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FAE} \cdot SFC_{AE}
\]

Not available - no innovative technologies used; **value = 0 g CO₂/h**

f) Correction factors

- **f_j** Correction factor for specific design elements
  No specific design elements → \( f_j = 1 \)

- **f_c** Cubic capacity factor
  not available for LNG carriers as defined in Reg. 2.38 of MARPOL Annex VI → \( f_c = 1 \)

- **f_i** Capacity factor for ship design
  No specific design elements → \( f_i = 1 \)

- **f_l** Factor for general cargo ships equipped with cranes or other cargo gears
  Not available for LNG carriers as defined in Reg 2.38 of MARPOL Annex VI → \( f_l = 1 \)

- **f_w** Weather factor\(^{54}\)
  No specific formula for LNG Carrier \( f_w \) determined by the ship specific simulation on its performance at **representative sea conditions as follows:**

  Mean Wind force: BFT 6.0 (Mean wind speed of 12.6 m/s)
  Mean wind direction: 0.0 deg (in relation to the ship’s heading)
  Significant wave height Hs 3.0 m
  Mean wave period 6.7 s
  Mean wave direction 0.0 deg (in relation to the ship’s heading)

  \( f_w = 0.90 \) for EEDI Attained calculation (retrieved from EEDI Technical file)
  \( f_w = 1.00 \) (for EEDI Required calculation) - constant value

\(^{54}\) For further details check MEPC Circ.1/796 Guidelines for \( f_w \) attained EEDI.
g) Attained EEDI Calculation

\[
\text{Attained EEDI (} f_w = 1) = \frac{1}{101} \times \left( 10.111.163.74 \text{ g CO}_2/\text{h} + 595.973.81 \text{ g CO}_2/\text{h} + 0 \text{ g CO}_2/\text{h} \right)
\]

\[
= \frac{72.72 \text{ g CO}_2/\text{ton x Nm}}{1 \times 1 \times 1.75 \times 50.000 \text{ tons x 1.00 x 18.5 nautical miles x hour (knots)}}
\]

Attained EEDI Weather (} f_w = 0.90) = 8.57 g CO2/ton x Nm

2.4.5.3. Calculation of required EEDI

Required EEDI = \((1-X/100) \times (a \times \text{DWT} - b)\)

Where X is a reduction factor (in percentage) as defined by Regulation 21 of MARPOL’s Annex VI, Chapter 4 (see chart Nº 2)

And a and b are parameters for determination of reference line for different type of ships (for further details refer to Chart Nº3)

Required EEDI = \((100-0/100) \times (2.253,7 \times 75.000 \text{ tons} ^{-0.474}) = 11,02 \text{ g CO}_2/\text{ton x Nm}\)

2.4.5.4. Conclusion of calculation and compliance

Regulatory compliance: Attained EEDI Accepted as 7,72 < 11,02 g CO2/ton x Nm

Attained EEDI is 29,95% less than Required EEDI.

From above mentioned calculation is evident that our LNG carrier complies not only with the phase 0 of EEDI implementation phases, but almost with all phases up to 2025 where estimated reduction factor is 30%.

From above examples it seems that use of LNG Diesel Fuel Diesel Electric propulsion is much more environmental friendly then use of pure diesel oil engines as a main propulsion. But it is important to have in mind that EEDI only reflects energy efficiency in terms of CO2 emissions. As described in IMO 3rd GHG study increase of use LNG as a fuel is associated with other gas emissions. Increase of LNG in the fuel mix cause methane (CH4) emissions to the atmosphere which are not regulated by the industry. In conclusion, use of other "innovative" technologies to improve energy efficiency of the ships is more efficient in the long term scenarios.
CHAPTER 3: EU ENERGY EFFICIENCY REGULATIONS

As per today there is no law or taxation on CO₂ emissions proceeding from shipping. As seen in data statistics the contribution of the maritime sector on carbon dioxide emissions is small in comparison with other type of transport. That’s why this sector was excluded from the Kyoto protocol and further more it was included in the "white paper of transport" of the European Union. This means that maritime transport is highly promoted by EU and logistic operators are encouraged to use it even on short sea shipping routes as a preferable way of transport. Estimated increase of maritime transport within next year’s involves more emissions of GHG. Even that IMO and its Environmental committee (MEPC) are adopting measurements leading to reduction of the impact of shipping industry to global warming (EEDI, EEOI and SEEMP) the control mechanism and taxation system to fine those not complying with regulation was missing.

In June 2013 European Commission (EC) took the first step to reduce contamination from the shipping industry and proposed legislation to obtain major control regarding CO₂ emissions from the ships and ports. On 29th of April 2015 “REGULATION (EU) 2015/757 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport” 55, and amending Directive 2009/16/EC was issued. Following lines will be dedicate to this regulation and main objectives of the same.

Highlights of the MRV Regulation and its main objectives:

MRV applies to all ships of 5 000 GT and more visiting EU Ports regardless of their flag except warships, naval auxiliaries, fish-catching or fish-processing ships, wooden ships of a primitive build, ships not propelled by mechanical means, or government ships used for non-commercial purposes.

It covers all intra-Union voyages, all incoming voyages from the last non-Union port to the first Union port of call and all outgoing voyages from a Union port to the next non-Union port of call, including ballast voyages and includes ships consumption at berth or moving within the port.

Ship movements and activities not serving for the purpose of transporting cargo or passengers for commercial purposes, such as dredging, ice-breaking, pipe laying or offshore installation activities are excluded.

Companies shall ensure that relevant data are obtained, recorded and analysed and there are no time or data gaps within the reporting period. By the august 2017 companies shall elaborate and submit to verifier their monitoring plan for each of their ships including method to be used or other relevant information. This plans will be checked annually to ensure they reflect reality and to analyze the plan for improvements. Monitoring will be based on voyage basis and will result into annual report.

55 MRV.
Minimum parameters required for voyage MRV report are:

(a) port of departure and port of arrival including the date and hour of departure and arrival;
(b) amount and emission factor for each type of fuel consumed in total;
(c) CO₂ emitted;
(d) distance travelled;
(e) time spent at sea;
(f) cargo carried;
(g) transport work.

Companies may also monitor information relating to the ship's ice class and to navigation through ice, where applicable.

Minimum parameters to be included in Annual Report:

(a) amount and emission factor for each type of fuel consumed in total;
(b) total aggregated CO₂ emitted within the scope of this Regulation;
(c) aggregated CO₂ emissions from all voyages between ports under a Member State's jurisdiction;
(d) aggregated CO₂ emissions from all voyages which departed from ports under a Member State's jurisdiction;
(e) aggregated CO₂ emissions from all voyages to ports under a Member State's jurisdiction;
(f) CO₂ emissions which occurred within ports under a Member State's jurisdiction at berth;
(g) total distance travelled;
(h) total time spent at sea;
(i) total transport work;
(j) average energy efficiency.

Companies may monitor information relating to the ship's ice class and to navigation through ice, where applicable.

Companies may also monitor fuel consumed and CO₂ emitted, differentiating on the basis of other criteria defined in the monitoring plan.

MRV Emission report shall use automated systems and data exchange format, including electronic templates as defined by Commission by implementing act as described in the article 24(2) of this regulation.

Four proposed monitoring methods shall be used as per annex I, part B (the use of Bunker Fuel Delivery Notes, bunker fuel tank monitoring on-board, flow meters for applicable combustion processes or direct emission measurements). Companies shall use standardised monitoring plans based on templates. These templates, including the technical rules for their uniform application, shall be determined by the Commission by means of implementing acts.
Same as in case of solutions provided by IMO, others GHG, non CO₂ pollutants, are excluded from this regulation. The MRV, as a EU energy efficiency project, is understood to be complementary to IMO’s EEDI and SEEMP mandatory requirements for new ships.

Also in this regulation, verification will be realized by accredited verifiers which are defined in Art. 15, 16 and Annex III of the MRV. For compliant ships verifier will issue "Document of Compliance" 56 and informs EU Commission about the issuance of the same. DoC should be kept on board and will be subjected to inspections. Penalties set up by Member States will be applied to non compliant ships. Those penalties should be effective, proportionate and dissuasive and Member State should ensure that they are imposed to the offender. Member States shall notify Penalties provisions to the Commission by 1st July 2017, and shall notify to the Commission without delay any subsequent amendments. This regulations enters into force on 1st July 2015 to ensure that the Member States and relevant stakeholders have sufficient time to take the necessary measures for the effective application of this Regulation before the first reporting period starting on 1st January 2018.

In order to achieve goals proposed by IMO or EU companies looked for solution which may allow a good compromise between energy efficiency and reasonable price of implementation. Many of current companies are implementing LNG as a alternative to traditional fuel oils, others choose to bet on electricity using Combined Diesel-Electric and Diesel-Mechanical (CODED) systems and some of them found out convenient to use both gas and electric methods implementing Combined Diesel-Electric and Gas (CODLAG) propulsion system for ships. But those are not unique alternatives. Some of them were already mentioned above in the text named as innovative energy efficiency technologies (EE Technologies). Let’s have a look now on present and future projects that from my point of view are worth to mention and they were true pioneers in energy efficiency solutions provided by the industry.

56 DoC.
CHAPTER 4: PROJECTS OF ENERGETICALLY EFFICIENT SHIPS - PRESENT & FUTURE

Nowadays there exist plenty of projects regarding use of alternative ways of energy to provide additional propulsion to new and existing vessels and increase their energy efficiency index as requested by IMO in order to fundamentally reduce their emissions and global impact from Maritime Transport to marine environment.

In this chapter I will divide these energies essentially in three sections. Ships using traditional sails, vessels using kite concept and others.

List of presented projects as follows:

a) Sailing technology
   B9 Energy group - project B9 ship
   Dykstra and Fair Transport - project Ecoliner
   STX Europe - project STX Eoseas cruise ship
   Tokyo University and Class NK - project UT Wind Challenger
   Wind Star Cruises - Windy Surf project
   Royal Clipper Cruises - Star Clipper

b) Kite technology
   Anbros Maritime S.A., Piraeus, Greece (Cargill Geneva, SUI) - Bulk Carrier Aghia Marina
   Wessels Reederei GmbH & Co. KG- MV Theseus and MS Michael A
   Briese Schiffsahrts GmbH /BBC Chartering & Logistic GmbH & Co. - MV BBC Skysails (former name Belluga Sky Sails)

c) Other alternatives
   Wallenius Wilhelmsen - project E/S Orcelle (car carrier)
   Use of Solar Energy
   Flettner Rotor Ship
   Nyk Super Eco Ship (estimated for 2030)

Above mentioned list is not exhaustive but it serves to demonstrate the potential of industry and solid number of companies involved in projects and investigations including universities and classification societies. This gives to the matter clear worldwide dimension. Following pages I would like to dedicate to further lookup on some of projects included in the list above.
4.1. SAILING TECHNOLOGY

4.1.1. Projects and prototypes

4.1.1.1. B9 energy group - B9 ship

The purpose of B9 Shipping is to create a fleet of small dry bulk and general cargo ships (3,000 DWT) which demand is estimated to increase about 1,400 units for 2020. The group, in their business case, estimates that if only 5% of this demand would be covered by their ships it will lead to global reduction of CO\textsubscript{2} emissions about 1%. Each unit will create 10 new jobs according to the minimum personnel needed for operation of their ships. The project is now in stage of testing.

It already passed validation tests at Wolfson Unit for Marine Technology and Industrial Aerospace at Southampton University (WUMTIA). These tests included wind tunnel and towing tank tests to evaluate her performance and risk analysis in comparison with similar sized vessels operating on estimated B9 shipping routes. The purpose of realized tests is to find optimal interaction between hull and the rig in order to generate sufficient power from sails to overcome hull’s resistance and minimize side way slip caused by the sails.

The WUMTIA Work Programme.

Meanwhile in wind tunnel test the main objective was to find optimum mast and sail configuration across the wind speed and directions to guarantee maximum performance of the
rig, in the towing tank test the hull was subjected to effects of waves and currents and their impact on the overall performance of the same at different heeling angles was analyzed. Results from tests were used in Velocity Prediction Program (VPP) in order to estimate overall sailing performance of the ship. In these tests Met Office\textsuperscript{57} data were used to simulate 105,000 journeys within 12 years period on specified study routes and estimated 46-55% fuel consumption savings comparing to equivalent conventional ship on the same route.

Below figure shows one of the route used in above mentioned tests including Met Office data relative to wind, waves and currents.

![Figure 30: Route Analysis for B9 Ship by Met Office](image)

Results of these test were analyzed by UCL’s\textsuperscript{58} techno-economic team to study viability of the project. It is estimated that capital costs would be slightly higher due to extra engineering with integration of hybrid propulsion system (Bio-Gas and Wind) and the mast. Having in mind fluctuations of fuel prices and possible introduction of International MBM\textsuperscript{59} costs the payback of the investment is estimated within 3-5 years.

\textsuperscript{57} Met office is UK National Weather Service. One of many objectives of this organization is to gather weather data for statistic purposes and understand weather patterns of today.

\textsuperscript{58} University College London’s Energy Institute.

\textsuperscript{59} Market-based Methods proposed by EU/IMO to reduce CO\textsubscript{2} emissions of world maritime fleet.
Dynarig square sail concept is intended to be used on B9 ships concept. This automated square rig sail system is based on original idea of Wilhelm Prolls from 1960’s and it’s proven on modern sailing luxury yacht Maltese Falcon. It’s design is similar to classical "square-rigger." In difference, Dynarig sails yardarms (horizontal spars) do not swing around the fixed mast, but they are attached to it permanently. It is the mast which can rotate in order to find the best wind angle. Traditional staying of the mast is replaced with free-standing design only available when using very light materials such as carbon. (Note: If the mast is stayed it does not allow the rotation of the same, that’s why stays are not compatible with dynarig system).

The sail area on one mast is divided into 5 rectangular panel sections stacked one above the other. The traditional terminology of each part of the sail has been retained as illustrated on below picture:

Dynarig sail parts

Figure 31: Dynarig sail parts
Source: Running Tide Yachts

Royals-Gallant-Top Sail-Course Sail (Seen from the Top to the Bottom).

Each section can be reefed accordingly (from the top to the bottom) to the desired sail area in order to reduce overturning forces and so the heeling of the vessel. As these forces are higher in the upper part of the sail, sail area is getting smaller from bottom to top with exception of course sail which is smaller than gallant for storm navigation purposes. The optimum arc for the sail is effective pointing to windward (approx. 12, 5º from the wind). Material used and tested for the sails is Dacron. Weight of the top Royals is just about 57 gr and can stand up the winds up to 80 knots which gives to the sail kind of blow-up protection against micro-bursts or severe squalls.
When the sail is fully reefed only Course sail is hoisted so the CE\(^{60}\) is very low at this stage and it guarantees balanced sail plan (in really heavy conditions can be also sheeted in). If weather conditions are of very light (or very heavy) wind and/or the vessels is approaching her port of call and she is sailing under engine all sails are furled in the mast cavity by fully automated 5 electric or hydraulic engines and permit single-handed operations (no extra crew needed for operation of the sail). This allows obtain desired sail area for each weather condition, but also to control aero/hydrodynamic balance of the ship to minimise resistance at all times.

![Figure 32: Dynarig furling system by Dykstra](image)

*Source: B9 Energy Group, Automated Square Sail System*

The mast rotation gear is accessible from big compartment below each mast. Regarding the mast I also would like to mention that it does not need exert additional compression load to its base, but it requires considerable bending and torque support. It is guaranteed by the X-structure\(^{61}\) formed by "space frame" bulkhead (arthwarthship/transverse) and longitudinal "backbone rib" nacelle.

**ADVANTAGES of an AUTOMATED FREESTANDING MAST**

- **Operational**
  - Operated from bridge, same number of crew as on a similar sized vessel
  - No rigging to interfere with sail operation
  - No rigging at deck level to impede loading/discharge

- **Health and Safety**
  - No manning requirement up rigs or on foredeck in foul conditions
  - Rig instantly turned out of wind in squalls

---

\(^{60}\) centre of effort - produced by the force of the wind (clr - centre of lateral resistance means resistance to the CE by means of the hull and keel). If the CE is aft to CLR the boat will have tendency to turn in to the wind and if is forward to the CE the boat has the tendency to turn away from the wind. In heavy weather this can be very dangerous as this can cause excessive heeling and even accidental jibe.

\(^{61}\) The X-structure as the support of the mast was extracted from design of 62´´ Catamaran design due to lack of information from B-9 Shipping as requested by attached e-mail from 25th of November 2014.
Bio-fuel engine

The B9 Ship’s engine was developed by Rolls-Royce using their gas spark ignition system which is fuelled literally by the food waste (2nd generation Bio-fuel). This bio fuel consist liquid bio methane or green gas produced by B9 Organic Energy or others big energy generators. The advantage of the fuel used is that it has same chemical and physical make-up as LNG and once washed is interchangeable with the same. This permits more flexibility of the vessel when the bio-fuel is not available in the port of call. The use of bio-fuel permits to B9 ship obtain 100% renewable fuel status valuable when financial incentives are introduced to stimulate sustainable green shipping and to get Renewable Obligation certificates and Renewable Transport Fuel Certificates.

Regarding engine itself I would like to mention that is proven high technology engine operating in 26 vessels up to date. The Power used for B9 Ships was not revealed. Use of LNG or Bio-fuel represents great contribute to reduction of NO\textsubscript{x} (by 90%) and CO\textsubscript{2} (by 23%) and emitting no Sulphur in accordance with IMO and EU environmental politics.

The plan for the next years is to realize further test of the model to give comfort to stakeholders and potential customers in the market. Whilst it’s proven technology and a system-integration job, it is a fairly big leap of faith for a big, long-term capital asset, Gilpin explains. So over the next two years we will develop the design concept, put it through further rigorous testing in the tank and tunnel and then run much more detailed economic analysis using comparable cargo on comparable routes so that we can give customers the confidence that it has been robustly analysed.

Main Particulars

Length: 100,0 m
Breadth: n/a - to be determined
Draught: n/a - to be determined
DWT 3,000 T (aprox.)
GT n/a
Cargo type: To be determined - possibly Dry bulk/Bio-fuel Tankers/ Cruise ships/Feeders for areas excluded from world shipping due to eco-system limitations
Status: Project - test phase completed

Performance and speed

Main Engine propulsion: 2x Rolls Royce LNG gas spark ignition engine - type unknown
Auxiliary engines: n/a
Fuel type: LNG/Bio fuel
Alternative propulsion Dynarig sails - sail area unknown
Speed: n/a

62 Diane Gilpin, leader of B9 Shipping project.
Cargo Capacity
Cargo capacity: n/a

Crew and others
Crew: n/a
Passengers n/a
Trainees and others n/a

Examples of potential markets for B9 Ships are Dry bulk cargo, Bio-fuel tankers, US cruises passenger vessels or support for small islands and areas excluded from world trade due their size or eco-system limitations.

To conclude I would like to remark the support of the project by the key players of the scientific and maritime sector in UK like WUMTIA, Rolls-Royce, Lloyd’s Register, UCL or FLAG (Future low carbon advisory group formed among others by British Shipping, P&O Ferries or Met Office).
4.1.1.2. Dykstra naval architects and Fair transport - ECOLINER project

Similar project, but in this case for container ship, was developed by Dutch Dykstra Naval architects upon initiative from Fair Transport BV. For Dykstra architects with long tradition of shipbuilding specialized in sailing vessels (Maltese Falcon, Rainbow Warrior III, Mikhail’s Vorontsov among others) the construction of competitive alternative for conventional cargo ship means big challenge.

Design of 138 m 8.000 DWT container/general cargo ship with maximum capacity of 13.000 m$^3$ which means 476 TEU’s\textsuperscript{63} is now in stage of testing.

The intended engine speed was designed to 12 knots, but in favourable conditions of wind and under sails it can easily reach up to 18 knots. Combination of both methods is available as in the time when the ships are motoring, the apparent wind is created and leads to higher propulsive force from the sails. This means that engine can work in slow steaming mode or at economic speed revolutions, so the fuel consumption stays at the minimum without significant loss of the speed. Setting of engine revolutions will be covered by automatic optimized routing algorithm to ensure the vessel will arrive on time with minimum fuel cost.

\textsuperscript{63} TEU - Twenty equivalent unit - 20 feet metres long container.
Comparison between conventional cargo ship and The Ecoliner

The vessel is designed especially to cover transoceanic routes where the wind conditions are more constant than in coastal navigation and examples of such routes are: A clockwise North Atlantic roundtrip, Europe-South America route or US West Coast - Japan route. The constructor in the vessel’s specification admits that different DWT/TEU capacities and design speeds are possible but not at this stage.

The Hull was designed in order to meet more sailing vessel criteria than standard motor ship in order to achieve minimum drag with heel and side force. Tests were performed at the towing tank of Technical University of Delft in Netherlands to ensure ship’s good manoeuvrability under sail and good rudder balance. For further analysis of the changes to the hull the CFD\textsuperscript{65} calculation method was used.

\textsuperscript{64} Opex means Operational expenses and Capex means plus capital expenses.

\textsuperscript{65} Computational fluid dynamics - branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Initial experimental validation of such software is performed using a wind tunnel.
Following figure shows the wave pattern of the Ecoliner from CFD Analysis and real wind tunnel test performed at Wolfson Unit in Southampton, UK (WUMTIA)

Figure 35 -36: Wave pattern CFD (left) and Wind Tunnel test at Delft Technical University facilities (right)
Source: ECO Liner Concept (pdf)

The Rigging

Similar Dynarig square sail concept as in B9 Ship has been developed for the Ecoliner. The vessel will be provided with 4 masts, each one containing following Sails

<table>
<thead>
<tr>
<th>Sail</th>
<th>As [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Royal</td>
<td>115</td>
</tr>
<tr>
<td>Top Gallant</td>
<td>179</td>
</tr>
<tr>
<td>Upper Topsail</td>
<td>200</td>
</tr>
<tr>
<td>Lower Topsail</td>
<td>203</td>
</tr>
<tr>
<td>Course</td>
<td>203</td>
</tr>
<tr>
<td>Total</td>
<td>900</td>
</tr>
</tbody>
</table>

This represents almost 3,000 m² sail area. The system of reefing and furling is the same as in previous B9 ship design. From the point of view of Dutch ship designers it is so far the best option in terms of performance, safety, reliability and easy handling. Same as in previous case, sails have full support from yardarms, so light and relatively cheap Dacron material can be used. When the ships is making way using sails, additional safety will be provided by monitoring loads in the masts and providing optimal sail setting as per below figure.

Figure 38: Optimum Sail setting and Mast loads monitoring
Source: ECO Liner Concept (pdf)
The mast height (62.5m - Panamax) can represent some restriction regarding under bridge clearance, but not on intended transatlantic routes and ports.

In terms of stability in all loading and weather conditions, The Ecoliner complies with Solas standards.

**Cargo handling**

Due to masts distribution cargo handling operations by shore cranes has the limitations in longitudinal direction, but as consulted with port operators in ports for which the ship is designed it does not represent any problem and on the other hand it increase her versatility as she can be used to operate ports without shore cranes as the each mast is equipped with one derrick.

**Performance analysis**

The analysis was performed in order to find economical feasibility of the project. For that purpose the consumption of fuel needs to be calculated for different engine settings and in different weather conditions (wind speed and direction, wave’s height, currents...)

Velocity Prediction Programme, Weather Routing Programme and Simulations were developed in order to find the right answer on the economical viability question.

![Figure 39: Daily running costs in thousands of euro. Source: ECO Liner Concept (pdf)](image)

It’s clearly demonstrated that Ecoliner solutions brings significant saving of fuel and operational costs.
Other interesting analyses performed by Dykstra are Engine Settings and Heel during Atlantic crossing as shown in figures below.

Even that engine settings (ES) are quite uniformly distributed I would highlight the fact that nearly the half of the voyage will be realized with engine working on 50% of its maximum power or less. Also the maximum heel of 10º achieved by different settings and reefing of the sails represents fair stability behaviour of the ship and comfort for the crew.

The important remark regarding represented graphics must be made. The rig performance is estimation as data on a motor ship that is currently in operation stage and will be available shortly. This will allow a better comparison. For the fuel consumption cost as an economical comparison was estimated the price of the fuel at 700€/ton MDO and building costs assumed to 23M € for Ecoliner/ 19M € for motor vessel. The difference of 4M € is given by the cost of rigging having in account that each 5 years new sails with 0,25M € cost needs to be provided to the vessel.

### Main Particulars

- **Length:** 138,0 m
- **Breadth:** 18,2 m
- **Draught:** 6,5 m
- **DWT:** 8,210 T
- **GT:** 7,548
- **Cargo type:** Dry bulk / Containers
- **Status:** Project - test phase completed

### Performance and speed

- **Main Engine propulsion:** n/a
- **Auxiliary engines:** n/a
- **Fuel type:** n/a
- **Alternative propulsion:** 2.700 m² of Dynarig sails
- **Speed:** 12 knots (only engine) / 18 knots (engine and sails)

---

66 Marine Diesel Oil.
Cargo Capacity
Cargo capacity: 13,000 m$^3$ of grain /476 TEU$^{67}$

Crew and others
Crew: 8
Passengers: 0
Trainees and others: 10

To conclude I would like to question the fact of low cargo capacity of the ship and restrictions for onshore cranes due to her masts. Meanwhile the B9 ship was designed to cover small ports in coastal areas of difficult access to fill the niche in the market, the ambitious Dykstra project is trying to compete with huge container ships with enormous capacities which are ploughing in 7 seas in our days. I am not sure of its economically viability. Maybe this can be a reason why Dykstra, as per today, did not sign any real contract for building of their ship. Notwithstanding my objections regarding the project as a container ship I think it’s very interesting project and as the company contemplates her use to carry dry bulk o general cargo it’s possible that she will find a customer for this kind of transportation in the future.

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$^{67}$ Means capacity of empty containers (2 T of weight approximately). Capacity of loaded containers with cargo depends on maximum permissible weight per square meter (T/m$^2$) in holds/on hatches available in technical specifications of the ship.
4.1.1.3. **STX Eoseas cruise ship**

This project of French based STX Eoseas Europe and Stirling Development International (SDI) pretends to build eco-friendly cruise ship reducing power and energy consumption by using combination of special design of the hull and sails.

![Image of Eoseas green cruise ship concept](source: 7th Annual Green Ship Technology conference)

The pentamaran, 5 hull concept, and patented STX sail concept\(^{68}\) pretend to reduce up to 50% of CO\(_2\), 100% of SO\(_2\), 90% of NO\(_x\) and 100% of Ash emissions. This could be achieved by using combination of innovative propulsion system, renewable energies and other energy saving technologies. In following lines we will review the main energy and fuel savings highlights of the project.:  

**Propulsion and design of the hull:**

Use of innovative pump propellers to increase fuel efficiency (up to 17% improvement vs. traditional propulsion/hull interaction), vertical bow.

**Hotel energy and HVAC**\(^{69}\)

Use of absorption chillers from the heat from engines and LNG vaporization to reduce chillers energy consumption, implementation of patented double skin concept to reduce air conditioning needs, use of natural day light and low consumption lighting for illumination.

By this means hotel energy consumption may be reduced up to 30%.

**Renewable energies:**

Installation of 8.300 m\(^2\) of photovoltaic panels producing average 270 kWe\(^{70}\)

(Max 1,08 MWc\(^{71}\))

**Organic waste gasification**

This system is designed to generates additional 300kWe.

\(^{68}\) No further details available regarding sail plan and its characteristics at this stage.

\(^{69}\) means: Heating, Ventilation, Air Conditioning.

\(^{70}\) kWe means kilowatts electrical (kilowatts produced).

\(^{71}\) MWc means Megawatt peak (from French Megawatt crête).
**Water management**
- **Fresh water** generated by Multi Stage Evaporators and Reverse Osmosis
- **AWP** for black and grey water treatment (cleaner cruise)
- **Laundry grey water** treated separately and recycled

**Energy saving technologies contribution to CO\(_2\) emission reduction:**

Propulsion/Hydrodynamics: 18%
Sails: 8%
Propellers: 5%
Hull shape and air lubrication: 5%
Power Plant and energy recovery: 31%
LNG (including life cycle consideration): 20%
Thermal energy recovery: 9%
Renewable energy (excl. sails): 2%
Hotel load: 3%
HVAC: 2%
Other electrical consumers: 1%
TOTAL: 52%

On one hand we are facing very ambitious project which pretends to reduce more than 50% of CO\(_2\) emissions using alternative means for energy savings, but at the same time it seems that technology used for this purpose is very realistic. The use of the same will mainly depend on the construction cost. But success of the project also depend on the ship’s main characteristics and convenience of her size depending on the ports and routes operated by cruise ship companies. This information is detailed as follows:

**STX EOSEAS CRUISE SHIP**

**Main Particulars**

Length: 305,0 m
Breadth: 60,0 m
Draught: n/a
DWT: n/a
GT: 105,000
Cargo type: Passenger cruise ship
Status: Project - test phase completed

---

\(^{72}\) Advanced Wastewater Purification.
**Performance and speed**

Main Engine propulsion: 4 x 8,000 kW Dual Fuel LNG diesel electric engines  
Auxiliary engines: n/a  
Fuel type: LNG/ HFO  
Alternative propulsion: 12,400 m² of STX sail concept  
Speed: 17 knots (engine and sails)

**Cargo Capacity**

Cargo capacity: No cargo spaces

**Crew and others**

Crew: 1,000  
Passengers: 3,000  
Trainees and others: 0

At this stage of the project the technology was already patented, numerical and CDF studies were completed and the wind Tunnel test was performed. Results of these tests confirmed up to 10% savings on Fuel bill. Now, when fuel prices are on historical minimums, economical feasibility of the project will mainly depend on constructions costs. Also the futuristic design of the cruise ship is a big question, are potential customers prepared to accept it?
4.1.1.4. UT Wind challenger

UT Challenger concept, project of Tokyo University and ClassNK classification society, is inspired in The *Shin-Aitoku Maru* ship from 1970’s constructed by JAMDA\(^73\) Japan, using metallic cambered board for sail.

![Model of UT Wind Challenger](Source: Third International Symposium on Marine Propulsors)

The total sail area of 9,000 m\(^2\) is expected to generate forward thrust enough to drive 180,000 DWT bulk carrier at the speed of 14 knots, in case of wind velocity of 12 m/s (23 knots) from a beam. The 9 masted ship is designed to hoist 9 telescopically retractable rigid sails from aluminium and fibre reinforced plastic (CFRP Composite). This material is rigid and is similar to the wing of an airplane. Approximate weight of all spares and sail is 100 T. Area of 1,000 m\(^2\) of each sail is divided in 5 parts of reefing or folding. Each sail angle is controlled individually to obtain their maximum performance. These operations are controlled by computer. Estimated cost of each sail is approximately 2,5 million USD. The sail system is estimated to reduce fuel consumption about 25%.

The great advantage is use of retractable masts for port manoeuvring, anchorage, cargo operations and to pass below bridges.

Test phase was already completed at this stage (including CFD calculations and Wind tunnel test) and it was estimated for the sea voyage in 2016. Unfortunately, due to the economic crisis, the same will be postponed and at the moment there is no further estimated date available for sea trails.

Previously half size prototype will be constructed to confirm results from performed testing.

\(^{73}\) Japan Machinery Development Association.
Conclusions of performed tests.

Below graphic represents composition of forces applied to the centre of gravity of the sail. It is very important to maintain optimum apparent wind angle to generate thrust force and minimize side force (reduce leeway).

From polar diagram (right) we can see that major thrust force is obtained for the "beam reach" courses. It is not possible to sail on "in-irons" or "close hauled" courses (wind angles of 30º on each side from bow). Similar problem is observed on broad reach and running courses (30º on each side from stern), but in this case minimum thrust is obtained. It is quite obvious, when the apparent wind comes to the ship from stern, the last sail remains on windward and make lee to sails situated more forward.

Figure 47 shows the thrust force distribution on every wing sail at different angles (30/120/150). As expected the major thrust coefficient is obtained for the limit of the beam reach at AWA 120º. This leads us to conclusion that the best AWA for the ship is situated between 30º of each beam (60-120º from bow on each side). On this course, and depending on the AWS, the ship driven only by the wind force is able to develop speeds shown in below table.

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74 For further details on "sailing courses" (point of sail) please check Figure 49.

75 Cx - Thrust coefficient, variable parameter according to apparent wing angle.
Furthermore these tests confirmed that the rigid sail of this construction concept is able to withstand the drag of 700 kN (0.7KN/m² in case of 30 m/s wind speed force Beaufort 11).
Route simulation: Yokohama - Seattle was tested in order to determinate fuel consumption savings when using sails. Figures shows 3 different scenarios as follows:

1 Great Circle (Ship Speed Constant)
2 Great Circle (Engine Power Constant)
3 Optimum Route (Engine Power Constant)

As we can appreciate the optimum route does not coincide with the great circle route and use the path of stronger winds from abeam as the vessel was designed to sail within the range of AWA 60-120°.

Constructor Note: 80% of the energy consumption can be reduced by the wing sail power in the condition of AWA/80 ∼ 120°and AWS of 25knots.

Specifications of designed Cape Size bulker as follows:

**UT Wind Challenger**

**Main Particulars**
- Length: 300,0 m
- Breadth: 50,0 m
- Draught: 16,0 m
- DWT: 180,000 T
- GT: n/a
- Cargo type: Cape size bulker
- Status: Project - test phase completed

**Performance and speed**
- Main Engine propulsion: 12,000 kW - type and number of engines unknown
- Auxiliary engines: n/a
- Fuel type: n/a
- Alternative propulsion: 9,000 m² of Telescopically retractable rigid sails
- Speed: 14 knots (sails only at wind speed 12m/s from the beam)
Cargo Capacity
Cargo capacity  n/a

Crew and others
Crew:  25 (maximum number of people on board including crew and others)
Passengers  n/a
Trainees and others  n/a

From my point of view this project is very ambitious due to dimensions of the ship, but on the other hand realistic due to the results from the test. The fact that Japanese maritime sector believe in the project is its support by big shipping lines and classifications societies like NYK, MOL, KLINE, Oshima Shipyard, TADANO and Class NK. Particularly I am very curious about the real sea-trails with announced half sized model.

4.1.2. Real ships

Even when there is lack of really big commercial merchant vessel at this stage, the interest of the sector is modestly represented by huge luxury modern or traditional sailing vessels. Among others I would highlight the Wind Star Company with a fleet of 3 sailing cruise ships with capacity up to 310 passengers. These are Wind Surf (310 pax), Wind Star (148 pax) and Wind Spirit all registered under Bahamas Flag offering private and luxury vacations in all important cruise destinations like Caribbean, Mediterranean, North Europe Fjords, Tahiti etc.

![Figure 52: Wind Surf](https://example.com/figures/WindSurf.jpg)

Source: Windstar Cruises

The flag ship of the company, Wind Surf, is 4 masted cruise ship with 7 triangular, self-furling, computer-operated sails with 2,600 m² of Dacron surface area. When using engine and sails it is able to develop speed of up to 15 knots. As in case of any sailing vessel the AWA is important factor to have in mind. No specific study regarding her performance on different wind angles is available for public, but it should be expected that it won’t be able to sail on "in-irons" course due to the wind angle and with minimum thrust on "running courses" due to significant reduction of sail area.

For major comfort of her clients, Wind Surf is equipped with 2 sets of **ACH Engineering** stabilizers, sails control system and 1.000 m³ of sea water hydraulic ballast system to limit heel when sailing.
Specifications of the ship are detailed as follows:

**WIND SURF IMO 8700785**

**Main Particulars**
- Length: 187,0 m (including bowsprit)
- Breadth: 20,0 m
- Draught: 5,0 m
- DWT: n/a
- GT: 14.745
- Cargo type: Passenger cruise ship
- Status: Active

**Performance and speed**
- Main Engine propulsion: 2 x Electrical propulsion motor - type unknown
- Auxiliary engines: 4 x diesel electric generating sets - type unknown
- Fuel type: HFO/MDO
- Alternative propulsion: 2.600 m² of Self furling computer operated Dacron sails
- Speed: 12 knots (engine) 15 knots (engine and sails)

**Cargo Capacity**
- Cargo capacity: no cargo spaces

**Crew and others**
- Crew: 191
- Passengers: 310
- Trainees and others: n/a

Although I did not find any further information regarding her sailing performance I would expect that rather than sailing vessel she should be considered as sail assisted vessel with main engine running at all times to meet scheduled ports on time.

In order to estimate fuel consumption reduction we can have a look on small example of her possible route between Spanish peninsula and Canary Islands and approximate distance of 700 nautical miles. Using only engine and developing speed of 12 knots, the distance is covered within 58 hours (almost 2,5 days). When using engine and sail developing speed of 15 knots is less than 47 hours (less than 2 days). This means almost 12 hours less of the main engine hours which is the same as half day of savings on fuel. Depending on the hourly fuel consumption of the main engine, this could mean significant cost savings for the shipping company.
ROYAL CLIPPER

As a next example I have choose five masted full rigged Tall Ship cruise sailing vessel inspired in legendary Preussen (1902-1910)

Royal Clipper is a flag ship of 3 vessels owned by Star Clippers Cruising Company.

Due to the traditional sail plan of the clipper the number of crew is high as hoisting, lowering and setting of sails is entirely manual. This permits to her guests enjoy the real sensation of sailing experienced by our ancestors with all comfort of modern cruise ship.

ROYAL CLIPPER 8712178

Main Particulars
Length: 133,81 m (including bowsprit)
Breadth: 16,46 m
Draught: 5,64 m
DWT n/a
GT 5.000
Cargo type: Five masted full rigged passenger cruise ship (Tall ship)
Status: Active

Performance and speed
Main Engine propulsion: 2 x 1.865 kW diesel engine - type unknown
Auxiliary engines: n/a
Fuel type: MDO
Alternative propulsion 5.202,57 m² of Traditional square rig and triangular head sails
Speed: 12 knots (engine only) / 18 knots (engine and sails)

Cargo Capacity
Cargo capacity no cargo spaces
Crew and others
Crew: 227
Passengers 106
Trainees and others n/a

Due to her classical rigging and the sails plan, this cruise ship can be included in A category of Tall Ships as defined by Sail Training International (STI). This association is responsible for organization of Tall Ship Regattas, the meeting of similar types of sailing vessels and their crews, all over the world. Most of the Tall ships are school (often military) vessels promoting traditional sailing and the seamanship between young people under 25 years old. But every person can sail onboard of those vessels as a cadet under payment fee for the food and accommodation. In September 2013 the Tall Ship Regatta took a place in Barcelona and it was organized by STI with cooperation of FNOB with assistance of volunteers including students from Barcelona School of Nautical Studies which forms part of Technical University of Barcelona (FNB-UPC).

As Royal Star Clipper is pure passenger ship, unfortunately we cannot see her on above mentioned STI meetings as she is dedicated uniquely to commercial transport of passengers.

76 Class A Tallship means all square-rigged vessel more than 40 m length overall. For more information about this association visit the Sail Training International (STI) web page as stated in webgraphy section.
77 Fundación de Navegación Oceánica Barcelona - Foundation of Ocean Sailing Barcelona.
4.2. SKYSAILS TECHNOLOGIES

In general terms "skysails" is the new concept of the eco or green ship. Also it means the engineering discipline of science which object is to study wind energy in order to move vessels through the water.

It is based on use of towing kites instead of motoring or combining effects of both wind and engine. The idea is exactly the same as the method used by kite surfers on the beach. But in order to move the big vessel the sail area just needs to be much bigger. The leader of automated towing kite, German Sky Sails GmbH company, is the first company who was able to implant the technology into maritime industry and use it on commercial routes (examples will be shown further in this text).

Principal advantages of using skysail technology are fuel cost reduction, and contribution to lower emissions in accordance with sustainable environmental politics promoted by IMO, EU and other institutions worldwide.

4.2.1. How does it work

The Skysail system is towing the ship using dynamical towing kites released to high altitude (100-300m) where the wind is stronger and more constant. This allows generating up to 25 times more energy per square meter than conventional sail of the same area. In good wind conditions this could mean 2.000 kW of propulsion hour. The cost of one kilowatt hour of skysail is just 6 US cents (roughly half of the kWh from main engine)

The system consist of "Flying and Launch & Recovery System."

Flying system is composed from Towing Kite, Towing rope and Control pod. The last one named allows steering control of the towing kite which performs regular dynamic flight in the air in front of the ship and generates propulsion. Inside the towing rope from strengthen synthetic fibre we can find integrated cable providing power supply to the control pod and communication with the control system on the ship.

All components are permanently installed and stored on the bow of the ship to not interfere with cargo spaces and operations. When the ship approaches the port, pass below bridge or simply there is no wind it is stored and it is not hindering any operations as it does not contain superstructures.

All system is operated by ship officer from the bridge. But the system is not fully automated as it needs few simple actions taken by the crew deck on the forecastle where the system is installed.

Figure 54: Skysail system components
Source: Marine Insight, Skysails: Pioneering "Greens Ship" Uniquely
When the towing kite is launched, firstly it is raised folded by telescopic mast from its storage compartment until gets unfurled to its full size and then the winch release towing rope to desired altitude. The whole operation would take approximately 20 minutes but only is possible in correct wind conditions (cannot sail against the wind) in order to work effectively. In flight mode the system is controlled by autopilot software to ensure maximum performance based on prevailing wind direction and wind speed. Deck officer has all the time information about operating status displayed on the bridge control panel. To ensure safety of the ship whole system can be deactivated by pressing emergency button situated on the bridge. Landing process is pretty same as the launching in reverse sequence order.

Managing launching, sailing or landing of the skysail is easy and after proper training by installing company it can be operated by same crew members without need any additional crew costs for the company.

The sailcloth of the towing kite is from synthetic material and therefore durable even when used in adverse weather conditions like a rain or snowfall.

4.2.2. Skysail types offered by Skysails GmbH company:

- **Skysails SKS C 160** of 160 m²
- **Skysails Prototype** of 320 m²
- **Skysails SKS C 320** of 320 m²

The system is classified by Germanischer Lloyd, Bureau Veritas or Japanese Class NK

**Basic steps on how to implant the Skysails system on the ship can be found on provider web page as follows:**

1. **Preparation** - of the foundations and laying the cables and hydraulic lines.
2. **Installation** - of SkySails components on the forecastle
   - of the bridge control panel
3. **Connection** - of the components to the electrical and hydraulic systems, winding the towing rope onto the winch and stowing the towing kite and control pod in the storage compartment.
4. **Commissioning** - Inspection and approval of the entire system installation on board the ship by the owner’s representative. System commissioning, sea trials and first flight.
5. **Crew** - Training on the job and handing over the system to the crew.

As the system is designed to save the fuel consumption, primary interest for the shipping companies, it also means reduction of CO₂ and other pollutants, which helps ship to increase its energy efficiency as promoted by international organizations. The IMO estimates that up to 100 million tons of CO₂ emissions could be eliminated every year using SkySail technology alone (equal to 11% of German emissions/year).

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79 Second IMO GHG 2009 Study.
Customers of SKYSAILS GmbH
Wessels reederei GmbH\textsuperscript{80}
4 x Sky sails SKS C 160
2x Project + 2x Installed (MV Theseus & MS Michael A)
Briese Schiffahrts GmbH & Co. KG / BBC Chartering & Logistic GmbH & Co. KG\textsuperscript{81}
1 x Sky sail prototype (up to 320m$^2$) installed for R&D purposes (MV BBC Skysails)
Cargill, Geneva, Switzerland / Anbros Maritime S.A., Piraeus, Greece\textsuperscript{82}
1x Skysail SKS C 320 (Aghia Marina cargo bulk carrier)

\subsection{4.2.3. Real ships}

\subsubsection{4.2.3.1. Aghia Marina}

Built in Japan (Kanda shipyard) for Greek Anbros Maritime SA, operated by Swiss based Cargill under 5 year time charter contract, equipped with the Mitsubishi engine providing 14 knots operational speed at cost of 20 T of IFO/hour and registered under Maltese Flag.

At first sight nothing special on this bulker. What makes the ship different to others is the largest 320 m$^2$ Kite on its bow provided by SkySails GmbH company and installed in 2012. In ideal weather conditions can save up to 35% of fuel and as well other polluting emissions which make her environmental friendly green ship.

\textbf{AGHIA MARINA - IMO 9087805}

\begin{tabular}{ll}
\textbf{Main Particulars} & \\
Length: & 170,00 m \\
Breadth: & 27,00 m \\
Draught: & 13,80 m \\
DWT & 28,522 T \\
GT & 17,425 T \\
Cargo type: & Bulk carrier \\
Status: & Active \\
\end{tabular}

\footnotesize\textsuperscript{80} Skysail on client’s ship [link]
\footnotesize\textsuperscript{81} Skysail on client’s ship [link]
\footnotesize\textsuperscript{82} Skysail on client’s ship [link]
### Performance and speed

- **Main Engine propulsion:** 1 x Mitsubishi Suec 52LA, 8MW
- **Auxiliary engines:** 2 x Yanmar M200L-UN generator sets
- **Fuel type:** IFO / MDO
- **Alternative propulsion:** 320 m² of SKS C 320 Skysail
- **Speed:** 14 knots (engine only)

### Cargo Capacity

- **Cargo capacity:** 37.694 m³ / 36.665 m³ (grain/bale)

### Crew and others

- **Crew:** n/a
- **Passengers:** n/a
- **Trainees and others:** n/a

#### 4.2.3.2. M/V BBC Skysails

On her maiden voyage from Bremen to Venezuela on January 2008, the Skysail was used successfully with no incidents reported. This almost 10,000 DWT vessel was the pioneer of SkySail Technology, using the towing kite prototype of 320m² installed by German SkySails GmbH company for R+D purposes. Unfortunately Belluga shipping declared bankruptcy in 2011, but the ship found a new owner; Briese Schifffahrts GmbH & Co. KG, and as on August 2016 is still in service. To increase her competitiveness this multipurpose vessels is designed to carry both general cargo and containers in total of 2 holds with total capacity of 12,822 m³ equal to 474 TEU’s. She is equipped with 2 cranes situated on port side of the vessel with safety working load (SWL) 40 T each or 80 T used together so she is able to visit ports without onshore cranes facilities.

Figure 56 M/V BBC SkySails

Source: Briese Schiffahrt, Fleet list - BBC Skysails Technical data

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83 This sea voyage was realized under former ship’s name MS Belluga SkySails.
**BBC SKYSAILS (former MS Belluga Skysails) - IMO 938260**

**Main Particulars**
- Length: 132.20 m
- Breadth: 15.87 m
- Draught: 7.73 m
- DWT: 9,821 T
- GT: 6,312 T
- Cargo type: General cargo / Containers
- Status: Active

**Performance and speed**
- Main Engine propulsion: 1 x MAK 8M32C, output 3,840 kW
- Auxiliary engines: 2 x 335 kW Diesel driven engine - type unknown
- Fuel type: HFO / MGO
- Alternative propulsion: 1 x Sky sail prototype (up to 320m²) installed for R&D purposes
- Speed: 14.5 knots (engine only)

**Cargo Capacity**
- Cargo capacity: 12,822 m³ (in holds) + 3,568 m³ (on hatch) or 474 TEU’s

**Crew and others**
- Crew: n/a
- Passengers: n/a
- Trainees and others: n/a

Unfortunately there is no information provided by a shipping company regarding fuel savings contributed to use of SkySail technology, but having in mind that she is equipped by main engine with total output of 3,840 kW and the SkySail is able to provide up to 2,000 kW, in favourable conditions, it is expectable that fuel savings on her oceanic routes are not insignificant.

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84 Marine Gasoil.
85 See chapter 4.2.1 How does it work.
USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

4.3. OTHER TECHNOLOGIES

4.3.1. Wallenius Wilhelmsen concept

Project of Green Flag Ship E/S Orcelle

It is an ambitious project of the Wallenius Wilhelmsen eco friendly car carrier which does not release any emissions to the atmosphere nor into the ocean (zero emission vessel). Her name is after the Irrawaddy dolphin (Orcelle in French) which is same as the beluga whale on the list of WWF critically endangered species and the E/S stands for Environmentally sound ship.

The vessel has innovative pentamaran hull made of aluminium and thermoplastic composites. Her capacity of 10,000 cars is based on current car standard unit dimensions (CEU).

The ship, estimated to be launched in 2025, will use only alternative source of energy for propulsion and services on board. These energy sources will include solar, wind and wave energy combined with fuel cell system powered by Hydrogen. Some of the hydrogen will be also produced on board from sun wind and waves. The only by-products of the production of electricity from fuel cells are water and heat.

Thanks to her pentamaran hull shape and elimination of traditional stern propeller and rudder no ballast water, one of the four major threats to the world’s ocean of IMO, will be needed.

Concept of clean sailing and Primary energy sources

The primary energy source will be as above mentioned fuel cells, sun, wind and waves. The energy obtained from these sources will be transformed onboard to create energy carriers. This means the way of transmitting energy for use. This will be used for propulsion and energy consumers (all equipment on board which needs energy).

Wind Energy

The wind energy will be generated through 3 sails from light weight material. Estimated area of each sail is 1.400 m$^2$. The concept of the sail will be similar to Dynarig rigid sails (not confirmed yet by the company) rotating around the mast to fit the best position to obtain better performance and to create sufficient thrust. These sails will need electric and hydraulic power supply in order to hoist/furl and rotate the sails. Requested energy will be obtained on board as explained later in the text.

Solar energy

It will be retrieved from solar panels located directly on rigid sails, occupying the area of 800 m$^2$ of each sail. When sails will not be used for propulsion they will be laid down and directed for maximum solar energy collection and used directly by energy consumers or stored

Wave Energy
She will be equipped with fins, of 210 m$^2$ each, enabling to vessel to harness and transform the energy from the waves into hydrogen, electricity or other type of energy. These fins will be the main propulsion unit, driven by wave energy or other generated onboard by means of wind or sun.

Fuel Cells
It is estimated that fuel cells will be providing about 50% of energy used for propulsion. The electricity will be generated by chemical elements of Hydrogen and Oxygen and will provide the energy to electric motors in the pod as well as to other electric equipment. The only by-products of those chemical reactions will be vaporized water and heat. The production and storage of hydrogen which needs to be done at high pressure and low temperature represents now the major obstacle for the project as the investigation of the system has not yet been finished.

Electric propulsion system
This will be guaranteed by 2 variable speed electric pods and complementary to propulsion energy generated by sails and fins. Each pod will house a motor, gearbox and propeller in a single compact unit. One pod will be fitted at each end of the main hull, providing full power and a 360-degree field of manoeuvrability.

For manoeuvring the vessel will be equipped with 2 aft rudder working upon electrical or hydraulic power supply. Ventilation and other onboard systems will use energy, which is primarily electrical energy. Hydraulic power will also be required for raising and lowering the stern ramp and for adjusting the height of the cargo decks.

E/S Orcelle
Main Particulars
| Length:    | 250 m |
| Breadth:   | 50 m  |
| Draught:   | 9 m   |
| DWT        | 13.000 T |
| GT         | n/a   |
| Cargo type:| Car carrier |
| Status:    | Project |

Performance and speed
| Main Engine propulsion: | 2.520 m$^2$ of fins (Wave energy) |
| Auxiliary engines:      | see alternative propulsion |
| Fuel type:              | Hydrogen |
| Alternative propulsion  | 1 x |
| Speed:                  | 15 knots |
4.3.2. Solar ships

Basic concept of solar ship consists of combination of wind and solar energy for propulsion and storage of energy (already seen in E/S Orcelle). The system using an array form rigid sails which can utilize both wind and solar energy was designed by the Eco Marine Power (EMP) Aquarius MRE System. It is estimated to be used on future prototype Aquarius Eco Ship. It will by fully automated and in case of storm or adverse weather will be lowered in order to ensure safety of sailing. System is basically designed for bulk ore carriers, tankers, cargo ships and others. Also it will be suitable for coast guard ships or supply vessels or even naval frigate.

The technology is being incorporated into Tonbo and Medaka hybrid power ferries (project phase).

Unfortunately there is no further information available on these projects.

4.3.3. Flettner rotor ships

Ships using flettner rotor technology will be equipped with special vertical spinning cylinders using Magnus effect for the propulsion. It is not a new concept and it was already used in 1922 by German engineer Anton Flettner, hence where the Flettner ship’s name coming from. But his sailing ship without sails was far away from modern concept of the modern sailing as he used an engine to spin the cylinders to generate the Magnus effect.  

It is estimated that ocean-going vessel using this concept should save up to 20-25% of fuel consumption and the payback of the implementation is estimated within 3 years.

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87 Car Equivalent Unit - Used aboard of Ro-Ro ships and similar. Based on 1966 Toyota Corona RT 43 dimensions (4.125 mm x 1.550 mm x 1.400 mm ≈ 6.4m²). There exists another standards like Passenger Car Equivalent Unit (PCE) or Vehicle Equivalent Unit (VEU) - its size is defined by each company.

88 For further information how does it work, please check following video: https://www.youtube.com/watch?v=Fk2xU8pEll#t=189.
4.3.3.1. WindAgain ship concept

In concept phase remained the project of Singapore based WindAgain company. During my investigations I just found previously used domains and addresses on sale with no further information about the project. Is that the sign that other company involved in innovative investigations was the victim of actual economic crisis?

4.3.3.2. E-Ship 1 (Real ship)

Example of real ship using flettner technology is E-Ship 1 - Ro-Lo carrier owned by the German Enercon GmbH company classified by DNV GL\textsuperscript{89} classification society. Built in 2009 and still in active service\textsuperscript{90} transporting wind energy convertors in Canada. As per information available on shipping company’s web page in favourable wind conditions use of the rotors can achieve up to 15% reduction of fuel consumption.

\textsuperscript{89} Det Norske Veritas and Germanishe Lloyd (merged in 2013).
\textsuperscript{90} Enercon Energy web, news: Class renewal for the E-Ship 1.
**E Ship 1 IMO 9417141**

**Main Particulars**
- Length: 130,0 m
- Breadth: 22,5 m
- Draught: 9,0 m
- DWT: 10.020 T
- GT: 12.968
- Cargo type: Ro-Lo
- Status: Active

**Performance and speed**
- Main Engine propulsion: 2 x 3.500 kW Diesel engine - type unknown
- Auxiliary engines: n/a
- Fuel type: MGO
- Alternative propulsion: 4 x Flettner rotors
- Speed: 17,5 knots

**Cargo Capacity**
- Cargo capacity: 20.500 m³

**Crew and others**
- Crew: n/a
- Passengers: n/a
- Trainees and others: n/a

*Main disadvantage* of this technology is limited manoeuvrability. Generated thrust is always perpendicular to AWA and its directions depends on the sense of rotation of the rotors as observed in below figure. The thrust power apart of AWS depends on the speed of rotors.

- the forward thrust is generated only when wind is received from AWA 270º (when rotor is turning clockwise).
- need to stop rotors and use other type of propulsion to tack (turn to windward) or gibe (turn to leeward).
- no reefing available when wind is rising (the solution could be to make rotors retractable as proposed by WindAgain project).
- less effective than conventional engine

*Main advantage* of Flettner rotor is its efficiency. It is approximately 10 times more effective than traditional sail (needs less area to generate same thrust).

Figure 59: Flettner rotor thrust
Source: Powerpoint "Apunts Teoria del Vaixell i Construcció Naval Propulsors" property of Technical University of Barcelona

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91 Roll-on/lift-off ship - normally equipped with stern ramp for wheeled cargo and with cranes for other cargo types.
4.3.4. Nyk super eco ship 2030

The zero emission dream of NYK Line projected and estimated to be launched by 2030 combine similar technologies as already seen E/S Orcelle. Between other use of Fuel Cells, Sails, Solar panels and other in order to reduce the emissions of CO$_2$ by almost 70%. New materials to be used are extra high tensile steel, alloys and other composites which mean the total reduction of 20% of the weight (comparing the same ships with traditional materials) which leads to the fuel consumption as it reduces the propulsion resistance through the water. The weight reduction is also achieved by new container distribution based on the closed main deck and the integrated loading system below it. This concept eliminates the dependency on shore based facilities and permit faster loading. Also gives additional strength, increase the stability and remove the ballast water needs making the vessel, fast, competitive and of course green and eco-friendly. No additional data are available at the moment. Let’s see if the project will be transformed in something tangible and hopefully will not stay only on paper as many others.

In this chapter many different solutions were proposed to reduce fuel consumption and so the environmental impact of shipping industry. From projects combining conventional propulsions with ecological friendly ones to those using only renewable sources of energy. It is not purpose of this work to determine which of explained solution is the best. From my point of view all reviewed examples are interesting and their success or not depends mainly on the economical feasibility of each project. Major threat for many of these solutions is now, in 2016, economic crisis and the low prices of fuel. Probably we will need to wait until these conditions will change or when our reserves of fossil fuels will be nearly finished.

Figure: 60 NYK Super Eco Ship 2030
Source: Marine Insight (Top 7 Green Ships Concepts Using Wind Energy)

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92 Nippon Yusen Kaisha Line.
CHAPTER 5: EXPECTATIONS OF SHIPPING COMPANIES TODAY

In order to investigate the global knowledge about technologies using wind and other alternative sources and interest of those between shipping companies I have prepared small survey and I send it to the most important companies of the maritime sector.

5.1. SURVEY ON USE OF ALTERNATIVE SAILING TECHNOLOGIES FOR MERCHANT VESSEL

5.1.1. Questionnaire

Below attached intended questionnaire sent to shipping companies. Unfortunately no reply was received on the same as on August 2016.

COMPANY NAME:

1) What type of vessels include your fleet?
(NOTE: If possible please state: Nº of ships per DWT/GT/TEU range example: 14x Tankers > 100.000DWT/2xContainer Ships 5.000-10.000 TEU etc.)

2) What kind of service does your company provide?
LINE  
TRAMP  
BOTH  
OTHER

3) Did you heard about any of below mentioned alternative way of propulsion?

Dyna-rig sail system  YES  NO
STX sail concept  YES  NO
Kite sail  YES  NO
Solar panels  YES  NO
Flettner Rotors  YES  NO

4) Did you implant/Do you consider to implant any of them to your fleet?

YES  NO
If yes, please specify which one:

5) If the implementation of the alternative way of propulsion means investment for your company in how many years will you expect recovery of the same?

Less than 5 years  
5-10 years  
More than 10 years  
I do not expect recovery of the investment, environmental protection is more important for me  

6) If the implementation of the alternative way of propulsion means reduction of the speed of your vessels (not below 12 knots) would you still consider to implement it to your fleet?
   YES ☐ NO ☐

7) If the implementation of the alternative way of propulsion means reduction of the speed (not below 12 knots) but the fuel consumption will be reduced would you consider to implement it to your fleet?
   YES, if the fuel consumption is reduced by less than 20% ☐
   YES, if the fuel consumption is reduced by 20-30% ☐
   YES, if the fuel consumption is reduced by more than 30% ☐
   NO, I would not consider to implement it ☐

8) If the implementation of the alternative way of propulsion means reduction of the speed (not below 12 knots) but it helps you to comply with required Energy efficiency design index (EEDI required) as per IMO Resolution MEPC 203 (62) as amended would you consider to implement it to your fleet?
   YES ☐ NO ☐
   Required EEDI does not apply to my fleet ☐

9) What type of fuel(s) do you use actually in your fleet?

10) Do you plan to refit your vessels with different type of fuel in the future?
    YES ☐ NO ☐
    If yes, specify type of fuel(s)

11) Do you plan to make any (major) conversion to your existing ships in order to meet established limit for SO\(_x\) and NO\(_x\) as per Annex VI of MARPOL?
    YES ☐ NO ☐
    If Yes specify type of conversion

12) Do you plan to make any (major) conversion to your existing ships in order to meet required Energy Efficiency Design Index (required EEDI) for 2025 as per IMO Resolution MEPC 203 (62)?
    YES ☐ NO ☐
    Required EEDI does not apply to my fleet ☐

13) Do you have any environmental management system (EMS) implemented on your fleet?
    YES, Ship Energy Efficiency Management Plan (SEEMP) ☐
    YES, ISO 14001:2004 ☐
    YES, Other ☐
    NO, I do not have implemented any environmental management system ☐
14) If Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) does not apply to you fleet, what are your politics regarding emissions reduction of greenhouse gases (GHG), especially CO₂?

15) When you will renew your fleet, what will be the most important factor for the construction?

- Price
- Fuel Consumption
- Environmental impact
- Other

5.1.2. List of intended surveyed companies contacted by e-mail:

In this section we can find the list of contacted companies. I have decided to contact the biggest companies of different shipping sector. This decision was made in order to obtain information from those representing relevant part of the sector. Due to absence of replies I realized that it could be more productive to start with smaller companies which are more open to participate in such kind of investigations. As this section was not the main purpose of this thesis I have decided to do not make proper follow up on my questionnaire.

List of intended surveyed companies contacted by e-mail:

- Maersk dancsimng@maersk.com (dancsimng@maersk.com);
- MSC rbarreto.bcn@mscspain.com (rbarreto.bcn@mscspain.com);
- EVERGREEN comments@shipmentlink.com (comments@shipmentlink.com); customer-care@cosco.com (customer-care@cosco.com);
- HAPAG LLOYD presse@hlag.com (presse@hlag.com);
- APL Shipping pamela_pung@nol.com.sg (pamela_pung@nol.com.sg);
- CSCL CSC@CNSHIPPING.COM (csc@cnshipping.com);
- HAMBURG SUD central@hamburgsud.com (central@hamburgsud.com);
- SCF Group scfcy@scf-group.com (scfcy@scf-group.com);
- TEEKAY media@teekay.com (media@teekay.com);
- MTM TANKERS singapore@mtmsm.com (singapore@mtmsm.com);
- DRYSHIPS Intl. dryships@capitallink.com (dryships@capitallink.com);
- DSX-Diana Shipping izafirakis@dianashippinginc.com (izafirakis@dianashippinginc.com);
- SAFEBulkers safebulkers@capitallink.com (safebulkers@capitallink.com);
- ARIES OFFSHORE SERVICES basant.konat@ariesoffshore.com (basant.konat@ariesoffshore.com);
- GREAT OFFSHORE info@goloffshore.com (info@goloffshore.com);
- GULF MARINE SERVICES gmsmena@gmsuae.com (gmsmena@gmsuae.com);
Companies contacted by web forms (no e-mail contact available): 
HANJIN SHIPPING / MOL / OOCL / NYK / FRONTLINE / AET TANKERS / NITC / NSC OF SA - BAHRI / 
DYNACOM TANKERS / SBLK Star Bulk Carrier Corp / BALT - Baltic trading / ATLANTIC TOWING 
(CAN) / CASPIAN MAINPORT (IRL) / FUGRO-ROVTECH (UK) / MERMAID MARINE (AUS) / 
TIDEWATER (USA) / VIKING SUPPLY SHIPS (SWE) / UNIFEERDER / X-PRESS FEEDER

5.1.3. Survey conclusions
Above mentioned survey form was sent to many companies as stated in paragraph 5.1.2 on 26th of November 2014, but no reply was ever received, hence no reliable analysis could be provided. As per my later experience when I was looking for deck cadet experience I understood that is very difficult to receive reply especially from big companies due to huge number of e-mails they receive every day. It requires further investigation in order to find out the right contact person for this kind of matters. Even though this chapter does not provide with any relevant information regarding expectations of shipping companies today I have decided to include it in my thesis for those who would like to continue on the investigation in the future.
CONCLUSIONS AND RECOMMENDATIONS

As stated previously in the text, consciousness of International Administrations and maritime industry in general is a good start point to make significant changes in environmental politics. Specific steps were taken and international regulations were adopted in order to increase energy efficiency of ships and reduce impact of international shipping on global warming. Those projects seems to have a good concept and they are focused on progressive reduction of emissions through the years within realistic time period. Hopefully those adopted measurements will not stay only at paper and Administrations will have enough strength to reinforce those laws and will find adequate and fair system to favour those companies who are compliant and penalise offenders.

From previous text, regarding project of energy efficient ships using alternative means of propulsion, I would like to highlight some text and make some conclusions regarding feasibility of explained project. From my point of view it is important to see advantages and disadvantages of each solution and it usefulness on different kind of routes.

In general terms Skysail technology seems to be more accepted so far by the sector due to its easy installation and small area which occupies parts of the ship not designated for cargo purposes. Also its great effectiveness to convert wind energy into propulsion which can lead up to 10 tons of fuel consumption savings per day in optimum wind conditions represents big deal and definitely strong point of this technology. Those strengths are demonstrated on 4 operating vessels using the same as per today.

On the other hand projects using traditional sail technology they are still in phase of studies and testing and we cannot provide with any example of ship using the same with great effectiveness. The big problem is extra fuel cost in low wind conditions due to additional resistance caused by masts. Those are also responsible for limitations in cargo operations as they impede access of shore cranes and they are limiting vessels access to ports with bridges as the vessel needs to assure sufficient under bridge clearance, which means additional navigational chart working for the crew. This part of the problem was partially solved by retractable masts used for example in UT Wind Challenge project.

The projects using wind (both kite and sails) as secondary propulsions are meant for different sizes of vessels operating on different kind of routes. From examples seen in the text it’s clear that those technologies only can be feasible on routes with certain constancy of wind direction and speed. If this condition is fulfilled I do not see any problem to apply those solutions on any kind and size of a vessel.

The key, to provide maximum performance, fuel consumption savings and reduction of emissions, is not only the technology chosen for the secondary propulsion, but also other design criteria like the shape of the hull and alternative sources of energy used to generate power supply on board and increase ship’s energy efficiency.

If all above mentioned conditions will be complied, there are no more barriers to have eco green ships sailing in our seas and oceans within the short or midterm horizon.
## ANNEX

### ANNEX I GLOSSARY (English/Spanish)

<table>
<thead>
<tr>
<th>English (Inglés)</th>
<th>Español (Spanish)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abeam</td>
<td>De través</td>
</tr>
<tr>
<td>Anchorage</td>
<td>Fondeadero</td>
</tr>
<tr>
<td>Apparent wind angle (AWA)</td>
<td>Ángulo de viento aparente</td>
</tr>
<tr>
<td>Apparent wind speed (AWS)</td>
<td>Velocidad de viento aparente</td>
</tr>
<tr>
<td>Arthwartship</td>
<td>En el través</td>
</tr>
<tr>
<td>Attained EEDI</td>
<td>EEDI obtenido</td>
</tr>
<tr>
<td>Auxiliary power reduction due to innovative electrical energy ($P_{AE_{eff}}$)</td>
<td>Reducción de la potencia de los motores auxiliares ($P_{AE_{eff}}$)</td>
</tr>
<tr>
<td>Availability factor of innovative energy efficiency technology ($f_{eff}$)</td>
<td>Factor de disponibilidad de una tecnología innovadora de eficiencia energética ($f_{eff}$)</td>
</tr>
<tr>
<td>Beam reaching</td>
<td>Través</td>
</tr>
<tr>
<td>Bow</td>
<td>Proa/Amura</td>
</tr>
<tr>
<td>Breadth over all (BOA)</td>
<td>Manga total</td>
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<td>Bridge</td>
<td>Puente</td>
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<tr>
<td>Broad reaching</td>
<td>Largo (aleta)</td>
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<td>Bulk carriers</td>
<td>Buques graneleros</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>Mamparo</td>
</tr>
<tr>
<td>Burst</td>
<td>Racha</td>
</tr>
<tr>
<td>Cadet</td>
<td>Alumno en prácticas</td>
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<tr>
<td>Capacity factor ($f_i$)</td>
<td>Factor de capacidad ($f_i$)</td>
</tr>
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<td>Car carrier</td>
<td>Buque porta coches</td>
</tr>
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<td>Car equivalent unit (CEU)</td>
<td>Unidad de coche equivalente</td>
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<td>Carbon dioxide CO₂</td>
<td>Dióxido de carbono CO₂</td>
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<td>Centre of effort (CE)</td>
<td>Centro de esfuerzo (CE)</td>
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<tr>
<td>Close hauled</td>
<td>Ceñida</td>
</tr>
<tr>
<td>Close reaching</td>
<td>Descuartelar</td>
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<tr>
<td>Coast guard ships</td>
<td>Buque de guarda costas</td>
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<tr>
<td>Combination carriers</td>
<td>Buques de carga combinado</td>
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<td>Combined diesel electric -diesel mechanical engine (CODED)</td>
<td>Motor diesel eléctrico - diesel mecánico</td>
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<td>Computational fluid dynamics (CFD)</td>
<td>Dinámica de fluidos computacional (CFD)</td>
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<td>Container ship</td>
<td>Buque de contenedores</td>
</tr>
<tr>
<td>Correction factor for ship specific design elements ($f_j$)</td>
<td>Factor de corrección para los elementos de proyecto específicos del buque ($f_j$)</td>
</tr>
<tr>
<td>English</td>
<td>Spanish</td>
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<tr>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Correction factor for ship specific design elements in ro-ro cargo and passenger ships ($f_{jroro}$)</td>
<td>Factor de corrección para los elementos de proyecto específicos de los buques de carga rodada y buques de pasaje de transbordo rodado ($f_{jroro}$)</td>
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<td>Course sail</td>
<td>Mayor</td>
</tr>
<tr>
<td>Crane</td>
<td>Grúa</td>
</tr>
<tr>
<td>Crew</td>
<td>Tripulación</td>
</tr>
<tr>
<td>Cruise passenger ship</td>
<td>Buque de crucero</td>
</tr>
<tr>
<td>Cruise speed</td>
<td>Velocidad de crucero</td>
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<td>Cubic capacity correction factor ($f_c$)</td>
<td>Factor de corrección de la capacidad cúbica ($f_c$)</td>
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<tr>
<td>Cubic capacity correction factor for ro-ro passenger ships ($f_{cropax}$)</td>
<td>Factor de corrección de la capacidad cúbica para buques de pasaje de transbordo rodado ($f_{cropax}$)</td>
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<td>Peso muerto (PM)</td>
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<td>Oficial de puente</td>
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<tr>
<td>Derrick</td>
<td>Grúa</td>
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<td>Document of compliance (DoC)</td>
<td>Declaración de conformidad (DoC)</td>
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<td>Draught/Draft</td>
<td>Calado</td>
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<td>Dry bulk cargo</td>
<td>Carga a granel seco</td>
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<td>Energy efficiency design index (EEDI)</td>
<td>Índice de eficiencia energética de proyecto (EEDI)</td>
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<td>Energy efficiency measures (EEM’s)</td>
<td>Medidas de eficiencia energética</td>
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<td>Motor</td>
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<td>Certificado Internacional de prevención de la contaminación atmosférica por la máquina (EIAPP)</td>
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<td>Engine settings</td>
<td>Régimen de motor</td>
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<td>Environmental politics</td>
<td>Política medioambiental</td>
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<td>European Union (EU)</td>
<td>Unión Europea (UE)</td>
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<tr>
<td>Ferry (Ro-Pax)</td>
<td>Ferry (Ro-Pax)</td>
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<td>Fins</td>
<td>Aleta/Estabilizador</td>
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<tr>
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<td>Flota</td>
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<td>Fore deck</td>
<td>Cubierta de proa</td>
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<tr>
<td>Forecastle</td>
<td>Castillo de proa</td>
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<td>Gas carrier</td>
<td>Buque gasero</td>
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<td>Gas spark ignition system</td>
<td>Sistema de la ignición por chispa de gas</td>
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<td>Gearbox</td>
<td>Caja de cambios</td>
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<td>General cargo</td>
<td>Carga general</td>
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<td>General cargo ship</td>
<td>Buque de carga general</td>
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<td><strong>Greenhouse gas (GHG)</strong></td>
<td><strong>Gas de efecto invernadero (GEI)</strong></td>
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<td>--------------------------</td>
<td>--------------------------------------</td>
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<tr>
<td>Greenhouse effect</td>
<td>Efecto invernadero</td>
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<td>Gross tonnage (GT)</td>
<td>Arqueo bruto (TRB)</td>
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<td>Guidelines</td>
<td>Directrices</td>
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<td>Barco aproado al viento</td>
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<td>Escora</td>
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<td>Hinder</td>
<td>Estorbar</td>
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<td>Hull air lubrication</td>
<td>Sistema de lubricación por aire del casco</td>
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<td>Infra red (IR)</td>
<td>Infra rojo (IR)</td>
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<td>Intergovernmental panel on climate change (IPCC)</td>
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<td>Certificado internacional de prevención de la contaminación atmosférica</td>
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<td>Convenio internacional para prevenir la contaminación por los buques (MARPOL)</td>
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<td>Certificado internacional de eficiencia energética del buque (IEEC).</td>
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<td>International Chamber of Shipping (ICS)</td>
<td>Cámara internacional de transporte marítimo</td>
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<td>Organización maritima internacional (OMI)</td>
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<td>Launch (ship)</td>
<td>Botadura</td>
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<td>Length (over all)</td>
<td>Eslora (total)</td>
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<td>Length between perpendiculars (LPP)</td>
<td>Eslora entre perpendiculares (EPP)</td>
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<td>Liner</td>
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<td>Gas natural licuado (GNL)</td>
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<td>Low friction coating</td>
<td>Revestimientos de baja fricción</td>
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<td>Lower topsail</td>
<td>Gavia inferior</td>
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<td>Maiden voyage</td>
<td>Viaje inaugural</td>
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<tr>
<td>Manoeuvrability</td>
<td>Maniobrabilidad</td>
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<td>Marine environmental protection Committee (MEPC)</td>
<td>El comité de protección del medio marino (MEPC)</td>
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<td>Maritime safety committee (MSC)</td>
<td>El comité de seguridad maritima</td>
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<td>Market based measures</td>
<td>Medidas basadas en el mercado</td>
</tr>
<tr>
<td>Mast</td>
<td>Mástil</td>
</tr>
<tr>
<td>Maximum continuous rating (MCR)</td>
<td>Potencia máxima continua (PMC)</td>
</tr>
<tr>
<td>Mean wind speed (V_w)</td>
<td>Velocidad media del viento (V_w)</td>
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<tr>
<td>Term</td>
<td>Translation</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>Merchant vessel</td>
<td>Buque mercante</td>
</tr>
<tr>
<td>Moulded breadth</td>
<td>Manga de trazado</td>
</tr>
<tr>
<td>Moulded depth</td>
<td>Puntal de trazado</td>
</tr>
<tr>
<td>Naval frigate</td>
<td>Fragata militar</td>
</tr>
<tr>
<td>Nitrogen oxides ($\text{NO}_x$)</td>
<td>Óxidos de nitrógeno ($\text{NO}_x$)</td>
</tr>
<tr>
<td>Non-dimensional conversion factor between fuel consumption of auxiliary engine measured in g and CO$<em>2$ emission also measured in g based on carbon content ($\text{CF}</em>{\text{AE}}$)</td>
<td>Factor de conversión adimensional entre el consumo de combustible y las emisiones de CO$<em>2$ de los motores auxiliares($\text{CF}</em>{\text{AE}}$)</td>
</tr>
<tr>
<td>Non-dimensional conversion factor between fuel consumption of the main engine measured in g and CO$<em>2$ emission also measured in g based on carbon content ($\text{CF}</em>{\text{ME}}$)</td>
<td>Factor de conversión adimensional entre el consumo de combustible y las emisiones de CO$<em>2$ de motor principal ($\text{CF}</em>{\text{ME}}$)</td>
</tr>
<tr>
<td>Ore carrier</td>
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<tr>
<td>Organisation for economic co-operation and development (OECD)</td>
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<td>Peak wave period ($T_p$)</td>
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<tr>
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<td>Power of the main engine ($P_{\text{ME}}$)</td>
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<td>Product of electrical efficiency of generator, transformer, convertor and motor - weighted average ($\eta_i$)</td>
<td>Producto de la eficiencia eléctrica del generador, el transformador, el convertidor y el motor, teniendo en cuenta la media ponderada, si es necesario ($\eta_i$)</td>
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<td>To furl</td>
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USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

BIBLIOGRAPHY


Ordás Jimenez, Santiago; Environmental Protection - Marpol Conventions

WEBGRAPHY

National Technical University of Athens, CO₂ emissions for the World Commercial Fleet (pdf) [Accessed 5/2/2016]
http://www.martrans.org/docs/publ/REFEREED%20JOURNALS/WMUJMA%20EMISSIONS%202009.pdf

International transport forum, CO₂ Statistics (OECD and Non-OECD countries) [Accessed 9/2/2016]
http://www.internationaltransportforum.org/statistics/CO₂/index.html


MAERSK LINES, Maersk Sustainability Report 2013 [Accessed 15/2/2016]
http://www.maersk.com/en/the-maersk-group/sustainability/~/media/97169832CA46458897FAE47C780CF69F.ashx

(IPCC) 5th assesment report; Climate Change 2014, Synthesis Report, Summary for Policymakers [Accessed on 18/02/2016]

United Nations Framework Convention on Climate Change (UNFCC), Kyoto Protocol to the UNFCCC [Accessed on 18/12/2015]
http:// unfccc.int/kyoto_protocol/items/2830.php

United States Environmental Protection Agency (EPA), Causes of Climate Change [Accessed on 07/02/2016]
https://www3.epa.gov/climatechange/science/causes.html

United Nations Environment Programme, Global environment outlook 4 [Accessed on 07/02/2016]

International Chamber of Shipping, Shipping, world trade and the reduction of CO₂ emissions [Accessed on 08/05/2016]

IMO, Second IMO GHG Study 2009 [Accessed on 20/01/2016]
http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/GHGStudyFINAL.pdf
USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

IMO, Third IMO GHG Study 2014 (Executive summary and final report) [Accessed on 20/01/2016]

IMO, Market-based Measures MBM [Accessed on 20/01/2016]
http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Market-Based-Measures.aspx

BIMCO, EEDI Calculator [Accessed 2/2/2016]
https://www.bimco.org/Products/EEDI.aspx

BIMCO, About Bimco [Accessed 17/02/2016]
https://www.bimco.org/About/About_BIMCO.aspx

IMO, Train the Trainer (TTT) Course on Energy Efficient Ship Operation [Accessed on 18/02/2016]
http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/IMO-Train-the-Trainer-Course.aspx

SCHONE SHEEPVAART PLATFORM, MEPC.1/Circ.815 [Accessed 17/02/2016]

IMO, Index of IMO Resolution [Accessed on 17/02/2016]

IMO, MEPC.245 (66) 2014 Guidelines on method of calculation of the attained energy efficiency design index (EEDI) for new ships. [Accessed on 17/02/2016] - Spanish version of the resolution

IMO, MEPC.245 (66) 2014 Directrices sobre el método de cálculo del EEDI. [Accessed on 17/02/2016]

IMO, MEPC 254 (67) 2014 guidelines on survey and certification of the Energy Efficiency Design Index (EEDI) as amended. [Accessed on 17/02/2016]

IMO, MEPC 233 (65) 2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI) for cruise passenger ships having non-conventional propulsion. [Accessed on 17/02/2016]

IMO, MEPC 231 (65) 2013 Guidelines for calculation of reference lines for use with the EEDI. [Accessed on 18/02/2016]

IMO, MEPC 213 (63) 2012 Guidelines for the development of a ship energy efficiency management plan (SEEMP). [Accessed on 21/02/2016]

IMO, MEPC Meeting summaries [Accessed on 09/08/2016]
http://www.imo.org/en/MediaCentre/MeetingSummaries/MEPC/Pages/Default.aspx

IMO, MEPC 261 (68) Amendments to 2014 Guidelines on survey and certification of the EEDI

IMO, MEPC 1/Circ.850/Rev.1 2013 Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, as amended

IMO, MEPC. 232 (65) 2013 Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, as amended
IMO, MEPC. 255 (67) Amendments to 2013 Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, as amended

IMO, MEPC. 262 (68) Amendments to 2013 Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, as amended

IMO, MEPC.1/Circ.815 Orientaciones de 2013 para el tratamiento de las tecnologías innovadoras de eficiencia energética en el cálculo y I verificación del EEDI obtenido


Skysails GmbH, Cargill reveals the name of the world’s largest kite powered vessel [Accessed on 25/07/2016]

Skysails GmbH, Propulsion for cargo ships [Accessed on 25/01/2016]


Kris De Decker for low tech magazine [Accessed on 2/2/2016]

Marine Insight, The Sail Propulsion System for Cargo Ships by B9 Shipping [Accessed on 27/11/2015]

B9 Energy Group, Design Validation Test [Accessed on 29/11/2015]


B9 Energy Group, B9 Shipping [Accessed on 29/11/2015]

Humphreys Yacht Design, B9 Shipping – Feasibility Study Successfully Completed [Accessed on 02/12/2015]

http://www.runningtideyachts.com/dynarig/index.php


Dykstra, Sailing cargo ship [Accessed on 01/12/2015]
http://www.dykstra-na.nl/designs/wasp-ecoliner/
USE OF ALTERNATIVE MEANS OF PROPULSION IN MARITIME INDUSTRY

Marin Research Institute Netherlands, ECO LINER CONCEPT (pdf) [Accessed 03/12/2015]
http://www.marin.nl/web/file?uuid=000bd829-eeea-4479-bc80-a1ba27fc8cb4&owner=bbe0c94c-375d-4ae8-b452-251a41c25d7

Tree Hugger, Hybrid Container Ship Wind-Driven With 'Automatic' Sails [Accessed on 30/11/2015]

Brian Walsh, Time Magazine online Aug 07 2013 [Accessed on 30/01/2016]

North Sea Region, NSR EU Sail Project 2012-2015 [Accessed on 09/08/2016]
http://www.nsrsail.eu/e-library/

Wolfson Unit website [Accessed on 02/12/2015]
http://www.wumtia.soton.ac.uk/

Maltese Falcon website [Accessed on 05/12/2015]
http://www.symaltesefalcon.com/

Marine Insight, Eoseas: A 5 Hulled Cruise Ship Concept [Accessed on 8/12/2015]

http://www.stirlingdesign.fr/presses/conferences/stirling_design_green_ship_copenhagen.pdf

Wordless Tech, Next generation cargo ship uses wind energy [Accessed on 10/12/2015]
http://wordlesstech.com/2012/05/01/next-generation-cargo-ship-uses-wind-energy/

Blue Bird Marine Systems, Wind Power [Accessed on 10/12/2015]
http://www.bluebird-electric.net/wind_powered_ships_marine_renewable_energy_research.htm

Wind Challenger Project HP, Questions for Wind Challenger Project [Accessed on 10/12/2015]
http://wind.k.u-tokyo.ac.jp/FAQ_en.html


Wallenius Wilhelmsen, Green Flag Ship [Accessed on 15/12/2015]

Windstar Cruises, Wind Surf overview [Accessed on 18/12/2015]
http://www.windstarcruises.com/yachts/wind-surf/overview/

Star Clippers, Royal Clipper Cruises [Accessed on 18/12/2015]
http://starclippers.co.uk/our-fleet/royal-clipper/introducing-royal-clipper.html

Sail Training International, What is sail training [Accessed on 22/12/2015]
http://www.sailtraininginternational.org/sail-on-board/what-is-sail-training

Mail Online, Return to sail power: Maiden voyage for world's first merchant ship powered by giant kite [Accessed on 25/01/2016]

Briese Schiffahrt, Fleet list - BBC Skysails Technical data [Accessed on 05/08/2016]
www.briese.de/fileadmin/fleet/prospekte/101_prospekt.pdf

Enercon web page, News - Class renewal for the E-Ship 1 [Accessed on 05/08/2016]