TOWARDS ZERO SHIP EMISSIONS II – PROJECT GREENSHIP

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Abstract

IMO's own International Shipping Facts and Figures report 2012 stated the number of vessels across the globe of 100 Gross Tonnage and over was 104,304, with cargo carrying vessels being 55,138 and expressed concern about the exponential increase of CO_2, NO_2, CH_4 and so forth in recent year. The EU responded by setting targets. The EU 2050 objectives set some intermediate targets for Eco-Efficient Vessel Emission Reduction for key pollutants: CO_2: >80% (-30% by 2020), NOx: 100% (-80% by 2020), SOx: 100% (-80% by 2020) and Noise Reduction: -3dB. A review of current research (Ziarati et al, 2018) clearly shows that the targets set for 2020 by both the IMO and EU were not achieved and the 2050 goals are unlikely to be achieved. The Industry is taking steps to reduce its air pollution and carbon footprint due to recent and upcoming IMO and EU regulations. The IMO GHG study, Buhang et al (2009) reports that the IMO has introduced some limits but has been unable to monitor ship emissions.

EMSA has tried the use of satellites and drones to monitor ships which pollute the sea but has been unable to monitor ship emissions and waste discharge at sea effectively due to technical difficulties and also vastness of the oceans.

As the regulations and technologies, governing energy efficiency on board ships becomes more complex, it is accepted by both the IMO and the shipping industry that seafarers require specific training to a much higher level in these fields. There needs to be a position specifically for managing, checking and controlling a ship's emissions for gases that are harmful to human health and the environment, an "Emissions Manager". As this is a brand new position, there are no defined competences for this role nor any specific knowledge, understanding or proficiency for it.

The paper gives full account of IMO efforts in recent years in setting legislation for key pollutants and reports on a new job specification for the Emissions Manager and proposes that an e-course being developed by several EU member states for the training of key ship officers and crew on how to minimise and monitor harmful emissions. The corresponding programme concerned with the current practice of managing emissions as well as the principle of making ships energy efficient. The new training programme targets both current cadets and existing seafarers in order to complement their skills.

1. Introduction

The issue of global warming is widespread, rapid and affecting every region of planet Earth and is widely known as the "greenhouse effect". This is mainly due to human action through the industries that use hydrocarbon fuels from crude oil. Fortunately, society in general is well aware of the impact on the environment and in particular by maritime transport. Without being the biggest polluter of the planet, only 2.7% of the total CO_2 emitted, a reduction in greenhouse gases of 80% by 2050 is the aim of the IMO.

Reducing air pollution by focusing on greenhouse gases is a task that is not the only responsibility of national and international governments and government agencies, etc. Adoption of regulations that avoid and reduce air pollution also requires the collaboration of the industry. Without the support of the manufacturers of the energy systems used in the propulsion and auxiliary services of the ship, ship designers and shipbuilders and finally of the seafarers who have to operate these systems efficiently, it would not be possible to help meet the goals of the IMO, as the representative of all maritime countries.

It is a well-known fact that once a ship's hull has been designed and built, there are few if any options available to reduce drag and improve fuel consumption. The same applies to propulsion and auxiliary machines, since their effectiveness is and will be what the manufacturer has achieved when designing them.

Whilst it is true that once a ship is constructed little can be done to reduce fuel consumption or ship emissions, nevertheless much can be done to keep its fuel consumption at an efficient level. For this reason, it is necessary to ensure that the crew has the necessary knowledge to operate the ship efficiently, including knowing when to slow steam or make use of wind, tide and currents. Therefore, the ‘Toward Zero Ship Emission’, the GreenShip project was initiated to ensure ships run efficiently and produce minimum emissions.

2. IMO GHG Studies

IMO, has been mindful of the need to reduce GHG from ships, and has conducted four studies on air pollution by CO_2, NO_2 and CH_4 from ships. The First IMO GHG Study on GHG emissions, published in 2000, and estimated that ships engaged in international trade in 1996 contributed to about 1.8% of the world’s total anthropogenic CO_2 emissions. The Second IMO GHG Study, published in 2009, estimated that international shipping emissions in 2007 were 880 million tonnes, 2.7% of the global total anthropogenic CO_2 emissions. The Third IMO GHG Study, published in 2014, estimated that international shipping emissions in 2012 were 796 million tonnes, 2.2% of the global total anthropogenic CO_2 emissions. The Study also updated the CO_2 estimates for 2007 to 885 million tonnes, or 2.8%.

The most recent estimates included in this Fourth IMO GHG Study 2020 show that GHG emissions of total shipping have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase) mostly due to a continuous increase of global maritime trade. The share of shipping emissions in global anthropogenic GHG emissions has increased from 2.76% in 2012 to 2.89% in 2018.

It can be concluded that even with IMO's concern about reducing fuel consumption on board ships, its four studies only focus on the amount of fuel consumed by ships and not on the measures that should be taken to reduce it. However, it is of great interest and a great step forward, to be aware of the amount of CO_2 that shipping releases into the atmosphere. However, in line with IMO's concern to reduce pollution, this intergovernmental organisation has created a course called "Train the Trainers" in which the measures that should be applied on board ships are studied in order to achieve the 2050 target of reducing GHG by 80%.

3. The STCW Code

The minimum mandatory standards for seafarers' training are set in the Seafarers' Training, Certification and Watchkeeping (STCW) Code. A review of the minimum training requirements in STCW Code shows that both in chapter 2, corresponding to the deck department and chapter 3, corresponding to the engineering department, the knowledge and skills contained in them, at both operational and management levels, address the design, operation and maintenance of onboard equipment. Although there is a specific focus on good practices and their safe operation there is little on aspects relating to reducing emissions or fuel consumption. For this reason, the current and future seafarers must have specific training in the field of ship design and construction, efficient operation and maintenance of the ship, in brief, in the GHG reduction and greater awareness of fossil fuels impact on the environment.

In addition, as part of the battle to reduce GHG to a minimum, fuels other than fossil based must be considered such as hydrogen, ammonia and bio-fuels or electric provided emissions elsewhere are not increased.

4. MARPOL Convention

The MARPOL Convention is entirely dedicated to the protection of the marine environment. Annex VI of this instrument establishes the measures to reduce air pollution including from GHG, CO_2, NOx and others such as PM and SOx. Regulation 20 and 21 of Annex VI of MARPOL: Energy Efficiency Design Index attained (EEDI attained) and EEDI required. As of January 1, 2013, every new ship must comply with an energy efficiency level according to the type of ship. This energy efficiency level is the Energy Efficiency Design Index (EEDI) and is has been gradually adjusted every five years. This has encouraged the use of more energy-efficient equipment and machinery, encouraging constant innovation and development of all the factors that affect fuel consumption and ship efficiency. The EEDI does not define a specific technology but focuses on a specific figure for a specific ship design, expressed in grams of CO_2 per ton of ship capacity and mile; the lower the EEDI, the higher the energy efficiency. By not restricting the technologies, ship designers and builders have some flexibility.

The equation for the EEDI is concerned with the basic amount of CO_2 produced by the main and auxiliary engines and elements of efficient energy generation such as shaft generators. Innovative energy efficient systems such as air lubrication systems, Flettner rotors or waste heat recovery systems could be considered for reducing fuel consumption hence engine emissions.

With the EEDI, an absolute value of the amount of CO_2 per ton-mile of fuel burned is obtained. The ship will emit with the equipment and technologies with which the ship has been equipped for, but it does not tell how to maintain this Index, as poor operation and maintenance of the equipment can cause an increase in the index, which means consequentially an increase in fuel consumption.

In very simple terms, EEDI can be represented by:

$$EEDI = \frac{emissions\ of\ CO_2}{ship\ capacity}$$

Main engine

Auxiliary engines

$$EEDI = \frac{\left(\prod_{f=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE^*}\right)}{f_i \cdot f_c \cdot f_l \cdot Capacidad \cdot f_w \cdot V_{ref} \cdot f_m} +$$

Efficient and innovative energy for power generation

$$\frac{\left(\left(\prod_{f=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right)}{f_i \cdot f_c \cdot f_l \cdot Capacidad \cdot f_w \cdot V_{ref} \cdot f_m}$$

Efficient and innovative energy for propulsion

$$- \frac{\left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME^{**}}\right)}{f_i \cdot f_c \cdot f_l \cdot Capacidad \cdot f_w \cdot V_{ref} \cdot f_m}$$

Source: IMO MEPC.322(74)

Regulation 22 of Annex VI of MARPOL: Ship Energy Efficiency Management Plan (SEEMP); as of January 1, 2013, states that it is a requirement for ships over 400 GT operating internationally. As for ships of 5,000 GT or more, no later than December 31, 2018, these must include in the SEEMP a description of the methodology that will be used to collect the data required under regulation 22A on Collection System of data on the fuel consumption of ships.

The purpose of the SEEMP is to establish a mechanism for the ship to improve efficiency during its operation, i.e. in its operational phase. In this way, it seeks to optimize the performance of the ship to consume less fuel and produce less CO_2 emissions. The SEEMP is an individualized plan that must be adapted to the characteristics of each ship.

The SEEMP consists of two parts: the first tries to provide guidelines to monitor the ship's efficiency over time; and for this, it uses four phases: planning, implementation, monitoring/self-evaluation and improvement. The second part deals with the methodology for collecting data.

The first part gives us the measures to improve energy efficiency. Greater energy efficiency means that the same amount of work is achieved by using less energy. As a result, less fuel is consumed hence emissions of all combustion exhaust gases are reduced.

Thanks to technology and engineering, there is a wide variety of options to increase the efficiency of ships and thus reduce CO_2 emissions. These measures can be divided into two groups. On one hand, the design measures would be part of the construction process of new ships or existing ships that go through a “refit” process. On the other hand, operational measures to optimise the ship such as trip planning, fleet management, energy management on board, speed optimisation, use of emerging alternative fuels, etc. can be considered by any type of ship, either existing or new.

However, there are many more options besides these. The options shown do not result in the same efficiency in all ships, nor are they applicable to all ships.

While both the EEDI and the SEEMP are indicators of improvement of a ship's energy efficiency, providing the values that can be achieved by reducing fuel consumption and the steps that can be taken to do so; they do not explicitly provide the means to enable maintaining and lowering these indices. The above entails that the only way to maintain and lower these values is through adequate training of seafarers, in addition to creating the position of the manager for the efficiency of the equipment and other elements related to the fuel consumption on board ships. To this end, the core of the GreenShip project incorporates a specific training course on energy saving of ships that clearly and concisely explains to future ship managers the energy consumed by the ships throughout its life cycle. The course provides knowledge of all the applicable technology and its efficient use, measures taken in the design, redesign, operation and maintenance of the ship's energy equipment.

5. Emission and Energy Manager Training Programme

The GreenShip course addresses the need for;

a) Qualified personnel to implement regulations and technologies.
b) Emission control and energy efficiency of ships through cost savings and more efficient use of fuels.
c) The mobility and enhancement of employability in the global labour market for EU/worldwide seafarers and cadets who take the qualification either as part of their initial studies or as part of a continuing Vocational Education and Training (VET), for career development.
d) IMO SEEMP and related requirements of Maritime and Education and Training (MET providers to offer courses that are relevant and comply with latest regulations and requirements of the industry and address new skills gaps that are emerging with the latest technologies, requirements and practices for maritime emissions control and energy efficiency and
e) The integration and development of e-learning and digital skills into the EU's MET so that they can design and deliver e-learning materials as an online learning platform for the maritime officers who can truly benefit from online access to learning and training materials.

6. Teaching, Learning and Assessment Strategy

a) This is a standalone maritime emission and energy management training programme delivered using an e-learning platform that can be integrated into an existing maritime education training programme or delivered as a training module for seafarers and those involved in the shipping industry and maritime administration.
b) This training is competence based incorporating several learning outcomes.
c) The programme is in line with relevant IMO rules and regulations and compliant with European Credit Vocational Education and Training (ECVET), and with the Institution of Marine Engineering, Science and Technology (IMarEST) Continuous Professional Development (CPD) requirements.
d) It contains a set of assessment criteria based on the learning outcomes.
e) The assessment is part of the learning strategy and there is a provision for online self-assessment followed by several in class assignments supported by scenario based final assessment and
f) The assessment has marking criteria awarding the trainee the grade of 'Competent' or 'Referral (not yet competent)'. The course is comprised of the following components.

7. Ship Emission Manager Job Specifications

Ship emission manager is primarily responsible for managing all aspects of emissions management on board vessels. The manager is expected to:

i. Have knowledge, understanding and application of IMO emissions requirements/regulations.
ii. Be familiar with all emissions management systems on board and IMO and national regulations in place including Energy Efficiency Operation Index, EEOI, and Energy Efficiency Design Index, EEDI, with a specific knowledge of toxins produced by the ship engines as well as other machinery.
iii. Have skills in emission reduction and energy saving practices including engine propulsion, heating cooling and so forth.
iv. Be familiar with the ISM practices, and company specific measures including aspects relating to any quality standards which may relate to ISO 29000 or ship specific standards such as ISO 58000; and
v. Be aware of IMO's MARPOL, SOLAS, and related standards including aspects concerning maritime environment protection.

8. Ship Emission Manager Training Specifications

The aim is development of the training specifications to:

i. Provide specific education, awareness and training that is in line with national and international legislations.
ii. Enable effective and efficient management of emission control and monitoring processes energy transformation systems used on board ships and the reduction of consumption with a view to saving energy, reducing emissions and improving the overall quality of emission management practices.
iii. Facilitate the initial assessment on board ships and identify areas in order to improve effective and efficient emission control and monitoring processes as well as transformation of energy and its use, with regard to the key processes concerning SEEMP, and in particular EEOI and EEDI and Energy Efficiency Existing Ships Index, EEXI.

9. Chapters and Learning Outcomes - Summary Content

The online training manual will primarily include five chapters of the training programme and one of the chapters (introductory) will provide the IMO and EU rules and regulations regarding energy efficiency and emissions. The training programme produced will include a full curriculum, which takes into account the ECVET system, delivery guidance, as well as sample learning materials. The training programme will also include provision for web based assessment tools. The content of the training programme contains primarily information on the IMO EEDI, EEXI; EEOI, SEEMP and good practices in other industries such as automotive and aerospace. A recognised professional body will evaluate the course.

The project will also take into account IMO model course 1.38 – Marine Environmental Awareness (2011). This is to ensure there are no overlaps.

9.1. Chapter 1

This chapter describes the challenges faced in reducing global warming and reports on aspects concerning climate change. The focus is on IMO and EU efforts and rules/regulations. It describes all IMO and EU's measures and regulations and gives practical examples of each measure and/or rule, assess compliance with international legislations and requirements, monitor different indices such as EEDI, EEXI, EEOI and assess compliance with inspection, approval and accreditations.

9.2. Chapter 2

This chapter deals with the systems and sub-systems of emission production, dispersion and monitoring on board ships identifying the differences in each main type of ship. It focuses on the ability to:

i. Identify the emission measures of different types/size of ship and their design.

ii. Assess safety concerns in different environmental conditions.
iii. Identify operational requirements at sea/in port and their environmental impact.
iv. Assess fuel emissions from vessels such as CO_2, NOx, SOx and PMs from the combustion of fuels and their compliance with legislations and
v. Identify different types of emissions generated from incinerated waste from cruise vessels and compliance with environmental requirements.

9.3. Chapter 3

This chapter focuses on the core part of the emission management programme namely, how emissions are reduced to a minimum while maximizing energy efficiency, by means of mechanisms such as slow steaming, wind direction and strength monitoring as well as energy saving records for future management decisions. The competence developed are the ability to:

i. Implement ship's emission management, assess different ship emission management options.
ii. Assess fuel emissions management systems of ships regarding CO_2, NOx, SOx and PMs from the combustion of fuels and their compliance with relevant legislations.
iii. Identify different types of waste discharges generated from incinerated waste mainly from cruise vessels in compliance with environmental requirements, audit and inspection requirements including ISO 50001 and/or ISO 14001 as well as EU Monitoring, Reporting and Verification (MRV), Directive (EU) 2015/757, as well as the IMO fuel oil consumption data collection system, and
iv. Develop the outline of company emission management plans in compliance with IMO SEEMP.

9.4. Chapter 4

This chapter describes the marine propulsion system and emission monitoring. The abilities developed are:

i. Assessment of different ships.
ii. Evaluation emission generation and its use on board.
iii. Assessment of the fuel emissions from ships regarding CO_2, NOx, SOx and PMs from the combustion of fuels and their compliance with legislations; communicate and manage conflicts with regards to effective and efficient use of engine energy usage, and
iv. Development of the outline of a company engine emission management sub-plan in compliance with IMO SEEMP.

9.5. Chapter 5

This chapter concerns navigation and examples of savings emanating from the application of good practices. The competences developed are ability to:

i. Describe good practice in navigation that help to save energy and reduce emissions.
ii. Provide guidance to crew with regards to any changes at sea and weather conditions.
iii. Identify the navigation and operational requirements at sea/in port and their environmental impacts, and
iv. Communicate and manage conflicts about effective and efficient use of overall use of energy.

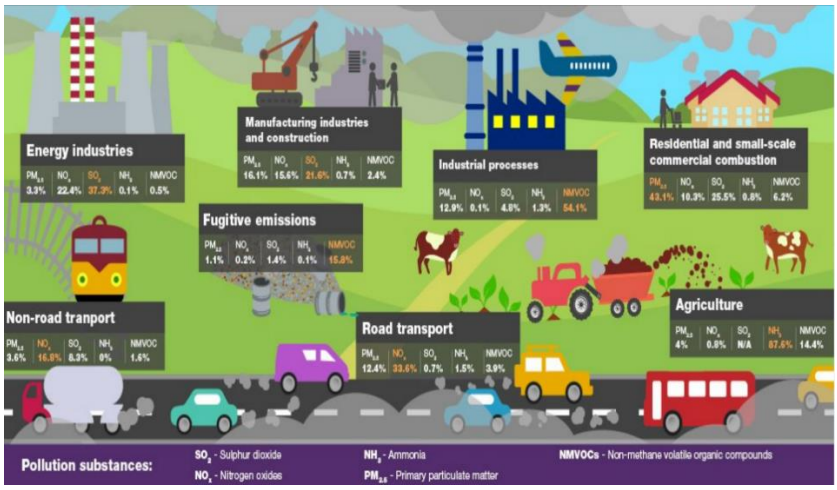
9.6. Chapter 6

This chapter concerns port operations and air pollution. In port areas, air pollution is primarily due to ships. However, other equipment use energy hence contributes to air pollution in port areas. For example cargo loading devices, trucks and other transportation units, buildings and energy needed for these buildings and harbour crafts that provide additional services to port and shipping companies. The abilities developed are:

i. Ship times in port and just-in-time operations as well as improved cargo handling.
ii. Other measures for avoiding ship waiting times in port.
iii. Technologies for port air quality improvements and GHG emission reduction.
iv. Ship in port operational energy efficiency measures, [5] onshore power supply facilities; and
v. Green port initiatives and port environmental programmes.

10. Conclusion

It must be appreciated that reducing the use of fossil fuels in power stations will greatly reduce emissions and will ease the pressure on transport system. The following diagram shows the contribution of each major sector to pollution levels with Transport producing the largest NO_x (33.6%) and being the third largest **$PM_{2.5}$** (12.4%) emitter. If non-road transport emissions are added to Road then the NO_x level would be over 50% of total and **$PM_{2.5}$** over 16% of the total.



Source – Public health England, 2018

$PM_{2.5}$ is the greatest threat to human Health. The smaller the particle the greater the risks to health as these have a greater chance of being inhaled deep into the lungs. The strongest evidence for impact on health is associated with $PM_{2.5}$, each 5mcg/m_3 increase in $PM_{2.5}$ leads to a 7% increase in mortality and over 1.3 million new cases of disease are attributable to $PM_{2.5}$ [9].

The average price of Electricity in the US dropped from $2.5 in 1900 to $0.1 in 2020 ($ per kWh at 1990 prices). In fact, the average price of electricity has dropped rapidly in the Western world and in many countries worldwide albeit not at the same rate as in the West. Yet, global carbon emissions from energy transformation have gone up from Zero in 1850 to almost 35 Gigatones in 2020. There has been almost an exponential rise in CO_2 level. Almost 26 billion tons of CO2 per year, more tons/person in the West/developed world and a lot less tons/person elsewhere, on average 5 tons per person worldwide.

On electrical energy, all the batteries on earth can store about 30 minutes of the world's energy needs. Just 2% of the world's cars are electric at this point. There are 289.5 million cars just on U.S. roads as of 2021. About 98 percent of them are gas-powered. Toyota selling 81% of its cars in the US warns that the grid and infrastructure simply are not there to support the electrification of the private car fleet. A 2017 U.S. government study found that we would need about 8,500 strategically placed charge stations to support a fleet of just 7 million electric cars. Electrifying the auto fleet will require a massive overhaul of the power grid and an enormous increase in power generation; hence, the reason for the success of Hybrid [3]. There are currently a limited number of electric ships and considering the life cycle of ships, their propulsion systems are likely to remain almost unchanged for some time to come, albeit the fuels used will change to great extent from diesel to LNG, Ammonia and bio fuels. Considering the growth of Emission Control Areas, worldwide opportunities are being created to either use non-fossil fuels or electric drive for entering these zones.

The greenhouse gas (GHG) emissions including carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2), expressed in CO2e of total shipping (international, domestic and fishing) have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase). In 2012, 962 million tonnes were CO2 emissions, while in 2018 this amount grew 9.3% to 1,056 million tonnes of CO2 emissions. The share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018 [4].

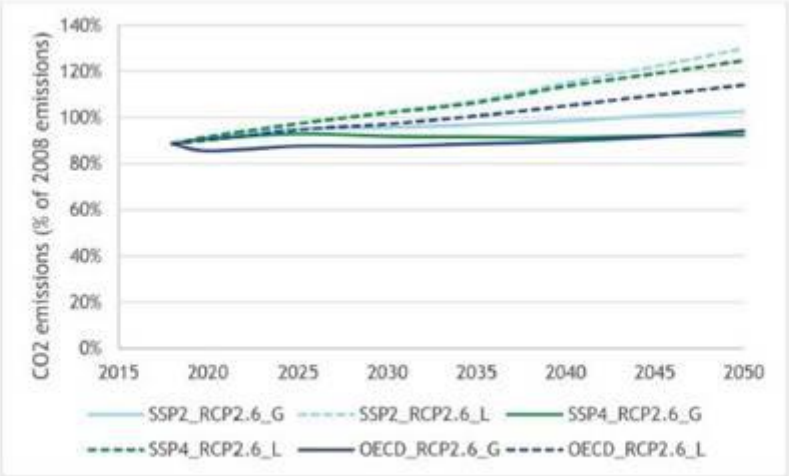


Figure 1 – *Projections of maritime ship emissions as a percentage of 2008 emissions*

The position of a ship emissions manager on board is very necessary as a specialist to reduce the consumption of fuel and the generation of GHG. Another conclusion is that all crew should receive training on the efficient use of fuels onboard. Finally, the use of EEDI, EEXI, EEOI and SEEMP is fundamental, but, it is necessary that the crew on board receives the most appropriate education and training on how to best operate and maintain all fuel consuming systems on board to achieve the maximum efficiency and optimum related indexes. Following are some of the current efforts in the marine industry:

LNG – An effective increase of 4% equivalent in both CO2 and CO2e due to Methane
Sails – A decrease of 2% in both CO2 and CO2e
Others – A decrease of 1% in both CO2 and CO2e – Most solution are potential benefits as shown below.

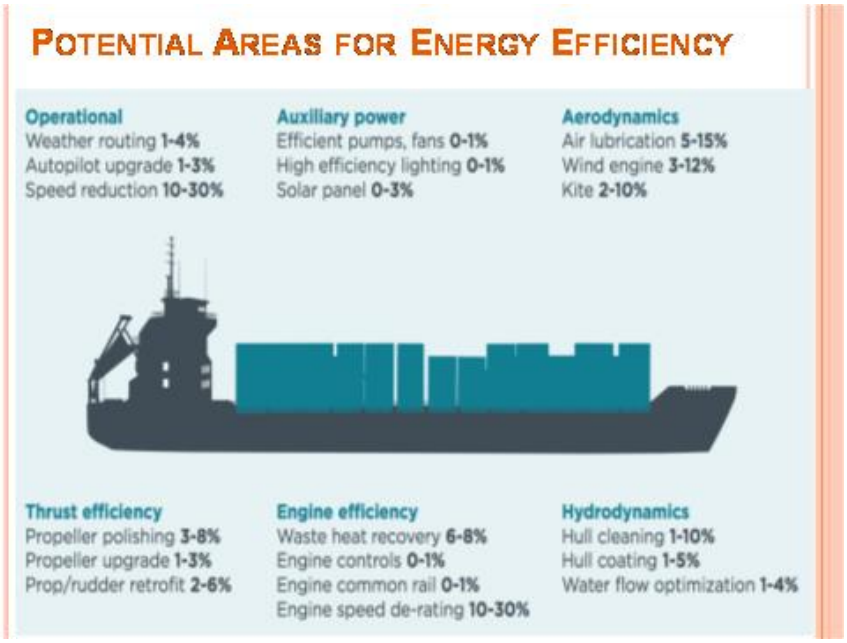


Figure 2

Recent research [6] by Arthurs has shown that provided the government invests in local supply chains and provide funds for shipping companies to take advantage of energy savings as well as encouraging port electrifications through renewable; these could substantially reduce the level of CO2 emissions by 25% by 2030 to counter the expected increase of possibly by 30% as shown in figure 1 above. So, the best scenario indicates status quo hence no reduction of CO2 is expected from the shipping industry.

To overcome the level of CO2 Emissions currently we are failing miserably in shipping but let us hope that taking the above potential areas for energy efficiency seriously into consideration the best we can do is to keep the CO2 emissions at 2018 level in 2030 which is still more than a safe level of pollution. One way of reducing CO2 is in the use of Ammonia and using Flettner cylinders and sails to assist in propelling ships.

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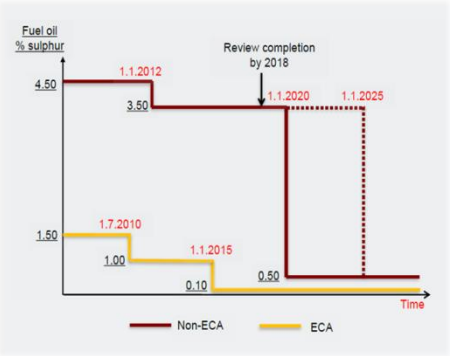
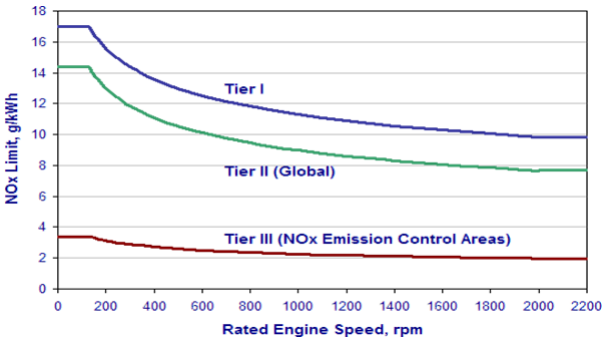
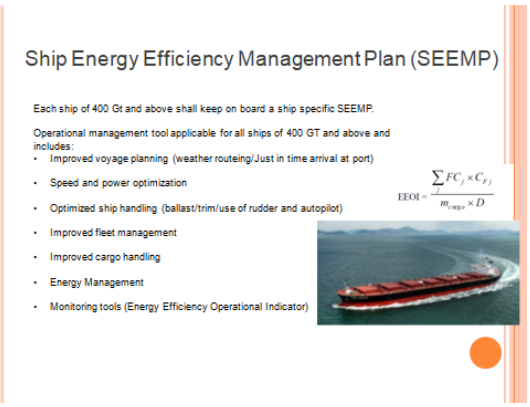
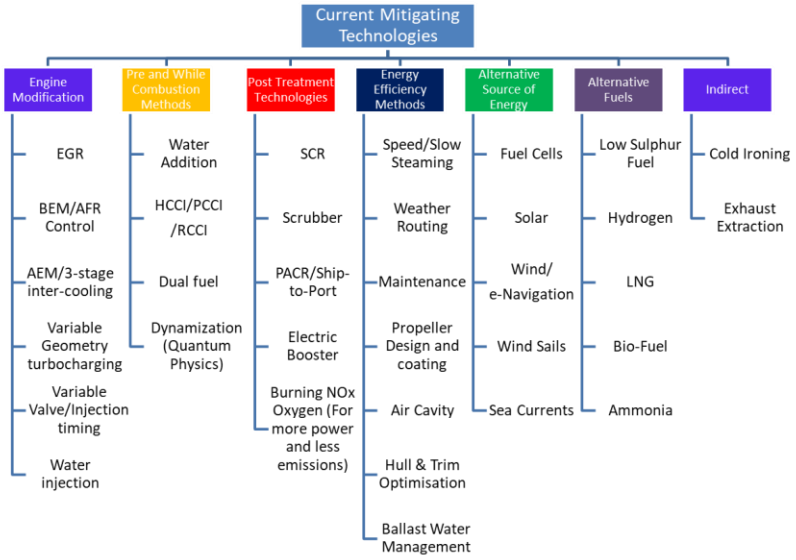
Slides









Current mitigation technologies in marine industry source [7]: based on C4FF and New Castle University, SIG Seminar and IMechE Lecture both in 2019; revised 2021

The shipping industry is responding and following are clear example that International legislation and creation of Emission Control Area has encouraged many shipping companies to seriously reduce their fuel consumption and take measures to reduce ship emissions.

All electric ship - Zero-emissions tanker Corvus Energy propulsion system on board the all-electric Asahi Tankers vessel and on the right LNG-Powered Purse Seine/Trawler

Stena converted a ballast water tank on Stena Germanica to store methanol securely on board IMO approves methanol as a safe ship fuel and on the right MHI tests pure hydrogen gas engine