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Study on energy efficiency technologies for ships

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Energy Efficiency Technologies for Ships

Inventory and technology transfer

Final Report

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Abstract

At global level the International Maritime Organization adopted several measures which are aimed at improving the energy efficiency of shipping. This report identifies the most important barriers which prevent the effective implementation of the measures and provides a list of possible measures to overcome these barriers.

One of the major barriers to the effective implementation of the measures is the heavy reliance it places on Flag States for inspection of vessels and enforcement of provisions. Some of these Flag States are not signatories to all MARPOL Annexes, which also hampers the implementation of the measures.

Flag States, where most merchant ships are registered, are commonly developing nations. Flag States have less resources to properly carry out vessel inspections. Consideration should be given to transfer knowledge to these states in order to further stimulate the adoption of energy efficiency technologies.

This reports provides a list of fourteen energy efficiency measures that both provide a large energy efficiency improvement and can be implemented in many ships in order to identify which measures should be included in the capacity building.

Furthermore this report provides cost estimations for several capacity building options like workshops, trainings and an online platform.

Executive Summary

In July 2011, the International Maritime Organization (IMO) adopted two energy efficiency measures, which entered into force in 2013: the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Managements Plan (SEEMP) for all ships. Nevertheless, the IMO recognises the need for further action to reduce emissions from international shipping in view of the continued expected growth of the world economy and associated transport demand.

One of the major barriers to the effective implementation of the EEDI and the SEEMP is the heavy reliance it places on Flag States for inspection of vessels and enforcement of provisions. Some of these Flag States are not signatories to all MARPOL Annexes, which also hampers the implementation of the measures. Flag States, where most merchant ships are registered, are commonly developing nations. Such Flag States often have less resources to properly carry out vessel inspections. Consideration should be given to transfer knowledge to these states in order to further stimulate the adoption of energy efficiency technologies. The most important technologies regarding efficiency improvement are summarised in the table below.

Table: Energy Efficiency Measures for ships

Main category	Measure	Efficiency at average circumstances	Ease of installation	Payback time	Investment
Hull	Bow optimisation	10%	all ship types	short (<3 years)	Medium
Main Engines	Wind power	20%	only special ship types	long (>15 years)	High
Propellers and Rudders	Ducted propeller	10%	all ship types except ferry and cruises	medium (4-15 years)	Medium
Propellers and Rudders	Contra-rotating propellers	13%	only special ship types	long (>15 years)	High
Propellers and Rudders	Wheels	10%	all ship types except ferry and cruises	short (<3 years)	Medium
Control Systems	Waste heat recovery	8%	new build only	medium (4-15 years)	Medium
Propellers and Rudders	Rudder bulb	4%	all ship types except ferry and cruises	medium (4-15 years)	Low
Propellers and Rudders	Post swirl fins	4%	all ship types except ferry and cruises	short (<3 years)	Low
Hull	Hull coating	5%	all ship types	short (<3 years)	Low
Hull	Air lubrication	9%	new build only	medium (4-15 years)	Medium
Propellers and Rudders	Twisted rudder	3%	all ship types except ferry and cruises	medium (4-15 years)	Low
Main Engines	Main engine de-rating	3%	all ship types except ferry and cruises	medium (4-15 years)	Low
Auxiliary engines	Common rail upgrade	-	all ship types	medium (4-15 years)	Very Low
Main Engines	Common rail upgrade	0.3%	all ship types	medium (4-15 years)	Very low

From this research it is clear that conventional technology is available to achieve high efficiency gains. It is possible to save 35% of fuel with only a few improvements that require an upfront investment that can be earned back within 15 years. High investments like contra rotating propellers and wind power (experimental technology) bring the highest savings (13 – 20%). The medium investments are in-between (5-10%) and the low investments only bring relatively small energy efficiency improvements (<5%).

When the ship owner has too few opportunities to share investment with charterers this leads to a split incentive: a ship owner may invest the up-front capital to put in energy-efficient technology but not receive the benefits. This is typically a problem for investments with a high payback time, i.e. the wind power and contra rotating propellers.

Several ways to overcome the knowledge transfer barriers were presented that can be categorised as follows:

- Workshops and trainings:
    - Capacity building workshops for administrations
    - Regional workshops
- Technical training
    - Training in calculating and verifying the EEDI
    - Development of model courses
- Online platform
    - Inventory of energy-efficiency technologies
    - Creation of a website with all relevant information for the target audience
    - Improved access to information and information sharing
    - Provide verified information on real-world energy efficiency improvements via a monitoring programme

This report provides cost estimations for each of these capacity building options. The most expensive being a capacity building project that would take all aspects into account, similar to GloBallast, which assists developing countries and their maritime industries in implementing international regulations on ballast water management and preventing risks arising from the transfer of harmful aquatic organisms. The total budget for GloBallast for the 2008-2012 period was US$23 million.

Résumé

En Juillet 2011, l'Organisation Maritime Internationale (OMI) a adopté deux mesures d'efficacité énergétique, qui sont entrées en vigueur en 2013: l'Indice de Conception d'Efficacité Energétique (EEDI en anglais) pour les navires neufs et le Plan de Gestion d'Efficacité Énergétique (SEEMP en anglais) pour tous les navires. Néanmoins, l'OMI reconnaît la nécessité de nouvelles mesures pour réduire les émissions du transport maritime international, compte tenu de la croissance continue de l'économie mondiale et de la demande de transport correspondante.

L'un des principaux obstacles à la mise en œuvre des mesures EEDI et du SEEMP est liée au fait que l'inspection des navires et l'application des dispositions sont de la responsabilité des États de pavillon. Certains de ces États de pavillon ne sont pas signataires de toutes les annexes de la convention MARPOL, ce qui entrave également la mise en œuvre des mesures. Les États de pavillon où la plupart des navires de commerce sont immatriculés sont souvent des pays en développement. Ils ont souvent moins de ressources pour mener à bien les inspections de navires. Il faudrait envisager de transférer des connaissances à ces États afin de stimuler davantage l'adoption des technologies d'efficacité énergétique. Les technologies les plus importantes concernant l'amélioration de l'efficacité sont résumées dans le tableau ci-dessous.

Catégorie principale	Mesure	Rendement en circonstances normales	Facilité d'installation	Retour sur investissement	Investissement
Coque	Optimisation de la proue	10%	Tous types de navires	court (<3 ans)	Moyen
Moteurs principaux	Energie éolienne	20%	Uniquement certains types de navires	long (>15 ans)	Élevé
Hélices et Gouvernails	Tuyère Kort	10%	Tous types, sauf ferry et paquebots	moyen (4-15 ans)	Moyen
Hélices et Gouvernails	Hélice contrarotative	13%	Uniquement navires spéciaux	long (>15 ans)	Élevé
Hélices et Gouvernails	Roues à Aubes	10%	Tous types, sauf ferry et paquebots	court (<3 ans)	Moyen
Systèmes de contrôle	Récupération de chaleur	8%	Uniquement navires neufs	moyen (4-15 ans)	Moyen
Hélices et Gouvernails	Ampoule de gouvernail	4%	Tous types, sauf ferry et croisière	moyen (4-15 ans)	Bas
Hélices et Gouvernails	Ailettes de turbulence	4%	Tous types, sauf ferry et paquebots	court (<3 ans)	Bas
Coque	Revêtement de coque	5%	Tous types de navires	court (<3 ans)	Bas
Coque	Injection d'air sous la coque	9%	Uniquement navires neufs	moyen (4-15 ans)	Moyen
Hélices et Gouvernails	Gouvernail tordu	3%	Tous types, sauf ferry et paquebots	moyen (4-15 ans)	Bas
Moteurs principaux	Ralentissement du moteur (de-rating)	3%	Tous types, sauf ferry et paquebots	moyen (4-15 ans)	Bas
Moteur auxiliaire	Modernisation du common rail	-	Tous types de navires	moyen (4-15 ans)	Très Bas
Moteurs principaux	Modernisation du common rail	0.3%	Tous types de navires	moyen (4-15 ans)	Très Bas

Cette recherche montre clairement que des technologies conventionnelles sont disponibles pour réaliser des gains élevés d'efficacité. La mise en œuvre des mesures dont l'investissement se rentabilise en moins de 15 ans permet déjà d'économiser 35% de carburant. Des investissements élevés comme les hélices contrarotatives et l'énergie éolienne (technologies expérimentales) permettraient des économies d'énergies les plus élevées (13-20%). Les investissements de taille moyenne rapportent des économies de 5-10% et les investissements les plus faibles apportent relativement peu d'économies (<5%).

Lorsque les propriétaires de navires n'ont pas la possibilité de partager les investissements avec les affréteurs, cela mène à une discordance des intérêts: un armateur peut investir le capital pour des technologies d'économie d'énergie mais n'en recevra pas les bénéfices. Ceci est un problème typique pour les investissements avec un temps de récupération élevé, à savoir l'énergie éolienne et les hélices contra rotatives.

Plusieurs façons de surmonter les obstacles de transfert de connaissances sont présentées qui peuvent être classées de la forme suivante:

- Ateliers et formations:
    - Ateliers de renforcement de capacité pour administrations nationales
    - Ateliers régionaux
- Formations techniques
    - Formations dans le calcul et vérification de l'EEDI
    - Développement de cours standardisés
- Plateforme en ligne
    - Inventaire de technologies d'efficacité énergétique
    - Création de site internet avec informations pertinentes pour le public cible
    - Amélioration de l'accès aux informations et partage de connaissances
    - Apport d'informations vérifiées sur les économies véritablement réalisées à travers un programme de monitoring

Ce rapport fournit des estimations de coûts pour chacune de ces options de renforcement de capacités. La plus coûteuse serait un projet de renforcement des capacités qui prendrait en compte tous les aspects, semblable au projet GloBallast, qui aide les pays en développement et leurs industries maritimes avec la mise en œuvre des règlements internationaux sur la gestion des eaux de ballast et la prévention des risques de transfert d'organismes aquatiques nuisibles. Le budget total pour GloBallast pour la période 2008-2012 était de $ US 23 millions.

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1 Introduction

The negotiations within the International Maritime Organization (IMO) on enhancing the energy efficiency of and reducing the greenhouse gas emissions from international shipping are a top-priority for the European Commission in view of the European Union's preference for a global measure to address greenhouse gas emissions from shipping.

In July 2011, the IMO adopted two energy efficiency measures, which entered into force in 2013: the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Managements Plan (SEEMP) for all ships.[1] Nevertheless, the IMO recognises the need for further action to reduce emissions from international shipping in view of the continued expected growth of the world economy and associated transport demand. Consequently, the IMO began working on further measures to increase the energy efficiency of international shipping, including the development of a global data collection system as a first step in April 2014.

At the time of the adoption of the EEDI and the SEEMP, it was agreed to complement them with a Resolution on the promotion of technical cooperation and transfer of technology relating to the improvement of energy efficiency of ships. The Resolution was intended to provide a framework for the promotion and facilitation of capacity building, technical cooperation, and technology transfer to support, in particular in developing countries, the implementation of the EEDI and the SEEMP. The Resolution was adopted in 2013 and an expert group, tasked to ensure the Resolution's effective implementation, was established in April 2014.

The EU is actively contributing to the work of the IMO Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships (AHEWG-TT) to ensure effective implementation of the Resolution and incidentally advance the related IMO negotiations on further measures to increase the energy efficiency of international shipping.

The goal of this project is to contribute to the work of the AHEWG-TT and to further stimulate the effective implementation of the International Maritime Organization (IMO) Resolution on the promotion of technical cooperation and transfer of technology[2].

To achieve this goal, this study provides a short overview of relevant stakeholders and existing technologies which could improve the energy efficiency of ships. Furthermore, barriers to transfer and uptake of energy efficient technologies are categorised and analysed and possible measures to overcome these barriers are being proposed.

[1] Amendments to MARPOL Annex VI (prevention of air pollution from ships)
[2] http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-Co-operation.aspx

2 Relevant Stakeholders

The IMO resolution on the promotion of technical cooperation and transfer of technology (regulation 23) is intended to support states which request technical assistance. Three main categories of stakeholders were identified that can be considered of relevance:

(1) Shipbuilding nations, where the ships are produced;
(2) Flag States (where the ships are registered) and Port States, who are allowed to inspect foreign ships compliance to international regulations;
(3) Ship owners and ship charterers who are responsible for the design and use of the ships.

2.1 Global Shipbuilding Nations

Shipbuilding nations typically provide incentives for the shipbuilding industry in their country. Therefore they play a role in the transfer of technologies to their industry.

In 2012, some 3,655 ships were built worldwide. The largest share of the tonnage was built in China, South Korea and Japan (Figure 1).

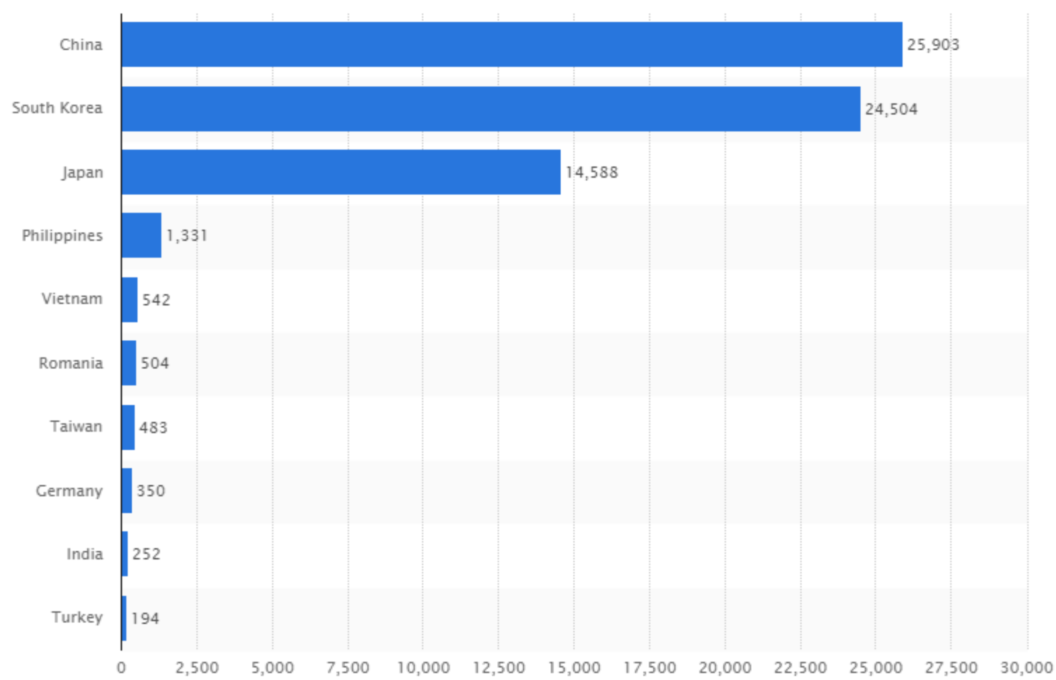

Figure 1. Ship building in 1,000 gross tons. Source: (Statista 2015), quoting IHS and Shipbuilders' Association of Japan

The world's leading shipyards include South Korea's Hyundai Heavy Industries, Japan's Mitsubishi Heavy Industries and China's Shanghai Waigaoqiao (Statista 2015). China, South Korea and Japan together are responsible for building about 90% of the ships in gross tons.

2.2 Flag States and their role in the implementation of MARPOL

Flag States have the responsibility for enforcing the rules set out under MARPOL. Every Flag State has the duty to ensure that its vessels fully comply with the applicable articles of MARPOL[3].

[3] MARPOL Regulation 6

At the end of 2013, about one-fifth of merchant vessels were registered in Flag State Panama, 12% in Flag State Liberia and 8% in the Flag State Marshall Islands (Figure 2 and (UK DfT 2014)). Therefore already 40% of the world fleet are registered in these three Flag States.

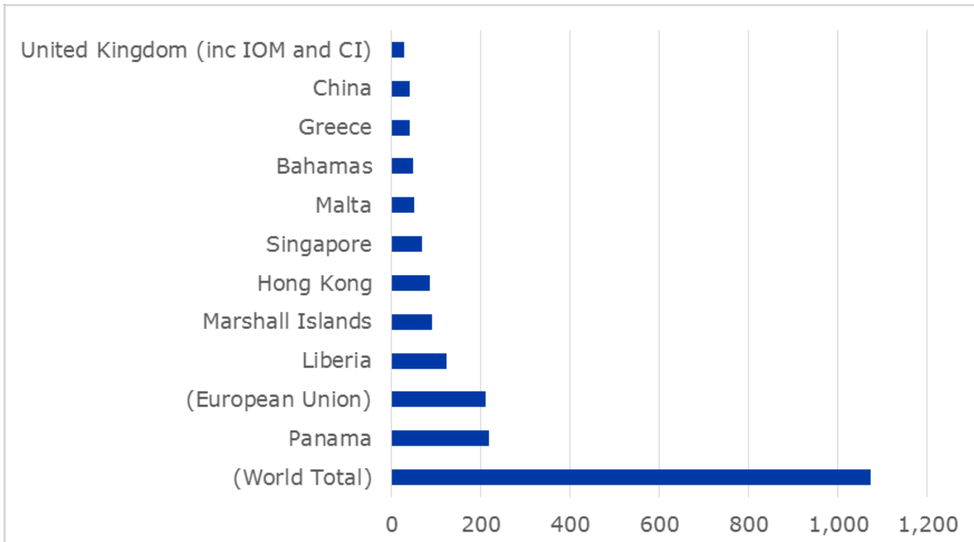

Figure 2. World fleet registered trading vessels of 100 gross tons and over 2009-2013. Source: UK DfT 2014

Under MARPOL, these parties (Flag States) can enforce ship-owners and operators obligations in three main ways:

- by survey/inspection of vessels to ensure that they meet minimum requirements[4],
- by monitoring vessel compliance with oil discharge requirements[5] (not relevant for energy efficiency), and
- by implementing punishments for failure to comply with requirements[6].

2.2.1 **Surveys**

MARPOL, Annex VI contains a set of requirements for survey and issuance of International Air Pollution Prevention Certificate (IAPP) and regulations regarding:

- Ozone depleting substances from refrigerating plants and firefighting equipment;
- Nitrogen Oxides (NO_x) from diesel engines;
- Sulphur Oxides (SO_x) from diesel engines;

[4] MARPOL, article 5
[5] MARPOL, Annex I, Chapter 4, Regulation 31
[6] MARPOL, article 4

- Volatile Organic Compound Emissions from cargo tanks of oil tankers;
- Shipboard Incineration;
- Fuel oil quality.

Flag States must conduct an initial survey before a new ship is put into service and before the IAPP is issued for the first time, a renewal survey at intervals specified by the Administration, but not exceeding five years, an intermediate survey within three months before or after the second anniversary date or within three months before or after the third anniversary date of the certificate, an annual survey within three months before or after each anniversary date of the certificate and, after prescribed repairs, an additional survey.[7]

For the EEDI and the SEEMP a new certificate, the International Energy Efficiency Certificate (IEEC), was established and must be kept available on board for inspections/surveys. The IEEC Certificate will be issued for new build ships upon the initial survey before the ship is put into service and for existing ships of 400 gross tonnage and above. The IEE Certificate will be issued once for each ship and is valid throughout the lifetime of the ship (except: flag change, major conversion or ship going out of service). There are no follow-up surveys on the IEEC Certificate.

The IMO has created guidelines for surveys that Flag States should follow. The energy efficiency related one is:

- 2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI) (resolution MEPC.254(67))

A Flag State cannot allow a vessel that does not pass inspection to sail, until it complies with MARPOL[8]. An International Energy Efficiency Certificate, in accordance with the provisions of regulation 5.4 to any ship of 400 gross tonnage and above, is needed before that ship may engage in voyages to ports or offshore terminals under the jurisdiction of other Parties.

2.2.2 **Punishments for failure to comply**

In case of failure to comply, the authority carrying out the inspection may detain the ship. Article 7 of MARPOL ensures that unduly delay or detain will be avoided where possible or compensated.

A Flag State is obliged to investigate an incident upon receipt of notification or evidence that one of its vessels has breached MARPOL. If the investigations reveal that a breach has occurred the Flag State has further obligations to initiate legal proceedings against the vessel and report back to the reporting state on actions taken.[9]

[7] MARPOL, Annex VI, Chapter 2, Regulation 5
[8] MARPOL, Annex VI, Chapter 2, Regulation 6
[9] MARPOL, article 6

Also other parties are allowed to inspect vessels under MARPOL Article 6 when violations are detected or for regular inspections. A Party may also inspect a ship to which the present Convention applies when it enters the ports or off-shore terminals under its jurisdiction, if a request for an investigation is received from any Party together with sufficient evidence that the ship has discharged harmful substances or effluents containing such substances in any place.

2.3 Role of Port States

Under "Port State Control" arrangements, Port States also have the authority to conduct vessel surveys on ships which visit their ports and to detain those ships that fall below MARPOL requirements. In relation to MARPOL Annex VI, chapter 4, "any port state inspection shall be limited to verifying, when appropriate, that there is a valid International Energy Efficiency Certificate on board".[10]

2.4 Cooperation between Port and Flag States

Under MARPOL, parties are required to co-operate in detecting vessel violations and are required to use all practical measures to detect and monitor violations. If a State has evidence of a violation they are obligated to forward this evidence to the vessel's Flag State.

All ships flagged under countries that are signatories to MARPOL are subject to its requirements, regardless of where they sail and member nations are responsible for vessels registered under their respective nationalities.

When incidents occur outside the country's jurisdiction or jurisdiction cannot be determined, the country refers cases to Flag States, in accordance with MARPOL. Some States are not happy with the lack of response from Flag States. United States experience of Flag States not responding has led to new policy which would take direct enforcement action against vessels for MARPOL V violations occurring between 3 and 200 nautical miles from the United States rather than referring such violations to the flag states (Dillingham 2000).

2.5 Ship owners and charterers

A ship owner is the owner of a commercial ship. A ship owner is someone who equips and exploits a ship, usually for delivering cargo at a certain freight rate. The ship owner determines the specifications of the ship and its energy efficiency measures, but the benefits of low fuel consumption are not always theirs, when the ship is chartered to someone else.

Depending on the type of ship and the type of charter, normally a standard contract form called a charter party is used to record the exact rate, duration and terms agreed between the ship owner and the charterer.

[10] MARPOL Annex VI, Regulation 10

A charterer may be a party without a cargo who takes a vessel on charter for a specified period from the owner and then trades the ship to carry cargoes at a profit above the hire rate. In some cases a charterer may own cargo and employ a shipbroker to find a ship to deliver the cargo for a certain price.

Two main types of charter can be distinguished, time charter and voyage charter. In a voyage charter the owner is still responsible for the port, fuel and crew costs. In a time charter the charterer selects the ports and directs the vessel where to go. The charterer pays for all fuel the vessel consumes, port charges, commissions, and a daily hire to the owner of the vessel.

When there are too few opportunities to share investment with charterers this leads to a split incentive: a ship owner may invest the up-front capital to put in energy-efficient technology, but doesn't then recoup the costs from fuel savings as they charter their ships out, as this goes to the charterers. This problem is particularly apparent for short-term time charters[11].

2.6 Conclusions

Regarding energy efficiency, the work of the AHEWG-TT[12] has shown that the main shipbuilding nations all have access to the necessary technologies, provided there is demand for them. It has also been noted that there is no need for transfers of intellectual property rights[13].

One of the major barriers to the effective implementation of the EEDI and the SEEMP is the heavy reliance it places on Flag States for inspection of vessels and enforcement of provisions. During the 1970's ships were being reflagged from high tax and high regulation countries, such as the United States and the United Kingdom, to countries offering Flags of Convenience ('FOC'). Under FOCs, ship-owners pay less tax to the relevant Flag State and are able to evade the majority of the environmental and construction standards set out under MARPOL (Leddy 2012). The main reason for that is that several Flag States are not signatories to all MARPOL Annexes (e.g. as of 2014/2015, the Bahamian, Bolivian, Cambodian, North Korean, Georgian, Honduran, Lebanese, and Sri Lankan flags of convenience had not ratified all MARPOL treaty annexes III-VI[14 15]).

Many FOCs are developing nations that do not have the resources to enforce, investigate or prosecute breaches by their flagged vessels (Aqorau 2000). As of 2014 55% of merchant ships are flagged by FOC and 40% of ships are flagged by FOC/developing countries. MARPOL only provides guidelines for Flag States to follow when surveying vessels under regulation 6 but none of these guidelines are mandatory. Conversely, Port States, which are developed, are better equipped to bear the cost of inspection, investigation, enforcement and prosecution costs. However, in relation to EEDI and the

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[11] http://ssi2040.org/what-we-do/work-streams/finance/
[12] MEPC 68/3/1 Progress report of the Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships
[13] Submission of the United States on Task 3 of the Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships, Jan 2015
[14] www.ics-shipping.org/docs/flag-state-performance-table
[15] http://www.imo.org/About/Conventions/StatusOfConventions/Pages/Default.aspx status of conventions

SEEMP, port state control is limited to verifying, when appropriate, that there is a valid International Energy Efficiency Certificate on board".

We therefore conclude that there needs to be a focus on enabling Flag States and Port States that lack the resources/capacity to enforce the EEDI and the SEEMP, in order to further stimulate the adoption of energy efficiency technologies. Also attention should be paid to overcoming the barrier of split incentives, i.e. where the benefits of energy efficiency measures are not transferred from the charterer to the investor (owner).

3 Energy Efficiency Measures for Ships

In order to understand the important energy efficiency measures that can help improve energy efficiency from shipping, it is interesting to see the split between new-built ships and existing fleet. In 2012, some 3,655 merchant ships were delivered worldwide, about 6% of the world's merchant fleet of about 60,000. The average age of the merchant fleet is 19 years. Therefore measures for both new ships and retrofits for old ships are important for improving the energy efficiency in the next decades. If only the new ships would be targeted only 50% of the fleet would be more efficient in the next decades, while there are many retrofit measures available. The total fleet can be broken down to about 4,000 passenger ships, just under 14,000 tankers and about 37,000 dry cargo ships including about 5,000 container ships (Statista 2015).

In order to identify the most interesting energy efficiency measures for ships we used the information from several reports to develop a long-list. Many measures improve the efficiency in the order of up to 5%. Here we would like to focus on measures that result in high savings that can be applied to many ship types and preferably also to existing ships. The resulting short-list is presented in the next table. We used the main categories identified by AHEWG-TT for structuring the measures.

The main categories defined by AHEWG-TT are:

1. Hull;
2. Main Engine;
3. Auxiliary engines;
4. Propellers and rudders; and
5. Control systems.

Since the auxiliary engines typically consume only a fraction of the energy that goes to the main engines, their energy efficiency measure results do not show in the short-list below. The measures are worked out in more detail in the paragraphs below. The main engine and auxiliary engine improvements are covered in the same paragraph.

The common rail upgrade is a simple measure that can be easily applied to all ships, even when the ship is not in the dry-dock. The details are available in the paragraph about engines.

From the list it is clear that conventional technology is available to achieve high efficiency gains. If the maximum gain per category is added up (for all but ferry and cruise) this would mean a total efficiency improvement of 35% even without taking two experimental technologies with potentially high efficiency gains into account (wind power and air lubrication). Note that some technologies are not applicable to all ships.

In order to find possible financial barriers the investments are rated from "very low" to "high", relatively to the size of the ships. The same measure on a larger ship is obviously more expensive.

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Table 1: Inventory/ranking of energy efficiency measures

Main category	Measure	Estimated efficiency (range)	Efficiency at average circumstances	Ease of installation	Payback time	Investment	Implementation	References
Hull	Bow optimisation	2.5-20%	10%	all ship types	short (<3 years)	Medium	conventional technology	(IMO 2009, IMO 2011, Crist 2009, Hochkirch und Bertram not dated)
Main Engines	Wind power	5-44%	20%	only special ship types	long (>15 years)	High	experimental technology	(IMO 2011, IMO 2009, Crist 2009, ICCT 2011, Brannigan, et al. 2009, Allenström 2013)
Propellers and Rudders	Ducted propeller	1-20%	10%	all ship types except ferry and cruises	medium (4-15 years)	Medium	conventional technology	(IMO 2011, IMO 2009, Crist 2009, ICCT 2011)
Propellers and Rudders	Contra-rotating propellers	6-20%	13%	only special ship types	long (>15 years)	High	conventional technology	(IMO 2011, IMO 2009, Crist 2009, WÄRTSILÄ 2009, Shuto 2010)
Propellers and Rudders	Wheels	10%	10%	all ship types except ferry and cruises	short (<3 years)	Medium	conventional technology	(IMO 2009, Schneekluth und Bertram 1998, Brannigan, et al. 2009)
Control Systems	Waste heat recovery	6-10%	8%	new build only	medium (4-15 years)	Medium	conventional technology	(IMO 2011, IMO 2009, Crist 2009, WÄRTSILÄ 2007, ICCT 2011)
Propellers and Rudders	Rudder bulb	2-5%	4%	all ship types except ferry and cruises	medium (4-15 years)	Low	conventional technology	(IMO 2011, IMO 2009, Nielsen, et al. not dated, Crist 2009, ICCT 2011)
Propellers and Rudders	Post swirl fins	2-5%	4%	all ship types except ferry and cruises	short (<3 years)	Low	conventional technology	(IMO 2009, MOL 2011, Hansen, Dinham-Peren und Nojiri 2011, Nielsen, et al. not dated)
Hull	Hull coating	1-9%	5%	all ship types	short (<3 years)	Low	conventional technology	(IMO 2011, IMO 2009, ICCT 2011, Voorham 2013, Crist 2009)
Hull	Air lubrication	5-15%	9%	new build only	medium (4-15 years)	Medium	experimental technology	(IMO 2011, IMO 2009, Crist 2009, DK Group 2015, CNSS 2015, ICCT 2011)
Propellers and Rudders	Twisted rudder	2-4%	3%	all ship types except ferry and cruises	medium (4-15 years)	Low	conventional technology	(IMO 2009, Schulze 2007, Nakashima 2015, Becker Marine System 2015, Nielsen, et al. not dated, Hollenbach und Friesch not dated, Rolls-Royce 2014)
Main Engines	Main engine de-rating	2-4	3%	all ship types except ferry and cruises	medium (4-15 years)	Low	conventional technology	(IMO 2011, IMO 2009, Crist 2009, Wettstein und Brown 2008, DNV GL 2015)
Auxiliary engines	Common rail upgrade	-	-	all ship types	medium (4-15 years)	Very Low	conventional technology	(DNV GL 2015) (ICCT 2011) (IMO 2009)
Main Engines	Common rail upgrade	0.1-0.5%-	0.3%	all ship types	medium (4-15 years)	Very low	conventional technology	(IMO 2009, Pakarinen 2007, ICCT 2011, Crist 2009)

3.1 Hull and superstructure

In general the optimisation of hull and superstructure focuses on minimising the resistance by reducing the wave resistance and friction between water and hull. It is important to recognise which type of vessel is to be optimised. The reduced frictional resistance increases energy performance of the vessel particularly at low speeds. Operability and performances of the ship must be considered in detail. The improvements measures are generally applied at new-built ships but also applicable to retrofitting.

3.1.1 **Bow optimisation**

The different bow optimisations can improve the water flow around the hull and reduce the wave-added resistance for large vessels with high block coefficient operating within commercial speed ranges. The average energy reduction potential ranges from 2.5-20%, on average 10% (Crist 2009, IMO 2011, Voorham 2013).

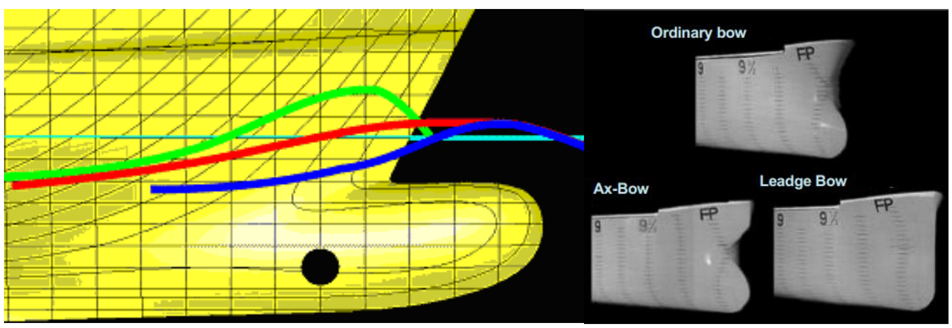

Figure 3: Left: The green line characterises the ordinary bow wave of the hull. The blue line characterises the wave formed by the bulb. The red line is the sum of these two. The altitude of the bow wave is noticeably reduced, which reduces the hull drag associated with the bow wave. This improves fuel economy and increases range (Selenetrawlers 2015). Right: Ordinary bulbous bow, leadge bow and ax-bow shape (JSEA 2006)

The below-the-waterline extension of the *bulbous bow (*Figure 3) modifies the way the water flows around the hull, reducing drag and thus increasing speed, range, fuel efficiency, and stability. An altered design is the *ax-bow* (Figure 3). The narrow designed bow slashes through the water in order to reduce slamming and reduces the size of bow generated wave. The propeller can act more efficient due to the absence of slamming. The *ax-bow* allows the ship to steer well, to maintain speed and the engine to save fuel (Crist 2009, IMO 2009). If the bulbous bow is modified during a regular docking period the investment is estimated to have short payback of about 1-3 years. It is most promising for container vessels (DNV GL 2015, Hochkirch und Bertram not dated).

Barriers: The bow optimisation (as retrofit) needs to be done in the dry dock. Dry-docking is not regularly happening for existing ships, because it means that the ship cannot operate and economic losses are suspected. Another obstacle might arise due to restricted access to the original contractual hull plans since shipyards are not always keen to provide detailed plans on their vessels to prevent

imitation (Hochkirch und Bertram not dated, DNV GL 2015). A major obstacle is the split incentive between ship owner and operator. Ship owners are responsible for investing in these technologies, and ship operators are those who pay for the fuel consumption and benefit from such technologies (ICCT 2011).
Technical maturity: The technique is available on the market and is effective. Only conventional material is needed and redesign can be done in a few weeks[16].
Applicability: Applicable to all ship types, but most efficient for ships with a high block coefficient like tankers and bulk carriers, since the reduction of the wave-added resistance is most impacting (IMO 2009).

3.1.2 Hull coating

Hull coatings (Figure 4) can lower frictional resistance and limit fouling by aquatic organisms. It can save between 1-9% fuel consumption on average 5% (ICCT 2011, Voorham 2013, Crist 2009).

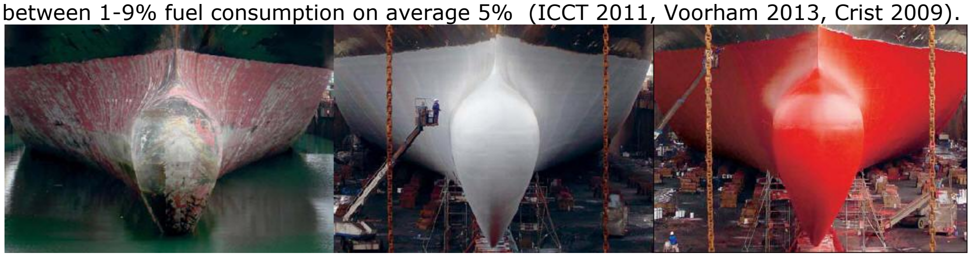

Figure 4: Example of hull coating (ECOSPEED 2015)

One way of lowering the frictional resistance is to improve the smoothness of a hull by means of coatings that reduce fouling. The costs are lifetime cost reduction and have to be recur every five years to be able to gain the fuel benefit.

Barriers: A new application is typically necessary during each dry-docking. The self-polishing coating must be renewed after a 3-5 years period (IMO 2009). A major obstacle is the divided interest between ship owner and operator. Ship owners are in charge for investing in these technologies, and ship operators are those who pay for the fuel consumption and profit from such technologies (ICCT 2011).
Technical maturity: Coating techniques are available on the market and roughly 5% of newly painted ships are painted with one of the advanced coating systems presently available (IMO 2011, ICCT 2011). The payback time is short (ICCT 2011) or 0-2 years according to others[17].
Applicability: The technology is applicable to all vessels.

3.1.3 Air lubrication

The air lubrication technique creates a layer of bubbles underneath an already streamlined hull in order to further reduce friction. An automation system regulates the compressors/blowers depending on

[16] http://www.ship-efficiency.org/onTEAM/pdf/14-Ship%20efficiency%20seminar%20-%20CMA%20CGM-%20HydrOcean%201.%20CMA%20.pdf
[17] https://www.dnvgl.com/maritime/energy-efficiency/efficiency-finder.html

speed. The blower keeps holes filled with air and required pressure. A thin layer of bubbles trailing behind of each cavity merge into single large "air layer" for the whole flat bottom part of the hull and reduces the friction (Figure 5). Depending on the ship type, the estimate fuel efficiency ranges between 5-15% (on average 9%), where tankers and bulkers can reduce more (10-15%, on average 12.5%) in comparison to container vessels (5-9%, on average 7%) (IMO 2009, DK Group 2015, CNSS 2015, ICCT 2011, Voorham 2013)[18].

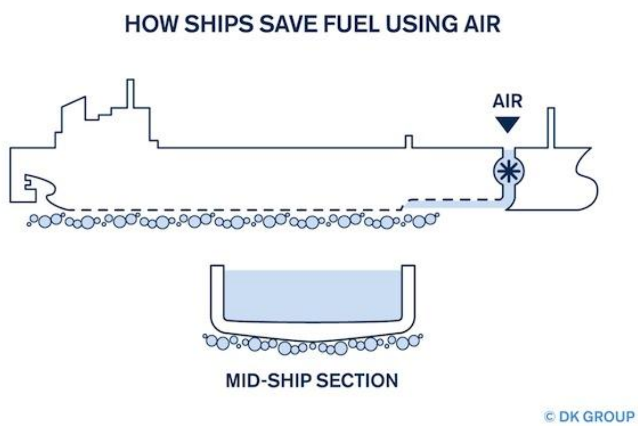

Figure 5: Schematic view of air lubrication (DK Group 2015)

Barriers: Large capital investment requirements with split incentive. The vessel owners are accountable for investing in these technologies, whereas vessel operators recompense for the fuel consumption and benefit from such technologies (ICCT 2011).

Technical maturity: The technology is available on the market, but still in a pilot phase. Sea trials have been performed with small demonstration ships. There are no vessels operating commercially that currently use this technique. Specifications about the payback time vary from short to medium (Silberschmidt 2014, Skinner 2009).

Applicability: The original technology would be likely be applied to new-built ships with at least a partly flat bottom and a minimum length of 225 metres, since the compressor may have technical problems maintaining air cavities for deep draft ships (IMO 2011, CNSS 2015). Air lubrication can be used for retrofitting as well (CNSS 2015).

3.2 Engines

Speed reductions on existing vessels provide opportunities for engine optimisation on low power (3.2.1). Similar measures as de-rating for the main engines that could be implemented are cylinder cut-out and new torsional vibration calculation (IMO 2009).

[18] It has to be noted that the extra fuel use caused by the system itself should also be taken into account.

Another propulsion supportive measure with a high potential measure is wind power. This is also explained in more detail below. In order to also provide a measure with a lower improvement potential per ship, but simple and applicable to all ships, we describe the common rail system for fuel injection.

3.2.1 Main engine de-rating

Slow steaming vessels are known as one of the most effective energy saving measure. The potential comes mainly from the operational behaviour side. From the technical side, the specific fuel oil consumption will decline when a ship is no longer operated at its design speed.

The design speed can be reduced by de-rating the main engine (IMO 2011, IMO 2009). Reduction of power combined with injection timing advanced to restore peak combustion pressure, can achieve a certain gain in shaft efficiency. Fuel efficiency can be improved by 2-4% when de-rating is performed for loads lower than the maximum design load (Wettstein und Brown 2008, Crist 2009), on average 3% energy efficiency potential (Crist 2009). Operational costs would be lower, mainly due to fuel savings (DNV GL 2015, Crist 2009, Wettstein und Brown 2008).

Barriers: A slower vessel will have lower incomes as it is not capable to perform as much transport load per unit of time as a faster vessel. De-rating the engine is usually done when it is clear that the ship will become a slower steaming ship. There is a split incentive between vessel owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies (ICCT 2011).
Technical maturity: This technique has been proven as successful, particularly on older engines, which are normally built with a low compression ratio and thereby have a significant potential to improve their efficiency (IMO 2009). De-rating measures have a low to medium payback time (Crist 2009, DNV GL 2015).
Applicability: The technologies are available on the market. It is applicable to all vessels (DNV GL 2015).

3.2.2 Common-rail upgrade (common-rail fuel injection)

Engines with common-rail fuel injection handle low-load working modes much better (IMO 2009). A common-rail fuel injection is technique of injecting fuel into an engine cylinder under total control and thereby achieving optimal combustion. Common-rail allows the start and duration of injection independent of the position of the pistons, in that way permitting an operationally optimised injection per stroke. In a normal diesel engine, fuel is injected at a static rate by a pump, and common practice is to optimise this pump to run at an optimal setting for the ideal injection time (Pakarinen 2007). The energy efficiency potential is estimated between 0.1-0.5% on average 0.3% (ICCT 2011, IMO 2009).

Barriers: Additional electronics can also introduce possibilities for failures. However recent advancements have increased the systems popularity[19]. There is a split incentive between vessel

[19] http://www.marineinsight.com/marine/an-overview-of-common-rail-system-in-marine-engines/

owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies (ICCT 2011).
Technical maturity: This measure is available on the market (ICCT 2011). Payback time is short to medium with an average of 5 years (IMO 2009, Crist 2009).
Applicability: This measure is applicable to new and retrofit vessels. It is applicable for tanker-, bulk-, container- and Roro-ships (Crist 2009).

3.2.3 **Auxiliary engines and systems**

Based on our own estimation, auxiliary engines improvement are not bringing >2-4% energy savings, because auxiliary engines consume much less fuel than the main engine. Similar measures as de-rating for the main engines and common rail upgrade could be implemented for the auxiliary engine.
Other options for improving auxiliary systems are speed control of pumps and fans, control strategies of cooling water systems, room ventilation, redesign of piping and instruments, advanced computation of air/gas temperature distribution with reduced storage ventilation and with optimised ventilation systems (DNV GL 2015).

Barriers: There is a split incentive between vessel owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies (ICCT 2011).
Technical maturity: This measure is available on the market (ICCT 2011). It is easy to apply and uncomplicated in maintenance (DNV GL 2015). Payback time is short (DNV GL 2015).
Applicability: This measure is applicable to all new and retrofit types of ships (DNV GL 2015).

3.2.4 **Wind power**

Wind power measures are available that can develop enough thrust to provide at least some supportive propulsion. Wind power can be utilised in various ways in shipping like traditional sails, solid wing sails, *Flettner*-rotor and kits (see Figure 6). The techniques are currently used as supplementary power (Brannigan, et al. 2009).

Figure 6: from left to right: Kite (Cargill, 2011), Flettner rotor (MIWB 2015) and solid sails (Wind Chellenger Project HP 2015)

Solid wing sails are structured similar to aircraft wings, which offer more thrust with less drag than conventional sails. Flettner rotors produce thrust from a rotating object in wind, using the so-called

Magnus effect. The techniques have different characteristics with regards to how the thrust that is produced relates to other factors, such as wind strength, wind angle, wind stability and ship speed (IMO 2009).

Towing kites vary from other concepts of wind power by having a small footprint during installation and therefore being quite feasible to retrofit (Allenström 2013). Studies conducted at the Technical University of Berlin indicated that the potential for sail energy has different prospective in the different regions in the world. Best scenarios exist in North Atlantic and North Pacific regions, the South Pacific seems a bit less potential. The studies have shown that under normal circumstances the typical savings using wind power may be 5 % at 15 knots and up to 20 % at 10 knots. This study also revealed that with optimal weather routing in the North Atlantic and given the best vessel with best sail type, savings can reach 15 percent at 15 knots and 44 % at 10 knots (IMO 2009, Crist 2009). Nevertheless the above figures should be considered indicative, since practical experiences are limited. Sail- and kite-assisted power does seem to be a potential opportunity saving energy in the medium- and long-term picture for shipping (IMO 2009). Christ estimates and average energy saving potential around 20% (2009).

Barriers: There is a split incentive between vessel owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies (ICCT 2011). Although this technology can bring high energy savings, the investment is so high that there is not a short payback time.
For solid wing sails complications could result in a need for masts to run down to the keel, which can be a bigger issue for retrofitting. Additionally the presence of the mast and rigging could have significant impacts on cargo handling (IMO 2009). Downside of the kite systems include the complex launch, recovery and control systems that are needed (IMO 2009).
Technical maturity: This is still considered as experimental technology. The technical barriers identified above need to be tackled for this measure to be applied widely in the future. Payback time is estimated to be medium to long term (Allenström 2013, Crist 2009).
Applicability: Wind power technologies are available and a number of cargo ships have been equipped with wind engines to reduce demands from diesel engines (ICCT 2011). Kites can be used on ships with a minimum length of 30m and works most energy efficient on ships with a typical speed not faster than 16 knots. Preferably tankers (crude oil, product, chemical, LPG, LNG, other) and bulk carriers are being considered as potential users, due to this speed restriction (IMO 2011).

3.3 Control Systems: Waste heat recovery

Waste heat recovery (WHR) technology can pass exhaust gases from a vessel's engines through a heat exchanger to generate steam for a turbine-driven generator. The heat energy from the exhaust gas is taken and transformed into electrical energy to reduce direct engine-fuel consumption for the propulsion system or reduce auxiliary engine needs (ICCT 2011). Energy saving potential is estimated between 6-10%, on average 8% (Crist 2009, ICCT 2011).

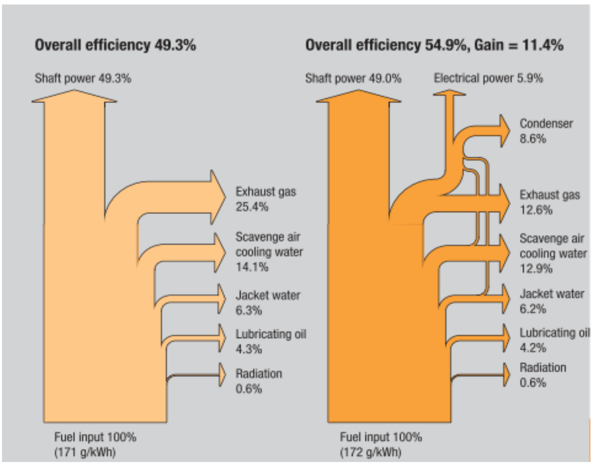

Figure 7: Efficiency of waste heat recover systems Sankey diagramme. *Even with high, 50% efficiency of modern low-speed engines there is still 50% of fuel input energy not being put to productive use. The possibilities are illustrated by this comparison of Sankey diagrammes for Wärtsilä 12RT-flex96C engines without heat recovery (left) and with high-efficiency waste heat recovery plant (right) showing in this case 11.4 % gain in overall efficiency with WHR* (waste heat recovery) (WÄRTSILÄ 2007)

Barriers: Large capital investment requirements (around $5-6 million for a large container ship[20]), and split incentive between ship owners and ship operators (ICCT 2011).
Technical maturity: The technology is available on the market and has medium to long payback time (WÄRTSILÄ 2007, Crist 2009).
Applicability: A WHR system is applied to vessels with a high production of waste heat and a high intake of electricity. WHR can be employed on ships with main engine average performance is higher than 20,000 kW and auxiliary engine average performance higher than 1,000 kW. This size requirements limit the number of ships using this technology (IMO 2011). Generally it is applicable to all ships types; new and retrofit (Crist 2009).

3.4 Propellers and Rudders

Numerous devices have been designed for improving the energy consumption of vessels by recovering as much as possible of this rotational energy in the flow from the propeller, or to provide some pre-or post-rotation of the in flow into and after the propeller to ensure best efficiency. The most important of these will be discussed in the following paragraphs (IMO 2009).

3.4.1 Ducted propeller (*Kort Nozzle*)

The accelerating ducted propeller consists of a screw propeller surrounded by a non-rotating duct (*nozzle*) (Figure 8). Compared to the conventional propeller of the same diameter and thrust, this

[20] http://gcaptain.com/power-exhaust-gas-paybacks-waste/

arrangement allows an increase inflow to the propeller, improving the operating conditions around the propeller and the ideal efficiency.

Figure 8: Right: photos of this Norwegian trawler (SetSail 2009)

The duct creates additional thrust load. The potential for energy savings on relevant vessels range between 1–20% (Crist 2009, IMO 2011, Barringhaus und Olds 1999, IMO 2009), whereupon 10% is a good average value (IMO 2009, Crist 2009). The improvement of the combination of propeller and duct overweigh negative effect of the increase water resistance caused by the duct.

Barriers: Since the duct has an optimal operational speed, it does not work efficient at all speeds. For instance, as drag increases with increasing speed, eventually this will become larger than the added thrust. Therefore at high speeds ducts are typically not used (IMO 2009). The split incentive is a barrier; between ship owners (investor) and ship operators (gainer), as explained earlier (ICCT 2011).
Technical maturity: Several standard designs are available on the market (IMO 2011) with a medium payback time (IMO 2011)
Applicability: Ducted propellers suits for vessels operating at high propeller loadings, such as tankers, bulk carriers, especially tugs and some offshore service ships. The duct leads to increased friction, but at higher propeller loadings this is more than rewarded for by the positive effect of the combination of propeller and duct (IMO 2009).

3.4.2 **Contra-rotating propellers (CRP)**

A rotating propeller induces a rotating motion in its backwash. Normally this rotation energy of the propeller gets lost. The contra-rotating propeller is used in order to recover part of this energy (Figure 9). In a contra-rotating configuration two propellers are facing each other, rotating in the opposite direction, with the aft propeller recuperating the turning energy in the wake from the forward propeller (IMO 2011). To avoid complications with cavitation, the aft propeller usually has a smaller diameter than the front propeller. Contra-rotating propeller arrangements involve a short shaft line and for that reason primarily suitable for vessels with single-screw.

Figure 9: Left, conventional propeller. Right, contra-rotating propeller. The working principle is simple and effective: the power is split in a forward and aft propeller which through the different direction of rotation cancel out the rotational energy losses behind the propeller (WÄRTSILÄ 2009).

Potential savings of such measures are assessed to be in the order of 6–20% of the power consumption with an average of 13%, although higher figures may be presented by industry for specific cases. Two different full-scale measurements reported gains of 15% and 16% (IMO 2009, Crist 2009).

Barriers: The mechanical installation of contra-rotating shafts is complicated and requires more maintenance (IMO 2011). The split incentive between ship owners (investor) and ship operators (gainer) is a barrier, as explained above. Although this technology can bring high energy savings, the investment is so high that there is not a short payback time.
Technical maturity: The technique is available on the market, but problems with gearboxes for contra-rotating propellers have been reported, as well as operational problems with mounting (IMO 2009, IMO 2011). Payback time is reported as short (WÄRTSILÄ 2009), but also as medium-long with about ~15-20 years (Shuto 2010) .
Applicability: The technology is particularly beneficial for rather heavily loaded propellers, as for example very fast cargo vessels like Ro-Ro ships or for container ships (IMO 2011, Crist 2009). Contra-rotating propellers need a short shaft line and hence mainly suited to single-screw ships (IMO 2011). Contra-rotating propellers can be implemented as retrofit, but it is more likely implemented in new built ships due to the complicated mechanical installation (Crist 2009).

3.4.3 **Post swirl devises**

A number of different techniques belong to the post swirl category. Several of them contain modifications to the rudder or propeller (IMO 2009). Depending on vessel type and operational field, various power saving measures can be mounted to optimise water velocity distribution to the propeller and to minimise slipstream losses due to swirl in the outflow of a propeller. The most important among these measures may be additional thrusting fins at the rudder, twisted rudder (Figure 12), rudder-bulb-systems with fins (Figure 13), and fins on the propeller fairwater; also called post swirl fins or boss cap fins (Figure 10).

Generally post swirl measures reported 1-8 % energy efficiency (test models). Even 8-9% energy efficiency from full-scale measurements for additional thrusting fins at the rudder. Payback time is estimated to be short to medium post swirl devices (DNV GL 2015, Crist 2009, ICCT 2011). Some of the post swirl measure can be combined. A good overview is given in Nielsen et al. (Combined Kappel propeller and rudder bulb system for improved propulsion efficiency not dated).

3.4.3.1 Post swirl fins

The post swirl fins (Figure 10) can recover energy loss of propeller hub vortex in the propeller backward flow and can lead to 3-5% energy saving, on average 4%, operating at the same speed (MOL 2011, Barringhaus und Olds 1999, Hansen, Dinham-Peren und Nojiri 2011, ICCT 2011).

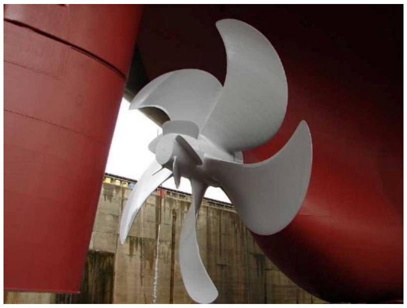

Figure 10: Example the post swirl fins or propeller boss cap fins (gcaptain 2012)

Barriers: It is simple and straightforward measure requiring only the removal of the propeller boss caps and replacement with the post swirl fins (no hull modification is needed) (Hansen, Dinham-Peren und Nojiri 2011, MOL 2011). However there is a split incentive between ship owners (investor) and ship operators (gainer), as explained above.
Technical maturity: The technique is available on the market. In 2013, post swirl fins were applied to over 2500 ships worldwide (MOL 2011). Further advantages of the post swirl fins are: reduction in propeller torque, reduced vibration in the stern and less underwater noise and reduced rudder erosion (MOL 2011). A payback time of 6 months was estimated for 4% efficiency improvement at $600/tonne oil price (Hansen, Dinham-Peren und Nojiri 2011). The investment is considered to be low[21].
Applicability: The technique is effective for all screw propellers irrespective of the type or hull form of the ship. Has been tested on large-scale container vessels (MOL 2011, Hansen, Dinham-Peren und Nojiri 2011).

3.4.3.2 Free rotating wheels

A vane wheel (Grim wheel) is a freely spinning propeller, mounted behind the main smaller propeller (see Figure 11 for example of use on retrofit Queen Elisabeth II in 1986). The vane wheel has a bigger diameter than the main propeller and increases the propeller diameter. The small propeller drives the freely revolving vane wheel fitted on the wake. The inner part of the vane wheel acts as a turbine and the outer part as an “additional” propeller.

[21] http://gcaptain.com/propeller-technology-ship-efficient/

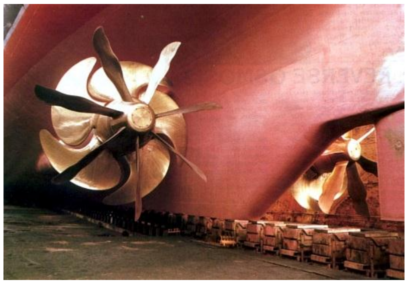

Figure 11: Example for a grim vane wheel (Boat design 2007)

This leads to a substantial recovery of the rotational energy. The energy saving potential is reported to be 10% (Brannigan, et al. 2009). It is stated that the important benefit of the vane wheel is that a smaller impulsion propeller can be installed which consumes less energy. The vane wheel gives a suitable energy improvement for cargo ships (IMO 2009, Schneekluth und Bertram 1998) and has short payback time. It is also stated that, if there is room for a vane wheel in the aft, there is also space for an impulsion propeller of larger diameter, leading about the same energy saving potential as the combination of a small impulsion propeller and a vane wheel (IMO 2009).

Barriers: A barrier is the split incentive between vessel owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies.
Technical maturity: Limited application: Vane wheels are subjected to strong fluctuations in loading. Problems with the strength of the blades have been encountered frequently (for example the vane wheels on the Queen Elisabeth II were short lived and not used after[22]).The payback time is estimated to be short.
Applicability: The technique is effective for all screw propellers irrespective of the type or hull form of the ship, both for new and existing ships (Chen, Reed und Kim 1989). Recommended for all ship types except ferry and cruises, because of their problem with strong fluctuations in loading as mentioned above[23] (IMO 2009).

3.4.3.3 Twisted rudder

Rudders can play a significant role of extra frictional resistance. Rudders are located in the backwash of a propeller and rotational energy will act on the rudder. Because of these effects the rudder gives prospects of efficiency gains (Schulze 2007).

[22] http://www.roblightbody.com/liners/qe-2/1987_Refit/index.htm
[23] http://www.roblightbody.com/liners/qe-2/1987_Refit/index.htm

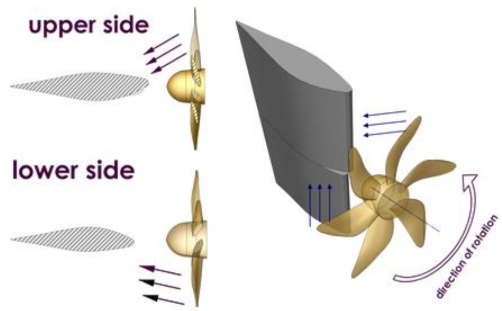

Figure 12: Schematic capture of twisted rudder (Nakashima 2015)

Twisted leading edge technology provides multiple benefits for high-speed vessels compared to conventional rudder designs. Conventional rudders are located behind the propeller with the rudder profile arranged symmetrically about the vertical rudder centre plane. This arrangement does not consider the fact that the propeller induces a strong rotational flow that strikes on the rudder blade. This consequences in areas of low force on the blade that induce cavitation and associated erosion problems (Becker Marine System 2015, Schulze 2007).

The twisted rudder is horizontally twisted on the lower and upper side of the segment that is an extension of the propeller shaft (Figure 12). This decreases cavitation rudder and improves manoeuvrability of the vessel (Schulze 2007). Twisted rudder types lead to energy efficiency improvements by approximately 2-4%, on average 3% for large-size high-speed vessels (Hollenbach und Friesch not dated, Nakashima 2015).

Barriers: Work needs to be done in the dry dock, this is not regularly happening for existing ships (Hochkirch und Bertram not dated). There is a split incentive between vessel owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies (ICCT 2011).

Technical maturity: This rudder type is a commercially used technology and easy to apply if the ship is in the dry dock (ICCT 2011).The payback time is estimated to be short to medium (Rolls-Royce 2014, Crist 2009).

Applicability: Twisted rudder can used by container vessels, reefers, Ro-Pax ferries, cruise ships and naval vessels. In South Korea, this type of rudder is recognised as a standard rudder for large-size high-speed container carriers (Nakashima 2015).

3.4.3.4 Rudder bulb

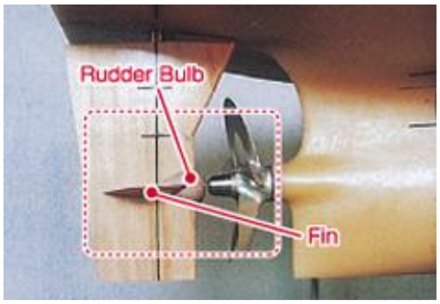

Figure 13: Example for a rudder bulb. Kawasaki RBS-F rudder bulb systems with fins (Kawasaki 2015)

The rudder bulb brings smooth inflows from the propeller and can reduce the drag of the rudder. The rudder fins produce thrusts in the rotational flows generated by the propeller (Figure 13). Rudder bulb measure can improve energy efficiency by 2-5% (Nielsen, et al. not dated, Becker Marine System not dated) on average 4% (Crist 2009).

Barriers: The work needs to be done in the dry dock, this is not regularly happening for existing ships. There is a split incentive between vessel owners who are responsible for investing in these technologies, and vessel operators who are those who compensate for the fuel consumption and benefit from such technologies (ICCT 2011).

Technical maturity: The technology is a commercially used technology and easy to apply while the ship is in the dry dock (Kawasaki 2015). Payback time is estimated to be medium (Crist 2009).

Applicability: For new and retrofit tanker-, bulk-, container- and Roro-ships with a propeller and rudder (Crist 2009).

4. Barriers to the transfer and uptake of energy efficiency technologies for ships and possible measures to overcome them

Although there are ways to reduce emissions (Chapter 3), and also drivers working towards the implementation of such measures, there are significant barriers to acting on cost-effective opportunities in the maritime industry. This is often referred to as barriers to energy or the energy efficiency gap (Michele Acciaro 2013), (Sepideh Jafarzadeh 2014), (OECD 2014). Some barriers are shared with other industries, while others are unique to the maritime industry. Furthermore, many of these barriers are not specific to the EEDI and the SEEMP, but apply to any rule under MARPOL. These barriers can exist on both the supply and the demand side. For example, there could be barriers to the development and implementation of measures that reduce CO_2 emissions from ships, and barriers to the expression of demand for these measures (ECORYS, 2012). Studies have, however, shown that there are relatively few barriers related to the development of new technologies or access to related intellectual property rights by the main shipbuilding nations, and that the supply of measures exceeds the demand (ECORYS, 2012). Existing studies on barriers to energy efficiency thus focus on what prevents the uptake of available measures.

This section presents an overview of the main barriers to the transfer and uptake of energy efficiency technologies in the shipping industry, and discusses potential ways of overcoming them.

Preliminary assessments of technology transfer and financial needs by both workshop participants and the IMO Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships (AHEWG-TT) have suggested that the type of assistance needed by Port State and Flag State administrations will be of a different nature than that required by shipbuilders and owners. Our assessment above has shown that the shipbuilding industry is expected to need less assistance than Port States and Flag States.

In the next table we list a summary of the main barriers and the stakeholders concerned in the main categories as identified by AHEWG-TT, as well as the possible measures that could help overcome these barriers. The possible measures to overcome the barriers are further detailed in the sections below. Related costs are estimated in a separate section in order to minimise overlap.

Table 2: Summary of main barriers, relevant stakeholders and possible measures to overcome them

Barrier	Stakeholders	Measures forward
Lack of awareness (administrative and industry) a. MARPOL in general; MARPOL, Annex VI; EEDI and SEEMP in particular b. Available energy efficiency technologies	• Flag and Port States • Ship owners	• Capacity building: - Workshops - Trainings • Model course for training • Inventory • Platform for information access and sharing • Agreements between industry and administrations
Technology concerns a. Lack of or limited technology supply chain in some states b. Lack of technology base for R&D in some states c. Lack of trust (in ability to reduce emissions; in ability to reduce operational costs; in compatibility with other measures)	• Ship owners • Investors	• Increase cooperation in ship design and building • Increased interaction between industry and educational/R&D institutes • Establish platform to share expertise/experience • Provide special investment or guarantee funds
Institutional concerns a. Increased administrative burden 1. Revision and amendment of existing legislation 2. Implement Port and Flag State obligations b. Limited technical capacity in state institutions to implement c. Lack of financial resources for additional compliance and enforcement activities by maritime administrations	• Flag States • Port States	• Promote increased cooperation and communication between administrations/within regional administrations • Regional information workshops for Port and Flag States • Establish platform to share regulatory experience • Development aid
Commercial a. Increased costs for ship owners to take up energy efficient technologies b. Lack of motivation of owners to take up energy efficient technologies (split incentive)	• Ship owners • Financiers	• Special EE funds • Smart contracts

4.1 Awareness Raising

Barriers: Lack of Awareness

The need to create awareness among Flag States, Port States and ship owners of the requirements of Annex VI in general and Chapter 4 in particular was highlighted by participants of the workshop and emphasised by the AHEWG-TT. The level of awareness in the various regions and even in the countries within the regions differed considerably. The AHEWG-TT further suggests it would be beneficial to undertake an initial evaluation of knowledge needs (gap analysis) in order to ensure workshops and other awareness-raising activities are appropriately tailored[24].

Furthermore, ship-owners are not always aware of the energy efficiency technologies available on the market or which operational measures can be implemented to save fuel. Ship owners can be companies, people and investment funds. Especially private equity groups tend to focus more on short term, looking for quick profit, while traditional ship owners tend to hold the ship for at least 20 years[25].

Measures forward:

Though Flag States and Port States should already have implemented measures to ensure that Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) requirements are complied with, both public administrations and industry representatives could benefit from additional training/capacity building and platforms to share experiences/receive information with regards the practicalities of these regulations and available energy efficiency technologies. The needs for each group can be determined through a gap-analysis, which we recommend to be carried out by an independent consultant, in cooperation with the flag and port states. Once the specific needs for each group have been determined, they can be addressed through the following awareness raising measures:

Capacity Building (workshops; trainings)

Workshops/trainings could be organised where formal training is combined with open discussions where experiences could be shared just within one stakeholder group or between educational institutes, auditors, operational managers of ships, shipbuilders and authorities. Such trainings/workshops could focus on just one or all aspects relating to the applicable rules, available energy efficiency measures or assessment methods of technologies (e.g. training in calculating and verifying EEDI and SEEMP, including development of tools to calculate EEDI and SEEMP). Trainings/workshops can be local or regional. Sending people physically to regional workshops is generally more conductive to networking and experience sharing but less adapted to the local situation and more costly.

To reduce the costs of training and ensure a certain level of training, the IMO or other qualified international partners (e.g. WMU) could develop model courses for training. In order to better understand the rules and regulations in detail, people use the help of trainers to better understand the elements that are important for them and to gain experience in doing calculations and other required

[24] Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships, 2nd Meeting

[25] http://www.ft.com/cms/s/0/dadcb240-3d97-11e3-b754-00144feab7de.html#axzz3aqC3tmNu

activities by the regulations. Trainers have to develop their courses and earn back their investments via trainings. Since the trainers are doing this simultaneous, it would be more efficient if there would be a model course available that can easily be tailored to the audience. This would reduce the costs for the development of trainings and would also ensure that the trainers provide the same level of depth in their trainings. Since the IMO is responsible for the rules and regulations it would be the logical responsible for the efficient implementation and therefore could take the initiative for developing model courses.

Information Sharing:

- Inventory of energy-efficiency technologies (for example, the IMO-GEF-UNDP project). Many studies and overviews on the internet are available. The quality and the scope is often different.
- Improved access to information and information sharing with international recognised organisations, including relevant survey and certification training. One example of establishing information sharing between governments is the work of the OECD Council Working Party on Shipbuilding (WP6)[26] which organises regular workshops aimed at facilitating the exchange of information on policy and industry developments.

Note that many of these measures overlap with the measures required to overcome institutional barriers, as laid out in section 4.3.

Agreements between industry and administrations could be envisaged to overcome the barriers:

In order to enhance the sharing of expertise for both administrations and industry technology transfer and technology cooperation agreements could be formulated in order to strengthen the cooperation. As identified before the technology transfer to the ship building industry is not a mayor barrier, so the agreements should help the administrations to become more aware of the possibilities to further promote the implementation of MARPOL Annex VI.

Typical agreements between industry and administrations could be in the form of initiatives like the Sustainable Shipping Initiative (SSI). SSI members have developed a vision for a sustainable shipping industry in 2040. They commit to working towards this in all their own operations and/or activities that involve shipping, and in all their dealings with and support for the shipping industry to make their vision a global reality by 2040. SSI members of over 19 companies represent ship owners and charterers, shipbuilders, engineers and service providers, banking, insurance, and classification societies. The SSI explored for instance how to overcome barriers to the uptake of new technologies and techniques which improve the operational efficiency of ships, potentially delivering energy efficiency savings of 10% or more and payback periods of less than 5 years. They also produce case studies to show good examples and also develop tools. By involving administrations in these kind of initiatives (even free of charge) they could be actively supported with knowledge about sustainable shipping.

[26] http://www.oecd.org/sti/ind/workshopongreengrowthinshipbuilding.htm

4.2 Technology Concerns

Barriers: Technology Concerns

One of key barriers to the implementation of energy efficient technologies (new and retrofit) relates to the lack of or limited technology supply chain. Furthermore the lack of a technology base for R&D in some states is a barrier. Also the existence of concerns relating to the ability of available energy efficiency measures to reduce emissions and operational costs and their compatibility with other measures of energy efficient technologies is a barrier. This is typically the problem in very isolated ship yards.

Measures forward:

Very successful shipyards (Japan and Korea) have already, since many years, a large number of licencing, technology transfer, and similar agreements and continuously exchange information with competitors in and outside their countries. For instance U.S. shipyards have adopted this methodology since the 1980s (office of technology assessment 1983).

Further technology sharing could be stimulated through educational/R&D institutes locally, regionally or globally in ship design and building. The technology will be transferred to the ship builders once the students start working there or through cooperation between industry and university. In order to facilitate this, we recommend the establishment of partnerships to share expertise/experience. Typically individuals who know both worlds are the driving force behind successful partnerships (AISBL 2012). These partnerships are built around a shared long term research vision. Many partners could contribute (e.g. financially) in order to establish the responsible management and research programme. The target of the platform could be for example to provide verified information on real-world energy efficiency improvements via a monitoring programme.

For example, in order to stimulate the deployment of energy efficient trucks, the Dutch government provides a website to share audited knowledge and data on about 15 energy efficiency technologies[27].

Additionally, climate financing could be leveraged to reduce the investment risk in unproven technologies. For example, IMO Member States could create a demonstration fund that can function as a guarantee for investments in new and immature technologies[28]. Similarly, investment guarantees can be provided by funds in the same way governments provide export credits to their companies. If the technology does not deliver the expected fuel-savings the fund can cover the difference, and hence reduce investment uncertainty. The main objective being to reduce investment risk.

4.3 Institutional Concerns

Barriers:

[27] http://www.truckvandetoekomst.nl/

[28] An example of a specific EE fund is http://www.eeef.eu/eligible-investments.html

For Flag and Port States, complying with new regulations of IMO and EEDI and SEEMP particularly represent and increased administrative burden. It requires revisions and amendments of existing legislation that need to be implemented at Port and Flag State functions. There is currently limited technical capacity in state institutions to implement these changes, especially in developing countries with a relatively low number of ships under their flag.

The lack of financial resources is also a barrier for additional compliance and enforcement activities by maritime administrations. This is particularly an issue for least developed countries and small developing island states. Implementation costs are relatively higher for small Flag States because of limited ability/capacity to implement new technical regulations. Note that this issue is not specific to the EEDI and the SEEMP but to most regulatory measures (maritime or other).

Measures forward:
Measures to assist states in implementing (existing and new) legislation include:

- Promote an increased cooperation and communication between administrations/within regional administrations of Port and Flag States, similarly to what has been suggested in sections 4.1 (Awareness raising through capacity building activities such as workshops) and 4.2 (Establish platform to share regulatory expertise/experience). Platforms could be managed by IMO, in conjunction with industry and development funds in order to share the costs as this has been done before for GloBallast for example. In that case the IMO is in the lead (executing agency), but the platform is supporting the collaboration with many stakeholders/funding partners. The goal of the programme is to assist developing countries, e.g. via e-learning courses.
- In addition, deterrents need to be put in place to discourage Flag States from performing substandard inspections. A system for detecting sub-standard inspections should be implemented whereby mandatory Port State Control inspections are carried out in close proximity to mandatory Flag State inspections (i.e. the Flag State inspection is carried out prior to the ship leaving port and the Port State inspection is carried out upon arrival at port). The two inspections should be carried out under a uniform mandatory checklist. The IMO should monitor inspections and investigate where discrepancies between inspections close in proximity are detected. If a Flag or Port State is found to have failed to meet the requisite inspection standards penalties in the form of substantial fines should follow.
- In order to overcome the financial barriers, financial assistance to states could help with capacity building and implementation. Financial resources are not only needed in the implementation of the new regulations (training of government experts), but governments of Flag States also need to be involved continuously in the ongoing discussion around developments new EEDI targets for 2020 and beyond, which requires continuous availability of experts to represent the interests of the state (Metselaar 2015). Financial aid can therefore be supplied in the following forms:
    - Increased financial support for compliance and enforcement activities by maritime administrations.
    - Financial support could be provided to Flag States so that they have the resources to properly carry out vessel inspections. Consideration should be given to the introduction of

an International Fund Convention set up for this purpose and contributed to by Port States and/or their major oil and other cargo exporters and importers.

4.4 Commercial

Barriers:
Private parties such as ship owners and investors are not always commercially incentivised to make investments in energy efficiency measures. This can be due to the split incentives between owner (who should make the investment) and charterer (who reaps the cost savings) of a ship (see paragraph 2.5). Furthermore, access to finance can be problematic for smaller players who operate in niche markets.

Measures:
Bottlenecks in financing private investments and new financing mechanisms could be addressed during regional or international workshops that include traditional and new financiers that could finance investments in energy efficiency technologies.

One solution that has been brought forward to address the problem of split incentives is the use of 'smart contracts' (Michele Acciaro 2013). The idea is to change charter contracts in a way that risks and benefits are shared among charterers and ship owners. In such contracts speed choice is more flexible, and the chartering cost of vessels is closer to fuel cost; as such ship owners get motivated to invest in energy-efficient technologies, and charterers get stimulated to run vessels in an energy conserving manner.

With respect to the shipbuilding industry, the following could facilitate the transfer of technology as well:

- Financial assistance to shipyards to be provided at the national level or through other arrangements;
- Foreign direct investment in software and hardware as an innovative way to support industry in implementing the requirements.

One type of incentive that governments can provide to enhance industry performance and technology adoption is a competition for top performers. Governments could contribute to a fund, from which money is distributed to the top 10% of best performers in a particular year.

4.5 Cost estimates

4.5.1 Workshops and training

Capacity building workshops for administrations are estimated at € 1,000 per attendee for an online workshop (1-2 days). Costs for the organisation of such workshops would include expert fees and administrative costs. These costs could be lower if the course material is already developed (model workshops). E.g. 2 attendees per Flag State, for the ten most important Flag States (covering 74% of total fleet tonnage) comes down to € 20,000, or less in case the courseware is already existent.

A situation that is more conductive to networking and experience sharing is to send people physically to **regional workshops**. The costs of such workshops, including participants travel and hotels for 50 participants would be between €20,000 - €100,000 per workshop, based on our international experience with organising workshops in the field of renewable energy and energy efficiency. Costs could be lower depending on the amount of preparation required, cost of location (could be sponsored by participating states).

4.5.2 **Technical training**

Trainings already exist for calculating and verifying EEDI, including development of tools to calculate EEDI. For example, MARIN offers 32h courses over 5 days in the Netherlands for € 5,000 per attendee (excluding travel and accommodation)[29]. Lloyds offers similar trainings for similar costs[30].

Model courses for training may need to be updated, depending on identified needs. Ecofys estimates the update of e.g. an existing EEDI model courses to cost in the order of € 50,000.

4.5.3 **Online platform for inventory of energy efficiency technologies**

Inventories of energy-efficiency technologies already exist (for example in reports like (IMO 2009) and on websites of for instance DNV-GL: the efficiency finder[31]), but they could be further developed, since the websites are either not independent or incomplete.

In order to facilitate information exchange a web-based platform could be established. The role of the platform would be for example to provide verified information on real-world energy efficiency improvements via a monitoring programme. For example, in order to stimulate the deployment of energy efficient trucks, the Dutch government provides a website to share audited knowledge and data on about 15 energy efficiency technologies[32]. The costs of such a website and corresponding programme are estimated to be around € 2 million for a 4 year period. Furthermore a platform can be used to inspire others by showing best practices and can be used for sharing of information regarding network opportunities like conferences and seminars.

4.5.4 **Capacity building project**

Currently the IMO-GEF-UNDP GloBallast project is a capacity building project, it assists developing countries and their maritime industries in implementing international regulations on ballast water

[29] http://www.marin.nl/web/Events/Courses/Specialist-Course-on-Ship-propulsion-model-tests-and-SpeedPower-trials-for-EEDI-Verifiers-2731-October-2014.htm
[30] http://www.lloydslist.com/ll/sector/ship-operations/article422262.ece
[31] https://www.dnvgl.com/maritime/energy-efficiency/efficiency-finder.html
[32] http://www.truckvandetoekomst.nl/

management and preventing risks arising from the transfer of harmful aquatic organisms. And has several aspects that could also be used for knowledge transfer of energy efficiency measures:

- web-site;
- e-learning course;
- databases/directories;
- library collections;
- newsletter;
- Regional Task Force (RTFs) to support development and adoption of a regional approach;
- Develop and implement communication, education, awareness raising and outreach programme;
- Develop introductory and more specialised training packages;
- Develop model legislations.

The total budget for the 2008-2012 period was US$23 million out of which US$5.64 million represents a GEF grant, the rest being mostly in-kind contributions from the participating countries, regional co-ordinating organisations (RCO) and strategic partners, including the private sector.

Improved access to information and information sharing with international recognised organisations, including relevant survey and certification training would further promote the different technologies.

5.Conclusions

This study provides an overview of existing technologies which could drastically improve the energy efficiency of ships. Furthermore, barriers to transfer and uptake of energy efficient technologies are analysed and categorised and implications of these barriers are listed, in order to facilitate the uptake of energy efficiency technologies for ships.

From this research it is clear that conventional technology is available that can cost-effectively (with a payback time of less than 15 years) achieve high efficiency gains. If the maximum gains per category are added up (for all but ferry and cruise) this would mean a total efficiency improvement of 35%. Even without taking two experimental technologies with potentially high efficiency gains into account (wind power and air lubrication).

High investments like wind power and contra rotating propellers bring the highest savings (13 – 20%). The medium investments are in-between (5-10%) and the low investments only bring relatively small energy efficiency improvements (<5%).

When the ship owner has too few opportunities to share investment with charterers this leads to a split incentive: a ship owner may invest the up-front capital to put in energy-efficient technology but not receive the benefits. This is typically a problem for investments with a high payback time, i.e. the wind power and contra rotating propellers.

The main barriers are related to the transfer of technology to Flag States. Flag States are generally third world and developing nations that often do not have the resources to enforce, investigate or prosecute breaches by their flagged vessels.

Several ways to overcome the knowledge transfer barriers were presented that can be categorised as follows:

- Workshops and trainings:
    - Capacity building workshops for administrations
    - Regional workshops
- Technical training
    - Training in calculating and verifying the EEDI
    - Development of model courses
- Online platform
    - Inventory of energy-efficiency technologies
    - Creation of a website with all relevant information for the target audience
    - Improved access to information and information sharing
    - Provide verified information on real-world energy efficiency improvements via a monitoring programme

The most expensive of the capacity building actions is the capacity building project, which takes all aspects above into account. If a project would be developed for knowledge transfer regarding energy efficiency measures similar to GloBallast, which assists developing countries and their maritime industries in implementing international regulations on ballast water management and preventing risks arising from the transfer of harmful aquatic organisms the total budget needed would be in the order of US$23 million for a period of 5 years.

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Appendix I - World fleet registered trading vessels

Table 3 World fleet registered trading vessels of 100 gross tons and over 2009-2013. Source: UK DfT 2014

Flag Country	2009	2010	2011	2012	2013
(World Total)	844.8	913.0	983.1	1,034.3	1,072.5
Panama	188.6	197.9	208.4	215.8	217.2
(European Union)	190.0	197.9	207.4	205.1	210.6
Liberia	90.8	103.7	116.7	123.8	124.1
Marshall Islands	47.5	59.0	71.1	81.1	90.0
Hong Kong	44.9	55.3	67.8	78.5	85.4
Singapore	39.8	43.4	51.2	59.2	67.7
Malta	34.8	38.0	43.8	45.0	49.6
Bahamas	45.2	46.9	48.1	48.3	48.5
Greece	38.8	40.7	41.1	41.1	41.5
China	28.2	32.7	35.6	38.8	41.1
United Kingdom (inc IOM and CI)	25.8	27.3	29.4	30.0	28.8
Cyprus	20.1	20.5	20.7	19.7	20.3
Japan	13.8	15.6	16.7	17.8	19.2
Italy	15.0	16.9	18.1	18.0	17.6
Norway	15.2	14.5	14.3	14.4	14.5
Germany	15.2	15.5	15.3	13.7	12.3
Denmark	10.7	11.5	11.3	11.3	12.2
Korea, South	12.0	12.4	11.6	11.1	11.2
Indonesia	6.9	8.2	9.1	10.1	11.1
Bermuda	9.4	10.0	10.6	10.9	10.5
Antigua & Barbuda	10.0	10.7	11.1	10.6	10.0
United States of America	10.7	10.8	10.2	9.9	9.7
India	8.3	8.3	8.9	8.5	8.2
Netherlands	7.6	6.1	6.7	6.6	6.9
Turkey	5.4	5.8	6.2	6.4	5.9
Malaysia	6.9	7.2	7.1	6.2	5.7
France	6.3	6.3	6.4	5.6	5.3
Russia	4.7	4.9	4.9	5.1	5.2
Philippines	5.0	5.1	5.0	4.3	4.3
Cayman Islands	2.7	2.9	3.2	3.2	3.1
Taiwan	2.5	2.6	2.7	3.0	3.1
Iran	0.9	0.8	0.5	2.1	3.1
Thailand	2.5	2.6	2.2	2.6	2.9
Sweden	3.9	3.5	3.3	2.8	2.7
St Vincent & the Grenadines	4.7	4.2	3.7	2.8	2.4
Canada	2.4	2.4	2.5	2.4	2.3
Spain	2.2	2.5	2.6	2.5	2.3
Kuwait	2.3	1.9	2.4	2.4	2.2
Brazil	2.0	2.0	1.9	1.9	2.0
Cambodia	1.8	1.7	1.3	1.3	1.2

Appendix II - Most important shipbuilding countries

China

China is an emerging shipbuilder that overtook South Korea during the 2008-2010 global financial crisis as they won new orders for medium and small-sized container ships (Bloomberg 2014, Bluebird-Electric 2014).

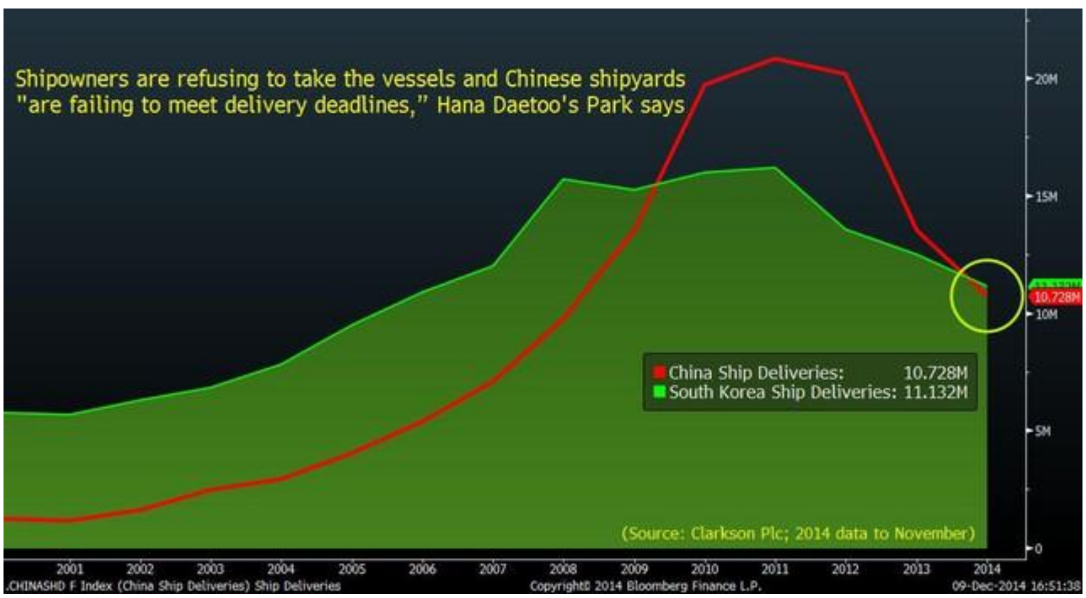

Figure 14 delivery of vessels from Chinese and South Korean shipyards in million compensated gross tons, a measure of building time and human resources used per ton. Source: (Bloomberg 2014)

China has more than 1,600 shipyards. Analysts have predicted that about one third of them will fold as the industry struggles with overcapacity. Last year, China laid out a three year plan for industry restructuring that urged yards to concentrate on building higher quality vessels and local governments to halt approvals for new projects (Bluebird-Electric 2014).

After two decades of a loan-fuelled boom, China’s shipbuilding industry has become saddled with debt and overcapacity, prompting some private firms to seek financial assistance from the state. In September, the government issued a list of 51 shipbuilders it deemed worthy of public support (Marinelog 2014).

New additions to the white list include subsidiaries of the China State Shipbuilding Corporation (CSSC) and the China Shipbuilding Industry Corporation (CSIC) and the AVIC Weihai Shipyard owned by the Aviation Industry Corporation of China (AVIC) (Marinelog 2014).

South Korea

By the end of 2014, it seemed, South Korea has overtaken China again as the world's largest shipbuilding country with a global market share of about 30%(see Figure 14) (Bloomberg 2014) (Bluebird-Electric 2014). South Korea leads in the production of large vessels such as cruise liners, super tankers, LNG carriers, drill ships, and large container ships.

South Korea's shipyards are highly efficient, with the world's largest shipyard in Ulsan operated by Hyundai Heavy Industries slipping a newly built, $80 million vessel into the water every four working days. South Korea's "big three" shipbuilders, Hyundai Heavy Industries, Samsung Heavy Industries, and Daewoo Shipbuilding & Marine Engineering, dominate global shipbuilding, with STX Shipbuilding, Hyundai Samho Heavy Industries, Hanjin Heavy Industries, and Sungdong Shipbuilding & Marine Engineering also ranking among the top ten shipbuilders in the world. In 2007, STX Shipbuilding further strengthened South Korea's leading position in the industry by acquiring Aker Yards, the largest shipbuilding group in Europe. (The former Aker Yards was renamed STX Europe in 2008). In the first half of 2011, South Korean shipbuilders won new orders to build 25 LNG carriers, out of the total 29 orders placed worldwide during the period.

To maintain their market position, Korean yards also focus more and more on greening opportunities. The Korean government introduced a GHG emission reducing program in 2008. The program is aiming at reducing GHG emissions throughout all economic sectors, including the shipping and shipbuilding industry. Also the Japanese Shipbuilding Association (SAJ) is looking into the possibilities to reduce GHG emissions, so that the shipbuilding industry becomes greener and more competitive (Ecorys 2012).

Japan

Japan had been the dominant ship building country from the 1960s through to the end of 1990s but gradually lost its competitive advantage to the emerging industry in South Korea which had the advantages of much cheaper wages, strong government backing and a cheaper currency. South Korean production overtook Japan's in 2003 and Japanese market share has since fallen sharply.

The Philippines

The Philippines has placed fourth among shipbuilding nations around the world producing more than six million deadweight tonnes of ships built in 2012. The country is anchored by South Korean Hanjin and Japan's Tsuneishi shipbuilders. The country has shipyards in Subic and Cebu.

Europe

For several decades European shipyards have been facing strong global competition from especially Asian enterprises (Japanese yards in the 1950s and 60s, Koreans from the 1970s and 80s, and Chinese since the 1990s). In Europe this has led to an almost complete exit from the mass production segments of tankers, bulkers and containerships. Response of the EU industry has been to focus on the higher value, more complex ship types such as ferries and passenger ships, non-cargo vessels and general cargo ships. In addition, only limited numbers of vessels of the same type are being built (in contrast with bulk vessels, which are mass produced). Europe has a 77 percent market share in building passenger vessels (including both cruise ships as well as ferries) and a 17 percent share in the construction of non-cargo vessels (Ecorys 2012). These segments make up a relatively small share of the world orderbook (in CGT). However, in value they represent a much higher share due to their relatively sophisticated characteristics. The position of the European shipbuilding industry in the manufacturing of specialised innovative vessels is still strong. At the same time European equipment manufacturers have acquired a leading role in quality products especially in complex / high value equipment components

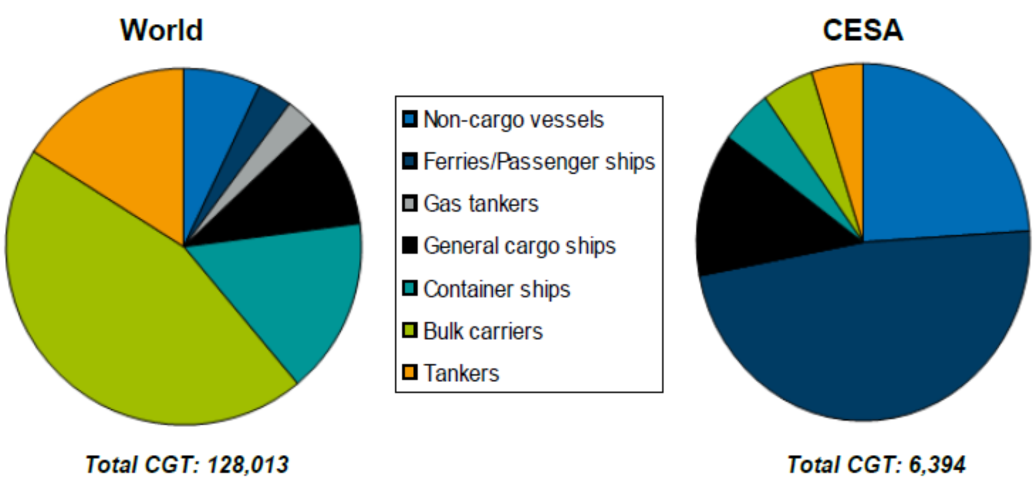

Figure 15 World orderbook and CESA orderbook by ship type in 2010 (CGT x 1000) (Source: Ecorys 2012)

Regarding the **marine equipment sector**, the European industry is renowned for propulsion, cargo handling, communication, automation, environmental and security systems. This equipment is not only destined for complex, European-built ships, but also exported to Asian yards, whether or not requested by their clients (Ecorys 2012).

Compared to the ship construction sector, the marine equipment segment is highly heterogeneous and consists of companies that are often also active in other business areas (i.e. automotive or aircraft industry). A study by (BALance 2014) found that the European marine equipment industry's competitiveness lies in a strong market position and technological leadership, at least for globally active European marine supply companies who build their position on a strong infrastructure and co-operative partners, skill of their employees and close relationship with their customer base. Conversely, identified weaknesses are the cost level in Europe and the heterogeneous structure of the industry with many SMEs which hinder in some cases attempts to follow the markets by globalisation strategies.

Turkey

Shipbuilding in Turkey has evolved from an old traditional activity in Anatolia to an internationally recognised industry, especially since the early 1990s. The industry has modern shipyards that can build ships, yachts, mega-yachts, and sailing boats, as well as carrying out extensive repair and conversion works. Turkey's shipyards are mainly located in the Marmara Region, namely Tuzla, Yalova, and İzmit, which have developed into dynamic shipbuilding centres. Also, in recent years the emerging Black Sea and Mediterranean Regions have increasingly attracted shipyard investments.

In the last decade, in parallel with developments in the global market, Turkish shipbuilding experienced a several-fold increase in its shipbuilding and export capacity, including a significant product diversification. According to order books, this resulted in Turkey being regularly placed in the top ten countries on the basis of its deadweight (dwt) production, and in the top five countries by the number of ships.

In recent years Turkey has increasingly tapped into niche markets, which in turn has led to a growing participation by Turkish shipyards in the international trade in new ships. In parallel, there has also been strong growth in the marine equipment manufacturing sector, which could increasingly also tap the export market. These developments reflect in part the strategic location of the yards, the experienced workforce, the quality of production and Turkey's significant role as a political, cultural and economic bridge between Europe and Central Asian and Middle Eastern economies (OECD 2011).

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