ETSAP ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAMME

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Shipping Transport

HIGHLIGHTS

■ **TECHNOLOGY STATUS –** Shipping carries around 90% of international world trade, and is almost exclusively powered by internal combustion engines. Currently, only around a third of the energy released during fuel combustion is converted to useful ship propulsion. There are many technical measures that can inprove fuel efficiency, including optimising the design of the vessel, engine and propellers. Most options to improve the design of the hull and engines are only suitable for new-build ships, whereas changes to the propulsion system are more readily applied in retrofit as well as new-builds. The majority of ships currently rely on heavy fuel oil (HFO). Alternative energy sources which are in use today include biofuels, liquefied natural gas (LNG), solar and wind propulsion. Other sources such as hydrogen and nuclear are less well developed.

■ **PERFORMANCE AND COSTS –** Various technical options are usually applicable to most ship types, although with varying degrees of effectiveness. Technical retrofit and maintenance strategies could reduce CO_2 emissions from the existing fleet by 20%. These include: hull coatings (short payback), waste heat recovery (medium payback) and advanced propeller designs (short/medium payback). The potential for CO_2 emission reductions from improved new-build vessel design is around 30%. Examples include: optimising the vessel size (long payback), lightweight construction (short payback), and designing the hull for reduced frictional resistance (short payback). Using alternative energy sources can also reduce fuel consumption and CO_2 emissions, e.g. biofuels (up to 75-85% CO_2 reduction), wind power (~15-25% fuel savings), solar (4% fuel savings) and LNG (20-25% GHG reduction).

■ **POTENTIAL AND BARRIERS –** Estimates of future shipping activity from the IMO predict a global increase of 150-300% from 2007 to 2050. International policies on mandatory requirements for shipping energy efficiency are being developed and are expected to play a crucial role in driving the uptake of advanced technologies. There is currently excess ship capacity in the market which will need to be cleared before investment in innovative new ship construction becomes attractive. Barriers include high costs, the long lifetime of ships (typically ~25-32 years) and the inherent conservatism of the ship building industry. In the short term, retrofit techniques are likely to be the major source of efficiency gains. LNG is seen as a potential alternative to HFO in the short term in some applications. Wind power – such as the use of kites or sails to supplement main engine power – is seen as a viable technology in the short to medium term. After 2020, other options are expected to become more important, such as hull optimisation, lightweight construction, and propulsion technology. By 2050, almost the entire fleet will have been replaced therefore measures which can only be applied to new ships will have diffused into the fleet.

TECHNOLOGY STATUS – Maritime transport currently carries about 90% of international world trade [1], and accounts for roughly 9% of total transport fuel use [2]. **International shipping** takes place between ports of different countries and excludes military and fishing vessels. It accounts for the majority of maritime fuel use (~90%) [2], and relies primarily on heavy fuel oil (77% of total maritime transport fuel) [3].

Shipping activity doubled between 1985 and 2007 [3], fuelled by increases in international trade – particularly Asian manufacturing and exports to other countries [2]. However, the global recession caused demand to contract by 4.5% in 2009, reflecting weak consumer confidence in the retail sector and low levels of capital investment [4]. Prospects for shipping are expected to recover in 2011 and beyond as manufacturing activity resumes.

Ships can be broadly categorised into the following types: **Container ships** are fully cellular ships which operate on scheduled voyages at high speeds. They are designed for efficient transport of containerised cargo. **Bulk carriers (bulkers)** transport dry cargo such as grain and coal. **Tankers** are for transporting liquid cargo such as chemicals and oil. Tankers and bulkers tend to operate on long distances with infrequent port calls; therefore design optimisations should be focussed on efficient running at sea. **Roll on-Roll off (RoRo) & vehicle** vessels are designed to transport wheel-based cargo. They are characterised by multiple short stops and high speeds. **Passenger vessels** such as ferries operate on short, fixed routes with variable speeds.

Container vessels account for the largest share of fuel use. In 2007 they represented 16% of all maritime trade by weight and a much larger share by value [3]. Tankers and bulkers also use significant amounts of fuels, while passenger vessels only account for around 10% (see Table 1).

Only one-third of the energy produced from fuel combustion results in propulsion; the rest is lost due to thermodynamic and mechanical inefficiencies [5]. A wide range of technical measures are available to improve shipping energy efficiency. Taking the options together, the overall potential for CO_2 emission reductions from improved new-build vessel designs is estimated to be around 30% [3]. Technical retrofit and maintenance strategies could reduce CO_2 emissions from the existing fleet by up to 20%. Operational improvements are alternatives to technical solutions

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which may reduce emissions. Examples include speed reduction, optimal cargo handling and optimising the shipping route to take into account currents and weather conditions. These are not considered here, but it is noted that they could deliver considerable savings – up to 40%, particularly from speed reduction measures [3]. An overview of the main technical options is provided in the following sections.

■ **Vessel design -** The overall size and construction of the vessel can be optimised in new-build ships. **Increasing vessel size** usually makes vessels of all types more efficient, although practical limits to ship size may be close to being reached [2]. Similarly, **increasing vessel length** can lower engine demand. Port restrictions may limit the uptake of these measures, as not all ports will be able to receive larger vessels. Designing for **reduced ballast**[1] lowers resistance by minimising the area of the hull that is submerged. Replacing non-structural steel elements with alternative **lightweight materials** can also result in lower power requirements, particularly for container vessels which have demanding steel structures.

Hull design and ensuring smooth flow into the propeller are critical factors; optimisation is regularly applied to new-build ships [5]. Examples of such techniques include: **Low-profile hull openings** to reduce flow disturbance around areas such as bow thrusters and tunnels. **Interceptor trim plates** are extensions at the rear the hull which create a lift effect by channelling the high-pressure flow behind the propellers downwards. **A tapered aft extension** of the vessel at the waterline can reduce wake turbulence. **Aligning the propeller shafts** minimises turbulent flow and frictional resistance. **Skeg**[2] **shape** can be optimised to deliver low-speed non-turbulent flows and thus reduce power demand. A **bulbous bow extension** can improve water flow around the hull and can reduce drag for large vessels operating at commercial speed.

Hull skin friction is a very significant contributor to total resistance, and this is increased if the hull surface is rough or fouled. **Hull coatings** are designed to make the hull surface as smooth as possible. Companies such as International Marine Coating are researching “slick” hull coatings which imitate shark skin to reduce drag. Other coatings are designed to inhibit organic fouling, by offering a soft surface that is difficult for foulants to hold on to. Traditionally, tributyl tin (TBT) was used as an inhibitor in coatings, but many nations have implemented a ban on its use due to its environmental impact [6]. Alternatives are silicon or copper-based inhibitors. MARINTEK has developed a number of self-polishing coatings. **Air lubrication** involves pumping compressed air along a vessel’s hull to lubricate the hull-water contact area. An example is the Air Cavity System, implemented by the DK group.

■ **Engine design -** Engines can be tuned to the task for which they are designed. They are usually optimised for the most commonly used load ranges (**enhanced engine tuning**), but operation outside of these conditions results in reduced efficiency. Adding an extra cylinder and operating the engine at a lower speed is known as **de-rating** and can reduce fuel consumption for a given vessel speed. **Common rail fuel-injection systems** share the same benefits as those used in the automotive sector. Multiple smaller engines may also be used so that some can be switched off under low power requirements to improve overall efficiency.

The conventional direct engine-propeller shaft can be replaced by, or coupled with, electric drives to deliver substantial efficiency gains. **Diesel-electric drives** are effective for vessels where frequent changes in shaft load and operating profiles are needed (e.g. RoRos and passenger vessels) [7].

Waste heat recovery involves capturing engine exhaust heat and converting it into electric energy for use in functions such as fuel heating. Various types of waste heat recovery systems have been installed on different types of ships.

■ **Propulsion system -** Propellers require sufficient hull clearance and submersion when the ship is operating, which limits their design. **Larger diameter propellers** which rotate at lower speeds are more efficient for tankers and bulk carriers. Fitting a completely new propeller to an existing ship has been carried out in a number of cases.

Propeller design and monitoring strategies can be adopted to increase efficiency such as: **propeller efficiency monitoring** to adjust the engine output according to measured variables such as speed, torque and thrust; **advanced propeller blade sections**; **optimising the propeller-rudder unit** (e.g. with a rudder bulb); **wing thrusters**[3] to lower resistance from the hull appendages; **winglets** on the propeller tips - known from the aircraft industry – to reduce turbulence; and **propeller nozzles,** which are rings circling the propeller that reduce trailing turbulence. Almost all of these strategies can be applied to new and existing ships, and overall, they can contribute to a 15% increase in efficiency [8].

Devices can be used to recover energy from the propellers, or to provide pre-rotation of the flow into the propeller. **Counter-rotating propellers** consist of a pair of propellers behind each other which rotate in opposite directions. This allows the rearmost propeller to recover some of the rotational energy from the slipstream of the

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[1] Ballast refers to additional weight added to the lowest part of the hull in order to increase stability.

[2] The skeg is an extension of the hull leading up to the propeller shaft line and disc.

[3] Wing thrusters have a propeller shaft in the middle and two thrusters pulling at the side

forward propeller. These work best for heavily loaded propellers with a short shaft line. **Pulling thrusters** combine steerable thrusters with a pulling propeller. They can be combined on a central shaft which results in less appendage resistance. This is useful for vessels requiring frequent operation at variable loads.

■ **Other technologies -** Most ships rely on heavy fuel oils (HFO). Marine diesel (MDO) is higher quality, giving fuel savings of 4 - 5% [7], and has a lower sulphur content; on the other hand it is more expensive. Ship engines can take a range of fuels, and may be able to use **biodiesel or biocrude** which could reduce CO_2 emissions by 75 - 85% [7]. A.P Moller-Maersk has launched a two-year pilot biodiesel programme. In addition to general concerns about sustainability of biofuels, there also technical issues in that biodiesel may be more corrosive and abrasive than standard fuels [7]. Other problems with biodiesel that may occur include: fuel filter failure due to the solvent properties of the fuel; unfavourable cold flow properties; and microbial contamination [15]. Controlling contamination is a particular problem in marine applications because fuel tanks are vented to the atmosphere, and the fuel is stored in the tank for longer periods than in road or rail applications. **LNG** (liquefied natural gas) is already used as a fuel, particularly for powering LNG tankers. The main advantage is its high energy content and potential to reduce CO_2 emissions by 20 - 25% [9].

Wind power could be used in several ways: spinning vertical rotors (**Flettner rotors)** convert side winds into propulsive energy. According to the IEA, they can only be fitted to tankers or RoRos, where fuel efficiency savings of up to 30% can be realised [3]. The application of **kites and sails** has been investigated since the 1980s – fuel efficiency savings of up to 20% are possible [3]. There are a number of wind assisted ships currently in operation such as the Modern Windship and vessels from Sail Log and Skysails [7]. Sails require available deck space for a strong mast and rigging. Kites have several advantages over sails in that there is no need for masts; they can be flown higher in the sky to take advantage of stronger winds; loading and unloading is cheaper and maintenance can be conducted remotely. Conversely, kites could involve complex launch, recovery and control systems.

Other potential power sources include hydrogen, fuel cells and nuclear reactors, however the pace of development has been slow and research has been limited [9]. Electricity and heat can be generated from on-deck **solar panels**. Current photovoltaic (PV) technology is only sufficient to cover a fraction of auxiliary power for most ship types even if the entire deck is covered in cells [5]. However, solar power is currently used in passenger ships in Europe and Australia.

PERFORMANCE AND COSTS – According to a recent International Maritime Organisation (IMO) study [10], shipping shows significant advantages in carbon emissions over road and air freight, and is competitive with rail. The efficiency (and emissions) of shipping vessels varies hugely from between 2.5 and 60.3 g CO_2/t-km [10]. Owing to overcapacity, prices for new ships have fallen in 2008, 2009 and early 2010. Average new-building prices have decreased between 2008 and 2009, by 24 - 29% for bulkers, 19 - 33% for containers, and 23 - 26% for oil tankers [3]. Indicative prices for these ship types are included in Table 1.

Tankers and bulkers experience 70 - 80% of total resistance due to frictional drag [3]; therefore smooth hull coatings are particularly beneficial. Their large, flat-bottomed hulls are also suitable for air lubrication, which can increase efficiency by up to 15%. Gains from air lubrication reduce to about half as much for container vessels and light duty vessels [3]. Hull coatings must be renewed approximately every 5 years, and costs vary significantly depending on the type, from US$ 43,000 to US$ 265,200 [9]. The hulls tend to have full forms and blunt ends, therefore hull resistance can be lowered by increasing its length to make it more slender. Propeller nozzles are effective for tankers and bulkers, as well as other ships operating at speeds of up to 20 knots [11]. Tankers and bulkers are considered to be the best potential users of kite systems [8]. For a kite area of 1,280 m^2, the purchase price is around US$ 1,755 [9]. The large deck areas are also suited to Flettner rotors and sails.

For **container ships**, frictional resistance is less than 40% of overall resistance, but hull fouling can increase this by up to 40% [3]. The most important component of overall resistance for these ship types is wave resistance, which can account for up to 60% [3]. Wave resistance can be reduced using a lightweight construction and bow modifications. Bulbous bows are most effective on long, narrow, fast-moving ships such as containers, where they can improve fuel efficiency by up to 20%; however they can actually increase resistance on other ship types [7]. Hull design changes have a greater effect on smaller ships because they have comparatively large wave resistance [5]. Optimising the design of the vessel is a well-known technique which can reduce carbon emissions for new vessels by up to 20% [7]. Doubling the size of a ship could increase efficiency by up to 30% [12]. Optimising propeller performance is also a particularly important measure for containers, such as use of winglets and advanced blade sections [3]. Additionally, the power levels needed for propulsion are high (due to the high speeds) which makes waste heat recovery attractive.

RoRos usually have low hull resistance, therefore the efficiency of the lightly-loaded propeller is usually high – this could be further improved with counter-rotating propellers [11]. Advanced propeller designs and improving rudder-hull interaction are the most important measures for this type of ship. For instance, the rudder has a drag in the order of 5% of ship resistance, which can be reduced by 50% with optimised design [11]. Pure Car and Truck Carriers (PCTCs) often have a fixed ballast to achieve sufficient stability. Reducing this can improve fuel efficiency by up to 7% [13].

Passenger vessels usually have a low draft[4] and twin screw propulsion. The twin shaft lines result in high drag; therefore concepts such as wing thrusters offer considerable power savings and give more flexibility in the engine arrangement [13]. Combined diesel-electric drives give high efficiency while manoeuvring. Alternative fuels are also an option for regular services between fixed ports, as refuelling logistics in these cases are easier.

Fuel costs accounted for up to 60% of total ship operating costs when oil prices surged in 2008 [14]. Biodiesel fuels are more expensive and their use incurs higher costs relating to fuel filtering and associated maintenance [15]. The benefit of solar power depends on the installed PV capacity and the solar climate. Although solar may be useful as a supplementary auxiliary power source, the capital costs are some 20-50% higher than for conventional vessels [7].

POTENTIAL AND BARRIERS

■ **Major drivers for performance and costs -** Projected growth in shipping is closely correlated with growth in the production and consumption of raw materials and manufactured goods, as well as the location of these activities [12]. International trade, particularly exports from markets such as China, is a key driver. The IMO projects a range of possible futures, with shipping increasing by between 150% and 300% from 2007 to 2050 [3], however published predictions for activity in 2050 vary by up to 300% [2]. The IEA estimates that there is potential to reduce energy intensity by up to 70% for some ship types by 2050 [3].

International policies are likely to be needed if large gains in shipping efficiency are to be achieved [3]. The majority of greenhouse gas emissions from maritime transport are still unregulated. For example, they are specifically excluded from national targets under the Kyoto Protocol. The IMO has initiated actions to introduce regulations, but agreement on binding targets has not been reached [1]. Standard-setting measures which may incentivise the uptake of more efficient technologies in the future include a draft text on the mandatory requirements of the Energy Efficiency Design Index (EEDI) for new ships, and the Ship Energy Efficiency Management Plan (SEEMP).

Other factors which might lead towards increased efficiency are: increased awareness of the environmental impacts, unpredictable increases in fuel costs (resulting in the reduction in the optimum cost-effective speed), and a desire for reduced dependency on fossil fuels [8].

■ **Market potential and prospects -** The industry trend has been towards massive container and cargo ships, however there are practical constraints such as port equipment and harbour depths [12]. Advanced computer aided design has made it easier to optimise vessel design. It is thought that most designers are using hull optimising techniques for new ships, due to increases in oil prices [7].

Developments in China are changing the supply and demand landscape of shipping. A quarter of global containerized exports were Chinese in 2009 [4]. Chinese shipping companies are growing rapidly. Chinese banks lent to foreign ship owners after the economic crisis in 2008, replacing the traditional sources of finance from Germany and the UK. It has been suggested by a European Commission study [4] that China is ensuring that there will be capacity to transport its foreign trade at low cost in the long term.

In the short term, retrofit techniques are likely to be the major source of efficiency gains because the capital outlay for a ship is large and they have long lifetimes (ca. 25 - 32 years [7], [3]). Retrofits are usually only cost-effective if they are installed when a ship undergoes a major overhaul, which causes a time lag of several years in implementation [9]. There are currently no viable options to completely replace petroleum based fuels [9]. Diesel engines provide power for the vast majority of ships – 96% of the maximum installed engine output of all civilian ships above 100 gross tonnes [16]. LNG is seen by many as a potential fuel for ships in the short term. The main issues are finding storage space for the fuel, and ensuring its availability. The use of large sails for tankers and bulkers could be a cost-effective option if oil prices continue to increase [16].

After 2020, other options such as hull optimisation, lightweight construction, and propulsion technology are expected to become increasingly important. Biofuels are currently more expensive than oil-derived fuels and incentives for their use are generally aimed at land-based applications. They are not expected to feature significantly in maritime fuels within the next 20 years [9]. Hydrogen is not currently considered to be a viable option until at least 2020 [5]. Fuel cells are mainly being researched as auxiliary power units rather than for propulsive power, except for very small vessels.

By 2050, almost the entire fleet will have been replaced [3]; therefore measures which can only be applied to new ships will have diffused into the fleet (see Table 2). Solar photovoltaics are not currently suitable for large

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[4] The draft is the vertical distance between the waterline and the bottom of the hull

power demands, but in the long term they could be more attractive for auxiliary power needs, especially if combined with (or integrated into) sails [5].

■ **Barriers to development and deployment -** Although the global recession caused a decline in shipping transport by 4% in 2009 compared to 2008, the world fleet grew by 7% [4]. This was due to orders placed before the downturn in demand, and the resulting oversupply caused a 300% increase in scrappage of older ships [4]. In 2009 there were only nine new orders for container ships, compared to 538 in 2007 [4]. As such, manufacturers may be less inclined to develop new technologies.

The shipping industry comprises different systems of ownership, operation and registration, which occur across different countries for a given ship. This may limit the market incentives to optimise ship efficiency [2]. Other barriers include high sensitivity to capital expenditure; long lead times when designing new vessels, and environmental concerns being secondary to safety and speed priority placed on operators [7].

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Table 1 – Summary Table: Key Data and Figures for Baseline Shipping Types

Ship type	Capital cost (million US$) [3], [17]	Non-fuel operating costs (million US$/yr) [17]	Average service speed (knots) [10]	Total efficiency [c] (g CO_2 / tonne-km) [10]	Energy consumption (MJ / tonne-km) [d]	Fuel cost (US$ /yr) [e] [10]	% of total maritime fuel consumption [18]	Total fuel consumption (thousand t) [18]
Container	10 - 105 [a]	7.0 – 16.1	17.0 – 25.1	16.6 – 32.1	0.21 - 0.41	1.95 – 21.05	25%	72,229
Bulk carriers	25 - 57 [a]	19.0 – 36.2	11.0 – 14.4	2.5 – 29.2	0.03 - 0.38	0.6 – 8.2	19%	54,889
General cargo	-	-	11.7 – 15.4	11.0 – 19.8	0.14 - 0.26	2.5 – 3.15	13%	36,712
Crude oil tankers	34 - 99 [a]	4.0 – 17.1	12.1-15.4	2.9 - 33.3	0.04 - 0.43	0.9 – 12.15	12%	33,560
Other tankers	27 – 63.5 [b]	-	11.0 – 19.6	5.7 – 45.0	0.07 - 0.58	0.5 – 16.9	14%	41,925
RoRo & vehicle	27.5 – 39.5 [b]	3.9 – 12.6	13.2 – 19.4	32.0 – 60.3	0.41 - 0.78	1.05 – 7.2	5%	13,722
Passenger	500 - 600 [b,f]	-	-	-	-	0.35 [g] – 24.75 [f]	11%	31,300

Notes: Table estimates are for the year 2007 unless otherwise stated. Fuel estimates exclude fishing, service and offshore supply vessels.

a) Representative newbuilding price as of March 2010; b) Representative new building price at end-2002; c) Estimated, based on the average service speed of each category of vessel from the Fairplay database and the number of main engine operating days (days at sea) from the 2007 inventory. The numbers of tonnes transported were estimated as the product of the assessed cargo weight capacity of the ship and the assessed average utilization factor. The average utilization factor takes into account the degree to which various ships typically need to do empty repositioning (ballast) voyages, multiple port deliveries as well as typical capacity utilization when loaded. See reference [10] for full details; d) Indicative values only. Calculated assuming heavy fuel oil as the energy source, using an emissions factor of 77,400 kg CO2 / TJ [19]; e) Assuming fuel is heavy fuel oil; energy content of 40.97 GJ/t and fuel price of US$500/t. Note that figures are highly dependent on fuel prices which are subject to wide variation, for example near term historical fluctuation has been around +/- 40% of this figure - from around US$300/t in 2007 to a peak around US$700/t in 2008). US$500/t has been selected as indicative of prices in early 2011; f) Figure(s) are for large cruise ships (>100,000 gt); g) Figure(s) are for small cruise ships (0–1,999 gt).

Table 2 – Shipping Energy Reduction Technology Options [3]

Vessel design	**Fuel efficiency gain %**	**Ship types**					**New Build**	**Retrofit**	**Payback**
		T	C	R	P	O			
Lightweight construction	7	✓	✓	✓	✓	✓	✓		S
Optimising hull dimensions	9	✓	✓	✓	✓	✓	✓		L
Low profile hull openings	5	✓	✓	✓	✓	✓	✓	✓	S
Interceptor trim plates	4			✓	✓		✓	✓	S
Aft waterline extension	7		✓	✓	✓		✓	✓	S
Shaft line alignment	2			✓	✓	✓	✓		S
Skeg shape – trailing edge	2	✓	✓	✓	✓	✓	✓		S
Hull coating	5	✓	✓	✓	✓	✓	✓	✓	S
Air lubrication	15	✓	✓	✓	✓		✓		M
Bulbous bow	20	✓	✓	✓	✓		✓		-
Engine design	**Fuel efficiency gain %**	**Ship types**					**New Build**	**Retrofit**	**Payback**
		T	C	R	P	O			
Engine de-rating	3.5	✓	✓	✓	✓		✓	✓	M
Diesel electric drives	5-30			✓	✓	✓	✓		M
Combined diesel-electric and diesel-mechanical drives	4				✓	✓	✓		L
Waste heat recovery	10	✓	✓	✓	✓		✓	✓	M
Enhanced engine tuning and part-load operation	4	✓	✓	✓			✓	✓	S
Common rail engine	1	✓	✓	✓	✓	✓	✓	✓	S
Propulsion system	**Fuel efficiency gain %**	**Ship types**					**New Build**	**Retrofit**	**Payback**
		T	C	R	P	O			
Wing thrusters	10			✓	✓	✓	✓		M
Counter-rotating propellers	12	✓	✓	✓	✓	✓	✓		-
Optimised propeller-hull interface	4	✓	✓	✓	✓	✓	✓		S
Propeller-rudder unit	4	✓	✓	✓			✓	✓	M
Optimised propeller blade sections	2	✓	✓	✓	✓	✓	✓	✓	S
Propeller tip winglets	4	✓	✓				✓	✓	-
Propeller nozzle	5	✓				✓	✓	✓	-
Propeller efficiency monitoring	4	✓	✓	✓	✓		✓	✓	S
Efficient propeller speed modulation	5		✓	✓	✓	✓	✓	✓	-
Pulling thrusters	10			✓	✓	✓	✓		L
Flettner rotor	30	✓		✓			✓	✓	L
Kites and sails	20	✓	✓	✓	✓		✓	✓	L
Other technologies	**Fuel efficiency gain %**	**Ship types**					**New Build**	**Retrofit**	**Payback**
		T	C	R	P	O			
Low loss electric drive	2			✓	✓	✓	✓		M
Hybrid auxiliary power generation	2	✓	✓	✓	✓	✓	✓		S
Variable-speed electric power generation	3				✓	✓	✓		M
Enhanced power management	5	✓	✓	✓	✓	✓	✓		M
Solar power	4	✓		✓	✓		✓	✓	M
Automation	10	✓	✓	✓	✓	✓	✓	✓	S

Ship types: T = tanker; C = cargo; R = RoRo; P = passenger; O = offshore supply; Payback: S = short (1-3 years); M = medium; L = long (>15 years)