Propulsion trends in tankers

MAN Energy Solutions
Future in the making

Future in the making

Contents

Not all economic regions of the globe have major sources of oil nearby. It creates a demand for transportation from major oil producing regions, for example the Middle East, Africa, and Brazil, to consumers in China, India, and Europe.

The slower growth in global demand along with an overcapacity in the market has resulted in fluctuating tanker freight rates for some years. This highlights the importance of designing newbuildings that go into the market for maximum efficiency. The requirement for Phase 3 Energy Efficiency Design index (EEDI) compliance from 2025 backs this up.

Introduction

The economic and technical conditions on the tanker market change continuously. For example, 30 years ago the size of a crude oil tanker had to be as large as possible. The limited safety and environmental demands gave room for the simple mono-hull construction, in comparison to the safer, and more advanced double-hull construction of today.

In consequence of the globalisation and, especially, the economic growth in China since the turn of the millennium, the demand for oil increased. The result was increased freight rates due to the increase in demand for oil tanker transports.

As the global demand for oil is expected to drop slowly through the transition towards renewable energy, tanker vessels will still be required to transport energy around the globe. Expectations are that biofuels and synthetic fuels will play a major role in ensuring carbon neutral transportation, and these must be hauled from producing to consuming regions.

The International Maritime Organization introduced regulations on the Energy-Efficiency Design Index (EEDI) in 2011, seeking to limit the emission of greenhouse gasses from international shipping. The tightening of the requirements for efficiency was divided into three phases.

For tankers:
1. Since phase 1 came into force in 2015, a 10% reduction from the baseline has been required
2. A 20% reduction has been required from 2020 by phase 2
3. Finally, phase 3 requires a 30% reduction by 2025.

Phase 2 has affected the present tanker designs. Small reductions of the service speed along with increasing propeller diameter, and the application of the latest engine technology. The methods for optimisation of the hull lines, though, ensure compliance without major changes.

From 2025, phase 3 requires 30% reduction from the baseline. To achieve compliance with the reduction required by phase 3, not only phase 2 implementations need consideration. Further initiatives and optimisations are required. Changes could be further speed reductions, energy saving devices, shaft generators, waste heat recovery, alternative fuels, and so on.

Looking even further into the future, emissions from ships are projected to grow at least 50% over the next three decades. IMO reacted on this by adopting a goal of 70% reduction of emissions on an individual ship level by 2050, and phase out emissions entirely by the end of the century.

Further EEDI phases have not been defined yet, but most likely, it can be expected that they will somehow follow the reduction pattern for the earlier phases. If a phase 4 reduction is implemented, and it follows the pattern from the earlier phases, the demand by 2030 will be a 40% reduction. An implementation of alternative fuels like LNG, methanol, or even carbon neutral fuels as ammonia will most likely be necessary to attain compliance with phase 4, along with the implementations mentioned for phase 2 and 3.

If none of these measures is applied, and a traditionally-fuelled vessel is ordered in 2030, a significant reduction of the vessel speed and, thereby, engine power will most likely be necessary.

The ultra-long-stroke G-type MAN B&W engine plays an important role in ensuring EEDI compliance with EEDI phases 2 and 3. As vessel speeds decrease, and the propeller diameter increase, the optimum propeller speed is reduced along with the required propeller power. The long stroke and resulting lower rpm of the G-type engine will ensure not only significant fuel savings, but also the containment of any operating point of a tanker within the engine layout diagram.

If diesel fuels are preferred, an engine power reduction will be necessary for vessels to be compliant in the future due to the EEDI restrictions. However, since vessels must comply with minimum criteria for speed, a lowered propulsion power can cause problems during harsh sea conditions. The Adverse Weather Condition (AWC) functionality permits compliance with EEDI restrictions on traditional fuels by a power reduction, and reaching the minimum speed requirements during harsh weather.

This paper illustrates the latest developments within tankers delivered over the last ten years, and explains the main particulars of various tankers categories above 5,000-deadweight tonnage (dwt). Based on an analysis of the latest deliveries, this paper outlines how various tankers sizes can attain compliance with EEDI phase 2, and the future phase 3.

Characteristics of tanker vessels

Dictionaries define bulk cargo as loose cargo loaded directly into a vessel hold. Bulk cargo is thus a shipment of oil, grain, ores, beans, cement, and so on, or one, which is not bundled, bottled, or otherwise packed. Furthermore, cargo is loaded without counting or marking.

It defines a bulk carrier as a ship that carries the cargo in bulk, rather than in barrels, bags, containers, and so on. Usually, a bulk carrier is loaded homogeneously and by gravity.

Based on the above definitions, there are two types of bulk carriers: Dry-bulk carriers and wet-bulk carriers referred to as bulk carriers, and tankers, respectively.

This paper describes tankers, whereas the separate paper: Propulsion trends in bulk carriers describe bulk carriers but has some similarities to tankers.

Tanker development

Initially, the transportation of oil took place in barrels (0.1590 m³) by rail, and by general cargo ships. As the oil demand increased, tanks replaced the barrels. In the mid-1920ies, the first fully welded tanker was built in the USA. Since then, the tanker fleet has by far taken over the market for transportation of oil and other liquid or gas products.

The largest tanker ever built is the 565,000-dwt Seawise Giant from 1976, measuring L_{OA} = 458.5 m and B = 68.9 m, with a scantling draught of 24.6 m. Figs. 1 and 2 show how the delivery of tankers has progressed through the last 20 years.

The deliveries peaked just after the financial crisis in 2008, as a lot of ships were ordered prior to 2008 before the crisis, but was not delivered before 2009. After that, it is easy to see the effect of the crisis, as the number of tankers and dwt declines. Although after 2015, the market seems to have stabilised on delivery figures seen in the years before 2006 whereas dwt delivered seems to fluctuate. What the long-term effects of the COVID-19 crisis will be for the tanker market is still too early to say.

Fig. 3 shows a comparison of average dwt delivered each year.

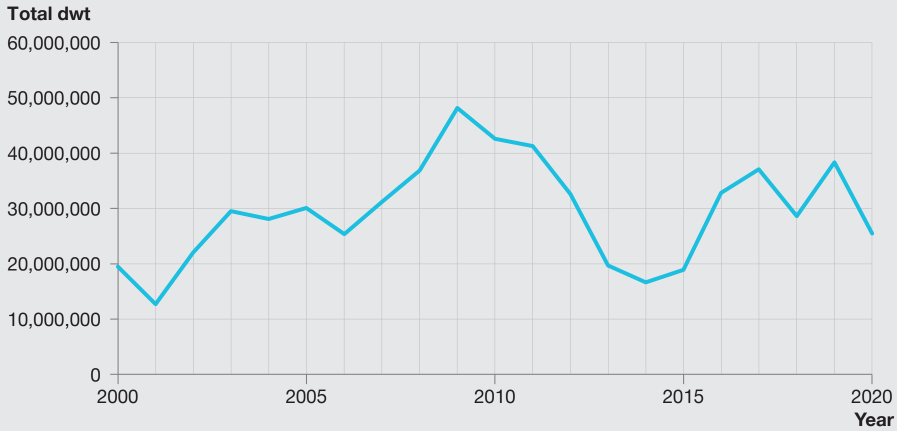

Fig. 1: Total dwt of tankers delivered per year for the past 20 years

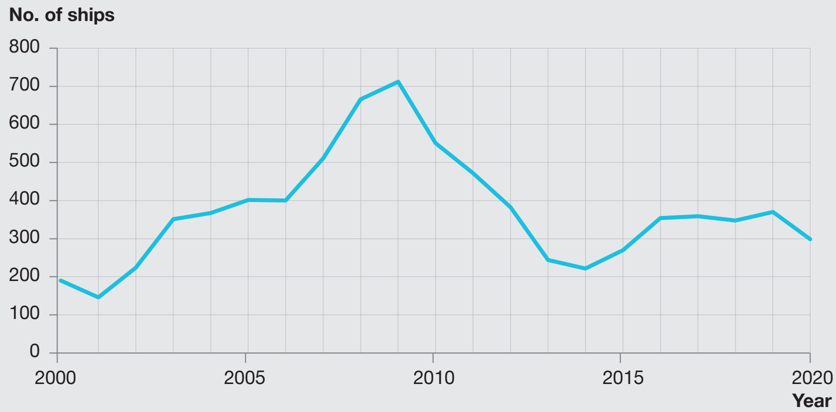

Fig. 2: Numbers of tankers delivered per year for the past 20 years

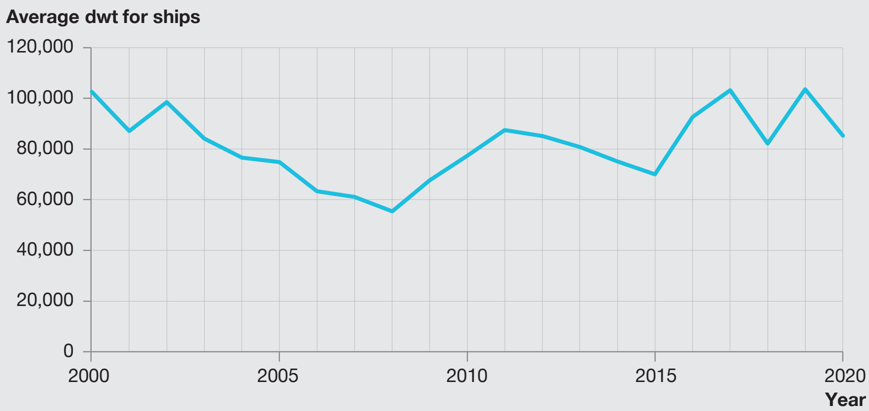

Fig. 3: Average dwt per ship delivered per year in a 20-year period

It is easy to see that the average dwt has increased since 2008, although, it seems to have started fluctuating in recent years. The lower speed implied by the EEDI makes it necessary to deploy larger ships to maintain the transport work of a former vessel travelling faster.

Tanker types

Depending on the products carried by the tankers, these are divided into the following main types:

- Chemical tankers
- Product tankers
- Crude oil tankers
- Gas tankers
- Shuttle tankers

The ship particulars of the gas tankers (LNG, LPG, ethane, and so forth) are different from those of other types of tankers, for example for transport of oil and chemical products. Therefore, this paper does not cover gas tankers. Shuttle tankers, hauling crude oil from offshore oil producing platforms not connected to shore via pipelines, have strict requirements for redundancy, which influences the layout of the propulsion system. Apart from these limited groups of tankers, the other tanker types follow the same propulsion principals and tendencies for engine selection.

As indicated by its name, the chemical tanker transports various types of liquid chemical products, whereas a product tanker carries products refined from crude oil, and other fluids like wine and juice. Crude oil tankers are also be referred to as dirty tankers, transporting the unrefined oil.

In total numbers, the product tankers and chemical tankers dominate ship sizes below 55,000 dwt. In the 60,000-75,000 dwt range, product and crude oil tankers split the market. Crude oil tankers dominate the larger segment.

Tanker sizes and classes

The deadweight of a vessel is the carrying capacity in metric tonnes (1,000 kg) including the weight of bunkers, and other supplies necessary for the vessel's propulsion.

Normally, the size of a tanker is stated as the maximum dwt, which corresponds to the fully loaded deadweight at full summer saltwater draught (normally at a density of 1.025 t/m^3). Often this correlates with the scantling draught, the maximum draught the strength of the hull can sustain. However, sometimes the deadweight tonnage used refers to the design draught. The design draught is commonly less than the scantling draught, and it equals the average loaded ship in service. Most often, scantling draught is referred to as the maximum allowed draught of the vessel. Therefore, the deadweight tonnage that refers to the design draught used for designing the propulsion system is never higher than the scantling draught based on deadweight tonnage.

In the context of tankers, sometimes the word barrel is applied to characterise the size of a vessel. For instance, a VLCC is a two million-barrel crude oil tanker, which stems from when crude oil was stored and transported in barrels. In the oil industry, a barrel (0.1590 m^3) has a standard size of 42 US gallons (which is equivalent to 35 of the slightly larger imperial gallons).

Table 1

	Class	Size, scantling [dwt]	Typical L_{OA} [m]	Typical max. breadth [m]	Typical scantling max. draught [m]
Product carriers	**Small**	<10,000	105	16	6
Product carriers	**Intermediate**	10–25,000	145	24	9
Product carriers	**Handysize**	25–35,000	155–170	25–28	10–11
Product carriers	**MR1**	35–45,000	170–180	28–31	9–13
Product carriers	**MR2**	45–55,000	180–190	31–32,2	11–13,3
Both	**Panamax/LR1**	55–85,000	225–230	32.26	14.5
Crude oil carriers	**Aframax/LR2**	85 – 120,000	228,6–260	42–46	14–16
Crude oil carriers	**Suezmax**	120–165,000	243–285	46–50	15–18
Crude oil carriers	**Shuttle tanker**	140–160,000	275–285	46–50	16–18
Crude oil carriers	**VLCC**	200–320,000	333	61	22

Table 1: Typical main and sub classes for tankers, and approximate measurements. Some of the classes have popular subclasses, referring to designs fulfilling specific limitations

In this paper, the tankers sizes described refer to scantling draught and a seawater density of 1.025 t/m³. All tankers are considered to be of the double-hull design due to restrictions. Depending on the deadweight tonnage and hull dimensions, tankers are split into the main groups or classes in Table 1.

Some shipowners and shipyards use other subdivisions or subdivision names, and some overlap between adjacent groups can occur.

Small tankers below 10,000 dwt
Small tankers, in particular chemical and product tankers, are comprehensive in numbers. Both four-stroke and two-stroke diesel engines are utilised for the main engine installation.

Intermediate
Chemical and product tankers dominate this class, with a scantling draught below 10 m and a relatively high ship speed. Two-stroke engines now dominate as the main source of propulsion.

Handy size
Chemical tankers and, in particular, product tankers dominate this class of tankers with an overall length of about 185 m. Almost all ships of this type (95%) have a two-stroke diesel engine installed for propulsion.

MR1
Most commonly, the medium range or MR1 tankers are of a certain size range as seen in Table 1. A few different definitions of the size of the MR1 tanker exist, but the most common size of MR1 tankers is 38,000 dwt. Sometimes, a vessel of 38,000-dwt capacity is referred to as Handymax tanker, underlining the overlap between adjacent groups.

MR2
Just like an MR1 tanker, these vessels are often product tankers, but with a capacity around 50,000 dwt. They are popular vessels, as they have a significant size and great stability. Furthermore, they are flexible because they fit in most ports, and in the old Panama locks. Sometimes, MR1 and MR2 tankers are categorised together as MR tankers.

Panamax/LR1
This size range represents both crude oil and product tankers, where the smaller vessels do not transport crude oil. The tankers have a breadth (beam) of 32.3 m (106 ft.), limited by the width of the old lock chambers of the Panama Canal.

The maximum overall length is 289.6 m (950 ft.), limited by the lock chambers. However, for passage through the canal, the term Panamax is defined as 32.2/32.3 m (106 ft.) breadth, 228.6 m (750 ft.) overall length, and no more than 12.0 m draught (39.5 ft.). The reason for the smaller length is that a large part of the world's ports, and corresponding facilities, are based on this length.

As Table 1 shows, the draught can be larger than 12 m, because the stated draught is the scantling draught.

The new Panama Canal locks opened in 2015. Typically, tankers of this capacity do not use the new locks, because it is more expensive to pass through. Therefore, most tanker designs still fit the old Panama locks, even if some LR1 tanker designs now have a breadth of up to 36 m.

Occasionally, Panamax tanker measures are referred to as LR1 tankers, or long range 1 tankers. The term LR1 is defined loosely though, and the use can vary from shipowner to shipowner. Back in the 1970s, tankers larger than 45,000 dwt were defined as LR1. As the ships became larger, the lower limit increased significantly, and the MR tankers have since overtaken this size.

Aframax/LR2
Crude oil tankers dominate the Aframax class. These have a relatively wide breadth of about 42–46 m and a high cargo capacity, but a relatively low draught. The low draught increases the number of port possibilities worldwide. A typical size of an Aframax is 110–120,000 dwt.

Sometimes, Aframax tankers are referred to as LR2 tankers, or long-range 2 tankers. For most shipowners, these are the same ranges independent of whether they are referred to as Aframax or LR2.

The term Aframax originates from the American Freight Rate Association, and it indicates the maximum tanker size for most ports of the world. However, AFRA, in the meaning of Average Freight Rate Assessment is often by mistake, referred to the term for the Aframax-sized ships. The Worldscale Association in London calculates the AFRA, or the average costs, for the freight of oil with tankers. The calculation is based on ongoing registrations of all freight rates at particular points in time.

Suezmax
The Suez size is a definition linked to the Suez Canal. Due to the limited cross-sectional area of the canal, the Suez Canal Authorities can, for a given ship breadth (beam), demand that the draught of a loaded ship passing the Canal does not exceed a given maximum draught. The maximum draught is listed in a Beam and Draught Table.

The latest revision of the canal size permits a length of 400 m and a cross-sectional area of about 1,005 m² after dredging of the canal. But the term Suezmax used for many years refers to ship sizes of approx. 150-160k dwt with a sectional area of less than about 820 m². This term reflects the former sectional area permitted through the canal.

Based on the present table, ships are, in general, authorised to transit the Suez Canal when the cross-sectional area of the ship (breadth x draught) below the waterline is less than about 1,005 m² . This means that a ship with a breadth of 50.0 m, for example, is allowed a maximum draught of 20.12 m passing through the canal [1].

Fig. 4 shows that tankers are designed either in the region of Suezmax restrictions or much larger.

The ships evaluated, all fit the cross-sectional requirements of the new Suezmax value of 1,005 m². The cross-sectional area in Fig. 4 is the scantling draught. If the design draught had been used, all ships above 820 m² but below the 1,005 m² line would still fit the old Suez Canal restrictions.

In the future, continued dredging of the canal can open up for the passage of even bigger ships. This could permit a further increase of the Suezmax tanker size, but restrictions could also be tightened considering recent accidents in the channel.

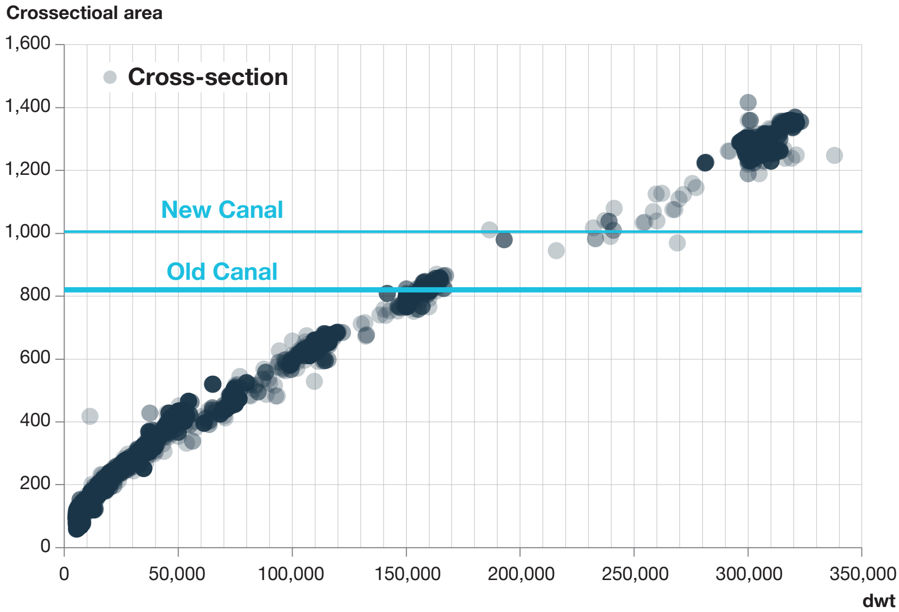

Fig. 4: Cross-sectional area compared to dwt for all tankers

Shuttle tankers

Another ship type common within the size range of Suezmax is the shuttle tankers. These ship types started with an operating area around the Northern Europe. Their task is to transport oil from rigs or FPSOs to refineries in areas where pipelines are not feasible due to the water depth, or the harsh weather conditions. Nowadays, the largest fleet of shuttle tankers operates around the east coasts of Brazil and North America.

The shuttle tankers need a dynamic positioning system to maintain position while loading cargo. They require a higher engine power to operate, especially when the weather is harsh. The shuttle tankers face different restrictions of power demand, and some have a twin-engine arrangement or an alternative system to ensure propulsion redundancy often utilising controllable pitch propellers. Representing a niche, this paper does not cover shuttle tankers.

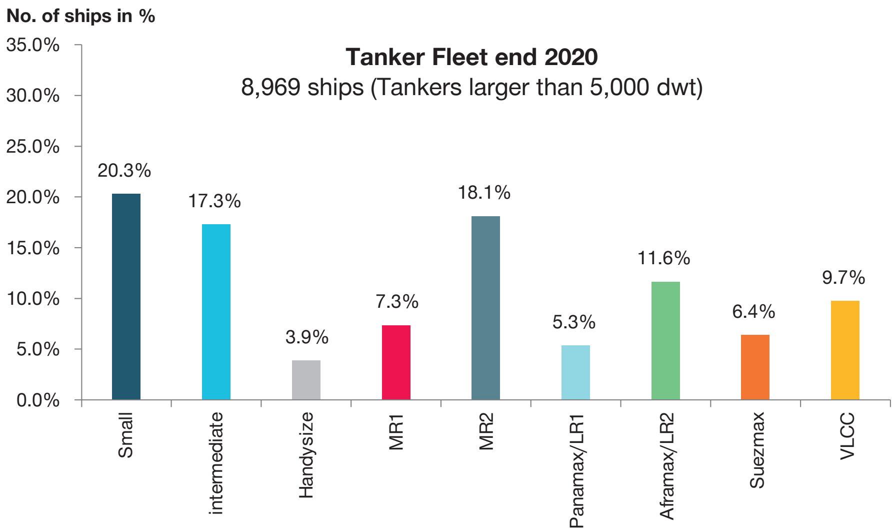

Fig. 5: Number of tankers distributed within the classes

VLCC

VLCC is an abbreviation of very large crude oil carrier. As indicated by the name, VLCCs transport only crude oil. Normally, VLCC sizes are within the deadweight range of 250,000–320,000 dwt, and the overall length is longer than 300 m.

Compared to Aframax and Suezmax tankers, the VLCC with its considerable size offers relatively lower transportation costs. However, the number of ports that they can call is limited.

Often, a vessel size bigger than the VLCC is referred to as ULCC or ultra large crude oil carrier. Most of these have a size of 440,000 dwt. The latest entry of such a vessel was around 2002.

Tanker fleet

At the end of 2020, the tanker fleet accounted for 8,969 tankers above 5,000 dwt. Fig. 5 shows the distribution of tankers according to classes as per end 2020.

Fig. 5 shows that 40% of all tankers are smaller than an MR1 tanker, that is, below 35,000 dwt. The small segment contributes with over 20% of the complete fleet. Another large contributor is the MR tanker segments.

When adding the numbers of MR1 and MR2 tankers, these account for more than 25% of the whole fleet.

The number of bigger tankers is limited compared to the smaller segments. Ships in the size range between Panamax (55,000 dwt) and VLCC (max) account for 30% of the fleet.

When comparing the deadweight distribution in Fig. 6, the tendency is different, and the deadweight is larger vessels.

While only 30% of the number of vessels were above the MR tanker range, this segment accounts for more than 75% of the overall deadweight of the fleet.

Looking at Table 2, the orders show the future tendency for the tanker market.

Table 2 shows that the smaller segments are on decline, while the larger segments increase compared to the current fleet. The MR1 segment constitutes 7.3% of the present fleet but only accounts for 2.0% of the vessels on order. Potentially, this is a result of the replacement of MR1 with MR2 tankers when new vessels are ordered.

The Panamax segment decreases from 5.3% in the fleet to 2.0% on order. By the opening of the new Panama locks, this vessel type has lost its importance, to some extent. The Aframax segment accounts for 11.6% of the current fleet, but 18.9% of new orders, which is the biggest change.

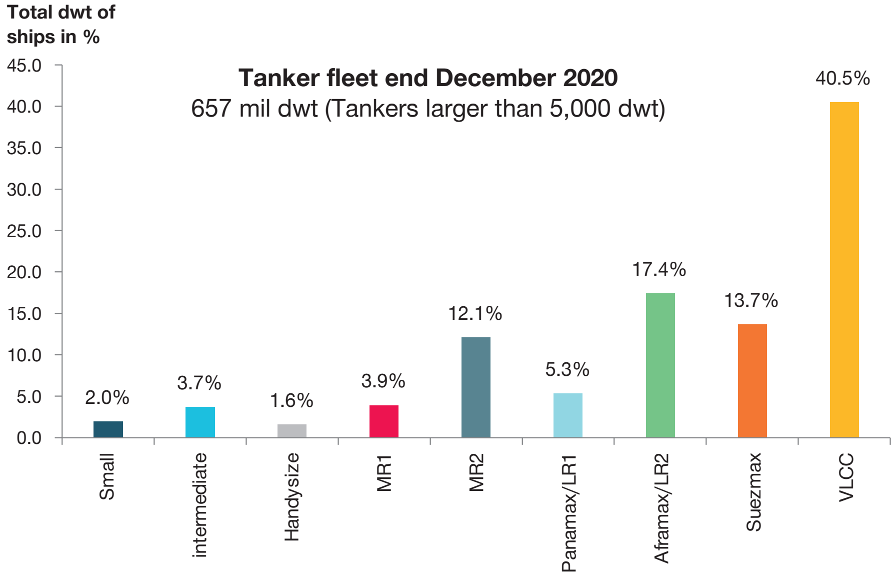

Fig. 6: dwt of tankers distributed within the classes

Table 2

Class	Vessels in the existing fleet		Ordered vessels		All vessels	
	No.	Percentage [%]	No.	Percentage [%]	No.	Percentage [%]
Small	1,819	20.3	74	13.3	1,893	19.9
Intermediate	1,551	17.3	72	12.9	1,623	17.0
Handysize	347	3.9	33	5.9	380	4.0
MR1	659	7.3	11	2.0	670	7.0
MR2	1,623	18.1	119	21.4	1,742	18.3
Panamax/LR1	478	5.3	11	2.0	489	5.1
Aframax/LR2	1,044	11.6	105	18.9	1,149	12.1
Suezmax	574	6.4	51	9.2	625	6.6
VLCC	874	9.7	80	14.4	954	10.0
Total	8,969	100.0	556	100.0	9,525	100.0

Table 2: Tankers in the fleet, and ordered, at the end of 2020

Yearly tanker delivery

Looking at the deliveries of tankers, Fig. 7 shows the distribution of deliveries for five-year periods over the past 50 years.

This compares well with Figs. 1 and 2, which show a peak at around 2008-2009 prior to the financial crisis. It is difficult to predict how COVID-19 will affect the order book for tankers.

Before the financial crisis, there seemed to be a boom in the number of delivers in the small segment. However, Fig. 7 shows that the small segment is declining in number.

Service life of a tanker

Fig. 8 shows that around 20% of the fleet is less than five years old, while more than 30% is 10–15 years old. This part of the fleet was constructed during the boom before the financial crisis.

Ships more than 25 years old only account for approximately 6% of the current fleet, and 14% of the tankers are more than 20 years old.

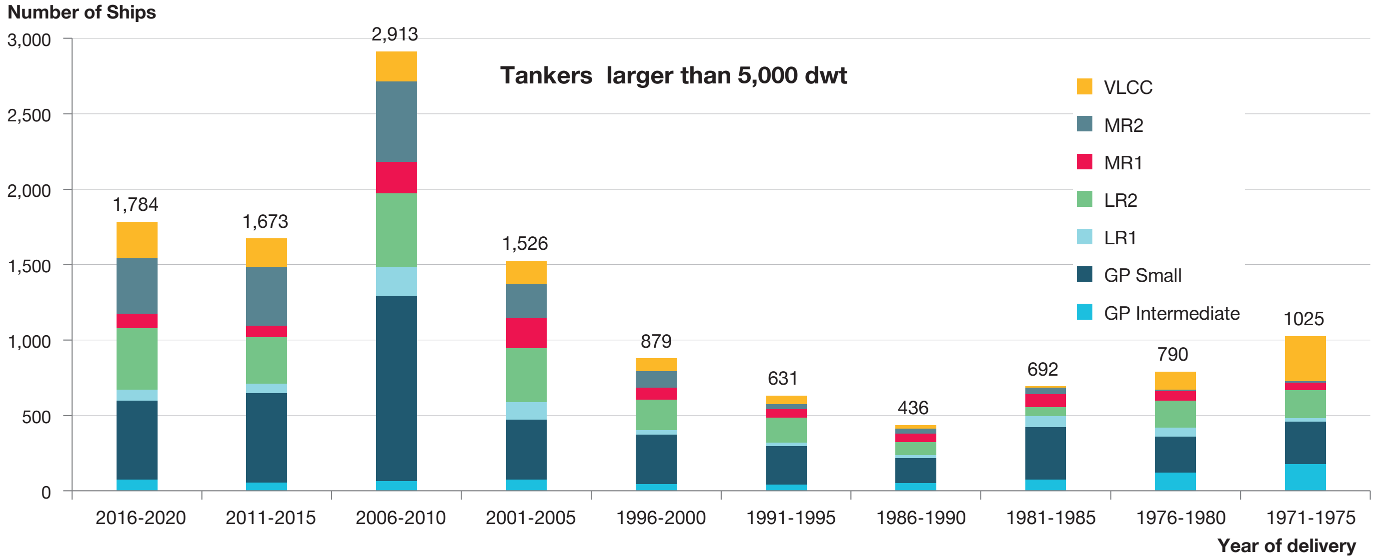

Fig. 7: Number of deliveries by vessel types

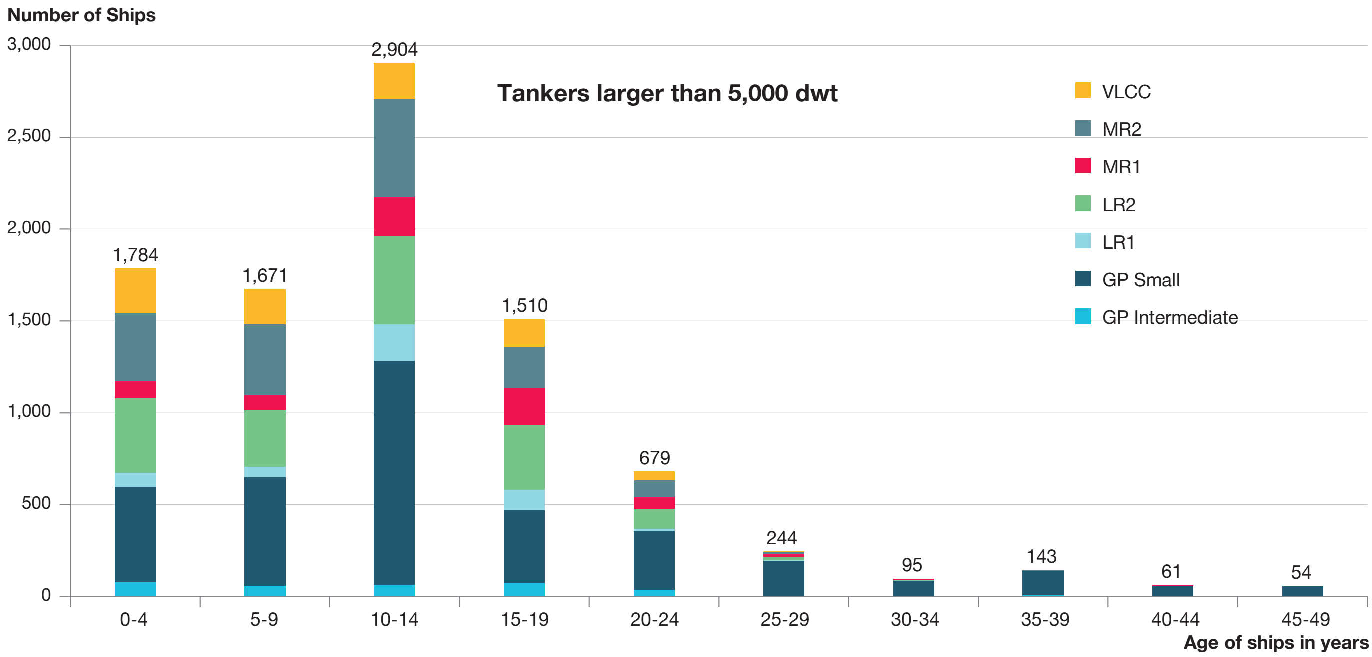

Fig. 8: Age and type of tankers within the fleet

Fig. 9 gives an overview of the expected lifetime of a tanker.

Fig. 9 shows that a tanker is typically in operation for 20 years (77%), even if some are scrapped between the ages of 15 and 20 years (22%). After 25 years, most tankers (60%) are out of service. At an age 30–40 years there seems to be a plateau, presumably due to some legislative advantage of keeping these vessels in the fleet.

When considering also environmental restrictions, and especially the EEXI for existing vessels, it is hard to tell what the expected future lifetime of a new tanker will be. However, certainly 20 years should be expected.

Investigating the ship segments further, Fig. 10 shows how the size of the ship affects its lifetime.

Fig. 10 shows that most ship sizes are taken out of operation before reaching 35 years of service. However, the small segment shows that 20% is still in operation up to a lifetime of 50 years. These vessels are typically chemical tankers, which due to the stainless steel tanks are expensive to build.

Hull design

All tankers built today have a double-hull design, which is required for safety and environmental reasons, that is, complying with IMO's MARPOL 73/78 Annex I Regulation 13F [2]. This regulation requires all new tankers of 5,000 dwt and above delivered after 6 July 1996 to be fitted with double hulls separated by a space of up to 2 m. Irrespectively of the year of delivery, single hull tankers have been banned from operation since 2010. Although some exceptions have been introduced for special tankers, which can continue in operation until 2015.

Demand for replacing tankers

Tankers older than 15 years constitute 30% of the fleet. It indicates that coming years will require newbuildings for replacing the existing tanker fleet, and for keeping up with the demand for tankers. When further considering that 30% of the current fleet is 10–15 years old, the need for replacements towards the end of the decade could grow significantly, following the tendency in Fig. 8.

Compared to the present non-pressurised product tankers, and considering the current market for oil and new fuels such as LPG, LNG, and methanol, there will be a need for diversifying the tankers delivered for the future. This effect has already been visible for the past five years with a massive increase in the number of LPG and LNG carriers delivered.

Even within the category of non-pressurised product tankers, an increased diversification can be expected, when considering that some vessels will carry future fuels of a lower density. This will lead to vessels that are more voluminous.

MAN B&W engines can operate on a large variety of fuels, for example, LPG, methanol, LNG; ethane, and in the future also ammonia. It ensures that an engine able to run on the cargo of the tanker can be ordered.

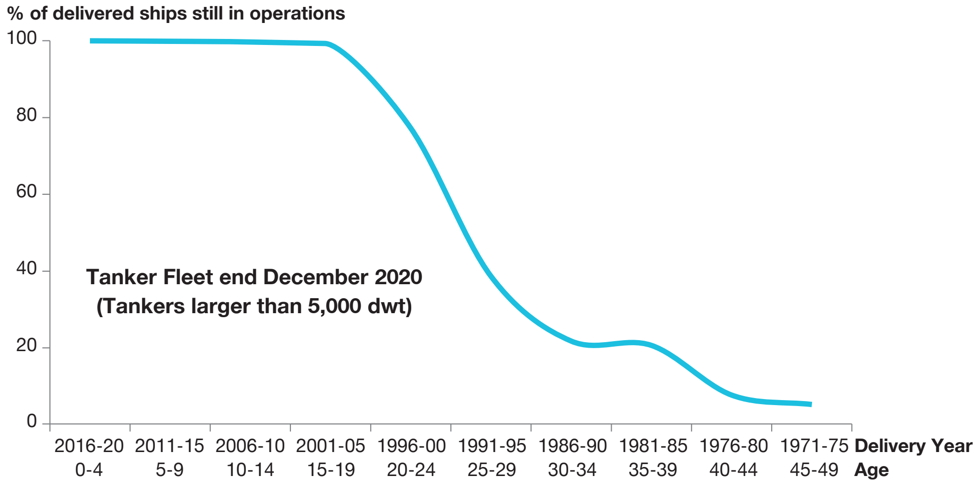

Fig. 9: Cumulative density function (CDF) of tanker age, and percentage of vessels still operating

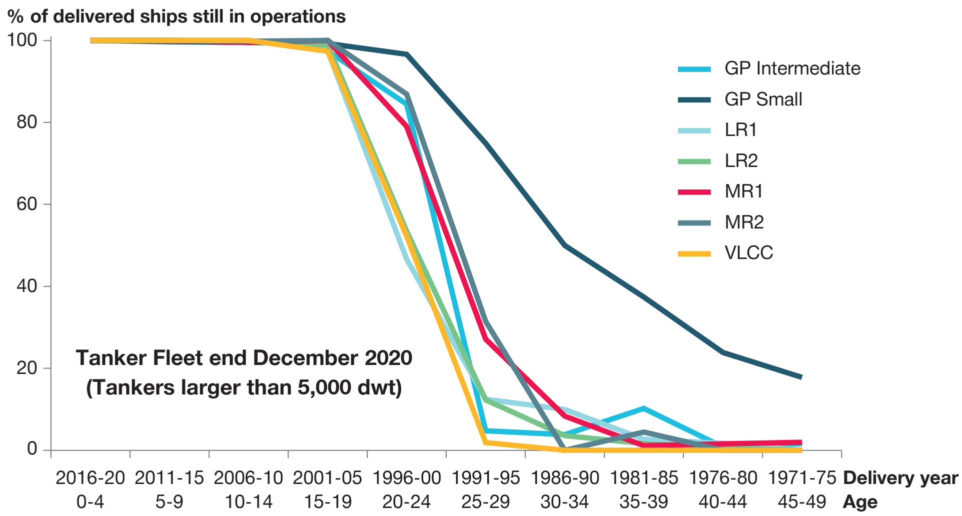

Fig. 10: CDF on the lifetime of a tanker, considering the category.

Average ship particulars dependency on ship size

Vessels delivered in the period 2010–2020 have been analysed to estimate the average particulars, considering an average of the particulars as a function of deadweight.

Average hull design factor F_{des}

The average hull design factor, F_{des}, describes the average design relationship between the ships particulars of tankers. See Fig. 11.

$F_{des} = L_{PP} \times B \times T_{scant}/dwt_{scant}$ (m³/t)

Where:

- L_{PP}: length between perpendiculars (m)
- B: ship breadth (m)
- T_{scant}: scantling draught (m)
- dwt_{scant}: deadweight tonnage at scantling draught (T_{scant})

For tanker sizes above 55,000 dwt, the design factor F_{des} shown in Fig. 10 is fairly exact, whereas the factor is less exact for smaller tankers due to larger variations in hull dimensions and cargo types. Based on the above design factor F_{des}, calculate any missing particular with a corresponding accuracy by:

- $L_{PP} = F_{des} \times dwt_{scant} /(B \times T_{scant})$ m)
- $B = F_{des} \times dwt_{scant} /(L_{PP} \times T_{scant})$ (m)
- $T_{scant} = F_{des} \times dwt_{scant} /(L_{PP} \times B)$ (m)
- $dwt_{scant} = L_{PP} \times B \times T_{scant}/F_{des}$ (t)

Figs. 12, 13, and 14 show the first three ship particulars as a function of the ship size (dwt_{scant}). The figures also show the main groups of tanker classes normally used. There might be some outliers, and overlapping, as these only show tendencies.

The draught and the length seem to increase linearly from 50,000 dwt and above. However, the beam shows a plateau at around 50-75,000 dwt due to the old Panama canal restriction of a maximum beam of 32.26 m. Above Panamax dimensions, the tendency appears to be linear as well. This is also illustrated in Fig. 14, showing the length-to-beam ratio, which peaks at the Panamax segment.

Average ship design speed and engine SMCR

Fig. 16 shows the average ship speed V_{des} as a function of ship size. V_{des} is used for the propulsion system design.

The use of V_{des} is valid together with the design draught D_{des} of the ship.

Smaller tankers, GP small, and Handysize vessels have a lower design speed than the larger tankers typically designed for 14.5 knots. However, the plot only shows the tendency. Therefore, it is possible to encounter smaller tankers going faster than vessels from the larger segment, especially amongst chemical carriers.

SMCR dependency on deadweight

Fig. 17 illustrates the specified maximum continuous rating (SMCR) as a function of the deadweight.

Fig. 17 shows a rapid increase of SMCR up to approx. 50,000 dwt followed by a lower rate of increase. Looking at the deadweight divided by the SMCR, Fig. 18 shows that the deadweight increases faster than the engine power, indicating that the economy of scale of the larger vessels. However, this also implies that the acceleration of a larger vessel is relatively slower than for a small vessel.

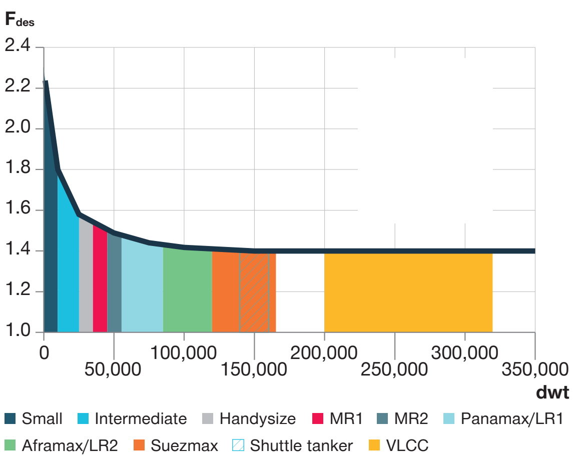

Fig. 11: The hull design factor dependency on the deadweight for tankers delivered 2010–2020

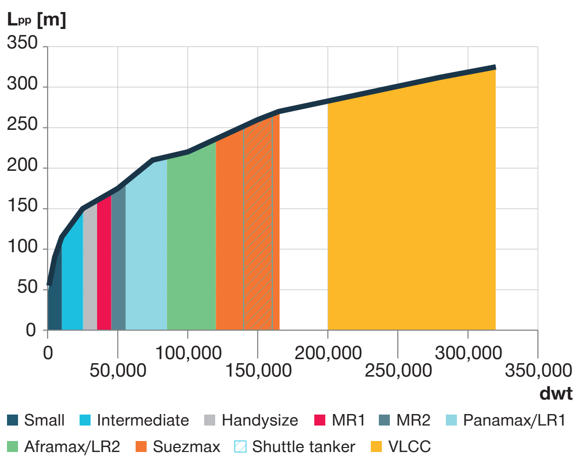

Fig. 12: Length between perpendiculars compared to deadweight for tankers delivered 2010–2020

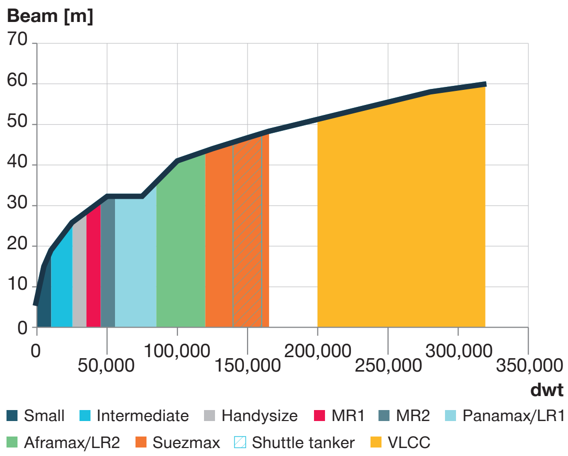

Fig. 13: Beam compared to deadweight for tankers delivered 2010–2020

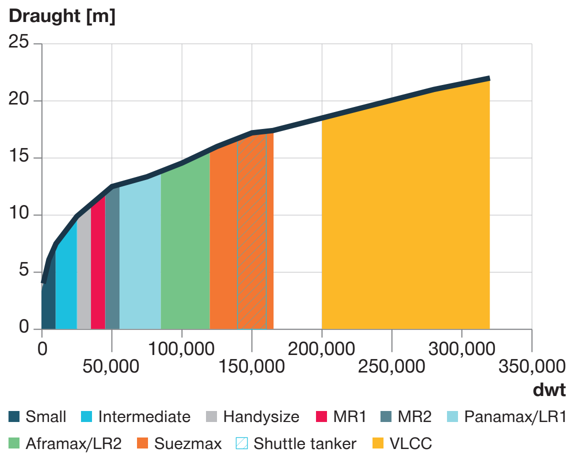

Fig. 14: Draught compared to deadweight for tankers delivered 2010–2020

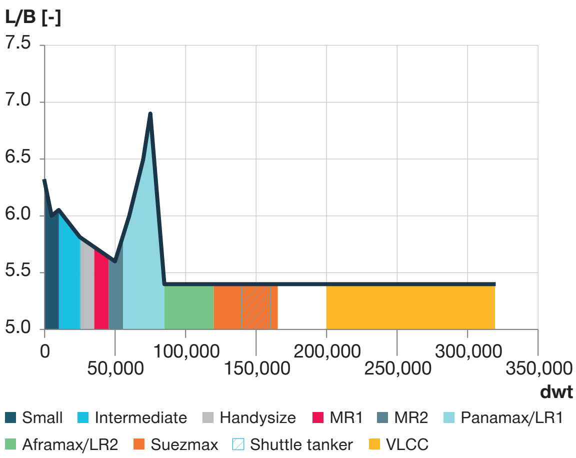

Fig. 15: Length to beam ratio compared to deadweight for tankers delivered 2010–2020

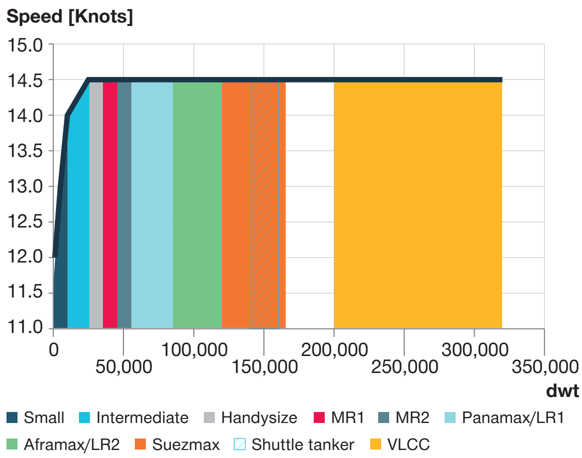

Fig. 16: Design speed compared to deadweight for tankers delivered 2010–2020

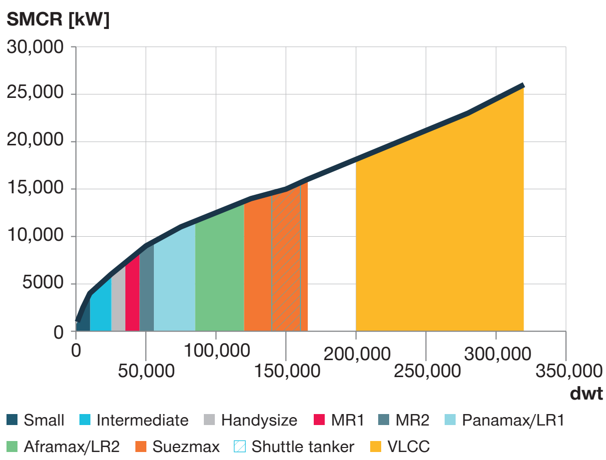

Fig. 17: Engine power compared to the deadweight of the ship for tankers delivered 2010–2020

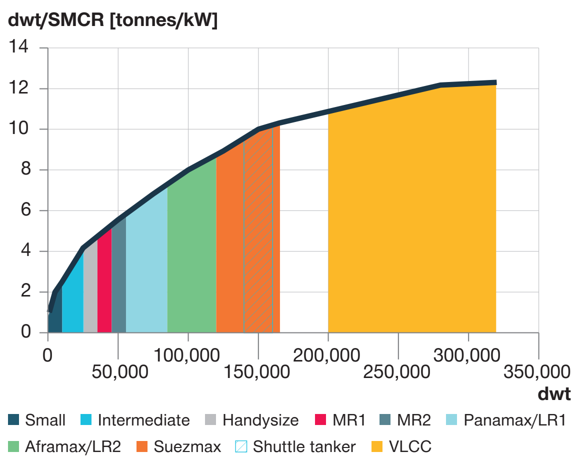

Fig. 18: Deadweight divided by SMCR compared to deadweight for tankers delivered 2010–2020

EEDI restrictions for tankers

The EEDI guideline is a mandatory instrument adopted by the IMO to ensure compliance with international restrictions on CO_2 emissions from new ships. The EEDI represents the amount in grams of CO_2 emitted when transporting one deadweight tonnage of cargo for one nautical mile. Equation 1 shows the EEDI calculation in simplified form.

Equation (1)

$$EEDI \approx \frac{CO_2}{\text{Transport work}} \approx EEDI \approx \frac{P_{ME} \times C_F \times SFC}{\text{capacity} \times V_{ref}}$$

The EEDI is calculated based on cargo capacity, propulsion power, ship speed, specific fuel consumption, and fuel type. However, by installing, for example, waste heat recovery systems (WHRS) certain correction factors apply, and reductions are obtainable

A reference index for a specific ship type is calculated based on data from ships built in the period from 2000 to 2010. According to the EEDI guidelines implemented on 1 January 2013, the required EEDI value for new ships is reduced in three phases. For a tanker built after 2025, this leads to an EEDI reduction of 30% (phase 3) compared to the reference value, see Fig. 19.

Further phases have not yet been implemented, as the discussion on a potential EEDI phase 4 is ongoing.

For a tanker, the reference and the actual EEDI values are calculated based on 100% utilisation of capacity (in dwt). The reference speed must be consistent with this loading of the vessel, at 75% SMCR, and with the hull in a condition as on sea trial. The actual EEDI may not exceed the required EEDI.

There are several methods for lowering the EEDI.

Mean effective pressure (mep) derating of the engine lowers the specific fuel consumption (SFC), since the mep is reduced relative to the constant maximum (firing) pressure.
Engine tuning methods, for example, exhaust gas bypass (EGB) or high-pressure tuning (HPT) can alter the fuel curve and reduce SFC at 75% load. This load is the EEDI reference value. Typically, part-load tuning provides the lowest SFC at the EEDI reference value, whereas low-load tuning also results in a reduction at this load compared to high-load tuning.

EcoEGR is a special option available for engines with EGR. Through activation of the EGR system, it is possible to optimise the combustion parameters for optimum efficiency even in Tier II mode. The EGR system reduces NOX emissions to meet Tier II requirements, while at the same time it decreases the SFOC. The use of EGR can reduce the fuel consumption significantly in Tier II mode.

The power installed constitutes an extra parameter that can be reduced to achieve a lower EEDI value. The reduction can be achieved by either lowering the vessel speed, improving the hull design to minimise resistance, optimising the propeller efficiency, or by installing energy saving devices (ESD).

Installing a Kappel propeller, or another high-efficiency propeller design, can improve the propeller efficiency. Typically, ESDs alter the flow at the propeller, or fore or aft of it, to regain some of the losses on the propeller, or to minimise the resistance, that is, through the application of a rudder bulb.

By installing a shaft generator for electricity generation, the fuel consumption of the main engine (SFC_{ME}) replaces the specific fuel consumption of the auxiliary engines (SFC_{AE}), which reduces the EEDI index.

In addition, if the power: PTO nameplate power/0.75 ($P_{PTO,\ NP}$ /0.75) is sufficient to cover P_{AE}, P_{ME} can be reduced by the value of $P_{PTO,\ NP}$. Note, subtract only P_{AE} from P_{ME} because of P_{PTO}.

Only the main engine power determines the auxiliary power required for onboard electricity production. The smaller the vessel, the larger, the part of the total EEDI constituted by P_{AE} will be. This implies that; the lower the main engine power of the vessel, the higher the effect of applying a PTO. Estimated EEDI reductions are approximately 3–4% for an MR tanker, and approximately 1–2% for a VLCC.

Since the reference speed (V_{ref}) must be consistent with P_{ME}, the reference speed also reduces when installing a PTO. However, the power consumption of a typical merchant vessel is proportional to the speed by an exponent of 3–4, $P \propto V^{3\text{ to }4}$. It means that the reduction of P_{ME} (in the numerator) by the PTO improves the attained EEDI more than the speed reduction to V_{ref}.

In addition, applying alternative fuels can change the EEDI significantly. When considering the effect of alternative fuels, it is important to consider not only the carbon factor (C_F) but also the lower heating value (LHV) of the alternative fuel considered. IMO has defined C_F and LHV for alternative fuels [3]. The same argumentation applies to pilot fuels.

For further information on the calculation of EEDI and other environmental regulations, see Chapter 4 of the paper: Basic principles of ship propulsion.

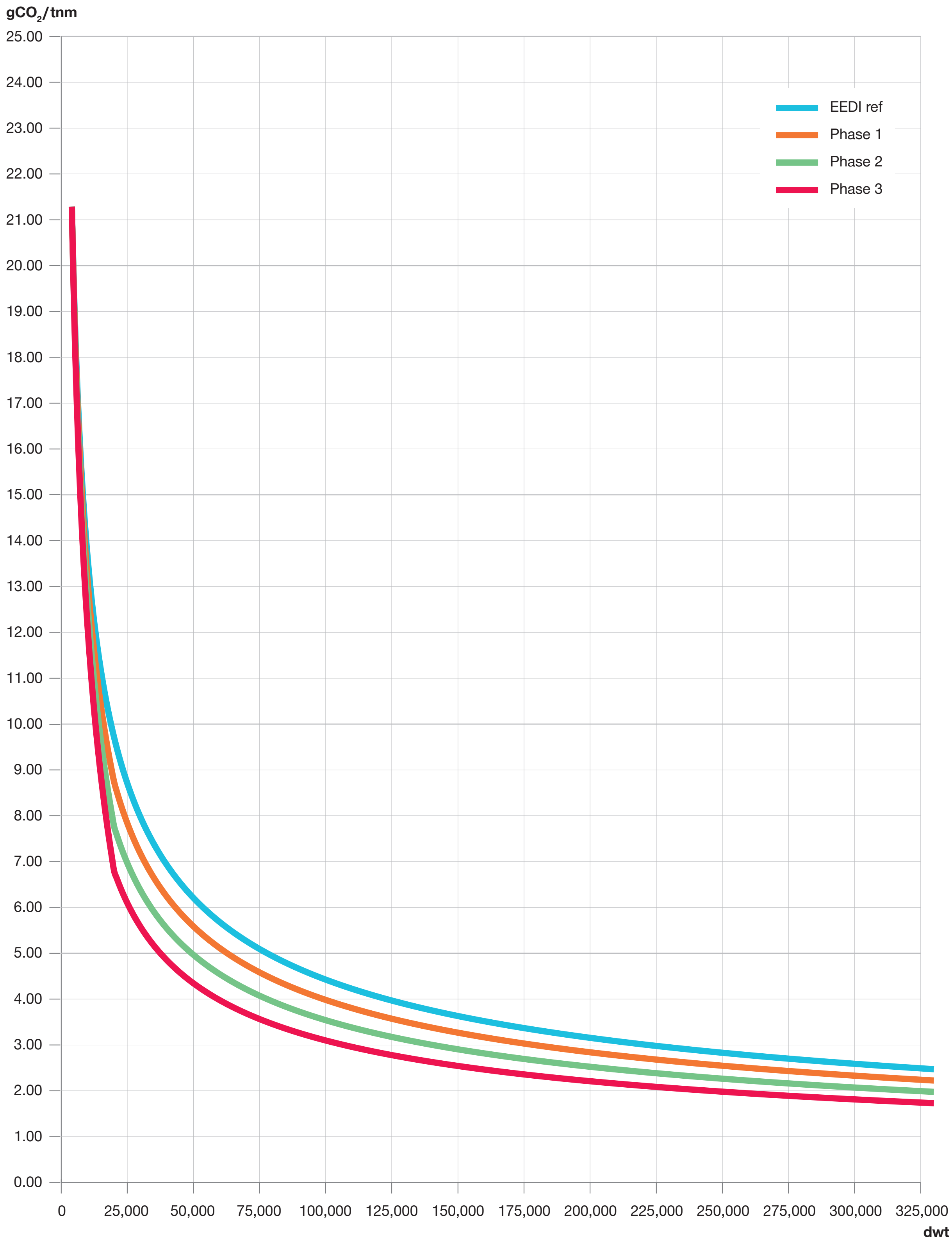

Fig. 19: EEDI reference line and requirements for tankers

Propulsion power demand for tankers

Minimum propulsion power

While lowering a ship's installed power has been acknowledged as a method to obtain a lower EEDI value, it has also raised the concern that it could result in underpowered ships with reduced manoeuvrability in heavy weather. As a result, IMO has published an assessment method for determining the minimum propulsion power required to maintain the safe manoeuvrability of ships in adverse conditions.

Minimum propulsion power determined by assessment level 1 or level 2

Assessment level 1 allows for calculation of the minimum power value required based on ship type and deadweight, with values a, and b according to IMO guidelines.

However, if the intended propulsion power is below the given minimum power line value of assessment level 1, an evaluation must be performed according to assessment level 2. For this level, the actual vessel design and propulsion system performance in head wind and waves are considered. Assessment level 2 evaluates whether the propeller operating point exceeds the load limitations of the engine for the rule set minimum manoeuvring speed in a set sea way.

If the vessel cannot fulfil the criteria in either of the assessment levels, there are various options to consider for achieving a compliant design.

One option is to increase the propeller light running margin since this reduces the torque required per revolution. This moves the operational point for assessment level 2 within the load limits of the engine. Increasing the light running margin, permits the engine to deliver maximum power within a broader range of operation and sea states.

Alternatively, or together with an increased light running margin, the MAN B&W engine can be ordered with an adverse weather condition (AWC) functionality. The functionality extends the load limits of the engine as long as required for an emergency. The following separate section provides further information on the AWC function, including the behaviour of a two-stroke propulsion plant in adverse weather conditions.

If the above-mentioned measures are not sufficient, alternative fuels lowering the EEDI will allow for a more powerful engine thanks to the lowered carbon factor.

The hull lines and the bow can be refined to minimise resistance in general, and from interactions with the waves specifically.

The use of controllable pitch propellers is also an option. In principle, this allows the propeller to load the engine at all points within the engine load diagram. Hereby, maximum power can be delivered in any weather condition. See Chapter 3 of the paper: Basic principles of ship propulsion.

Adverse Weather Condition functionality

In the merchant fleet, a two-stroke engine directly coupled to a fixed-pitch propeller is one of the most applied propulsion solutions thanks to its superior efficiency. When a vessel with this propulsion system experiences added resistance in adverse weather, the torque required by the fixed-pitch propeller to maintain the rpm increases. In harsh cases, the torque required can increase beyond the torque limits of the main engine. The result is that the power output from the engine is limited to less than MCR power.

With ever-tightening EEDI phases, aiming at reducing the emission of greenhouse gasses, the installed propulsion power for new vessels is decreasing. This means that less power is available for maintaining a safe course in adverse weather. The adverse weather condition (AWC) functionality makes it possible to increase the engine load limits significantly in adverse conditions as long as required. Herewith the accessible MCR percentage with a heavy running propeller increases. In turn, this increases the obtainable vessel speed, which helps ensuring the manoeuvring capacity of the vessel.

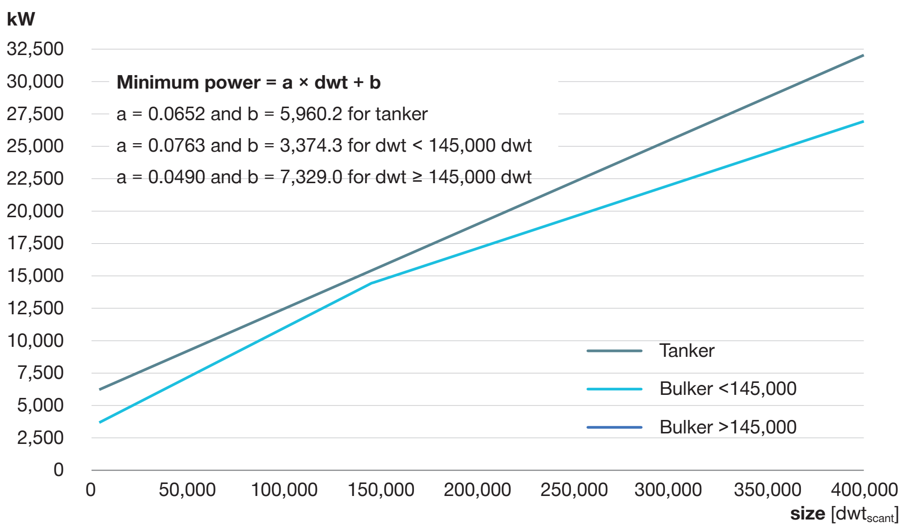

Fig. 20: Figure and text from propulsion trends of bulkers

Heavy running propeller
When sailing in adverse weather, the vessel experiences increased resistance and the propeller becomes heavy running. As a result, the propeller needs more torque to maintain the same rate of revolution. A heavy running propeller is equivalent to the experience of a cyclist going uphill without changing gear. As the slope inclines, the cyclist has two options, either to provide a greater torque input to the pedals, and maintain the rpm of the wheels, or accept that an unchanged torque will result in lower rpm.

A similar experience of heavy running occurs, when a cyclist bikes on a flat road at a uniform speed and suddenly encounters headwind. Because of the wind resistance, the cyclist has the same two options: Either to increase the torque input to the pedals, and hereby maintain rpm, or accept that an unchanged torque input reduces rpm.

The two-stroke engine has the same options, either to increase the engine torque and maintain the rate of revolution, or to maintain the torque and accept a reduction in rpm. Increasing the torque of an engine is, however, only possible to a certain extent within the limits of the engine load diagram. The AWC functionality extends these limits for the MAN B&W two-stroke engine.

Fig. 21 shows the AWC functional area of the engine load diagram, the location of the light propeller curve with 5% light running margin, and the propeller curve resulting from the added resistance when sailing in head seas of a significant wave height, H_S = 4 m on a 50,000-dwt vessel.

If the sea state develops further to H_S = 5.5 m, the degree of heavy running increases and pushes the operational point of the propeller (at 2 knots) beyond the regular load limits of the engine, and well into the area of the AWC functionality. Fig. 22 shows this scenario.

Without the AWC functionality, the vessel speed would go down, because the operational point of the propeller and engine is reduced along the regular torque limit of the engine. See reference [4] for further explanations about predicting the operational point of propeller and engine.

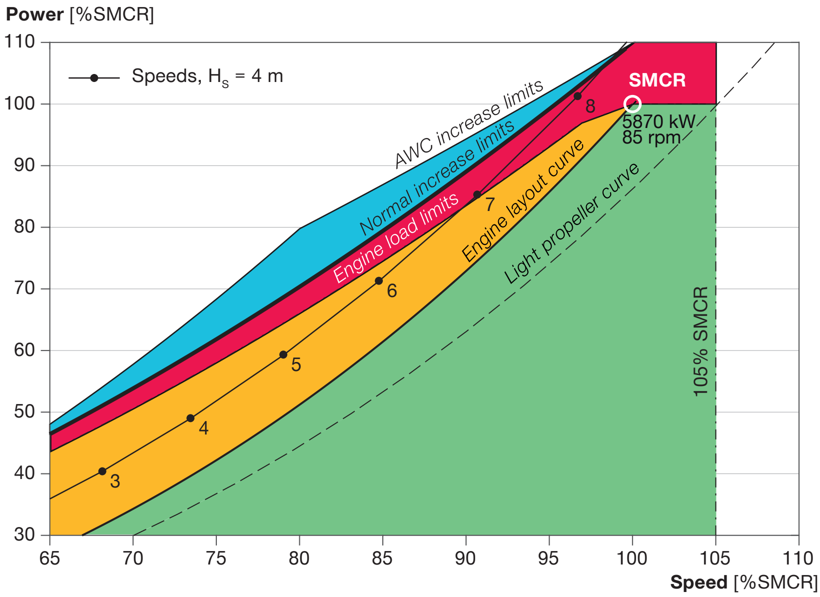

Fig. 21: Expected performance of the Handymax bulk carrier in Beaufort 7. Numbers along the black speed curve represent the attainable vessel speeds in knots.

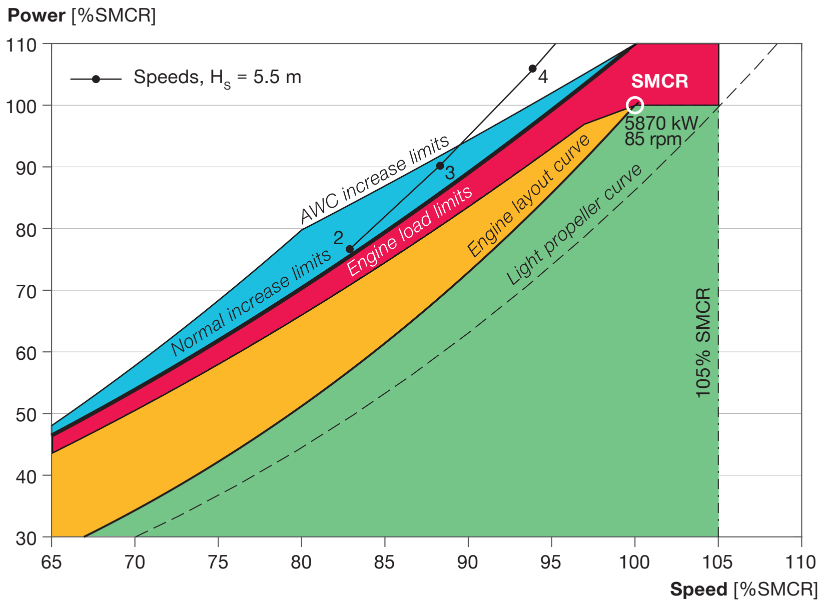

Fig. 22: Expected performance of the Handymax bulk carrier in Beaufort 8. Numbers along the black speed curve represent the attainable vessel speeds in knots.

Barred speed range - the dynamic limiter function

Similar to issues with minimum propulsion power, power reductions for compliance with EEDI may lead to extended passage times of barred speed ranges (BSR). The BSR imposed by vibrations in the shafting must be passed sufficiently fast not to risk any damage of the shafting by excessive stress from the vibrations.

Since the installed power on board bulk carriers is reduced to meet the EEDI requirements, less power is also available for accelerating the shafting and the ship. A sufficiently fast passage of BSR has become increasingly important and it must be paid careful consideration.

What sufficiently fast means depends on how high the shaft stresses are, compared to the strength of the shaft material. In general, the BSR must be passed within seconds, not minutes.

Furthermore, the definition depends on how often the BSR will be passed during the expected lifetime of the ship. The engine of an intermediate size vessel with many port calls, for example, will pass the BSR more frequently than a VLCC mostly crossing the oceans.

It can be a challenge to ensure the sufficiently fast passage of the BSR. Especially for 5- and 6-cylinder engines due to the vibrational mode shapes for these cylinder numbers. The paper: The dynamic limiter function explains this situation further, and the dynamic limiter function (DLF) handling it. Some classification societies have developed guidelines for the acceptable passage time of the BSR. DNV, for example, has issued rules for classification: part 4, chapter 2, section 2.5.2.

The most basic guidance to avoid slow passage of the BSR is to avoid barred speed ranges extending higher than 60% of engine SMCR-rpm. A more detailed approach ensures a design with a BSR-power margin (BSR_{PM}) of at least 10%.

Calculation of BSR_{PM}:

$$BSR_{PM} = \frac{P_L - P_p}{P_P}$$

- P_p is the power required in the bollard pull propeller curve in the upper end of the BSR
- P_L is the engine power limit without DLF at the same rpm.

See also Fig 23.

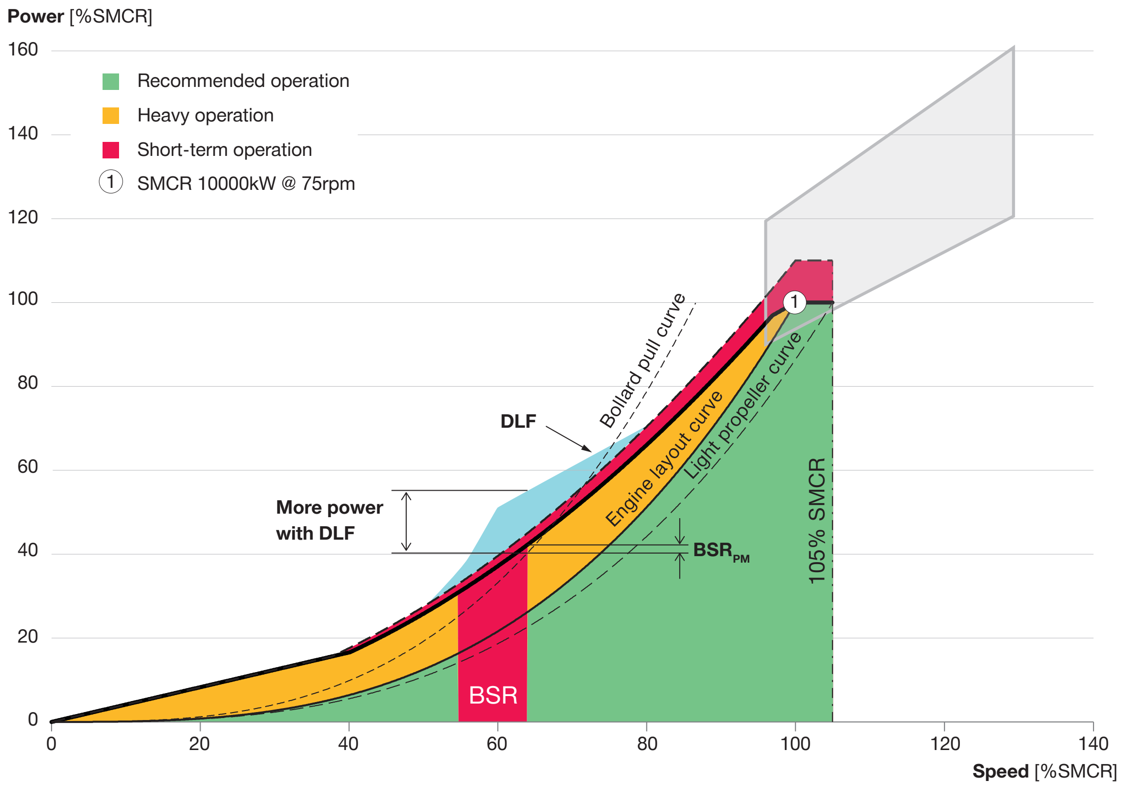

Fig. 23: Increased possibility for passage of a barred speed range with DLF

Propulsion power demand as a function of vessel size

A power prediction has been performed for various typical tanker sizes based on particulars described in the chapter: Average ship particulars as a function of ship size in this paper, and also vessel statistics delivered recently. The outcome is an overview of possible engine types for various vessel sizes as shown in table 3 (see pages 22-23).

The EEDI values given in Table 3 have been calculated by including a 6% tolerance on the SFC for the main engine, obtained from CEAS (computerised engine application system), the MAN Energy Solutions application for engine modelling, and by using an SFOC of 200 g/kWh for auxiliary engines operating at 50% load. The EEDI has been calculated for marine diesel oil for phase 2 and 3, and for LNG for phase 3.

The overview covers vessels with a typical design speed, and with typical sea and engine margins applied for the specific size. For the EEDI phase 3 designs, both four- and three-bladed propellers are considered. Be aware of the engine margin, which changes with the size of the vessel, reflecting the statistics, see Chapter 3 of Basic principles of ship propulsion. In general, the tendency is a higher engine margin for large tankers aimed at a low SFC during normal operation at the design speed.

For tankers above 100,000 dwt, the engine margin is increased from 15% to 30%. For these vessel sizes and larger, the service speed has to be reduced significantly, compared to the present fleet, to ensure compliance with future EEDI restrictions and to maintain the high engine margin. This has led to a recent tendency for the largest tankers to apply a reduced engine margin.

The present discussion on engine margin is mostly of theoretical interest. The top speed that a vessel can obtain only depends on the SMCR-power of the main engine. Regardless of whether the power is labelled as power for a high service speed or for a high engine margin. However, the engine load at which the engine operates in service will naturally influence the specific fuel consumption.

Table 3 shows that, typically, smaller vessels with low service speed and low engine margin can obtain compliance with EEDI phase 2 by applying the latest engine technology. Moreover, compliance is achieved without significant reductions of the reference speed. This is a result of the modern camshaft-less ME engine technology, which provides many handles for optimisation of the fuel consumption. Especially compared to the mechanically controlled MC engine, applied at the time when the EEDI reference line was established.

For typical tankers, the application of LNG as an alternative fuel will give an EEDI reduction of 16-18%. Hereby, compliance with EEDI phase 3 is easily attained without extra equipment, even if the traditional SMCR is maintained.

When considering the option of a speed reduction, it is important to consider the vessel's capabilities regarding minimum propulsion power, and performance in adverse weather conditions. See also the previous section Minimum propulsion power. Adequate attention must be paid to obtain a sufficiently large propeller light running margin.

Table 3

	Small		Handysize			Handymax				Panamax
dwt (Scantling)	5,000	8,000	10,000	15,000	20,000	25,000	30,000	38,000	50,000	75,000
Scantling draught (m)	6.1	7.0	7.5	8.5	9.2	9.9	10.4	11.2	13.7	14.5
Design Draught (m)	5.6	6.5	6.9	7.8	8.5	9.0	9.6	10.2	11.0	12.2
Length overall (m)	97	112	120	135	147	158	167	179	184	229
Length between pp (m)	94	108	115	130	142	152	160	172	180	220
Breadth (m)	16.3	18.8	20.1	22.7	24.8	26.5	28.1	30.2	32.2	32.2
Sea margin (%)	15	15	15	15	15	15	15	15	15	15
Engine margin (%)	10	10	10	10	10	10	10	10	10	10
No. Engines (-)	1	1	1	1	1	1	1	1	1	1
Phase 2										
Average ship speed	13.8	14.1	14.1	14.1	14.0	14.2	14.3	14.4	14.5	15.3
SMCR power	2,495	3,230	3,400	4,250	4,600	5,200	5,800	6,600	7,800	9,500
SMCR speed	180	155	150	130	115	110	105	102	93	87
Propeller blades	4	4	4	4	4	4	4	4	4	4
EEDI % of reference	86*	86*	84*	81*	75	74	74	74	75	74
Main Engine options:										
1	5S30ME-B9	5S35ME-C9	6S35ME-C9	7S35ME-C9	6S40ME-C9	5G45ME-C9	5S50ME-C9	5S50ME-C9	6G50ME-C9	6S60ME-C10
2	6S30ME-B9	7S30ME-B9	5S35ME-C9	5S40ME-C9	5S40ME-C9	5S46ME-C8	6G45ME-C9	6G45ME-C9	6S50ME-C9	5S65ME-C8
3		6S30ME-B9	7S30ME-B9	6S35ME-C9	5S46ME-C8	7S40ME-C9	6S46ME-C8	6S46ME-C8	7S50ME-C9	5G60ME-C10
4			7S35ME-C9	6S40ME-C9		6S40ME-C9	5G45ME-C9			7S50ME-C9
5			5S40ME-C9							5S60ME-C10
Phase 3										
Average ship speed	13.8	14.0	14.0	13.8	13.5	13.6	13.7	13.8	13.9	14.6
SMCR power	2,500	3,200	3,500	3,800	3,900	4,400	4,800	5,500	6,400	8,000
SMCR speed	180	155	146	125	118	112	107	101	94	88
Propeller blades	4	4	4	4	3	3	3	3	3	3
EEDI % of reference	86*	83*	82*	74*	66	66	65	65	65	65
Main Engine options:										
1	5S30ME-B9	5S35ME-C9	6S35ME-C9	6S35ME-C9	6S35ME-C9	6S40ME-C9	6S40ME-C9	5S50ME-C9	6S50ME-C9	5S60ME-C10
2	6S30ME-B9	7S30ME-B9	5S35ME-C9	7S35ME-C9	7S35ME-C9	7S35ME-C9	5G45ME-C9	6G45ME-C9	6G50ME-C9	7G50ME-C9
3		6S30ME-B9	6S30ME-B9	5S35ME-C9	6S40ME-C9	7S40ME-C9	5S46ME-C8	6S46ME-C8	5G50ME-C9	7S50ME-C9
4			7S35ME-C9	6S40ME-C9			7S40ME-C9	5G45ME-C9	5S50ME-C9	6G50ME-C9
5									6G45ME-C9	6S50ME-C9
Phase 3 - LNG										
Average ship speed	14.9	15.0	15.0	15.0	14.7	14.9	15.0	15.1	15.3	16.2
SMCR power	3,600	4,500	4,900	5,500	5,700	6,500	7,200	8,200	9,600	12,000
SMCR speed	186	160	165	143	126	119	114	107	100	94
Propeller blades	5	4	4	4	4	4	4	4	4	4
EEDI % of reference	84*	82*	79*	72*	65	65	64	66	65	65
Main Engine options:										
1	7S30ME-B9	6S35ME-C9	7S35ME-C9	6S40ME-C9	5S46ME-C8	6S46ME-C8	7S46ME-C8	7S50ME-C8	5S60ME-C10	7S60ME-C10
2	6S30ME-B9	5S35ME-C9	6S35ME-C9	5S46ME-C8	7S40ME-C9	5S50ME-C8	7G45ME-C9	6S50ME-C9	7G50ME-C9	6G60ME-C10
3		7S30ME-B9	5S40ME-C9	7S40ME-C9	6S40ME-C9	7S40ME-C9	5S50ME-C9	7G45ME-C9	7S50ME-C9	5S65ME-C8
4		7S35ME-C9	5S35ME-C9	5S40ME-C9		5S46ME-C8	6S50ME-C8	5S50ME-C9	6G50ME-C9	6S60ME-C10
5				7S35ME-C9		5S50ME-C9	6G45ME-C9	7S46ME-C8	6S50ME-C9	5G60ME-C10

*EEDI not in full phase due to small ship size

Aframax			Suezmax (shuttle 155,000)				VLCC			
85,000	105,000	115,000	125,000	150,000	155,000	165,000	260,000	280,000	300,000	320,000
14.2	15.2	15.0	16.0	17.2	17.2	17.4	19.9	20.3	20.7	21.1
13.0	13.9	14.0	14.6	16.0	16.0	15.9	18.1	18.5	18.9	19.2
228	242	250	255	270	280	277	317	323	330	336
219	233	241	246	259	265	267	305	311	317	323
38.9	42	44	44	46	49	48	57	58	60	61
15	15	15	15	15	15	15	15	15	15	15
10	30	30	30	30	30	30	30	30	30	30
1	1	1	1	1	1	1	1	1	1	1
14.7	13.8	13.8	13.8	13.8	13.8	13.8	13.7	13.6	13.8	13.8
10,223	11,500	12,100	12,700	14,000	14,200	14,700	18,491	19,200	21,000	21,800
83	85	77	76	73	73	72	66	65	66	65
4	4	4	4	4	4	4	4	4	4	4
74	74	74	74	73	74	74	75	73	77	76
6G60ME-C10.5	6G60ME-C10	6G60ME-C10	5G70ME-C10	6G70ME-C10	6G70ME-C10	6G70ME-C10	7G70ME-C9	6G80ME-C10	7G80ME-C10	7G80ME-C10
7S60ME-C10.5	7G60ME-C10	7G60ME-C10	5G70ME-C9	7S70ME-C10	6G70ME-C9	6G70ME-C9	6G80ME-C10	7G70ME-C9	6G80ME-C10	6G80ME-C10
5S65ME-C8.6	5S70ME-C10	5S70ME-C10	6S70ME-C10	6G70ME-C9	6S70ME-C10	6S70ME-C10	5G90ME-C10			
6S60ME-C10.5			7G60ME-C10	6S70ME-C10	7S70ME-C10	7S70ME-C10	5S90ME-C10			
5G60ME-C10.5				5G70ME-C10	5G70ME-C10	5G70ME-C10	6S80ME-C9			
14.0	13.1	13.1	13.1	13.0	13.0	13.0	12.7	12.7	12.6	12.7
8,512	9,500	10,000	10,500	11,500	11,700	12,000	15,051	15,600	16,100	17,100
84	80	78	77	74	74	67	67	66	65	65
3	3	3	3	3	3	3	3	3	3	3
65	65	65	64	65	65	66	67	65	65	66
5G60ME-C10	6G60ME-C10	6G60ME-C10	6G60ME-C10	7S65ME-C8	5G70ME-C10	5G70ME-C10	7G70ME-C9	7G70ME-C9	6G80ME-C10	6G80ME-C10
5S60ME-C10	5G60ME-C10	5G60ME-C10	5S70ME-C10	7G60ME-C10	5G70ME-C9	6S70ME-C10	6G70ME-C10	6G70ME-C10	7G70ME-C9	7G70ME-C9
7G50ME-C9	7G50ME-C9	7S60ME-C10	5G60ME-C10	5S70ME-C10	7G60ME-C10	7G60ME-C10	6G70ME-C9	6G80ME-C10	6G70ME-C10	6G70ME-C9
7S50ME-C9	7S60ME-C10			6S65ME-C8	5S70ME-C10		5G70ME-C9			
6G50ME-C9				6G60ME-C10			7S70ME-C10			
15.6	14.7	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.7	14.8
12,925	14,600	15,400	16,100	17,746	18,100	18,700	23,718	24,700	25,600	27,200
90	86	84	83	80	79	78	72	71	70	70
4	4	4	4	4	4	4	4	4	4	4
65	65	65	64	64	65	65	64	64	65	65
7G60ME-C10	6S70ME-C10	6S70ME-C10	7S70ME-C10	7G70ME-C9	7G70ME-C9	7G70ME-C9	7G80ME-C10	7G80ME-C10	7G80ME-C10	7G80ME-C10
5S70ME-C10	5G70ME-C9	5G70ME-C9	6G70ME-C9	7S70ME-C10	7S70ME-C10	7S70ME-C10	5G95ME-C10	6G80ME-C10	6G80ME-C10	
6S65ME-C8	7G60ME-C10	7G60ME-C10	6S70ME-C10	6G70ME-C10	6G70ME-C10	6G70ME-C10	6G90ME-C10			
6G60ME-C10	5S70ME-C10	5S70ME-C10	5G70ME-C9	6G70ME-C9	6G70ME-C9	6G70ME-C9	6G80ME-C10			
7S60ME-C10				6S70ME-C10	6S70ME-C10	6S70ME-C10	7S80ME-C9			

Summary

Tankers carry liquid goods as oil or other products around the world, and will continue to form a vital part of the global supply chain. With the application of the latest electronically controlled engine technology of, for example, the ultra-long stroke G-type ME engine, a speed reduction will provide EEDI phase 3 compliance for traditional fuels.

With the introduction of the adverse weather condition (AWC) functionality, low-powered traditionally-fuelled vessels fulfilling EEDI phase 3 by a speed reduction can attain compliance with minimum propulsion power requirements.

Significant EEDI reductions can be achieved by including a shaft generator/PTO and/or EcoEGR and, in addition, the owner is ensured significant economic savings.

The diverse range of alternative fuels utilised by the MAN B&W two-stroke engines, offers an alternative path for tankers to attain EEDI phase 3 compliance. Thus, the application of alternative fuels constitutes an alternative to a speed reduction.

The low rpm of the modern engine designs allows for application of larger propellers than usual, which brings large benefits to tankers as the power required is reduced greatly. With these combinations of technical advantages, tankers will continue to deliver liquid products all over the world.

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