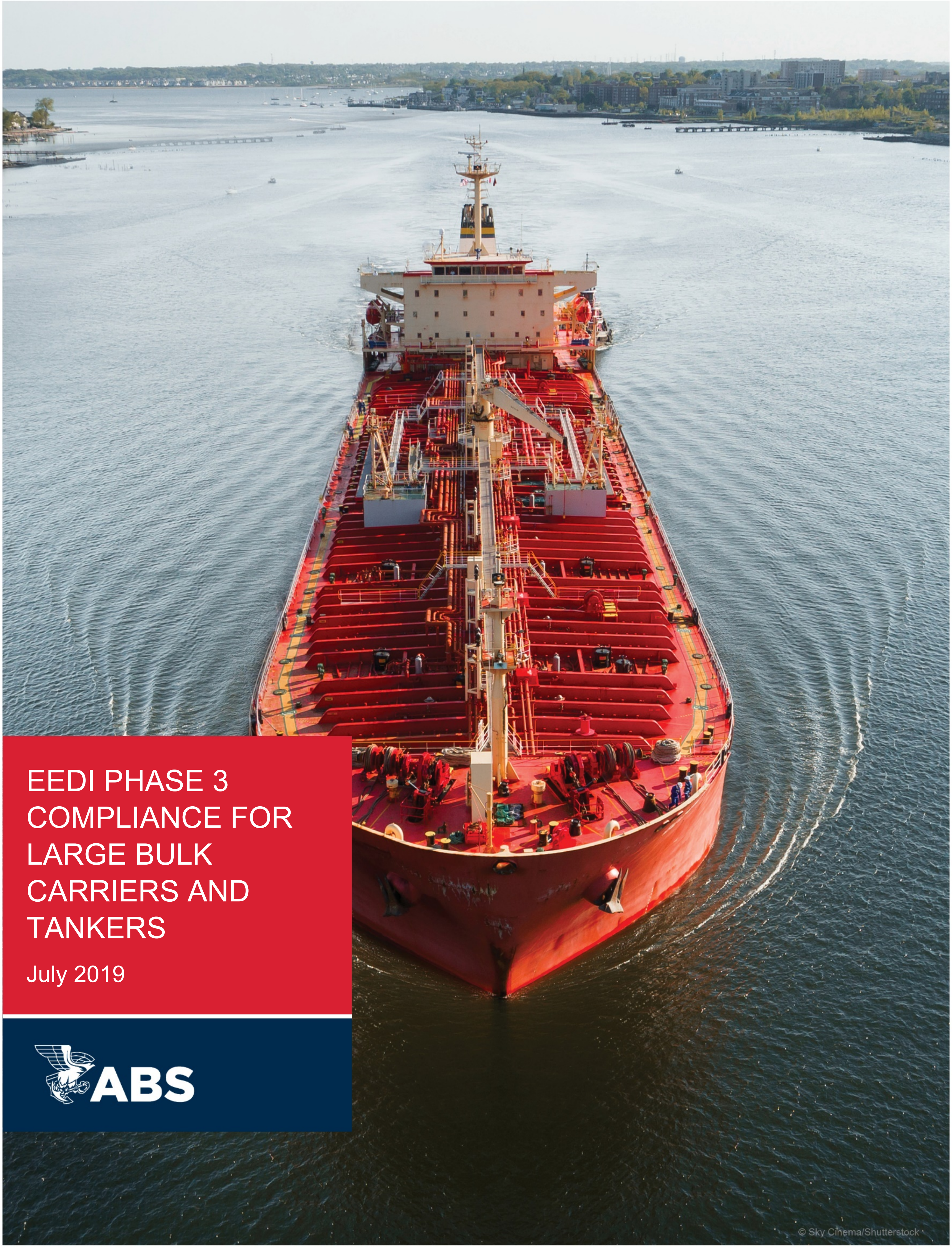
EEDI PHASE 3 COMPLIANCE FOR LARGE BULK CARRIERS AND TANKERS

July 2019



ABS

EEDI PHASE 3 COMPLIANCE FOR LARGE BULK CARRIERS AND TANKERS

OVERVIEW

The Energy Efficiency Design Index (EEDI) is a regulatory measure for ships mandating a minimum required level of efficiency and a reduction of carbon dioxide (CO2) emissions. Since 2011, the IMO has established the EEDI as a goal-based technical standard and introduced an energy efficiency benchmark for vessel designs of different ship type and size segments.

While compliance with the strengthened EEDI requirements has been achieved by a large number of ships in different class categories, concerns have been raised regarding the challenges for certain ship types - in particular those built using conventional technology and fuel - to meet the upcoming Phase 2 and Phase 3 compliance levels.

This white paper provides insights into the compliance landscape of bulk carriers and tankers within the context of the EEDI regulations, given that these vessels comprise a significant proportion of the world fleet. The document also discusses the contribution of potential technical measures for large capacity ships and examines different paths to achieve the regulatory compliance.

EEDI FRAMEWORK

For the past decade, energy regulations and global demand to reduce greenhouse gas (GHG) emissions have progressively stimulated innovation and targeted technology readiness.

The EEDI for new ships was established as part of the International Maritime Organization's (IMO's) goal of reducing carbon dioxide (CO2) emissions from shipping, and aims to promote the use of more energy efficient hull forms, equipment and engines along with low carbon fuels. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. ton mile) for different ship types and size segments. Starting on 1 January 2013, an initial two year 'Phase 0' required new ship designs to meet the reference level for their specific ship type. From that point on, new designs are required to become progressively more efficient in three more 'Phases' reaching a 30% reduction between 2025 to 2030 for applicable ship types. The regulations on EEDI are designed in such a way to stimulate continued innovation and technology development of key components influencing the fuel efficiency of a ship from its design phase.

Introduced as a non-prescriptive, performance-based mechanism, the EEDI is a goal-based technical standard that leaves the choice of technologies and ship's design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations.

The EEDI provides a specific numerical figure for an individual ship type, expressed in grams of CO2 per ship's capacity-mile (the smaller the EEDI, the more energy efficient is the ship's design) and is calculated by the formula below, which is based on the technical design parameters for a given ship:

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE} *\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME} **\right)}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_w \cdot V_{ref}}$$

The items that primarily influence EEDI are:

- Installed main engine power, fuel type and energy needed for propulsion; this is represented by the first term (and the third term for cases where shaft motor is installed) in the numerator of the formula.
- Auxiliary power requirements of the ship, fuel type and consumption; this is represented by the second term in the numerator.
- Innovative electrical technologies such as electricity from waste heat recovery or solar power, commonly referred to as "4th term".
- Innovative mechanical technologies that provide power for ship propulsion such as wind power (sails, kites, etc.), referred to as "5th term".

For the majority of ships whose EEDI data has been reported to the IMO and made publicly available, several of the parameters in this formula are taken as 0 or 1. More specifically,

- Correction factor f_j = 1 as it represents ship specific design elements of ice class vessels, Ro-Ro ships, general cargo, or shuttle tankers with propulsion redundancy.

- Availability factor f_{eff} = 0 as reported innovative technologies are currently limited to numbered waste heat recovery system installations for electrical power generation.
- Correction factor f_l =1 as this is only applicable to general cargo vessels.
- Correction factor f_w =1 as the weather factor f_w demonstrates the reduction of ship speed in representative sea conditions of wave height, wave frequency and wind speed (e.g., Beaufort Scale 6). The current IMO guidelines on the f_w calculation are interim.

OVERVIEW OF EEDI REGULATIONS - MARPOL ANNEX VI

EEDI regulations were introduced following a series of discussions at the IMO MEPC sessions. The committee, at its 62nd session in July 2011, reached a consensus to add a new Chapter 4 to MARPOL Annex VI to stipulate new requirements for energy efficiency (IMO, 2011). A short description of these regulations is provided below.

Regulation 19

Regulation 19 specifies the domain of application of the energy efficiency regulations. Chapter 4 of MARPOL Annex VI applies to all ships of 400 gross tonnage (GT) and above that are engaged in international voyages. It gives limited power to Administrations to waive the requirements for EEDI for a new ship contracted before January 1st 2017 up to a delivery date of 1 July 2019; subject to informing the IMO and other Parties to MARPOL Annex VI of this decision.

Regulation 20

This regulation addresses the Attained EEDI and specifies the need for its calculation and verification. Attained EEDI is the actual EEDI of a ship as calculated using the EEDI formula (IMO, 2014).

EEDI was initially applicable only to ships with conventional propulsion, i.e. engines that are either direct driven or geared. At a later stage, the IMO expanded the scope to cover cruise ships with diesel electric propulsion and LNG carriers with diesel electric or steam turbine propulsion. The regulation defines specific vessel types. If the vessel type in question does not fall under one of the 13 mandatory vessel types (bulk carrier, tanker, containership, gas carrier, general cargo ship, combination carrier, refrigerated cargo, passenger ship, ro-ro cargo ship, ro-ro vehicle carrier, ro-ro passenger ship, LNG carrier, cruise passenger ship), then it is not mandatory to comply with Regulation 20.

EEDI regulations do not apply to category A ships as defined in the Polar Code but do apply to ice-strengthened ships.

Regulation 21

Regulation 21 provides the requirement and guidelines for calculating the Required EEDI and verifying that a vessel's Attained EEDI is less than the Required EEDI. The Required EEDI is the regulatory limit for EEDI and its calculation is dependent on a reference line value and a reduction factor.

The basic concepts included in this regulation are:

- Reference line

- This is a baseline EEDI for each ship type, representing reference EEDI as a function of ship size (DWT or GT). The reference line is a regression, i.e. a mathematical distribution of data, representing the average efficiency for ships built between 1999 and 2009. The regression equations for each ship type are embodied in Regulation 21 in the form of a formula where parameters a, b, and c are dependent on ship type.

$$\text{Reference EEDI} = \text{a} * \text{b}^{-\text{c}}$$

- Reference lines have been developed for each individual ship type and relate the EEDI value to the vessel's size (deadweight, DWT or gross tonnage, GT). Details of how reference lines are developed including sources of data, data quality checks, number of ships selected and year of build, ship sizes, etc. are described in the relevant IMO guidelines (IMO, 2013a and IMO, 2013c).

- Implementation Phases
  - Required EEDI will be implemented in phases. Currently, it is in Phase 1 that runs from year 2015 to the end of 2019. Phase 2 will run from year 2020 to 2024 and Phase 3 starts from year 2025 onwards.
- Reduction factor
  - This is a phased in percentage value for EEDI reduction relative to the reference line. The reduction factor is dependent on the vessel's type, deadweight, contract and delivery date and applies a structured approach to tighten EEDI regulations over time.
- IEEC
  - Following the verification of a vessel's EEDI, the International Energy Efficiency Certificate (IEEC) is issued following the requirements of Regulation 6, Chapter 2 of MARPOL Annex VI. The certificate is valid throughout the life of the ship except in cases where the certificate is rewritten or reissued (IMO, 2011).

Regulation 21.5 - Interim Guidelines for Determining Minimum Propulsion Power to Maintain the Maneuverability of Ships in Adverse Conditions

One of the most effective ways of reducing a ship's EEDI is by reducing the ship's design speed.

While fast ships (e.g. containerships) have ample ability to reduce their design speed safely, slow speed ships (tankers and bulk carriers) do not. Reducing the design speed can lead to reducing installed propulsion power. Concerns were expressed by the shipping industry that if speed reduction was implemented to reduce Attained EEDI, tankers and bulk carriers may not have sufficient propulsion power to maneuver in adverse weather.

To enable safe manoeuvring in adverse conditions, a requirement was introduced to the EEDI regulations (Regulation 21.5, Chapter 4 of MARPOL Annex VI): "For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the maneuverability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization."

At the request of the IMO, the International Association of Classification Societies (IACS) initiated the development of the guidelines referenced in the Regulation 21.5. The studies conducted by the IACS working groups served as a basis for the 2013 Interim Guidelines for Determining Minimum

Propulsion Power to Maintain the Maneuverability (IMO, 2013b) which were further updated in 2015 and 2017 (IMO, 2015a, IMO 2015b and IMO, 2017).

The Guidelines currently apply to:

- Tankers
- Bulk carriers
- Combination carriers

Investigation showed that the above ship types are the most critical with respect to the sufficiency of power for maneuverability in adverse conditions. Views have been expressed by IMO member states that further consideration for other ship types should be performed at a later stage.

The applicability of the guidelines from a capacity perspective is currently limited to ships of 20,000 DWT and above. The main reason behind this restriction is that a systematic evaluation of the required standard environmental conditions for ships with deadweight less than 20,000 DWT has not yet been completed. A solid proposal is envisaged for the future, and ongoing studies in the IMO are currently addressing this issue.

The current methodologies for estimating the minimum power are based on two assessment levels.

Assessment Level 1 – Minimum Power Lines Assessment

A simple approach that involves calculation of the required minimum propulsion power as a function of ship DWT.

Assessment Level 2 – Simplified Assessment

A more mathematically complex assessment procedure consisting of two key steps:

1. Definition of the required advance speed in head wind and waves, ensuring course-keeping in all wave and wind directions.
2. Assessment whether the installed power is sufficient to achieve the above required advance speed.

The Level 2 assessment requires the determination of wave added resistance through model tests in regular waves. Empirical formulae are also referenced although not directly specified.

COMPLIANCE LEVELS OF BULK CARRIERS AND TANKERS

For bulk carriers and tankers, the reduction factor applied to define the Required EEDI is increasingly tightened through Phases 1, 2 and 3 by 10%, 20% and 30%, respectively. For lower deadweight ranges between 10k and 20k, the reduction factor is interpolated and increases linearly as the vessel size increases.

The reference lines developed by the IMO for bulk carriers and tankers are shown in Figure 1 with corresponding values for parameters a, b, and c used in the regression line equations given in Table 1 below:

Table 1: EEDI Reference Line Calculation for Bulk Carriers and Tankers

Ship Type	Reference Line
Bulk Carrier	$961.79 \times DWT^{-0.477}$
Tanker	$1218.80 \times DWT^{-0.488}$

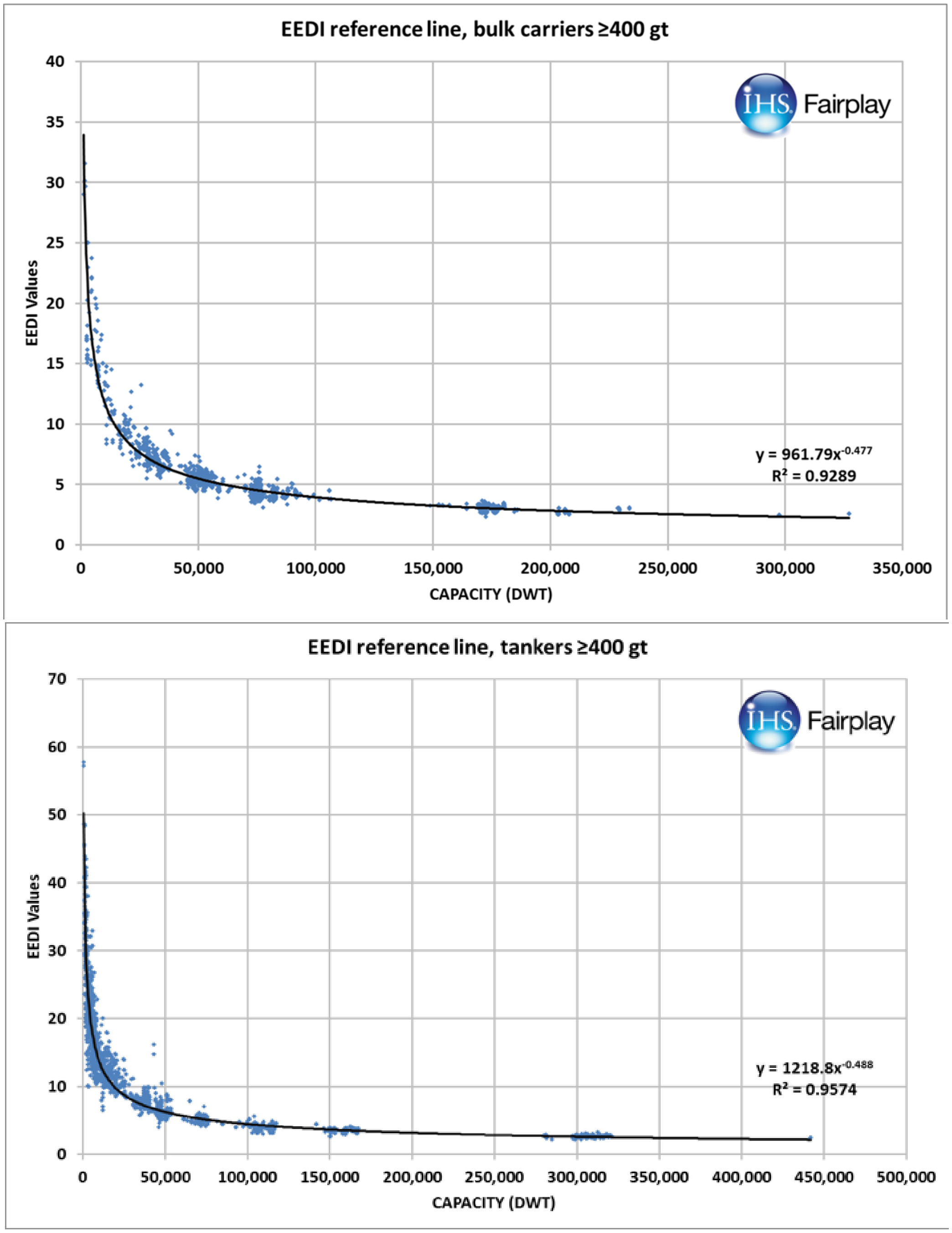


Figure 1: EEDI Reference Line for Bulk Carrier Developed by the IMO (Source: Fairplay)

It is evident from Figure 1, that due to insufficient data at the time, data points representing smaller size bulk carriers and tankers weigh much more on the regression than those for larger ships. The largest DWT size bulk carrier included in the IMO regression curve has been confirmed around 327,000, a significantly smaller capacity compared to the recent construction VLOC vessels (in the 400,000 range). This means that while the reference line is appropriate for smaller ships, it is not directly representative of and might even penalize the largest capacity segments.

Figure 2 shows a broader comparison across the different ship types subject to EEDI regulations. As one gets into further detail on the scope of EEDI Regulation 21, in particular the minimum propulsion power criteria that apply to bulk carriers and tankers, arguments that the most stringent EEDI requirements apply to the most energy efficient segment of the world fleet are becoming prevalent.

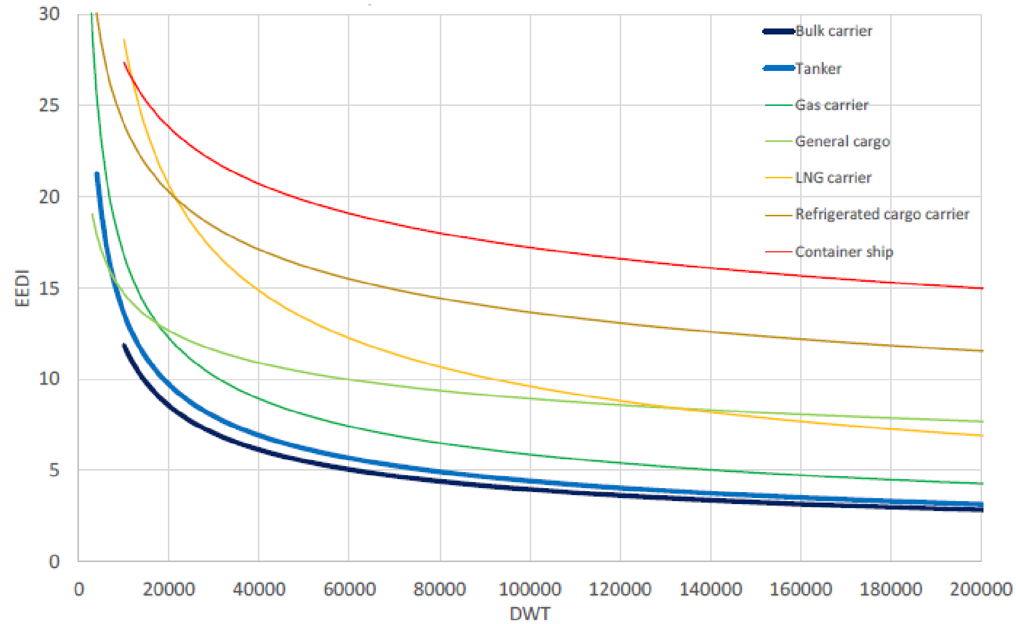


Figure 2: Comparison of EEDI Reference Lines for Various Ship Types [Source: IMO (2018a)]

MINIMUM PROPULSION POWER AND SAFE SHIP OPERATION

The industry funded projects, namely SHOPERA (Energy Efficient Safe Ship Operation) in close collaboration with JASNAOE (Japan Society of Naval Architects and Ocean Engineers) submitted to the IMO a revision proposal for the 2013 Interim Guidelines.

Extensive studies involved the development and validation of numerical and empirical methods for the time-average wave forces, including added resistance, and also aimed to calibrate the standard weather conditions using assessment results of existing ships with respect to the revised criteria.

The SHOPERA project was launched in 2013 and concluded in 2016. The following results were produced on possible conflicts between the requirements to safe maneuvering in adverse conditions and the strengthening requirements of the later EEDI Phases:

1. When existing vessels that satisfy a certain EEDI Phase are compared across all ship types, bulk carriers and tankers show similar marginal wave heights (i.e., maximum wave height, up to which the vessel can fulfil an examined criterion), which are also the lowest among all ship types.
2. When selected vessels satisfy the criteria proposed by SHOPERA for maneuverability in adverse conditions at the standard wave heights according to the 2013 Interim Guidelines, bulk carriers and tankers marginally fulfill EEDI Phase 2 requirements, but not Phase 3. In contrast, vessels of other types that satisfy the maneuverability criteria subject to the standard wave heights according to the 2013 Interim Guidelines, are able to meet or even exceed the EEDI phase 3 requirements (in the present formulation).
3. For EEDI phase 3-compliant bulk carriers and tankers to pass the proposed maneuverability requirements in adverse conditions, the standard wave heights may need to be lowered compared to those in the 2013 Interim Guidelines.

During the course of research, the IMO carefully followed developments, examined inputs and assessed the introduced alternative approaches. At MEPC 68 in May 2015, the strengthening of existing Level 1 assessment criteria was agreed upon and adopted as a tentative measure (IMO, 2015b).

Discussions in the IMO for the Level 2 assessment are still ongoing. The research project conclusions were once again examined by the member states at MEPC 71 but were considered not mature enough to revise the 2013 Interim Guidelines for calculation of minimum propulsion power (IMO, 2017).

The IMO MEPC at its 72nd session agreed to extend the 2013 Interim Guidelines to EEDI Phase 2 and requested member states and participating bodies to continue discussions on the matter to further develop the revision to the guidelines in upcoming sessions.

In support of the IMO efforts, ABS' technical leadership stays at the forefront of developments through active participation through IACS and joint industry initiatives.

ATTAINED “EEDI WEATHER"

EEDI is a theoretical index of ship's performance at one draft and in ideal sea conditions (no wind and no waves). As a result, ships with same EEDIs may have very different performance in real sea conditions.

The weather coefficient, f_w, is a measure of the ship speed reduction at 75% MCR in Beaufort 6 weather conditions. The calculation guidelines for f_w remain interim and, therefore, the common practice is for f_w to be taken as 1.0. Applying the realistic value of the weather factor in the EEDI formula to account for "Attained EEDI weather" is more representative of the ship’s efficiency in actual operating conditions,

A typical range for f_w for slow speed ships (e.g. bulk carriers and tankers) is 0.80 – 0.95, which is an indication of the extreme variation in design efficiency that is not yet captured in the EEDI. Each ship design has its own f_w which can be determined experimentally by model tests. IMO (2012) provides guidelines for the calculation of f_w as well as standard f_w curves for different ship types, graphs for bulk carriers and tankers are shown in Figure 3. Experimental values show that, for ships of the same deadweight, the f_w can vary widely. For example, for 300,000 DWT tankers, f_w ranges from 0.83 to 0.94. Since this speed variation is at the fixed power of 75% MCR, it is a direct measure of the efficiency of the ship’s hull lines (especially bow shape).

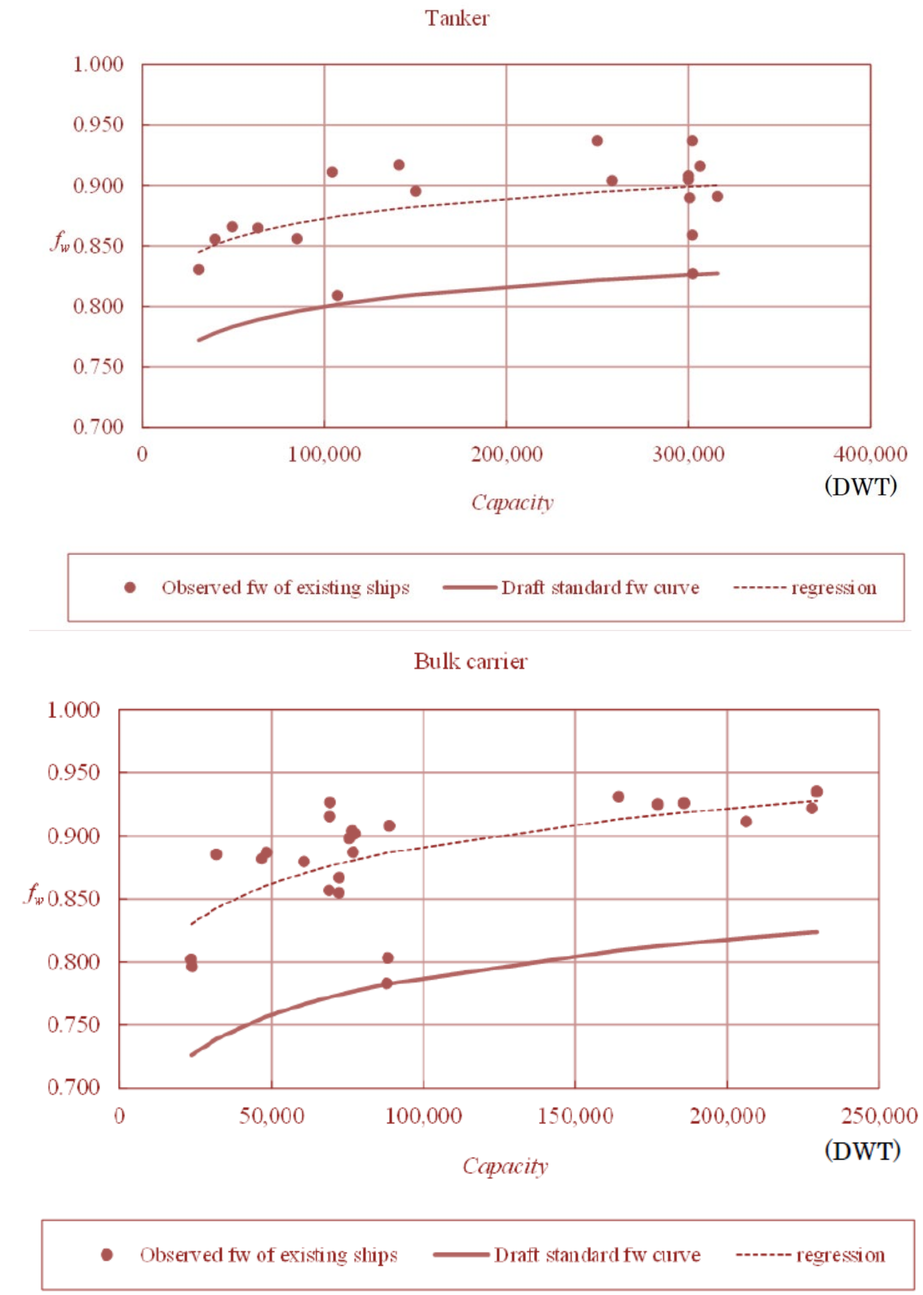


Figure 3: Standard f_w Curve for Tanker [Source: IMO (2012)]

As demonstrated in Figure 3, f_w and "Attained EEDI weather" are crucial pieces of information of a ship's real efficiency.

CURRENT STATUS

The IMO MEPC met at its 74th session in May 2019 and approved proposed amendments to MARPOL Annex VI Regulation 21 with a view to adoption at MEPC 75.

The amendments accelerate the implementation of EEDI Phase 3 to 2022 (from 2025) for a number of ship types (Container Ships, General Cargo ships, Gas Carriers, Refrigerated Cargo Carriers, Combination Carriers, LNG Carriers, and Cruise Passenger Ships) and strengthen the requirement up to 50% for container ships through a DWT-based incremental increase of the current 30% EEDI Phase 3 reduction factor.

Despite concerns raised about the ability of bulk carries and tankers to comply with the current Phase 3 requirements, the EEDI Phase 3 reduction factors remain unchanged. The Committee however approved to amend the original baseline, by increasing the required EEDI for large bulk carriers of 279k DWT and above as shown in Table 2.

Table 2: EEDI Reference Line Calculation for Bulk Carriers

Ship Type	Reference Line
Bulk Carrier	$961.79 \times DWT^{-0.477}$ when DWT of the ship ≦ 279,000 MT $279{,}000^{-0.477}$ when DWT > 279,000 MT

The Committee further adopted the introduction of a correction factor $f_m = 1.05$ applicable to ice-strengthened ships of ice class IA and IA Super. For all other vessels, f_m value should be taken as 1.

Regarding potential conflicts between EEDI compliance and the requirements of the minimum propulsion power interim guidelines, a submission by member states has been reviewed by the MEPC for an option to limit propulsion shaft power while ensuring a sufficient safety power reserve for the vessel in adverse weather conditions (IMO, 2018c).

The submission recommends that the IMO guidelines allow for non-permanent limitation of a ship's shaft power below the installed Maximum Continuous Rating for EEDI calculation purposes and to apply 75% of the limited power as P_{ME} for the calculation of the attained EEDI and for the determination of the EEDI reference speed V_{REF}. The full rated installed propulsion shaft power shall only be enabled when the ships' safety is at risk.

ABS examined the bulk carrier and tanker EEDI datasets published as of March 2019 on the IMO Global Integrated Shipping Information System (GISIS).

Figure 4 and Figure 5 provide a graphic demonstration of the currently achieved efficiency levels for bulk carriers and tankers respectively.

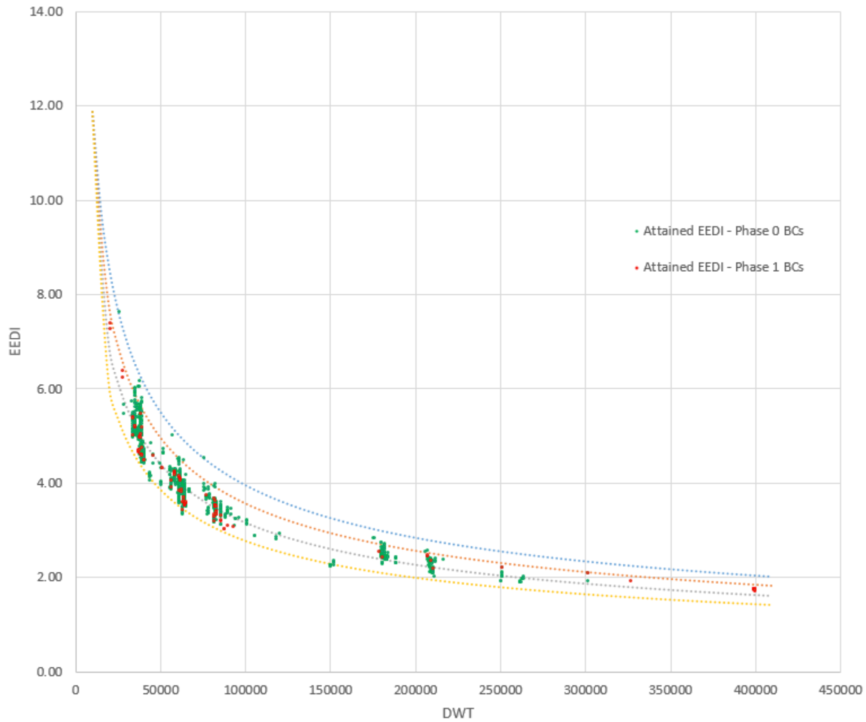


Figure 4: IMO EEDI Data for Bulk Carriers (GISIS 2019)

Figure 5: IMO EEDI Data for Tankers (GISIS 2019)

For the purpose of this study, bulk carriers and tankers were examined by main industry categories (MAN Diesel & Turbo 2013, 2014):

Bulk Carriers

Handysize 10,000-35,000 DWT

Handymax 35,000-55,000 DWT
Panamax 55,000-80,000 DWT
Capesize 80,000-200,000 DWT
Large Capesize 200,000-300,000 DWT
VLBC >300,000 DWT

Tankers
Small to Handysize up to 30,000 DWT
Handymax 30,000 - 55 000 DWT
Panamax 60,000 - 75,000 DWT
Aframax 80,000 - 120,000 DWT
Suezmax 125,000 - 200,000 DWT
VLCC/ULCC 300,000 and above

A summary of observations (non-exhaustive) is presented below, as these are discussed in this white paper:

1. Design efficiency is improving slowly across different DWT segments of bulk carriers and tankers. However, compliance with Phase 3 and, in certain cases, even Phase 2 criteria remains a challenge. More specifically:

    - For large Capesize bulk carriers (200k – 300k DWT), the number of delivered hulls meeting EEDI Phase 2 appears to be increasing between years 2016 – 2019 with vessels showing improved average achieved efficiency. In a similar manner, Suezmax tankers (125k – 200k DWT) built in 2016-2019 show increasing compliance margins against EEDI Phase 2. No vessel in either of these categories though has achieved 30% reduction compared to the baseline yet.

    - A small number of VLCC tankers (DWT >300k) have achieved EEDI Phase 2 criteria though no VLOC bulker (DWT > 300k) has reported compliance. No vessel in either of these categories has achieved a 30% reduction compared to the baseline yet.

    - Smaller DWT segments such as Panamax bulk carriers (55k – 80k DWT) and Aframax tankers (80k – 120k DWT) appear to meet Phase 2 criteria more comfortably when compared to larger capacity peers. However, these better performers have marginal compliance with Phase 3 by only a few vessels.

2. Proposals to strengthen EEDI compliance criteria need to be carefully examined by the IMO MEPC with consideration of the 2013 interim guidelines on minimum propulsion power.

3. The lack of innovative technology uptake (4^{th} and 5^{th} term) by bulk carriers and tankers has been repeatedly discussed at MEPC meetings. It should be noted that the innovative technology applications fitted on a few VLCC tankers delivered between 2017- 2019 and reported to the IMO GISIS are 4^{th} term. The most common 4^{th} term innovative technologies fitted on commercial cargo vessels are waste heat recovery systems (WHS) for electric power generation. A direct comparison with the same capacity VLCC tankers with identical main parameters, EEDI power (P_{ME}) and reference speed (V_{REF}), shows that efficiency benefits can range between 1.9 – 2.7%.

4. The IMO EEDI database provides no reference for comparison of energy saving devices (ESD). These technologies (e.g. pre-swirl stators, rudder bulbs) together with optimized propeller/rudder configurations are commonly found on newer bulk carrier and tanker vessels. Their efficiency benefits though cannot be separated from the overall performance of the vessel as they are accounted for in the EEDI reference speed (V_{ref}) during model tests and speed trials.
5. The experimental case studies reviewed at MEPC 72 (IMO, 2018b) suggest that with practical energy saving devices applied, the latest bulkers and tankers are likely to achieve approximately 25% EEDI reduction rate but only few can meet a 30% reduction. As shown in Figure 6, in order for these ships to meet EEDI Phase 3 criteria, it is necessary to use lower main engine MCR. This conclusion iterates back to the need to finalize the minimum propulsion power requirements (item 2 above). In Figure 6, Case 1 applies deductions achieved with pre/post-swirl devices, air lubrication system or low friction coating, waste heat recovery system and solar power. Case 2 applies deductions achieved by a coaxial contra-rotating propeller, air lubrication system or low friction coating, waste heat recovery system, and solar power.
6. Substantial improvement of a vessel's Attained EEDI can be achieved through the use of gas fuels and dual fuel engine installations. Even though a number of ships have been fitted with such engines and verified for EEDI, the IMO GISIS currently provides no reference for comparison.

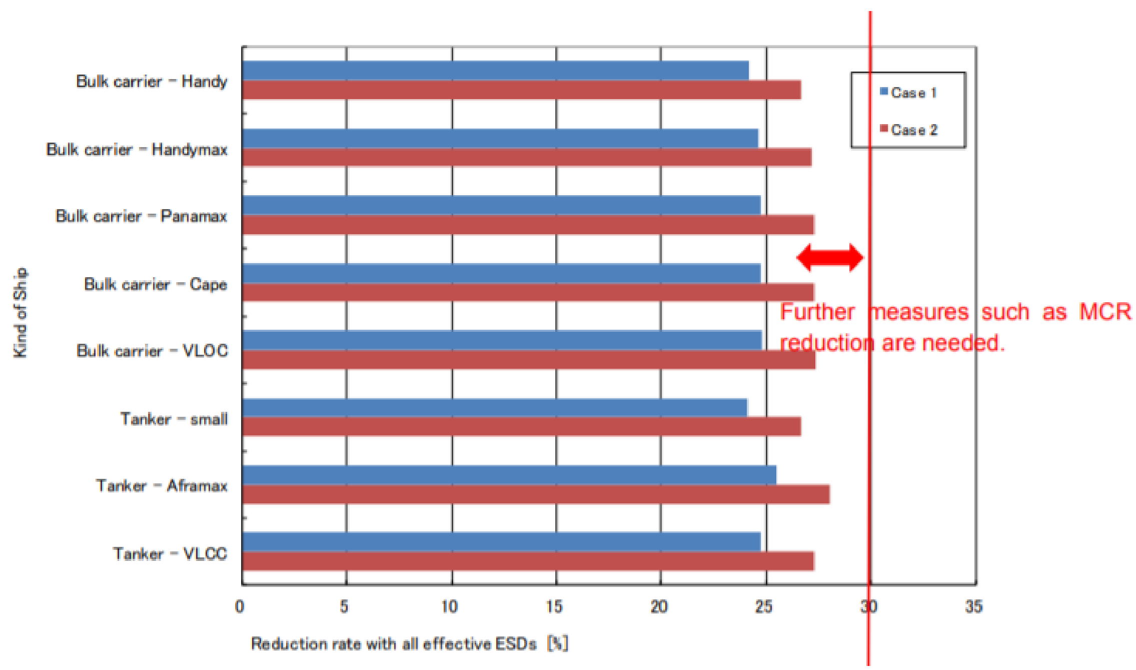


Figure 6: Achievable Reduction Rate for Bulkers and Tankers [Source: IMO (2018b)]

In view of calls for strengthening EEDI further and given that with the existing regulatory scheme, shipyards and owners are challenged to meet difficult efficiency targets, the IMO discussions are expected to evaluate compliance expectations based on current industry performance metrics.

INNOVATIVE TECHNOLOGIES – CALCULATION OF EFFICIENCY AND VERIFICATION

The verification of innovative energy efficiency technologies is a complex process as documented in the IMO guidelines (IMO, 2013d). This is an interim guidance document expected to evolve over time with experience gained from using these technologies.

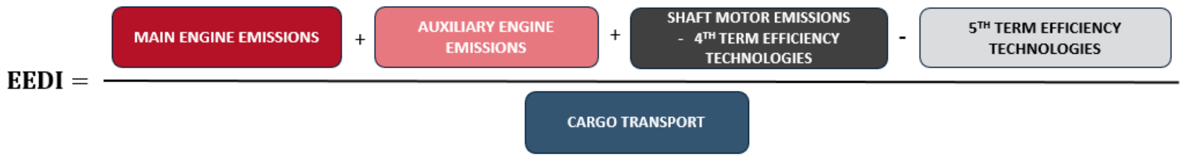
The evaluation of the benefit of innovative technologies for EEDI is to be conducted with the assessment of the hull form and propulsion system with which it is intended to be used. As a result, existing model test data or sea trial measurements of innovative technology may not cover different hull forms or propulsion systems.

The *ABS Ship Energy Efficiency Measures Advisory* details some of the energy saving measures that can be applied to new and existing vessels. Potential energy savings are estimated in terms of reductions in engine specific fuel oil consumption, reduction in propulsion fuel consumption, and reduction in overall vessel fuel consumption. These estimates are based on values derived from vendor and manufacturer claims, industry reports, practical operating experience, and ABS engineering review.

Categorization of Technologies

Innovative energy efficiency technologies are allocated to category (A), (B) and (C), depending on their characteristics and the way they influence the EEDI formula as shown in Figure 7. Furthermore, innovative energy efficiency technologies of category (B) and (C) are categorized into two sub-categories: category (B-1) and (B-2), and (C-1) and (C-2), respectively.

- Category (A): Technologies that directly influence and shift the ship speed-power curve and can change the combination of Propulsion Power (PP) and V_{ref}. For example, such technologies at constant V_{ref} can lead to a reduction of PP; or for a constant PP they could lead to an increased V_{ref}. This category covers ESDs such as pre-propeller fins, ducts, post-swirl stators, rudder fins and combinations of them along with low-friction coatings and hull/propeller/rudder optimization efforts that directly impact ship hydrodynamic performance.
- Category (B): The commonly known "5th term" technologies that reduce PP, at a V_{ref} but do not generate electricity. The saved energy is counted as P_{eff} .
    - Category (B-1): Technologies which can be used at all times during the operation (e.g. hull air lubrication) and thus the availability factor (f_{eff}) should be treated as 1.00.
    - Category (B-2): Technologies which can be used at their full output only under limited conditions and periods (e.g. wind power). The setting of availability factor ($_{feff}$) should be less than 1.00.
- Category (C): The commonly known "4th term" technologies that generate electricity. The saved energy is counted as P_{AEeff}
    - Category (C-1): Technologies which can be used at all times during the operation (e.g. waste heat recovery) and thus the availability factor (f_{eff}) should be treated as 1.00.
    - Category (C-2): Technologies which can be used at their full output only under limited condition (e.g. solar power). The setting of availability factor (f_{eff}) should be less than 1.00.



INNOVATIVE TECHNOLOGY	Category A	Category B	Category C	EFFECTED COMPONENT OF EEDI FORMULA
Hull Optimization	X			
Superstructure Optimization	X			
Propeller Optimization	X			
Podded Drives	X			
Contra Rotating Propellers	X			
Vane Wheel	X			
Ducted Propeller	X			
Pre-Swirl Device	X			
Post Swirl Device	X			
Twin Skeg	X			
Waste Heat Recovery			X	
Hybrid Propulsion				*Efficiency benefit cannot be realized within current EEDI scheme*
Fuel Cell				*Efficiency benefit cannot be realized within current EEDI scheme*
Coatings	X			
Air Lubrication		X		
LNG, Gas fuels				
Biofuels				*Efficiency benefit cannot be realized within current EEDI scheme*
Wind Propulsion		X		
Solar Power			X	
Lightweight reduction	X			
Hull vane	X			

Figure 7: Innovative Energy Efficiency Technologies – EEDI Formula

Category A Innovative Technology

Innovative technologies that qualify for Category A influence on the EEDI formula consist of technologies whose performance cannot be separately assessed from overall performance of the vessel. An ESD is one example that affects the vessel speed and required propulsive power.

Unconventional Propulsion and Energy Saving Devices

The effect of unconventional propulsion and ESD fittings on a vessel's fuel efficiency has been investigated by a number of model basins worldwide. Results of experimental studies were presented in Copenhagen at the 2014 International Towing Tank Conference 27th session (ITTC, 2014)

The studies assessed the performance of unconventional propulsion and ESDs under the below key groups and summarized their results in the Conference Proceedings:

- ESDs in front of propeller such as pre-swirl ducts, wake-equalizing ducts, and flow-regulating fins. The efficiency for ships tested in towing basins was generally in the range of 3 - 5%.
- ESDs after propeller to utilize the swirling effect in the propeller slipstream, such as rudder bulb fins, post-swirl stators, and Grim Vane wheels. These applications demonstrated a benefit in the towing tank ranging between 3% for rudder fins up to 6% for the Grim Vane wheel.
- Unconventional tip shape propellers, propeller boss cap fins (PBCF) and contra-rotating propellers. The energy savings observed in the towing tank and full scale trials were 1-2% for the commonly used PBCFs, and up to 5% for new type propellers with blade tips bent forward or backward (Kappel, CLT).

Experimental assessments have been carried out in model basins in conjunction with ESD manufacturers for optimization of their designs. The procedures to obtain the propulsion improvement effect at full scale require testing and calibration by a sufficient amount of sea trial data and onboard measurements. This information, however, is in most cases proprietary to the stakeholders involved (shipyard, owner) and difficult to access.

Full Scale Evaluation of Energy Saving Devices

The prediction of power savings by ESD is of growing interest, as focus is given to meet the upcoming EEDI phases. EEDI verification is based on full scale speed-power performance which incorporates the benefit by ESDs when fitted.

The performance of various energy saving measures has been examined by manufacturers, shipyards and owners since the early implementation stages of the EEDI regulations. A suitable method to verify the efficiency gains by use of ESDs is an integral part of the process with CFD analysis playing an important role, validated through model tests and full scale sea trials.

However, further work is required for a standard process to be established given the uncertainty and differences between testing facilities, assumptions made, and methodologies applied.

ABS has been actively involved in relevant industry projects working together with manufacturers, shipyards and owners to provide technical guidance.

Category B Innovative Technologies

Innovative technologies that qualify as 5th term or Category B improve the propulsive power (PP) while maintaining a constant V_{ref} without generating electricity. The two primary 5th term innovative technologies used in industry are air lubrication and wind assisted propulsion. In practice, adoption of these technologies for large bulkers and tankers has been limited.

Air Lubrication Systems

Air lubrication systems reduce the vessel skin friction to improve propulsive power. These systems are not dependent on the environmental conditions and can be deployed at any time during operation. Thus, air lubrication systems satisfy Category B-1 criteria of the EEDI formula and can be achieved through the methods below.

- Bubble Drag Reduction
    - This method uses bubbles to reduce the liquid density and lower the skin friction on the hull surface
- Air layer Drag Reduction (ALDR)
    - This system relies on injecting air bubbles that coalesce into a continuous layer of air. These devices may feature a small backward step to introduce a separation point on the fluid flow along the hull. The thickness of the air layer is thinner than the near wall region of the turbulent boundary layer
- Partial Air Cavity Drag Reduction
    - Taking the concept of a backward step on the hull further, a partial air cavity on the hull bottom is inflated with air. The air layer is thicker than the turbulent boundary layer on the ship hull.

ABS has published the *2018 ABS Guide for Air Lubrication System Installation* which details the requirements for the installation of these systems on newbuild and retrofit marine vessels. Guidance is provided on the installation of air lubrication system on marine vessels with regard to the piping system, pneumatic system, electrical system, hull penetration, and stability.

Wind-Assisted Propulsion

Wind-assisted propulsion systems reduce the propulsive power required to maintain a constant speed by converting wind energy into thrust through pressure differentials. In general, wind-assisted propulsion can only be deployed when certain environmental conditions are met, which qualifies for a Category B-2 5th term technology. Wind-assisted propulsion is not a novel concept. However, the challenge for wind-assisted propulsion is more related to adapting existing technology for use on larger vessels rather than developing new technology. Four available forms of wind-assisted propulsion are described below.

- Wingsails or Rigid Sails
  - Rigid sails utilize the same operating principle as an aerofoil by manipulating the lift and drag forces to produce a net propulsive force.
- Square Rig Sail Systems
  - Flexible sail systems allow for larger surface sail areas when compared to rigid sails.
- Towing Kites
  - Large surface kites are connected to the vessel forecastle and deployed at higher altitudes to harness higher wind speeds.
- Flettner Rotors
  - Rotating columns utilize the Magnus effect to generate forward thrust creating a pressure differential.
  - Flettner rotors can be used in lower wind speeds but require energy input to rotate the column.

Formal guidelines on the method to verify the fuel efficiency contribution of wind-assisted ship propulsion systems have not been issued by the IMO. MARIN in collaboration with ABS has proposed a Joint Industry Project to assess the performance evaluation and regulatory compliance of ships equipped with wind-assisted propulsion. The objectives are to:

- Establish recommended procedures to determine the performance of wind-assisted ship propulsion (WASP). This will allow for fair comparison of the different designs in the current market and enable a higher overall quality of performance predictions.
- Demonstrate that the recommended procedures through case studies
- Document challenges in existing regulation and propose new regulations catered to WASP.

Specific to tankers and bulkers, assessing the performance of WASP in a way that allows for fair comparison will help ship designers and owners better understand how these measures will affect compliance with EEDI Phase 3.

Category C Innovative Technologies

Electricity generating innovative technologies include waste heat recovery systems and photovoltaic (PV) solutions. Waste heat recovery technology utilizes the energy contained in the exhaust gases and converts the excess heat, gas flow and pressure into mechanical energy. ABS provides Machinery and Systems Performance analysis to evaluate the proportion of efficiency that can be recovered with consideration of complex system constraints of engine room space, safety, operation and cost of installation.

Photovoltaic technology for use in marine environments is a not-yet mature alternative to traditional marine fuels. Fortunately, the cost of PV modules has decreased while its efficiency potential appears to have increased significantly. According to IMO (2016b), solar power technology should be considered for on-board applications. However, due to the spatial requirements of PV modules and the constraints of large electric energy conversion on vessels, solar power is limited to supplementing auxiliary power plants rather than providing power exclusively.

FUEL SOLUTIONS

Compliance with EEDI Phase 3 is a milestone on the IMO's future path to decarbonization. Common liquid fuel options include:

- Residual Marine Fuels (RM);
- Distillate Marine Fuels (DM);
- Ultra-low sulfur fuel oil (ULSFO) such as ULSFO-DM (max. 0.10% S) and ULSFO-RM (max. 0.10% S);
- Very low sulfur fuel oil (VLSFO) such as VLSFO-DM (max. 0.50% S) and VLSFO-RM (max. 0.50% S); and
- High sulfur heavy fuel oil (HSHFO) exceeding 0.50% S.

However, these fuel types may result in prohibitive carbon dioxide levels when solely considered to achieve the more strenuous EEDI criteria of the later phases. As such, alternative fuels are poised to have the most significant impact on reducing the EEDI.

ABS is exploring the decarbonization technologies available to vessel designers. Alternative fuels such as LNG, LPG, methanol, biofuel, ammonia, batteries, solar power, and wind power can reduce the carbon output of vessels. Specific to large bulkers and tankers, use of LNG and LPG through dual fuel systems can reduce CO_2 emissions to some extent and thus influence the vessel's EEDI.

Dual Fuel Engines

Dual fuel main engine propulsion can significantly improve a vessel's EEDI in view of the upcoming regulatory criteria. Based on use of gas (commonly LNG) and pilot (liquid) fuel, this technology solution is gaining ground with an increasing number of new vessels incorporating dual fuel engines into their design, propulsion system configuration and machinery space requirements.

A number of challenges however need to be addressed to render propulsion by use of dual fuel engines a viable solution for ocean-going vessels. These include the use of gas as a marine fuel, storage (i.e. the additional space and weight that the vessel design needs to allocate for gas fuel on board) taking into account class rules, statutory regulations and operational requirements. It should also be noted that reduction in GHG emissions through the use of LNG may be offset by for example methane slip in the engine.

The EEDI calculation methodology initially issued by IMO MEPC.245(66) allowed for the properties of gas fuel to be applied only for gas being the vessel's primary fuel, i.e. when the ratio of calorific value of gas fuel to total marine fuels onboard is equal to or larger than 50%. This condition was based solely on fuel tank capacity and did not discern vessels fitted with gas-fuel capable engines from those that are not.

The IMO introduced relevant amendments (IMO, 2016a) and revised the EEDI calculation methodology to grant a partial credit to owners who invest in dual fuel engines (ME and/or AEs) with gas as non-primary fuel due to reduced LNG fuel tank capacity.

Figure 8 is a graphic demonstration of the potential improvement to the EEDI of an example vessel case (81k DWT bulk carrier) considering different dual fuel main and auxiliary engine system configurations with LNG and MDO as gas and pilot fuel options, respectively.

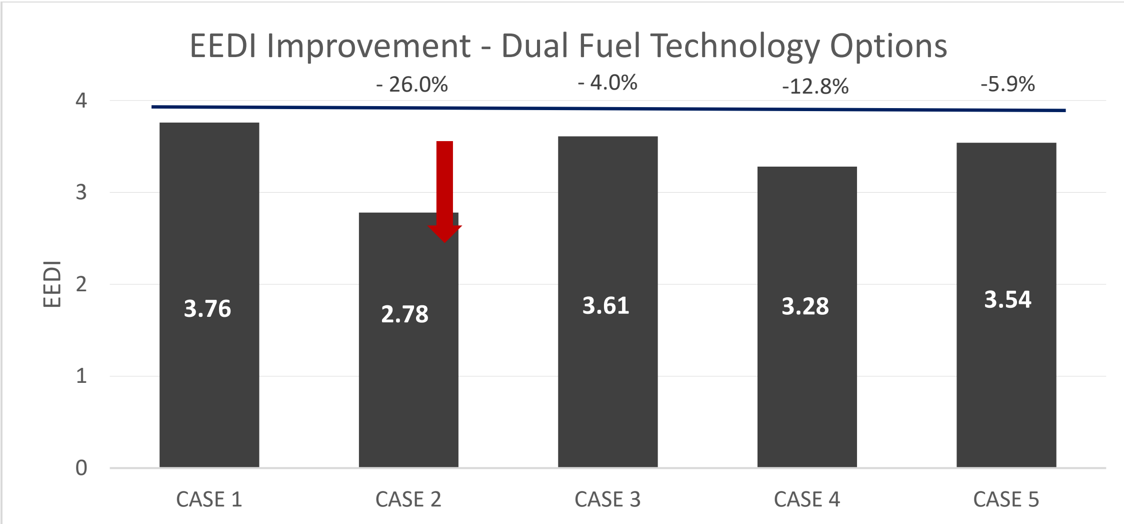


Figure 8: EEDI Improvement Potential for Bulkers and Tankers [Source: IMO MEPC 281(70)]

- Case-1 One main engine (MDO), standard auxiliary engines, no shaft generator
- Case-2 Dual-fuel main engine and dual-fuel auxiliary engine, no shaft generator. LNG is primary fuel, the vessel is equipped with bigger LNG tanks
- Case-3 Dual-fuel main engine and dual-fuel auxiliary engine, no shaft generator. LNG is not the primary fuel, the vessel is equipped with smaller LNG tanks
- Case-4 One dual-fuel main engine and one main engine (MDO) with dual-fuel auxiliary engine, no shaft generator. LNG is the primary fuel
- Case 5 One dual-fuel main engine and one main engine (MDO) with dual-fuel auxiliary engine, no shaft generator. LNG is not the primary fuel

Vessels for which the Flag Administration has decided that gas (LNG) is the primary fuel based on intended voyage, are subject to the limitations on fuel usage that this decision entails.

Use of Alternative Fuels

Several studies have been submitted to the IMO MEPC on the use of alternative fuels and its effect on a vessel's EEDI. A switch to LNG (or other alternative fuels such as LPG, methanol) has been examined by some IMO member states as one of the possible measures to achieve compliance with EEDI Phase 3.

Even though natural gas is an abundant energy source, with huge deposits confirmed all around the world, its availability as bunkering fuel, especially in the immediate future, appears to be one of the hurdles to overcome. Bulk carriers, in particular those that often trade in remote global locations, require high endurance given that most of these trading areas lack the supporting bunkering infrastructure. When compared to conventional fuel oil, LNG has a lower volume density (lower energy per volume unit), which creates a need for increased storage space of specialized configuration (SOME, 2018).

ABS has supported a milestone joint industry initiative and issued approval in principle (AIP) to an 82k Kamsarmax bulk carrier design powered by liquefied natural gas (LNG). The vessel was designed with adequate LNG tank volume to cover a long range operating profile without compromise of the intended cargo carrying capacity, and with high propulsion efficiency. The design is compliant with EEDI Phase 3, IMO regulations for sulphur oxide (SOx) post-2020, and nitrogen oxide (NOx) Tier III standards.

CONCLUSION

The world fleet will face compliance challenges as the IMO takes the path to meet ambitious GHG reduction targets set for 2050. EEDI Phase 2 and Phase 3 limits should encourage the uptake of innovative technology, which have had limited implementation by the industry until now. The minimum propulsion power criteria need to be finalized by the IMO to address compliance difficulties; this is especially relevant for large bulk carriers and tankers.

Various measures to assist in achieving EEDI compliance have been examined in this paper, considering extensive industry research and studies so far. The technical background and properly quantified efficiency metrics associated with energy saving technologies are not always available. A summary overview of potential solutions has been outlined - some already tried and evaluated, others currently proposed but under debate at the IMO or at a nascent stage.

ABS SUPPORT

ABS' thorough knowledge of international regulations coupled with industry recognized leadership on sustainability can assist ship owners, builders and designers to address compliance requirements while examining different technology alternatives. Comprehensive project assessments can include sensitivity studies to support the client's investment strategy and decision making process.

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