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PREVENTION OF AIR POLLUTION FROM SHIPS

Analysis on the appropriate values of the reduction rates of the required EEDI

Submitted by Japan

SUMMARY

Executive summary:	Japan, Norway and the United States proposed a draft text for making the EEDI mandatory under MARPOL Annex VI in document MEPC 60/4/35, which includes the concept on how to establish the reduction rates of the required EEDI. In this document, Japan explains the analytical methods of setting the values of reduction rates of the required EEDI, based on extensive case studies on the envisaged efficiency improvement for new ships
Strategic direction:	7.3
High-level action:	7.3.1
Planned Output:	7.3.1.3
Action to be taken:	Paragraph 19
Related documents:	MEPC 60/4/35 and MEPC 60/4/7

Introduction

1 The general ideas on making the EEDI mandatory are explained in document MEPC 60/4/35, and this document should be read together with MEPC 60/4/35. For new ships of a certain tonnage and above, the following should be satisfied:

Attained EEDI $\leqq$ Required EEDI = (1-X/100)* Baseline

where:

The attained EEDI is to be calculated in accordance with the interim Guidelines on the method of calculation of the Energy Efficiency Design Index for new ships ("the Calculation Guidelines", hereafter);

The EEDI baseline is to be determined by the Organization for each ship type category as contained in the Calculation Guidelines, through statistical analysis using data from the Lloyds-Fairplay database, following the methodology given in the “Guidance of Developing the Baselines”, of which a draft is proposed in document MEPC 60/4/7 (Denmark and Japan).

2 The EEDI reduction rate X would be determined according to the year when ships are constructed.

Phase 1: For ships of which contract is signed from [1 January 2013 to 31 December 2017]

X= aa %;

Phase 2: For ships of which contract is signed from [1 January 2018 to 31 December 2022]

X= bb %; and

Phase 3: For ships of which contract is signed from [1 January 2023 to 31 December 2027]

X= cc %.

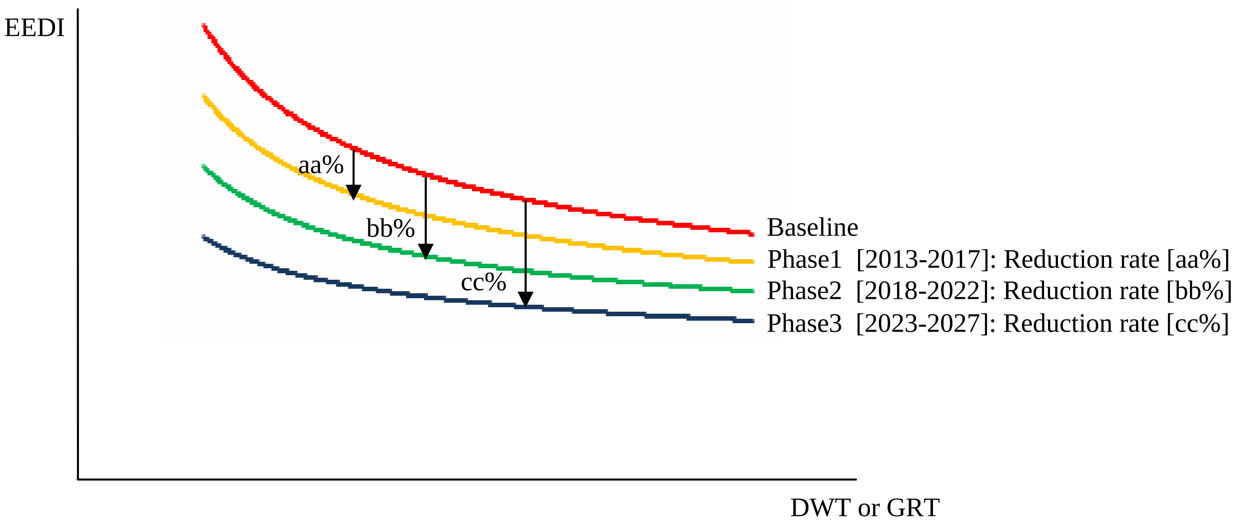


Figure 1: Phased approach to set the EEDI requirements

Simply put, there are three approaches to improve the EEDI value: (a) DWT Enlargement, (b) Speed Reduction, and (c) Application of New Technologies.

3 Figure 2 illustrates the relationship between the EEDI and improvement measures. The effect of (a) size increase is to move the EEDI in parallel with the baseline; thus, it does not contribute to the downward shift of the lines. The effect of (b) speed reduction does contribute to the downward shift, however, it should be recalled that the required EEDI value for a new ship is a “minimum” requirement for every new ship. No matter what special circumstances (route-specific) ships are obliged to operate under, they would have to satisfy this minimum requirement. In view of the above, Japan considers that speed reduction should be kept aside as an option or used as a margin for shipowners to meet the required EEDI value. In conclusion, reduction rates should be determined by the effects of (c) application of new technologies only. Extensive case studies would be necessary to find out which technologies could be applied to a representative ship type to be built in a certain year.

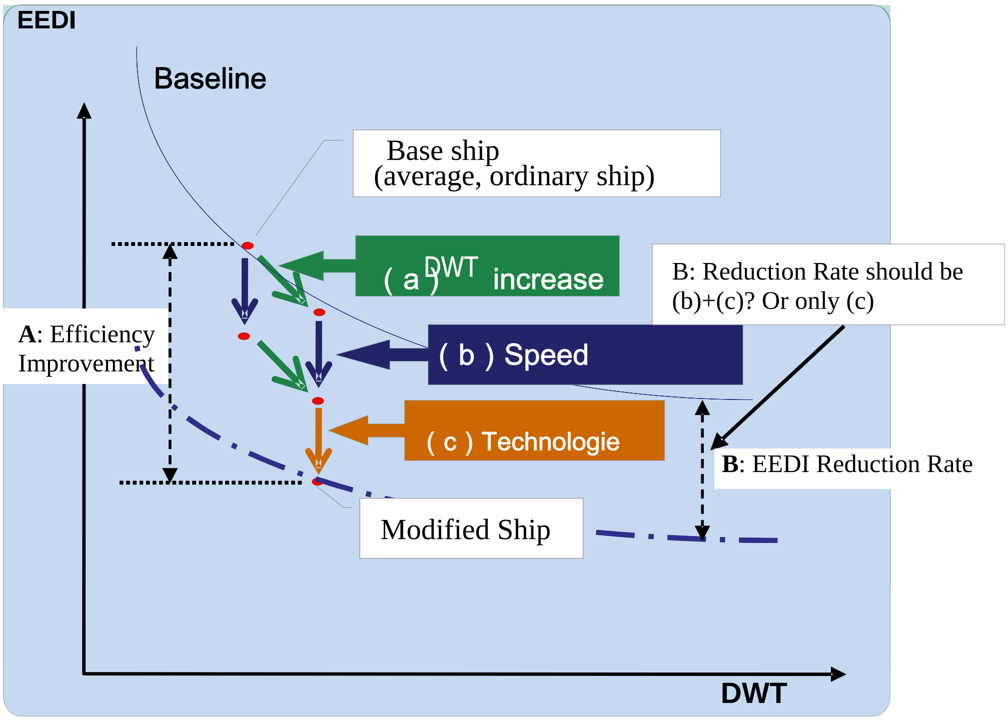


Figure 2: Improvement measures for EEDI

Case studies for estimation of EEDI improvement potential

4 There are a lot of technical measures for energy efficiency improvement, such as optimization of a hull and a propeller, optimization of the superstructure, recovery of propeller energy, after-body-flow-control system and engine waste heat recovery. Japan conducted case studies to estimate the degree of efficiency improvement which examined different components of resistance and propulsion, and various new technologies, based on six components as contained in annex 2. This does not exclude the possibility of using other technologies. In the case studies, only these new technologies whose development prospects (installation costs, technological maturity and availability) are relatively clear are considered. In other words, innovative technologies, such as fuel cells, are not considered because it is difficult to estimate the costs and the time when such technologies can be applied to ships.

		Base Ship	Modified Ship	
Speed		14.0 kt	14.0 kt	No change
DWT		50,000 t	50,000 kt	No change
Technologies	A		Applied	
	B		Applied	
	C		Not applied	
	D		Applied	
Estimated Fuel Consumption (its proportional change is equal to that of EEDI)			15% improvement over Base Ship	

Table 1: Concept of the case studies on the application of technologies and the efficiency improvement as an outcome

5 It should be noted that some technologies should not be used together. A particular technology "A" and another technology "B" may not be effective if applied together, as the supposed effects of "A" may be diminished by the effects of "B". Such incompatibility of technologies should also be taken into account in choosing the package of new technologies.

6 In addition, the installation costs of new technologies have been considered to confirm the economical feasibility of applying such technologies. The packages of new technologies in annex 2 were selected so that the total installation costs did not exceed the fuel cost reduction (present value of the saved fuel costs for eight years).

7 The case studies covered eight ship types: dry cargo carrier, gas tanker, tanker, containership, ro-ro cargo ship vehicle carrier and general cargo ship, as defined in the Calculation Guidelines. Several "base ships" of different sizes, which were considered to be "average" or "representative" in each respective ship type categories, were selected.

8 Information on the new technologies used in the studies – i.e. improvement rate, saturation year and installation costs, and total improvement rate by application of the new technologies – are based on numerical simulation by National Maritime Research Institute (NMRI) of Japan, as well as other information from NMRI and shipbuilders.

Results of case studies

9 Annex 2 indicates the results of the case studies for representative ship types on how significant EEDI improvements could be achieved by applying a combination of relevant technologies. The "*Summary Table of Case Study on EEDI improvement*" on the first page of annex 2 shows that the potential EEDI improvement rates were different from each type of ship, because of different applicability of technologies depending on ship types. Even in the same ship category, the EEDI improvement was limited for smaller size ships since their main engine powers were not large enough to make waste heat recovery systems effective.

How to derive the proposed reduction rates from the results of the case studies

10 The proposed EEDI reduction rates shown in annex 1 have been derived from "potential" EEDI improvement rates obtained by the case studies contained in annex 2. The thoughts behind this process are described below.

Phase 1: For ships of which contract is signed from [1 January 2013] to [31 December 2017]

11 Phase 1 is the nearest future for the EEDI requirement, thus giving the shortest preparation period for the industry. Since this is the first ever requirement on energy efficiency of ships, the simplicity and the easiness of understanding would have higher priority, for the purpose of smooth implementation, than setting ambitious requirement levels. Therefore, the proposed reduction rates for phase 1 are relatively conservative, in the sense that they are set in line with the improvement potential of smaller-sized vessels, which is lower than that of larger vessels.

Phase 2: For ships of which contract is signed from [1 January 2018] to [31 December 2022]

Phase 3: For ships of which contract is signed from [1 January 2023] to [31 December 2027]

12 The proposed reduction rates in phases 2 and 3 can be more progressive than those in phase 1, and should be set, as a basic principle, to be in line with those potential EEDI improvement rates for larger vessels taking into account the necessity for CO_2 emissions reduction from large-sized ships which are the prime target. For example, in the case of a dry cargo carrier, the reduction rate for this category is proposed to be set at 25%, in line with the potential EEDI improvement rates for vessels above 50,000 DWT, which are about 25%.

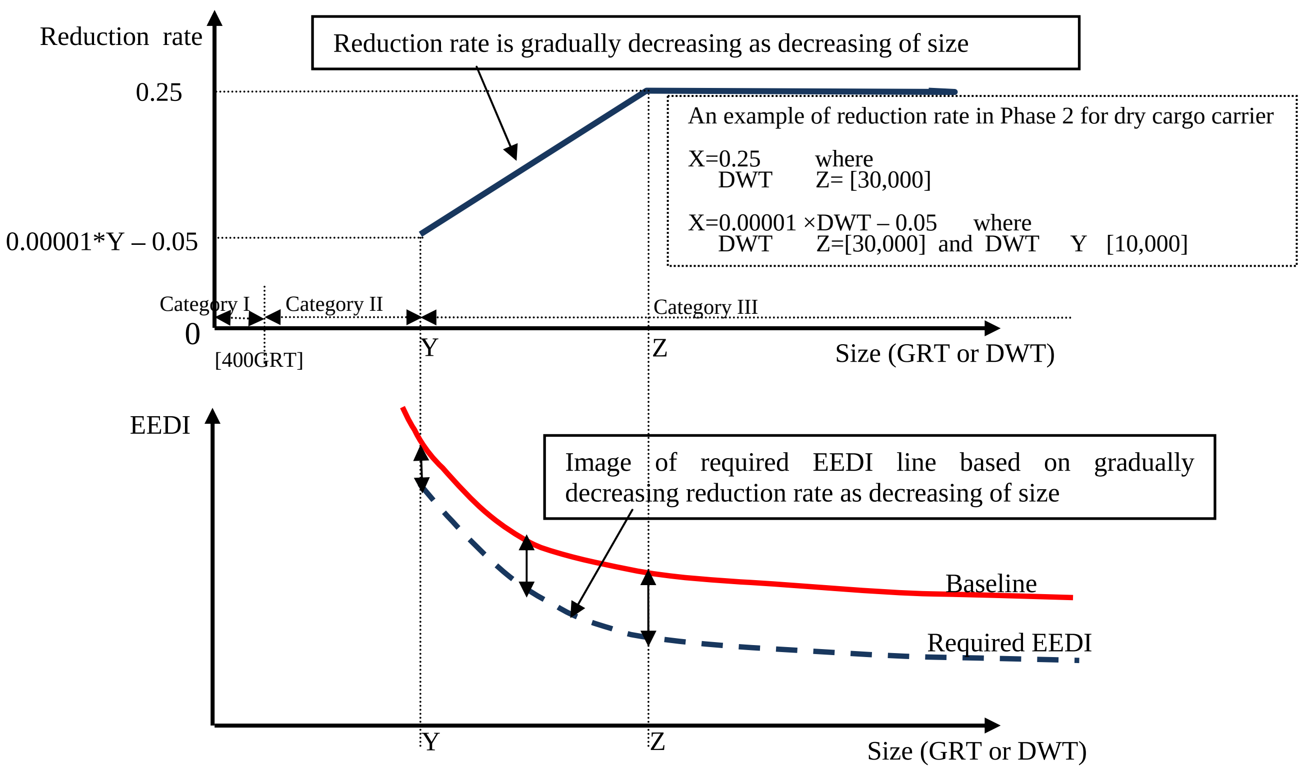
13 There would be sufficient lead time for considerably changing the ship design, and it is considered appropriate to make the review of the reduction rates in phase 2 and later requirements “built-in” in the Convention so that the technology development can be monitored and duly reflected in the requirement level in the next phase (see also document MEPC 60/4/35).

Need of further consideration for small ships

14 It is clear that the EEDI improvement potential is limited for smaller vessels, and this point should be carefully considered in setting the reduction rates. As mentioned above, the proposed reduction rates for phase 1 are in line with the EEDI improvement potential for smaller vessels, thus smaller vessel problems are already considered. However, this is not the case for phases 2 and 3. For example, annex 2 shows that the EEDI improvement rate for a 20,000 DWT dry cargo carrier is estimated at 17%, while a dry cargo carrier of 50,000 DWT and above can improve its EEDI by 25% in phase 2, and the proposed reduction rates are based on the improvement potential of those vessels of 50,000 DWT and over (25%).

15 A possible solution for this size challenge above would be to gradually decrease the reduction rate as the ship size goes smaller. An illustration for this way of setting the reduction rate is given below in Figure 3. “Z” means the tonnage or DWT threshold from which the reduction rate is to be fixed regardless of size.

16 Japan is of the opinion that this issue should be further considered at later sessions of the Committee.



Category I*	Very small vessels of less than [400] GT, for which both the calculation of the attained EEDI and the comparison of the attained EEDI to the required EEDI is not necessary
Category II**	Vessels which are [400] GT and above, but less than a certain tonnage or DWT threshold [Y], for which the calculation of the attained EEDI is required but the comparison of the attained EEDI to the required EEDI is not necessary
Category III	Vessels which are above a certain tonnage threshold [….], but below another tonnage or DWT threshold [….], for both the calculation of the attained EEDI and the comparison of the attained EEDI to the required EEDI is required, but which reduction rate is gradually decreasing

* The above categorization was proposed by Japan at GHG-WG 2 (GHG-WG 2/2/16), and the GHG-WG in principle agreed to the concept, except that the originally proposed upper threshold for Category II (10,000 GT) was replaced with "[Y]" GT:
GHG-WG 2 avoided putting any figures for such threshold for future consideration (paragraph 2.8 of MEPC 59/4/2).

Figure 3: An example of reduction rate in phase 2 for dry cargo carrier

Other issues to be considered in the context of the EEDI requirements

17 There are many points that necessitate thorough consideration in order to implement the EEDI requirements appropriately. For example, it has been pointed out in the previous sessions of MEPC that future safety and environment regulations may worsen the EEDI values of new ships; therefore, those ships, by the reasons of abiding by the newly introduced regulations, may have difficulties in satisfying the required EEDI. It was argued that this possible situation should be taken into account in setting the level of mandatory standards, namely the reduction rates of the required EEDI.

18 Further analyses on such issues to be considered for the design and implementation of the EEDI requirements are set out in annex 3 to this document.

Action requested of the Committee

19 The Committee is invited to consider the above proposal and take action as appropriate.

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ANNEX 1

PROPOSED REDUCTION RATES FOR REQUIRED EEDI

Year of Contract	2013-2017	2018-2022	2023-2027
Ship type	Phase 1	Phase 2	Phase 3
Passenger ship*			
Dry cargo carrier	10%	25%	35%
Gas tanker (Excluding steam turbine ship)	10%	25%	35%
Tanker	10%	25%	35%
Container	10%	15%	30%
Ro-Ro cargo ship (Vehicle carrier)	10%	15%	30%
Ro-Ro cargo ship (Volume and Weight carrier)*			
General cargo ship	10%	15%	35%
Ro-Ro passenger ship*			

* For passenger ship, ro-ro cargo ship (Volume and Weight carrier) and ro-ro passenger ship, the reduction rates are not proposed in this document, because there are no sufficient data to conduct the case studies of EEDI improvement. Furthermore, there is wide variation in design in these ship categories, making it difficult to choose “base case” ship, that should be “average” and “representative” in each category, on which the EEDI improvement case studies should be carried out.

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ANNEX 2

SUMMARY TABLE OF CASE STUDY ON EEDI IMPROVEMENT

Summary Table of Case Study on EEDI improvement

	Year of Contract	2013-2017	2018-2022	2023-2027
Ship type	Size	Phase 1	Phase 2	Phase 3
Dry cargo carrier	20,000 DWT	9.9%	17.2%	25.3%
	52,000 DWT	14.5%	25.7%	36.9%
	77,000 DWT	14.5%	25.5%	36.4%
	175,000 DWT	14.5%	26.1%	37.7%
Gas tanker (Excluding steam turbine ship)	9,000 DWT	9.9%	16.7%	24.3%
	45,000 DWT	14.5%	25.0%	35.8%
Tanker	45,000 DWT	14.5%	25.4%	36.4%
	84,000 DWT	14.5%	25.9%	37.3%
	300,000 DWT	14.5%	26.1%	37.7%
Container	12,000 DWT	13.4%	17.1%	29.2%
	39,000 DWT	13.4%	17.2%	29.2%
	91,000 DWT	13.4%	17.3%	29.3%
Ro-ro cargo ship (Vehicle carrier)	7,000 DWT	13.2%	17.0%	28.8%
	18,000 DWT	13.5%	17.4%	29.2%
General cargo ship	9,000 DWT	9.9%	17.0%	24.9%
	13,000 DWT	9.9%	16.6%	35.4%

* Tendency of the EEDI improvements are different between container ship, ro-ro cargo ship (Vehicle carrier) and other fat ship types, because applicable package of technologies is different by ship type.

* The reduction rates at phase 2 of general cargo ship are lower than other fat ships, because waste heat recovery is not applied.

* The EEDI Calculation Guidelines (MEPC.1/Circ.681) indicates that EEDI of containerships is calculated at the 65% DWT. The EEDI improvements of containership mentioned above are based on 100% DWT, because the speed at 65% DWT can not be calculated.

Dry cargo carrier (20,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1 (Year of Contract 2013-2017)	Phase 2 (2018-2022)	Phase 3 (2023-2027)	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use with CRP.
Waste heat recovery		-	-				Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	9.9%	17.2%	25.3%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	44,229	39,867	36,632	33,047	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	1.59	2.78	4.09	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).
* New technologies indicated above are examples of possible combination of new technologies.
* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.
* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).
* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.
* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Dry cargo carrier (52,000 DWT)			Year of Contract	2013-2017	2018-2022	2023-2027	
Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1	Phase 2	Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	25.7%	36.9%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	76,442	65,343	56,785	48,197	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	4.06	7.18	10.32	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).
* New technologies indicated above are examples of possible combination of new technologies.
* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.
* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).
* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.
* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Dry cargo carrier (77,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Year of Contract Expected year the improvement reaches the maximum	2013-2017 Phase 1	2018-2022 Phase 2	2023-2027 Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	25.5%	36.4%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	95,127	81,315	70,853	60,521	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	5.05	8.87	12.65	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Dry cargo carrier (175,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1 (Year of Contract 2013-2017)	Phase 2 (2018-2022)	Phase 3 (2023-2027)	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	26.1%	37.7%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	147,027	125,679	108,612	91,590	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	7.80	14.04	20.26	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).
* New technologies indicated above are examples of possible combination of new technologies.
* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.
* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).
* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.
* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Gas Tanker (9,000 DWT)

			Year of Contract	2013-2017	2018-2022	2023-2027	
Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1	Phase 2	Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-				Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	9.9%	16.7%	24.3%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	43,779	39,461	36,489	33,144	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	1.58	2.66	3.89	These are estimated by following assumptions. Bunker price: 400($/t)　Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Gas Tanker (45,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1 (2013-2017)	Phase 2 (2018-2022)	Phase 3 (2023-2027)	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	25.0%	35.8%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	130,291	111,374	97,654	83,666	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	6.91	11.93	17.04	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Tanker (45,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1 (Year of Contract 2013-2017)	Phase 2 (Year of Contract 2018-2022)	Phase 3 (Year of Contract 2023-2027)	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	25.4%	36.4%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	76,329	65,246	56,921	48,516	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	4.05	7.09	10.17	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Tanker (84,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Year of Contract / Expected year the improvement reaches the maximum	2013-2017 Phase 1	2018-2022 Phase 2	2023-2027 Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	25.9%	37.3%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	114,036	97,479	84,497	71,533	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	6.05	10.80	15.54	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).
* New technologies indicated above are examples of possible combination of new technologies.
* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.
* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).
* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.
* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Tanker (300,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Year of Contract / Expected year the improvement reaches the maximum	2013-2017 Phase 1	2018-2022 Phase 2	2023-2027 Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	14.5%	26.1%	37.7%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	247,921	211,924	183,238	154,557	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	13.16	23.64	34.13	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Container (12,000 DWT)

			Year of Contract	2013-2017	2018-2022	2023-2027	
Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1	Phase 2	Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape	10	2009	○	○	○	Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct						Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013	○	○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct						
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system						Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	13.4%	17.1%	29.2%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	70,480	61,046	58,403	49,924	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$ ）	-	3.45	4.41	7.51	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Container (39,000,DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Year of Contract / Expected year the improvement reaches the maximum	2013-2017 Phase 1	2018-2022 Phase 2	2023-2027 Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape	10	2009	○	○	○	Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct						Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013	○	○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct						
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system						Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	13.4%	17.2%	29.2%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	233,235	201,997	193,017	165,048	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	11.42	14.70	24.92	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Container (91,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1 (Year of Contract 2013-2017)	Phase 2 (2018-2022)	Phase 3 (2023-2027)	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape	10	2009	○	○	○	Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct						Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013	○	○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct						
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system						Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	13.4%	17.3%	29.3%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	510,202	441,704	422,056	360,708	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years (M$)	-	25.04	32.22	54.64	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Ro-ro vehicle (7,000 DWT)

			Year of Contract	2013-2017	2018-2022	2023-2027	
Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1	Phase 2	Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape	10	2009	○	○	○	Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct						Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013	○	○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct						
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system						Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	13.2%	17.0%	28.8%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	68,255	59,215	56,664	48,625	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	3.30	4.24	7.18	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

Ro-ro vehicle (18,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Expected year the improvement reaches the maximum	Phase 1 (2013-2017)	Phase 2 (2018-2022)	Phase 3 (2023-2027)	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape	10	2009	○	○	○	Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct						Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013	○	○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct						
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system						Post-swirl system can not use CRP.
Waste heat recovery		-	-	○	○	○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	13.5%	17.4%	29.2%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	125,817	108,804	103,929	89,018	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$）	-	6.22	8.00	13.45	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

General Cargo (9,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Year of Contract / Expected year the improvement reaches the maximum	2013-2017 Phase 1	2018-2022 Phase 2	2023-2027 Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-				Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	9.9%	17.0%	24.9%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	34,249	30,871	28,435	25,721	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years (M$)	-	1.23	2.13	3.12	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).
* New technologies indicated above are examples of possible combination of new technologies.
* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.
* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).
* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.
* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

General Cargo (13,000 DWT)

Component of resistance and propulsion	New technologies	Improvement effect of each technology(%)	Year of Contract / Expected year the improvement reaches the maximum	2013-2017 / Phase 1	2018-2022 / Phase 2	2023-2027 / Phase 3	Note
Reduction of air and wind resistance	Optimization of superstructure	30	2019			○	In the case of transition to electric population system which will be able to transfer engine room to bow-side, streamlining superstructure will be adopted.
Reduction of wave making resistance by shape of stern	Optimization of stern shape						Optimization of stern shape mainly has effect in ocean waves.
Reduction of friction resistance	Low friction coating	5	2012	○			Low friction coating can not be used with air lubrication method.
	Air lubrication method	10	2020		○	○	Effectiveness of air lubrication method further improves by adopting sprit stern together.
	Stern duct	2	2013	○	○	○	Stern duct has effect on reduction of friction pressure resistance.
	Stern fin						Stern fin can not be used with stern duct.
Improvement of propeller efficiency	CRP	8	2013		○	○	CRP can not be used with Post-swirl system.
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	4	2024			○	Sprit stern has effect on improvement of propeller efficiency caused by mitigation of propeller loading, and is suitable to beamy ship.
	Hybrid pod						Hybrid pod has effect on improvement of propeller efficiency compared to multishaft ship.
Improvement of propulsion efficiency by shape of stern	Stern duct	4	2013	○	○	○	
	Pre-swirl fin						Pre-swirl fin can not be used with stern duct.
	Sprit stern	-	-			○	
	Post-swirl system	4	2013	○			Post-swirl system can not use CRP.
Waste heat recovery		-	-			○	Phase 1 : 5% (T/G), Phase 2 : 10% (+ Power Turbine), Phase 3 : 15% (+ Low boiling point medium, etc.)

	Present	Phase 1	Phase 2	Phase 3	
Improvement rate of FOCME (%)	-	9.9%	16.6%	35.4%	The source of improvement rate of Fuel Oil Consumption of Main engine (FOCME) is based on simulation by National Maritime Research Institute (NMRI) and information on new technology from shipbuilders.
FOCME(t) for 8 years	46,681	42,077	38,929	30,159	FOCME for 8 years is estimated by following formula. NOR (90%MCR) *SFCME*Days at sea * 8 years Days at sea is based on IMO GHG Study.
Present Value of fuel cost reduction for 8 years （M$ ）	-	1.68	2.83	6.04	These are estimated by following assumptions. Bunker price: 400($/t) Interest rate: 2.0(%)

* The scenario assumes that new technologies will be adopted taking into account the estimated cost and the time when its technological development becomes mature (i.e. the effect on fuel consumption reached the maximum).

* New technologies indicated above are examples of possible combination of new technologies.

* "Improvement effect of components (%)" are estimated effectiveness for improvement of each "Component of resistance and propulsion" at actual sea, and are just for reference.

* The package of new technologies is selected so that the total installation costs do not exceed the fuel cost reduction (present value for 8 years). The cost of each new technology is estimated by cost per power ($/kwh).

* Effectiveness of air lubrication method is estimated as reduction rate of friction resistance, 5% at phase 2, and 10% at phase 3 by adopting sprit stern together.

* Waste heat recovery is adopted in case its initial cost is lower than fuel cost reduction (Present Value for 8 years).

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ANNEX 3

OTHER ISSUES TO BE CONSIDERED

Effects of the future safety and environment regulations on the design and implementation of EEDI requirements

GHG-WG2, as mentioned in paragraph 2.44.4 of document MEPC59/4/2, exchanged views on the issues and it was highlighted that the impacts of new IMO safety and environmental regulations may be taken into account when applying the EEDI to different ship types and sizes.

Among lots of new regulations which are envisaged to take effect, there are several sets of regulations, such as the Ballast Water Management Convention and revised MARPOL Annex VI (Tier II and Tier III of the NO_x emission requirements), which allegedly would have major impacts on the attained EEDI values in negative manner; it has been argued that such regulations would lead to technical constraints in ship design and construction such as deadweight decrease by taking up more machinery space or increase of steel weight, as well as the deterioration of SFC (Specific Fuel Consumption) of main and auxiliary engines. However, no concrete analysis has been provided, and the real impact of those sets of regulations on the attained EEDI values is thus unknown.

It is a general perception that, while Tier II of the NO_x emission requirements (20% reduction from the present regulations) can be coped with by the engine itself and thus may worsen EEDI of each ship by only a few per cent (marginal deterioration of SFC), Tier III (80% reduction) may have larger effects.

Below is an analysis on whether the Tier III would have significant impacts on the EEDI and thus the reduction rates of the required EEDI that have been proposed in the main part of this document would have to be modified by this reason.

Firstly, here is a brief review of the Tier III requirements. MEPC 59 adopted, by resolution MEPC.176(58), the revised MARPOL Annex VI and by resolution MEPC.177(58), revised Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NO_x Technical Code 2008). By paragraph 5.1 of a regulation 13 in the revised MARPOL Annex VI, the marine diesel engine which is installed on a ship constructed on or after 1 January 2016 is prohibited, as NO_x emissions reduction of Tier III, except when the ship is operating outside of an Emission Control Area (hereafter, "ECA") designated under paragraph 6 of that regulation, and when the emission of NO_x from engine is within the following limits, where n=rated engine speed (crankshaft revolutions per minute):

.1 3.4 g/kWh when n is less than 130 rpm;

.2 9*n(-0.2) g/kWh when n is 130 rpm or more but less than 2,000 rpm; and

.3 2.0 g/kWh when n is 2,000 rpm or more.

The above emission limits mean 80% NO_x emissions reduction compared to Tier I (ship constructed on or after 1 January 2000 and prior to 1 January 2011). The use of NOx reducing devices is envisaged in the NO_x Technical Code 2008, and a Selective Catalytic Reduction (SCR) System would be the most prospective one among such devices. It is assumed that energy efficiency improvement by the waste heat recovery is reduced by operation of the SCR, because waste heat passes through the catalytic substance of the SCR.

As shown in annex 2 of this document, the waste heat recovery is highly effective technology for energy efficiency improvement. If its effectiveness is considerably lost throughout the voyage due to the installation and operation of SCR, the EEDI requirements would have to be alleviated (i.e. lower reduction rates) because of the limitation of available technologies.

However, it should be noted that the operation of SCR (application of Tier III emission limits) would be necessary only within ECA. Overwhelming share of the voyage takes place outside ECA, where the SCR is not in operation. The question is whether the machinery system is arranged in a way that the efficiency improvement potential of waste heat recovery is fully utilized. Figure 1 is a machinery arrangement with an SCR; there are two independent exhaust lines so that exhaust gas goes through SCR inside ECA, and the line bypassing the SCR is to be used outside ECA. A machinery arrangement like this has being developed by the Japan Marine Equipment Association (JSMEA), the Japan Ship Technology Research Association (JSTRA), and some shipbuilders in Japan. This means that the waste heat recovery system could work in full potential, being unaffected by SCR outside the ECA. The reduction rates of the required EEDI analysed and proposed in this document would not be affected as far as ships use machinery arrangement such as Figure 1 and the EEDI calculation is based on the "normal sea-going" outside ECA.

It is impossible to foresee what portion of CO_2 is emitted from the ships operating within ECA and outside ECA, because the only NO_x-ECA in the pipeline (i.e. its implementation is envisaged) is US-Canada coastal areas and no other NO_x-ECA has been proposed yet. It should be noted that, in the calculation of the EEDI, lots of assumptions on "hypothetical situation" of ship have been made: e.g., ships are at full displacement, auxiliary power for cargoes are excluded, but auxiliary power for running main engines and accommodation ("normal maximum seaload") are included. These sets of assumptions do not necessarily represent all of different situations and conditions in which ships are operating, but these assumptions are necessary to compare the energy efficiency potential of different ships.

By the same token, it is quite natural and appropriate to set another assumption that the EEDI is to be calculated in the condition that ships are navigating outside ECA. With this assumption to be explicitly included in the EEDI requirements, possibly in accompanying guidelines, Tier III emission limits would not have significant effects on the design and implementation of the EEDI requirements.

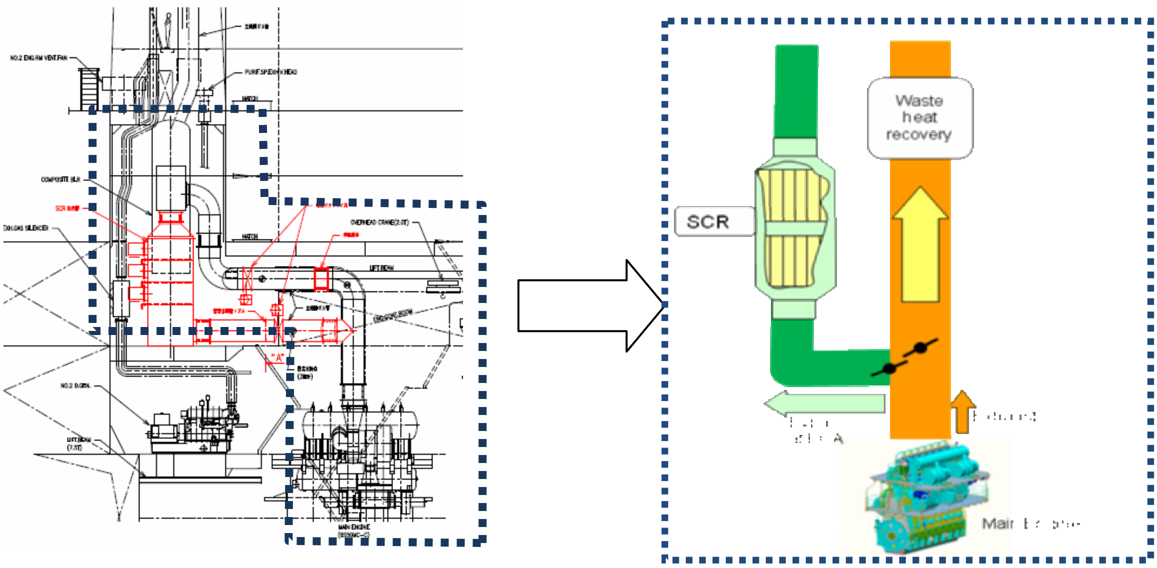

Figure 1: Example of an arrangement plan for installation of the SCR

Treatment of coefficient "f_w" under the mandatory requirement of EEDI

"f_w" is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions, and can be determined by conducting the ship-specific simulation of its performance at representative sea conditions, and its treatment is stipulated in paragraph 2.9.3 of the interim Guidelines on the method of calculation of the Energy Efficiency Design Index for new ships (MEPC.1/Circ.681)(the "EEDI Calculation Guidelines", hereafter), as follows:

"f_w should be taken as one (1.0) until the Guidelines for the ship-specific simulation (paragraph .9.1) or f_w table/curve (paragraph .9.2) become available."

The draft of f_w simulation guidelines, as well as the draft f_w standard, was first submitted by Japan at MEPC 58 (MEPC 58/4/27, MEPC 59/4/29). Japan subsequently submitted the progress report including the revised draft of the f_w simulation guidelines (GHG-WG 2/2/15).

Due to the urgency and importance for the MEPC of agreeing on the EEDI Calculation Guidelines, f_w simulation guidelines has not been considered. Since then, Japan, especially has been trying to obtain wider understanding on the methodologies of estimating the ship performance under actual sea conditions, as contained in (GHG-WG 2/2/15), in the academic community.

As indicated in MEPC 60/4/35, Japan is of the view that the priority for MEPC is to develop the mandatory EEDI requirements as expeditiously as possible; for this purpose, f_w should be treated as 1.0, while being retained in the EEDI formula, as far as the currently proposed mandatory EEDI requirements are concerned.

Despite such clarification of treating f_w coefficient, if there should be still some concerns in keeping the f_w coefficient in EEDI formula, a possible solution would be to clarify that the EEDI values with calculated f_w value (not equal to 1.0) by the simulation guidelines (to be agreed in the future) would be an optional indication on the international certificate relating to the EEDI. This means that such future certificate would include:

.1 mandatory indication of the EEDI (with f_w being 1.0) which shall be compared to and satisfy the required EEDI; and

.2 optional indication of the "$EEDI_{weather}$" (with calculated f_w value, not equal to 1.0), which will not be compared to the required EEDI, but is for reference to show the estimated ship performance under representative (not calm) sea conditions.

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