Cost Simulation Based on IMO's Mid-term GHG Reduction Measures

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1. INTRODUCTION

The international shipping sector is currently at a major turning point, facing the strengthening of greenhouse gas (GHG) emission reduction regulations led by the International Maritime Organization (IMO) and the European Union (EU). These regulations are not merely frameworks for achieving international environmental goals, but also elements that directly affect corporate strategies and the entire life cycle of ships. The choice of fuels, operational costs, and investment decisions for newbuilding or retrofitting are expected to be subject to the evolution of these regulatory frameworks. Under the IMO's proposed Mid-term measures currently under discussion, a progressive reduction in the GHG intensity of marine fuels will be required.

At the second extraordinary session of the Marine Environment Protection Committee (MEPC/ES.2) held in October 2025, discussions on the adoption of the Mid-term measures were postponed for one year due to differing views among the Member States. Although no agreement was reached, the overall direction toward maritime decarbonization as indicated by the IMO remains unchanged. This means that the industry will continue to be required to implement comprehensive GHG reduction measures, including fuel transition, under a global framework. Consequently, measures focusing solely on improving energy efficiency will no longer be sufficient to comply with future regulations. Medium- to long-term preparations, including the transition to alternative fuels, will be indispensable.

Against this background, it is increasingly important for the shipping industry to conduct economic assessments that comprehensively consider both fuel selection and regulatory compliance costs. Under this new framework, it will be essential to assess in advance the economic implications of fuel transition when formulating future strategies.

This paper utilizes ClassNK's cost simulation tool to analyze the potential impact of the IMO's Mid-term measures, with a particular focus on the cost implications arising from regulatory compliance, and outlines fundamental concepts for strategic assessment. It should be noted that the actual cost impact may vary significantly depending on future discussions at the IMO. The simulation results presented herein are based on assumptions established by ClassNK using information available at the time of publication, and are subject to change if underlying assumptions such as fuel prices, supply volumes, or GHG intensity are altered. Therefore, this paper should be regarded as an illustration of scenario analysis using ClassNK's simulation tool.

2. REGULATORY COST ASSESSMENT

The IMO's Mid-term measures are designed not only to encourage the transition to low- and zero-emission fuels, but also to account for the GHG emissions throughout the entire life cycle of fuels from fuel production to end use. Unlike previous regulations that focused only on emissions from combustion, the new framework aims to achieve actual emission reductions across the entire fuel supply chain, including production, transportation, storage, and use. In this context, the IMO's Mid-term measures represent a comprehensive regulatory approach to decarbonization across both ship operation and the broader energy value chain. Accordingly, to correctly understand the regulatory costs under the IMO's Mid-term measures, it is essential to grasp the concept of "Well-to-Wake (WtW)," which serves as the new evaluation framework. The specific assessment boundaries and calculation methods are described below.

(1) Concept of Well-to-Wake Emissions

The existing IMO regulations on CO2 emission reduction have primarily targeted direct emissions from onboard fuel combustion, that is, Tank-to-Wake (TtW) emissions. In contrast, under the IMO's Mid-term measures, GHG emissions are evaluated comprehensively across all stages of the fuel life cycle from production (Well) to combustion (Wake). Therefore, even if a fuel emits no GHG during combustion, it may still have high total emissions if fossil-based energy or raw materials are used in its production process. On the other hand, fuels such as e-fuels, which are produced using electricity derived from renewable energy and CO2 captured by direct air capture (DAC) can achieve a significant reduction in emissions across their entire life cycle. Thus, the production pathway of a fuel has a direct impact on the associated regulatory cost. This is one of the key characteristics of the IMO's Mid-term measures.

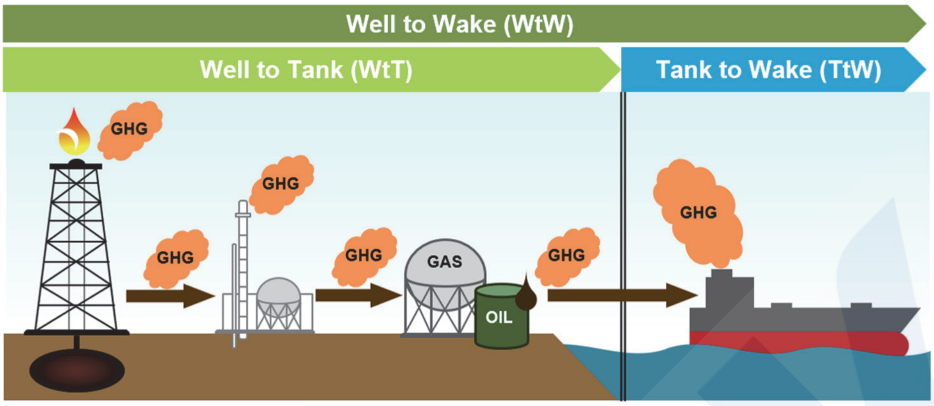

Fig. 1　Conceptual image of GHG emissions in the marine fuel life cycle

(2)　Calculation of GHG Intensity

A representative indicator of a fuel's environmental performance is its GHG intensity, defined as the amount of life-cycle GHG emissions per unit of energy. As illustrated in Fig. 2, the GHG intensity of a single fuel can be calculated based on its emission conversion factor and lower calorific value.

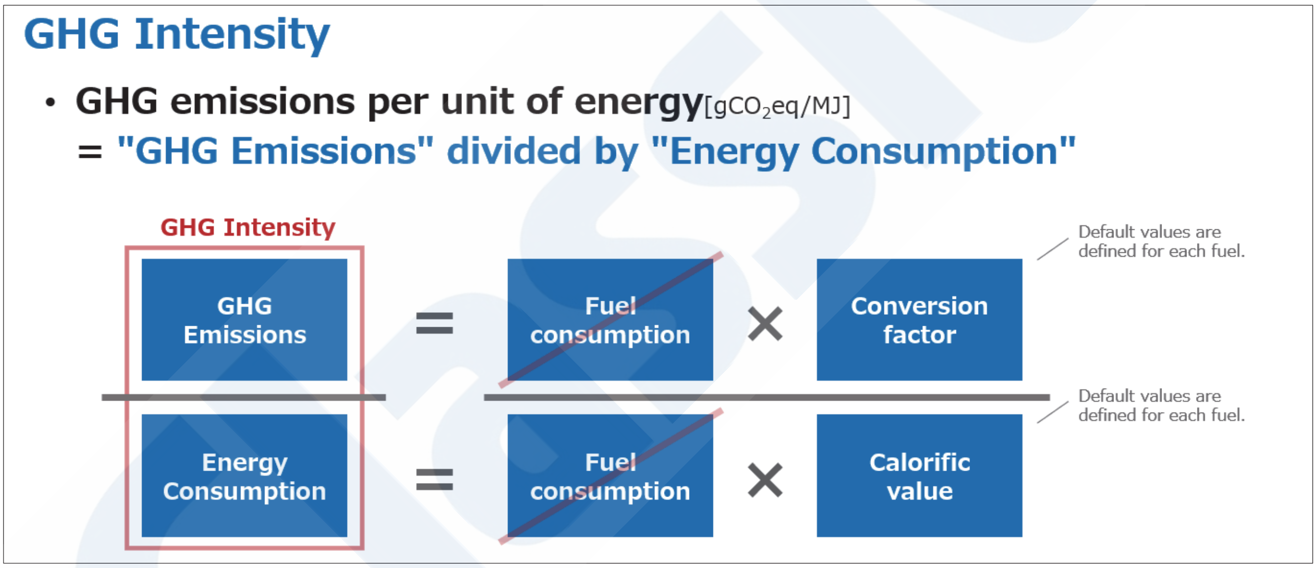

Fig. 2　Calculation of GHG intensity

However, since ships use multiple fuels in actual operation, rather than a single fuel, the average GHG intensity should be calculated as a weighted average based on the proportion of energy consumed from each fuel. For example, as shown in Fig. 3, if a ship uses equal amounts of energy derived from heavy fuel oil (HFO) and biodiesel (B100) with GHG intensities of 95.48 gCO2eq/MJ and 22.12 gCO2eq/MJ, respectively, the combined average GHG intensity is approximately 60.22 gCO2eq/MJ.

This means that even ships which mainly use conventional heavy fuel oils can reduce their overall GHG intensity below the regulatory target values by partially introducing low-carbon fuels such as B30, B100, or e-fuels. Partial introduction of low-carbon fuels offers flexibility in coping with uncertainties in fuel availability and price fluctuations, making it a practical mid-term transitional approach.

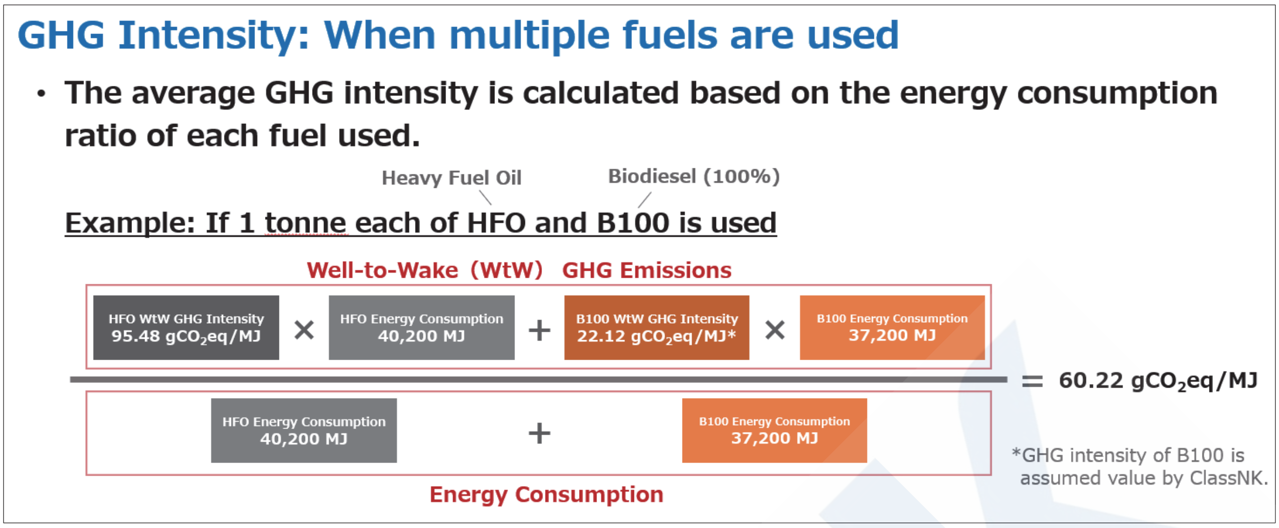

Fig. 3 Calculation of GHG intensity when multiple fuels are used

(3) GHG Intensity of Each Fuel

The LCA Guidelines developed by the IMO define a total of 128 fuel supply pathways, and default GHG intensity values can be calculated for each. However, at present, the default values for many fuels have not yet been finalized. For reference purposes, Fig. 4 provides approximate Well-to-Wake GHG intensity values for representative fuels. As shown in this figure, there are substantial differences in GHG intensity among various fuels. For example, the GHG intensity of low-sulfur heavy fuel oil (LSHFO) is approximately 95 gCO2eq/MJ, and decreases to about 77 gCO2eq/MJ for LNG (combustion system: diesel slow), 76 gCO2eq/MJ for biofuel B30, and 22 gCO2eq/MJ for B100. Synthetic fuels such as e-methanol and e-ammonia are expected to reach even lower levels of around 10 to 13 gCO2eq/MJ, while fossil-based grey methanol has a higher intensity of about 103 gCO2eq/MJ, exceeding that of heavy fuel oil. These results indicate that Well-to-Wake GHG intensity can vary significantly depending on the energy sources and feedstocks used in the production process, even for the same type of fuel.

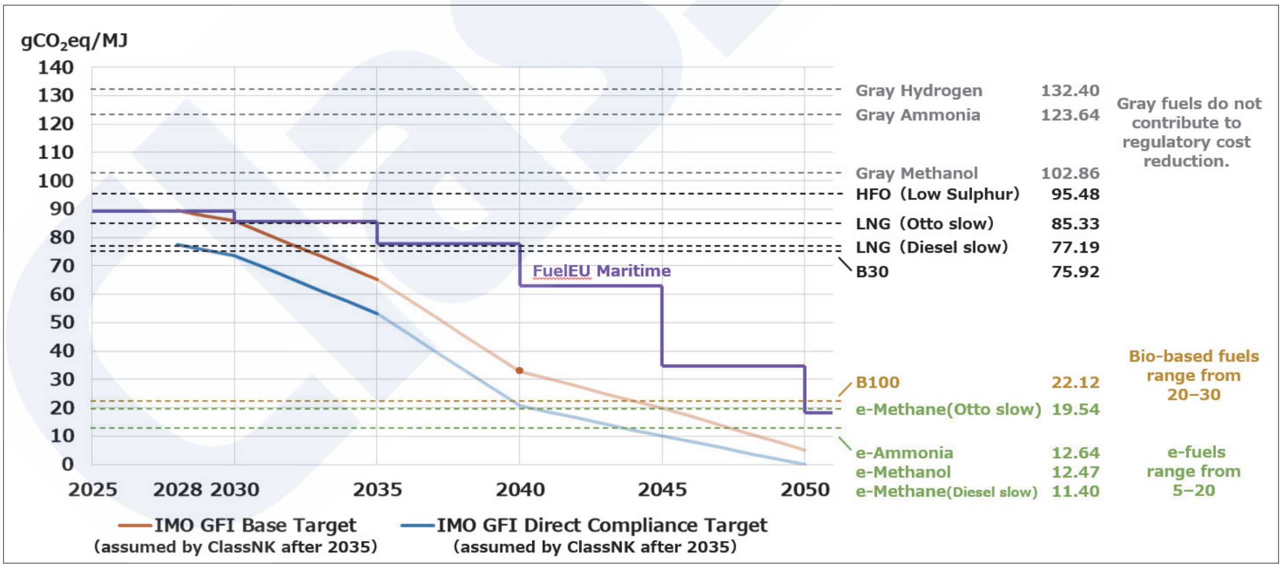

Fig. 4 Approximate Well-to-Wake GHG intensity and regulatory targets for various fuels

(4) Structure of Regulatory Costs and Optimization

Compliance with the regulations by paying contributions is also a key component of the IMO's Mid-term measures. Under this system, when a ship's actual GHG intensity exceeds the target, a contribution is paid in proportion to the excess amount. The amount of the contribution is calculated as shown in Fig. 5. For the period up to 2030, the proposed contributions are 100 USD/t-CO2eq for the excess above the Direct Compliance Target (Tier 1), and 380 USD/t-CO2eq for the excess above the Base Target (Tier 2).

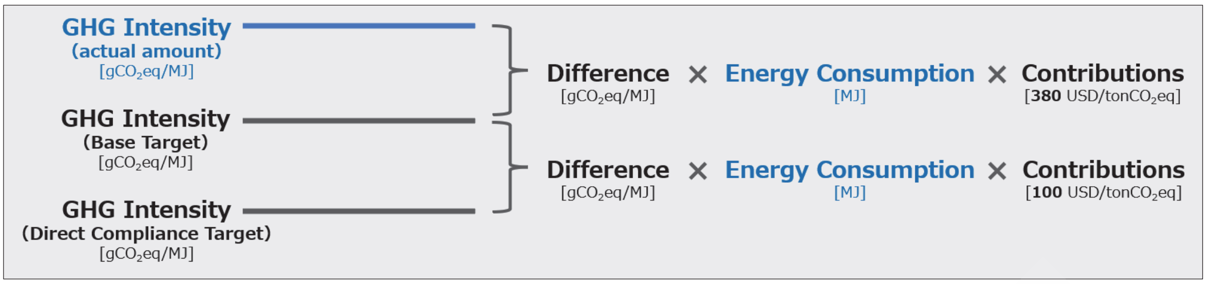

Fig. 5　Calculation method for contributions

Under this framework, there are two main elements by which the cost burden can be reduced through voluntary efforts:

(a)　Reduction of annual GHG intensity (use of low-carbon fuels)

(b)　Reduction of annual energy consumption (improvement of fuel efficiency)

Optimization of these factors will be the key to cost control and maintaining competitiveness in the coming years. While the introduction of low-carbon fuels is attracting attention as a primary compliance measure, the options actually available to ships remain limited. Therefore, in addition to fuel transition, improvements in operational efficiency and energy efficiency, that is, fuel efficiency improvement, will become an increasingly important element.

3.　COST IMPACT OF THE MID-TERM MEASURES

In order to estimate the potential cost impacts associated with the IMO's Mid-term measures, in this chapter, a representative 64,000 DWT bulk carrier was assumed as the model vessel, and a cost projection was made assuming continued use of conventional fuel over the coming decades. The underlying assumptions applied in this estimation, which are kept constant through 2050, are as follows.

- Annual fuel consumption: 5,000 tons of HFO
- Fuel price: 500 USD/ton
- Contribution unit price:
  - Tier 1 (Direct Compliance Target exceedance): 100 USD/ton-CO2eq
  - Tier 2 (Base Target exceedance): 380 USD/ton-CO2eq
- Assessment period: 2025-2050

As shown in Fig. 6, assuming that fuel prices remain constant, the annual cost in 2025 is estimated to be approximately USD 2.5 million. However, due to the progressive strengthening of the IMO's Mid-term measures, regulatory costs are expected to rise year by year, surpassing fuel costs in the early 2030s. In particular, the additional contributions associated with exceeding the Base Target (Tier 2) have a significant impact, with total costs projected to increase by +102 % in 2035 compared to 2025, +202 % in 2040, and ultimately +280 % by 2050. In other words, if ships continue to use heavy fuel oil, regulatory costs are expected to substantially increase overall operating expenses, and could fundamentally alter the existing fuel cost structure. This outcome indicates that the IMO's Mid-term measures will serve as a strong price signal to accelerate the transition to low carbon fuels. Without fuel transition, rising regulatory costs in proportion to GHG emissions will rapidly undermine the economic advantage of conventional fuels. In particular, in segments such as bulk carriers and tankers, where the combined amount of fuel expenses and contributions under the IMO's Mid-term measures accounts for the majority of operating costs, the impact on the profitability of shipowners and operators will be direct and significant. As a result, a comprehensive restructuring of cost management strategies, including the introduction of alternative fuels, improvement of fuel efficiency, and management of contributions and potential refunds, will be indispensable.

As shown in Fig. 7, regulatory costs tend to increase roughly in proportion to fuel consumption. According to the estimate for 2028, assuming continuing use of heavy fuel oil, ships with higher fuel consumption, such as large container ships and Very Large Ore Carriers (VLOCs), will face a significantly higher burden, exceeding USD 15 million per year in some cases. In contrast, for small- and medium-sized vessels with lower fuel consumption (for example, Handy size bulk carriers and small container ships), the absolute amount of regulatory cost remains relatively limited, but will still be non-negligible in terms of operating profitability.

These results indicate that although the impact of the IMO's Mid-term measures will vary depending on the ship type and size, improving fuel performance and operational efficiency is a common challenge for all vessels. In particular, it is imperative that ships with high fuel consumption prioritize countermeasures such as introduction of alternative fuels and optimization of operation.

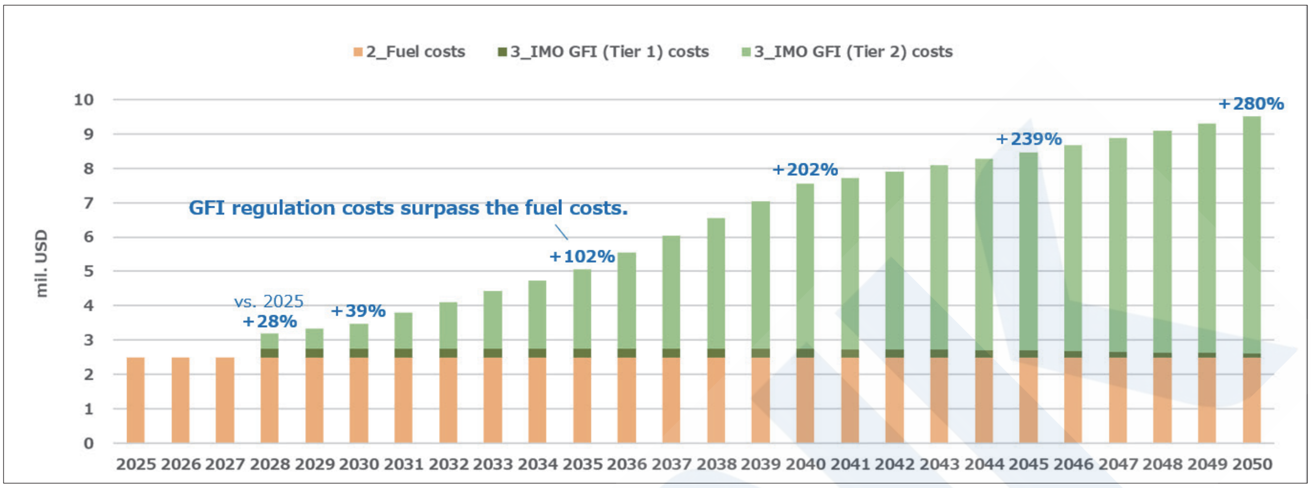

Fig. 6 Estimated cost trend assuming continuing use of conventional fuel oil

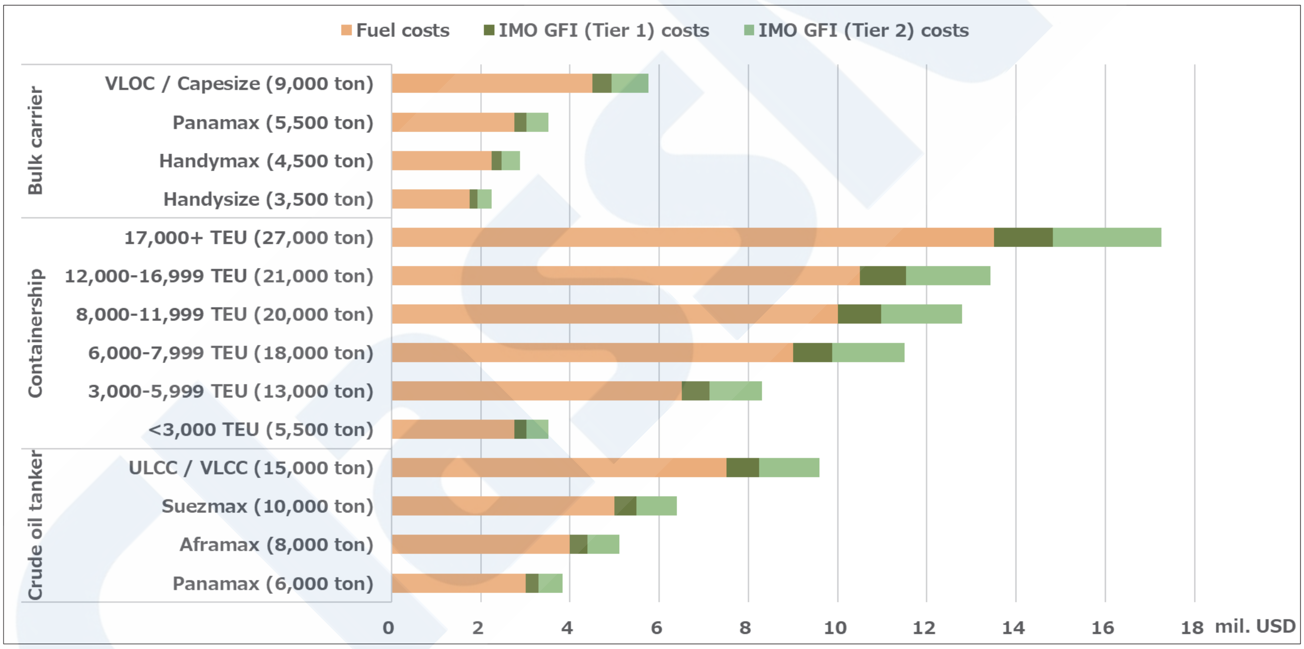

Fig. 7 Estimated regulatory cost by ship type and size in 2028

4. MEASURES FOR REDUCING COSTS

This chapter examines various measures aimed at reducing regulatory costs, focusing on their underlying concepts and effectiveness based on specific case examples. Under the IMO's Mid-term measures, the contribution burden linked to the GHG intensity of fuels will be introduced as a new cost component. Consequently, initiatives that combine economic efficiency with environmental performance, such as improving operational efficiency and introducing low carbon fuels, will become increasingly important. This chapter highlights three representative approaches, fuel efficiency improvement, slow steaming, and the use of multiple fuels, and clarifies how each measure affects the overall cost structure of ship operation through case studies.

4.1 Improvement of Fuel Efficiency

Under the IMO's Mid-term measures, improving fuel efficiency should be the primary step to mitigate cost increases.

Compared with fuel switching or conversion to alternative fuels, fuel efficiency improvement can deliver immediate and tangible benefits with relatively limited capital investment. This case study assumes a vessel consuming 5,000 tons of HFO annually, and evaluates the impact of a 5 % improvement in fuel efficiency, which corresponds to reducing annual fuel consumption to 4,750 tons. The results are presented in Fig. 8. A 5 % improvement in fuel efficiency directly reduces fuel costs through lower fuel consumption, while simultaneously reducing the regulatory costs imposed in proportion to GHG emissions. In other words, improving fuel efficiency is a highly cost-effective approach that reduces both fuel costs and regulatory costs at the same time. Over a cumulative period of 13 years up to 2040, the total cost savings resulting from a 5 % improvement in fuel efficiency are as follows:

- Fuel cost reduction: approx. USD 1,625,000
- Regulatory cost reduction: approx. USD 1,617,042

The combined effect of these measures are expected to result in a total cost reduction of approximately USD 3.24 million by 2040. These results confirm that the reduction in regulatory costs achieved through efficiency improvements can be almost equivalent to the savings in fuel costs.

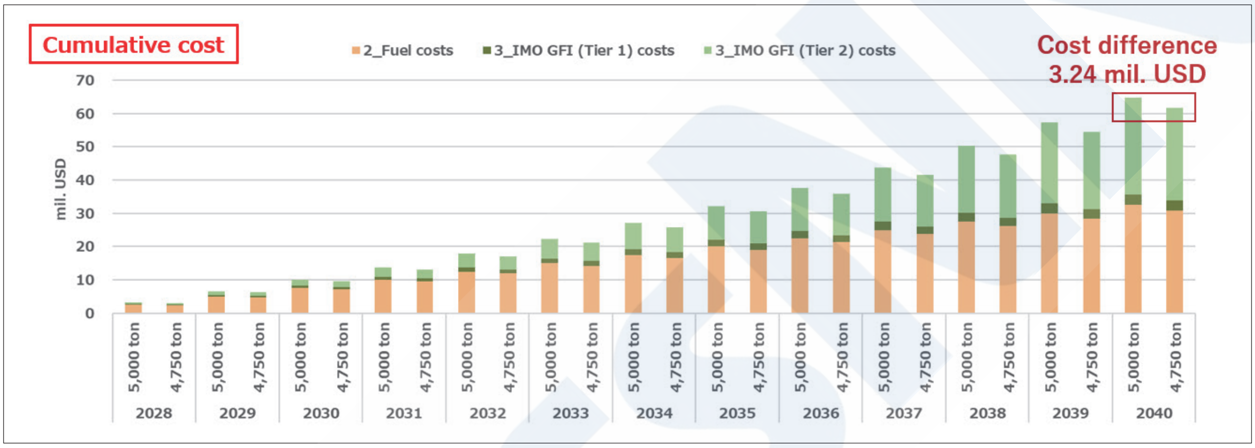

Fig. 8 Cost reduction effect through fuel efficiency improvement

4.2 Slow Steaming

As a specific measure to improve fuel efficiency, the effect of slow steaming, which can be implemented immediately, is examined. Reducing vessel speed also reduces fuel consumption, not only reducing GHG emissions but also decreasing regulatory costs. For this reason, slow steaming is regarded as an effective and practical option for the short to medium term. In this case study, a fleet of 10 bulk carriers was analyzed to compare the effects of operating at reduced speeds over an eight-year period from 2028 to 2035. The fuel price was assumed to be 500 USD per ton, and the estimates were made considering differences in sailing days and fuel consumption. When the operating speed was reduced to 10.45 knots from 11.5 knots, it was found that both the fuel costs and regulatory costs of the entire fleet could be minimized:

- Normal operation (11.5 knots × 10 ships): Total cost = Approximately USD 704 million
- Slow steaming (10.45 knots × 11 ships): Total cost = Approximately USD 675 million

Since slow steaming reduces operational efficiency, one additional vessel would be required to maintain the same transport volume over the same period. However, the analysis takes into account the total fleet cost, including vessel capital expenditure, and as noted above, resulted in an overall cost reduction of approximately 29 million USD. This indicates that the economic and environmental benefits gained from reduced fuel consumption outweigh the moderate loss in operational efficiency.

Fig. 9 Cost reduction effect of slow steaming for an entire fleet

4.3 Use of Multiple Fuels

Under the IMO's Mid-term measures, the life cycle GHG intensity of fuels is subject to regulation. If high GHG intensity fuels such as heavy fuel oil (HFO) continue to be used, regulatory costs will increase cumulatively, in addition to fuel prices. By partially using fuels with lower GHG intensities, it is possible to suppress emission-related costs while optimizing the overall operating cost. In this case study, a vessel consuming 5,000 tons of HFO per year is assumed, and the cost trend is estimated for a scenario in which the proportion of biodiesel (B30) used in place of HFO is gradually increased in order to achieve the Base Target. The assumptions applied are as follows:

- Annual fuel consumption: 5,000 tons
- Fuel price: HFO = 500 USD/ton, B30 = 746.7 USD/ton
- Assessment period: 2028-2040

In 2028, the scenario begins with a 30 % share of B30, and the proportion is gradually increased thereafter. From 2033 onward, B30 becomes the primary fuel used. The estimation results shown in Fig. 10 indicate that the introduction of low carbon fuels is not merely an environmental countermeasure, but also an economically rational option in the medium to long term. In particular, fuels such as biodiesel, which can utilize existing infrastructure, allow a smooth transition when used together with heavy fuel oil, and contribute to the reduction of regulatory costs. Furthermore, if the price of biofuels decreases in the future, they could provide a clear cost-saving advantage compared with operation using heavy fuel oil alone. Therefore, combined use of fuels can be regarded as a practical and effective transitional step under the IMO's Mid-term measures.

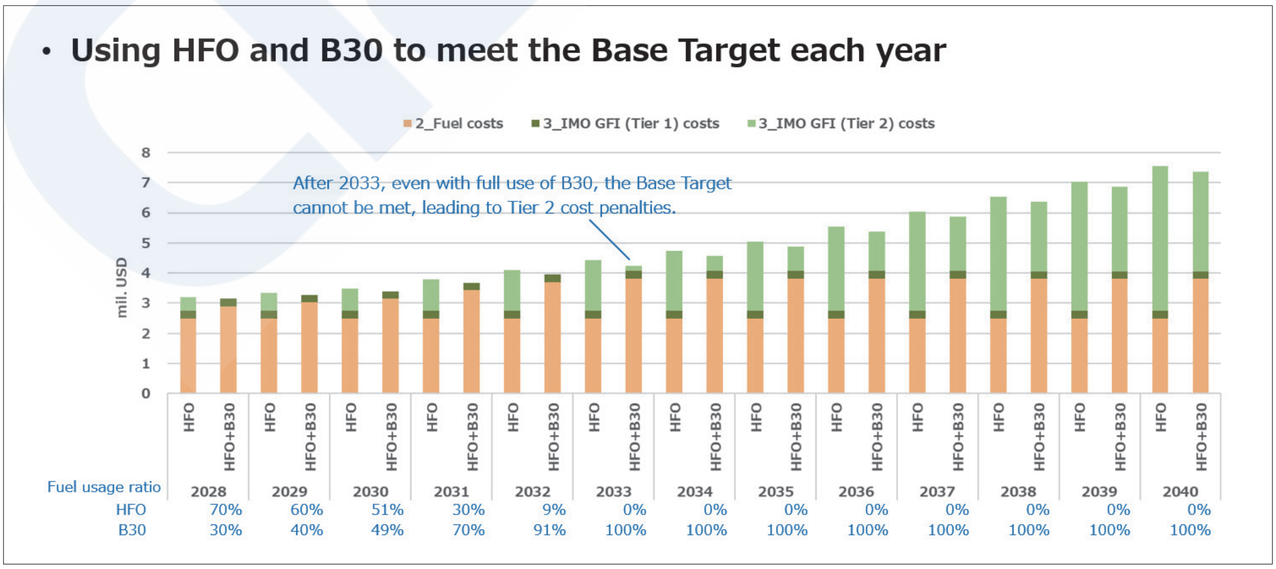

Fig. 10 Cost reduction by combined use of fuels meeting the annual Base Target

5. CLASSNK SERVICES

To appropriately address GHG emission reduction regulations such as the IMO’s Mid-term measures, EU-ETS, and FuelEU Maritime, it is essential to conduct a comprehensive cost simulation that takes into account not only the compliance costs associated with these regulations but also changes in shipbuilding costs and fuel costs resulting from fuel transition.

ClassNK provides the “ClassNK Fleet Cost Simulation” service to support clients in conducting such complex and comprehensive cost assessments. This service combines the “ClassNK Fleet Cost Calculator” with customized simulation reports that present fleet-wide cost projections through clear graphs and tables. The Fleet Cost Calculator covers not only compliance costs associated with the IMO’s Mid-term measures, EU-ETS, and FuelEU Maritime, but also shipbuilding costs and fuel costs, providing a comprehensive basis for long-term fleet strategy planning. The tool also allows flexible customization of assumptions such as fuel prices, the timing of vessel replacement, energy-efficiency improvement rates, and emission factors according to user requests.

Through simulations and analytical support that account for fuel transition, ClassNK assists companies in formulating effective decarbonization strategies and making informed investment decisions for the future.

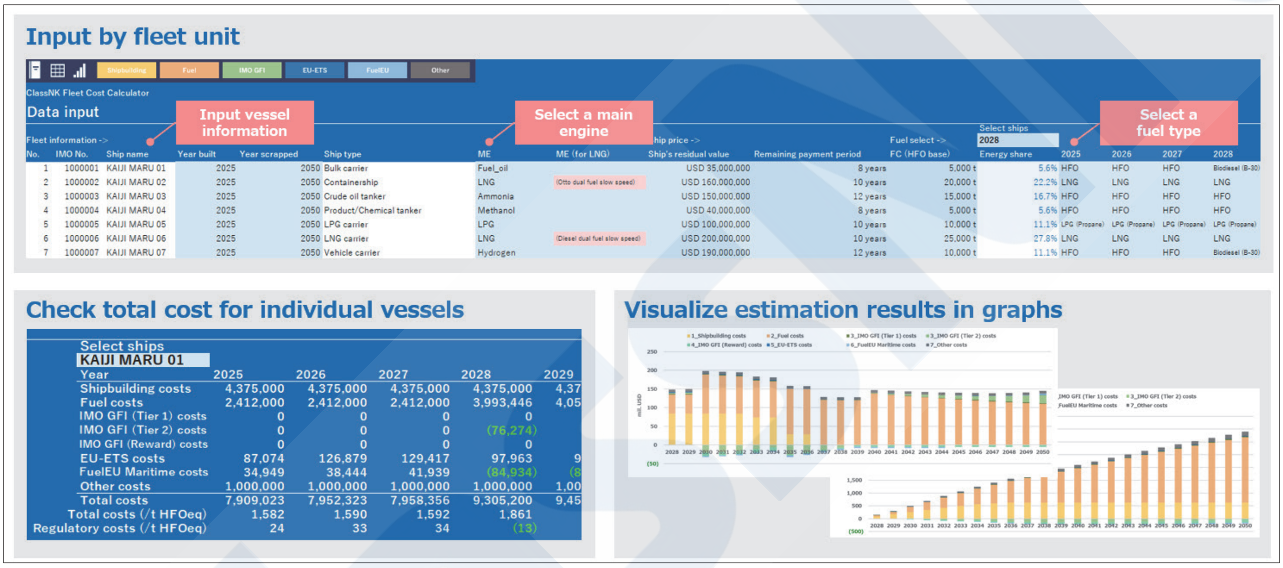

Fig. 11　Interface image of the ClassNK Fleet Cost Calculator

6. CONCLUSION

With the introduction of the IMO’s Mid-term measures, the choice of fuel and fuel efficiency performance are expected to have a direct impact on the asset value of ships and on investment decisions. In the years ahead, factors such as the ability to use specific fuels and the relative efficiency of ship performance are likely to become key determinants of market value. From an investment perspective, companies are increasingly evaluated based on the clarity of their decarbonization strategies, and such evaluations may in turn influence ship prices and financing conditions.

On the operational side, fleet deployment planning and cost management are expected to become more complex than ever. Whether optimized ship operations, fuel procurement, and bunkering strategies are in place will have a direct bearing on profitability. To effectively control total costs, close coordination across the entire supply chain, including all relevant stakeholders, will be essential.

As part of future preparations, continuous monitoring of developments in the relevant regulations is essential. In addition, however, companies should also conduct simulations to assess the economic feasibility of conventional and alternative-fuel vessels, as well as the potential impacts on charter rates and freight levels. It will be important for stakeholders to develop a common view of the future outlook to ensure a smooth transition and maintain competitiveness following the implementation of the IMO’s Mid-term measures.

ClassNK will continue to assist industry stakeholders in taking practical actions by providing up-to-date information and cost simulation services that reflect the latest international trends. Through these efforts, the Society aims to further promote the decarbonization of the global maritime sector.

REFERENCES

1) 2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (2024 LCA Guidelines) (Resolution MEPC.391(81))