ClassNK Alternative Fuels Insight

Version 2.2
February 2025

Issuance of ClassNK Alternative Fuels Insight

- Amidst the pressing need for society-wide reduction of GHG emissions, it is anticipated that GHG emission regulations in international shipping, spearheaded by organizations like the IMO and the EU, will be further strengthened. Consequently, we are entering an era where **GHG emissions from ships become a cost factor**. In such a business environment, strategically reducing GHG emissions from ships is crucial. This necessitates not only further energy efficiency improvements but also the essential adoption of alternative fuels with lower environmental impacts.
- On the other hand, there is a wide range of alternative fuels available for use in ships. When adopting alternative fuels, it is crucial to **select the appropriate fuel** based on factors such as the ship type, size, and route. Therefore, it is essential to not only consider technical aspects but also to grasp the overall trend of alternative fuels, including factors such as fuel availability and cost projections.
- The "**ClassNK Alternative Fuels Insight**," issued by ClassNK, aims to support your future fuel selection. We hope that the ClassNK Alternative Fuels Insight will be a helpful resource in your efforts to reduce GHG emissions.

Four Steps for Introducing Alternative Fuels

Step 1	Step 2	Step 3	Step 4
Understanding regulations	Understanding trends	Understanding alternative fuels	Understanding costs

A Snapshot of the Current State of Energy Transition in International Shipping

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Demand side

In service:

38,700 ships[*1]

Conventional fuel ships
37,200 ships
(96%)

Alternative fuel ships[*2]
1,500 ships
(4%)

A transition of 37,200 ships to alternative fuels is necessary. (Alternative fuel ships can use zero-emission fuels.)

*1 5,000 gross tonnage and above (as of the end of December 2024, adjusted for fractions)
*2 LNG-fueled LNG carriers are included.

Fuel consumption:

216 mil. tons/year[*3]

Conventional fuel oil
200 mil. tons
(93%)

Alternative fuel
16 mil. tons[*4]
(7%)

The required amount for a full transition to zero-emission fuels would be…

For methanol	440 mil. tons/year
For ammonia	470 mil. tons/year
For methane/LNG	180 mil. tons/year
For hydrogen	70 mil. tons/year

*3 The annual fuel consumption for ships engaged in international voyages with 5,000 gross tonnage and above (abt. 30,000 ships subject to IMO DCS) in 2023 (conventional fuel oil equivalent)
*4 Conventional fuel oil equivalent (of which 98% is LNG fuel.)

Supply side

Shipyard

Newbuildings:

1,500 ships[*5]

Conventional fuel ships
1,200 ships
(80%)

Alternative fuel ships
300 ships
(20%)

*5 5,000 gross tonnage and above (2024, adjusted for fractions)

Green fuel producers

- ✓ **Methanol** 3.2 mil. tons/year[*6]
- ✓ **Ammonia** 6.4 mil. tons/year[*6]
- ✓ **Methane** 0.01 mil. tons/year[*6]
- ✓ **Hydrogen** 1.5 mil. tons/year[*6]

*6 Operational, construction, FID (for all sectors)

Other sectors

- ✓ **Methanol**
  Chemical, etc.
- ✓ **Ammonia**
  Electricity, Agriculture, Chemical, etc.
- ✓ **Hydrogen**
  Electricity, Automobile, Steel, etc.

Much of the green fuels and green chemicals produced are expected to be directed towards demand from other sectors.

While biofuels contribute to GHG emission reductions, there are constraints on the resource availability of biomass, which serves as their raw material. Moreover, demand for biomass competes across sectors.

Correction / Revision Record - 1

ClassNK

Version	Date	Page	Details
1.0	2024.05	-	-
2.0	2024.09	Page 3	Update figures
2.0	2024.09	Page 15 – Page 25	Update to information as of June 30, 2024
2.0	2024.09	Page 29	Add explanation
2.0	2024.09	Page 38 – Page 40	Newly added (Result of CII ratings)
2.0	2024.09	Page 42	Update figures, Add information for methane
2.0	2024.09	Page 43	Update figures, Add information for methane
2.0	2024.09	Page 44	Newly added (Demand outlook for alternative fuels)
2.0	2024.09	Page 56 – Page 57	Newly added (Green methane production project)
2.0	2024.09	Page 59	Newly added (Steps from installation of onboard CCS systems to certification of captured CO_2 volume)
2.0	2024.09	Page 63	Newly added (GHG emissions assessment of biofuels)
2.0	2024.09	Page 64	Update to the latest information
2.0	2024.09	Page 65	Update to the latest information
2.0	2024.09	Page 73 – Page 77	Update analysis with additional cost simulation example for ammonia-fueled ship
2.0	2024.09	Page 83 – Page 93	Newly added (Appendix)

Correction / Revision Record - 2

ClassNK

Version	Date	Page	Details
2.1	2024.11	Page 3	Update figures
2.1	2024.11	Page 12	Update to the latest information
2.1	2024.11	Page 42	Update figures
2.1	2024.11	Page 46 – Page 57	Update figures
2.1	2024.11	Page 58	Update figures
2.1	2024.11	Page 64	Update to the latest information
2.1	2024.11	Page 65	Update to the latest information
2.2	2025.02	Page 3	Update figures
2.2	2025.02	Page 15 – Page 25	Update to information as of December 31, 2024
2.2	2025.02	Page 44	Update figures
2.2	2025.02	Page 61	Newly added (Biofuel production)
2.2	2025.02	Page 63	Correct the information
2.2	2025.02	Page 64	Update to the latest information
2.2	2025.02	Page 69	Update figures
2.2	2025.02	Page 73 – Page 78	Update figures

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— Step 1

Understanding regulations

When considering the adoption of alternative fuels, understanding the GHG-related regulations that are expected to be strengthened in the future is crucial above all else. In this section, we will introduce the GHG-related regulations of the IMO and the EU, which will play a central role in GHG emission reduction measures in international shipping moving forward.

Key Takeaways

- ✓ Successive regulations promoting the use of zero or low-emission fuels are being introduced in international shipping.
- ✓ The IMO is to implement the "mid-term measures," while the EU has "EU-ETS for Shipping" and "FuelEU Maritime" playing central roles.
- ✓ The additional costs that ships will incur due to these regulations depend on their specific provisions. However, it’s possible that these costs could far exceed annual fuel costs in the future.
- ✓ Since the scope of emissions targeted and the anticipated costs vary between each regulation, it is crucial to thoroughly understand the details of each regulation in order to minimize regulatory costs across the fleet.
- ✓ ClassNK provides information to support understanding of these regulations.

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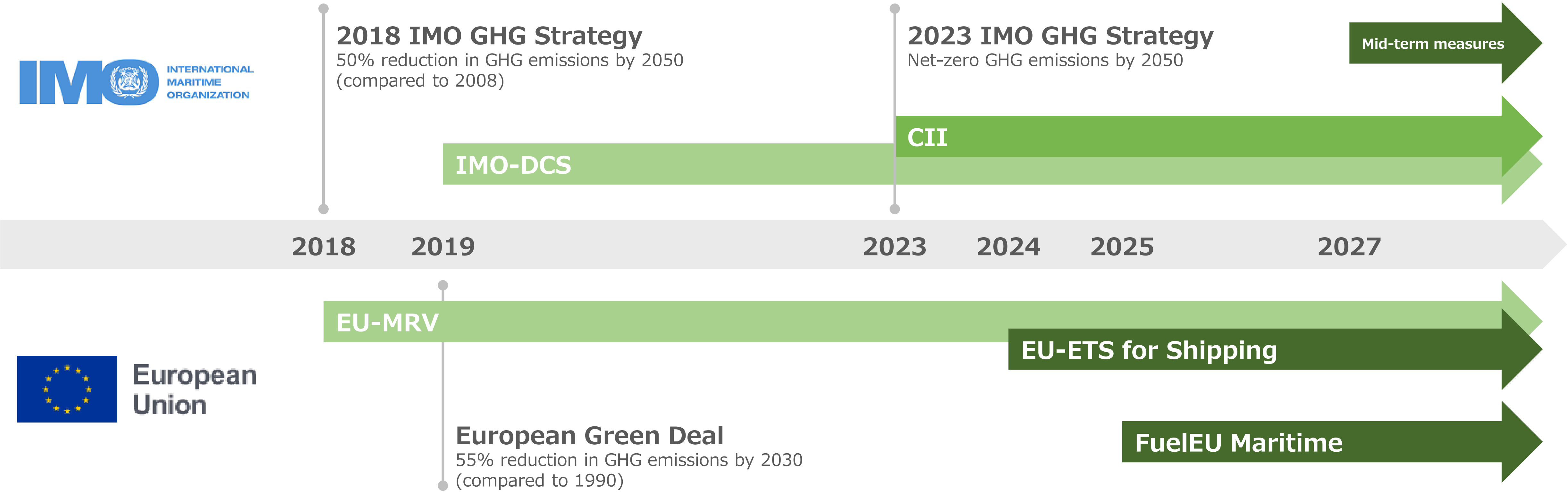
Carbon pricing

In order to further reduce GHG emissions from ships, successive regulations promoting the use of zero- and low-emission fuels are being introduced in international shipping. The IMO is currently discussing a new regulatory framework for mid-term measures, aiming for implementation in 2027. In Europe, the European Union Emissions Trading System (EU-ETS), a carbon pricing mechanism, has been expanded to include the maritime sector since 2024. In 2025, FuelEU Maritime will be introduced to drive the decarbonization of shipping fuels. With these regulations in place, GHG emissions from ships will become a cost factor, making it crucial for the future of maritime business to strategically reduce GHG emissions from ships.

Introduction schedule of GHG-related regulations*

*Only operational GHG-related regulations are listed here.



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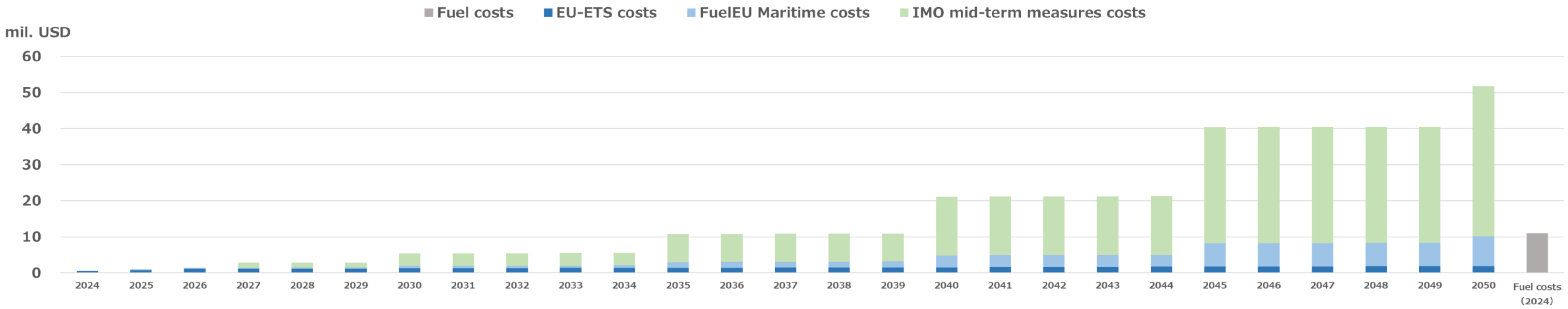
Increase in the cost of GHG emissions

The regulations set by the IMO and the EU are aimed at promoting the transition to zero- or low-emission fuels. Therefore, it is anticipated that the costs associated with regulatory compliance (GHG emission costs) will gradually increase. Understanding the extent to which GHG emission costs will affect the fleet in the future is the first step in considering the adoption of alternative fuels.

Image of increasing GHG emission costs (Continuing to use conventional fuel oil: e.g. 14,000 TEU containership)



- The figure above illustrates the annual increase in GHG emission costs if a 14,000 TEU containership continues to use conventional fuel oil.
- Depending on the specifics of the IMO's planned mid-term measures*, there is a possibility that the annual GHG emission costs may surpass fuel costs sooner rather than later.

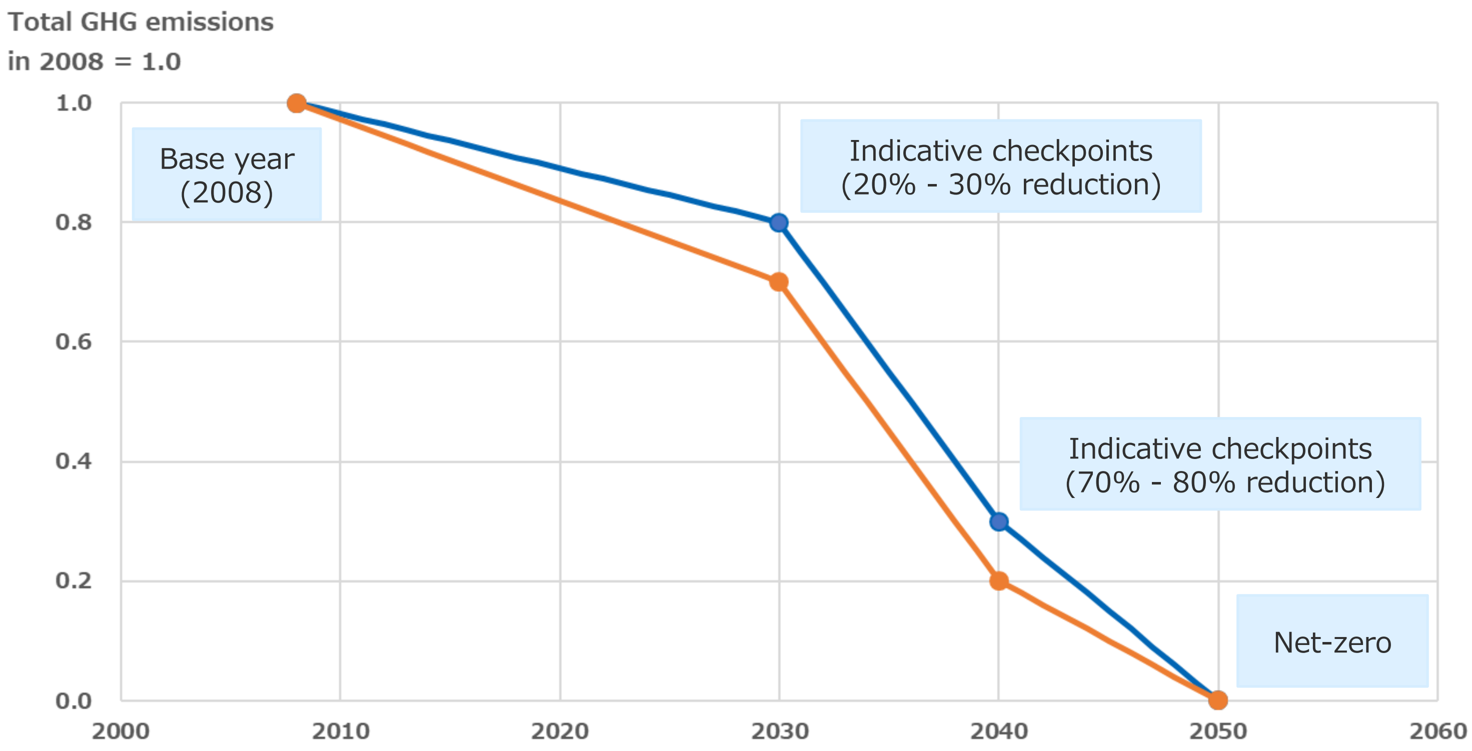
  *The figure assumes the introduction of GHG intensity regulations on a Well-to-Wake basis as part of the mid-term measures in 2027.
- Especially noteworthy is the difference between the EU regulations (EU-ETS and FuelEU Maritime), which only regulate GHG emissions from EU-related voyages, and the IMO regulations, which cover GHG emissions from all voyages. Consequently, the introduction of the IMO regulations (mid-term measures) is expected to have a significantly larger impact on the burden of GHG emission costs.

Detailed cost simulations are provided in Step 4. ➡

IMO GHG Strategy

In July 2023, the IMO revised its initial strategy on the reduction of GHG emissions from ships and adopted the "2023 IMO GHG Strategy," which includes the goal of achieving net-zero GHG emissions by or around 2050. Serving as the foundation for future discussions on reducing GHG emissions from international shipping, understanding this strategy is crucial for the shipping industry. ClassNK has published a white paper titled "Pathway to Zero-Emission in International Shipping - Understanding the 2023 IMO GHG Strategy -" to facilitate understanding of this strategy.

IMO GHG reduction goal



White Paper "Pathway to Zero-Emission in International Shipping - Understanding the 2023 IMO GHG Strategy -"

(English)

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IMO mid-term measures

Currently, the IMO is engaged in discussions to introduce new regulations (mid-term measures) aimed at promoting the use of zero- and low-emission fuels. Scheduled to be finalized in 2025 and enforced in 2027, these mid-term measures will have a significant impact on the maritime industry. It is important for stakeholders in the shipping business to closely monitor the progress and discussions at the IMO regarding these regulations.

The outline of the mid-term measures proposed to the IMO* (As of October 2024, MEPC 82)

*The mid-term measures are expected to be finalized by combining the contents of these proposals.

Schemes		Proposed by	Summary
Combination of technical and economic elements	**GHG fuel intensity regulation** **(Technical elements)** + **GHG levy** **(Economic elements)**	EU member states EC Japan	• Reduction of GHG fuel intensity (gCO_2eq/MJ) with flexibility mechanisms* for regulatory compliance *1. Flexibility among multiple vessels for over-/under- achievement of compliance (=Pooling) 2. Utilization of banking from previous years 3. Payment of contributions to the IMO • Levying based on GHG emissions
	GHG fuel intensity regulation **(Technical elements)**	China Brazil Norway UAE, etc.	• Reduction of GHG fuel intensity (gCO_2eq/MJ) with flexibility mechanisms* for regulatory compliance *1. Flexibility among multiple vessels for over-/under- achievement of compliance (=Pooling) 2. Utilization of banking from previous years 3. Payment of contributions to the IMO * There is a correction factor for ships serving eligible ports of developing countries that are expected to be negatively impacted by the mid-term measures.
	GHG fuel intensity regulation **(Technical elements)** + **GHG levy** **(Economic elements)**	Island countries (10 countries)	• Reduction of GHG fuel intensity (gCO_2eq/MJ) with flexibility mechanisms* for regulatory compliance *Payment of contributions to the IMO only • Levying USD150/ton CO_2eq based on GHG emissions (periodically reviewed)

✓ Scope of emissions: Well-to-Wake
✓ Use of revenues: Reward for ships using zero- and near-zero GHG fuels, promotion of R&D for energy transition of shipping, support for developing countries

- Timeline for regulatory implementation: Approval (April 2025), Adoption (October 2025), Entry into force (2027)
- Key issues: Introduction of GHG levy, level of GHG fuel intensity limits and GHG levy, use of revenues

European regional regulations

In Europe, the implementation of the European Union Emissions Trading System (EU-ETS) in the maritime sector began in 2024, and FuelEU Maritime was introduced in 2025. When assigning ships to European routes, it is essential to accurately understand the contents of these regulations in order to minimize regulatory compliance costs as much as possible. ClassNK has issued "FAQs on the EU-ETS for Shipping" and "FAQs on the FuelEU Maritime," each explaining the overview of the regulations and the essential preparations for compliance in a Q&A format specific to European regional regulations.

FAQs to understand EU’s GHG-related regulations

FAQs on the EU-ETS for Shipping (Edition 2.1)

(English)

FAQs on the FuelEU Maritime (3rd Edition)

(English)

— Step 2

Understanding trends

When considering the adoption of alternative fuels, it is important to understand the trends and future prospects of these options. Demand-side trends also influence the fuel supply-side. In this section, we will introduce the adoption trends of alternative fuels, including their utilization across different ship types and sizes.

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Key Takeaways

- ✓ ClassNK periodically compiles data on the trends in the adoption of alternative fuels in shipping.
- ✓ The data includes ships with a gross tonnage of 5,000 and above, which are also subject to IMO DCS and CII (these ships are likely to be subject to IMO's mid-term measures). Additionally, LNG carriers have been excluded from the data on alternative fuel ships to provide a more accurate representation of the adoption status in ship types other than LNG carriers.
- ✓ The most popular alternative fuel ships is likely to remain LNG-fueled ships. Although the proportion of LNG-fueled ships in the orderbook decreased from 64% at the end of December 2023 to 57% at the end of June 2024, it maintained a 58% share as of the end of December 2024 (the share of methanol-fueled ships was 25%).
- ✓ While the adoption rate of alternative fuel ships remains high for ship types such as vehicle carriers, LPG carriers, and containerships, it has not yet significantly progressed for ship types such as bulk carriers, product/chemical tankers, and crude oil tankers.
- ✓ For ammonia-fueled ships, which are expected to see increased demand in the future, a certain number of adoptions continue to be seen not only in ammonia carriers but also in bulk carriers, and it is important to pay close attention to whether ammonia fuel will become a solution for decarbonization.

Understanding trends

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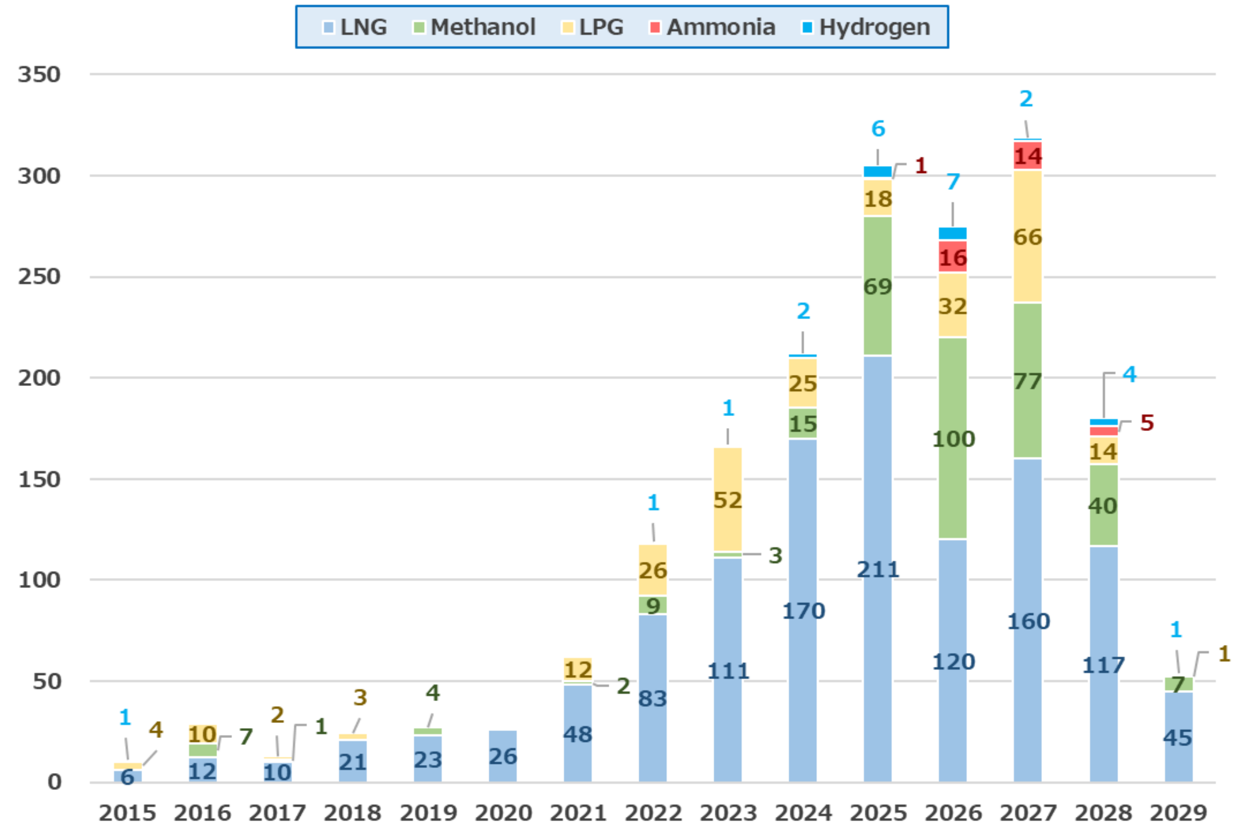
Trends in alternative fuel ships

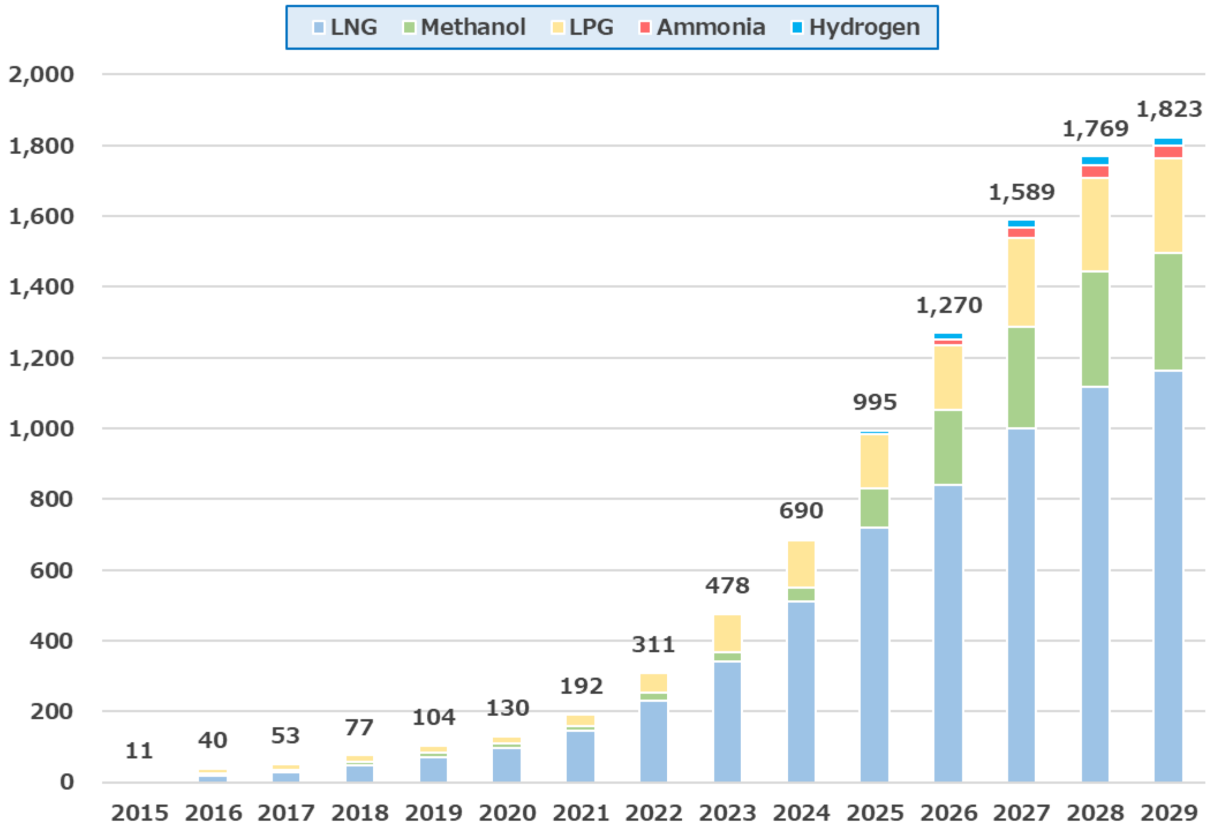
"Newbuilding" alternative fuel ship trend



- ✓ As of the end of December 2024 (Orderbook is included after 2025.)
- ✓ 5,000 gross tonnage and above
- ✓ LNG carriers are excluded from LNG-fueled ships.
- ✓ Alternative fuel ready ships are not included.

"In service" alternative fuel ship trend*

*Cumulative number of ships delivered since 2015, without considering scrapping



- ✓ As of the end of December 2024 (Orderbook is included after 2025.)
- ✓ 5,000 gross tonnage and above
- ✓ LNG carriers are excluded from LNG-fueled ships.
- ✓ Alternative fuel ready ships are not included.

Source: The figures and tables presented in this section are created by ClassNK based on data from Clarkson Research Services Limited.

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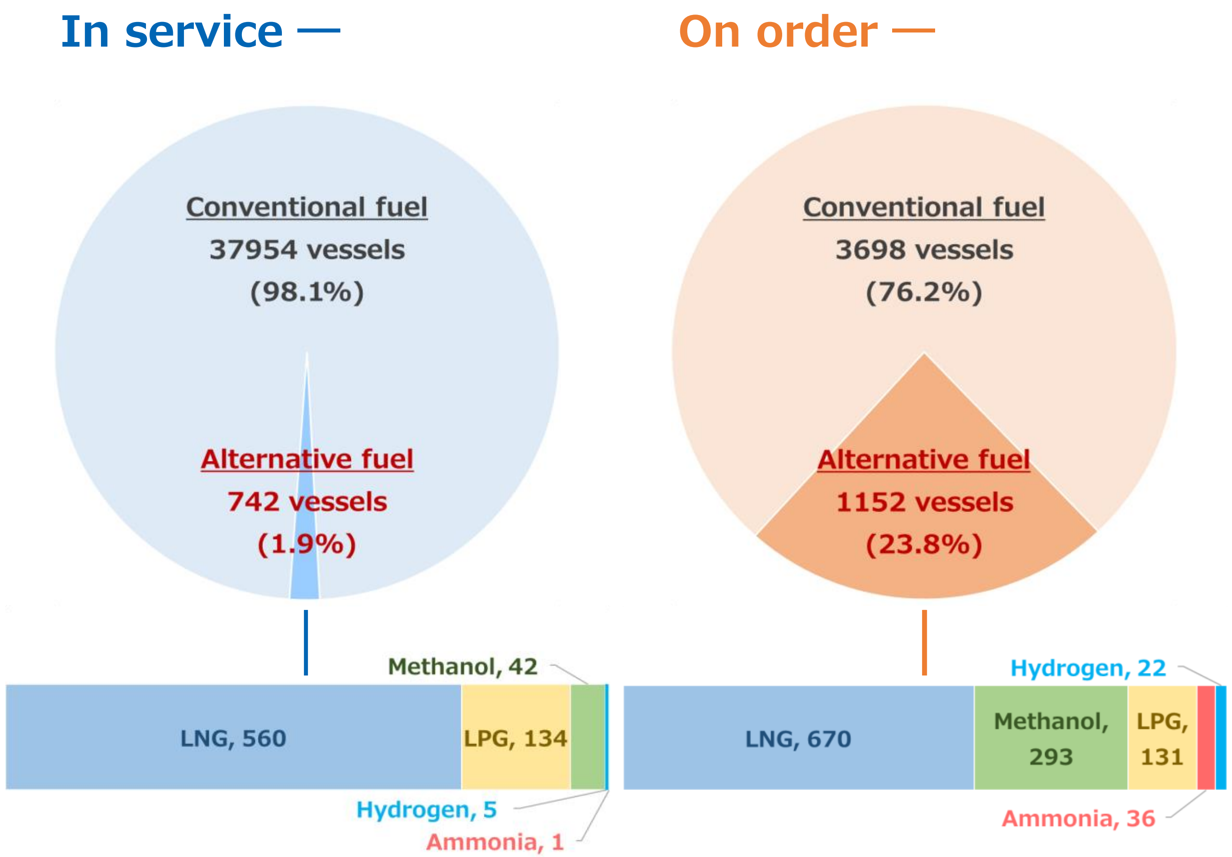
Trends in alternative fuel ships

Share of alternative fuel ships



- ✓ As of the end of December 2024
- ✓ 5,000 gross tonnage and above
- ✓ LNG carriers are excluded from LNG-fueled ships.
- ✓ Alternative fuel ready ships are not included.

Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	628 vessels (1.7%)	742 vessels (1.9%)
Total GT	42,327,700 GT (2.7%)	50,810,660 GT (3.2%)

There was an increase of 114 vessels totaling 8.4 million GT in six months. Notably, the delivery of LNG-fueled ships was prominent (86% of the total), with deliveries seen in many ship types, particularly Containerships and Vehicle carriers. On the other hand, the delivery of methanol-fueled and LPG-fueled ships was limited, with only 7 vessels each.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	901 vessels (21.5%)	1,152 vessels (23.8%)
Total GT	69,624,584 GT (30.4%)	102,557,464 GT (36.9%)

There was an increase of 251 vessels totaling 32.9 million GT in six months. The increase in GT is significant compared to the increase in the number of vessels, indicating that the adoption of alternative fuel ships has progressed, mainly for large containerships. By fuel type, orders for LNG-fueled ships accounted for 70% of the total.

Understanding trends

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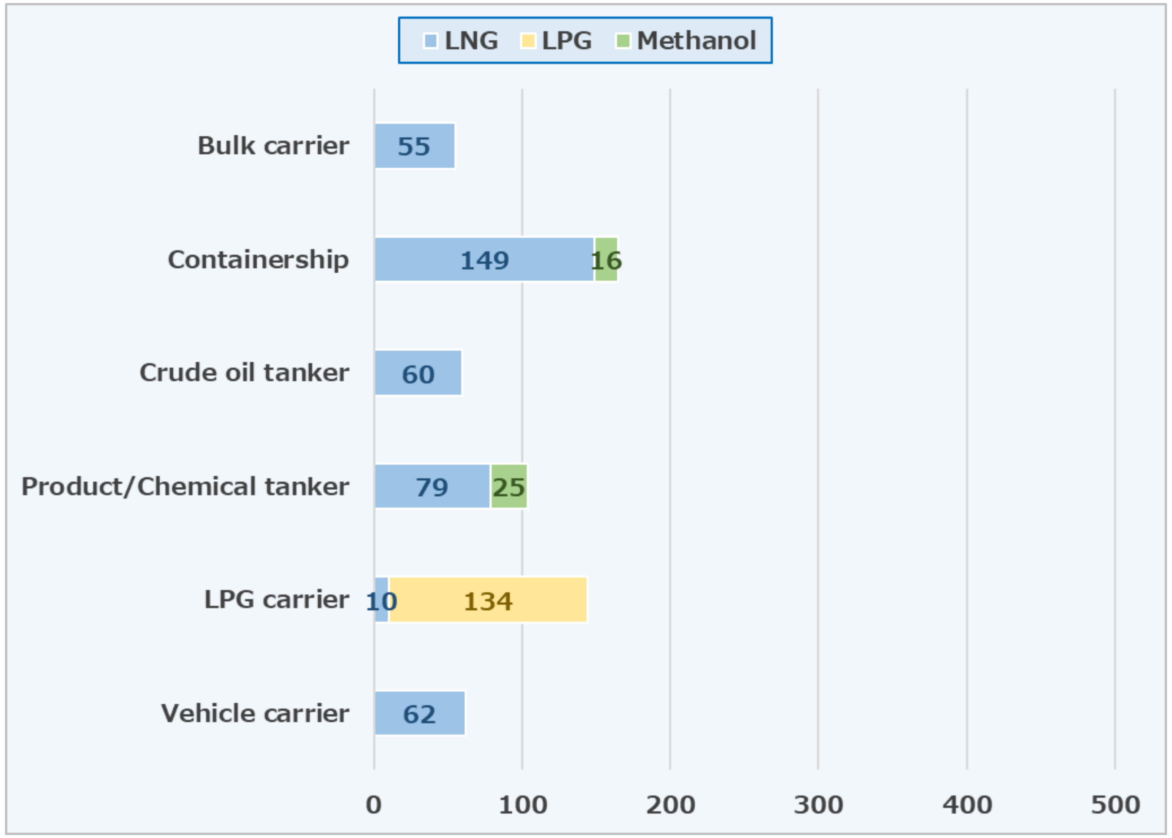
Trends in alternative fuel ships (by ship type)

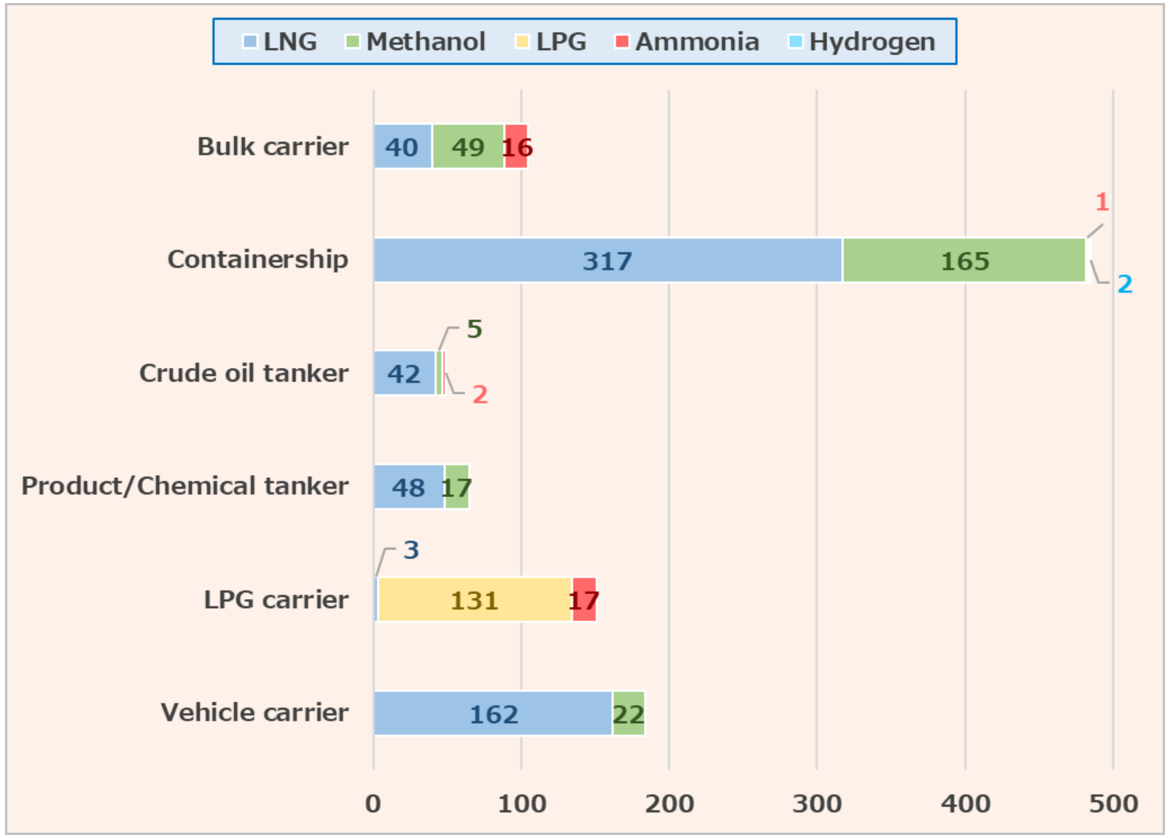
In service —



✓ As of the end of December 2024 / 5,000 gross tonnage and above / Alternative fuel ready ships are not included.

➢ LNG-fueled ships make up the majority of ships of all types, with the exception of product/chemical tankers, which include methanol carriers, and LPG carriers.

On order —



✓ As of the end of December 2024 / 5,000 gross tonnage and above / Alternative fuel ready ships are not included.

➢ Several fuels are being adopted across all ship types, and it is unclear which fuel will become mainstream.

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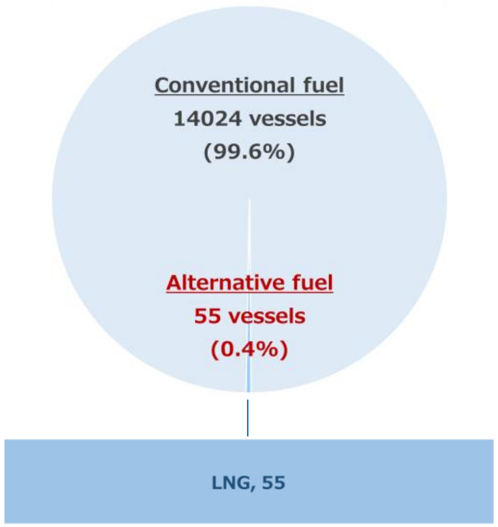
Trends in alternative fuel ships (by ship type)

Bulk carriers

In service —



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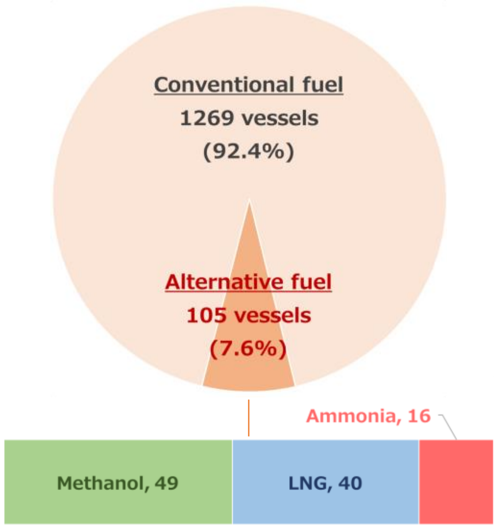

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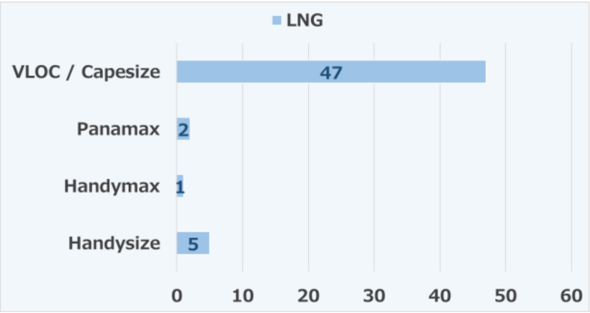

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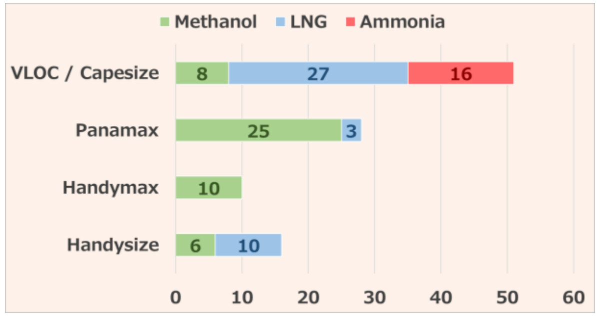

Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	53 vessels (0.4%)	55 vessels (0.4%)
Total GT	5,072,048 GT (0.9%)	5,286,685 GT (0.9%)

There was an increase of two vessels totaling 0.2 million GT in six months. By ship size, all delivered vessels were VLOC/Capesize, and all were LNG-fueled ships .

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	65 vessels (5.2%)	105 vessels (7.6%)
Total GT	5,070,849 GT (9.6%)	7,788,386 GT (12.9%)

There was an increase of 40 vessels totaling 2.7 million GT in six months. By fuel type, methanol-fueled ships accounted for the majority, but new orders for LNG-fueled ships were also seen in VLOC/Capesize and Handysize.

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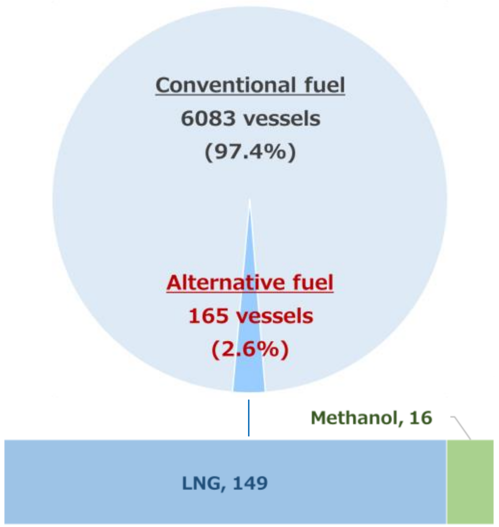
Trends in alternative fuel ships (by ship type)

Containerships

In service —



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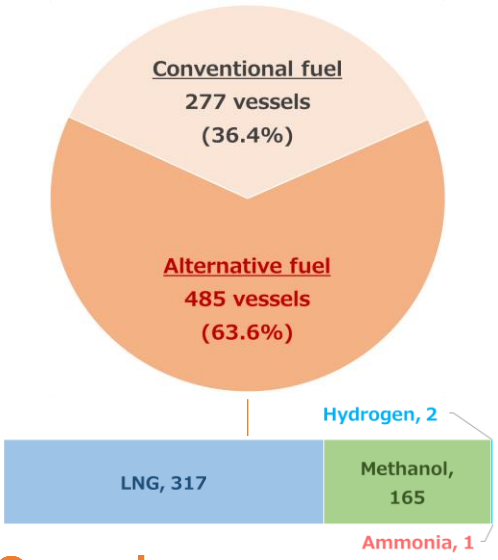

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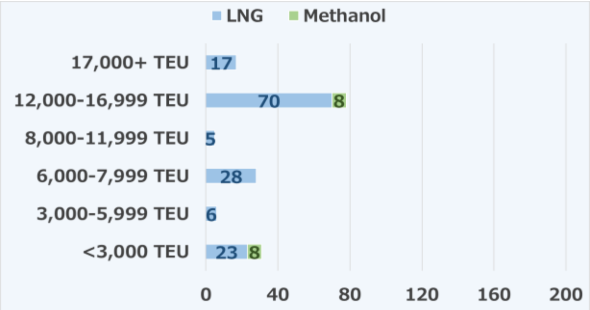

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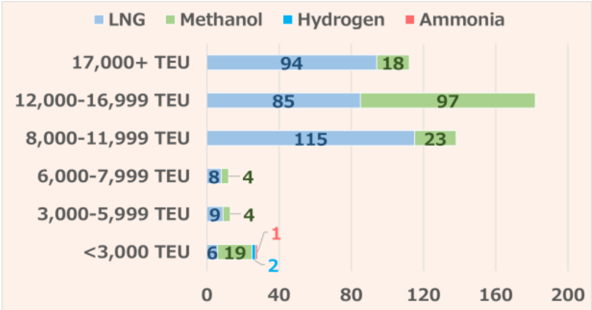

Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	113 vessels (1.9%)	165 vessels (2.6%)
Total GT	14,083,720 GT (4.5%)	19,224,301 GT (5.9%)

There was an increase of 52 vessels totaling 5.1 million GT in six months. By ship size, deliveries were prominent in the 12,000-16,999 TEU and 6,000-7,999 TEU ranges, with the majority being LNG-fueled ships.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	314 vessels (49.3%)	485 vessels (63.6%)
Total GT	35,665,036 GT (64.5%)	63,695,621 GT (78.2%)

There was an increase of 171 vessels totaling 28.0 million GT in six months. By fuel type, while the majority of new orders in the first half of 2024 were for methanol-fueled ships, LNG-fueled ships accounted for most new orders in this six-month period (84% share), indicating a significant shift in fuel selection trends.

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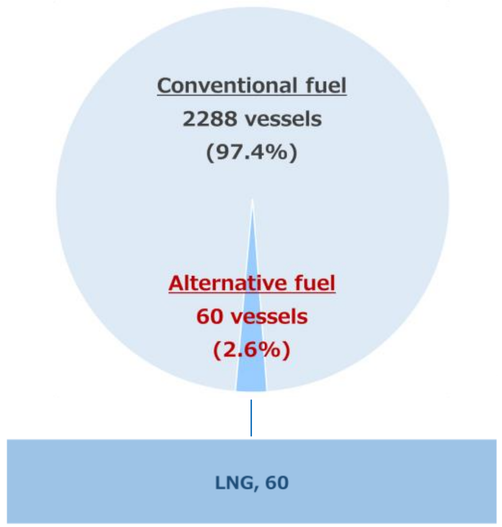
Trends in alternative fuel ships (by ship type)

Crude oil tankers

In service —



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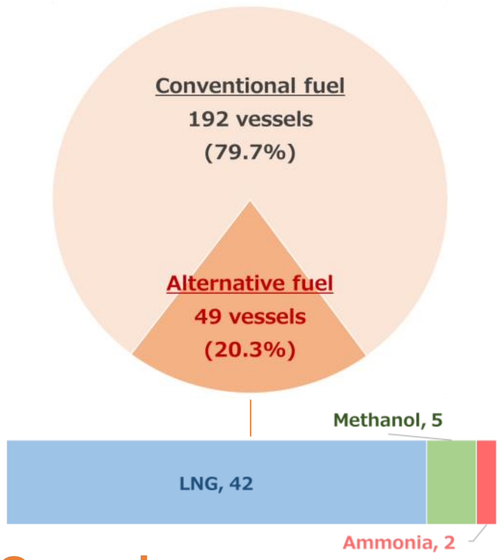

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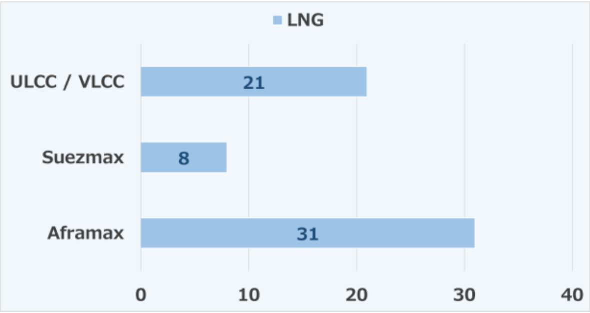

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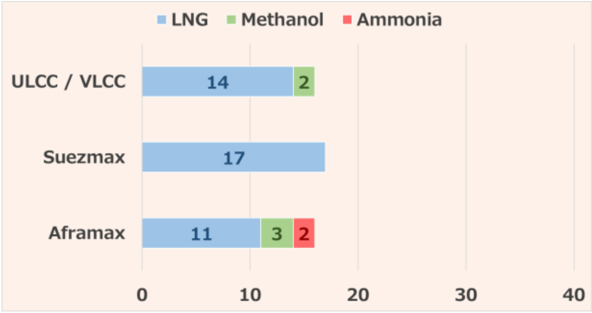

Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	60 vessels (2.6%)	60 vessels (2.6%)
Total GT	6,060,939 GT (2.5%)	6,060,939 GT (2.5%)

The number of vessels and gross tonnage remained unchanged in six months. Only 10 crude oil tankers were delivered during this period, and all of them were conventional fuel ships.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	57 vessels (28.5%)	49 vessels (20.3%)
Total GT	5,611,417 GT (27.9%)	4,914,979 GT (19.7%)

There was a decrease of 8 vessels totaling 0.7 million GT in six months. This is due to factors such as the change of some ships, which were ordered as LNG-fueled ships as of the end of June 2024, to conventional fuel ships as of the end of December 2024.

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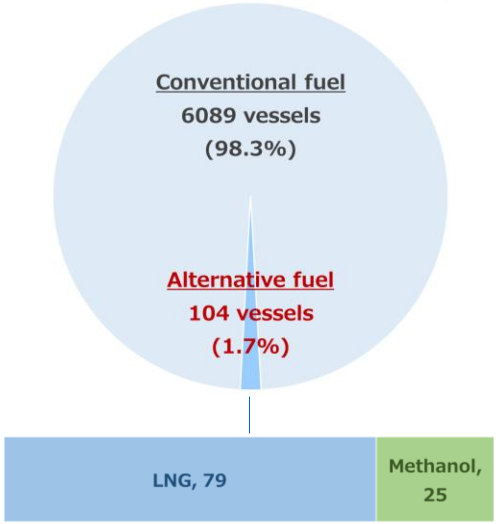
Trends in alternative fuel ships (by ship type)

Product/Chemical tankers

In service —



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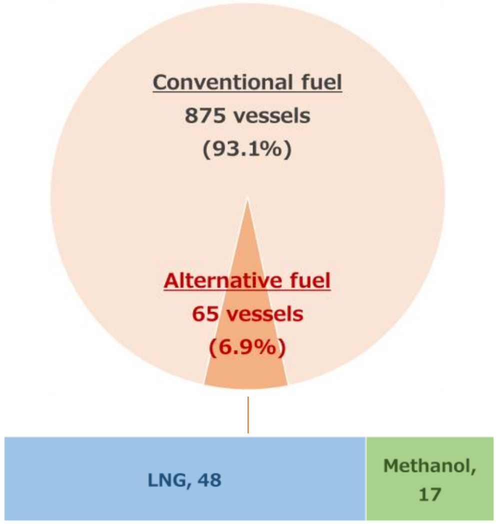

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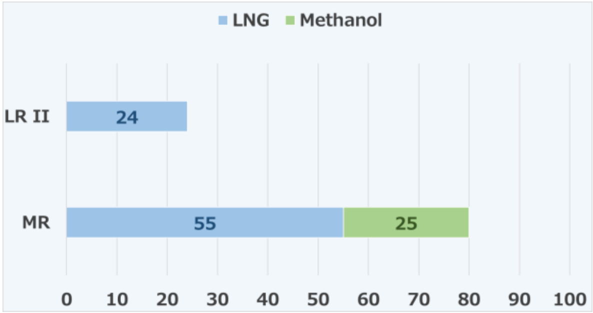

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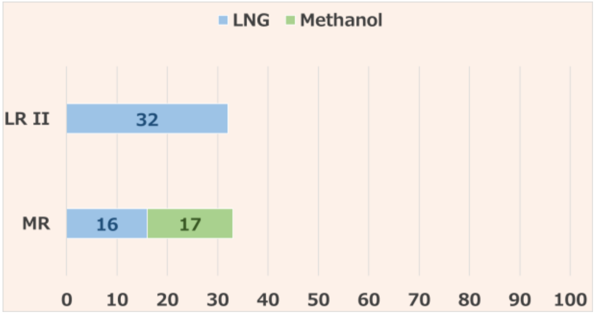

Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	95 vessels (1.5%)	104 vessels (1.7%)
Total GT	2,974,245 GT (2.1%)	3,094,617 GT (2.2%)

There was an increase of 9 vessels totaling 0.1 million GT in six months. By ship size, MR were delivered, while no LR II or LR I were delivered. By fuel type, all were LNG-fueled ships, and no methanol-fueled ships were delivered.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	53 vessels (7.7%)	65 vessels (6.9%)
Total GT	1,787,476 GT (8.5%)	2,702,139 GT (9.5%)

There was an increase of 12 vessels totaling 0.9 million GT in six months. By ship size, LR II were prominent among new orders. By fuel type, all were LNG-fueled ships, and no methanol-fueled ships were ordered.

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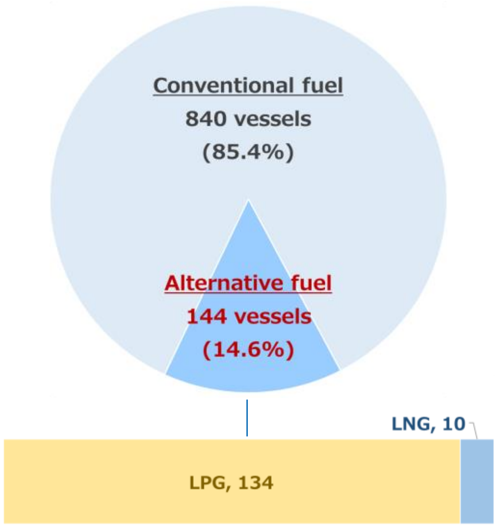
UPDATED

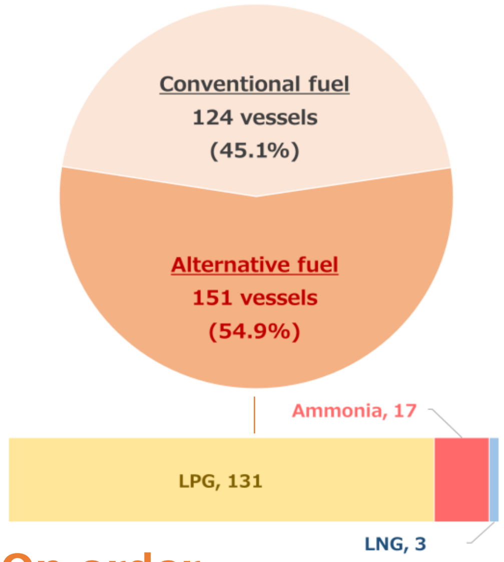
Trends in alternative fuel ships (by ship type)

LPG carriers

In service —



On order —



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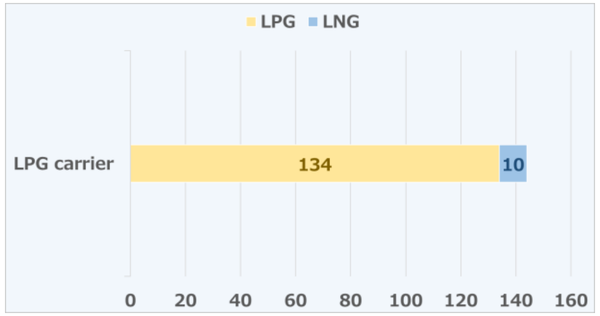
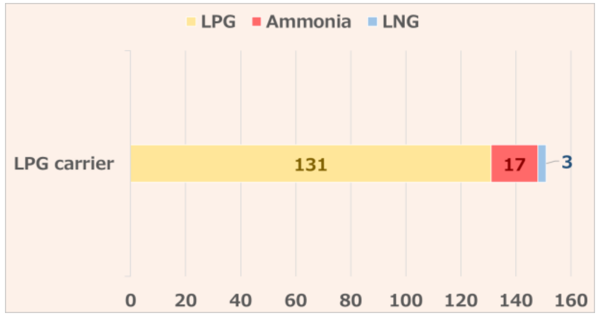


On order —



Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	133 vessels (13.7%)	144 vessels (14.6%)
Total GT	5,816,222 GT (20.2%)	6,170,553 GT (21.0%)

There was an increase of 11 vessels totaling 0.3 million GT in six months. Half of the delivered ships were VLGCs (over 80,000 m^3), and all were LPG-fueled ships.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	127 vessels (59.1%)	151 vessels (54.9%)
Total GT	4,952,445 GT (59.2%)	6,032,335 GT (54.8%)

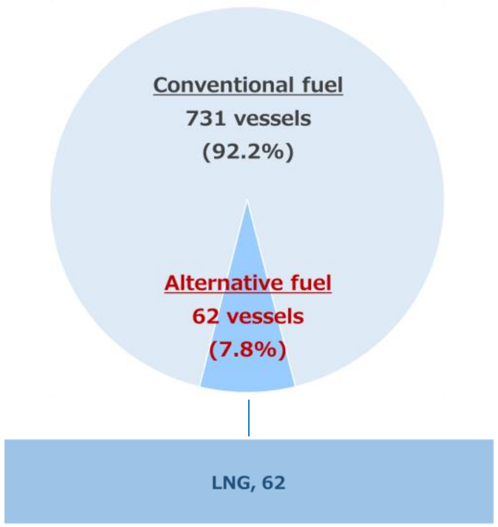
There was an increase of 24 vessels totaling 1.1 million GT in six months. By fuel type, while orders for LPG-fueled ships accounted for the majority, orders for ammonia-fueled ships were also seen.

UPDATED

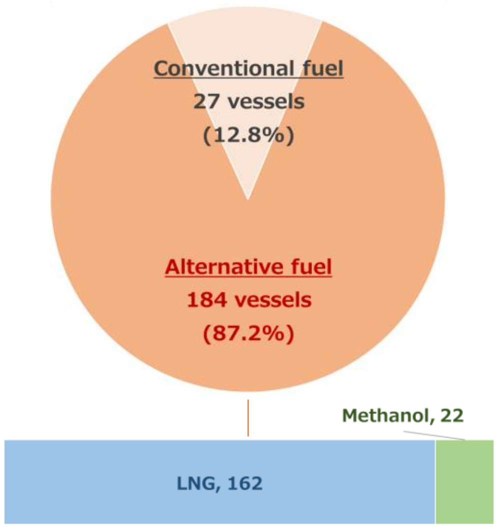
Trends in alternative fuel ships (by ship type)

Vehicle carriers

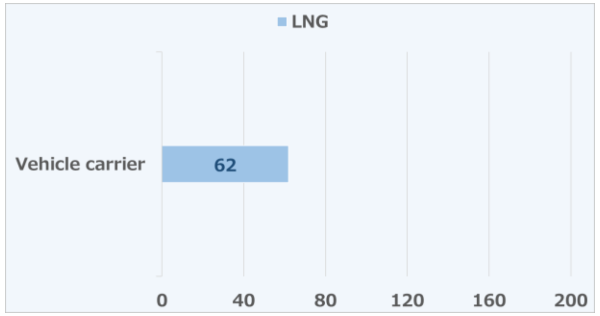
In service —



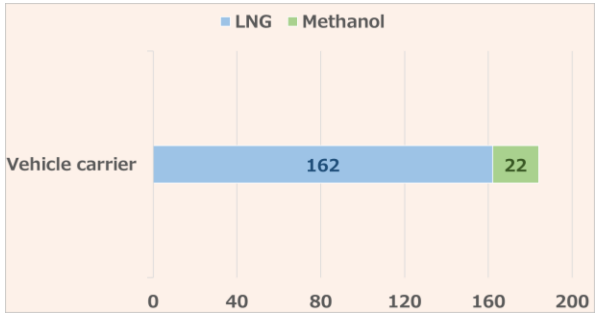
On order —



In service —



On order —



Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	31 vessels (4.1%)	62 vessels (7.8%)
Total GT	2,023,411 GT (5.1%)	4,249,562 GT (10.2%)

There was an increase of 31 vessels totaling 2.2 million GT in six months, significantly increasing the share of alternative fuel ships overall. By fuel type, all delivered ships were LNG-fueled ships.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	180 vessels (87.0%)	184 vessels (87.2%)
Total GT	11,563,177 GT (84.9%)	11,453,222 GT (84.8%)

There was an increase of 4 vessels, with a decrease of 0.1 million GT in six months. By ship size, orders were seen across a wide range, from 4,000 CEU to 11,000 CEU. By fuel type, LNG-fueled ships accounted for the majority, but some methanol-fueled ships were also ordered.

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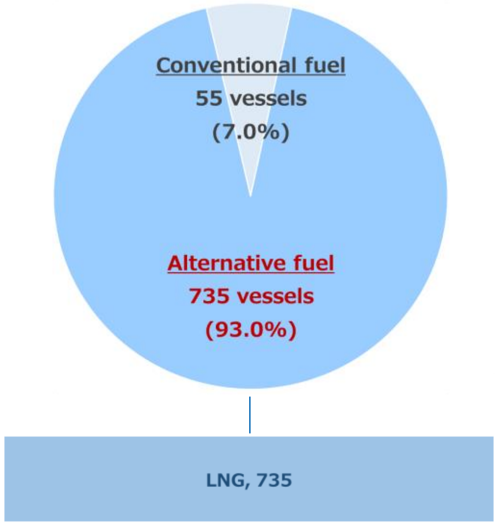
UPDATED

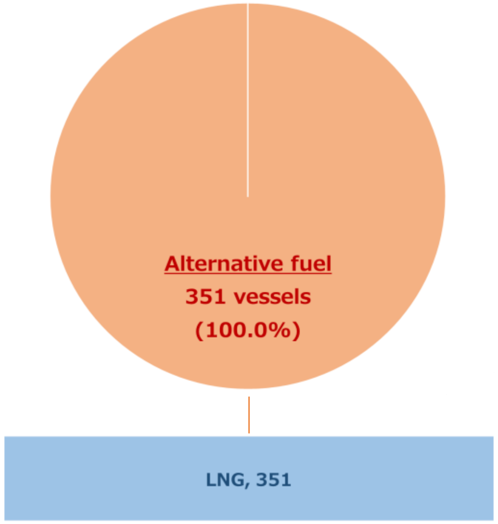
Trends in alternative fuel ships (by ship type)

LNG carriers (for reference)

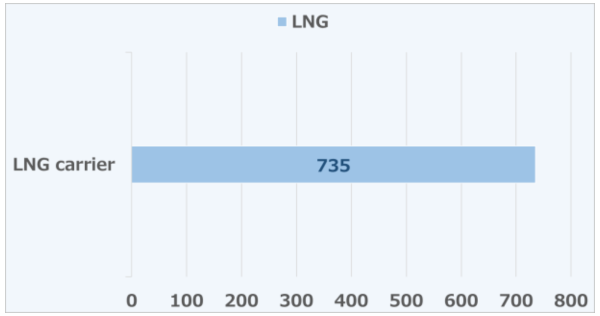
In service —



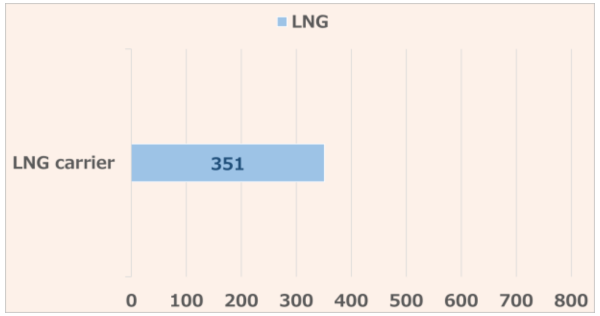
On order —



In service —



On order —



Details of alternative fuel ships (Jun. 2024 → Dec. 2024)

In service —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	705 vessels (92.8%)	735 vessels (93.0%)
Total GT	72,486,110 GT (91.2%)	75,839,495 GT (91.6%)

There was an increase of 30 vessels totaling 3.4 million GT in six months. All were LNG-fueled ships, and no other alternative fuel ships were delivered.

On order —

	As of Jun. 30, 2024	As of Dec. 31, 2024
Number of vessels	355 vessels (100.0%)	351 vessels (100.0%)
Total GT	39,722,960 GT (100.0%)	38,576,761 GT (100.0%)

There was a decrease of 4 vessels totaling 1.1 million GT in six months. The orderbook decreased due in part to the impact of the large number of deliveries in this six-month period. All newly ordered ships were LNG-fueled ships.

— Step 3

Understanding alternative fuels

When considering the adoption of alternative fuels, it is important to understand the characteristics of each fuel, such as their properties and GHG emissions, and to grasp factors like cost and projected supply. In this section, we will outline the attributes of various alternative fuels envisaged for use in international shipping, providing insights into their costs, supply prospects, and other relevant factors.

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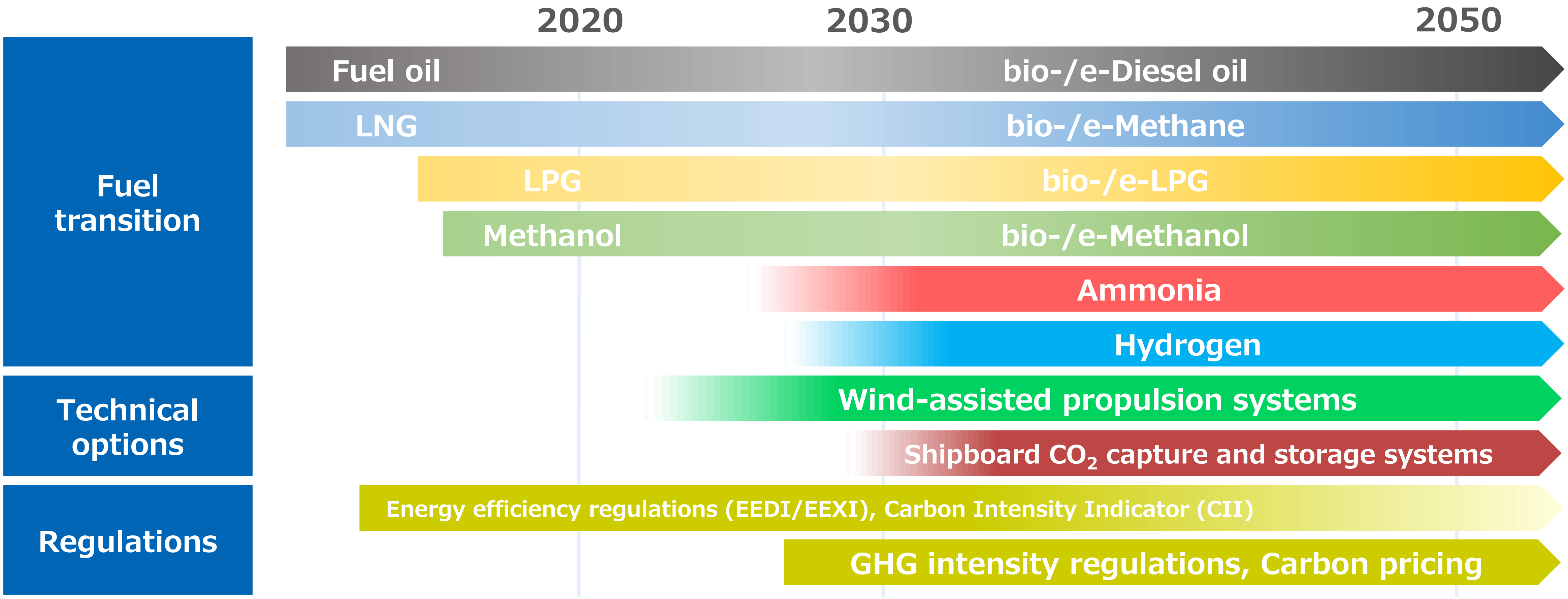
Key Takeaways

- ✓ Each alternative fuel envisaged for use in international shipping has the potential to become zero-emission or carbon-neutral fuel.
- ✓ Due to differences in calorific value, alternative fuels require larger fuel tank capacities compared to conventional fuel oil, potentially resulting in reduced distance covered with the same fuel tank capacity. Therefore, comprehensive fleet-wide consideration, including planned routes, is necessary when adopting alternative fuel ships.
- ✓ The GHG emissions of each alternative fuel differ significantly not only during combustion but also throughout their lifecycle. Therefore, it is important to fully understand the scope of GHG emissions targeted by regulations and to weigh the pros and cons of each fuel under regulation.
- ✓ The cost of zero-emission or carbon-neutral fuels is generally considered to be lower for biomass-derived fuels than for green hydrogen-derived fuels. However, biomass-derived fuels face supply constraints, requiring careful attention to their availability.
- ✓ ClassNK has conducted surveys on the production volumes of biodiesel and zero-emission/carbon-neutral fuels. Considering their demand in international shipping, current production volumes are vastly insufficient, necessitating rapid expansion of production scale.

Fuel transition, technological options, and regulations in international shipping

Various alternative fuels are envisioned for use in shipping, and it remains uncertain which fuel will become predominant. Depending on the manufacturing method, each fuel has the potential to become zero-emission or carbon-neutral throughout its lifecycle, and it is essential to consider the manufacturing technology trends, cost projections, and supply trends of each fuel when selecting fuels.

Timeline for fuel transition, etc.



Fuel properties - 1

As alternative fuels vary significantly in energy density (per weight and volume) depending on the fuel type, the required fuel amount and necessary fuel tank capacity can differ greatly compared to conventional fuel oil. Accurately understanding the physical properties of each fuel is the first step in considering the adoption of alternative fuels.

List of fuel properties (Overview)

Fuel type	HFO	LNG (Methane)	LPG		Methanol	Ammonia	Hydrogen
			Propane	Butane			
TtW CO_2 emission (/MJ) [HFO = 1]	1	0.73	0.85	0.86	0.90	0	0
TtW GHG emission (/MJ) [HFO = 1]	1	0.82	0.85	0.86	0.92	0.04	0.01
Required to obtain the same amount of energy Fuel ton [HFO = 1]	1	0.84	0.87	0.88	2.02	2.16	0.34
In liquid form Fuel tank capacity [HFO = 1]	1	1.89	1.69	1.41	2.47	3.07	4.63
Flammability (Lower Explosive Limit)	0.7 vol%	5.0 vol%	2.1 vol%	1.8 vol%	6.0 vol%	15.0 vol%	4.0 vol%
Toxicity (TLV-TWA*)	-	-	-		200 ppm	25 ppm	-
Cyrogenic (Boiling point)	- (Liquid at normal temp.)	-161℃	-42℃	-0.5℃	- (Liquid at normal temp.)	-33℃	-253℃

*TLV-TWA: Threshold Limit Value Time Weighted Average

Source: CO_2 emission and GHG emission are calculated by ClassNK based on emission factors specified in the FuelEU Maritime regulation.

- ✓ While CO_2 and GHG emission reductions are limited for on-board use of LNG, LPG, and methanol, significant reductions are expected for ammonia and hydrogen.
- ✓ The fuel tank capacity of each alternative fuel is greater than that of conventional fuel oil. To get the same energy as conventional fuel oil, LNG requires a fuel tank capacity 1.89 times larger than that of conventional fuel oil, methanol 2.47 times larger, ammonia 3.07 times larger, and hydrogen 4.63 times larger.
- ✓ Ammonia does not explode unless it is present in the atmosphere at concentrations of 15.0 vol% or higher, making it less explosive than other alternative fuels.
- ✓ Both methanol and ammonia are toxic, with ammonia being of particular concern due to its extremely high toxicity.
- ✓ When storing alternative fuels in liquid form, especially LNG and hydrogen, extremely low temperatures are required.

Fuel properties - 2

Here, we focus on the environmental aspects as we introduce the characteristics of each fuel.

List of fuel properties (Environment-related)

Fuel type	HFO	LNG (Methane)	LPG		Methanol	Ammonia	Hydrogen
			Propane	Butane			
TtW CO_2 emission (/MJ) [HFO = 1]	1	0.73	0.85	0.86	0.90	0	0
TtW GHG emission (/MJ) [HFO = 1]	1	0.82	0.85	0.86	0.92	0.04	0.01
Emissions	✓ NOx ✓ SOx ✓ PM	✓ NOx ✓ Methane slip	✓ NOx		✓ NOx ✓ Methanol slip ✓ Formaldehyde	✓ NOx ✓ Ammonia slip ✓ N_2O	✓ NOx ✓ Hydrogen slip

Source: CO_2 emission and GHG emission are calculated by ClassNK based on emission factors specified in the FuelEU Maritime regulation.

Fuel properties - 3

Here, we focus on the design aspects as we introduce the characteristics of each fuel.

List of fuel properties (Design-related)

Fuel type	HFO	LNG (Methane)	LPG		Methanol	Ammonia	Hydrogen
			Propane	Butane			
In liquid form Energy density per unit volume [HFO = 1]	1	1.89	1.69	1.41	2.47	3.07	4.63
Liquid density [ton/m^3]	0.96	0.42	0.5	0.6	0.79	0.68	0.07
Liquefaction temp. (Boiling point)	-	-161℃	-42℃	-0.5℃	65℃	-33℃	-253℃
Lower calorific value [MJ/kg]	40.2	48.0	46.3	45.7	19.9	18.6	120.0
Engine type (2 stroke)	Diesel	Diesel/ Otto	Diesel		Diesel	Diesel	Diesel
Engine type (4 stroke)	Diesel	Otto	-		Diesel	Diesel/ Otto	Otto
Onboard storage methods	Gravity tank	Type A/B/C Membrane	Type A/B/C		Gravity tank	Type A/B/C Membrane	Low-temp. (Type C, Membrane) High pressure (Type 1/2/3/4)

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Fuel properties - 4

Here, we focus on the safety aspects as we introduce the characteristics of each fuel.

List of fuel properties (Safety-related)

Fuel type	HFO	LNG (Methane)	LPG		Methanol	Ammonia	Hydrogen
			Propane	Butane			
Flammability [Vol%]	0.7 - 5	5 - 15	2.1 – 9.5	1.8 – 8.4	6 - 50	15 – 33.6	4 - 75
Flash point	>60℃	-187.7℃	-104℃	-60℃	9℃	132℃	-
Ignition point	>400℃	537℃	450℃	365℃	440℃	630℃	560℃
Minimum ignition energy	-	0.3 mJ	0.26 mJ	0.26 mJ	0.14 mJ	680 mJ	0.017 mJ
Toxicity [ppm] (ACGIH, TLV-TWA*1)	-	-	-		200	25	-
Toxicity [ppm] (ACGIH, TLV-STEL*2)	-	-	-	1000	250	35	-

*1 Toxicity criteria established by American Conference of Governmental Industrial Hygienist (ACGIH). TLV-TWA (Threshold Limit Value Time Weighted Average) represents the concentration that is believed not to cause adverse health effects to workers who are repeatedly exposed to it during an average workday of 8 hours or a workweek of 40 hours.
*2 Toxicity criteria established by American Conference of Governmental Industrial Hygienist (ACGIH). TLV-STEL (Threshold Limit Value Short Term Exposure Limit) represents the concentration that is believed not to cause adverse health effects to workers if exposed continuously for 15 minutes, provided that their daily exposure does not exceed the TLV-TWA.

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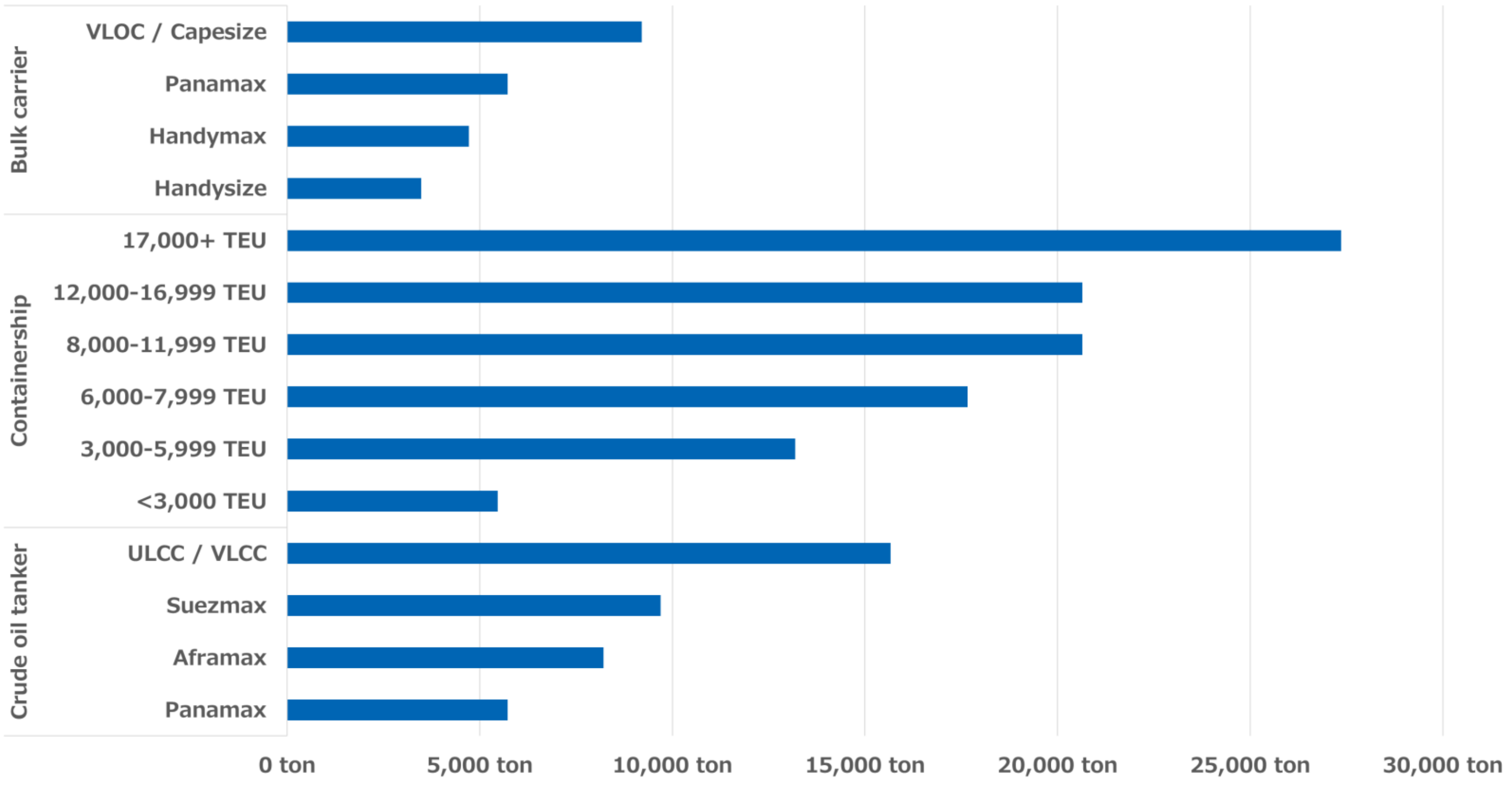
Understanding fuel consumption - 1

Alternative fuels have different calorific values compared to conventional fuel oil, resulting in changes in the required fuel volume (in tons) when transitioning to alternative fuels. It is important to understand the estimated required fuel volume for each fuel type depending on the ship type and size when considering the adoption of alternative fuels.

Image of annual fuel consumption (For conventional fuel oil: HFO) — Bulk carrier, Containership, Crude oil tanker



Required amount of fuel when transitioning to alternative fuels (tons) [Relative to conventional fuel oil]

LNG	0.84 times
LPG	0.87 times
Methanol	2.02 times
Ammonia	2.16 times
Hydrogen	0.34 times

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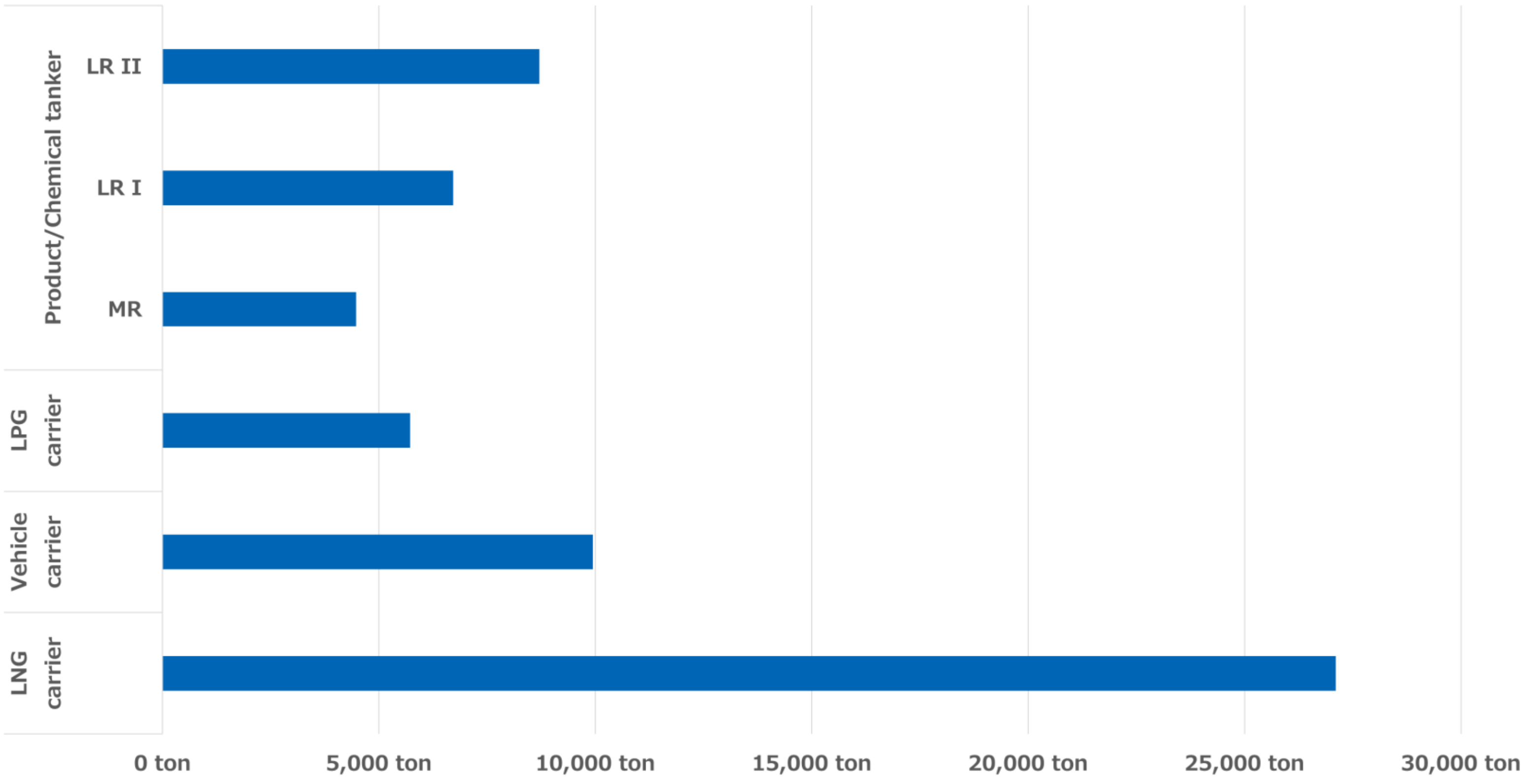
Understanding fuel consumption - 2

Alternative fuels have different calorific values compared to conventional fuel oil, resulting in changes in the required fuel volume (in tons) when transitioning to alternative fuels. It is important to understand the estimated required fuel volume for each fuel type depending on the ship type and size when considering the adoption of alternative fuels.

Image of annual fuel consumption (For conventional fuel oil: HFO) — Product/Chemical tanker, LPG carrier, Vehicle carrier, LNG carrier



Required amount of fuel when transitioning to alternative fuels (tons) [Relative to conventional fuel oil]

- **LNG** 0.84 times
- **LPG** 0.87 times
- **Methanol** 2.02 times
- **Ammonia** 2.16 times
- **Hydrogen** 0.34 times

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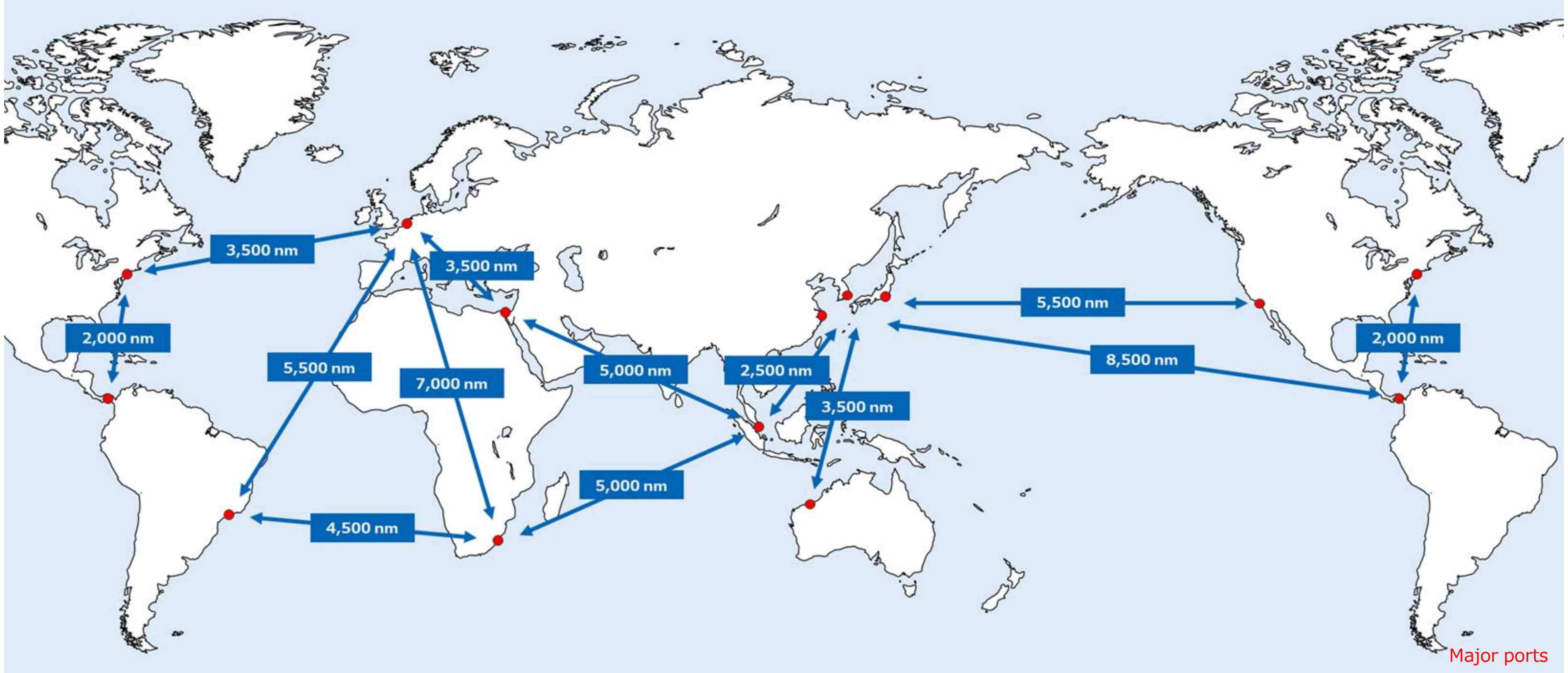
Route selection

Alternative fuel ships cover shorter distances and require different fuel amounts (in tons) compared to conventional fuel ships, even with the same fuel tank capacity. When considering the adoption of alternative fuel ships, it is important to select routes considering the type of fuel and bunkering locations.

Voyage distance on major routes



The amount of fuel required for a 206,000 DWT bulk carrier to sail one way (laden) from Japan to Australia over a distance of 3,500 nm.

- Fuel oil :500 tons
- LNG :420 tons
- LPG :435 tons
- Methanol :1,010 tons
- Ammonia :1,080 tons
- Hydrogen :170 tons

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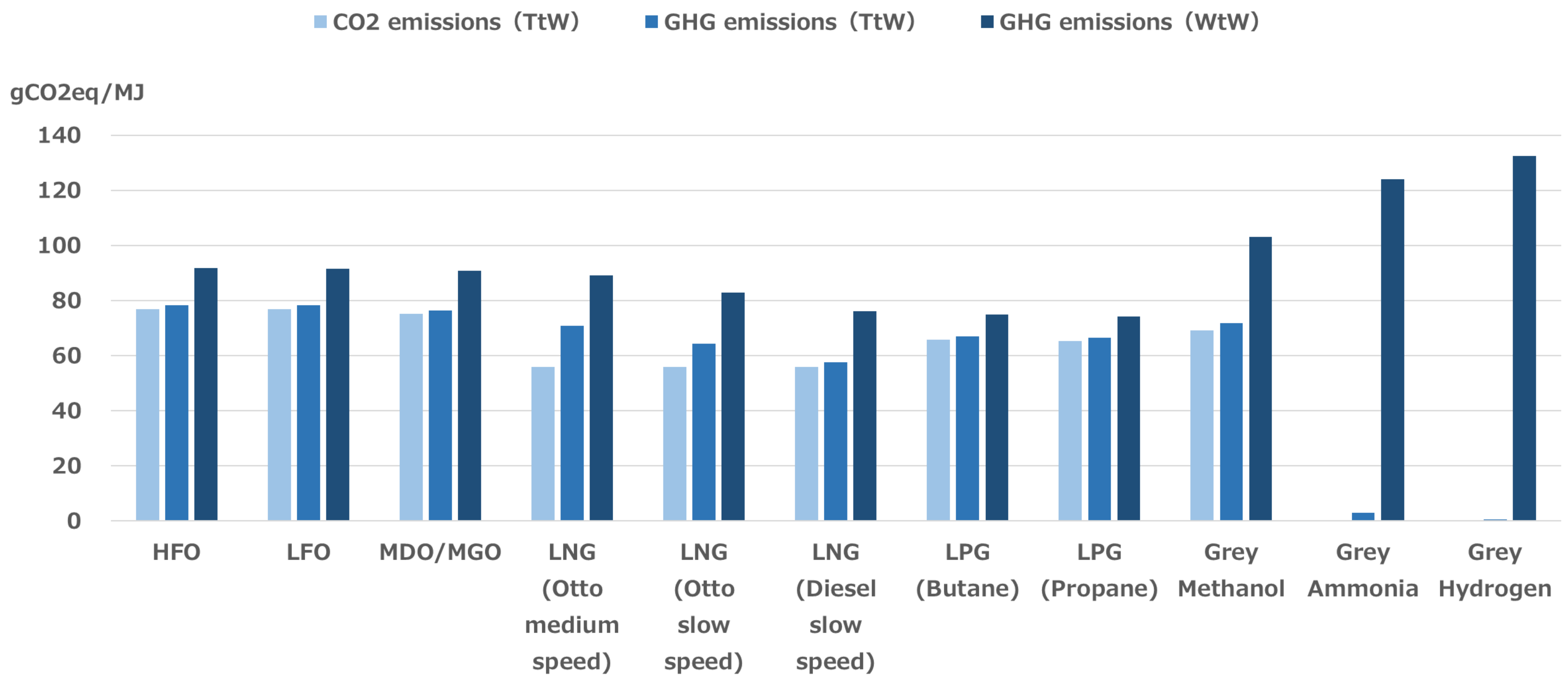
"CO_2 emissions (TtW)" vs. "GHG emissions (TtW)" vs. "GHG emissions (WtW)"

The scope of emissions targeted by regulations varies, including "CO_2 or GHG" and "Tank-to-Wake or Well-to-Wake." To minimize regulatory compliance costs, it is important to understand the default values of emission factors in each regulation and the differences in emissions for each fuel. (TtW: Tank-to-Wake, WtW: Well-to-Wake)

Emissions per unit of energy



Source: Calculated by ClassNK based on emission factors specified in the FuelEU Maritime regulation

Emissions targeted by each regulation

The emissions targeted by regulations within the IMO and the EU include the following:

- ✓ CII :**CO_2 (TtW)**
- ✓ EU-ETS (2026-) :**GHG (TtW)**
- ✓ FuelEU Maritime :**GHG (WtW)**
- ✓ IMO mid-term measures :**To be determined**

Most emission cost-competitive fuel

The fuel with the lowest emissions in each emission scope is as follows* (excluding zero-emission/carbon-neutral fuels):

- ✓ For CO_2 (TtW) :**LNG**
- ✓ For GHG (TtW) :**LNG**
- ✓ For GHG (WtW) :**LPG**

*When compared using the emission factors specified in the FuelEU Maritime regulation

Comparison of CII ratings resulting from fuel transition

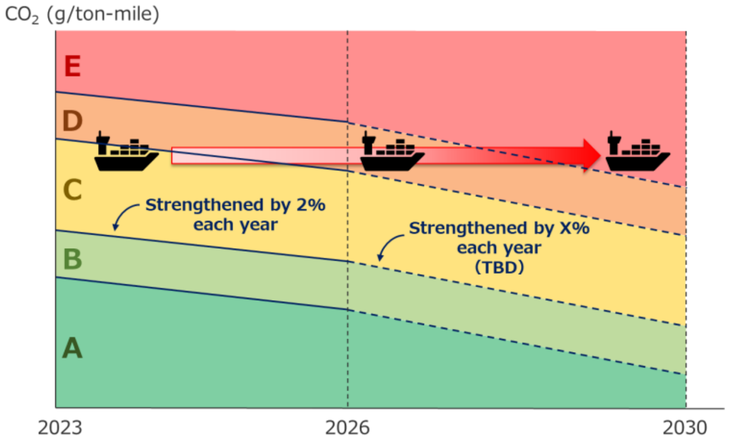
The adoption of alternative fuels is also highly effective in improving CII ratings. Here, we present a comparison of CII ratings for a handymax-sized bulk carrier transitioning from a conventional fuel ship to either a methanol or LNG-fueled ship. (CII: Carbon Intensity Indicators)

Comparison of CII ratings (Conventional fuel oil ship vs. Methanol-fueled ship vs. LNG-fueled ship: e.g. Handymax bulk carrier)

Fuel type	CII ratings				
	2023 (5%)	2024 (7%)	2025 (9%)	2026 (11%)	After 2027 (TBD)
Conventional fuel oil	C	C	D	D	-
Methanol [10% CO_2 reduction compared to conventional fuel oil]	B	C	C	C	-
LNG [27% CO_2 reduction compared to conventional fuel oil]	A	A	B	B	-

The reduction rate (compared to 2019) from the CII reference line in setting the required CII is provided in parentheses.

Image of CII rating transition



- Based on the average energy efficiency performance in 2022, the CII rating for a handymax-sized bulk carrier (using conventional fuel oil) would be **C** as of 2023, and it will follow the trends as indicated in the table (without assuming energy efficiency improvements).
- If it transitions from conventional fuel oil to methanol, the CII rating would improve from **C** to **B** as of 2023 (without assuming fuel efficiency improvements).
- If it transitions from conventional fuel oil to LNG, the CII rating would improve from **C** to **A** as of 2023 (without assuming fuel efficiency improvements).

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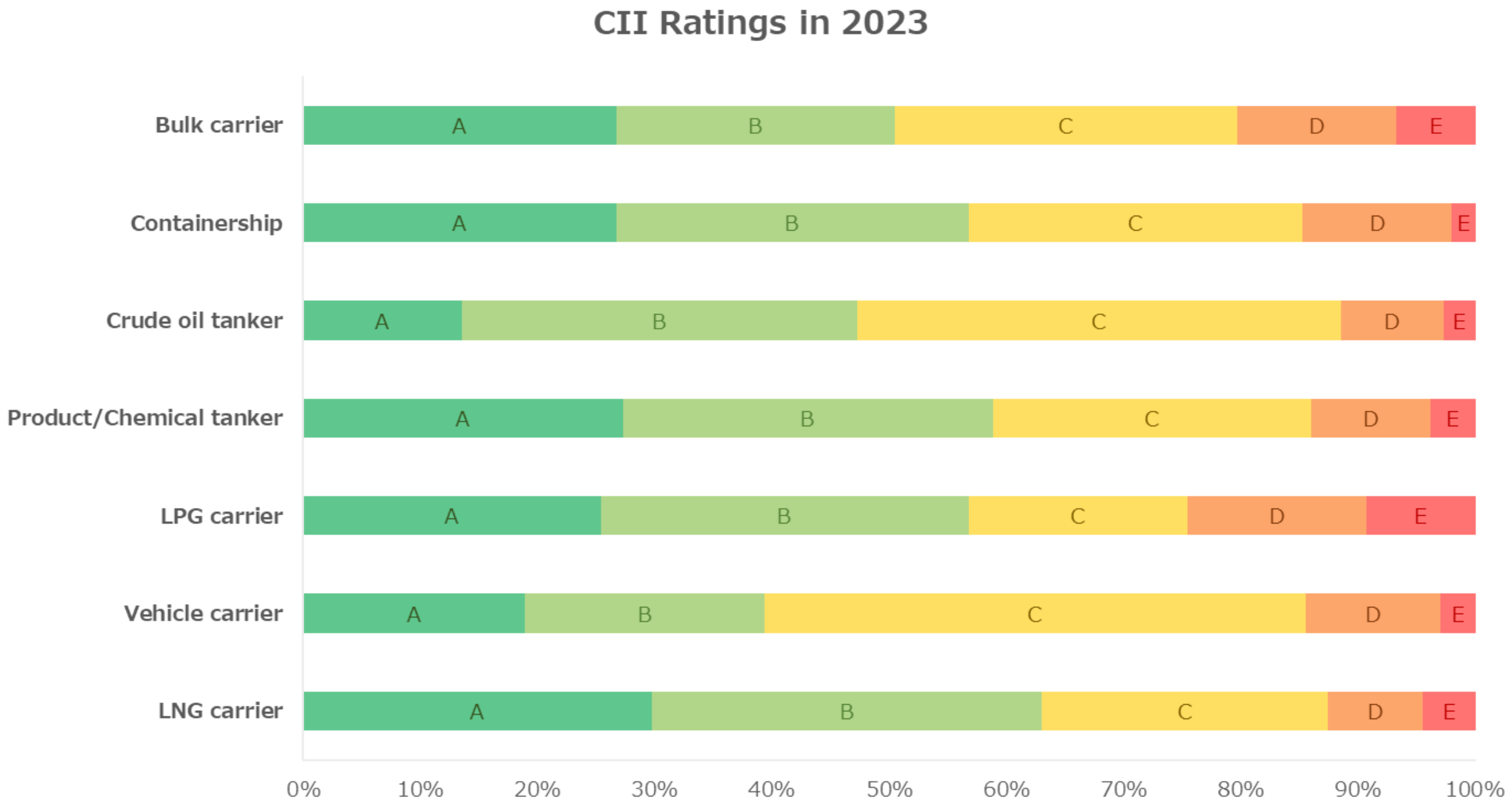
<Reference> Result of CII ratings (2023, verified by ClassNK)

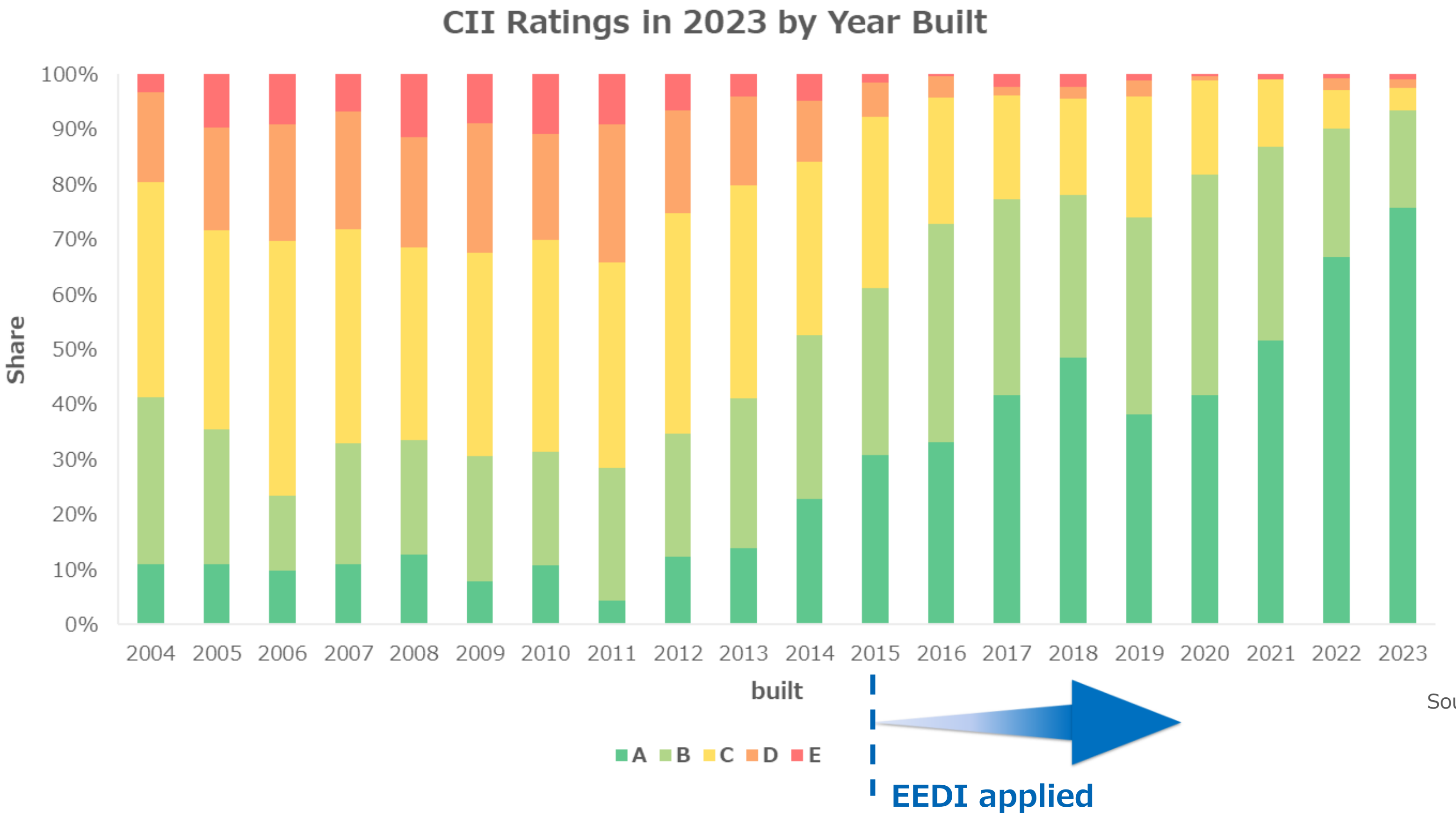


Source: Verified by ClassNK (as of June 2024)

Rating	Total (NK)	Total (IMO)
A	27 %	22 %
B	27 %	25 %
C	29 %	31 %
D	12 %	16 %
E	5 %	6 %
Source	Verified by ClassNK (as of June 2024)	Calculated based on MEPC 82/6/38, Table 1

- ClassNK compiled the CII ratings of ships whose voyage data it verified. As ClassNK-verified ships tended to be relatively young, meaning they had good design energy efficiency, the CII ratings of ClassNK-verified ships were better than the overall average.

<Reference> Result of CII ratings (2023, verified by ClassNK, by year built)



Source: Verified by ClassNK (as of June 2024)

➢ The CII rating results show that younger ships, which tend to have better design energy efficiency, have achieved better ratings. This trend is particularly evident after 2015 when the EEDI applicable ships are available.

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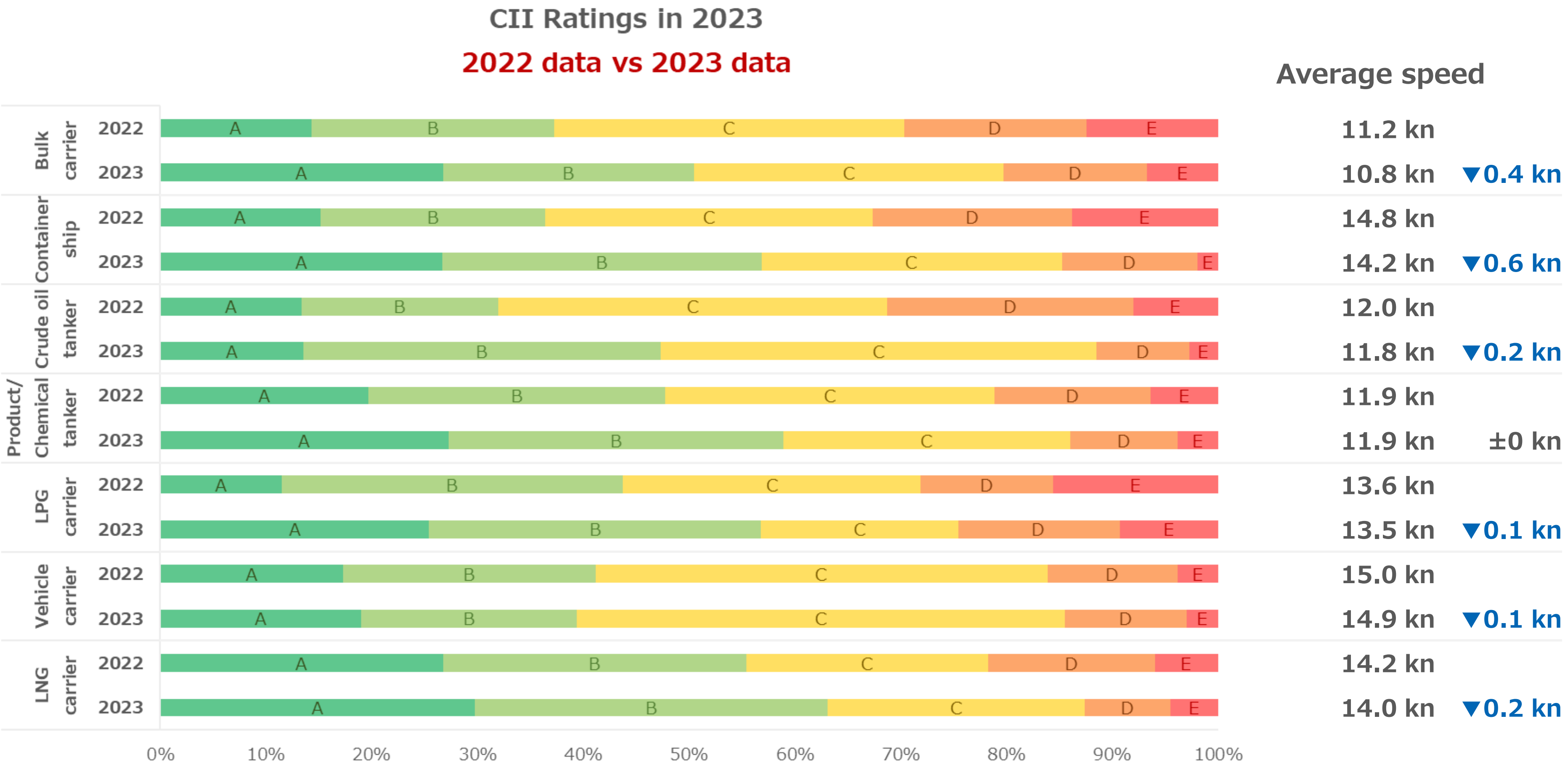
<Reference> Result of CII ratings (2022 vs. 2023, verified by ClassNK)



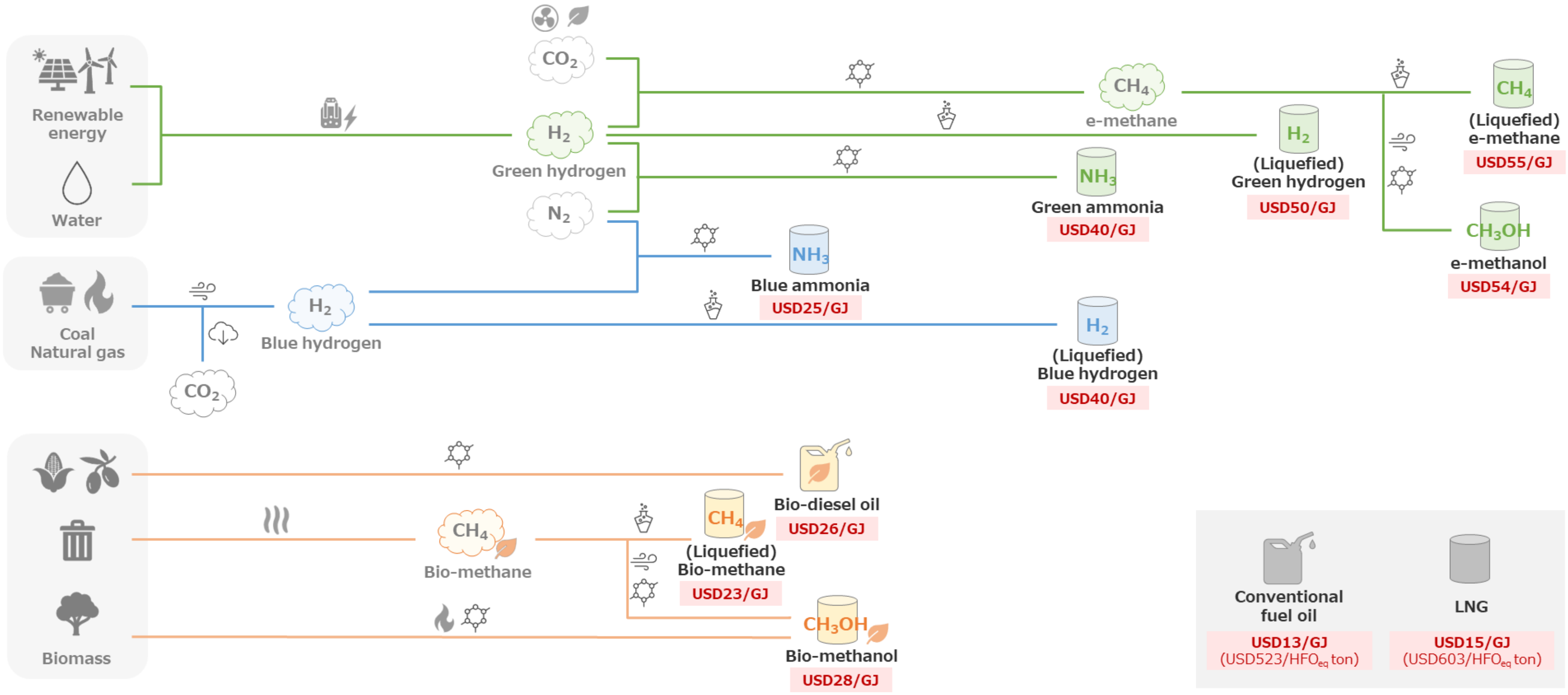
Source: Verified by ClassNK (as of June 2024)

- ClassNK compared the CII rating results between the 2022 and 2023 voyage data. As a result of factors such as slow steaming, the CII ratings in the 2023 voyage data were better than those in the 2022 voyage data.

Alternative fuel costs

Alternative fuels available for ships vary widely, but the cost of each alternative fuel is expected to be 1.5 to 4 times higher than that of conventional fuel oil by 2030. While the cost gap between conventional fuel oil and alternative fuels is expected to narrow in the future as production expands and regulations are introduced, price trends based on supply and demand remain uncertain. Therefore, when considering the adoption of alternative fuels, it is crucial to assess the trend of fuel costs.

Production pathways and costs of alternative fuels (The costs are projected as of 2030.)



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Share of alternative fuels

Alternative fuels such as LNG, LPG, and methanol account for only 7% of the annual fuel consumption of the world fleet, which is 216 million tons (as of 2023). With an expected increase in orders for alternative fuel ships, this proportion is expected to increase. Therefore, further expansion of production capacity is essential to meet the growing demand for alternative fuels in the future.

Fuel Consumption of ships subject to the IMO DCS (5,000 gross tonnage and above engaged in international voyages) [Unit: ton]

	Heavy Fuel Oil (HFO)	Light Fuel Oil (LFO)	Diesel/Gas Oil (MDO/MGO)	LNG	LPG (Propane)	LPG (Butane)	Methanol	Ethanol	Other (Mainly biofuels)	Total (HFO eq)
2021 (28,171 ships) (1.25 bn GT)	109,169,447	64,479,128	25,732,999	12,623,121	34,973	2,028	13,031	4,849	170,501	217,710,495
2022 (28,834 ships) (1.29 bn GT)	116,576,283	57,077,835	28,285,802	10,950,408	88,774	16,673	35,523	10,890	226,739	218,339,992
2023 (28,620 ships) (1.30 bn GT)	130,441,745	40,416,174	26,600,016	12,890,011	192,405	49,887	93,876	4,137	428,263	215,833,384

Source: Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS

If we aim to replace all 216 million tons of Heavy Fuel Oil (HFO) with alternative fuels...

- **HFOeq 216 mil. tons** ▶ **For all methanol** **440 mil. tons of methanol needed** (Current global production volume for all sectors: 106 mil. tons/year*)
- **HFOeq 216 mil. tons** ▶ **For all ammonia** **470 mil. tons of ammonia needed** (Current global production volume for all sectors: 183 mil. tons/year*)
- **HFOeq 216 mil. tons** ▶ **For all methane/LNG** **180 mil. tons of methane needed** (Current global production volume for all sectors: 401 mil. tons/year*)
- **HFOeq 216 mil. tons** ▶ **For all hydrogen** **70 mil. tons of hydrogen needed** (Current global production volume for all sectors: 97 mil. tons/year*)

*Approximately 99% of the production volume is derived from fossil resources.

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Amount of renewable energy electricity required for green hydrogen production

Expanding the production of green hydrogen, which serves as the raw material for green ammonia and green methanol, requires an increase in the adoption of renewable energy. Here, we introduce an estimate of the renewable energy electricity capacity needed for green hydrogen production.

Amount of renewable energy electricity required for green hydrogen production

Annual fuel consumption in international shipping[*1]

*1 Subject to ships 5,000 gross tonnage and above engaged in international voyages

HFO eq 216 mil. tons

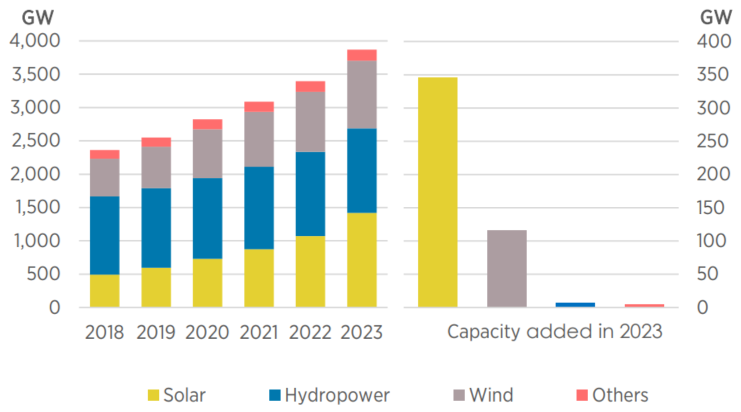
Methanol eq	Ammonia eq	Methane eq	Hydrogen eq
440 mil. tons	470 mil. tons	180 mil. tons	70 mil. tons
Required Hydrogen 84 mil. tons	Required Hydrogen 85 mil. tons	Required Hydrogen 90 mil. tons	
530 GW	540 GW	570 GW	450 GW

Required renewable energy electricity capacity[*2]

x 365 days of operation (8,760h)

*2 The calculated power consumption is based on 5.0 kWh per Nm^3-H_2.

Trend of global renewable energy capacity



Source: IRENA (2024), Renewable capacity statistics 2024, International Renewable Energy Agency, Abu Dhabi. (Highlights)

- Renewable energy capacity is steadily increasing, and the capacity required for green hydrogen production (as shown in the left figure) has been met, but currently, most of it is used directly as electricity. For the decarbonization of international shipping, the key point moving forward will be finding ways to introduce and expand the use of renewable energy for green hydrogen production purposes.

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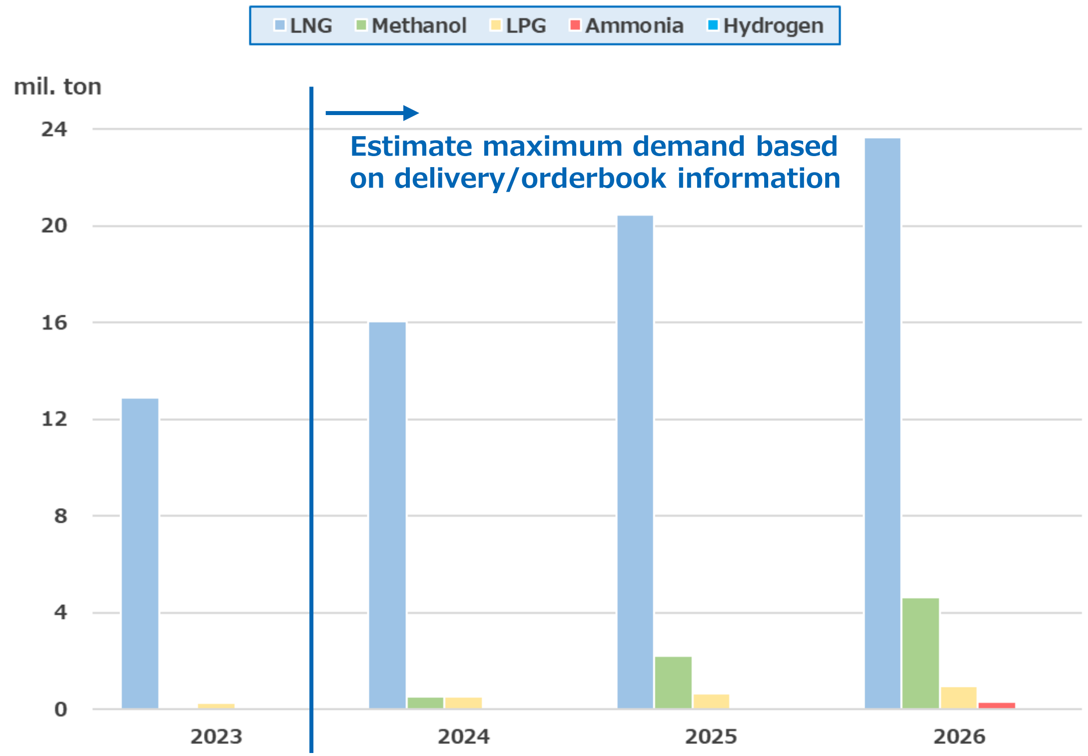
Demand outlook for alternative fuels

Understanding the demand outlook for alternative fuels is critical for securing alternative fuels and estimating procurement costs. Here we presents an estimated demand forecast for alternative fuels based on orderbook data for alternative fuel ships.

Maximum demand outlook for alternative fuels



- ✓ 5,000 gross tonnage and above / LNG carriers are included. / Alternative fuel ready ships are not included.
- ✓ The data for 2023 are from the IMO DCS.

- ✓ ClassNK has estimated the maximum* demand for each alternative fuel through 2026, using orderbook data for alternative fuel ships as of December 31, 2024.

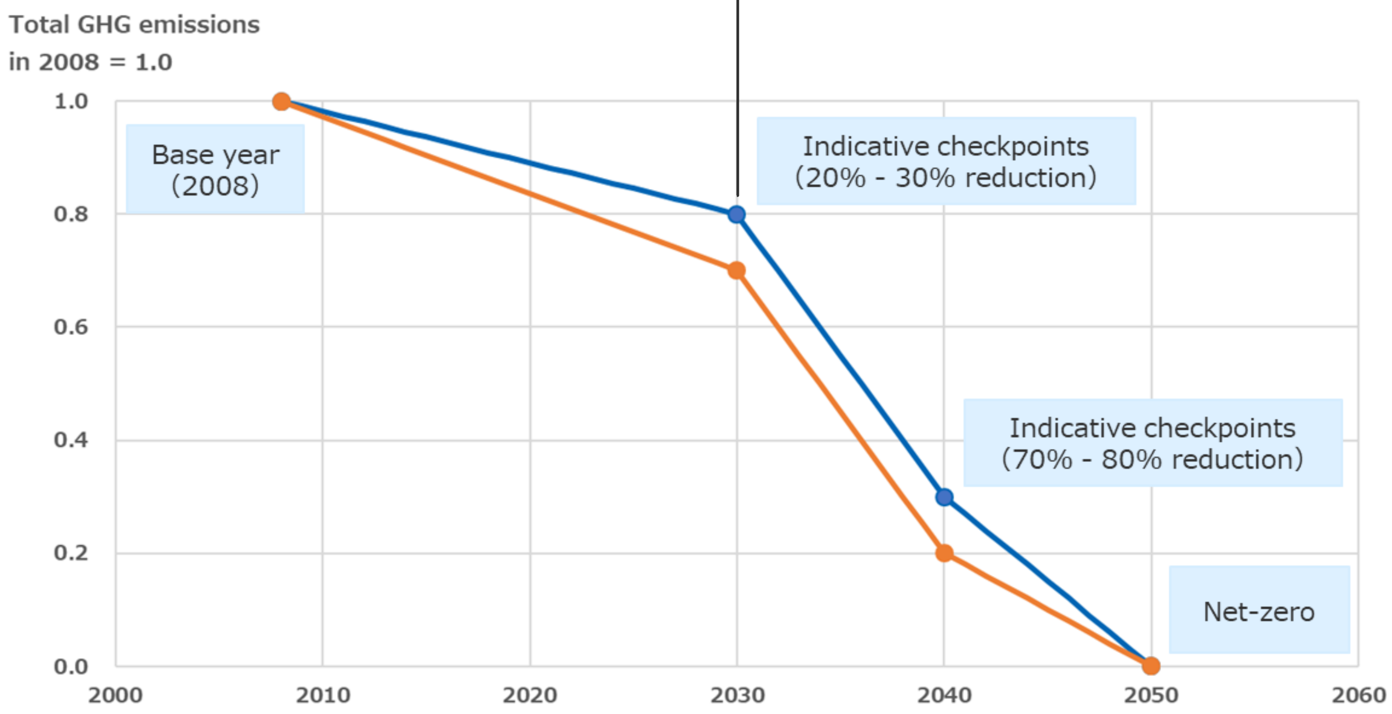
  *For alternative fuel ships delivered/to be delivered after 2024, it is assumed that they will operate solely on alternative fuels, with no pilot fuel use.

- ✓ **LNG**: The mass delivery of LNG-fueled ships, on a scale comparable to the current fleet, could lead to a peak demand of **24 million tons** by 2026.
- ✓ **Methanol**: The successive delivery of methanol-fueled ships, especially containerships, could lead to a peak demand of **4.5 million tons** by 2026.
- ✓ **LPG**: Given that the only ship type anticipated to use this fuel is the LPG carrier, the peak demand is forecast to be capped at **1 million tons** by 2026.
- ✓ **Ammonia** and **Hydrogen**: Despite the current limited demand, future growth is anticipated as these fueled ships are delivered.

Zero-emission fuels and zero-emission ships required for international shipping

The "2023 IMO GHG Strategy" has set new GHG reduction targets, and international shipping will now chart a course towards achieving net-zero GHG emissions by or around 2050. Here, we introduce the volume of zero-emission fuels and zero-emission ships needed along this pathway.

Introduction volume of zero-emission ships/fuels needed to achieve the 2030 indicative checkpoint in the IMO's GHG reduction goal



Introduction volume of zero-emission ships/fuels needed to achieve the 2030 indicative checkpoint (Well-to-Wake)*:

*Calculations for ships of 5,000 gross tonnage and above engaged in international voyages (ships subject to IMO DCS)

✓ Zero-emission fuels

25% of the fuel used in international shipping to be zero-emission fuel (as of 2030)

- For all green methanol :106 million tons
- For all green ammonia :114 million tons

✓ Zero-emission ships

Zero-emission ships needed to consume the above fuel volume (as of 2030)

- 352 million gross tonnage

Please refer to the ClassNK-issued white paper titled "Pathway to Zero-Emission in International Shipping - Understanding the 2023 IMO GHG Strategy" for more details.

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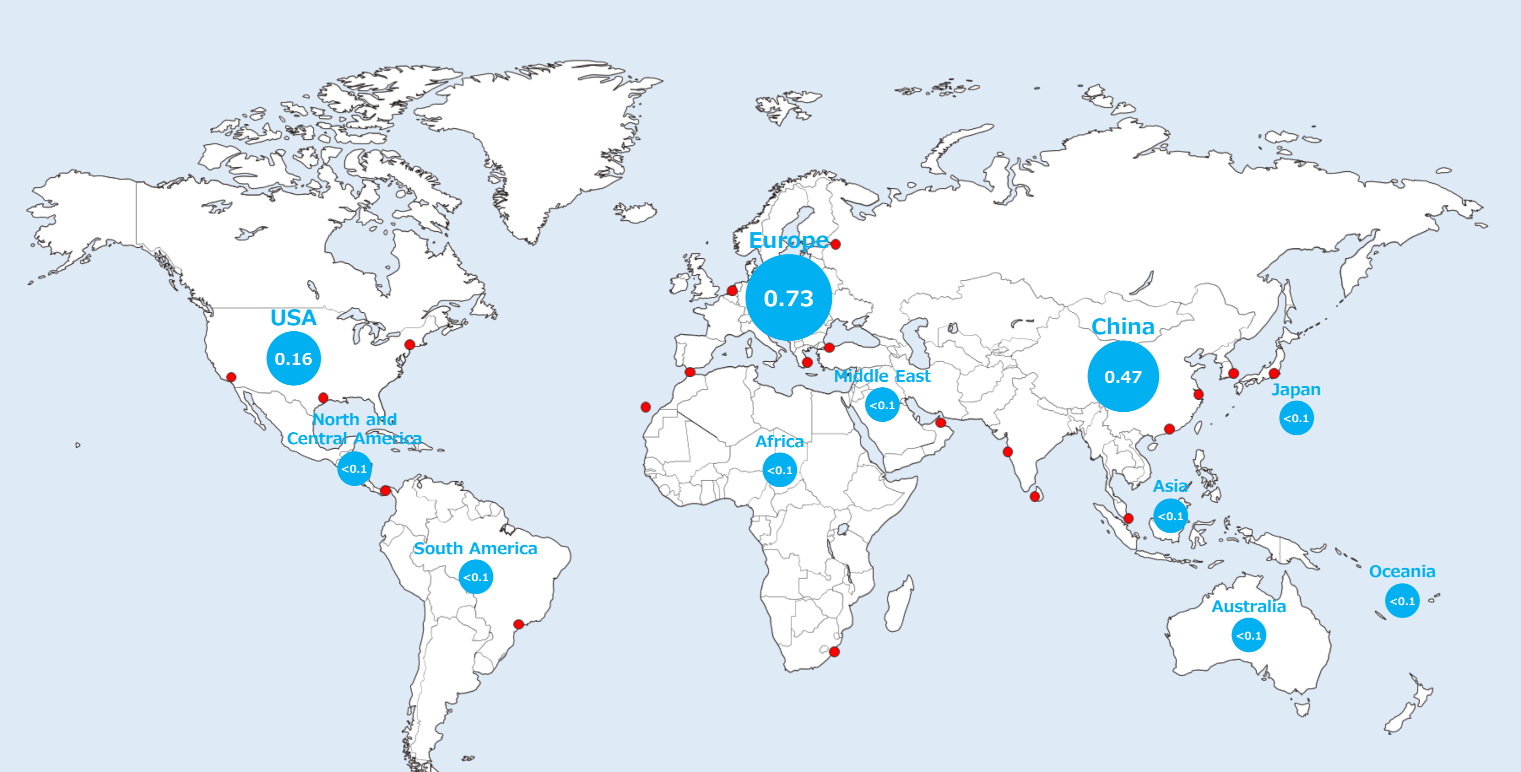
Alternative fuel production projects - 1 (Green hydrogen)

Understanding the projected supply of each fuel is essential when adopting alternative fuels. Here, we present the production scale (including planned production) of green hydrogen. Hydrogen can be used not only directly as marine fuel but also as a raw material for ammonia and methanol. Please note that production projects are not limited to the shipping sector.

Distribution of green hydrogen production projects (Operational/Construction/FID, for all sectors, as of October 2024)



Unit: million tons H_2/year

Main bunkering ports for conventional fuel oil

Country/ Region	Number of projects	Annual production capacity (total) [Unit: ton H_2/year]
Europe	301	730,727
China	33	479,120
USA	26	160,928
Australia	29	61,705
North and Central America	14	29,801
Asia	31	24,982
Africa	5	14,239
South America	17	5,422
Japan	17	3,097
Oceania	1	225
Middle East	3	215
Total	**477**	**1,510,461**

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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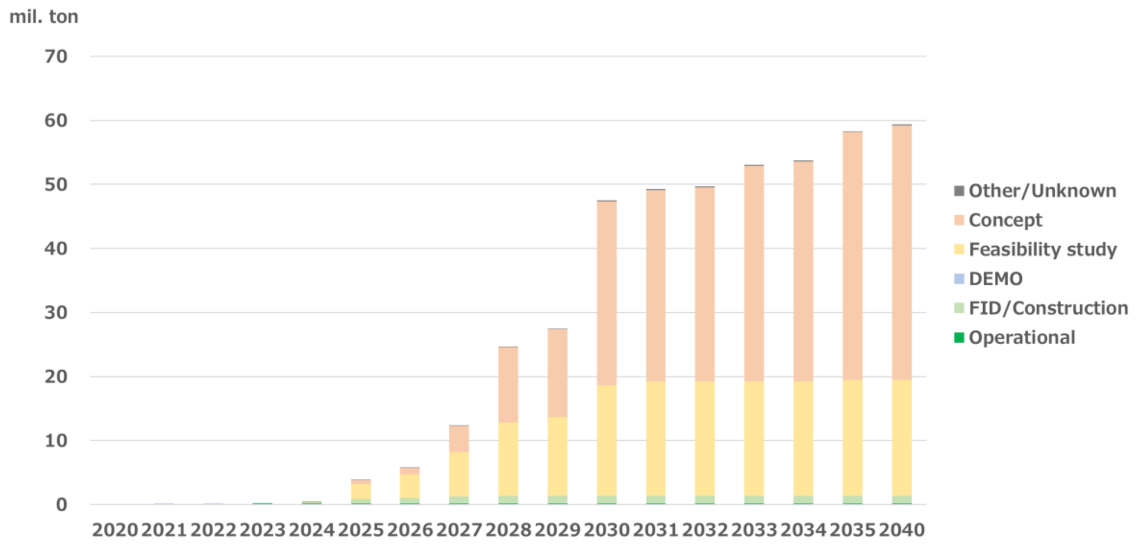
Alternative fuel production projects - 1 (Green hydrogen)

The majority of green hydrogen projects slated to commence production by 2040 are still in the conceptual or feasibility study stages and have not reached the final investment decision. It is necessary to continue monitoring the progress of these projects to assess the expected production volume in the future.

Projected production capacity of green hydrogen (for all sectors, as of October 2024)

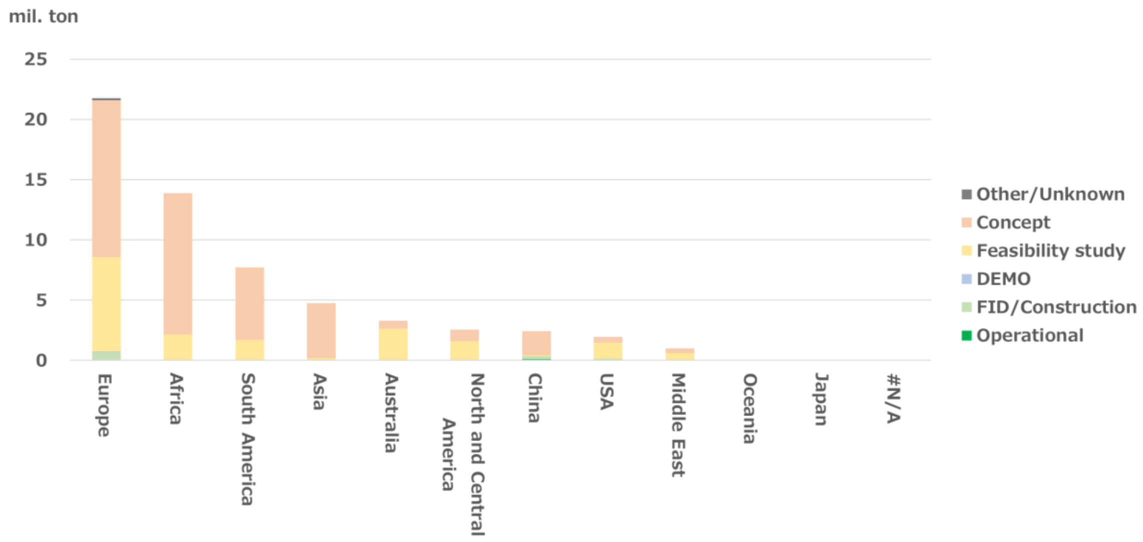
Projected production capacity by year



➢ The green hydrogen production capacity is expected to increase rapidly after 2030, but most of the projects are still in the conceptual or feasibility study stages.

Projected production capacity by country/region (as of 2040*)

*After 2040, there are no projects planned.



➢ Many of the green hydrogen projects slated to start production by 2040 are located in Europe, followed by Africa and South America, which are considered suitable locations for green hydrogen production.

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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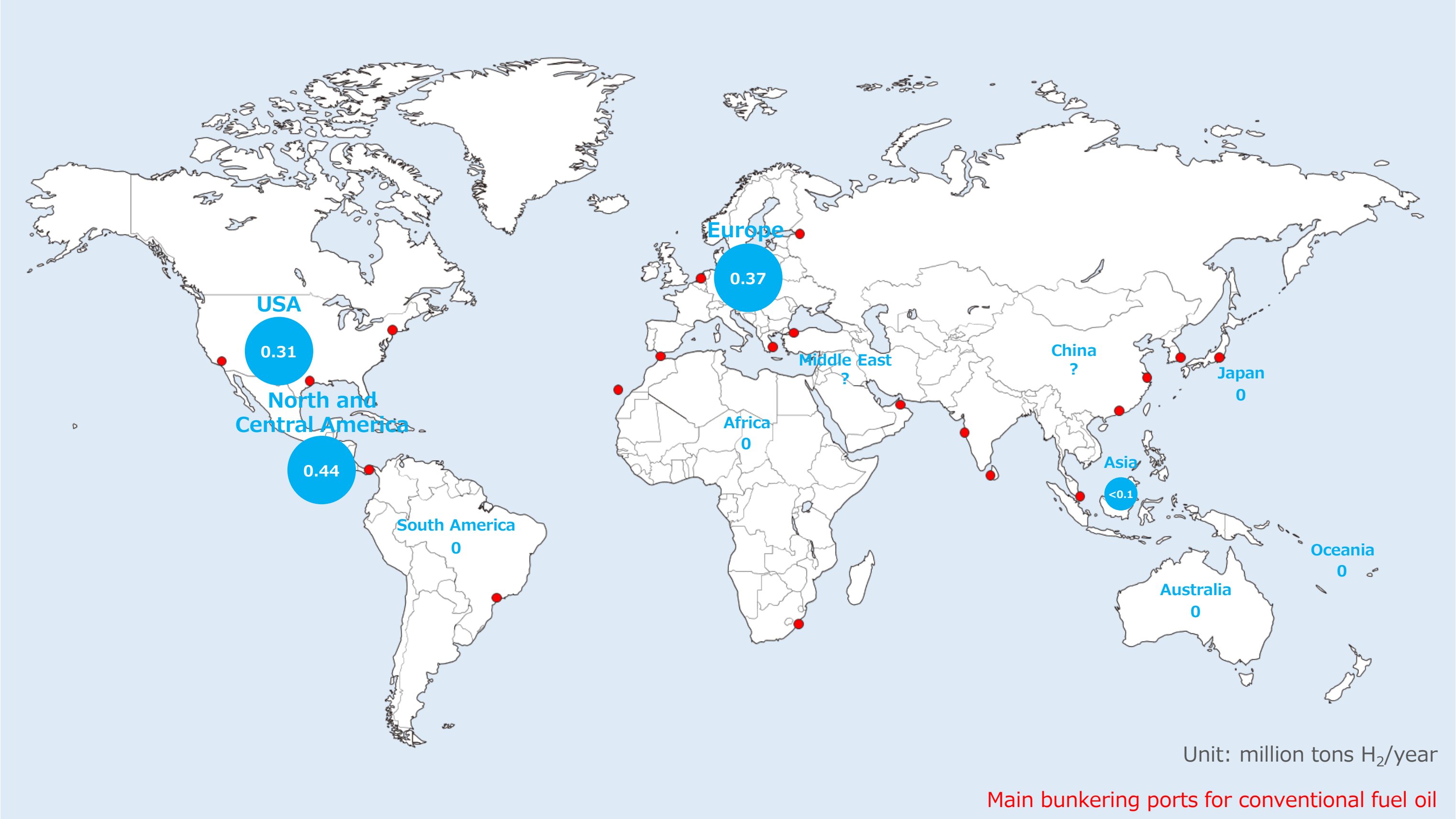
Alternative fuel production projects - 2 (Blue hydrogen)

Here we introduce the production scale of blue hydrogen (including planned production). Hydrogen can be used not only directly as marine fuel but also as a raw material for ammonia and methanol. Please note that production projects are not limited to the shipping sector.

Distribution of blue hydrogen production projects (Operational/Construction/FID, for all sectors, as of October 2024)



Country/ Region	Number of projects	Annual production capacity (total) [Unit: ton H_2/year]
North and Central America	5	440,000
Europe	7	371,410
USA	4	316,155
Asia	1	1,825
China	2	?
Middle East	1	?
Total	**20**	**1,129,390**

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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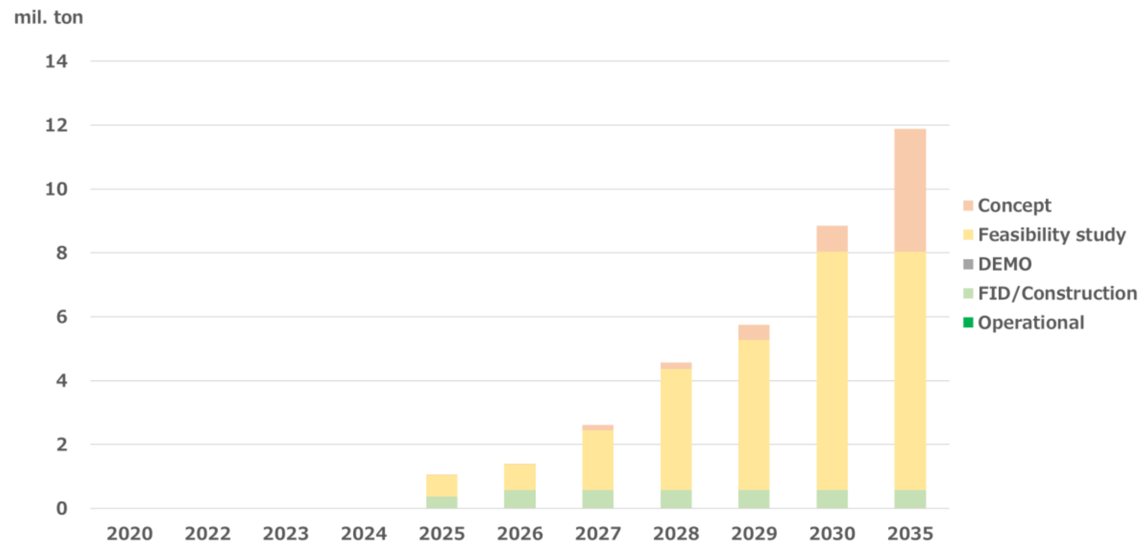
Alternative fuel production projects - 2 (Blue hydrogen)

The majority of blue hydrogen projects slated to commence production by 2035 are still in the feasibility study stages and have not reached the final investment decision. It is necessary to continue monitoring the progress of these projects to assess the expected production volume in the future.

Projected production capacity of blue hydrogen (for all sectors, as of October 2024)

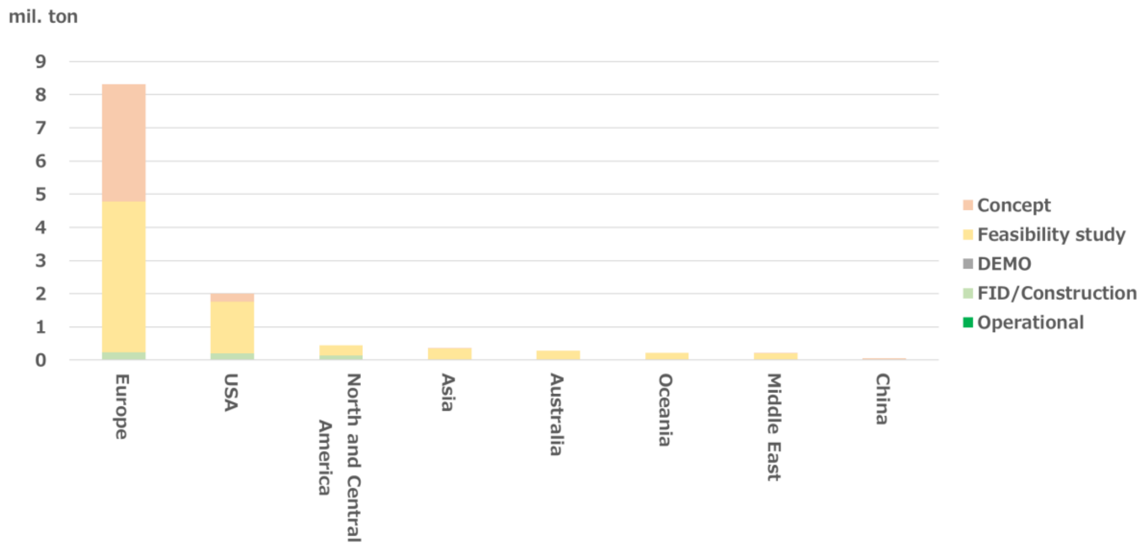
Projected production capacity by year



➢ The blue hydrogen production capacity is expected to increase in the latter half of the 2020s, but most of the projects are still in the feasibility study stages.

Projected production capacity by country/region (as of 2035*)

*After 2035, there are no projects planned.



➢ Most of the blue hydrogen projects slated to start production by 2035 are located in Europe.

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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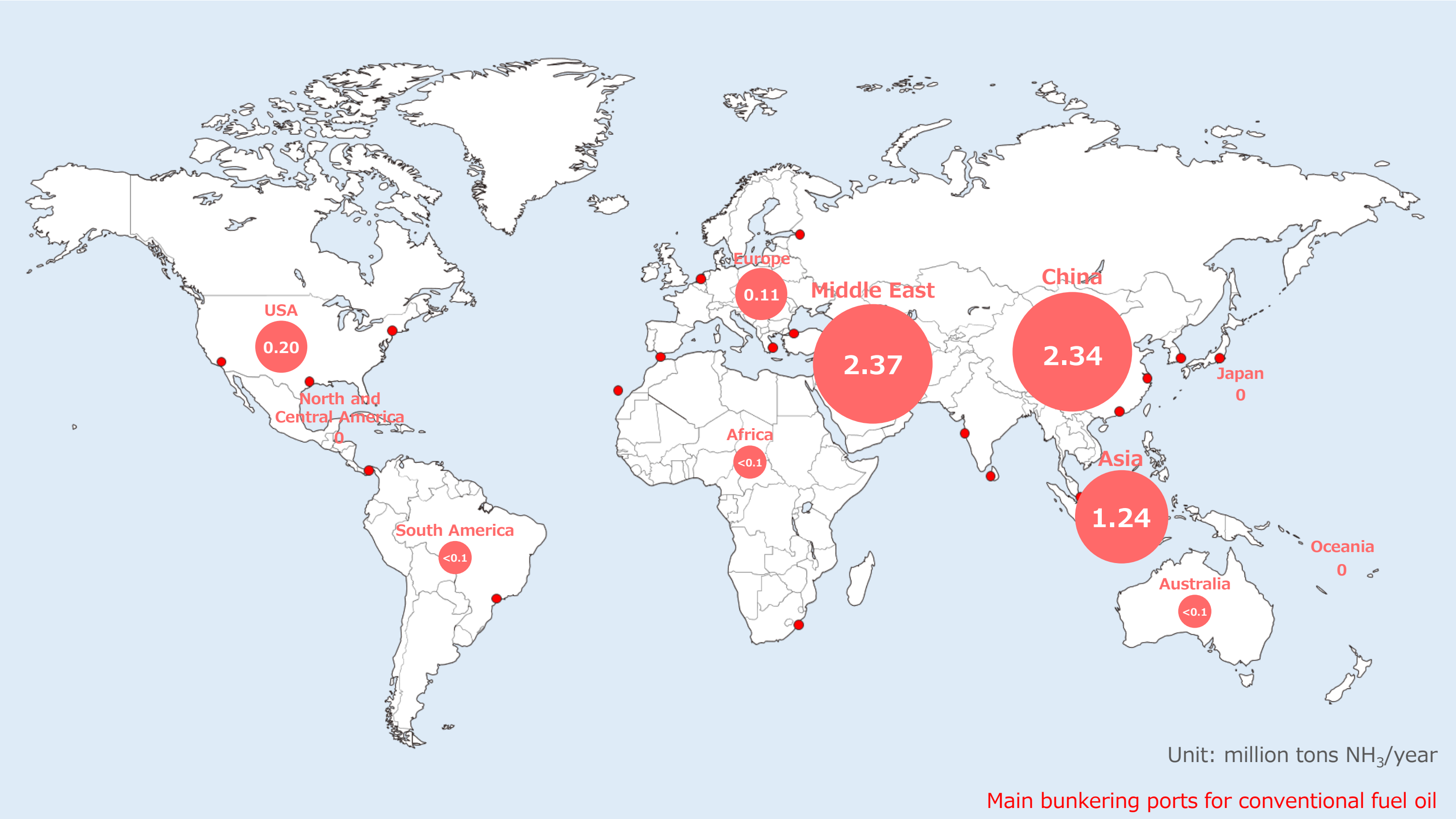
Alternative fuel production projects - 3 (Green ammonia)

Here we introduce the production scale of green ammonia (including planned production). Ammonia is expected to be used not only directly as marine fuel but also as a hydrogen carrier. Please note that production projects are not limited to the shipping sector.

Distribution of green ammonia production projects (Operational/Construction/FID, for all sectors, as of October 2024)



Country/ Region	Number of projects	Annual production capacity (total) [Unit: ton NH_3/year]
Middle East	2	2,378,562
China	14	2,343,089
Asia	3	1,244,428
USA	2	207,068
Europe	5	114,229
South America	4	82,862
Australia	2	62,330
Africa	3	12,730
Total	**35**	**6,445,298**

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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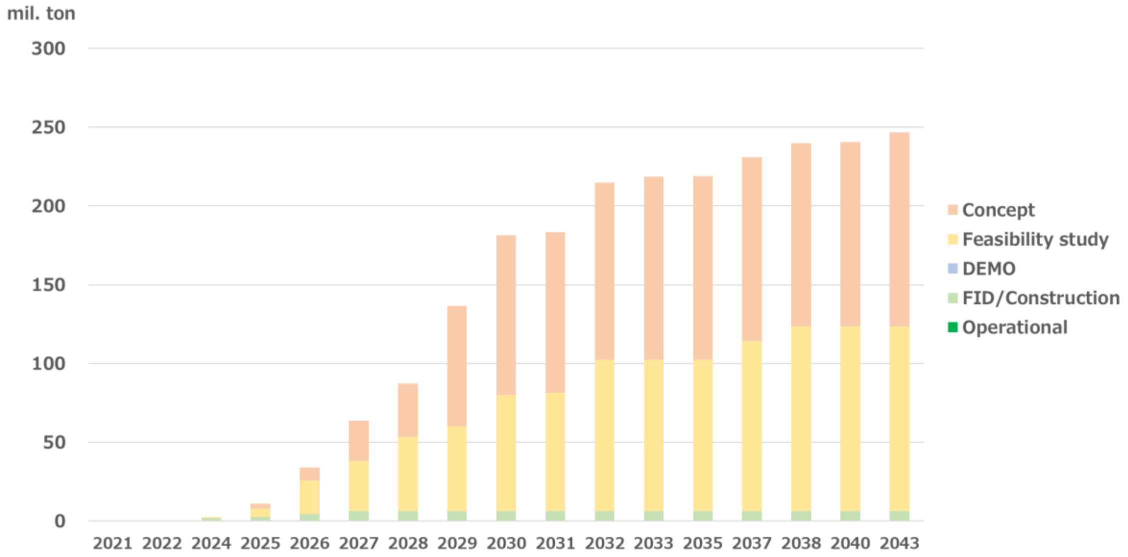
Alternative fuel production projects - 3 (Green ammonia)

The majority of green ammonia projects slated to commence production by 2043 are still in the conceptual or feasibility study stages and have not reached the final investment decision. It is necessary to continue monitoring the progress of these projects to assess the expected production volume in the future.

Projected production capacity of green ammonia (for all sectors, as of October 2024)

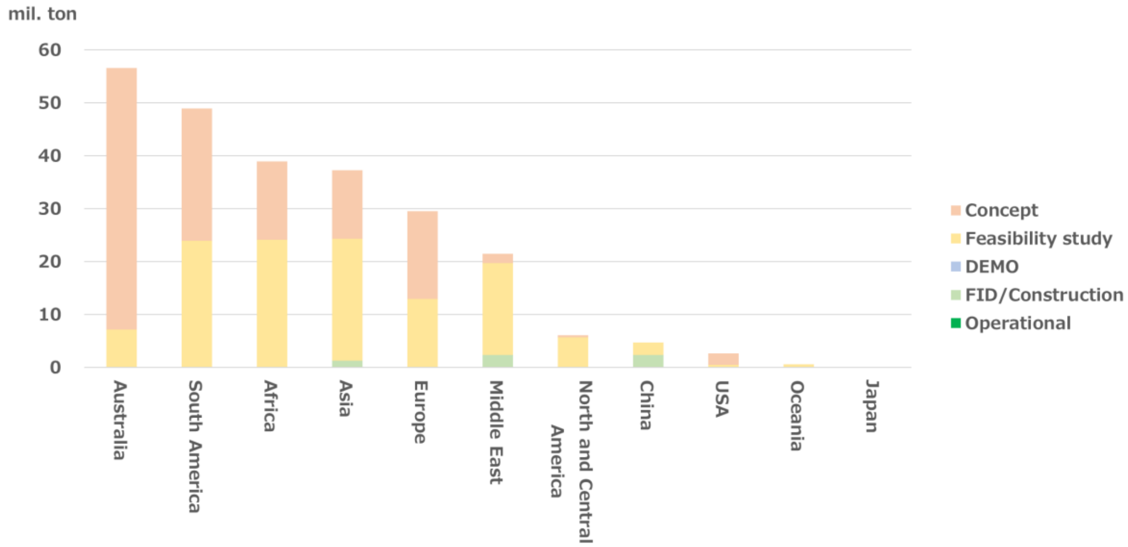
Projected production capacity by year



➢ The green ammonia production capacity is expected to increase gradually, but most of the projects are still in the conceptual or feasibility study stages.

Projected production capacity by country/region (as of 2043*)

*After 2043, there are no projects planned.



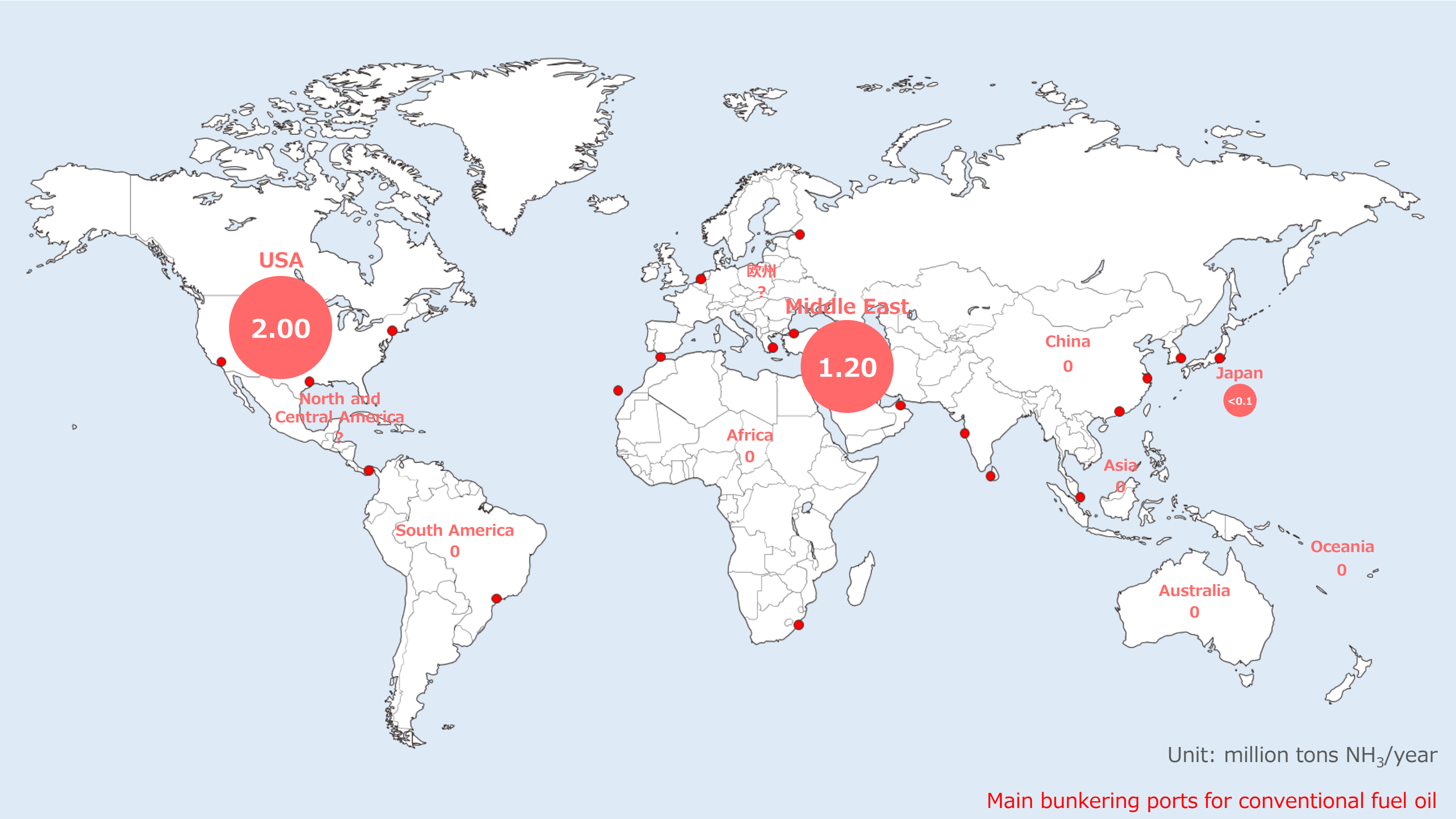
➢ Many of the green ammonia projects slated to start production by 2043 are located in Australia and South America, etc., which are considered suitable locations for green hydrogen production.

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

Alternative fuel production projects - 4 (Blue ammonia)

Here we introduce the production scale of blue ammonia (including planned production). Ammonia is expected to be used not only directly as marine fuel but also as a hydrogen carrier. Please note that production projects are not limited to the shipping sector.

Distribution of blue ammonia production projects (Operational/Construction/FID, for all sectors, as of October 2024)



Country/ Region	Number of projects	Annual production capacity (total) [Unit: ton NH_3/year]
USA	7	2,000,000
Middle East	1	1,200,000
Japan	1	3,887
North and Central America	1	?
Europe	1	?
Total	**11**	**3,203,888**

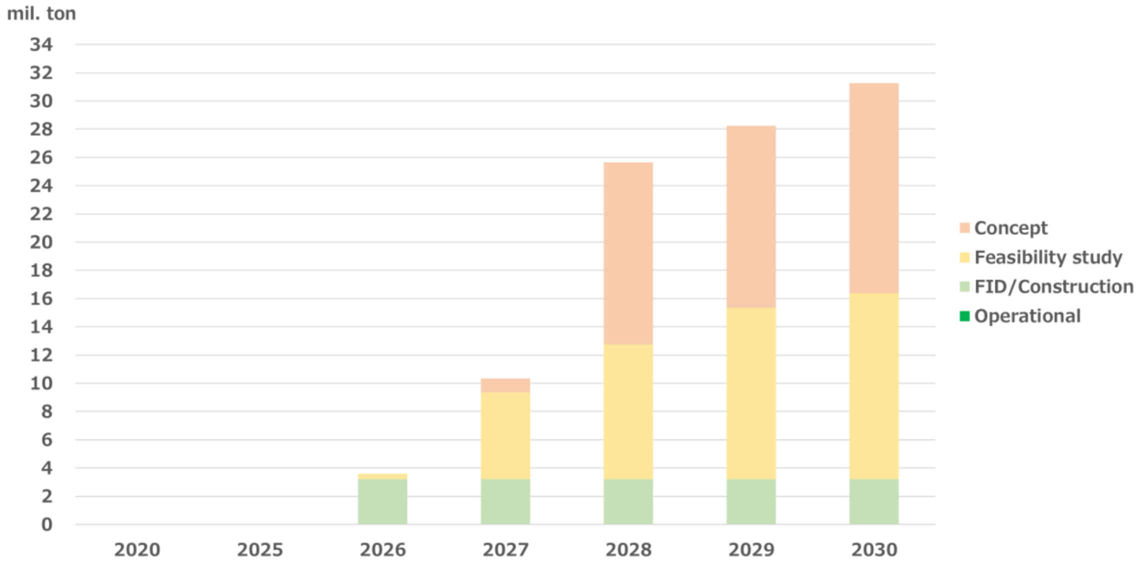
Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

Alternative fuel production projects - 4 (Blue ammonia)

The majority of blue ammonia projects slated to commence production by 2030 are still in the conceptual or feasibility study stages and have not reached the final investment decision. It is necessary to continue monitoring the progress of these projects to assess the expected production volume in the future.

Projected production capacity of blue ammonia (for all sectors, as of October 2024)

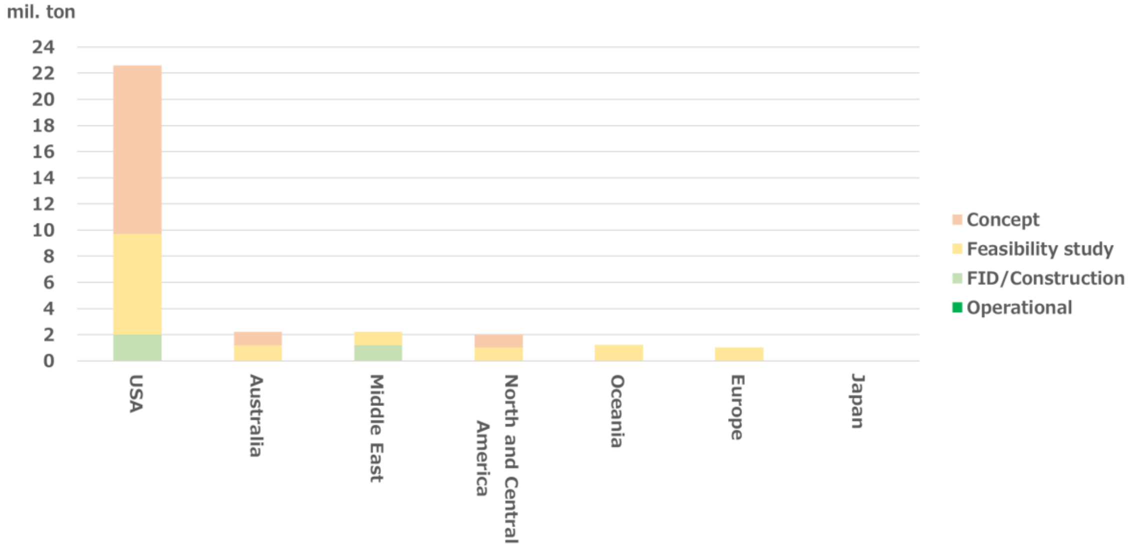
Projected production capacity by year



➢ The blue ammonia production capacity is expected to increase gradually, but most of the projects are still in the conceptual or feasibility study stages.

Projected production capacity by country/region (as of 2030*)

*After 2030, there are no projects planned.



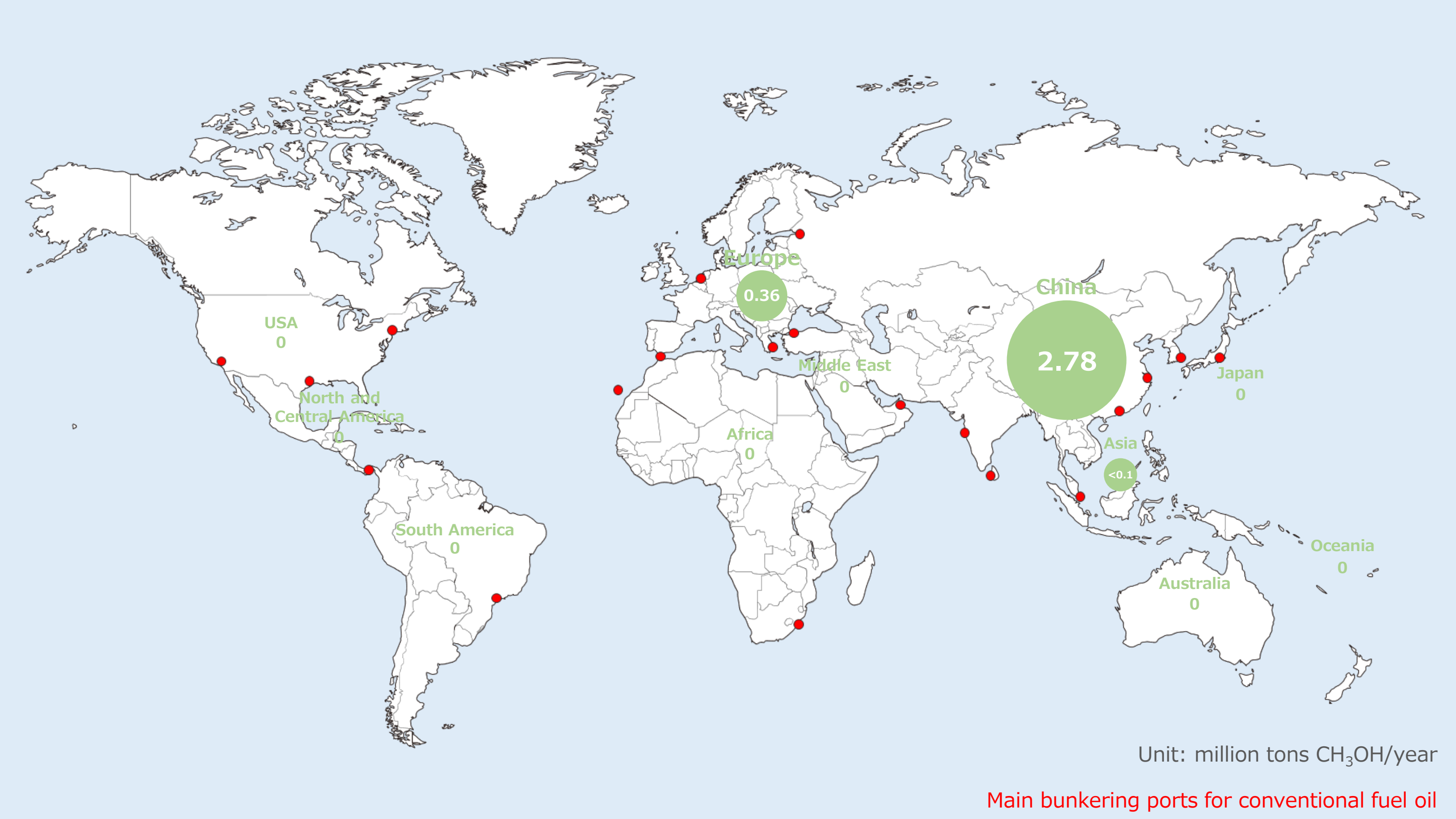
➢ Most of the blue ammonia projects slated to start production by 2030 are located in the USA.

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

Alternative fuel production projects - 5 (Green methanol)

Here we introduce the production scale of green methanol (including planned production). Methanol is not only used directly as marine fuel but also required for the production of biodiesel such as FAME (Fatty Acid Methyl Ester). Please note that production projects are not limited to the shipping sector.

Distribution of green methanol production projects (Operational/Construction/FID, for all sectors, as of October 2024)



Country/ Region	Number of projects	Annual production capacity (total) [Unit: ton CH_3OH/year]
China	9	2,785,667
Europe	10	363,733
Asia	1	3,918
Total	**20**	**3,153,319**

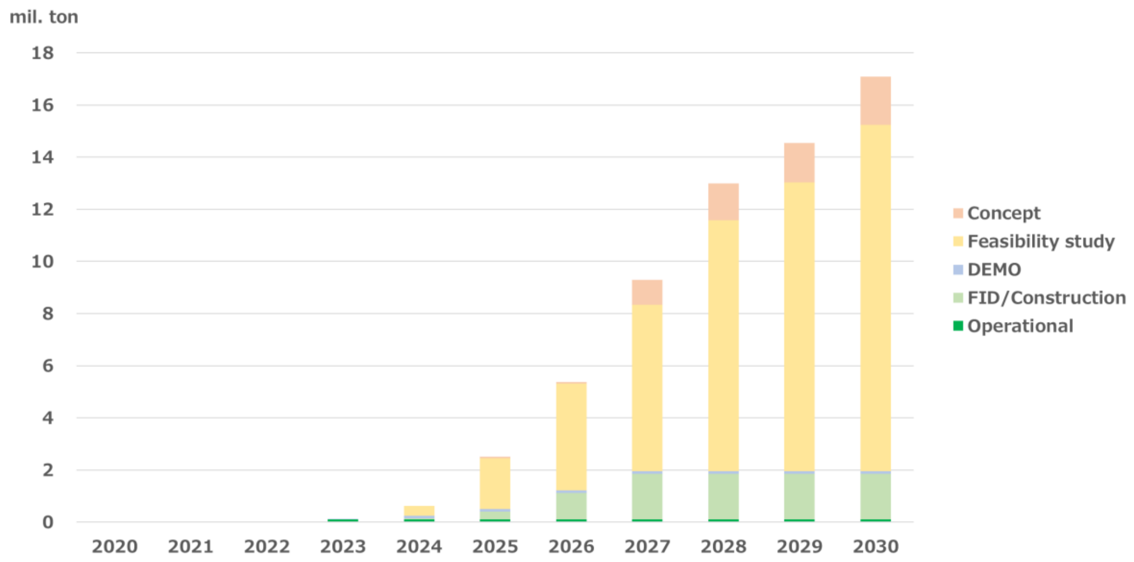
Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

Alternative fuel production projects - 5 (Green methanol)

The majority of green methanol projects slated to commence production by 2030 are still in the feasibility study stages and have not reached the final investment decision. It is necessary to continue monitoring the progress of these projects to assess the expected production volume in the future.

Projected production capacity of green methanol (for all sectors, as of October 2024)

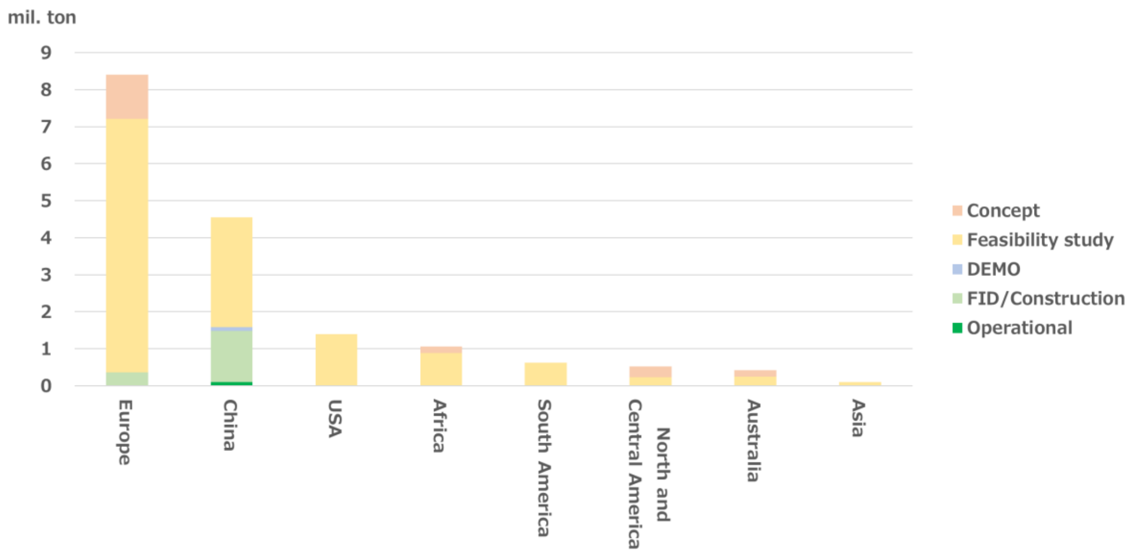
Projected production capacity by year



- The green methanol production capacity is expected to increase gradually, but most of the projects are still in the feasibility study stages.

Projected production capacity by country/region (as of 2030*)

*After 2030, there are no projects planned.



- Many of the green methanol projects slated to start production by 2030 are located in Europe and China.

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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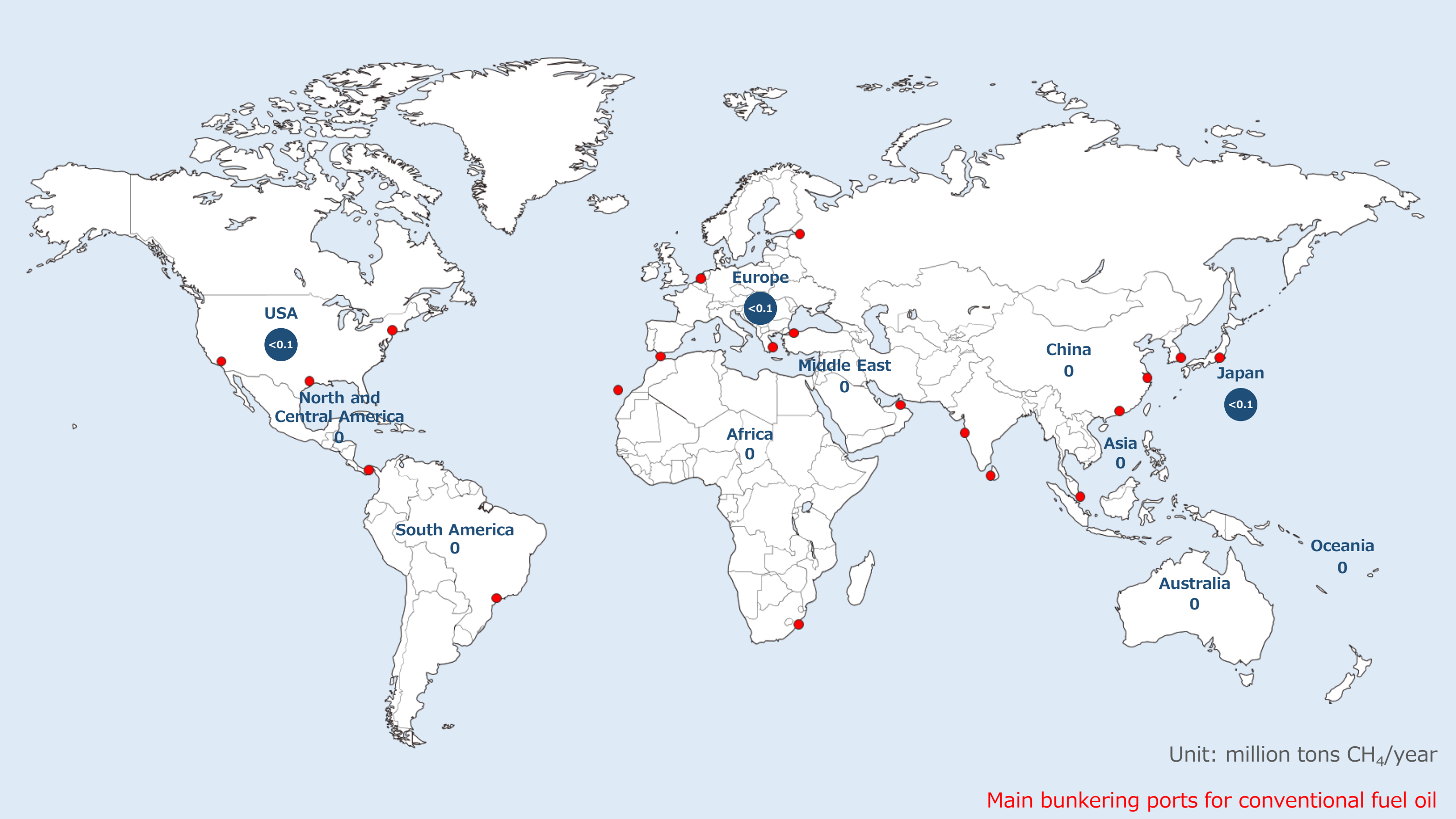
Alternative fuel production projects - 6 (Green methane)

Here we introduce the production scale of green methane (including planned production). Although methane is a potent GHG, progress in reducing methane slip is mitigating its negative impacts, thereby attracting attention. Please note that production projects are not limited to the shipping sector.

Distribution of green methane production projects (Operational/Construction/FID, for all sectors, as of October 2024)



Country/ Region	Number of projects	Annual production capacity (total) [Unit: ton CH_4/year]
Europe	18	12,341
USA	1	86
Japan	1	25
Total	**20**	**12,452**

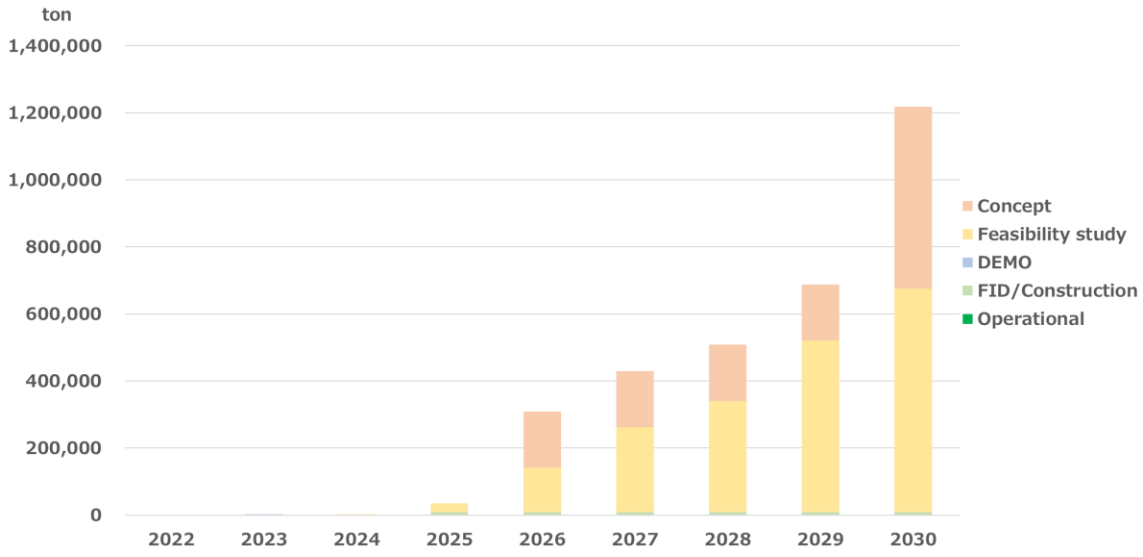
Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

Alternative fuel production projects - 6 (Green methane)

The majority of green methane projects slated to commence production by 2030 are still in the feasibility study or conceptual stages and have not reached the final investment decision. It is necessary to continue monitoring the progress of these projects to assess the expected production volume in the future.

Projected production capacity of green methane (for all sectors, as of October 2024)

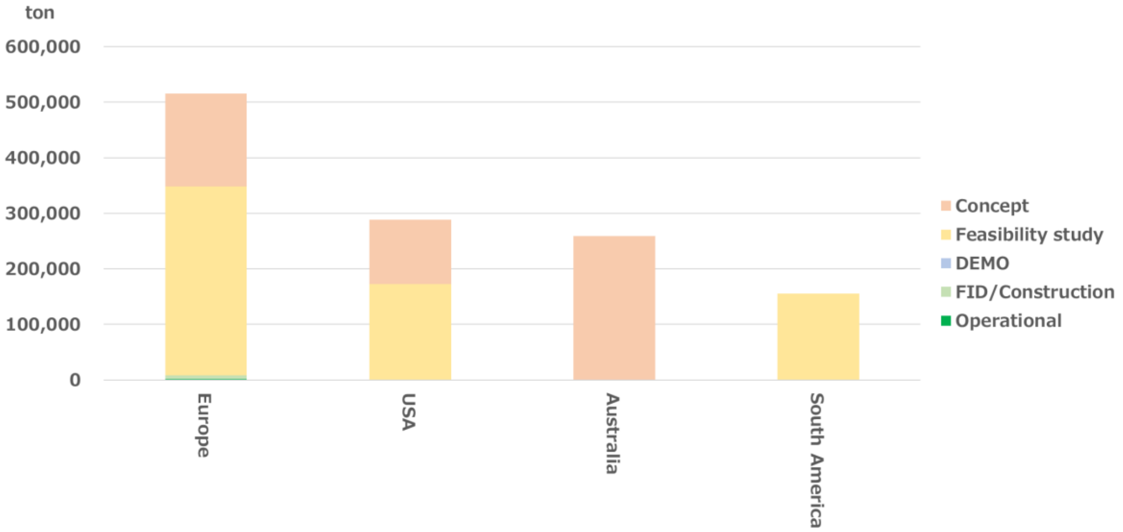
Projected production capacity by year



- The green methane production capacity is expected to increase gradually, but most of the projects are still in the feasibility study or conceptual stages.

Projected production capacity by country/region (as of 2030*)

*After 2030, there are no projects planned.



- Many of the green methane projects slated to start production by 2030 are located in Europe.

Source: Prepared by ClassNK based on IEA (2024), Hydrogen Production Projects Database

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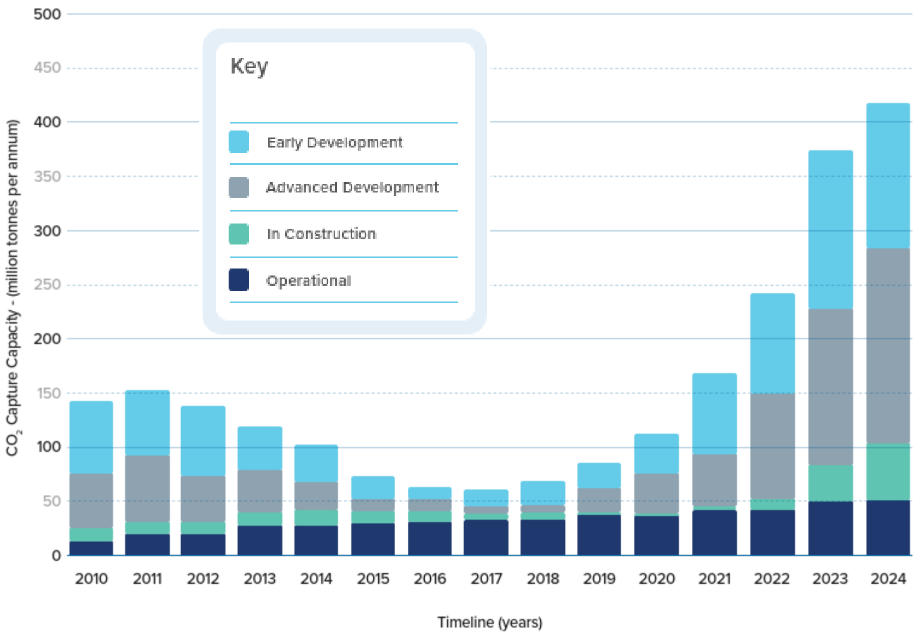
CCS projects

To reduce GHG emissions from ships, not only the use of alternative fuels, but also the utilization of onboard CCS (Carbon Capture and Storage) are effective measures. In the utilization of onboard CCS, it is important to consider where the captured CO_2 will be unloaded and stored. Here, we introduce the trends and distribution of CCS facility development.

Development trends and distribution of CCS facilities

Development trends of CCS facilities

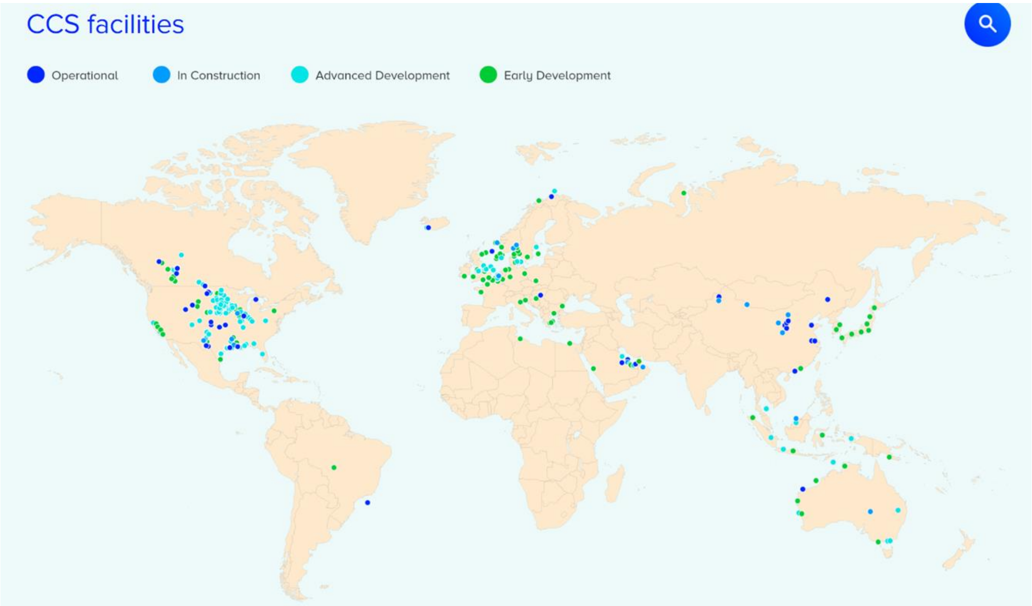


➢ There were approximately 51 million tons*1 of CO_2 storage capacity worldwide in 2024.

*1 Equivalent to emissions from about 16 million tons of heavy fuel oil

Source: Global CCS Institute, 2024. The Global Status of CCS: 2024. Australia. (partially edited by ClassNK)

Distribution of CCS facilities



➢ As of 2023, operational facilities*2 are concentrated in the USA, but construction and development are progressing in various regions worldwide, including Europe.

*2 Most of these are CO_2 storage aimed at enhanced oil recovery.

Source: Global CCS Institute, 2023. The Global Status of CCS: 2023. Australia.

Steps from installation of onboard CCS systems to certification of captured CO_2 volume

Utilizing onboard CCS requires a comprehensive approach, including site selection of CO_2 unloading and storage, selection of onboard CCS system, and certification for the captured CO_2 volume. Also, the standards have yet to be established by the IMO for assessing CO_2 reductions from onboard CCS, meaning that flag state approval is required to recognize these reductions in regulations. Here we outline key considerations for onboard CCS and our supports including flag state approval.

Steps from installation of an onboard CCS system to certification of captured CO_2 volume

STEP 01

Planning CO_2 capture

- Planning for capture volume
- Selecting onboard CCS systems and checking safety requirements

ClassNK's support — Introduction support

- ✓ Providing information
- ✓ Reviewing plans — *Notation "SCCS-Ready"*

STEP 02

Installing onboard CCS systems

- Preparing for surveys
- Maintaining onboard CCS systems

ClassNK's support — Introduction support

- ✓ Initial surveys
- ✓ Periodical surveys

Notation "SCCS"

STEP 03

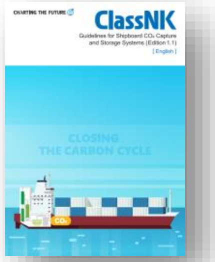
Capturing/unloading CO_2 and certification

- Complying with regulations related to capture and storage
- Confirming captured CO_2 volume

ClassNK's support — Certification support

- ✓ Certification of captured CO_2 volume
- ✓ Support for regulatory compliance

Guidelines for Shipboard CO_2 Capture and Storage Systems



- Outlines onboard CCS systems
- Stipulates safety requirements for systems and its onboard installation

These guidelines can be accessed from the "Guidelines" menu on the ClassNK website's My Page after logging in.
https://www.classnk.or.jp/account/en/rules_guidance/ssl/login.aspx

A notation will be granted to a ship that comply with the requirements of the guidelines.

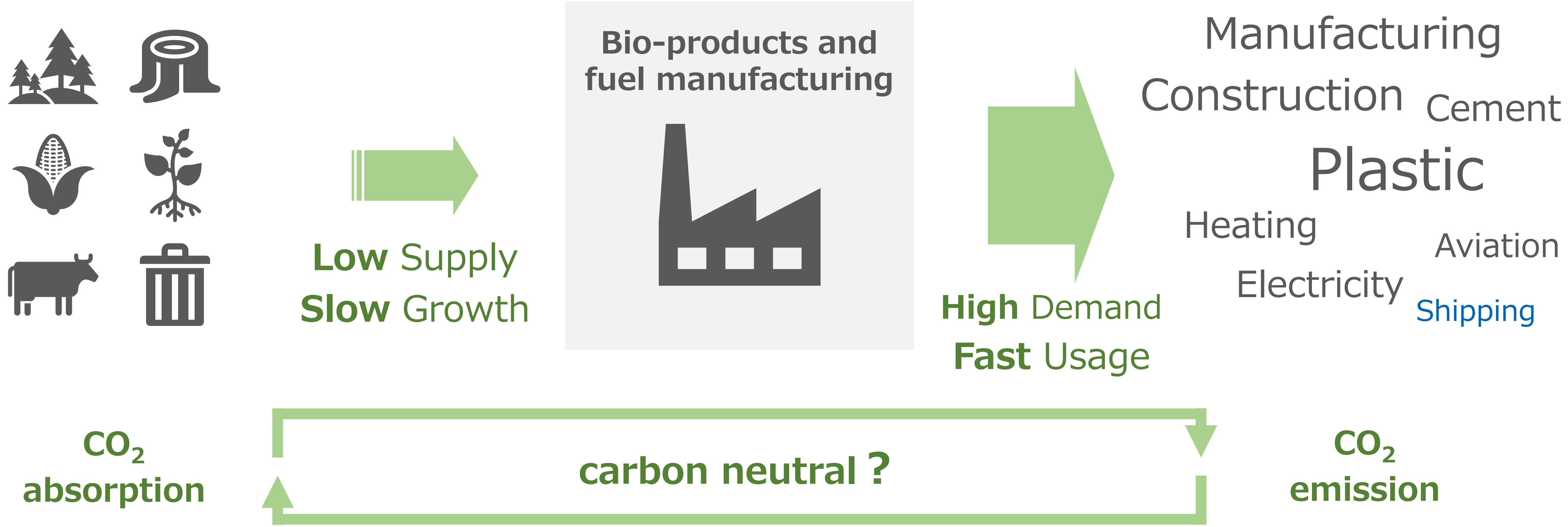
CO_2 Capture and Storage Systems	
SCCS-Full	
CO_2 Capture Systems	**CO_2 Storage Systems**
SCCS-Capture	*SCCS-Storage*

SCCS: Shipboard Carbon dioxide Capture and Storage

Feasibility of biofuel supply

Biofuels are considered carbon-neutral fuels over their entire lifecycle because the plants used as their raw materials absorb CO_2 from the atmosphere during their growth. Additionally, they attract attention as drop-in fuels that can be used without extensive modification of existing engines. However, biofuels face constraints due to the limited availability of biomass resources, and competition for these resources with other sectors highlights the importance of ensuring stable procurement.

The gap between "supply and demand" and "growth time and usage time"



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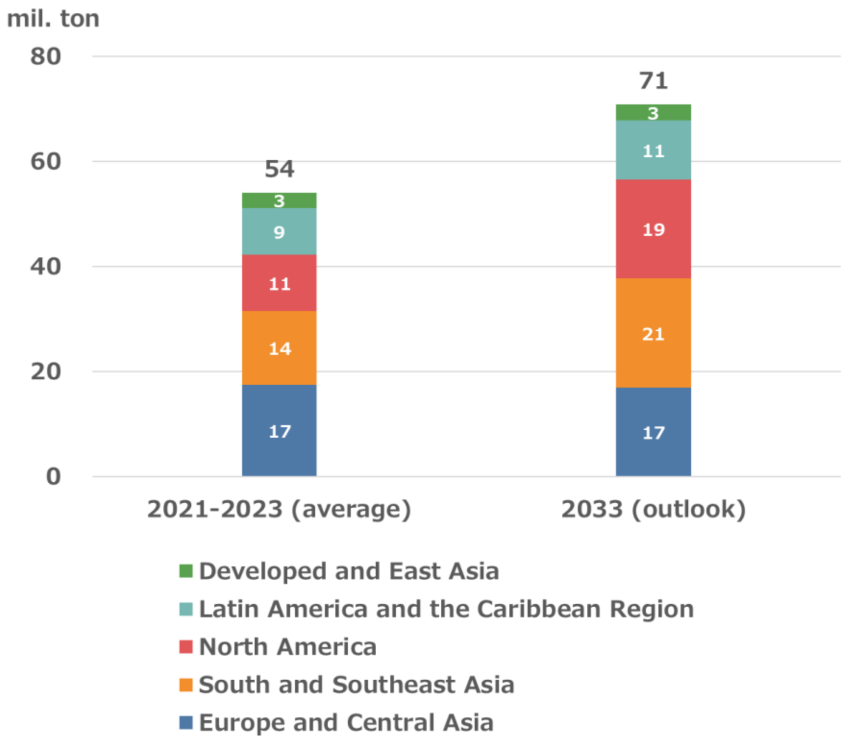
Biofuel production

Biofuels, which are drop-in fuels usable without major modifications to existing engines, are an effective means of reducing GHG emissions from existing ships. Here, we will introduce the production volume of biodiesel. It should be noted that the demand for biodiesel is expected to increase not only in the maritime sector but also in other sectors. Therefore, it is necessary to pay close attention to the risk of rising fuel prices due to tight supply and demand.

Biodiesel production by region



Source: Prepared by ClassNK based on OECD/FAO (2024), OECD-FAO Agricultural Outlook 2024-2033, Paris and Rome, https://doi.org/10.1787/4c5d2cfb-en.

- ✓ The average annual production of biodiesel reached **54 million tons** from 2021 to 2023.
- ✓ The largest producing region is Europe and Central Asia, with an average annual production of 17 million tons.
- ✓ Of the world's 54 million tons of production, 65% is derived from vegetable oils, **27% from used cooking oils**, and 8% from non-edible oils and animal fats.
- ✓ The consumption of biofuels in international shipping is minimal, with **approximately 400,000 tons** consumed in 2023. This represents **0.7%** of global production.

  *Source: Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS
- ✓ Production is expected to expand mainly in North America and South and Southeast Asia in the future, and global production is projected to increase to **71 million tons** by 2033.
- ✓ Assuming a 27% share of used cooking oils as the feedstock, similar to the current share, the production of biodiesel from used cooking oils is projected to reach 19 million tons by 2033.

Use of biofuels

Reducing GHG emissions from ships is important, and the use of biofuels stands out as a significant option. However, it's crucial to fully understand the considerations associated with their use and to identify in advance the types of biofuels acknowledged for their GHG reduction effects under regulations.

Two steps to using biofuels

1. **Understand safety precautions**

   Biofuels vary widely in their characteristics depending on the feedstock and production methods. When using them, it's essential to understand the features of each fuel, any precautions for use, and potential issues that may arise. ClassNK provides support for the use of biofuels through information in the "Technical Guide for Using Biofuels."

2. **Make arrangements to use recognized biofuels for GHG reduction**

   Biofuels that are recognized for their GHG reduction effects may vary depending on regulations. When arranging to use biofuels, please ensure beforehand whether the biofuels meet the requirements of the regulations.

   → Compliance with the requirements can be confirmed by a Proof of Sustainability or equivalent, arranged by the fuel supplier.

Technical Guide for
Using Biofuels (Edition 1.1)
April 2024

This technical guide can be accessed from the "Guidelines" menu on the ClassNK website's My Page after logging in.
https://www.classnk.or.jp/account/en/Rules_Guidance/ssl/guidelines.aspx

Image of
Proof of Sustainability

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<Reference> GHG emissions assessment of biofuels

The GHG emissions assessment of biofuels in the CII, EU-ETS for Shipping, and FuelEU Maritime are as follows.

Regulation	Requirements for biofuels to contribute to GHG emissions reductions	GHG emissions assessment (in case of B-100*3) *3 In the case of blended oils like B-24 and B-29, the GHG emissions reduction is attributed solely to the biofuel component.
CII (Scope: TtW)	• **Certified by an international certification scheme (ISCC, RSB, etc.), meeting its sustainability criteria** • **Not exceeding WtW GHG intensity 33gCO_2eq/MJ*1** *1 Reduction of at least 65% compared to the 94gCO_2eq/MJ (MGOeq) Note: Temporary measures in place until the IMO finalizes its LCA guidelines	e.g.) In case of biofuels derived from used cooking oil*4 *4 WtW GHG intensity 14.9gCO_2eq/MJ **Approx. 80% reduction compared to conventional fuel oil** <Explanation> ✓ Calculate the TtW emission factor, using the WtW GHG intensity *WtW GHG intensity 14.9gCO_2eq/MJ × LCV 0.037MJ/g fuel* *= 0.551gCO_2eq/g fuel* (Ref.: HFO 3.114gCO_2eq/g fuel) Note: Temporary measures in place until the IMO finalizes its LCA guidelines
EU-ETS for Shipping (Scope: TtW)	• **Compliance with the sustainability and GHG emissions reduction criteria*2 as defined in the EU Renewable Energy Directive (RED)** *2 Different criteria are required for biofuels depending on the operation date of the installations producing the fuels. ✓ Starting operation on or before 5 October 2015 At least 50% reduction from 94gCO_2eq/MJ ✓ Starting operation from 6 October 2015 At least 60% reduction from 94gCO_2eq/MJ ✓ Starting operation from 1 January 2021 At least 65% reduction from 94gCO_2eq/MJ	Regardless of the origin of the biofuel **Approx. 99% reduction compared to conventional fuel oil** <Explanation> ✓ CO_2 emissions=0, but account CH_4 and N_2O emissions
FuelEU Maritime (Scope: WtW)		e.g.) In case of biofuels derived from used cooking oil*5 *5 WtW GHG intensity 14.9gCO_2eq/MJ **Approx. 80% reduction compared to conventional fuel oil** <Explanation> ✓ Account for the TtW CH_4 & N_2O in addition to the WtW GHG intensity *WtW 14.9 (=WtT 14.9 + TtW 0) + TtW CH_4 0.03 + TtW N_2O 1.5 = 16.4*

UPDATED

Regulatory trends

The IMO has been actively developing rules and guidelines for various alternative fuels, including zero- and low-emission fuels. Here, we introduce the rules and guidelines of the IMO regarding each alternative fuel, as well as the corresponding rules and guidelines provided by ClassNK.

Rules and guidelines concerning alternative fuels

Alternative fuels/ Related technologies	IMO Rules/Guidelines	ClassNK Rules/Guidelines
LNG	IGF Code	Rules for the Survey and Construction of Steel Ships / Guidance Part GF SHIPS USING LOW-FLASHPOINT FUELS
Methanol	Interim Guidelines for the Safety of Ships Using Methyl / Ethyl alcohol as Fuel (MSC.1/Circ.1621)	Guidelines for Ships Using Alternative Fuels (Edition 3.0) Part A Guidelines for Ships Using Methyl/Ethyl Alcohol as Fuels Part B Guidelines for Ships Using LPG as Fuel Part C Guidelines for Ships Using Ammonia as Fuel Part D Guidelines for Ships Using Hydrogen as Fuel Annex 1 Alternative Fuel Ready
LPG	Interim Guidelines for the Safety of Ships Using LPG Fuels (MSC.1/Circ. 1666)	
Ammonia	Interim Guidelines for the Safety of Ships Using Ammonia as Fuel	
Hydrogen	Under development (Scheduled to be finalized at CCC 11 in September 2025.) (Scheduled to be approved at MSC 111 in May 2026.)	
Fuel Cell	Interim Guidelines for the Safety of Ships Using Fuel Cell Power Installations (MSC.1/Circ.1647)	Guidelines for Fuel Cell Power Systems On Board Ships [Second Edition]

Existing rule | Existing guidelines | Guidelines under development

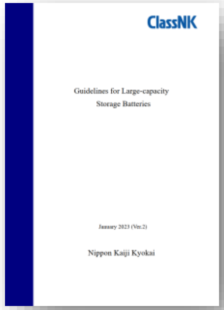
ClassNK's guidelines

ClassNK provides technical support for various aspects, such as issuing Approval in Principle and retrofitting alternative fuel ships, through the issuance of various guidelines. When considering the adoption of alternative fuel ships, we encourage you to make use of these guidelines.

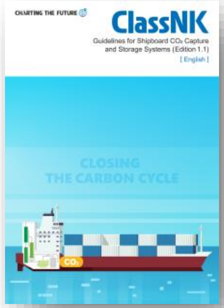
ClassNK List of alternative fuel-related guidelines

Guidelines for Technology Qualification
March 2022

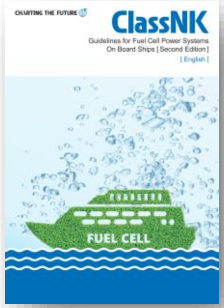
Guidelines for Approval in Principle and General Design Approval
March 2022



Guidelines for Large-capacity Storage Batteries
January 2023

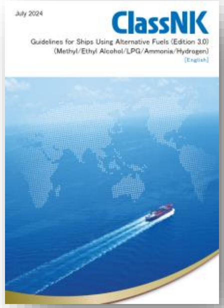


Guidelines for Shipboard CO_2 Capture and Storage Systems
June 2023

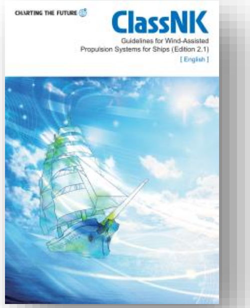


Guidelines for Fuel Cell Power Systems On Board Ships
September 2023

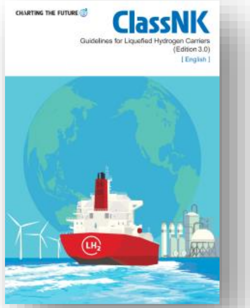
Technical Guide for Using Biofuels
April 2024



Guidelines for Ships Using Alternative Fuels
July 2024



Guidelines for Wind-Assisted Propulsion Systems for Ships
July 2024



Guidelines for Liquefied Hydrogen Carriers
September 2024

These guidelines can be accessed from the "Guidelines" menu on the ClassNK website's My Page after logging in.
https://www.classnk.or.jp/account/en/rules_guidance/ssl/login.aspx

— Step 4

Understanding costs

When considering the adoption of alternative fuels, understanding the total cost for each fuel is paramount. In this section, we will introduce the cost factors to consider during fuel transition and discuss the cost simulation conducted by ClassNK.

Key Takeaways

- ✓ The main costs associated with the adoption of alternative fuel ships are shipbuilding costs, fuel costs, and regulatory costs.
- ✓ Regulatory costs to comply with IMO and EU regulations depend on the GHG emissions resulting from fuel use. To understand regulatory costs, it's necessary to grasp each ship's GHG emissions, including the potential for reduction through fuel transition.
- ✓ It's worth noting that EU regulations (EU-ETS for Shipping and FuelEU Maritime) target GHG emissions in EU-related voyages, while IMO regulations (mid-term measures) may cover GHG emissions in all voyages. Consequently, the regulatory cost burden may be relatively higher, requiring attention.
- ✓ ClassNK is prepared to conduct cost simulations for fuel transition. As soon as the contents of IMO regulations (mid-term measures) are finalized in 2025, ClassNK will provide calculation services for cost simulations.

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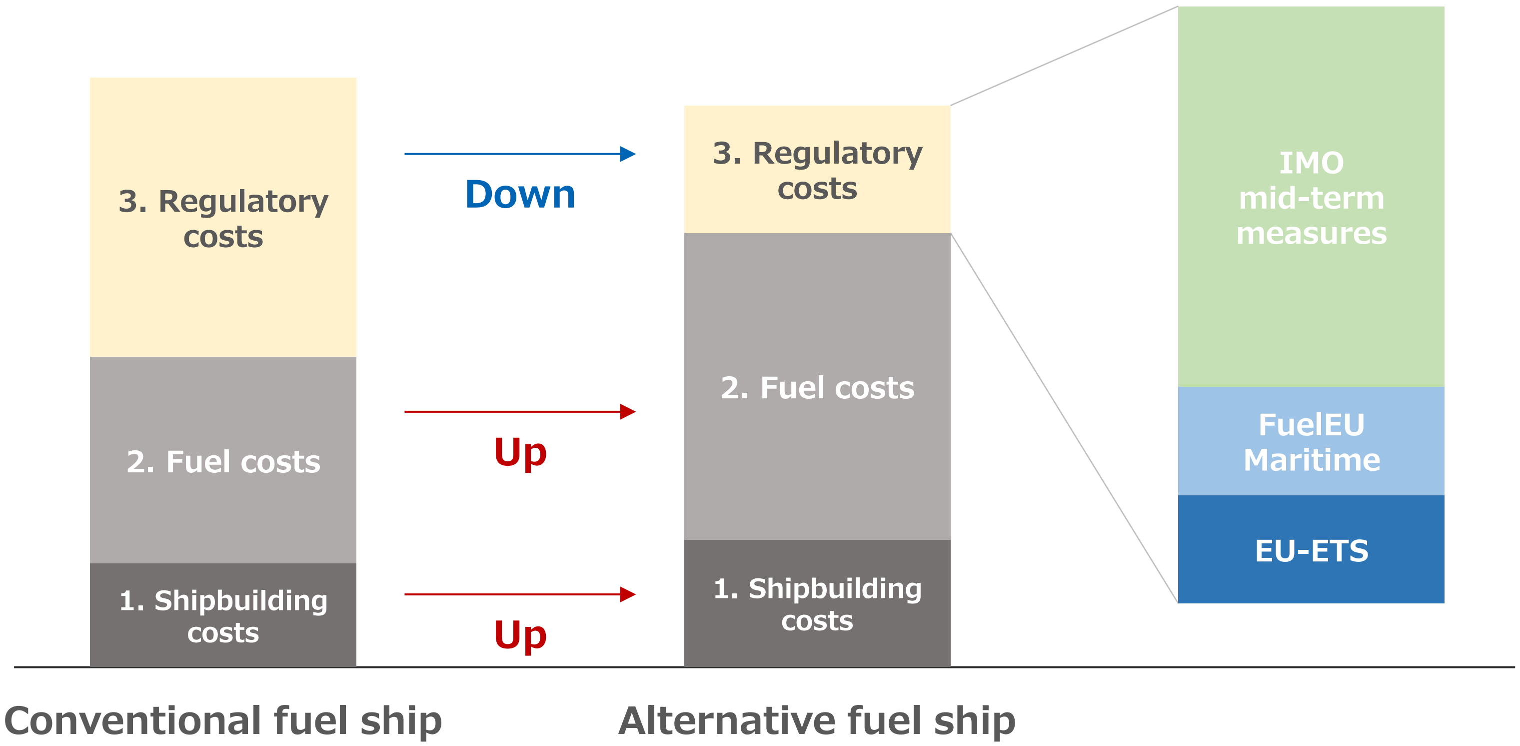
Uncertain factors in costs (1. Shipbuilding costs, 2. Fuel costs, 3. Regulatory costs)

When considering the adoption of alternative fuels, it's crucial to understand the total costs associated with each fuel option for comparison. Among the various cost factors, shipbuilding costs, fuel costs, and regulatory costs stand out as significant components. It's essential to forecast how these costs will change in the future and make the right fuel selections at the appropriate timing, as this will determine the competitive advantage in the maritime business going forward.

Image of primary costs



- ✓ The adoption of alternative fuel ships is expected to result in increased shipbuilding costs and fuel costs compared to conventional fuel ships, while regulatory costs are anticipated to decrease.
- ✓ The primary factors contributing to regulatory costs are the EU's EU-ETS and FuelEU Maritime, as well as IMO's mid-term measures.
- ✓ While EU regulations target GHG emissions in EU-related voyages, IMO regulations are likely to cover GHG emissions in all voyages, potentially leading to relatively higher regulatory cost burdens.

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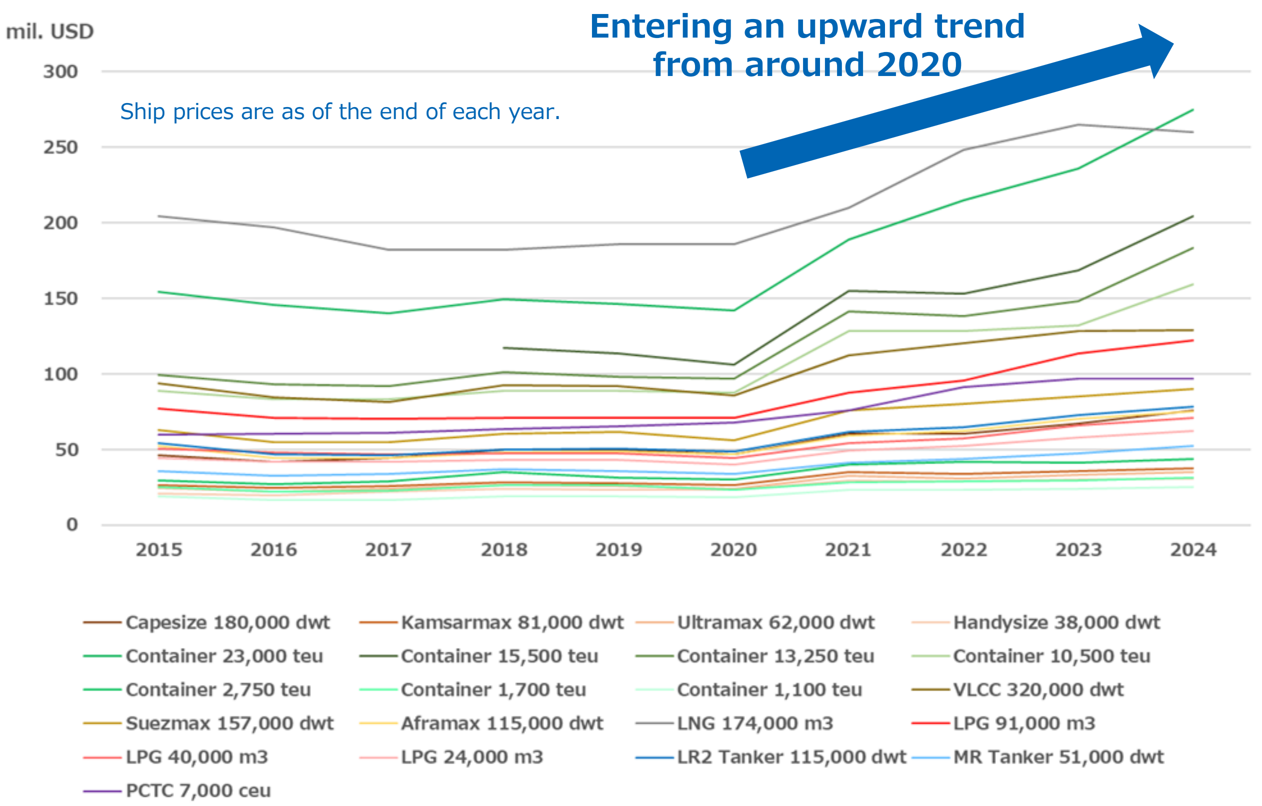
Uncertain factors in costs (1. Shipbuilding costs)

The shipbuilding cost of alternative fuel ships, which require different fuel tanks and fuel supply systems, is expected to be higher than that of conventional fuel ships. The outlook for shipbuilding costs until 2050 is uncertain due to significant fluctuations in steel prices, but it's important to invest based on a long-term assessment of ship pricing levels.

The historical trend of shipbuilding costs (ship prices) and the shipbuilding costs of alternative fuel ships



Source: Prepared by ClassNK based on data from Clarkson Research Services Limited

Shipbuilding costs of alternative fuel ships (relative to conventional fuel ships)

LNG	+30% - +40%
LPG	+30% - +40%
Methanol	+20% - +30%
Ammonia	+30% - +40%

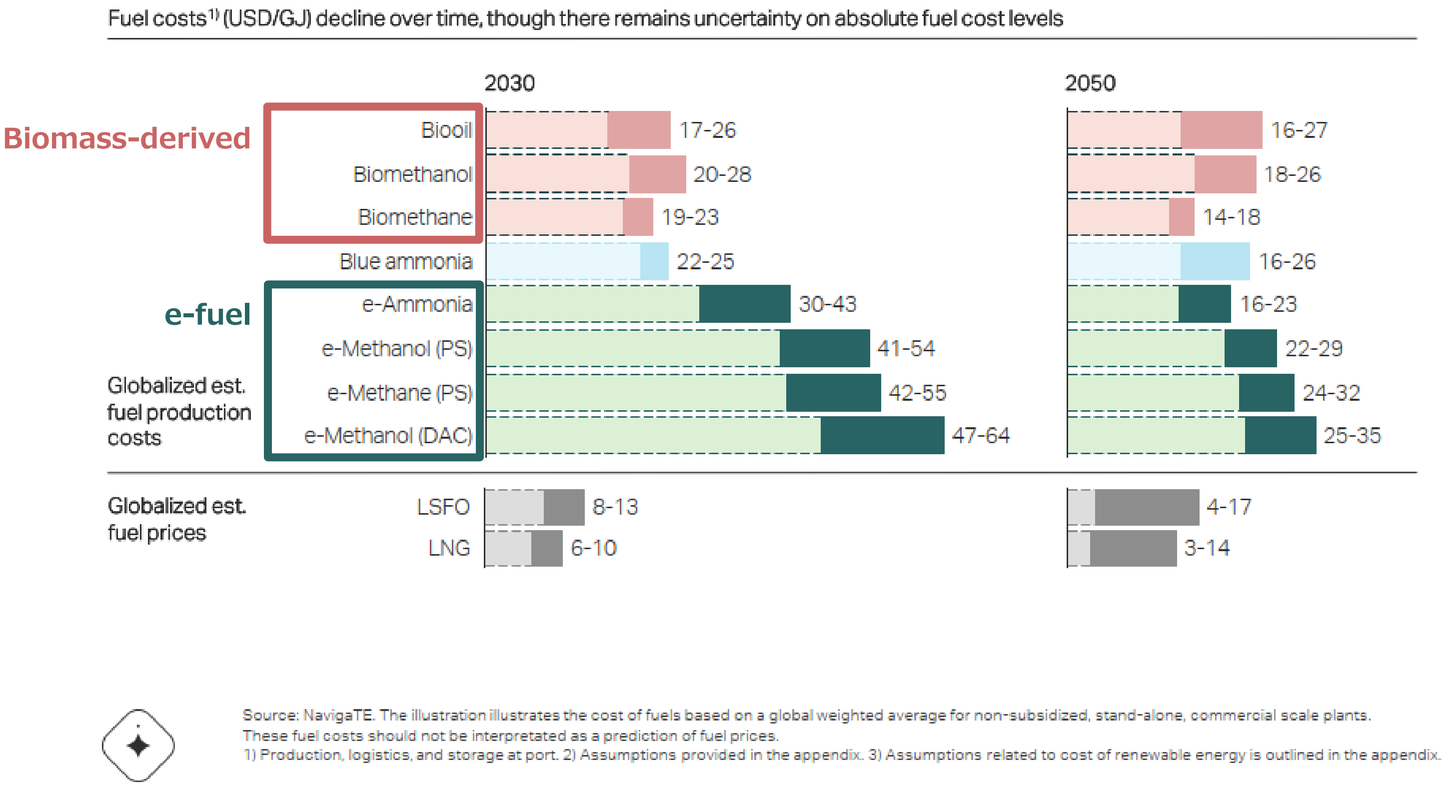
Source: ClassNK

✓ The shipbuilding cost of alternative fuel ships is typically 20% to 40% higher compared to conventional fuel ships, depending on the ship types and sizes.

Uncertain factors in costs (2. Fuel costs)

There is a wide range of alternative fuels available for use in ships, but it is anticipated that the cost of each alternative fuel will be higher than conventional fuel oil. However, with the expected expansion of production and the introduction of regulations in the future, the cost gap between alternative fuels and conventional fuel oil is expected to narrow. When considering the adoption of alternative fuels, it is crucial to closely monitor the trends in fuel costs.

Image of fuel costs



Source: Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2021), Position Paper Fuel Option Scenarios (partially edited by ClassNK)

- ✓ Alternative fuels can be broadly categorized into "biomass-derived fuels" and "e-fuels produced from green hydrogen and captured CO_2."
- ✓ The main cost factor for "biomass-derived fuels" is the price of biomass itself. The price of biomass is influenced by factors such as the availability of biomass resources and the demand trends in other sectors.
- ✓ For "e-fuels produced from green hydrogen and captured CO_2," the main cost factor is the price of green hydrogen. The price of green hydrogen is influenced by the costs of renewable energy and electrolysis equipment.
- ✓ It is possible that the cost of alternative fuels will remain higher than that of conventional fuel oil even by the year 2050.
- ✓ It is important to note that the actual procurement price can vary depending on supply and demand conditions.

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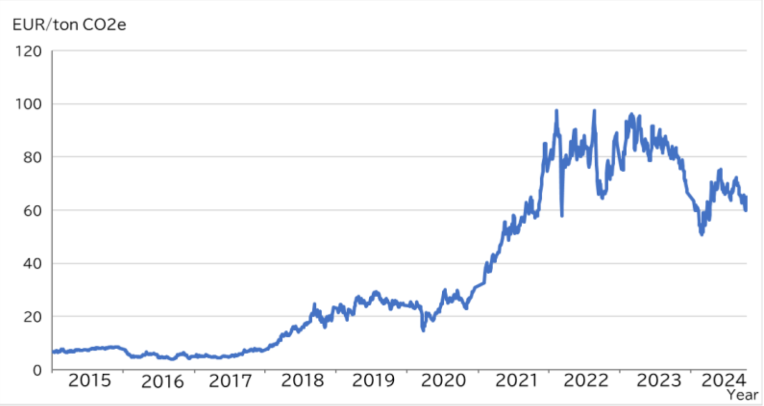
Uncertain factors in costs (3. Regulatory costs)

In the future, a series of regulations encouraging the use of zero and low-emission fuels will be introduced in international shipping. In Europe, the European Union Emissions Trading System (EU-ETS) is expanding to the maritime sector from 2024, and the FuelEU Maritime was introduced in 2025. Meanwhile, the IMO is discussing a new regulatory framework (mid-term measures) for implementation in 2027. Each regulation entails uncertainties in the resulting costs, necessitating caution in total cost estimations.

The three major GHG regulations in international shipping going forward

1. **EU-ETS (2024 -)**
   - ✓ It requires the surrender of emission allowances corresponding to the targeted GHG emissions.
   - ✓ Emission allowances must be procured through the market, and their prices fluctuate daily based on supply-demand balances, etc.
   - ✓ The fluctuating prices of emission allowances are a major uncertain factor in EU-ETS costs.
2. **FuelEU Maritime (2025 -)**
   - ✓ It sets limits for the GHG intensity of fuels (GHG emissions per unit of energy) and requires ships exceeding these limits to pay penalties.
   - ✓ The total amount of penalties is determined by the "degree of excess over the limit" and the "amount of energy consumed."
   - ✓ Flexibility mechanisms (banking, borrowing, pooling) are available to avoid penalties, and the adept use of these flexibility mechanisms affects the costs of FuelEU Maritime.
3. **IMO mid-term measures (Scheduled for 2027 -)**
   - ✓ The contents of the regulation itself are not determined (the regulation details are expected to be finalized in 2025).

Transition of the price of allowances at the European Energy Exchange (EEX)

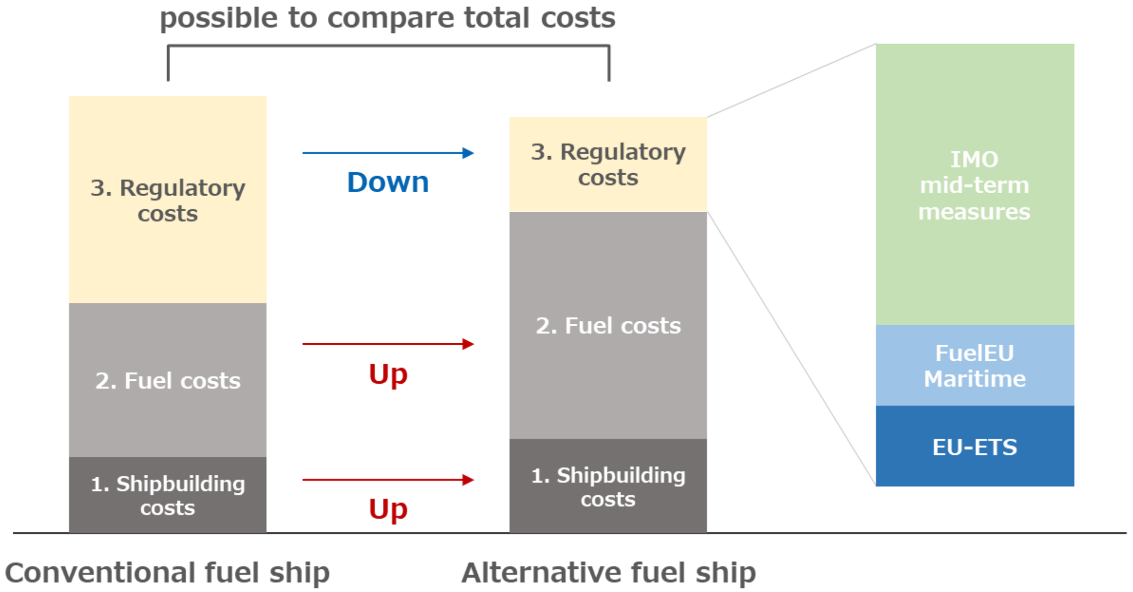


Source: Prepared by ClassNK, based on the emission allowance price data publicly available from the EEX

Conducting cost simulation

ClassNK conducts cost simulations with the aim of supporting your future fuel selections, particularly regarding the transition (replacement) of conventional fuel ships to alternative fuel ships. Here, we provide an overview of the cost simulation process.

Overview of cost simulation



- ✓ Calculate while focusing solely on the major components of costs, namely shipbuilding costs, fuel costs, and regulatory costs, which constitute the majority of the total costs.
- ✓ Compare the total costs of adopting conventional fuel ships with those of alternative fuel ships for ships of the same type and size.
- ✓ Calculated the expected fuel costs and regulatory costs based on the fuel type and fuel consumption. Assumptions regarding fuel costs and regulatory costs can be set as follows:

> • Gradual transition case (Regulatory costs: **low**, Zero-emission fuel costs: **high**)
> A case assuming a gradual transition to decarbonization in shipping. GHG emission regulations are lenient, and the cost decrease of zero-emission fuels progresses gradually.
> • Stepwise transition case (Regulatory costs: **middle**, Zero-emission fuel costs: **middle**)
> A case that falls between the "gradual transition case" and the "rapid transition case."
> • Rapid transition case (Regulatory costs: **high**, Zero-emission fuel costs: **low**)
> A case assuming a rapid transition to decarbonization in shipping. GHG emission regulations are stringent, and the cost decrease of zero-emission fuels progresses rapidly.

- ✓ Once the contents of the IMO's mid-term measures are finalized (scheduled for 2025), more accurate calculations will be possible. ClassNK plans to provide cost simulation calculation services in response to this.

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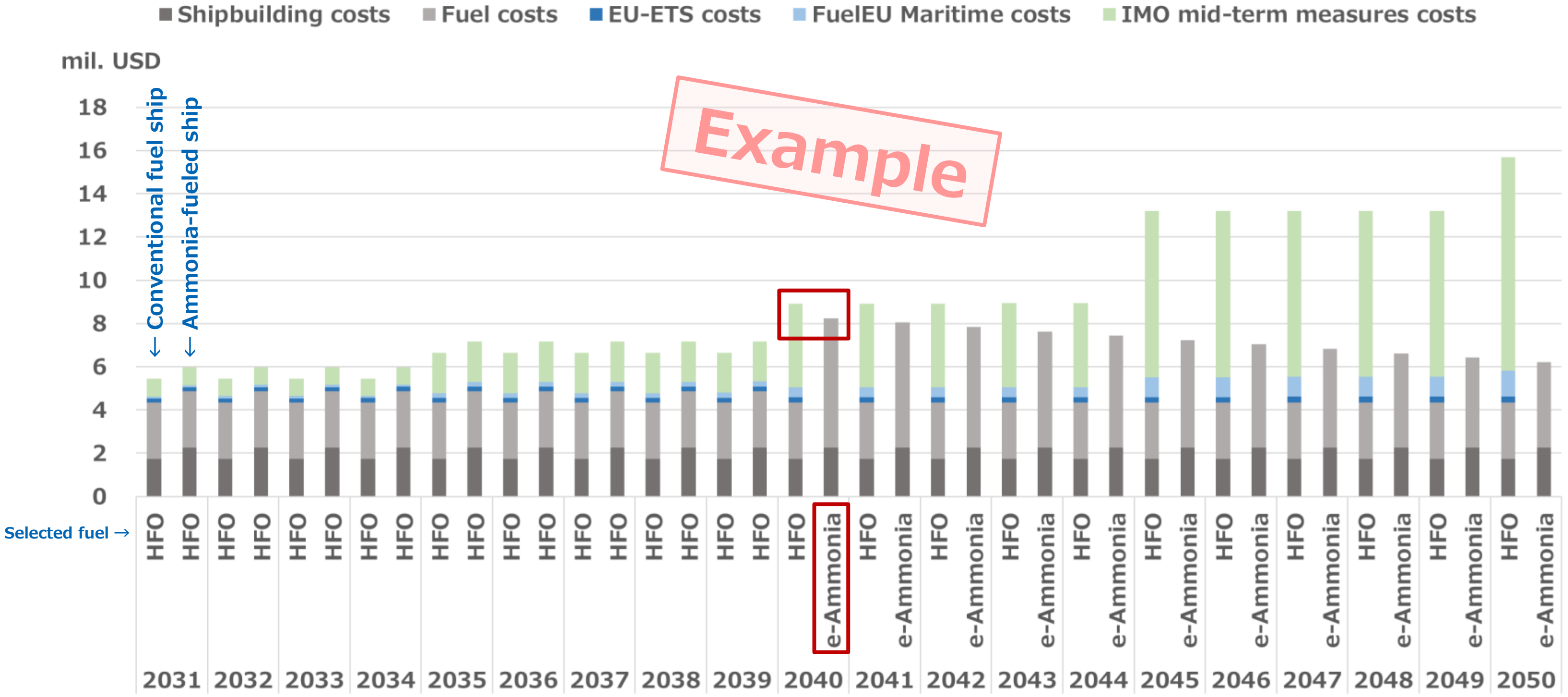
Cost simulation example - 1

When adopting alternative fuel ships, it's important to consider fuel costs and regulatory costs while aiming for a timely transition to zero-emission fuels. Here, we present a comparison of total costs between adopting conventional fuel ships and ammonia-fueled ships in a stepwise transition case, using a 64,000 DWT bulk carrier as an example.

Cost simulation example (Conventional fuel ship vs. Ammonia-fueled ship 64,000 DWT bulk carrier: Stepwise transition case)

Annual costs ver.



➢ **Identify the timing when annual costs will cross over**

(In this case, for the ammonia-fueled ship, selecting e-Ammonia from 2040 onwards will be more cost-effective, meaning that "e-Ammonia fuel costs" < "HFO fuel costs + regulatory costs", and the annual costs will be less than those of the conventional fuel ship from 2040.)

<Assumption>

- ✓ Delivery in 2031 (Lifetime 20 years)
- ✓ Shipbuilding costs
  - → Amortized over 20 years
- ✓ Fuel price
  - → HFO: **Fixed**
    13.0 USD/GJ (=522.6 USD/ton)
  - → e-Ammonia: **Decrease annually**
    【2031】38.9 USD/GJ (=723.8 USD/ton)
    【2050】19.7 USD/GJ (=366.2 USD/ton)

<How to read the graph>

- ✓ Bar graph on the left side:
  Annual costs in case a conventional fuel ship is adopted
  (Fuel selection: HFO only)
- ✓ Bar graph on the right side:
  Annual costs in case an ammonia-fueled ship is adopted
  (Fuel selection options include HFO or e-Ammonia)
  (Select the fuel that lowers total costs each year)

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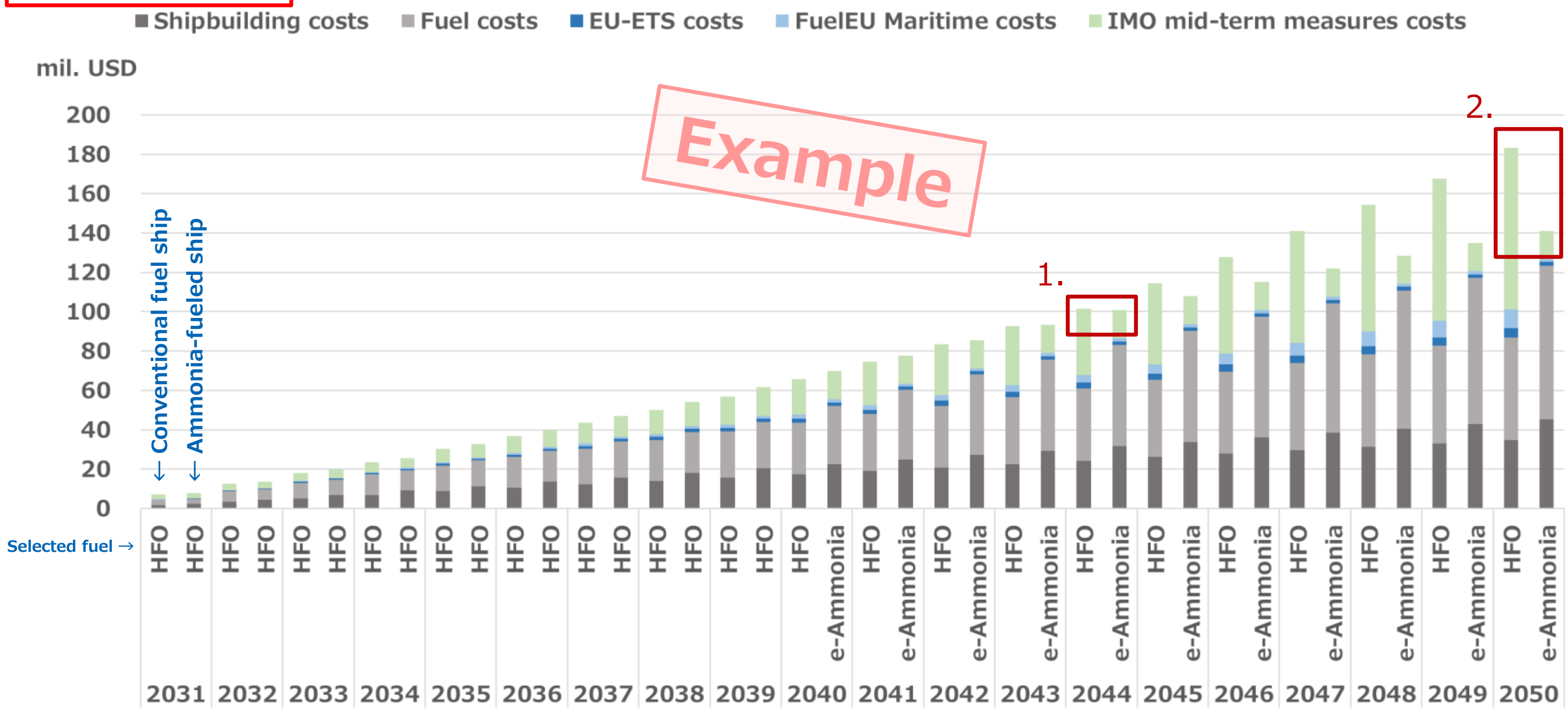
Cost simulation example - 1

When adopting alternative fuel ships, it's important to consider fuel costs and regulatory costs while aiming for a timely transition to zero-emission fuels. Here, we present a comparison of total costs between adopting conventional fuel ships and ammonia-fueled ships in a stepwise transition case, using a 64,000 DWT bulk carrier as an example.

Cost simulation example (Conventional fuel ship vs. Ammonia-fueled ship 64,000 DWT bulk carrier: Stepwise transition case)

Cumulative costs ver.



- **1. Identify the timing when cumulative costs will cross over** (2044 in this case)
- **2. Identify the lifetime total cost difference** (approx. 42 million USD over 20 years in this case)

<Assumption>

- ✓ Delivery in 2031 (Lifetime 20 years)
- ✓ Shipbuilding costs
  - → Amortized over 20 years
- ✓ Fuel price
  - → HFO: **Fixed**
    13.0 USD/GJ (=522.6 USD/ton)
  - → e-Ammonia: **Decrease annually**
    【2031】38.9 USD/GJ (=723.8 USD/ton)
    【2050】19.7 USD/GJ (=366.2 USD/ton)

<How to read the graph>

- ✓ Bar graph on the left side:
  Cumulative costs in case a conventional fuel ship is adopted
  (Fuel selection: HFO only)
- ✓ Bar graph on the right side:
  Cumulative costs in case an ammonia-fueled ship is adopted
  (Fuel selection options include HFO or e-Ammonia)
  (Select the fuel that lowers total costs each year)

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<Reference> Assumptions for cost simulation example - 1

The assumptions for the cost simulation example for a 64,000 DWT bulk carrier are as follows:

The items in blue represent the main uncertainties in costs.

Category			Unit	2024 (ref.)	2031	2050	Comments
Base	**Newbuilding price** (Ammonia-fueled ship)		-	-	-	-	USD 45,175,000 (Conventional fuel ship +30%)
Base	**Fuel consumption** (HFO)		ton	-	5,000	5,000	Same energy consumption in ammonia-fueled ship
Base	**Fuel price** (HFO)		USD/ton	522.6 (=13.0 USD/GJ)	522.6 (=13.0 USD/GJ)	522.6 (=13.0 USD/GJ)	
Base	**Fuel price** (e-Ammonia)	Gradual transition case	USD/ton	855.6 (=46.0 USD/GJ)	735.8 (=39.6 USD/GJ)	410.7 (=22.1 USD/GJ)	2.0% decrease each year compared to 2024
Base	**Fuel price** (e-Ammonia)	Stepwise transition case*1	USD/ton	855.6 (=46.0 USD/GJ)	723.8 (=38.9 USD/GJ)	366.2 (=19.7 USD/GJ)	2.2% decrease each year compared to 2024
Base	**Fuel price** (e-Ammonia)	Rapid transition case	USD/ton	855.6 (=46.0 USD/GJ)	711.9 (=38.3 USD/GJ)	321.7 (=17.3 USD/GJ)	2.4% decrease each year compared to 2024
EU regulations-related	**Emissions subject to EU reg.** (% in total emissions)		%	12	12	12	
EU regulations-related	**EU-ETS allowance price**	Gradual transition case	USD/tonCO_2eq	80.0	85.6	100.8	1% increase each year compared to 2024
EU regulations-related	**EU-ETS allowance price**	Stepwise transition case*1	USD/tonCO_2eq	80.0	96.8	142.4	3% increase each year compared to 2024
EU regulations-related	**EU-ETS allowance price**	Rapid transition case	USD/tonCO_2eq	80.0	108.0	184.0	5% increase each year compared to 2024
EU regulations-related	**FuelEU Maritime costs**		-	-	As per the reg.	As per the reg.	HFO's GHG intensity (gCO_2eq/MJ) is 91.7. e-Ammonia's GHG intensity is calculated as 0.0.
IMO regulation-related	**Emissions subject to IMO reg.** (% in total emissions)		%	-	100	100	
IMO regulation-related	**IMO mid-term measures costs***2		-	-	The same contents as FuelEU Maritime	The same contents as FuelEU Maritime	HFO's GHG intensity (gCO_2eq/MJ) is 91.7. e-Ammonia's GHG intensity is calculated as 0.0.

*1 The cost simulation example on pages 73 & 74 was calculated under the "stepwise transition case."

*2 The IMO's mid-term measures are aligned with FuelEU Maritime, and the emissions targeted by the regulations cover emissions in all voyages.

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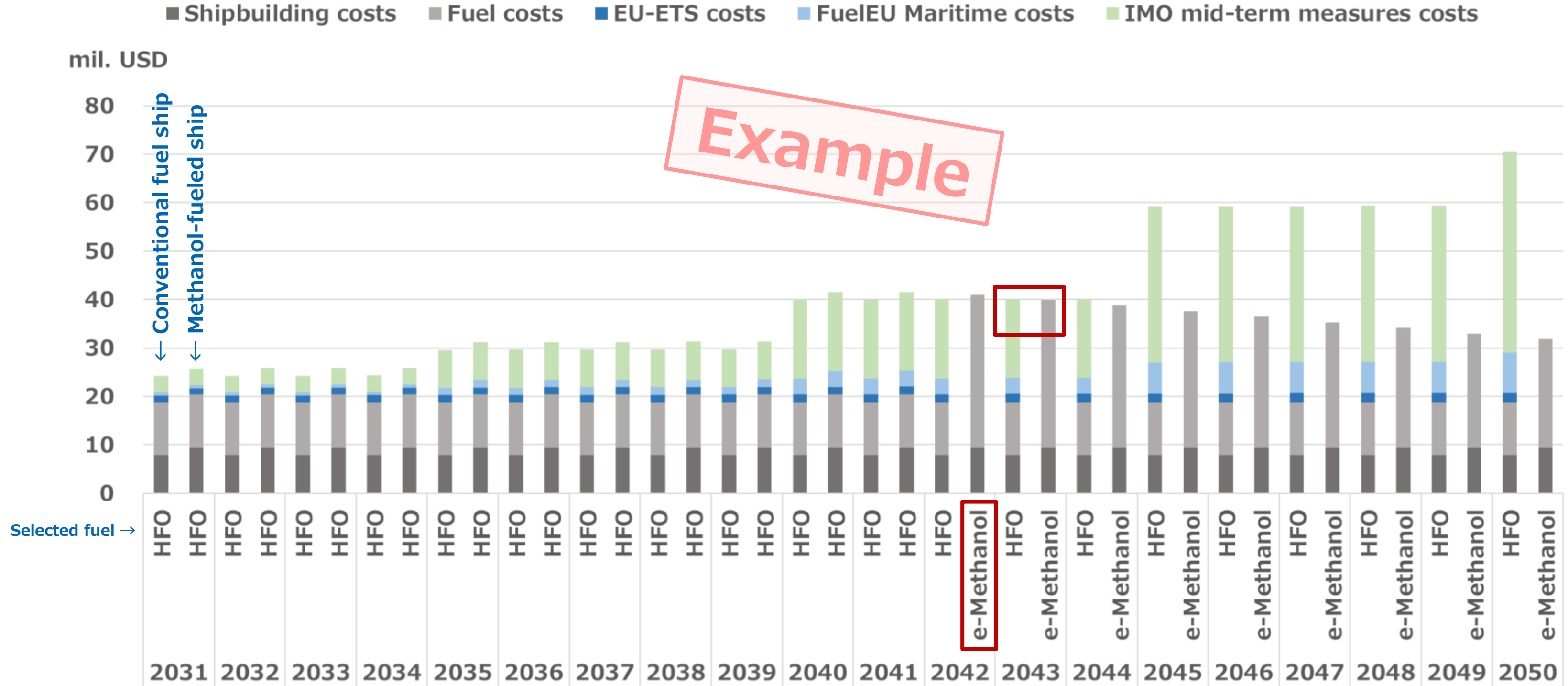
Cost simulation example - 2

When adopting alternative fuel ships, it's important to consider fuel costs and regulatory costs while aiming for a timely transition to zero-emission fuels. Here, we present a comparison of total costs between adopting conventional fuel ships and methanol-fueled ships in a stepwise transition case, using a 14,000 TEU containership as an example.

Cost simulation example (Conventional fuel ship vs. Methanol-fueled ship 14,000 TEU containership: Stepwise transition case)

Annual costs ver.



➢ **Identify the timing when annual costs will cross over**

(In this case, for the methanol-fueled ship, selecting e-Methanol from 2042 onwards will be more cost-effective, meaning that "e-Methanol fuel costs" < "HFO fuel costs + regulatory costs", and the annual costs will be less than those of the conventional fuel ship from 2043.)

<Assumption>

- ✓ Delivery in 2031 (Lifetime 20 years)
- ✓ Shipbuilding costs
  - → Amortized over 20 years
- ✓ Fuel price
  - → HFO: **Fixed**
    13.0 USD/GJ (=522.6 USD/ton)
  - → e-Methanol: **Decrease annually**
    【2031】52.5 USD/GJ (=1,043.8 USD/ton)
    【2050】26.5 USD/GJ (=528.1 USD/ton)

<How to read the graph>

- ✓ Bar graph on the left side:
  Annual costs in case a conventional fuel ship is adopted
  (Fuel selection: HFO only)
- ✓ Bar graph on the right side:
  Annual costs in case a methanol-fueled ship is adopted
  (Fuel selection options include HFO or e-Methanol)
  (Select the fuel that lowers total costs each year)

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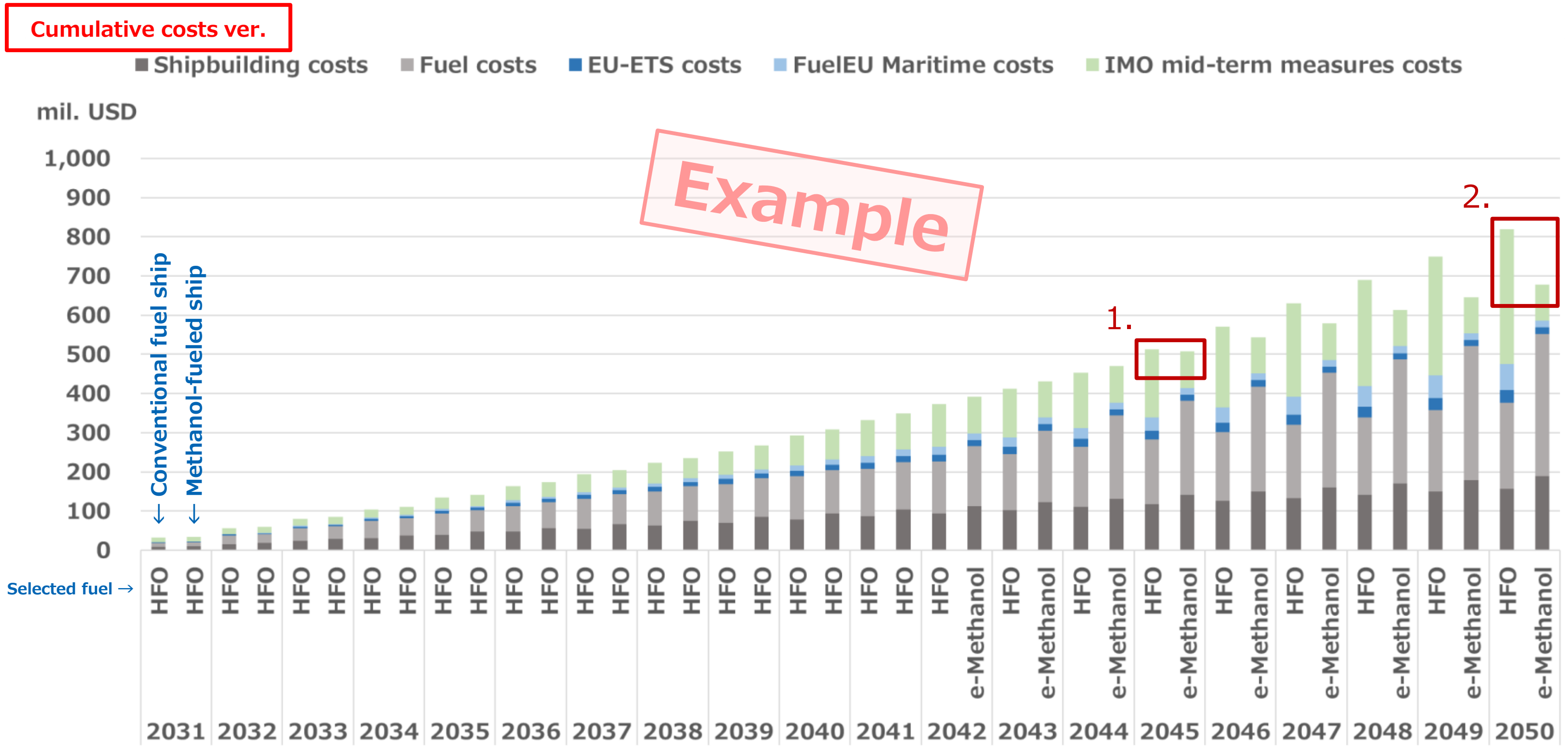
UPDATED

Cost simulation example - 2

When adopting alternative fuel ships, it's important to consider fuel costs and regulatory costs while aiming for a timely transition to zero-emission fuels. Here, we present a comparison of total costs between adopting conventional fuel ships and methanol-fueled ships in a stepwise transition case, using a 14,000 TEU containership as an example.

Cost simulation example (Conventional fuel ship vs. Methanol-fueled ship 14,000 TEU containership: Stepwise transition case)



➢ **1. Identify the timing when cumulative costs will cross over** (2045 in this case)

➢ **2. Identify the lifetime total cost difference** (approx. 142 million USD over 20 years in this case)

<Assumption>

✓ Delivery in 2031 (Lifetime 20 years)

✓ Shipbuilding costs
  → Amortized over 20 years

✓ Fuel price
  → HFO: **Fixed**
  13.0 USD/GJ (=522.6 USD/ton)
  → e-Methanol: **Decrease annually**
  【2031】52.5 USD/GJ (=1,043.8 USD/ton)
  【2050】26.5 USD/GJ (=528.1 USD/ton)

<How to read the graph>

✓ Bar graph on the left side:
Cumulative costs in case a conventional fuel ship is adopted
(Fuel selection: HFO only)

✓ Bar graph on the right side:
Cumulative costs in case a methanol-fueled ship is adopted
(Fuel selection options include HFO or e-Methanol)
(Select the fuel that lowers total costs each year)

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UPDATED

<Reference> Assumptions for cost simulation example - 2

The assumptions for the cost simulation example for a 14,000 TEU containership are as follows:

The items in blue represent the main uncertainties in costs.

Category			Unit	2024 (ref.)	2031	2050	Comments
Base	**Newbuilding price** (Methanol-fueled ship)		-	-	-	-	USD 188,300,000 (Conventional fuel ship +20%)
	Fuel consumption (HFO)		ton	-	21,000	21,000	Same energy consumption in methanol-fueled ship
	Fuel price (HFO)		USD/ton	522.6 (=13.0 USD/GJ)	522.6 (=13.0 USD/GJ)	522.6 (=13.0 USD/GJ)	
	Fuel price (e-Methanol)	Gradual transition case	USD/ton	1,233.8 (=62.0 USD/GJ)	1,061.1 (=53.3 USD/GJ)	592.2 (=29.8 USD/GJ)	2.0% decrease each year compared to 2024
		Stepwise transition case*1	USD/ton	1,233.8 (=62.0 USD/GJ)	1,043.8 (=52.5 USD/GJ)	528.1 (=26.5 USD/GJ)	2.2% decrease each year compared to 2024
		Rapid transition case	USD/ton	1,233.8 (=62.0 USD/GJ)	1,026.5 (=51.6 USD/GJ)	463.9 (=23.3 USD/GJ)	2.4% decrease each year compared to 2024
EU regulations-related	**Emissions subject to EU reg.** (% in total emissions)		%	20	20	20	
	EU-ETS allowance price	Gradual transition case	USD/tonCO_2eq	80.0	85.6	100.8	1% increase each year compared to 2024
		Stepwise transition case*1	USD/tonCO_2eq	80.0	96.8	142.4	3% increase each year compared to 2024
		Rapid transition case	USD/tonCO_2eq	80.0	108.0	184.0	5% increase each year compared to 2024
	FuelEU Maritime costs		-	-	As per the reg.	As per the reg.	HFO's GHG intensity (gCO_2eq/MJ) is 91.7. e-Methanol's GHG intensity is calculated as 0.0.
IMO regulation-related	**Emissions subject to IMO reg.** (% in total emissions)		%	-	100	100	
	IMO mid-term measures costs*2		-	-	The same contents as FuelEU Maritime	The same contents as FuelEU Maritime	HFO's GHG intensity (gCO_2eq/MJ) is 91.7. e-Methanol's GHG intensity is calculated as 0.0.

*1 The cost simulation example on pages 76 & 77 was calculated under the "stepwise transition case."

*2 The IMO's mid-term measures are aligned with FuelEU Maritime, and the emissions targeted by the regulations cover emissions in all voyages.

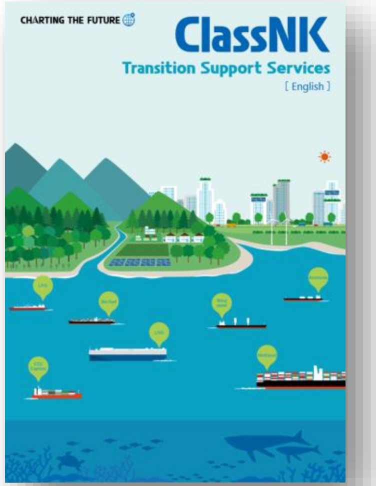
ClassNK’s support

ClassNK provides services to support your efforts in achieving a smooth transition to zero emissions.

Towards net-zero GHG emissions by 2050

The international shipping industry is expected to undergo a significant fuel transition period toward achieving net-zero GHG emissions by or around 2050. However, the infrastructure for supplying zero-emission fuels is currently underdeveloped. Therefore, in the meantime, it is necessary to transition to zero emissions while utilizing various GHG emission reduction measures. ClassNK has launched the "ClassNK Transition Support Services" to provide comprehensive support for seamless transitions to zero emissions for our clients by leveraging insights gained from activities such as issuing Approval in Principle (AiP) for alternative fuel ships, participating in demonstration projects for energy efficiency improvement technologies and onboard CCS, and verifying GHG emissions. We encourage you to take advantage of our "ClassNK Transition Support Services" for your efforts to reduce GHG emissions from ships.

ClassNK Transition Support Services



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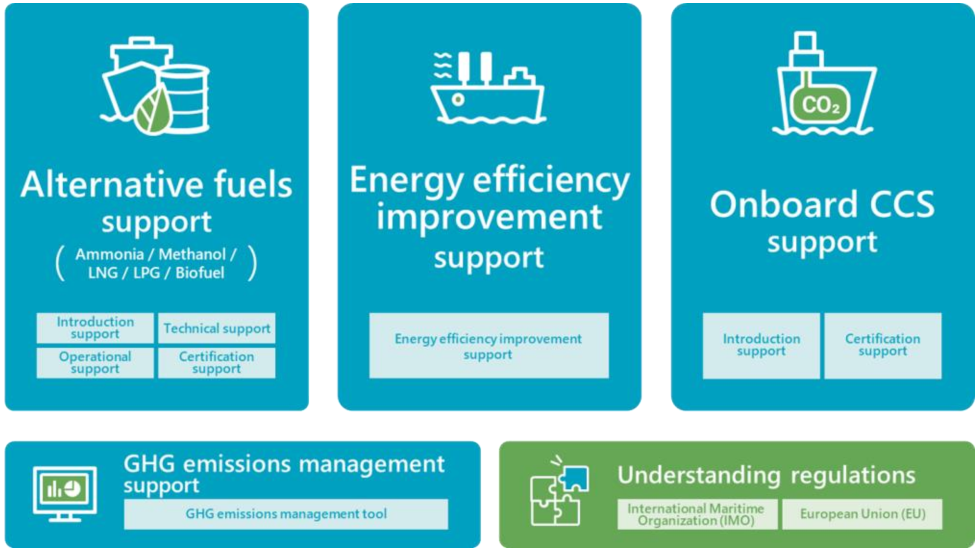

For inquiries regarding ClassNK Transition Support Services in general, please contact us at the following:

NIPPON KAIJI KYOKAI (ClassNK)
Green Transformation Center
TEL: +81-3-5226-2031
E-mail: gxc@classnk.or.jp

ClassNK Alternative Fuels Insight will continue to be updated according to the alternative fuel trends. For more detailed information about the contents of this document or for any feedback or requests, please contact us.

NIPPON KAIJI KYOKAI (ClassNK)

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102-8567
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E-mail: gxc@classnk.or.jp

Inquiries can also be made using this feedback form.

THANK YOU

Appendix

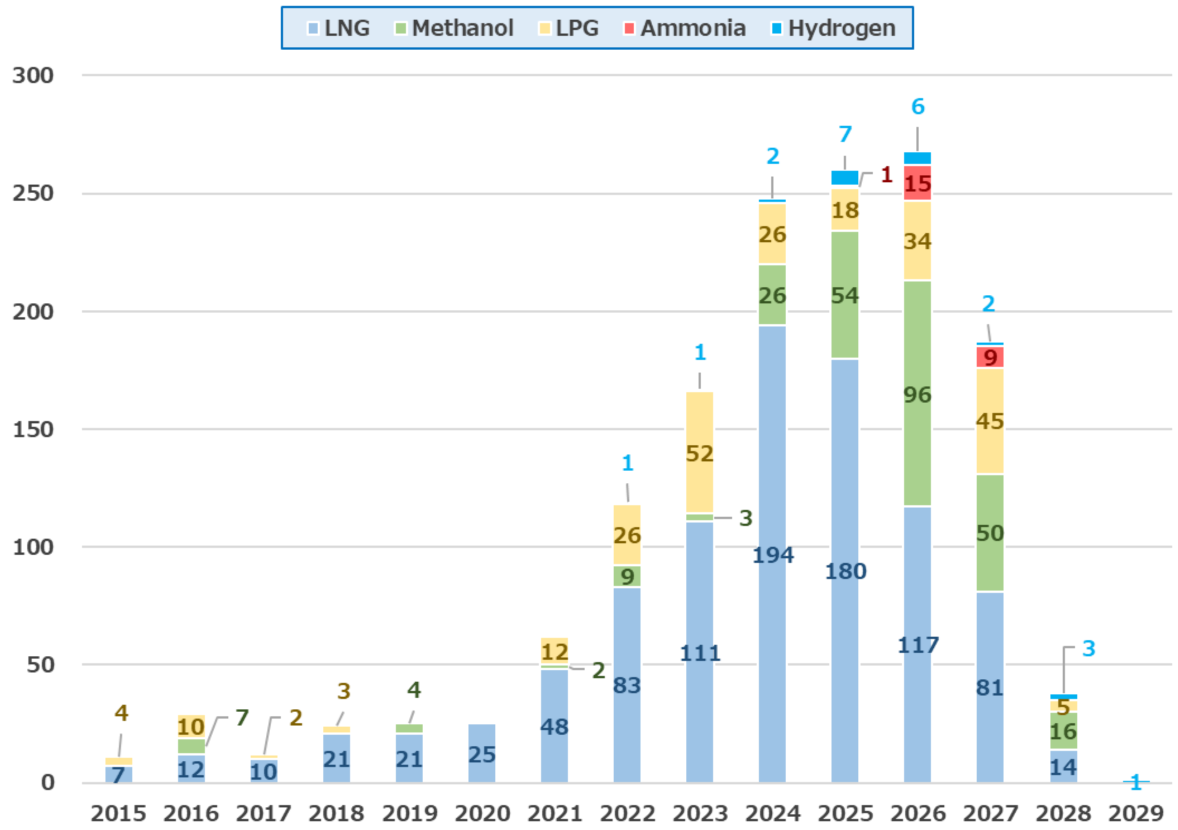
To provide a more comprehensive view of the changing adoption of alternative fuels, we present data on the number of alternative fuel ships in service and on order as of June 30, 2024, based on ClassNK Alternative Fuels Insight (Version 2.1).

ClassNK

Trends in alternative fuel ships

As of the end of June 2024

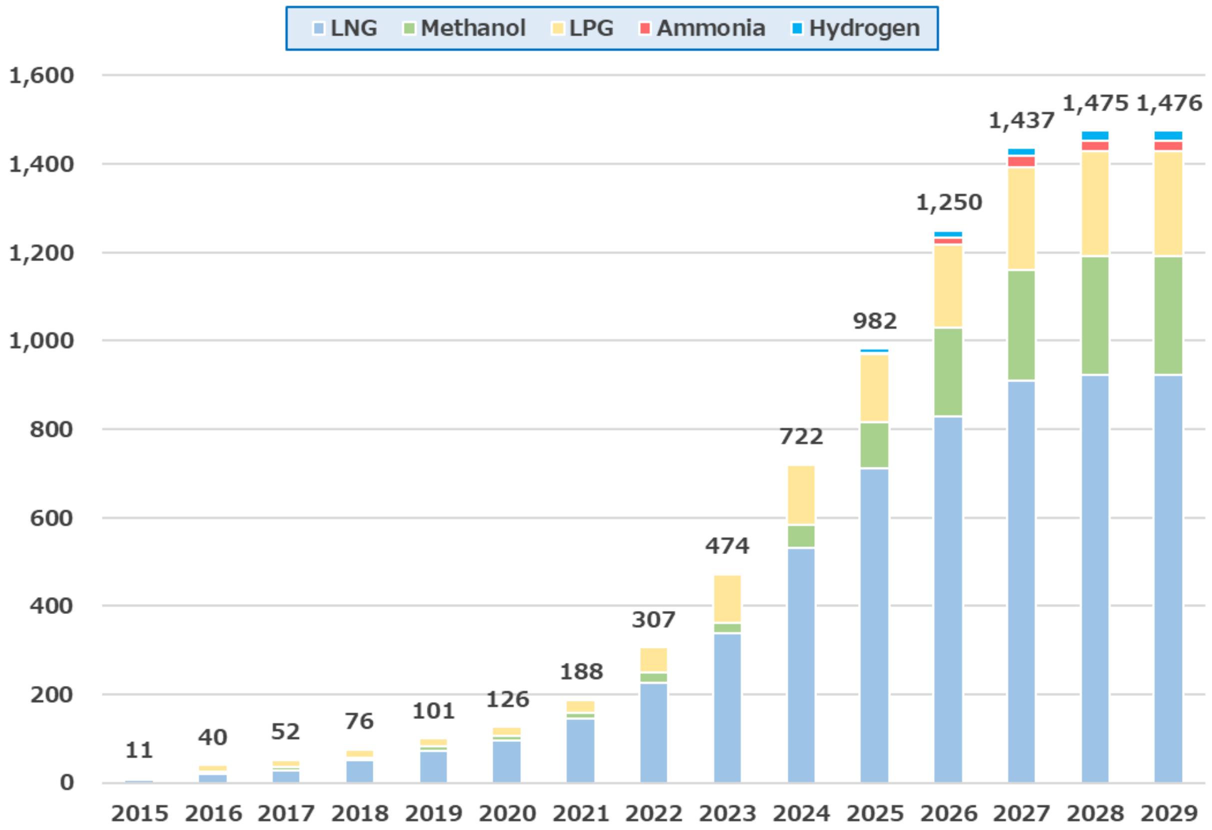
"Newbuilding" alternative fuel ship trend



- ✓ As of the end of June 2024 (Orderbook is included after 2024.)
- ✓ 5,000 gross tonnage and above
- ✓ LNG carriers are excluded from LNG-fueled ships.
- ✓ Alternative fuel ready ships are not included.

"In service" alternative fuel ship trend*

*Cumulative number of ships delivered since 2015, without considering scrapping



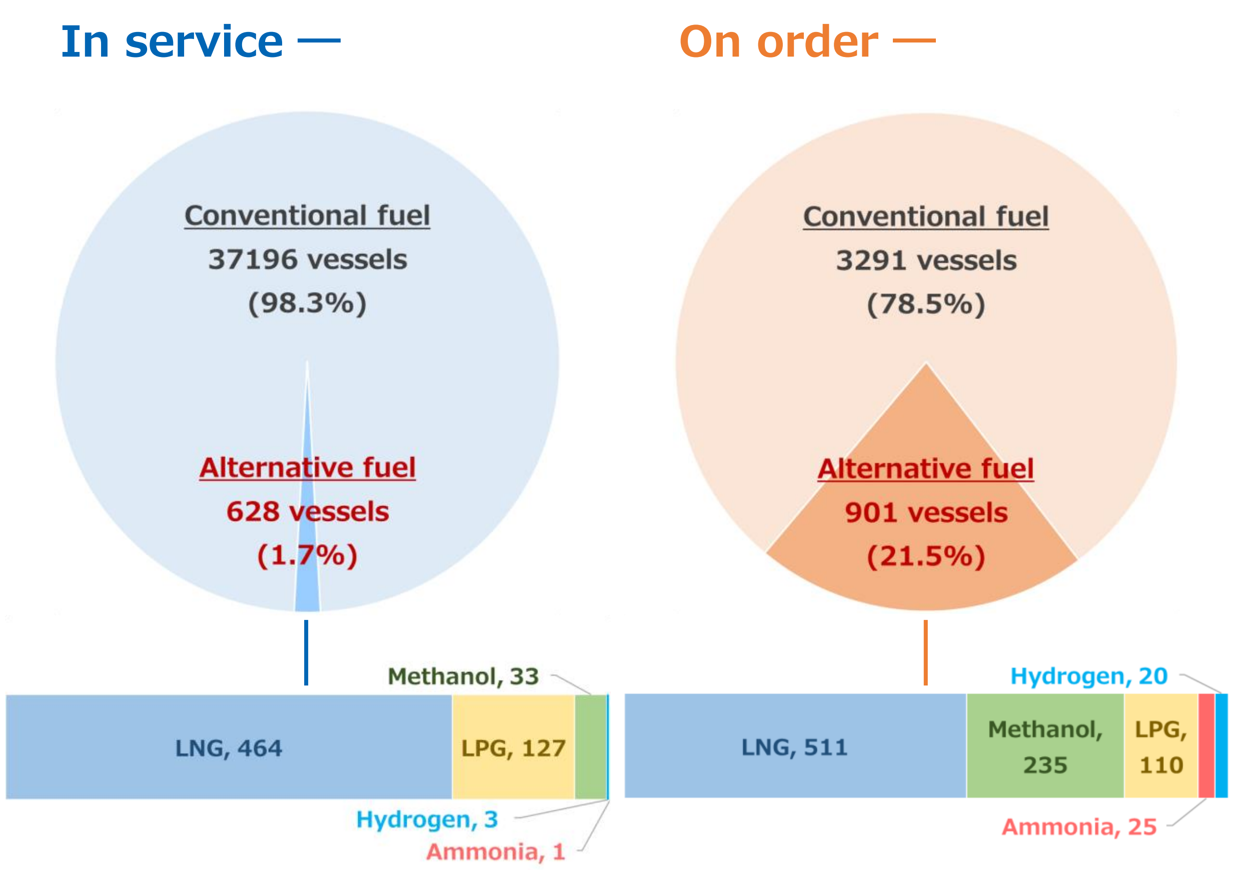
- ✓ As of the end of June 2024 (Orderbook is included after 2024.)
- ✓ 5,000 gross tonnage and above
- ✓ LNG carriers are excluded from LNG-fueled ships.
- ✓ Alternative fuel ready ships are not included.

Source: The figures and tables presented in this section are created by ClassNK based on data from Clarkson Research Services Limited.

As of the end of June 2024

Trends in alternative fuel ships

Share of alternative fuel ships



- ✓ As of the end of June 2024
- ✓ 5,000 gross tonnage and above
- ✓ LNG carriers are excluded from LNG-fueled ships.
- ✓ Alternative fuel ready ships are not included.

Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	522 vessels（1.4%）	628 vessels (1.7%)
Total GT	33,560,005 GT（2.2%）	42,327,700 GT (2.7%)

During the past six months, there has been an increase of 106 vessels totaling 8.8 million GT. This growth can be attributed to the successive deliveries of LNG-fueled containerships, bulk carriers, vehicle carriers, and product/chemical tankers, etc. A certain number of LPG-fueled ships (LPG carriers only) have also been delivered.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	835 vessels (21.8%)	901 vessels (21.5%)
Total GT	66,431,935 GT (30.9%)	69,624,584 GT (30.4%)

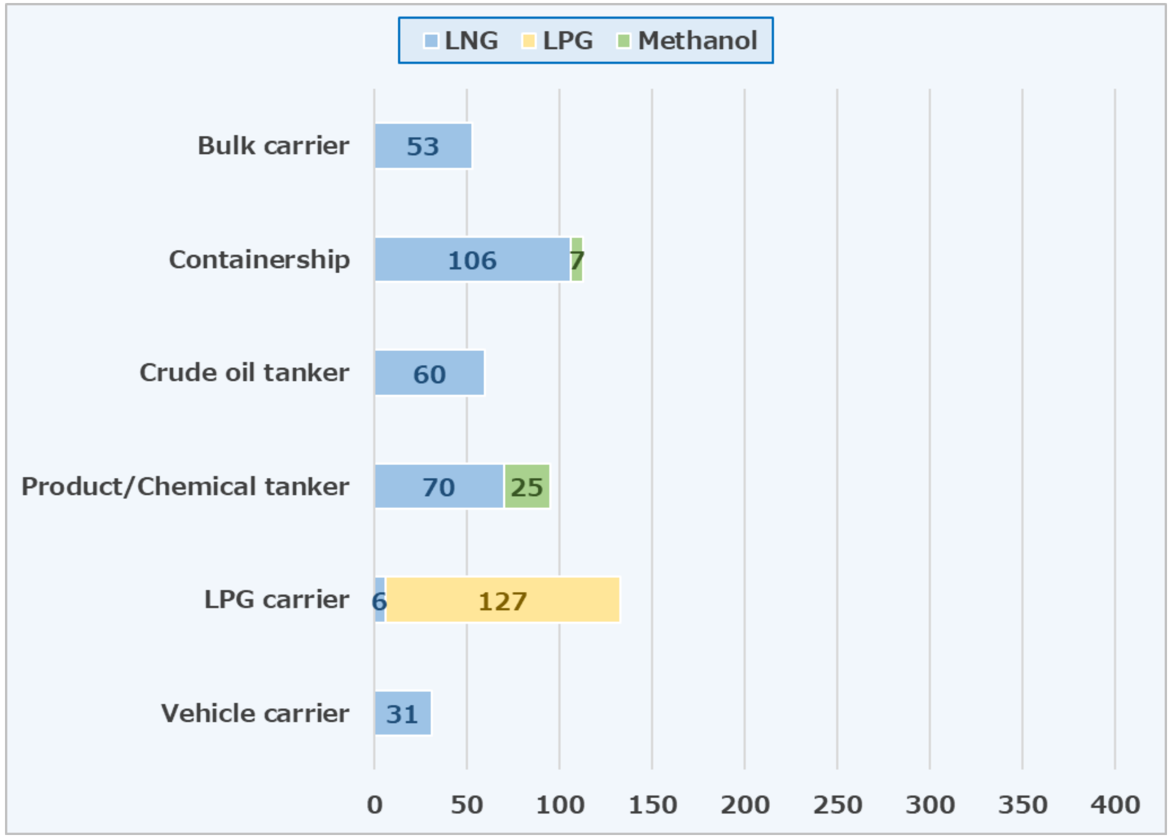
During the past six months, there has been an increase of 66 vessels totaling 3.2 million GT. In terms of fuels, LNG, methanol and LPG (LPG carriers only) shared most of the new orders, with the main fuel still uncertain. A certain number of vessels were also ordered for ammonia-fueled ships, despite the ongoing development of engines.

ClassNK

As of the end of June 2024

Trends in alternative fuel ships (by ship type)

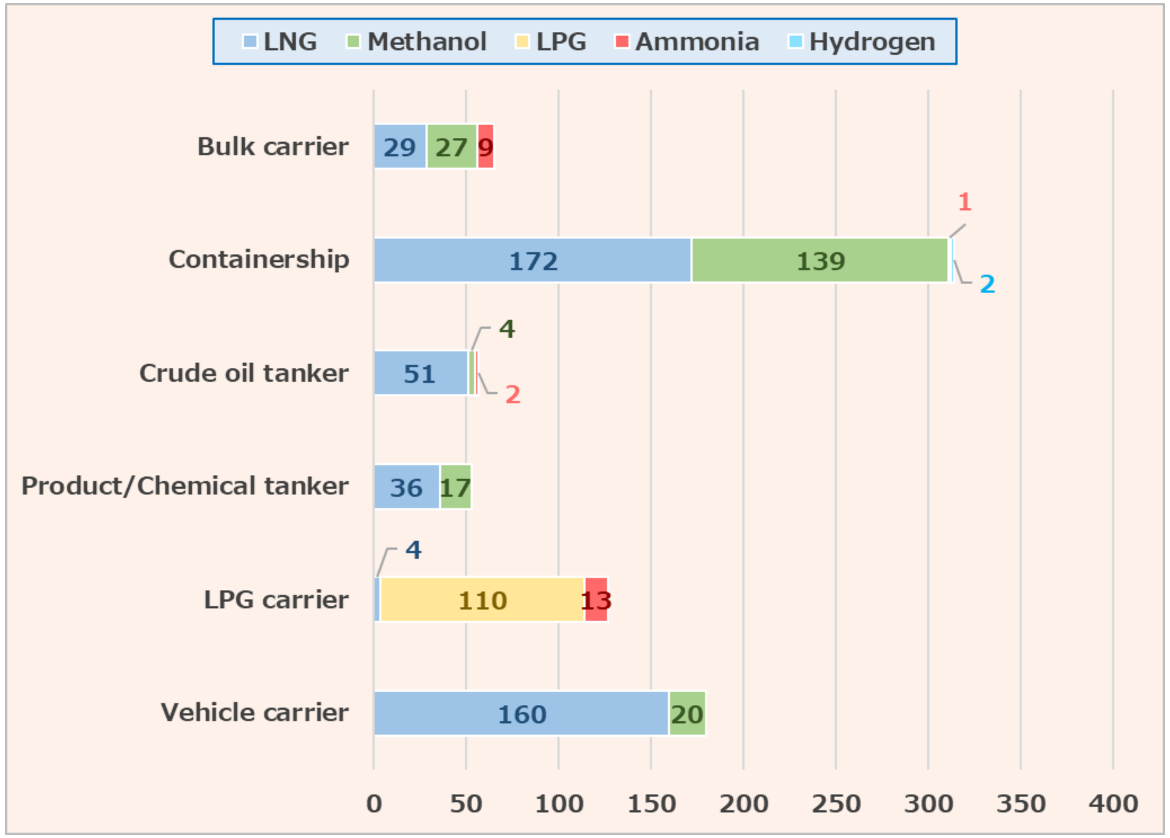
In service —



✓ As of the end of June 2024 / 5,000 gross tonnage and above / Alternative fuel ready ships are not included.

➢ LNG-fueled ships make up the majority of ships of all types, with the exception of product/chemical tankers, which include methanol carriers, and LPG carriers.

On order —



✓ As of the end of June 2024 / 5,000 gross tonnage and above / Alternative fuel ready ships are not included.

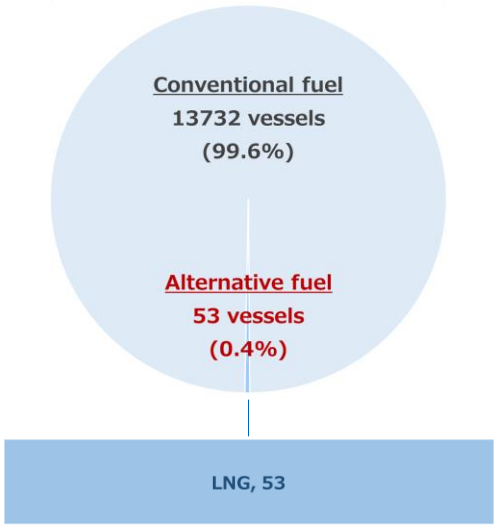
➢ Methanol-fueled ships are expanding to other ship types besides containerships. Ammonia-fueled ships have also been ordered for some ship types.

As of the end of June 2024

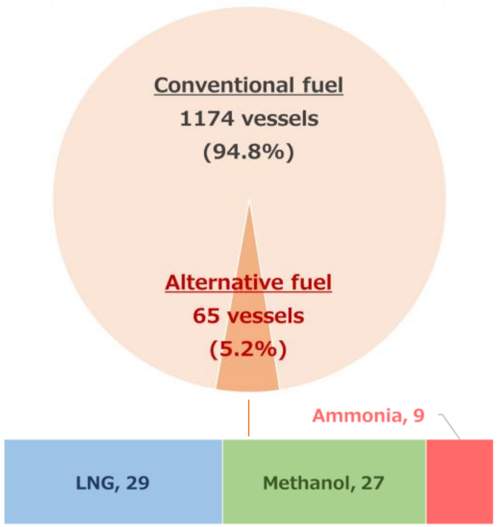
Trends in alternative fuel ships (by ship type)

Bulk carriers

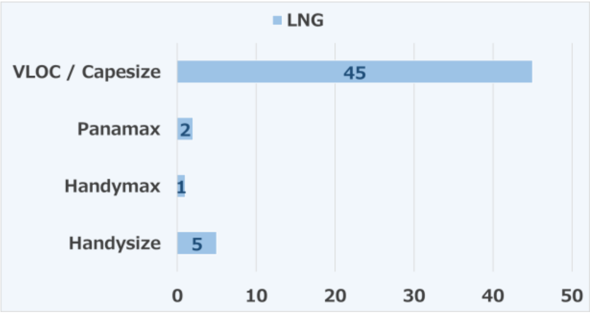
In service —



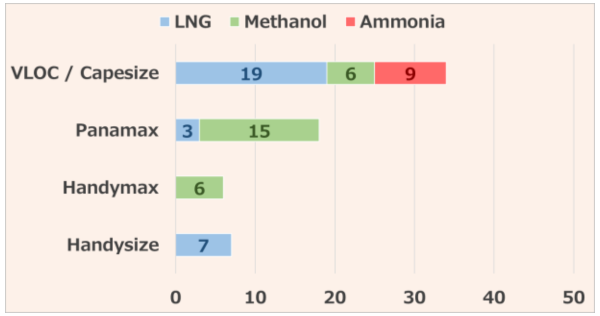
On order —



In service —



On order —



Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	39 vessels (0.3%)	53 vessels (0.4%)
Total GT	3,622,799 GT (0.7%)	5,072,048 GT (0.9%)

During the past six months, there was an increase of 14 vessels totaling 1.4 million GT. By ship size, the majority of ships delivered are VLOC/Capesize and bulk carriers have a marked tendency to use alternative fuels, especially in the larger sizes. All delivered ships were LNG-fueled ships.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	63 vessels (5.5%)	65 vessels (5.2%)
Total GT	4,926,559 GT (10.3%)	5,070,849 GT (9.6%)

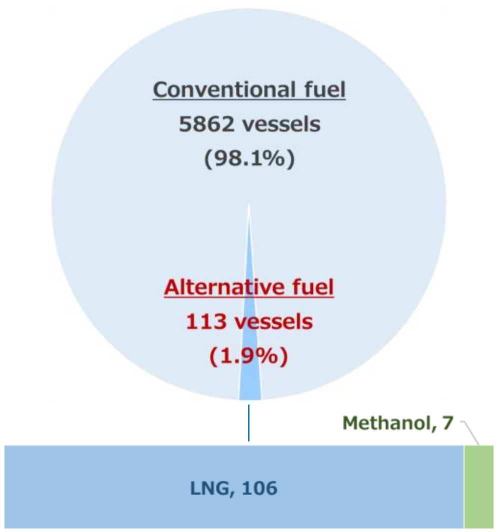
During the past six months, there was an increase of 2 vessels totaling 0.1 million GT. While ammonia and methanol-fueled ships have been ordered in VLOC/Capesize, no LNG-fueled ships have been ordered.

As of the end of June 2024

Trends in alternative fuel ships (by ship type)

Containerships

In service —



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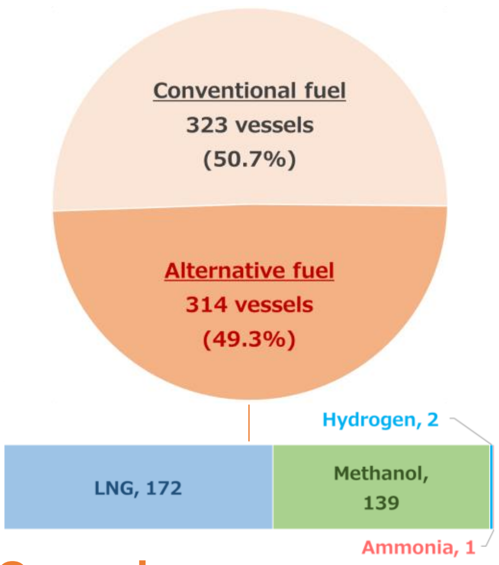

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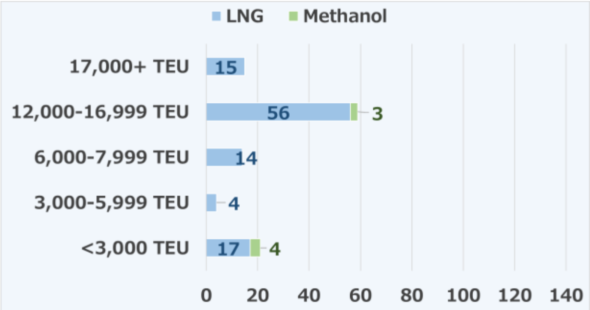

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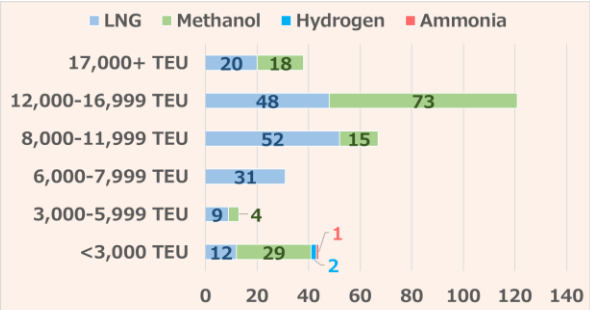


Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	75 vessels (1.3%)	113 vessels (1.9%)
Total GT	9,683,956 GT (3.3%)	14,083,720 GT (4.5%)

During the past six months, there was an increase of 38 vessels totaling 4.4 million GT. By ship size, the largest number of ships were delivered at 15,000 TEU, most of which were LNG-fueled ships, while methanol-fueled ships of less than 3,000 TEU and 15,000 TEU were also delivered.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	340 vessels (41.3%)	314 vessels (49.3%)
Total GT	38,028,991 GT (56.5%)	35,665,036 GT (64.5%)

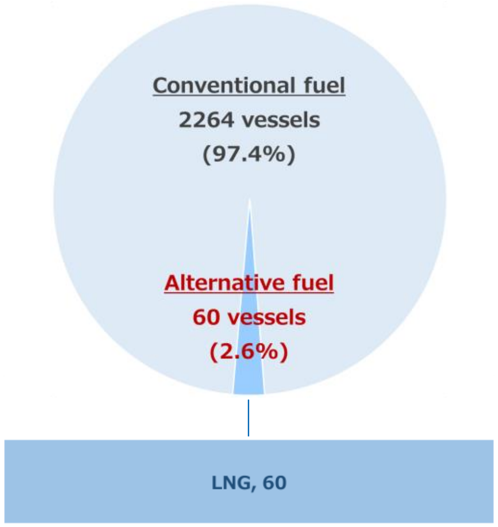
During the past six months, there was a decrease of 26 vessels totaling 2.4 million GT. This was due to a number of deliveries and a decrease in new orders. By fuel type, the majority of new orders were for methanol-fueled ships, in contrast to the trend in deliveries. Ammonia-fueled ships were also ordered for the first time.

Trends in alternative fuel ships (by ship type)

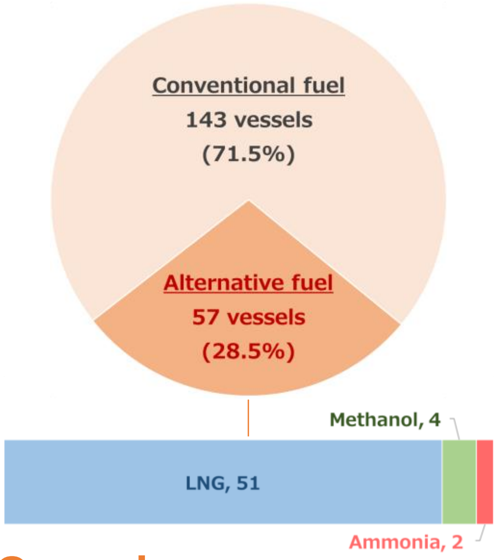
As of the end of June 2024

Crude oil tankers

In service —



On order —



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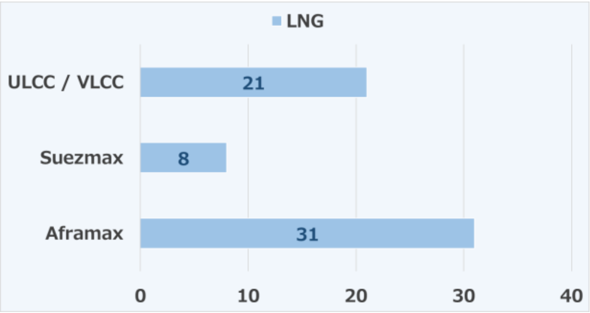

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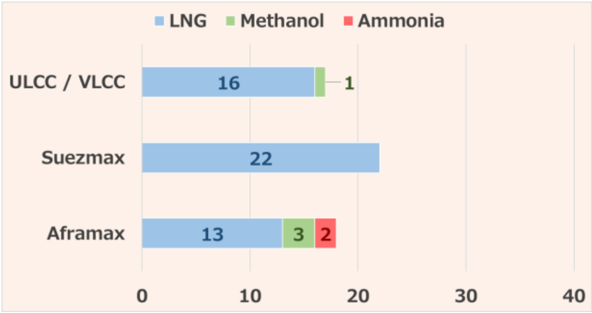


Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	57 vessels (2.5%)	60 vessels (2.6%)
Total GT	5,775,831 GT (2.4%)	6,060,939 GT (2.5%)

During the past six months, there was an increase of 3 vessels totaling 0.3 million GT. The delivered ships were ULCC/VLCC and Aframax, all of which were LNG-fueled ships. No alternative fuel ships for Suezmax were delivered in the past six months.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	42 vessels (33.9%)	57 vessels (28.5%)
Total GT	3,736,624 GT (33.6%)	5,611,417 GT (27.9%)

During the past six months, there was an increase of 15 vessels totaling 1.9 million GT. By ship size, the majority of orders were for ULCC/VLCC. By fuel type, LNG-fueled ships accounted for the majority of orders, while ammonia-fueled ships were ordered for the first time. There were no orders for methanol-fueled ships.

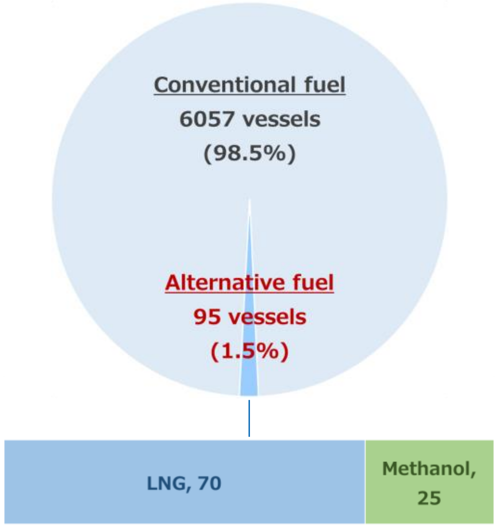
ClassNK

Trends in alternative fuel ships (by ship type)

As of the end of June 2024

Product/Chemical tankers

In service —



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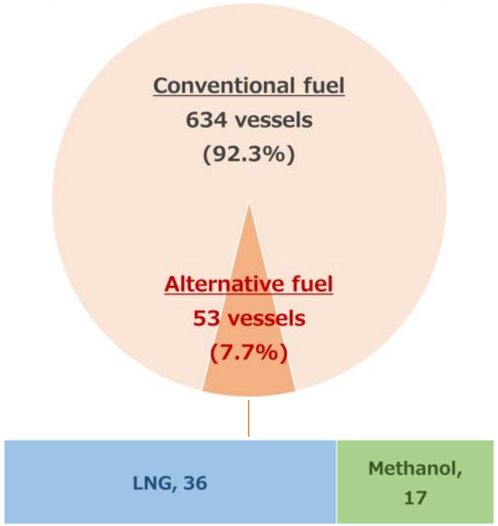

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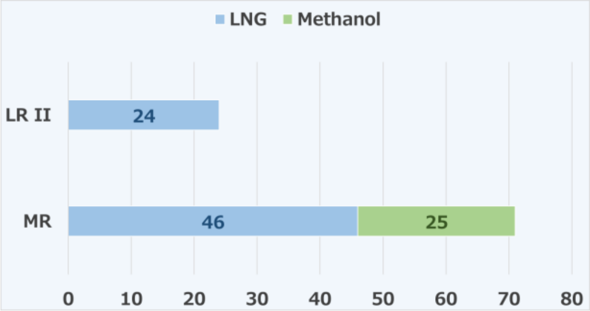

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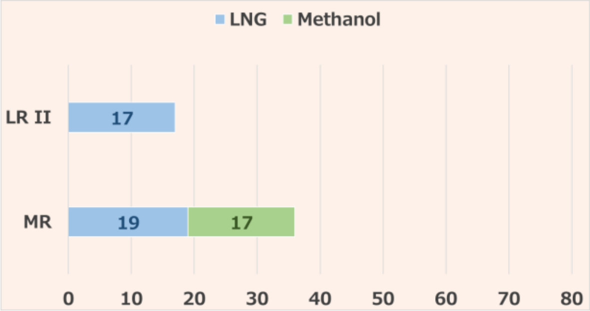


Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	83 vessels (1.4%)	95 vessels (1.5%)
Total GT	2,596,463 GT (1.8%)	2,974,245 GT (2.1%)

During the past six months, there was an increase of 12 vessels totaling 0.4 million GT. By ship size, while MR and LRII were delivered, no LRI were delivered. By ship type, LNG-fueled ships accounted for the majority of deliveries, while some methanol-fueled ships were also delivered.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	47 vessels (9.8%)	53 vessels (7.7%)
Total GT	1,280,079 GT (8.3%)	1,787,476 GT (8.5%)

During the past six months, there was an increase of 6 vessels totaling 0.5 million GT. By ship size, LRII were the most ordered ships. By fuel type, LNG-fueled ships accounted for the majority of orders, with methanol-fueled ships accounting for the remainder.

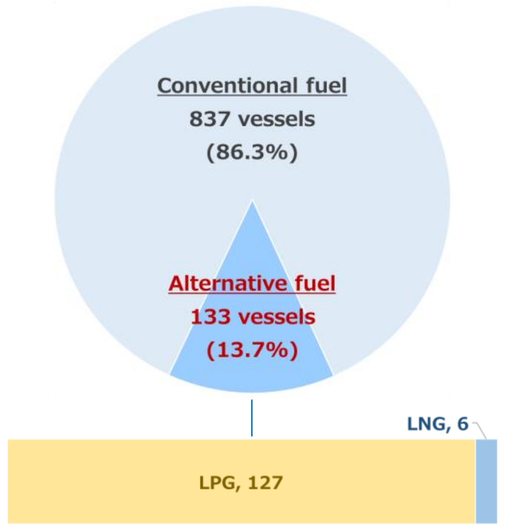
ClassNK

As of the end of June 2024

Trends in alternative fuel ships (by ship type)

LPG carriers

In service —



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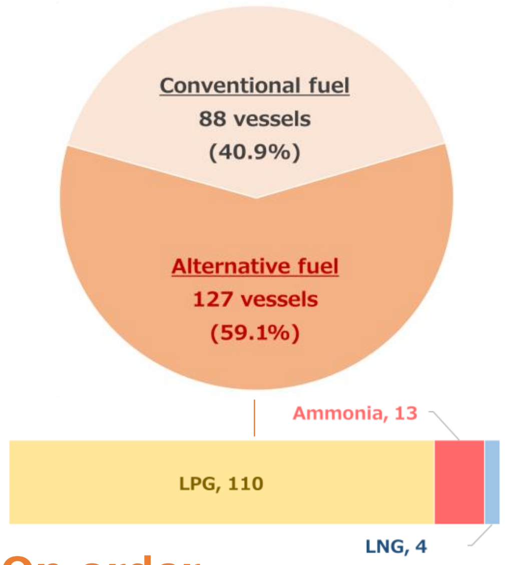

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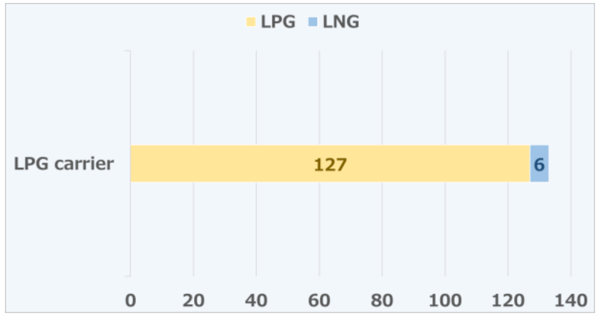

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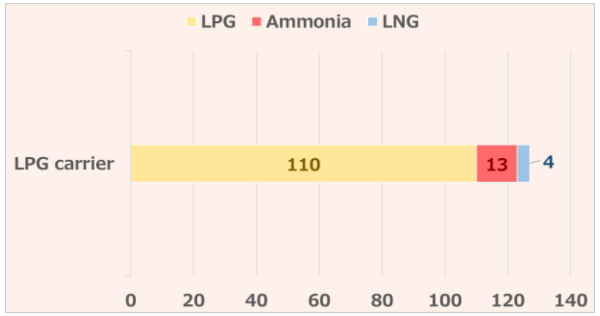


Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	112 vessels (11.9%)	133 vessels (13.7%)
Total GT	4,834,491 GT (17.4%)	5,816,222 GT (20.2%)

During the past six months, there was an increase of 21 vessels totaling 1.0 million GT. VLGC (over 80,000m^3) were mainly delivered, all of which were LPG-fueled ships.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	91 vessels (54.5%)	127 vessels (59.1%)
Total GT	3,781,639 GT (55.8%)	4,952,445 GT (59.2%)

During the past six months, there was an increase of 36 vessels totaling 1.2 million GT. In anticipation of increased demand for the transportation of ammonia fuel, orders for LPG carriers have increased rapidly over the past six months. By ship size, VLGC (over 80,000m^3) accounted for the majority of orders, all of which were for LPG-fueled ships.

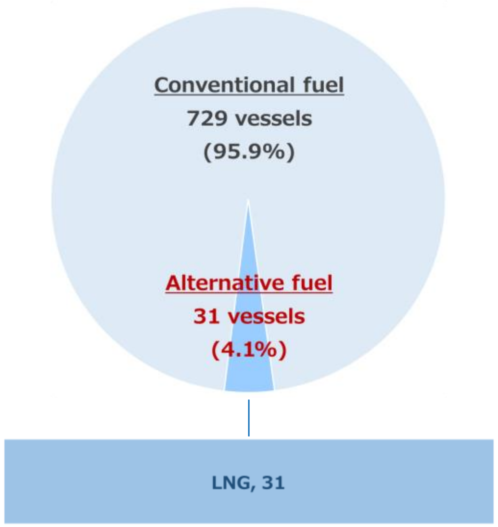
ClassNK

Trends in alternative fuel ships (by ship type)

As of the end of June 2024

Vehicle carriers

In service —



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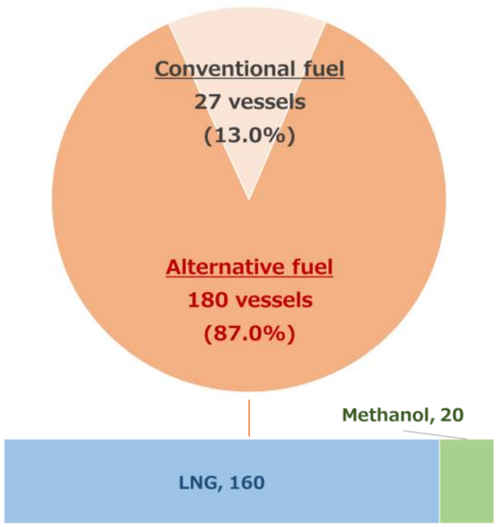

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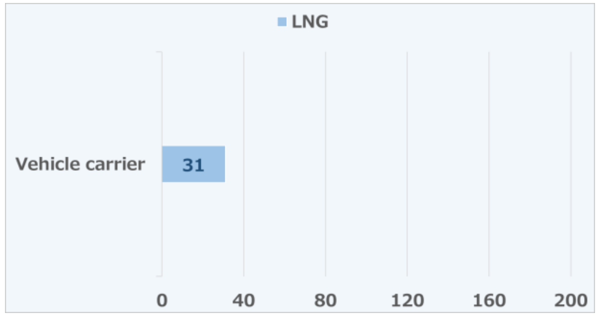

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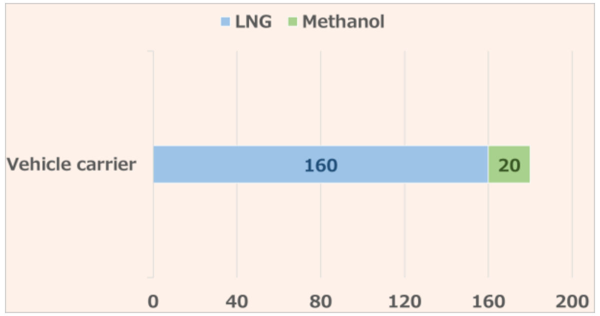


Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	20 vessels (2.7%)	31 vessels (4.1%)
Total GT	1,275,216 GT (3.3%)	2,023,411 GT (5.1%)

During the past six months, there was an increase of 11 vessels totaling 0.7 million GT. All were around 7,000 cars in size, and all were LNG-fueled ships.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	157 vessels (84.9%)	180 vessels (87.0%)
Total GT	9,978,269 GT (82.5%)	11,563,177 GT (84.9%)

During the past six months, there was an increase of 23 vessels totaling 1.6 million GT. By ship size, orders were seen across a wide range of sizes from 2,000 cars to 10,000 cars. By fuel type, LNG-fueled ships accounted for the majority, but more methanol-fueled ships were ordered than ever before.

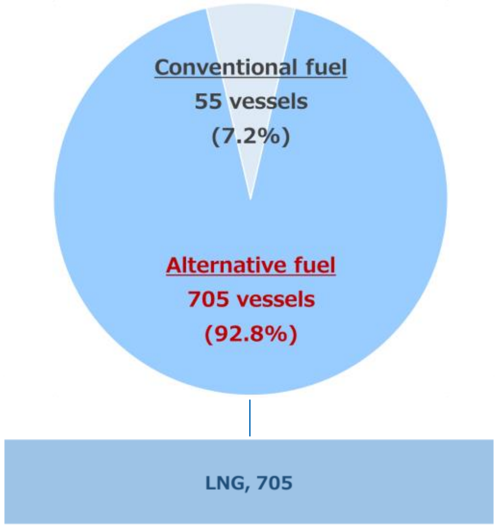
ClassNK

Trends in alternative fuel ships (by ship type)

As of the end of June 2024

LNG carriers (for reference)

In service —



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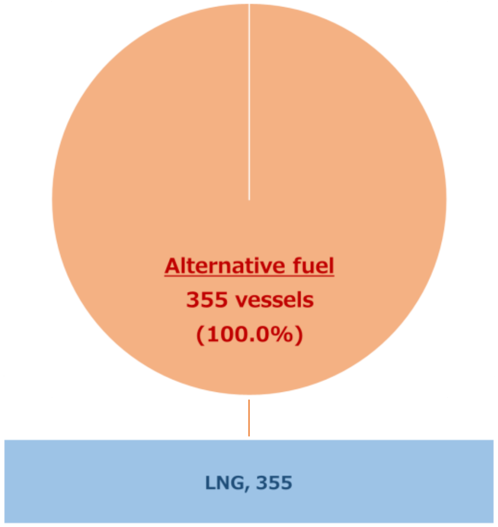

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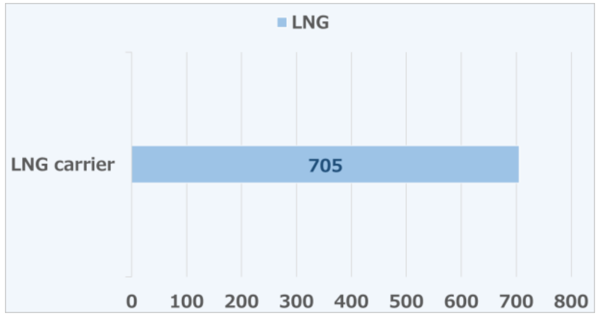
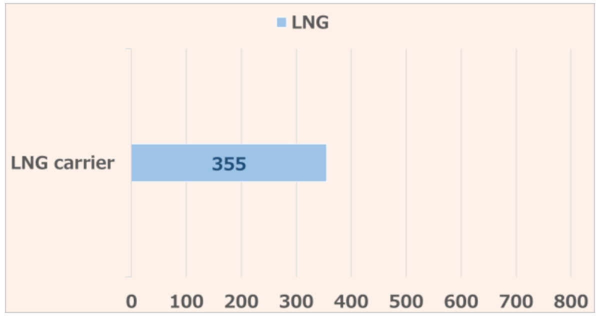


On order —



Details of alternative fuel ships (Dec. 2023 → Jun. 2024)

In service —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	681 vessels (92.5%)	705 vessels (92.8%)
Total GT	70,096,187 GT (90.9%)	72,486,110 GT (91.2%)

During the past six months, there was an increase of 24 vessels totaling 2.4 million GT. All were LNG-fueled ships, and no other alternative fuel ships were delivered.

On order —

	As of Dec. 31, 2023	As of Jun. 30, 2024
Number of vessels	339 vessels (99.7%)	355 vessels (100.0%)
Total GT	36,855,375 GT (99.9%)	39,722,960 GT (100.0%)

During the past six months, there was an increase of 16 vessels totaling 2.9 million GT. All were LNG-fueled ships, and no other alternative fuel ships were ordered. All ships on orderbook are LNG-fueled ships.