International marine initiatives for decarbonization and LNG bunkering

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1. Introduction

In recent years, marine environmental regulations have been tightened with the aim of reducing sulphur oxides (SOx), particulate matter (PM), nitrogen oxides (NOx) and greenhouse gas (GHG) emissions such as CO_2 from ships. Vessels that do not meet these emission standards are forced to withdraw from the market, which has a great impact on economic activities. Moreover, in Japan, which relies on imports for most of its natural gas and oil, the impact on energy security will be enormous.

In response to these environmental regulations, the introduction of exhaust gas cleaning equipment to ships and conversion to low-sulphur fuels are progressing, and particularly use of liquefied natural gas (LNG) fuels that do not contain any sulphur is expanding. Ship transportation represented 99.6% of Japan's total export and import in 2019 (on a tonnage basis), and the Japanese merchant ships (ocean-going vessels operated by Japanese shipping companies) transported 63.1% of the global maritime transportation of goods[2]. That is why Japan should take the initiative in international shipping. This paper gives an overview of the status of tightening environmental regulations in the ocean, explains next-generation ship fuels as countermeasures, and then summarizes the progress of LNG bunkering (fuel supply to ships) circumstances and issues for the future.

2. Environmental regulations in the ocean

In March 1958, the International Maritime Organization (IMO), a specialized agency of the United Nations, was established to promote intergovernmental cooperation on issues in the maritime sector, such as the prevention of marine pollution. As of September 2021, 174 countries including Japan are members. The targets of marine air pollution regulations set by the IMO are roughly divided into three categories: 1) sulphur content in fuel oil (SOx, PM), 2) NOx and 3) GHG (energy efficiency) (Fig. 1).

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[2] JSA, SHIPPING NOW 2020-2021

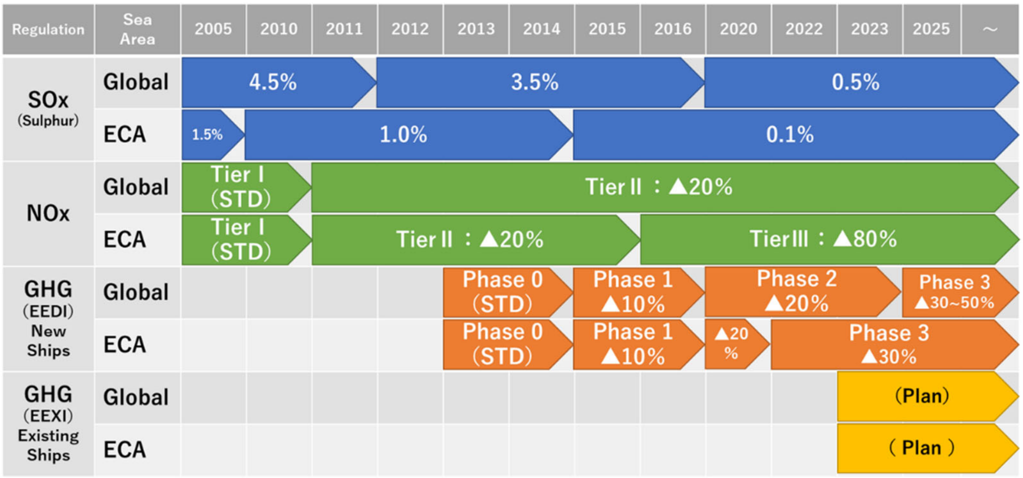


Figure 1: Marine environment regulations
Source: summarized from IMO

(1) MARPOL Convention: Marine Pollution Control Convention

In November 1973, the MARPOL Convention was adopted with the aim of preventing marine pollution caused by the ships. In February 1978, the "73/78 MARPOL Convention" was adopted and came into effect in October 1983. Currently, there are six annexes: (I) Oil, (II) Noxious Liquid Substances, (III) Harmful Substances, (IV) Ship Sewage, (V) Ship Garbage, (VI) Air Pollution. Of these, Annex VI was adopted in September 1997 and came into effect in May 2005, and SOx, PM and NOx are regulated.

i) Emission control area and Global area

Environmental regulations are applied separately to the ECAs (Emission Control Areas) and other general "Global" sea areas (Fig. 2). Initially, ECAs were designated as the North American Sea, Baltic Sea, and North Sea ECAs. China set its own ECA in January 2019 and Korea set its in April 2020. The Mediterranean ECA application may come into effect as early as March 2024.

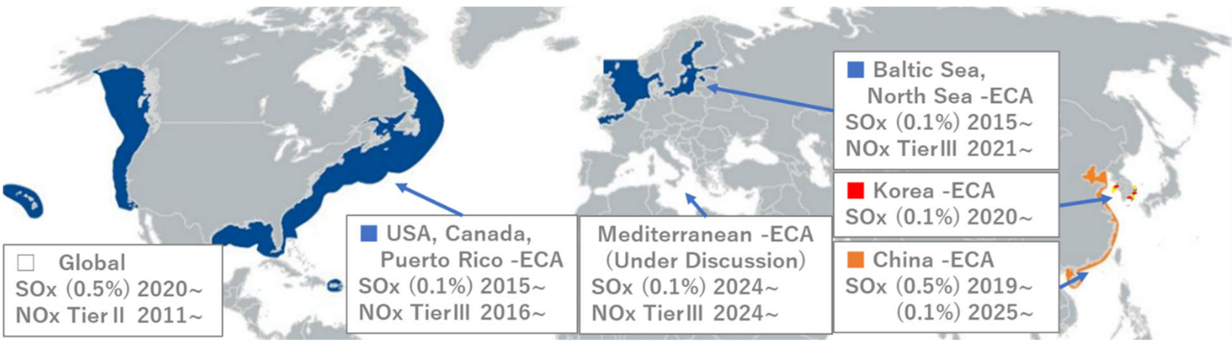


Figure 2: ECA and Global area
Source: summarized from DNV[3]

[3] DNV: An international accredited registrar and classification society headquartered in Oslo, Norway. Established in 1864.

ii) SOx and NOx emission regulations

The SOx regulations have been tightened with sulphur content of fuels in ECA to 0.1% or less from 2015, and in Global areas to 0.5% or less from 2020 (Fig. 3). The NOx regulation is based on the emissions at the engine rated speed of during 2000-2010 laying vessels in Tier I, 20% reduction in laying vessels since 2011, and 80% reduction was requested in ECA since 2016 for Tier III. (Fig. 4). Tier III regulations have been imposed in the North American ECA since 2016 and in the Baltic Sea and North Sea ECAs since 2021.

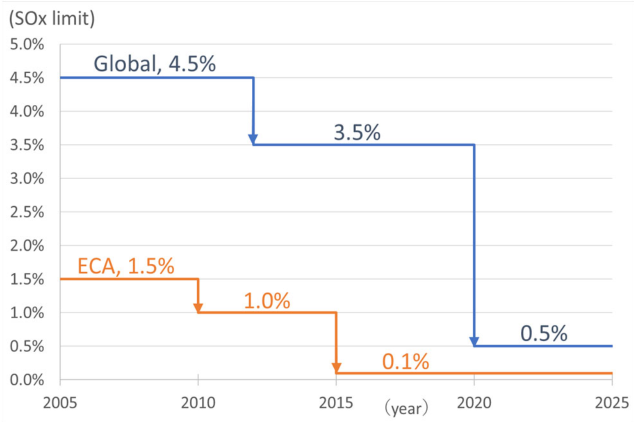


Figure 3: SOx regulations
Source: summarized from IMO

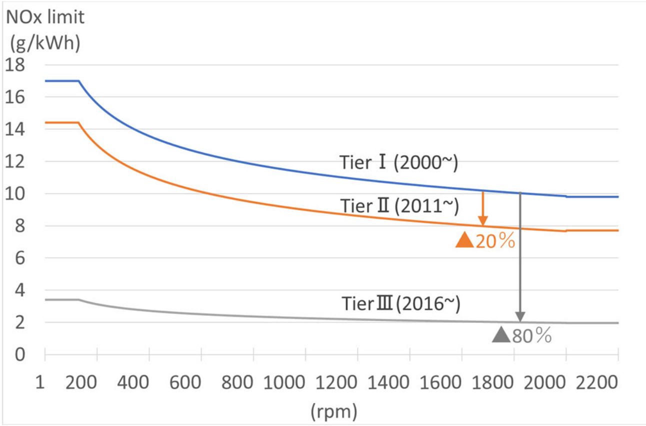


Figure 4: NOx regulations
Source: summarized from IMO

(2) Measures for GHG emissions

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted and entered into force in 1994. At the third Conference of the Parties (COP 3) in 1997, the "Kyoto Protocol" was adopted and GHG reduction targets were set. Next, at COP 21 in 2015, the "Paris Agreement" was adopted to keep the global average temperature rise below 2°C and further to promote efforts to 1.5°C. Among them, regarding the NDC set by each country, a reduction target is set every five years.

On the other hand, in the international shipping sector, according to the "Kyoto Protocol[4]", IMO's own climate change measures are set separately from UNFCCC (Fig. 5). This is because it is difficult to set the boundaries of responsibility for GHG emissions by shipping company, cargo owner, port and region. In the international aviation sector, emission control measures have been set by the United Nations specialized agency, ICAO (International Civil Aviation Organization).

[4] Kyoto Protocol Article 2, Paragraph 2 " The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the ICAO and the IMO, respectively".

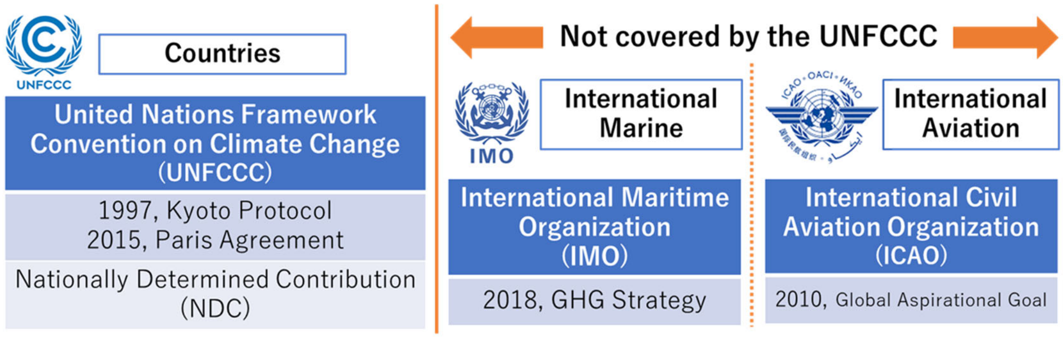


Figure 5: GHG reduction measures outside the UNFCCC framework

Source: based on UNFCCC, IMO and ICAO

i) <u>CO_2 emissions from international shipping</u>

According to the International Energy Agency (IEA), global energy-derived CO_2 emissions in 2018 were 33.5 billion tonnes, of which international shipping accounted for 708 million tonnes, or 2.1% of the total (Figs. 6, 7). The value is ranked between the fifth and sixth largest emitting countries, namely, Japan's 1.08 billion tonnes and Germany's 696 million tonnes.

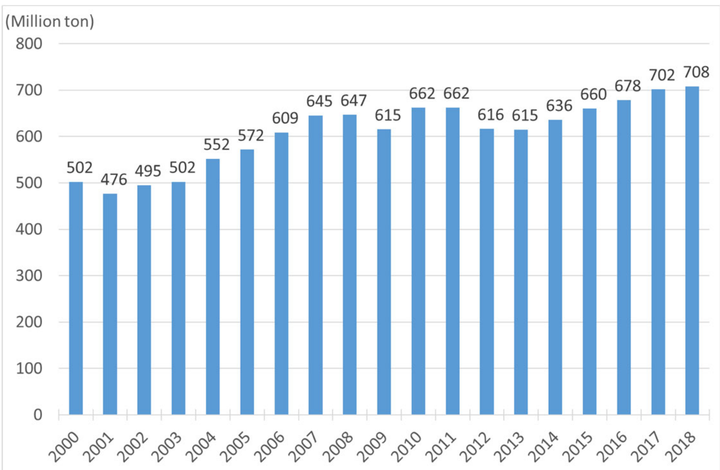


Figure 6: CO_2 emission from international shipping

Source: IEA

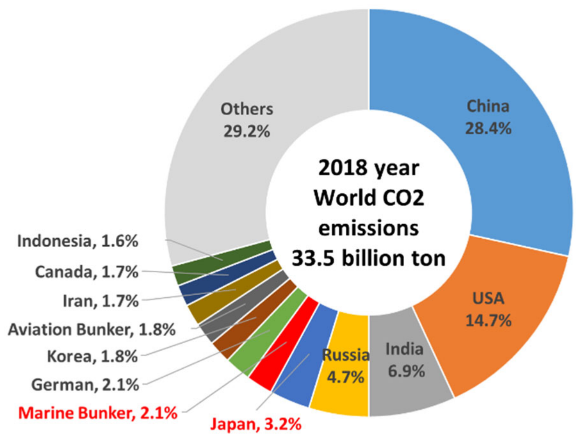


Figure 7: Global CO_2 emission ratio

Source: IEA

ii) <u>IMO GHG emission reduction strategy</u>

MEPC (Marine Environment Protection Committee), one of the IMO committees, has been considering pollution prevention and regulations from ships. At the 72nd meeting (MEPC 72) in April 2018, the "IMO GHG Reduction Strategy" was adopted. The strategy aims to peak out GHG emissions from shipping as soon as possible, to reduce emissions by 50% by 2050 compared to 2008, and to achieve zero emissions by 2100 (Fig. 8). In addition, it aims to improve efficiency in terms of emission intensity of transportation per unit of transported volumes by 40% in 2030 and 70% in 2050 compared to 2008.

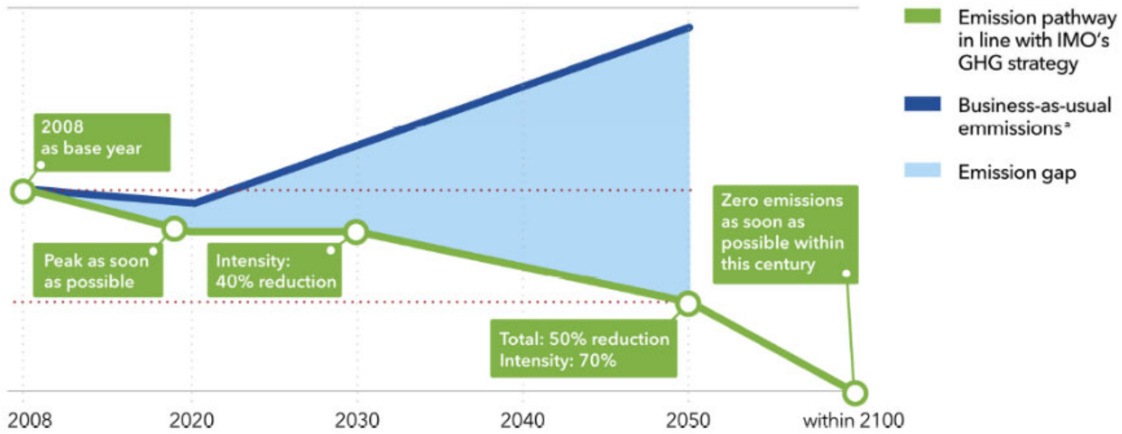


Figure 8: IMO GHG emission reduction strategy

Source: DNV

iii) Initiatives in Europe

In September 2020, the European Parliament passed a bill to incorporate shipping-derived CO_2 emissions into the EU-ETS[5]. And then, in July 2021, the European Commission proposed to include shipping emissions in the EU-ETS gradually from 2023 and phase them in over a three-year period.

If the shipping version of EU-ETS is adopted, it will be necessary to purchase emission allowances according to the CO_2 emissions based on EU-MRV[6], which will increase operating costs. In addition, there is concern that the GHG measures for international shipping will be taken by the IMO, resulting in double standards. In June 2021, Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) also issued an "opposition to the expansion of EU-ETS international shipping". The shipping version of EU-ETS is expected to be discussed intensively in the future.

iv) Initiatives in Japan

As policies for reducing GHG, energy efficiencies of ships should be improved and conversions to low-carbon fuels will be made in the short term, and to decarbonized fuels in the long term. In March 2020, the MLIT announced that it would formulate a roadmap for decarbonization of international shipping and aim for commercial operation of "zero emission vessels" by 2028 (Fig. 9).

[5] EU-ETS (EU-Emission Trading Scheme): Effective in 2005. Multilateral CO_2 emissions trading system in the EU.

[6] EU-MRV (EU-Monitoring, Reporting and Verification): Effective in 2018. A regulatory system that imposes the obligation to report shipping data on vessels departing from and arriving in the EU.

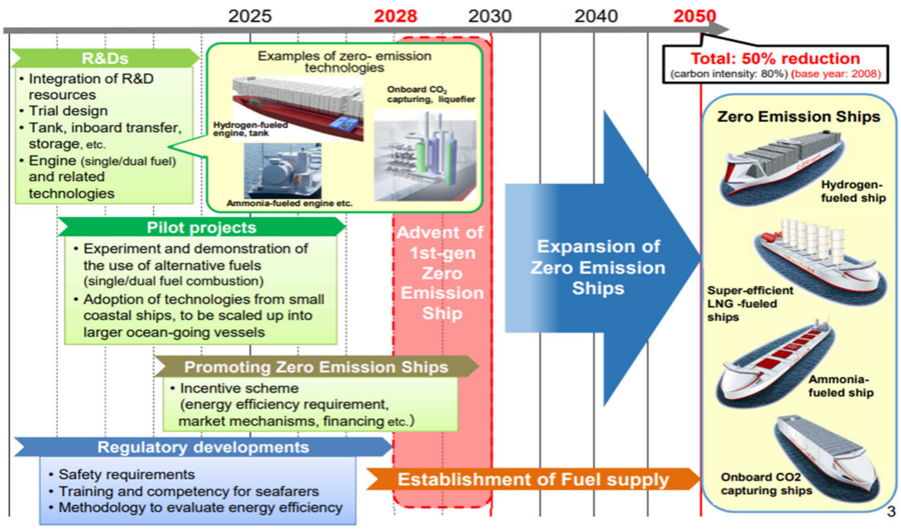


Figure 9: Roadmap to Zero Emission from International Shipping

Source: MLIT

In December 2020, the Ministry of Economy, Trade and Industry (METI) announced the establishment of a JPY 2 trillion (USD 18 billion) "Green Innovation Fund" to support companies over the next 10 years and the implementation plan "Green Growth Strategy" in 14 important fields. In June 2021, METI announced an implementation plan of the strategy. In the shipping industry, the plan calls on work on strengthening the shipbuilding and shipping industries and carbon neutrality (Fig. 10).

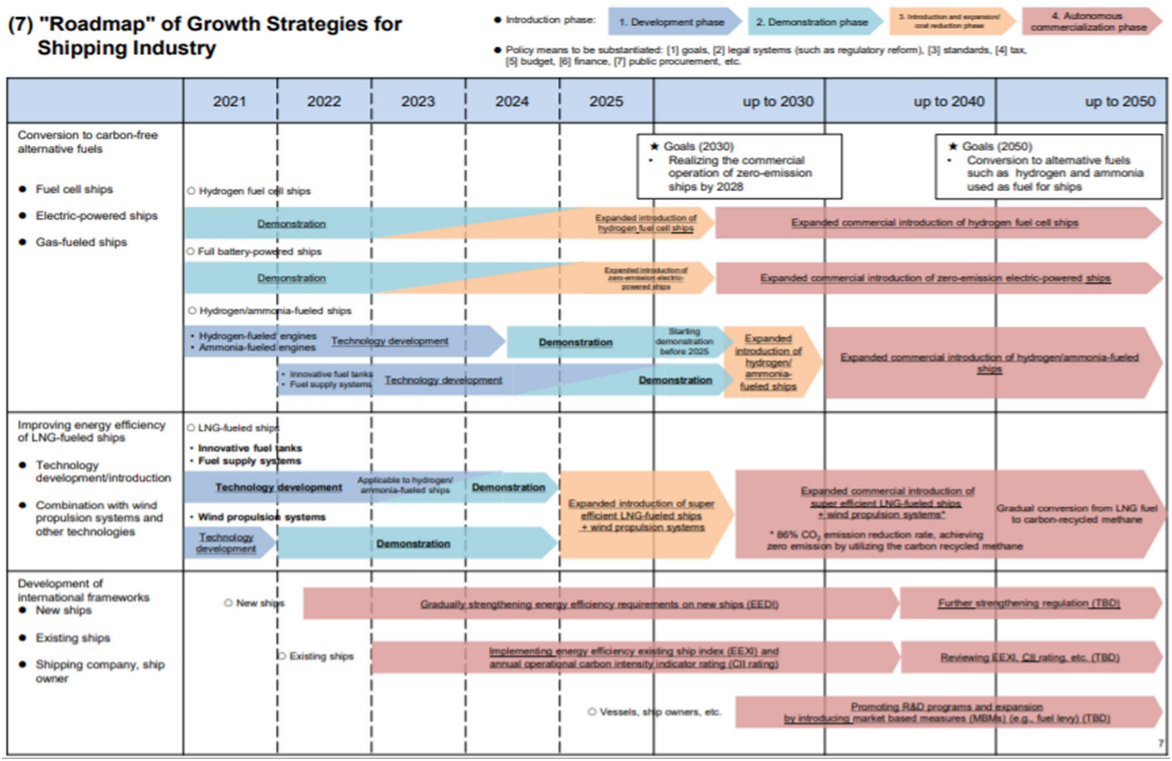


Figure 10: Road map of Growth Strategies for Shipping Industry

Source: METI

(3) Existing GHG emission regulations

MEPC 62 was held in July 2011 when (1) SEEMP and (2) EEDI were adopted for the purpose of reducing CO_2 emissions. SEEMP and EEDI came into effect in January 2013. They have been applicable to international vessels with a gross tonnage of 400 tonnes or more.

i) SEEMP (Ship Energy Efficiency Management Plan)

In order to improve energy efficiencies of all ships, it has been obligatory to prepare a management plan (SEEMP) showing operational efforts before each voyage, operate according to the plan during the voyage and make a review after the voyage. MEPC70 was held in October 2016, when a SEEMP revision proposal was adopted. Since 2019, international vessels with a gross tonnage of 5,000 tonnes or more have been required to collect and report operational data such as fuel consumption.

ii) EEDI (Energy Efficiency Design Index)

Fuel efficiency standards have been applied to new ships depending on construction contract and delivery date of them. Based on the average emission per ton/mile of ships built from 1999 to 2008, Phase 0 is set. The standard has been stricter for those ships built in and after 2020 at Phase 2 (20% reduction) and even stricter for those to be built in and after 2025 at Phase 3 (30% reduction) (Fig. 11). However, Phase 3 will be applied ahead of schedule to large new ocean-going vessels such as VLGC (Very Large Gas Carrier), container vessels, cruise vessels, general cargo vessels and LNG carrier vessels, for which construction contracts are made in and after April 2022.

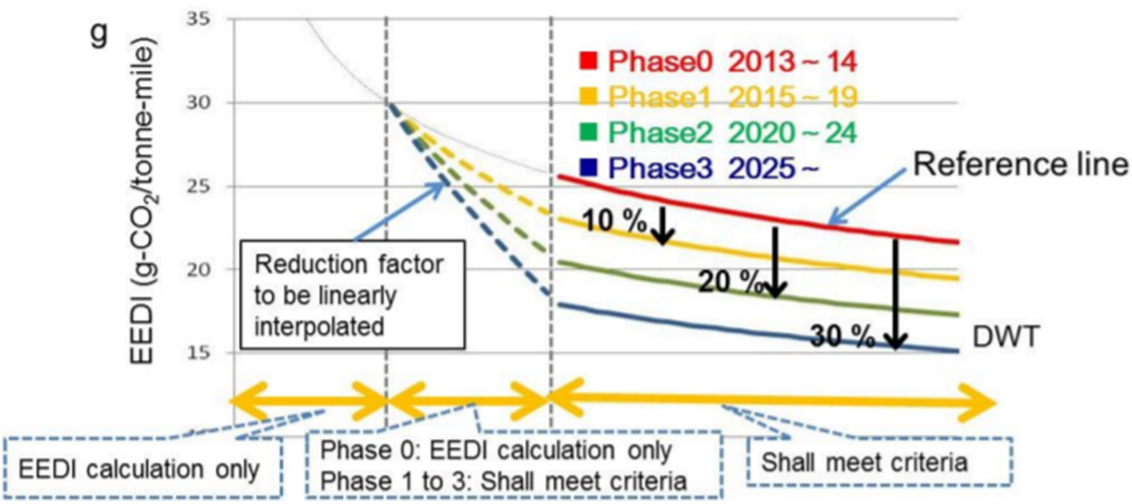


Figure 11: EEDI regulations

Source: MLIT

(4) Future GHG emission regulations

MEPC 75 was held in November 2020, when (1) EEXI and (2) CII were agreed as short-term GHG measures. Adopted by MEPC 76 in June 2021, the regulation will enter into force in January 2023.

i) EEXI (Energy Efficiency Existing Ship Index)

Fuel efficiencies of existing ships will be evaluated in advance, to apply the same fuel efficiency standards as new ships (EEDI). If an existing ship does not meet the standards, Engine Power Limitation (EPL)[7] and/or modifications will be required, prompting the conversion to new ships (Fig. 12).

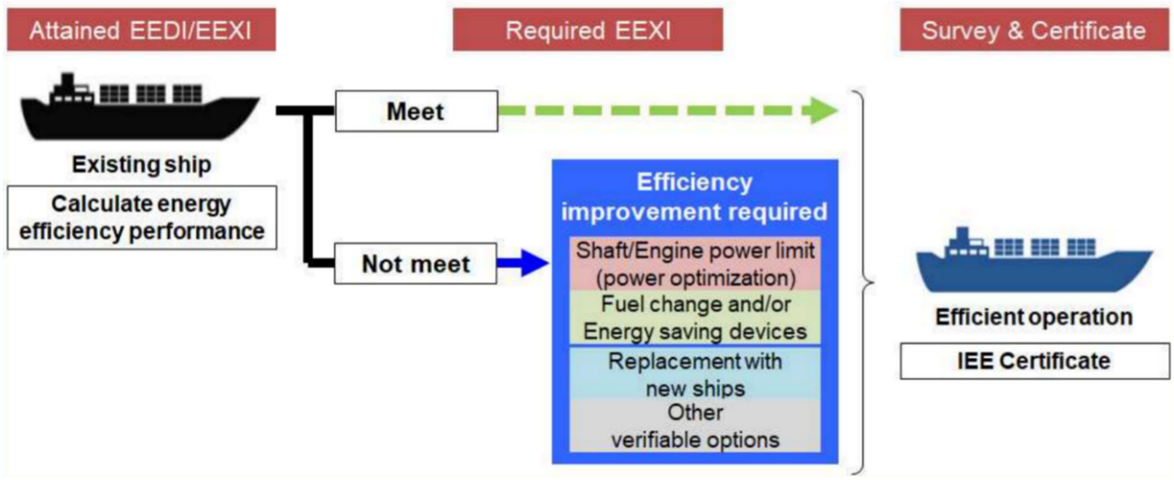


Figure 12: EEXI regulations

Source: MLIT

ii) CII (Carbon Intensity Indicator)

This is a system that verifies the fuel efficiency performance annually and evaluates it on a five-point scale (A to E). In case of E or D evaluations for three consecutive years, submission and execution of an improvement plan are required (Fig. 13).

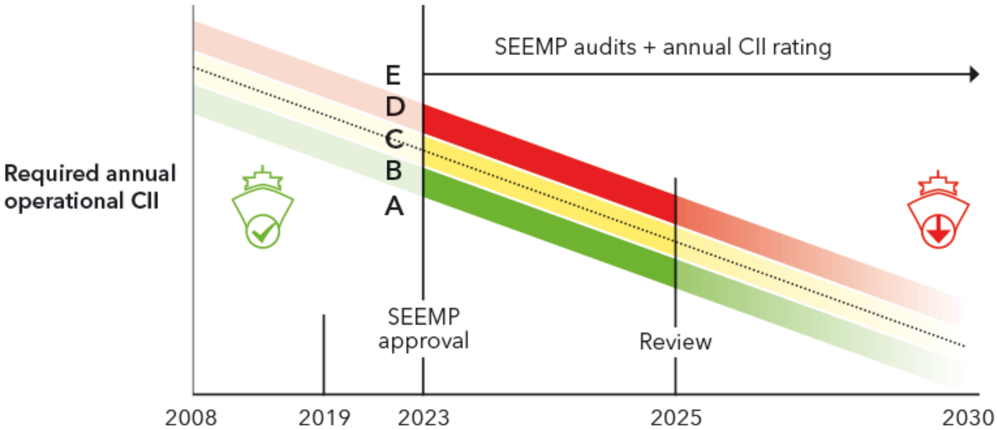


Figure 13: CII regulations

Source: DNV

[7] Engine power limitation (EPL) is one possible solution to improve energy efficiency of an existing ship by limiting its engine power fulfilling the requirements of the Energy Efficiency Existing Ship Index (EEXI). EPL represents one of the effective measures although it is considered as a tentative solution.

iii) Impact of GHG regulations on LNG carrier ships

The IMO's GHG regulations on existing vessels are expected to have limited impacts on Japanese vessels in general as they are relatively. However, some of the LNG carrier vessels that transport LNG to Japan are estimated to have lower energy efficiencies than the standards as they are old due to its fuel characteristics and durability.

Table 1: Features of each propulsion system of ships

type	propulsion system	feature
Steam	ST: Steam Turbine	BOG / heavy oil is boiler burned and turbine driven by steam
	Reheat Steam Turbine	Reheat the steam output and drive the lower pressure turbine
Diesel	SSDR: Diesel Re-Liquefaction	Heavy oil exclusive firing diesel (with BOG reliquefaction)
	DFDE: Dual Fuel Diesel Engine	BOG / heavy oil combustion, medium-speed diesel engine
	TFDE: Tri-Fuel Diesel Engine	BOG / heavy oil / light oil combustion, medium-speed diesel
	MEGI/XDF: Low-Speed Diesel Engine	BOG / heavy oil combustion, low-speed diesel engine
Mix	STaGE: Steam Turbine & Gas Engines	Combination of high efficiency steam turbine and diesel

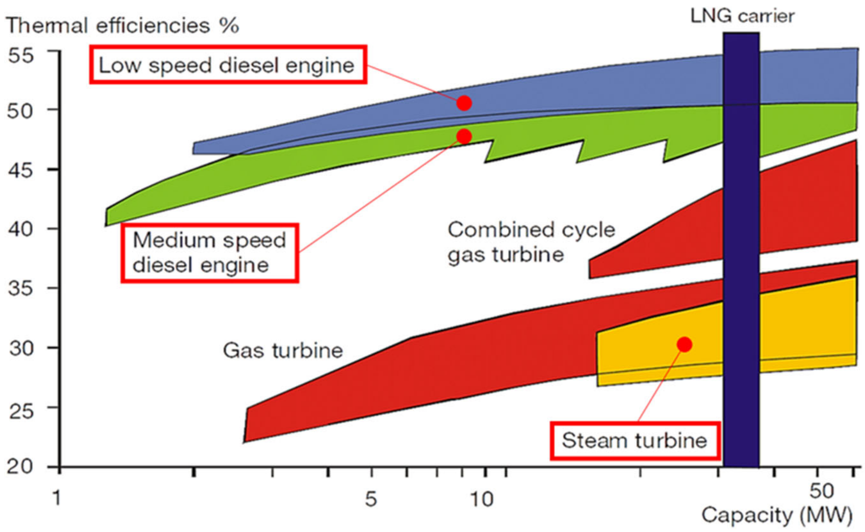


Figure 14: Thermal efficiencies of steam turbines and diesel engines

Source: MAN Energy Solutions

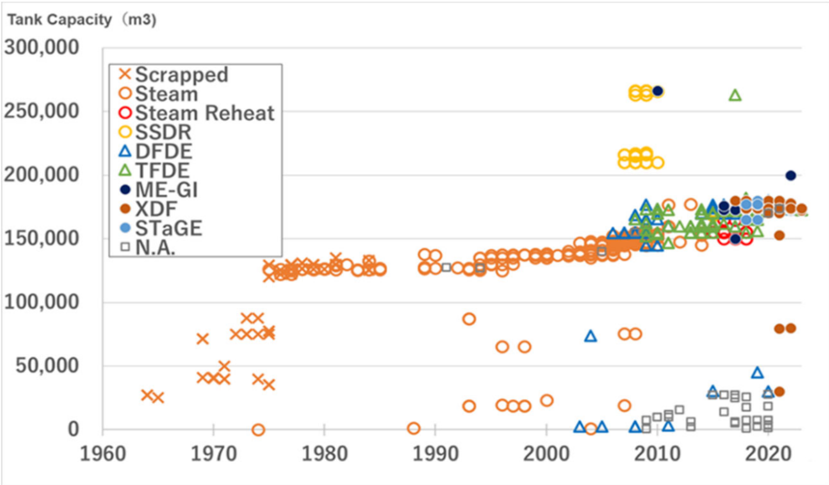
Marine propulsion systems are divided into two categories, steam turbines[8] and diesel engines[9] (Table 1). As their thermal efficiencies[10] differ significantly (steam turbine: 30%, diesel: 50%. Fig. 14), after the 1970s oil crisis almost all ships (except for LNG carriers) adopted diesel engines. On the other hand, steam turbines were used in almost all over 300 LNG shipping up to the 2000s (Fig. 15). The reason is that it was difficult to reliquefy or stably burn BOG (boil-off gas from LNG cargo tanks) in a diesel engine

[8] Steam turbine: Boil the fuel and drive the turbine with high temperature and high-pressure steam.

[9] Diesel engine: Piston is driven by injecting fuel into high-temp and high-pressure air inside the cylinder and burning it.

[10] Thermal efficiency: The ratio that can be utilized as energy from the amount of heat generated when fuel burned.

with the conventional technology[11]. Although steam turbines with a low failure rate are expected to account for 34% of LNG shipping as of 2023 (Fig. 16), future GHG regulations may add pressure to decommission them.



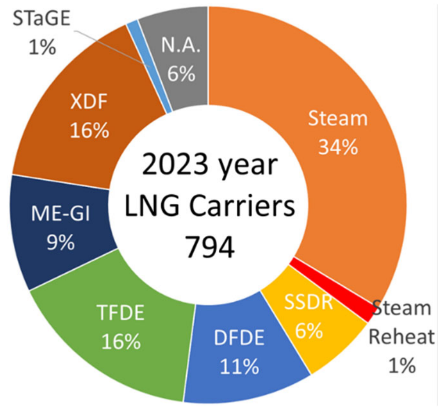


Figure 15: Number of LNG carrier ships by propulsion type Figure 16: propulsion type ratio

Source: Summarized from IGU and GIIGNL reports, and company data

3. Measures against environmental regulations

Environmental regulations include (1) Oil conversion, (2) Scrubber and (3) Fuel conversion.

(1) Conversion to low-sulphur oil

Due to the tightening of SOx regulations after January 2020, the conversion of marine fuel has progressed from HSFO (High Sulphur Fuel Oil) with a sulphur content of 3.5% to VLSFO (Very Low Sulphur Fuel Oil) with 0.5% or less and MGO (Marine Gas Oil) with 0.1% or less. Japan's MOL Group (Mitsui O.S.K. Lines) reports that it has handled 90% of more than its 800 vessels with low sulphur oil and 10% with scrubbers. Challenges include conversion to cleaner fuels to reduce GHGs, and 20%-30% higher costs of the cleaner fuels (Fig. 17).

[11] BOG (Boil Off Gas): LNG is vaporized by external heat into the tank, and naturally generated gas

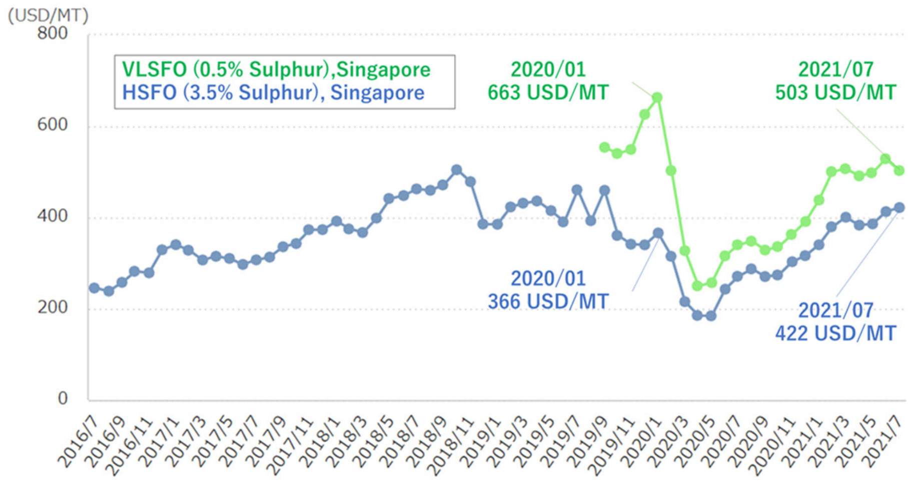


Figure 17: HSFO and VLSFO price trends

Source: Summarized from K-Line

(2) Installation of scrubber equipment

Scrubber devices (Fig. 18) can remove 90% of SOx and PM and 60% of black carbon. With scrubber equipment, there is an advantage that HSFO can be used continuously.

Figure 18: Scrubber equipment

Source: MARINELOG, MOL

Although the total number of scrubbers installed by 2017 was only 400, as of 2021, it has exceeded 4,000 (Fig. 19). About 2,400 vessels installed scrubbers in 2019, reflecting the last-minute demand to respond to the tightening of SOx regulations in January 2020.

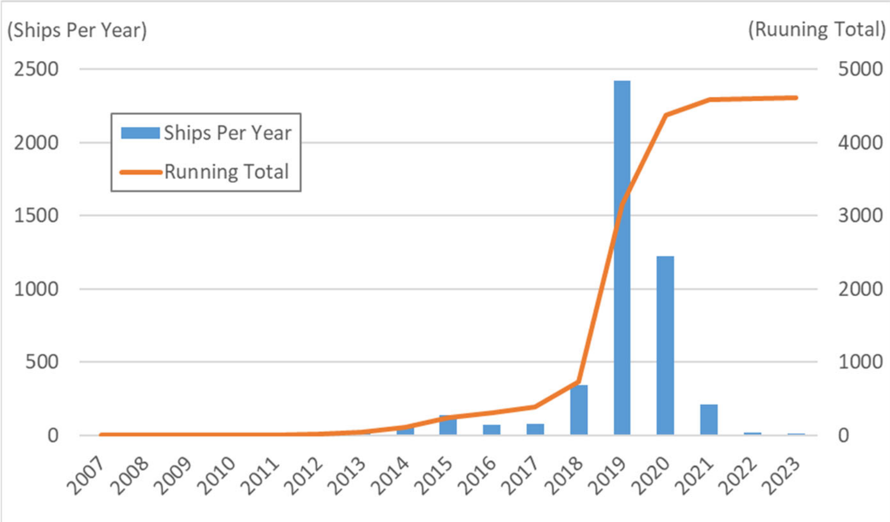


Figure 19: No. of ships equipped with scrubbers
Source: summarized from DNV

However, further penetration of scrubbers is limited as they are not effective for GHG reduction and drainage flows out into the ocean. In addition, scrubber auxiliary devices deteriorate fuel efficiency by about 3%.

(3) Fuel Conversion: ⅰ) LNG, ⅱ) Synthetic fuel (e-fuel), ⅲ) LPG, ⅳ) Methanol, ⅴ) Hydrogen, ⅵ) Ammonia, ⅶ) Battery

ⅰ) LNG: Compared to the conventional petroleum fuels, SOx and PM can be reduced by about 100%, NOx and CO_2 reduced by 80% and 30%, respectively. Issues include limited CO_2 reduction effects and methane slip emitted from engines. However, LNG is considered as the most promising alternative fuel in the short/medium term, due to its environmental performance and potential extensive supply facilities.

As of February 2021, 133 LNG receiving terminals are operating in 39 countries, and 42 liquefaction plants are operating in 21 countries (Fig. 20) [12]. LNG trade is expected to increase significantly from 356.1 million tonnes in 2020 for foreseeable future[13]. It is expected that the fuel will continue to be stably supplied in the future. These LNG marine fuel initiatives are described in the next chapter.

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12 IGU World LNG Report 2021

13 GIIGNL Annual Report 2021, IEEJ Outlook 2022 (to be published in October 2021)

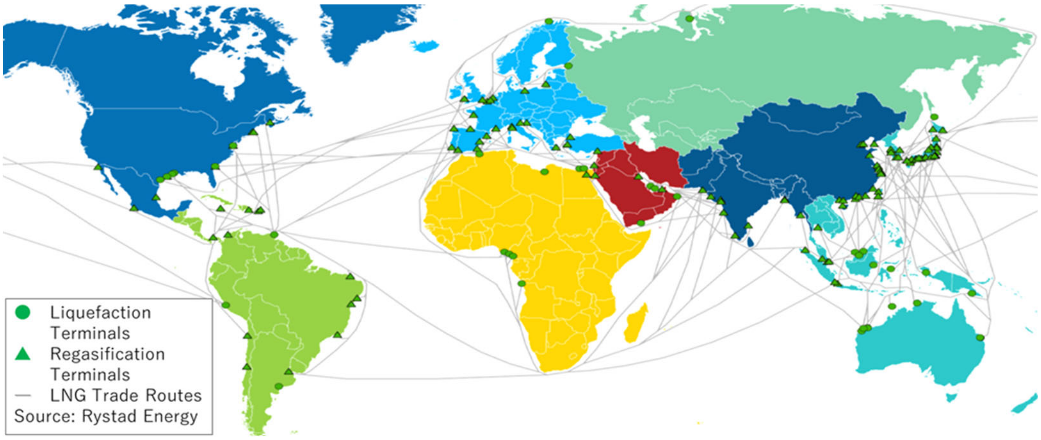

Figure 20: Map of LNG trade routes and LNG liquefaction /regasification terminals
Source: IGU

ii) SYNTHETIC FUEL (e-fuel): Synthetic hydrocarbons (e-methane, etc.) can be produced by methanation using hydrogen derived from renewable energy and CO_2 (Fig. 21). Its biggest advantage is that the existing equipment can be used as it is. However, renewable energy hydrogen production equipment and CO_2 extraction technology are required, which is currently very expensive.

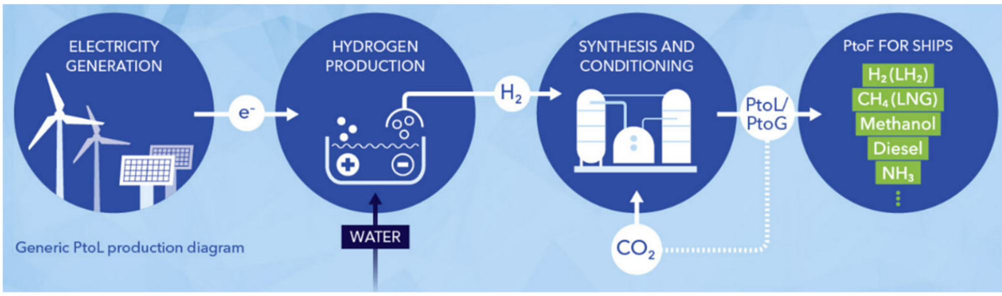

Figure 21: the production flow of synthetic fuels
Source: DNV

In August 2019, MOL held the "Cross-Industry WG on Ship Zero Emission Alternative Fuel" at the CCR (Carbon Capture & Reuse) Study Group and indicated use of synthetic methane. In July 2020, nine companies including JFE Steel, Japan Marine United (JMU) and MOL announced a study group "Ship Carbon Recycling WG" to formulate a roadmap for the methanation fuel of marine.

iii) LPG: CO_2 emissions can be reduced by 20%. As an advantage, cryogenic materials used for LNG are not required. Challenges include underdeveloped legislation and inadequate global infrastructure. In October 2020, Singapore BW LPG completed the world's first LPG dual fuel VLGC modified ship BW Gemini. In June 2021, Belgium Exmar completed the world's first LPG fueled dual-fuel VLGC new ship, Flanders Innovation. In Japan, in April 2020, Iino Kaiun decided to build Japan's first LPG fueled dual-fuel VLGC new ship at Kawasaki Heavy Industries (KHI). According to DNV, as of May 2021, 15 LPG dual-fuel modified vessels have been ordered and 53 new vessels have been ordered.

iv) METHANOL: SOx and PM can be reduced by 100% and NOx reduced by 20%. The GHG reduction effect depends on the manufacturing process, with a reduction against conventional fuels of 10% for natural gas sources and 80% for biofuels and synthetic fuels. Methanol has the advantage of being relatively easy to produce and has already been put to practical use in methanol tankers. The challenge is high fuel costs.

MOL completed the world's first methanol and heavy oil dual fuel ship MANCHAC SUN in September 2016, and started long-term charter in Canada. In May 2021, NYK Bulkship's dedicated methanol tanker Takaroa Sun provided the world's first Barge-to-Ship methanol fuel supply at the Port of Rotterdam. According to DNV, there are 25 methanol fuel vessels including the ordering stage.

v) HYDROGEN: The GHG reduction effect depends on the manufacturing process. The challenge is very expensive capital investment, and it is necessary to maintain liquefied hydrogen fuel at -253℃ or 70MPa in fuel tanks.

As an initiative for hydrogen fuel cells, in September 2020, NYK, Toshiba Energy Systems, KHI, Japan Maritime Association (JMA), and ENEOS launched a "demonstration project for the practical application of ships equipped with high-power fuel cells" in Japan. The companies plan to conduct a demonstration operation with hydrogen fuel supply by 2024.

As an initiative for hydrogen engines, in April 2021, KHI, Yanmar Power Technology, and Japan Engine signed a basic agreement to establish "HyEng," a joint development company for hydrogen fuel engines for large vessels.

vi) AMMONIA: The GHG reduction effect depends on the manufacturing process as hydrogen. The advantage is that liquid ammonia (-78℃) reduces investment costs such as storage and transportation compared to liquid hydrogen (-253℃). Problems include strong toxicity and corrosiveness, and there is also the problem of emitting NOx during combustion.

In August 2020, Nippon Yusen (NYK), IHI Motor, and the JMA signed a joint research agreement for the world's first commercialization of an ammonia fuel tugboat. In March 2021, six companies, including Sumitomo Corporation and Yara, signed a memorandum of understanding (MOU) for the commercialization of fuel supply for green ammonia vessels at the Port of Singapore. In May 2021, MOL, ITOCHU, Pavilion and other six companies signed an MOU for joint development of marine ammonia fuel in Singapore. Also in May 2021, NYK, Nippon Shipyard, and the JMA issued a joint study MOU between Yara and a dedicated liquefied ammonia gas carrier (AFAGC: Ammonia Fueled Ammonia Gas Carrier) that uses ammonia as its main fuel. In June 2021, a total of 23 domestic and overseas companies, including ITOCHU, Kawasaki Kisen (K-Line), and JERA, signed a MOU on the use of ammonia fuel and launched a council.

vii) BATTERY: At the moment a small capacity battery can be applied to small vessels for short distances. However, commercially available large-capacity battery technology is still under development, and charging equipment is underdeveloped. According to DNV, about 500 electric propulsion vessels are in operation, and 60% of the total is introduced in Europe, centered on Norway (Figs. 22, 23).

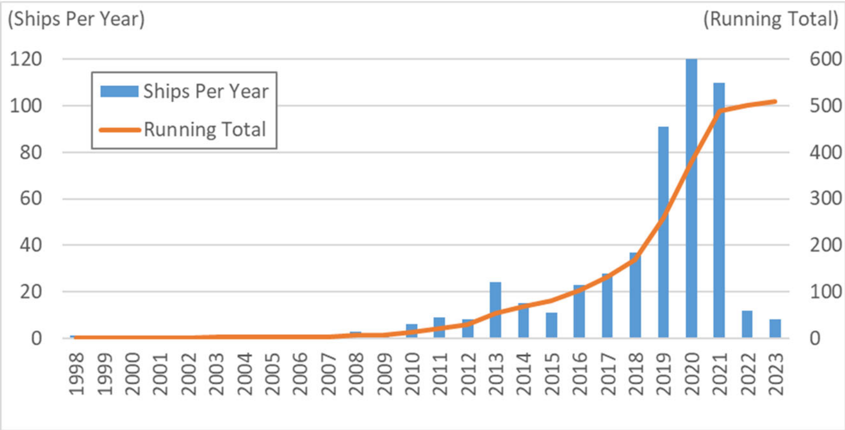

Figure 22: No. of battery vessels
Source: summarized from DNV

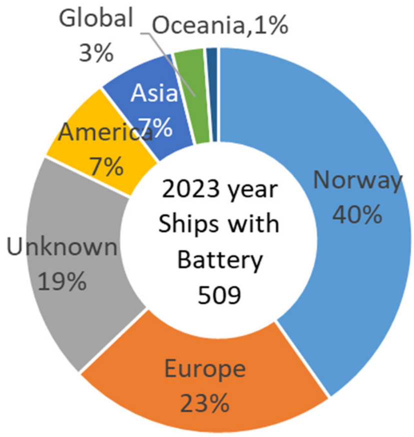

Figure 23: Battery country ratio
Source: summarized from DNV

In May 2020, seven companies, including Asahi Tanker and MOL, established the e5 Consortium (Secretariat: e5 Lab) aiming for a zero-emission electric propulsion vessel (EV vessel). As the first step, in October 2020, Asahi Tanker and e5 Lab ordered two of the world's first EV tanker vessels, which are scheduled to enter service in Tokyo Bay in 2022/23. In December 2020, e5 Lab completed the concept model of the world's first large EV bulk carrier (KAMSARMAX).

4. LNG bunkering

(1) LNG bunkering methods

There are the following three methods for supplying fuel to ships with LNG (Table 2, Fig. 24). Currently, in Japan, 1) the Truck-to-Ship (TTS) method is the main method, and 3) the Ship-to-Ship (STS) method[14] was first implemented in October 2020.

Table 2: LNG bunkering methods

No.	Methods	Feature
1)	Truck to Ship (TTS)	✓ Supply from a tank truck. Low initial investment. ✓ Suitable for small LNG fuel ships (30m^3 etc.).
2)	Shore to Ship (Shore TS)	✓ Supply by shore tank and pipeline near LNG terminal ✓ Possible for large LNG fuel ships
3)	Ship to Ship (STS)	✓ Supply from a bunker vessel. Flexible operation on the ocean ✓ Possible for large LNG fuel ships (20,000m^3 etc.)

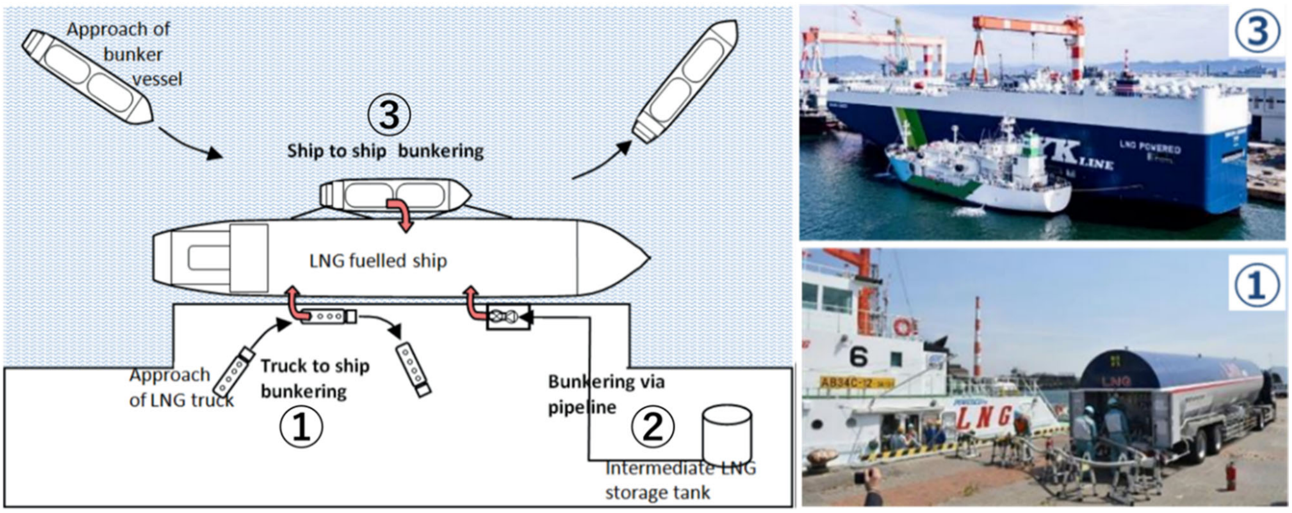

Figure 24: LNG bunkering methods

Source: IMO, JERA, and Saibu Gas

[14] A ship that supplies LNG to an LNG fueled vessel is referred to as an LNG bunkering ship.

(2) LNG Bunkering Demand: World and Asia

In 2020, the world's LNG consumption volume as ship fuels reached 1.5 million tonnes, which is equivalent to 0.4% of the global LNG traded volume of 356.1 million tonnes[15]. Demand has doubled since 2019, and this trend is expected to continue. In addition, the forecast of LNG demand for ships of different institutions[16] is expected to be 4-10 million tonnes in 2025, 7-30 million tonnes in 2030, and 10-70 million tonnes in 2040, and is expected to expand consistently (Fig. 25).

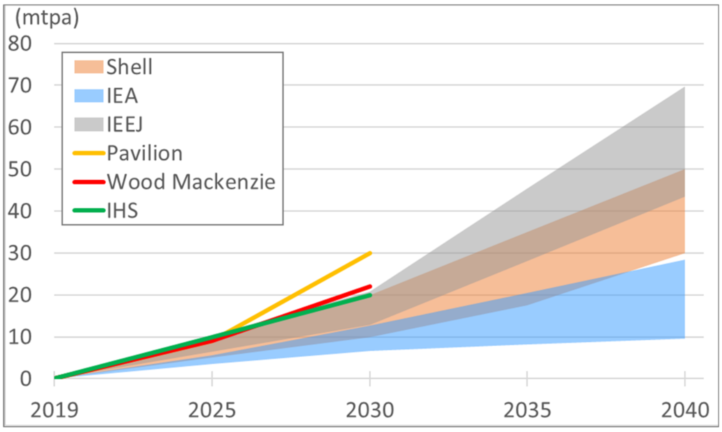

Figure 25: Global LNG bunkering demand Outlook

Source: Shell, IEA, IEEJ, Pavilion, Wood Mackenzie and IHS

In Asia, Japan's LNG bunkering demand outlook is still under consideration, but figures are shown in China and Korea. The CNOOC[17] of China forecasts a demand of 3-5 million tonnes by 2030 (Fig. 26) and KEEI[18] of Korea expects 1.36 million tonnes by 2030 and 3.4 million tonnes in 2040 (Fig. 27).

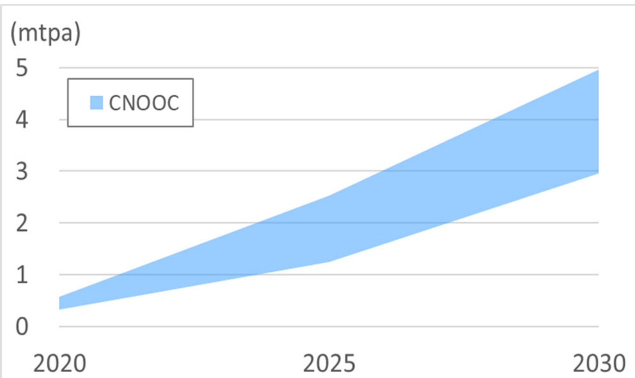

Figure 26: China LNG bunkering demand

Source: summarized from data of CNOOC

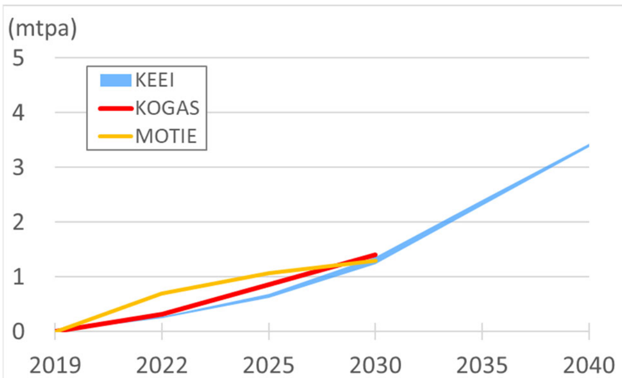

Figure 27: Korea LNG bunkering demand

Source: KEEI, KOGAS, MOTIE

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[15] IGU World LNG Report 2021, GIIGNL Annual Report 2021

[16] Shell LNG Outlook 2020, IEA WEO 2020, IEEJ Outlook 2021

[17] CNOOC (China National Offshore Oil Corporation): one of the largest national oil companies in China.

[18] KEEI (Korea Energy Economics Institute): Public research institute established by the Korean government

(3) Number of LNG-fueled ships ※ excluding LNG carrier ships

As of June 2021, 200 LNG-fueled vessels are in operation, 270 have been ordered, and 150 are planned. In particular, the number of operations in 2021 has increased sharply, quadrupling from the previous year. In addition, crude oil tankers, container ships, and product/chemical tankers were rarely introduced until the latter half of the 2010s, but over the next three years, the number will increase rapidly to 138 (57 crude oil, 51 containers, 30 chemicals) and are scheduled to be completed. It accounts for half of the 279 vessels (Figs. 28, 29).

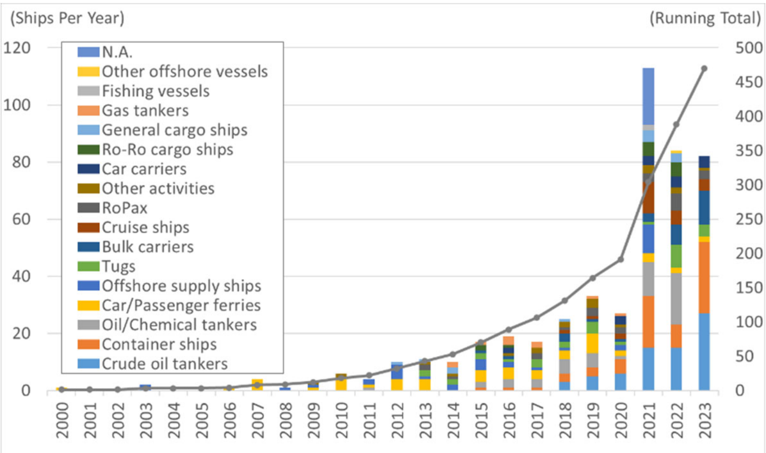

Figure 28: No. of operating LNG-fueled ships by type
Source: IGU, GIIGNL, DNV

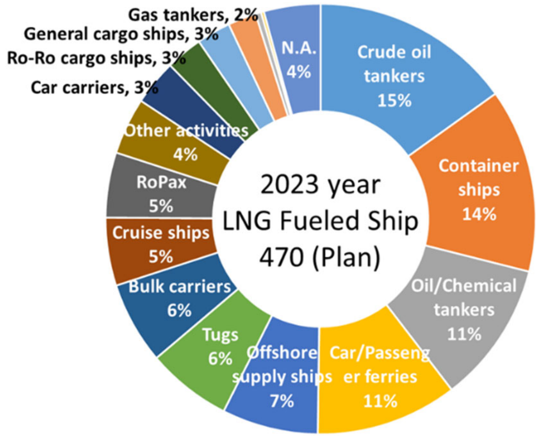

Figure 29: ship type ratio
Source: IGU, GIIGNL, DNV

Europe accounted for 70 to 90% of LNG-fueled ships for about 20 years after the world's first LNG-fueled ship ferry Glutra in 2000, but the proportion of "Global" (international ocean going) ships has increased since 2020. (Fig. 30). In particular, the number of Global vessels introduced over the next three years (2021 - 2023) will be 164, accounting for about 60% of the 279 vessels scheduled to be completed.

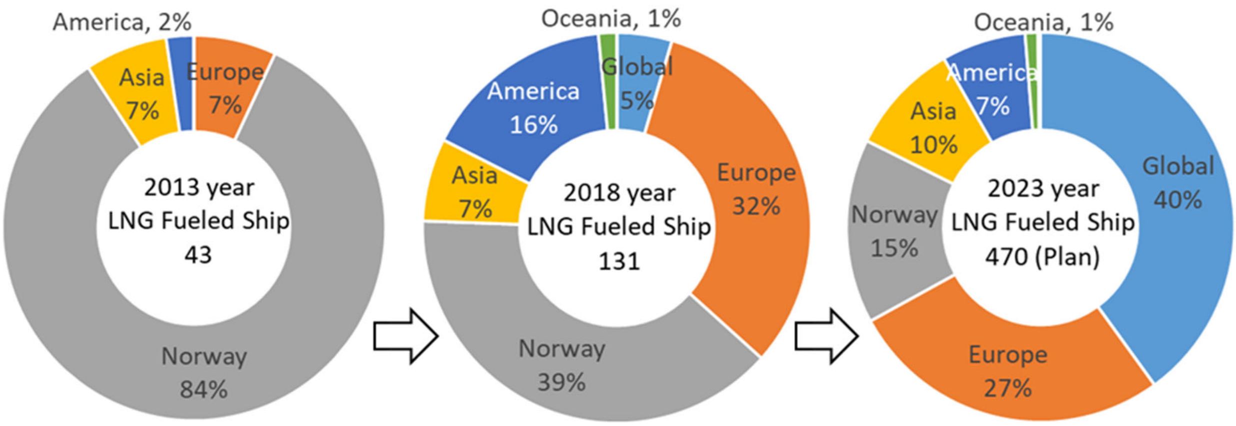

Figure 30: LNG fuel ships by country
Source: Summarized from data of IGU, GIIGNL, DNV

(4) Number of LNG bunkering vessels

As of May 2021, 30 LNG bunkering vessels are in operation, 20 have been ordered, and 17 are planned. In particular, the number of bunkering vessels in 2021 increased four-fold from the previous year, showing the same tendency as LNG fueled vessels. In addition, the introduction is progressing in Asia, and in the next three years (2021 - 2023), 13 vessels will account for about 40% of the total (37 vessels) (Figs. 31, 32).

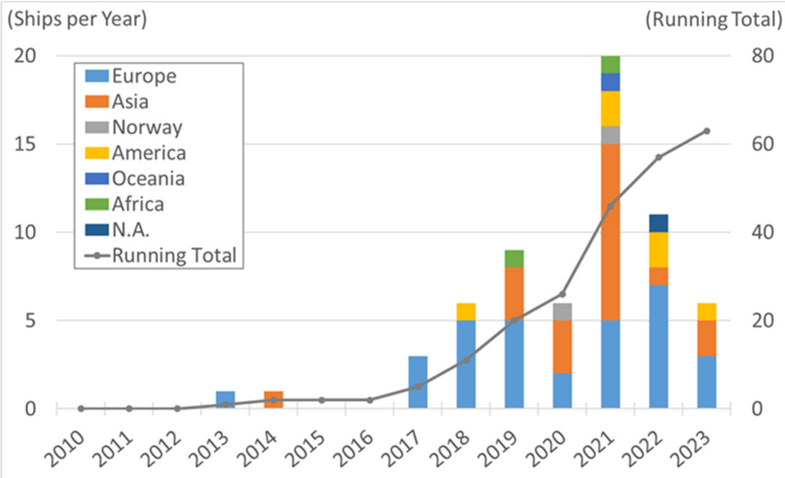

Figure 31: World's LNG bunker ships by area
Source: IGU, GIIGNL, DNV

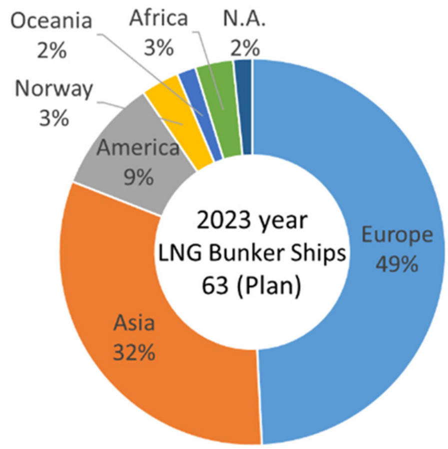

Figure 32: Bunker ship ratio by area
Source: IGU, GIIGNL, DNV

In the world, the world's first modified LNG bunkering vessel Seagas (capacity 167m^3) was put into operation in Europe in 2013, and Asia's first LNG bunkering barge (500m^3) was put into operation in the Yangtze River, China in 2014. In June 2017, the world's first newbuilt LNG bunkering vessel, Green Zeebrugge[19] (5,100m^3), went into operation in Belgium. In September 2020, the world's largest LNG bunkering ship, Gas Agility (18,600m^3), was completed, and in November, 17,300m^3 was supplied to a container ship at the Port of Rotterdam, the Netherlands.

Japan's first LNG bunkering ship Kaguya (3,500m^3) went into operation in Ise Bay in October 2020, performing Japan's first STS-type LNG fuel transfer to the car carrier ship "SAKURA LEADER." In 2021, Japan's second LNG bunkering vessel, Eco Bunker Tokyo Bay (2,500m^3), is scheduled to start operation.

[19] Green Zeebrugge: The initial name in June 2017 was Engie Zeebrugge, which was renamed in November 2020.

(5) Number of LNG-fueled ships and LNG bunkering ships

The progress of LNG-fueled and LNG bunkering vessels is often described as a "chicken and egg" issue. Challenges include the fact that the construction cost of LNG-fueled ships is higher by 20% to 30% compared to the conventional method, the LNG education and training of seafarers will be essential, and the size of LNG tanks should be twice as large as the conventional fuel tanks so that cargo loading capacity is squeezed. However, in recent years, the number of introductions has increased rapidly due to its effectiveness to comply with environmental regulations. The trend is summarized below (Table 3).

Table 3: Total No. of LNG fuel ships / bunkering ships

Area	Ships	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Global	Fueled	–	–	–	–	2	5	6	11	24	65	118	188
	Bunker	–	–	–	–	–	–	–	–	–	–	–	–
Europe	Fueled	32	39	49	60	70	79	93	114	124	177	197	199
	Bunker	–	1	1	1	1	4	9	14	17	23	30	33
Asia	Fueled	–	3	3	5	6	6	9	13	17	28	37	44
	Bunker	–	–	1	1	1	1	1	4	7	17	18	20
America	Fueled	–	1	1	5	9	14	21	24	24	31	32	33
	Bunker	–	–	–	–	–	–	1	1	1	3	5	6
Oceania	Fueled	–	–	–	–	2	2	2	2	2	2	3	5
	Bunker	–	–	–	–	–	–	–	–	–	1	1	1
Middle East	Fueled	–	–	–	–	–	–	–	–	–	1	1	1
	Bunker	–	–	–	–	–	–	–	–	–	–	–	–
Africa	Fueled	–	–	–	–	–	–	–	–	–	–	–	–
	Bunker	–	–	–	–	–	–	–	–	–	1	1	1
N.A.	Fueled	–	–	–	–	–	–	–	–	–	–	–	–
	Bunker	–	–	–	–	–	–	–	1	1	1	2	2
Total	Fueled	32	43	53	70	89	106	131	164	191	304	388	470
	Bunker	–	1	2	2	2	5	11	20	26	46	57	63

The world's first LNG-fueled vessel appeared in Europe in 2000, and the operation was limited to 30 vessels for the next 10 years, but since then the number of LNG-fueled vessels in Europe reached 70 in 2016. It is expanding at the pace of one bunkering vessel against five LNG-fueled vessels. As of 2023, 199 LNG-fueled vessels and 33 LNG bunkering vessels are expected in Europe.

In Asia, starting with the operation of three LNG-fueled vessels in 2013, against two LNG-fueled vessels approximately one LNG bunkering vessel has been launched, which is faster than in Europe (Fig. 33), and in 2023. At that time, 44 LNG-fueled vessels and 20 LNG bunkering vessels are expected.

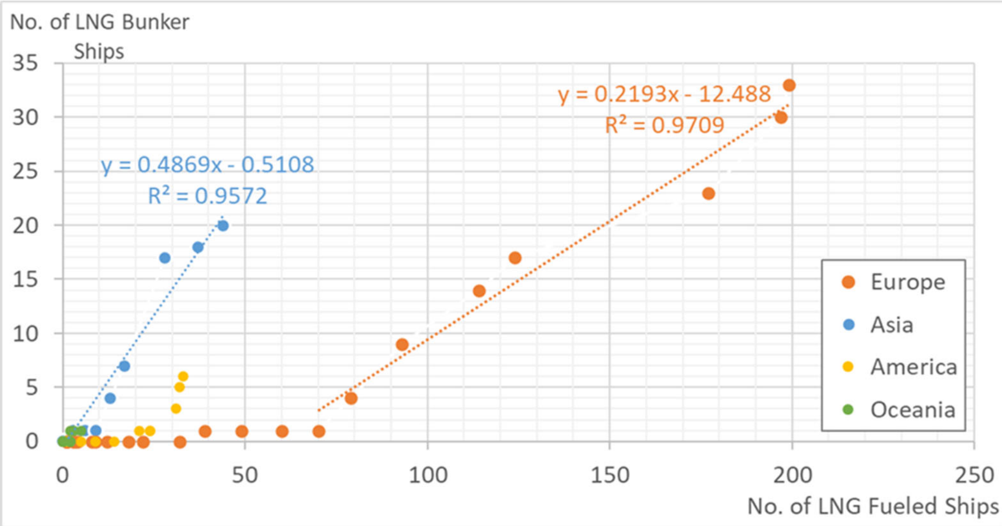

Figure 33: Comparison of the No. of LNG bunkering and LNG-fueled vessels (2000-2023)
Source: IGU, GIIGNL, DNV

(6) Regional Trends: ⅰ) North America, ⅱ) Oceania, ⅲ) Middle East, ⅳ) Africa, ⅴ) Asia

LNG bunkering is expected to grow globally, and the major regional trends are summarized below.

ⅰ) North America: In August 2018, North America's first LNG bunkering barge, Clean Jacksonville (2,200m^3), was completed at the Port of Jacksonville, Florida. In August 2020, Eagle LNG plans to plan a larger facility at the Talleyrand LNG bunker base in Jacksonville, Florida, which will be equipped with North America's first Shore-to-Ship facility. In May 2021, Puget LNG and GAC Bunker signed an MOU from the Tacoma LNG terminal to carry out the first LNG bunkering on the west coast of North America. They are scheduled to start operations within 2021.

In September 2020, Sumitomo Corporation signed an MOU with Cryopeak LNG of Canada to jointly develop an LNG bunkering supply chain in the Pacific region of North America. Cryopeak plans to launch 4,000m^3 LNG bunkering barge in 2023. In February 2020, FortisBC Canada submitted a proposal to start a federal impact assessment of the Tilbury LNG liquefaction terminal expansion PJ, including their STS bunkering facility, and plans to start construction in 2022.

ⅱ) Oceania: In May 2020, the Pilbara Port Authority issued Australia's first LNG bunkering license to Woodside at Dampier and Port Hedland in Western Australia. In December 2020, BHP, one of the world's largest mining companies, signed an LNG supply contract for five Australian iron ore carriers Newcastlemax for China from 2022.

ⅲ) Middle East: LNG bunkering is being considered at UAE Fujairah Port, the second largest fuel oil bunkering hub in the world, and a 1 million tonne annual LNG bunkering hub base is under consideration at Total Energies at Sohar Port in Oman. In December 2018, they signed an agreement with INPEX and ADNOC L&S, and in September 2019 with Shell and Qatar Petroleum, respectively, to establish an LNG bunkering venture.

ⅳ) Africa: South Africa's Algoa Bay Coega port is strategically located on the route of the Brazilian iron ore carrier Valemax. In October 2020, South Africa's DNG Energy obtained Africa's first LNG bunkering business license from port authorities and expects to start operations by 2021 at the earliest.

v) Asia: The main trends in LNG bunkering are summarized below (Table 4).

Table 4: Total No. of LNG fuel / bunker ships in Asia

Area	Ships	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
China	Fueled	—	2	2	3	4	4	4	5	7	17	17	17
	Bunker	—	—	1	1	1	1	1	1	1	7	7	8
Singapore	Fueled	—	—	—	—	—	—	2	4	5	6	10	14
	Bunker	—	—	—	—	—	—	—	2	2	4	4	4
Japan	Fueled	—	—	—	1	1	1	1	2	3	3	4	7
	Bunker	—	—	—	—	—	—	—	—	1	2	3	3
Korea	Fueled	—	1	1	1	1	1	2	2	2	2	2	2
	Bunker	—	—	—	—	—	—	—	1	2	3	3	4
Others	Fueled	—	—	—	—	—	—	—	—	—	—	4	4
	Bunker	—	—	—	—	—	—	—	—	1	1	1	1
Total	Fueled	–	3	3	5	6	6	9	13	17	28	37	44
	Bunker	—	—	1	1	1	1	1	4	7	17	18	20

i) China: Pursuing the most ambitious implementation plan in Asia. In May 2020, CSSC (China State Shipbuilding Corporation) signed the Guangdong LNG Carrier Agreement, which expects 1,500 modified fuel vessels, 19 supply facilities and 400,000 tonnes of demand by 2025. In March 2021, CNOOC said it would supply LNG to 50 new bulk carriers. In September 2021, Dalian Shipbuilding (DSCI), a subsidiary of China State Shipbuilding Corporation, said the world's first LNG-fueled very large crude carrier (VLCC) has completed its sea trials in Chinese waters.

ii) Korea: The spread of LNG bunkering is expected to have a synergistic effect on the shipbuilding industry. In June 2020, the Korean Ministry of Trade, Industry and Energy (MOTIE) announced support for the construction of bunkering vessels with a capacity of 7,500m^3 or more, and said that it would support a total of 30%, up to KRW 15 billion (USD 13 million). In November 2020, an STS test was conducted on Korea's first LNG carrier vessel, SM JEJU LNG 2. Korea LNG Bunkering was established in December 2020, and Korea's first TTS-type LNG supply was implemented in January 2021. In 2023, Korea's first LNG bunkering vessel (7,500m^3) is planned.

iii) Singapore: The world's largest supplier of heavy fuel oil for marine use, and LNG fuel is also promoted by national policy. In January 2021, Singapore's first LNG bunkering vessel, FueLNG Bellina, was completed. In March 2021, the Maritime and Port Authority (MPA) granted the LNG bunkering license to Total Energies Marine Fuels in addition to the two existing vendors (FueLNG[20], Pavilion).

[20] FueLNG: A joint venture between Keppel Offshore & Marine/Shell, in January 2016 the Keppel O&M/BG Group and Pavilion Energy were granted the first two LNG bunkering licenses in Singapore.

iv) Malaysia: In October 2020, Avenir LNG carried out the first LNG bunkering vessel in Southeast Asia, Avenir Advantage (7,500m^3), to Petronas for three years, and the first LNG bunkering in November 2020.

v) Indonesia: In June 2021, Pertamina International Shipping signed a HoA for its five new vessels to receive LNG and bunkering equipment from PGN.

(7) International cooperation of LNG bunkering port

In October 2016, "Memorandum of Cooperation on the Development of LNG as Ship Fuel" was announced by eight port authorities in seven countries (Japan, Singapore, Ulsan Port in Korea, Antwerp/Zeebrugge Port in Belgium, Rotterdam Port in the Netherlands, Norway, and Jacksonville Port in the United States. In July 2017, three parties (Vancouver in Canada, Marseille France, and Zhejiang Province in China) joined, and in October 2018, the Suez Canal Economic Zone Authority of Egypt joined, reaching a total of 12 port authorities from 11 countries (Fig. 34). In October 2020, the MLIT of Japan signed an "MOU on Inter-Port Cooperation for Future Ship Fuels" with the Singapore MPA and the Rotterdam Port Authority of the Netherlands.

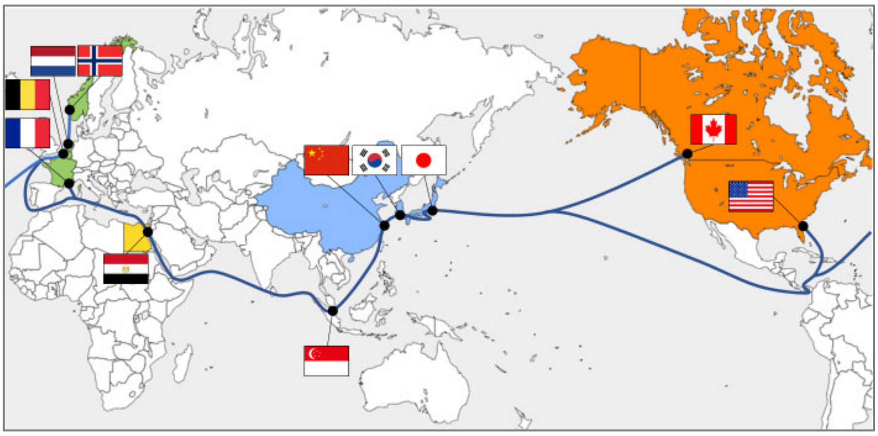

Figure 34: Port map of the MOU regarding LNG carrier fuel

Source: summarized from MLIT

(8) LNG bunkering in Japan

The following is a summary of domestic LNG bunkering and port incentives[21] (Table 5, Fig. 35).

Table 5: Japan's LNG bunkering and progress

	Category	Kyushu/Seto Inland Sea	Osaka Bay	Ise / Mikawa Bay	Tokyo Bay
LNG bunkering (Supply)	Trucks (TTS)	May 2019 Kitakyushu Port to tugboat "Sakigake"	Jan. 2019, SakaiSenboku Sep. 2019, Kobe Port to tugboat "Ishin"	Nov. 2019 Nagoya Port to tugboat "Ishin"	July 2015, **Japan's First** Tokyo Bay to tugboat "Sakigake"
	Terminal	Hibiki LNG	Osaka Gas Senboku / Himeji	Toho Gas Chita Midorihama	Tokyo Gas Negishi
	Company	NYK, Kyushu Electric Power, Saibu Gas, Chugoku Electric Power	MOL Osaka Gas	MOL Toho Gas	NYK Tokyo Gas
	Ships (STS)	2022 (Plan)	―	Oct. 2020, **Japan's First** "Kaguya"	2021 (Plan) "Eco Bunker Tokyo Bay"
	Capacity	―	―	$3500m^3$	$2500m^3$
	Terminal	―	―	JERA Kawagoe	Tokyo Gas Sodegaura
	Company	―	―	Central LNG Shipping (NYK, K-Line, JERA, Toyota Tsusho)	Eco Banker Shipping (Sumitomo Corp, Ueno Transtech, Yokohama International Port, DBJ)
LNG fueled (Receive)	ship 1)	2022-2023 (Plan), **Japan's First** Ferries (between Beppu and Osaka) 2 ships "Sunflower Kurenai / Murasaki"		Oct. 2020, **Japan's First** Car carrier "SAKURA LEADER" (international ship)	Sep. 2015, **Japan's First** Tugboat "Sakigake"
	Company	MOL Group / Ferry Sunflower		NYK	NYK
	ship 2)	2023 (Plan), **World's First** Large-sized coal carrier, 2 ships (for Kyushu coal-fired power)	Feb. 2019 Tugboat "Ishin"	Dec. 2020, **Japan's First** Coastal cargo ship "Ise Mirai" (for JERA Thermal Power)	2025 (Plan), **World's First** Medium-sized cruise ship (Asuka Cruise)
	Company	NYK, MOL, Kyushu Electric Power	MOL	MOL group, Techno Chubu, Kyodo Kaiun	NYK (NYK Cruises)
	ship 3)	―	―	Mar. 2021 Car carrier "CENTURY HIGHWAY GREEN" (international ship)	―
	Company	―	―	K-Line	―
Incentive (Port entry fee exemption)	Green Award Certification	Nov. 2014, **Japan's First** Kitakyushu Port LNG carrier: ▲10%	June 2020, Osaka Port LNG Carrier: ▲10%	Nov. 2016, Nagoya Port LNG Carrier: ▲10%	Mar. 2017, Yokohama Port LNG Carrier: ▲10% + IP ESI System: ▲5%
	Others	―	Apr. 2021, Osaka Bay fueled ship: ▲10%	Apr. 2019, **Japan's First** Ise / Mikawa Bay bunkering ship: ▲100% fueled ship: ▲100%	Apr. 2021, Tokyo Bay bunkering ship: ▲100% fueled ship: ▲100%

[21] Green Award Certified by a Dutch NPO corporation aimed at marine environment protection.
International Port ESI (Environmental Ship Index) System: Operated by the World Port Climate Initiative (WPCI) aimed at reducing air pollutant emissions from ships.

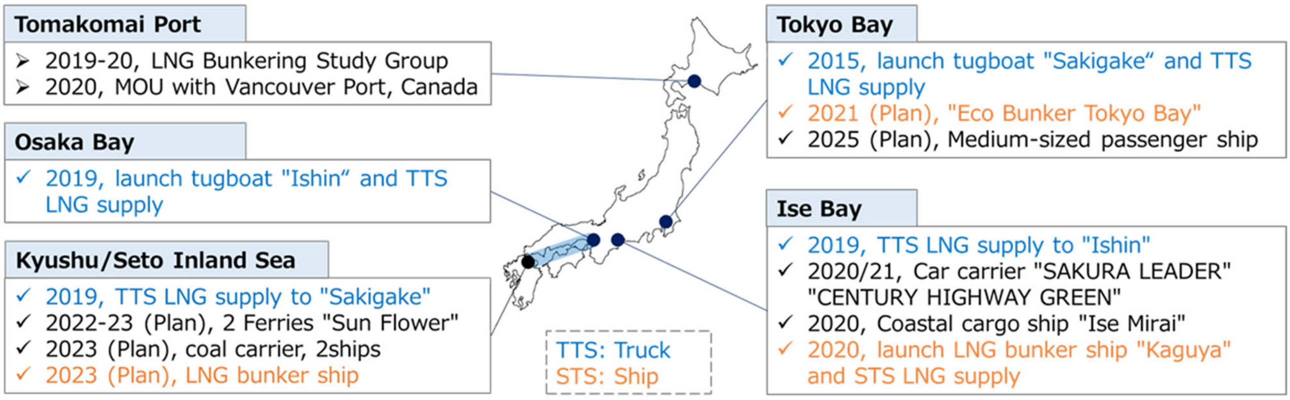

Figure 35: LNG bunkering in Japan

Source: Summarized from each company information

【Initiatives in Japan】

i) Tomakomai Port, Hokkaido: In February 2019, Tomakomai Port and Japan Petroleum Exploration (JAPEX) established the LNG Bunkering Study Group, which had held a total of six meetings by April 2020, and then completed the study. In March 2020, Tomakomai Port and Vancouver Port, Canada signed an "MOU to Promote LNG Bunkering."

ii) Tokyo Bay: In February 2021, Sumitomo Corporation and Petronas Trading signed a memorandum of cooperation to jointly sell marine fuel LNG-related businesses in Malaysia and Tokyo. In May 2021, NYK Cruise, NYK, Eco-Bunker Shipping and Yokohama City signed an MOU on the acceptance of LNG-fueled cruise ships.

iii) Domestic companies: NYK has set up a "Sail GREEN PJ", and has set a goal of about 40 new car carriers for the next 10 years as LNG fueled vessels, aiming for zero-emission vessels such as hydrogen from around 2030. Eight LNG-fueled ships will be introduced by 2024 and 12 LNG-fueled ships will be set from 2025 to 2028, and the total investment in 20 ships will be close to JPY 200 billion.

MOL announced "Environmental Vision 2.1" in June 2021 and it would launch about 90 LNG fueled vessels by 2030 and about 110 zero-emission vessels by 2035. Approximately JPY 200 billion will be invested in the low-carbon and decarbonization fields over the next three years.

K-Line has established a long-term policy "Environmental Vision 2050". In September 2021, eight LNG-fueled car carriers were ordered, bringing the total to 10 including the two ordered so far, which will be procured from 2023 to 2025.

iv) Collaboration with foreign companies: In February 2021, JERA and Petronas signed a memorandum of cooperation on the field of decarbonization. Consider ammonia and hydrogen fuel supply in Asian countries and LNG bunkering supply chain internationally. In September 2021, NYK Line and bp signed an MOU to collaborate on future fuels. The two companies will collaborate and identify opportunities to help transition from current marine fuels to alternatives such as LNG, biofuels, and methanol, and to develop future fuels such as ammonia and hydrogen.

5. Challenges and recommendations

Undeveloped incentives for LNG-fueled ships, slow progress of cooperation between international ports, and a decline in Japan's presence in the LNG market may pose challenges for penetration of LNG bunkering in Japan.

First, about Incentives. LNG-fueled ships have challenges such as higher construction costs than those fueled with conventional fuels, fluctuating LNG-fuel costs, securing crew members who have received LNG education/training, and limitation of cargo capacity that is squeezed by LNG fuel tanks. Incentives such as port entry fee exemption should be effective. Currently, full exemption is set for only two ports in Japan, Ise/Mikawa Bay and Tokyo Bay, and it is essential to strengthening preferential treatment on a nationwide scale.

Next, about cooperation between international ports. As of now, the MLIT has signed a "Memorandum of Cooperation for Developing LNG as Ship Fuel" among 12 port authorities in 11 countries, and has issued a "Memorandum of Cooperation for Future Ship Fuels to Support Decarbonization" which has been signed between the port authorities of the three countries. However, Southeast Asian countries such as Malaysia and Indonesia, Australia which have close ties with Japan in terms of LNG trade, have not yet participated in this initiative. In order to establish a supply chain system not only for low-carbon fuels such as LNG but also for future decarbonized fuels, it is necessary to strengthen cooperation between international ports.

Finally, about the LNG market presence. Japan has maintained the world's largest LNG handling volume for about half a century, but China is expected to replace Japan as the world's largest by 2021. In the future, in order for Japan to maintain and strengthen its influence in the LNG market, it is necessary to play the role of an LNG hub and lead LNG trading, infrastructure exports, active personnel exchanges in the Asian region.

6. Summary

With the tightening of marine environment regulations in international shipping, it is necessary to switch to low-carbon fuels such as LNG in the short and medium term, and to decarbonized fuels such as hydrogen, ammonia and synthetic fuels in the long term. LNG has already begun to play a role of transition fuel, and demand for marine LNG reached 1.5 million tonnes in 2020 and is expected to grow about 10-fold over the next 10 years. In particular, Asia is expected to become the world's largest LNG demand region in combination with economic growth and the conversion of coal-fired power generation, and in order to develop a more efficient LNG bunkering system, cooperation between ports and rapid facility construction are necessary. Japan, which has utilized the largest volumes of LNG in the world for half a century and has utilized it cleanly, has a major role to play in international shipping.

[References]

1) GIIGNL Annual Report 2021 (2021/04), https:

//giignl.org/sites/default/files/PUBLIC_AREA/giignl_2021_annual_report_apr27.pdf

2) IEA, CO2 Emissions from Fuel Combustion (2020/07), https: //www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

3) IEA, World Energy Outlook 2020 (2020/10), https://www.iea.org/reports/world-energy-outlook-2020

4) IGU World LNG Report 2021 (2021/06), https: //www.igu.org/resources/world-lng-report-2021/

5) JSA, SHIPPING NOW 2020-2021, https://www.jsanet.or.jp/data/pdf/shippingnow2020-2021.pdf

6) Shell LNG Outlook 2020 (2020/02), https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng/lng-outlook-2020.html#iframe=L3dlYmFwcHMvTE5HX291dGxvb2sv

7) Shell LNG Outlook 2021 (2021/02), https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng/lng-outlook-2021.html#iframe=L3dlYmFwcHMvTE5HX091dGxvb2svMjAyMS8

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