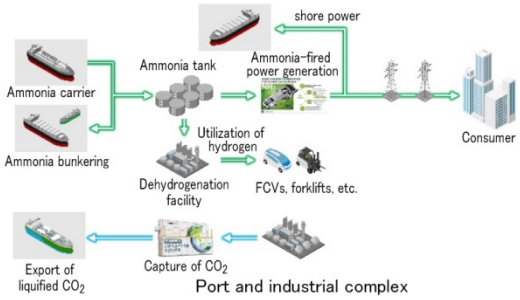
Carbon Neutral Port (CNP)
- Expansion of Decarbonization Solutions from Sea Port -

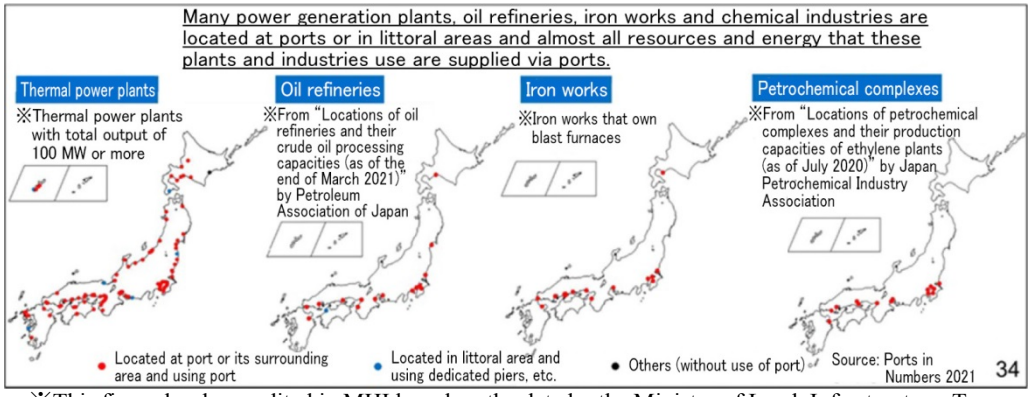


MASAHIRO YOSHIOKA[*1] YUYA YAMAMOTO[*2]
NAOHISA ADACHI[*3] JUNYA UJIIE[*4]
SADAKUNI NAGASAWA[*1] RYO NISHIDA[*1]

Various efforts are underway toward decarbonization all over the world and the Mitsubishi Heavy Industries Group (MHI Group) also made the declaration of achieving carbon neutrality by 2040. The MHI Group has defined two growth areas: "Energy Transition" on the supply side and "Smart Infrastructure" on the demand side to contribute toward achieving a carbon neutral society. This report introduces our decarbonization solutions starting from ports and describes the current status of activities.

1. Introduction

The Japanese government declared "2050 Carbon Neutrality", meaning that Japan would aim to reduce greenhouse gas emissions to net zero by 2050 and start working toward the achievement of a decarbonized society. According to the data on the location environment of CO_2 emission sources, power generation plants and steel and chemical industries that account for about 60% of CO_2 emissions in Japan are mostly located at ports or in littoral areas and most of the fuel and resources that are used in these industries are supplied via ports (**Figure 1**).



※This figure has been edited in MHI based on the data by the Ministry of Land, Infrastructure, Transport and Tourism.

Figure 1 Locations of industries that emit large amount of CO_2[(1)]

In addition, fuel to vessels is also supplied via ports, which have the function of fuel supply bases for onshore and offshore. Hydrogen and ammonia have attracted attention as fuels essential to carbon neutrality. In the future, through utilization of these decarbonized fuels, which are stored in ports, decarbonization not only at ports but also onshore and offshore will be efficiently promoted.

To promote carbon neutrality at ports, the Ministry of Land, Infrastructure, Transport and Tourism set up "Study Committee for Formation of Carbon Neutral Port (CNP)" in FY2021. This study committee has indicated the direction of upgrading, in consideration of decarbonization, ports that are bases of international supply chains as well as industrial bases and forming CNPs. At 65

*1 Chief Staff Manager, Energy Transition Department, Energy Systems, Mitsubishi Heavy Industries, Ltd.
*2 Energy Transition Department, Energy Systems, Mitsubishi Heavy Industries, Ltd.
*3 Director, Energy Transition Department, Energy Systems, Mitsubishi Heavy Industries, Ltd.
*4 Manager, Energy Transition Department, Energy Systems, Mitsubishi Heavy Industries, Ltd.

ports in Japan (as of March 27, 2023), a "port decarbonization promotion council" or similar organization in which people in a wide range of parties involved participate. The establishment of a hydrogen/ammonia supply chain utilizing the characteristics of each region and a basic policy on the sophistication of port functions are being studied. Based on the study, a port decarbonization promotion plan and a road map toward achievement of the goal will be formulated and initiatives will be promoted[(2)].

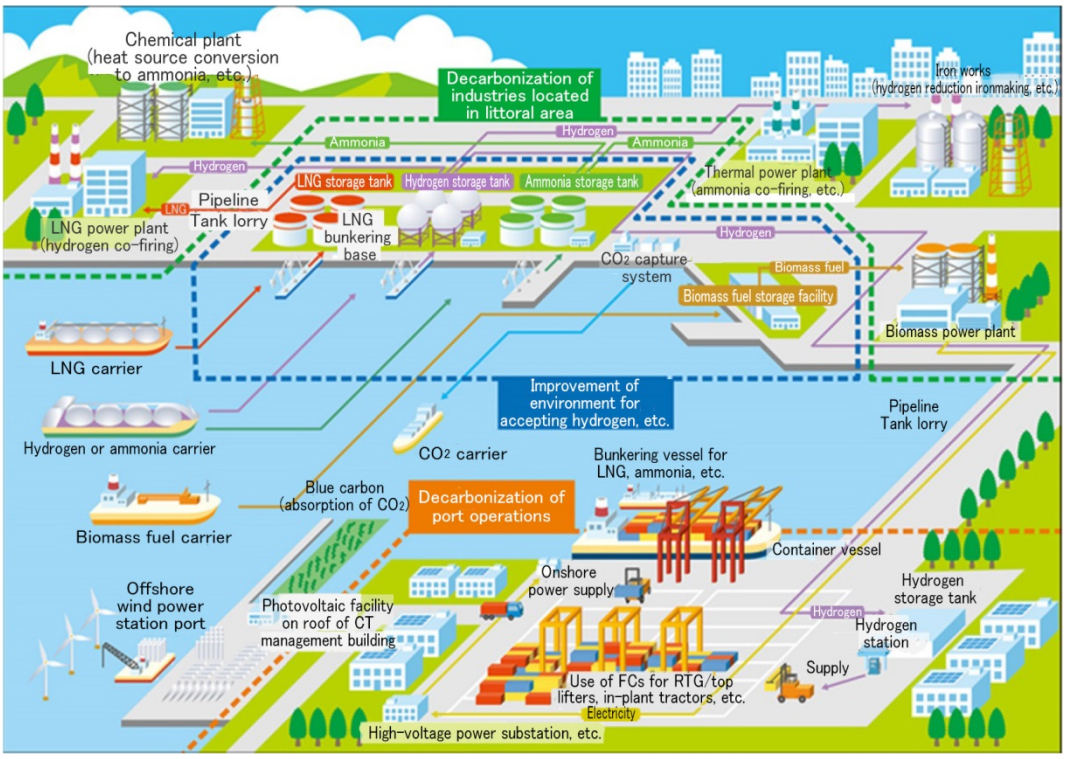
In foreign countries as well, the decarbonization of ports with industrial complexes to be used as hubs for hydrogen/ammonia production, transportation and utilization has been studied. The Port of Rotterdam, the Netherlands, presented "Hydrogen Vision," in which a large-scale hydrogen network should be established, thereby making Rotterdam a transportation hub for hydrogen production, import, utilization and export to other countries in Northwest Europe, and initiatives have already started toward the realization of such transportation hub.

In addition, to reduce CO_2 emissions from vessels anchored at ports, the ports of Antwerp (Belgium), Bremerhaven (Germany), Hamburg (Germany), Haropa (France) and Rotterdam (Netherlands) have been committed to expand the shore power to the full. At the ports of Los Angeles and Long Beach (US), the shore power to container vessels has already been conducted and the needs for decarbonized power supply to vessels are increasing.

In bunkering (supplying fuel to vessels) which is an important function of ports, moves toward the utilization of low carbonized or decarbonized fuels such as methanol, hydrogen and ammonia are accelerating. The Port of Antwerp plans to introduce methanol/hydrogen bunkering by 2025, and Singapore is conducting a feasibility investigation of ammonia bunkering as well as a study toward the implementation of methanol bunkering. Both in Japan and overseas, studies and initiatives toward the realization of CNPs have been promoted.

2. MHI's solutions for ports

The vision of CNP organized by the Ports and Harbours Bureau, the Ministry of Land, Infrastructure, Transport and Tourism is shown in **Figure 2**. It shows the needs for (1) decarbonization of industries located in littoral areas, (2) improvement of the environment for accepting hydrogen, etc., and (3) decarbonization of port operations. Our solution proposals corresponding to these needs are described below.



※This figure has been edited in MHI based on the data by the Ministry of Land, Infrastructure, Transport and Tourism.

Figure 2 Image of Carbon Neutral Port (CNP) formation[(3)]

(1) Decarbonization of industries located in littoral areas

MHI is developing power generation facilities using hydrogen/ammonia which are essential to decarbonization in the power sector (**Figure 3**). When decarbonization fuels that are stored in ports are utilized for supply of power generation and heat energy, CO_2 emissions from the port and its surrounding industries can be reduced. In addition, the decarbonized electricity can be sent to remote areas through transmission and distribution lines, and it becomes possible to expand decarbonization starting from ports to remote areas.

Figure 3 Hydrogen/ammonia-fired gas turbine (left) and hydrogen gas engine single-cylinder test machine (right)

Furthermore, the introduction of CO_2 capture systems contributes to the reduction of CO_2 generated from ports and their surrounding industries. Concerning CO_2 capture systems, MHI has a global market share of more than 70% based on the installed capacity of CO_2 capture from exhaust gas[4]. As of April 2023, we have delivered a total of 15 commercial CO_2 capture systems to various places throughout the world and 3 systems are under construction. Moreover, we have added small-sized CO_2 capture systems to our lineup so that it would be easy to try to introduce our system for customers who are working on decarbonization. Thus, we will contribute to the decarbonization in power and industrial sectors and various other fields (**Figure 4**).

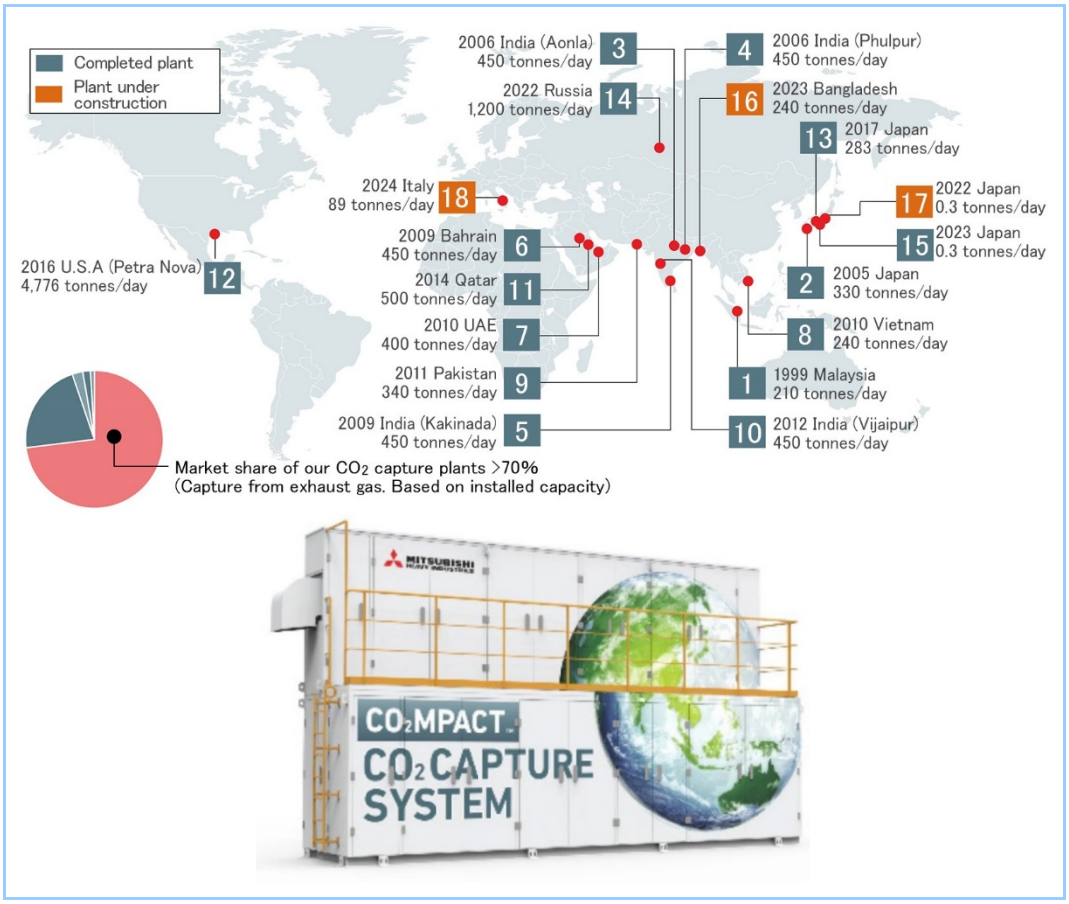


Figure 4 Introduction results of CO_2 capture plants (upper) and small-sized CO_2 capture system (lower)

(2) Improvement of environment for accepting hydrogen, etc.

Concerning the environment for accepting hydrogen, etc., we are developing fuel ammonia carriers that play an important role in hydrogen/ammonia supply chains and bunkering vessels for ammonia-fueled carriers which will appear on the market in the near future. We also completed the concept study of Ammonia Floating Storage and Regasification Unit (Ammonia FSRU) (**Figure 5**). The ammonia FSRU is a floating facility that accepts and stores ammonia transported in a liquid state offshore and regasifies and supplies ammonia onshore according to demand. It can be introduced at lower cost and in a shorter time compared to the construction of an ammonia storage base on land and is expected to contribute to an early stable supply of fuel ammonia as there is an increasing interest in utilization of ammonia toward decarbonization.

Figure 5 Ammonia carrier and FSRU that contribute to improvement of environment for accepting hydrogen, etc.

Ports play important roles not only in handling of decarbonized fuels but also in handling of CO_2. In many cases, the place where CO_2 is emitted and the places where it is stored and utilized are far apart from each other, and it is assumed that CO_2 is transported from ports as starting points. We are also working on development of a CO_2 value chain to transport CO_2 safely and at low cost. In addition to the development of the CO_2 capture system described above, we aim to develop a liquified CO_2 carrier that transports the captured CO_2 and plan to complete a world's first validation test ship for CCUS (Carbon dioxide Capture, Utilization and Storage) in the latter half of FY2023. We also have technologies of the CO_2 liquefier, CO_2 tank and CO_2 compressor for efficient transportation and storage of CO_2, the fertilizer plant where utilization of CO_2 is expected, the digital platform CO_2NNEX® that visualizes CO_2 in the value chain to support distribution and trading, etc. We will work toward the establishment of a value chain through these technologies (**Figure 6**).

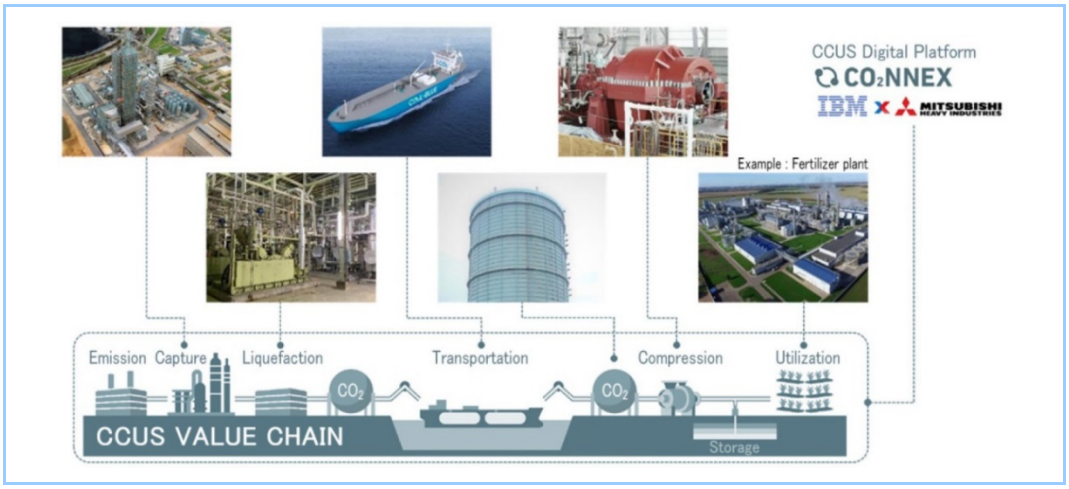


Figure 6 CO_2 value chain and our products

As described above, ports are key places in hydrogen/ammonia value chains and CO_2 value chains. The formation of CNP can promote efficient and effective decarbonization as shown in **Figure 7**.

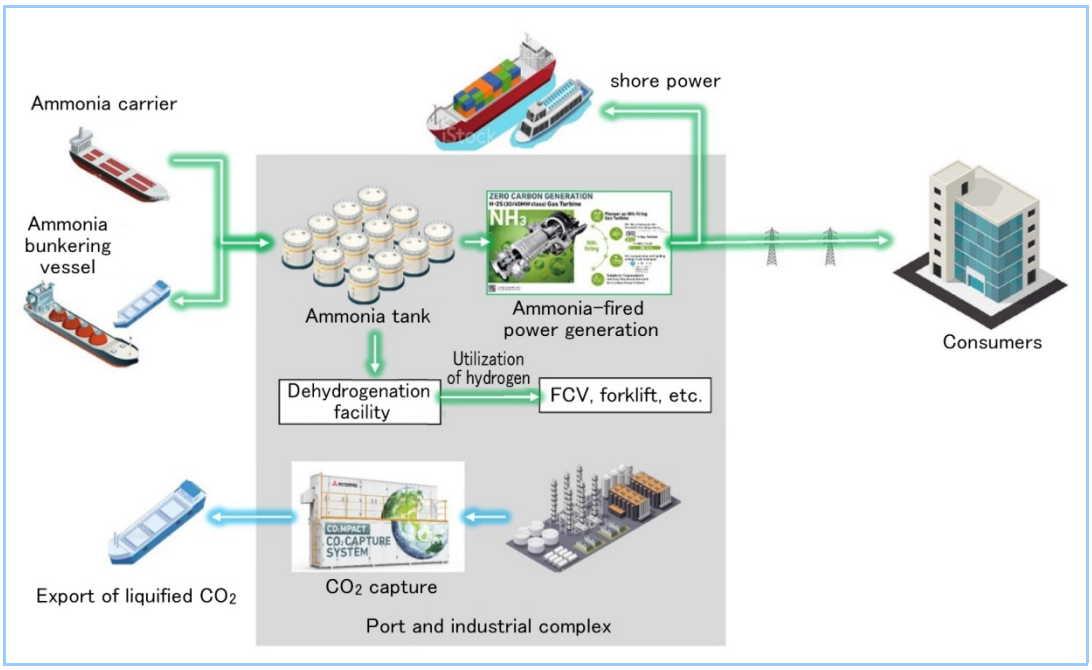


Figure 7 Image of decarbonization starting from port

(3) Decarbonization of port operations

We also have various other products and solutions. For decarbonization of port operations, for example, the Rubber Tired Gantry Crane (RTG) (**Figure 8**) is one of the solutions. This model reduces diesel engine displacement and power while keeping the same capacity as that of the storage battery used in conventional hybrid types and allows an optimal and efficient combustion with a newly installed engine controller, so that it complies with exhaust gas regulations (Tier 4 standard values) of the Ministry of Land, Infrastructure, Transport and Tourism. It can reduce emissions of CO_2, nitrogen oxide (NOx) and particulate matter (PM) and also improve fuel efficiency by 15% or more compared to conventional types. In the near future, the diesel generator will be replaced with fuel cells and the CO_2 emissions from this model can become zero. For various models of forklifts (Figure 8) that are used at ports, we are also studying the use of fuel cells as their power source. Because the use of fuel cells is expected to spread in the regions where the infrastructure for hydrogen supply has been established and will greatly contribute to carbon neutrality, we are conducting tests in the market toward practical use.

Figure 8 RTG (left) and forklift (right) contributing to decarbonization of port operations

Furthermore, we have various products with high compatibility with port operations. Those include air conditioners and heat pumps using environmentally friendly low-GWP refrigerants for distribution warehouses at ports, emergency generator for disaster and a triple-hybrid power generation system (EBLOX®) that combines a reliable engine generator, with renewable energy such as solar energy, and batteries energy storage system. As the needs for decarbonization are increasing all over the world, the introduction of new facilities is

required, but there are many technologies that have not been introduced in ports so far. As a technical provider of decarbonization solutions, we will provide optimal solutions to customers and support their decarbonization efforts for the medium and long term starting from initial planning stages.

3. MHI joins CNP project

In August 19, 2022, MHI, Jurong Port Pte Ltd. in Singapore (hereafter, Jurong Port) and JERA Asia Pte. Ltd. (hereafter, JERA Asia) signed a memorandum for a collaborative study on construction and operation of an ammonia terminal in Singapore as well as ammonia-fired gas turbine power generation business.

Singapore has set the goal of reducing GHG emissions by 36% from the 2005 level and by about half of the 2030 level by 2050 and it is one of the countries that have been actively taking a step forward toward carbon neutrality. Singapore is planning to utilize low-carbon hydrogen and hydrogen-derived fuels in the electric power, maritime and aviation sectors and leads decarbonization in Southeast Asia.

Singapore, located at the entrance to the Strait of Malacca, which is a strategic point for maritime transportation in Asia, is one of the world's major sea lanes and is the world's top bunkering port. The Singapore government has placed bunkering as one of its most important policies and aims to form an ammonia bunkering base so that Singapore can keep its position as the world's top bunkering port even if decarbonization of marine fuels is promoted in the future.

This requires large capital investment, and the commercialization of ammonia-fueled vessels is expected in 2030 and onward. For early realization of a CNP, MHI proposed to the government-affiliated operator, Jurong Port, to promote onshore decarbonization by using fuel ammonia at the ammonia-fired gas turbine power generation facility that MHI is developing, and as soon as ammonia-fueled vessels appear on the market, offshore decarbonization should be promoted through bunkering (**Figure 9**). Then, MHI and Jurong Port signed a memorandum on this matter in August 2021. As a result of a simplified economic rationality verification, it was found that fuel ammonia accounted for a large part of the levelized cost of electricity (LCOE). To increase economic efficiency, we decided to conduct a collaborative study with JERA Asia, which is the Singapore subsidiary of JERA Co., Inc. and has expertise about low-cost and stable procurement of ammonia. Moving forward, we will promote the study with those concerned toward the realization of a 60 MW-class 100% ammonia-fired gas turbine combined cycle and bunkering.

The needs for formation of CNPs using hydrogen/ammonia have become apparent not only in Singapore but also in Australia, the Middle East and Europe. We will listen to customers' needs and continue to promote onshore and offshore decarbonization projects.

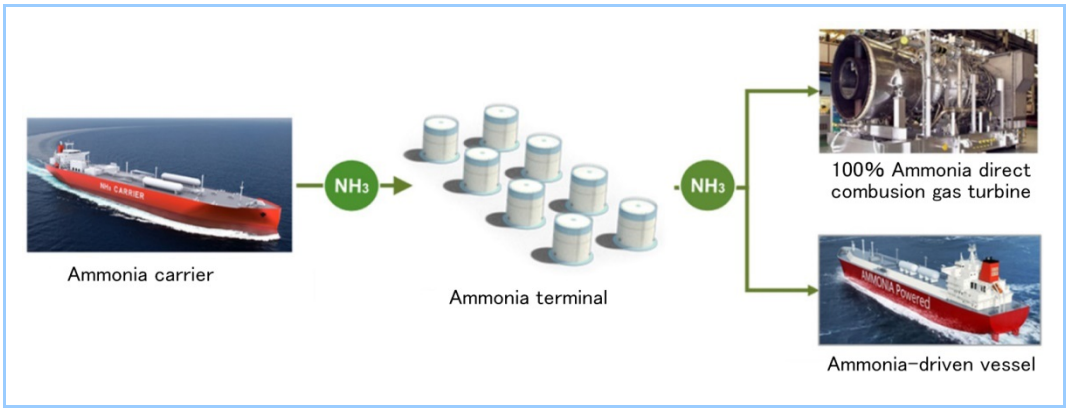


Figure 9 Concept of CNP in Singapore

4. Conclusion

Use of decarbonized fuels such as renewable energy, hydrogen and ammonia as well as CO_2 capture, storage and utilization are important for the achievement of carbon neutrality. On the other hand, the energy producing place and its consuming place or the place where CO_2 is emitted and the place where it is stored are far apart from each other, and it is necessary not only to develop

individual technologies but also to establish a worldwide supply value chain, in which a port plays an important role as a place connecting individual places. We will develop decarbonization solutions starting from ports, thereby contributing to the achievement of carbon neutrality in Japan and the world.

References

(1) Ports in numbers (2021), The Ports & Harbours Association of Japan, Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism
(2) Ministry of Land, Infrastructure, Transport and Tourism, Study Committee for the Formation of Carbon Neutral Ports (CNP), https://www.mlit.go.jp/kowan/kowan_fr4_000050.html
(3) Ministry of Land, Infrastructure, Transport and Tourism, Carbon Neutral Ports (CNP), (2023), https://www.mlit.go.jp/kowan/kowan_tk4_000054.html
(4) Kohei Higaki et. al, MHI Group's Recent CO_2 Capture Technology for Carbon Neutral Society, Mitsubishi Heavy Industries Technical Review, Vol.59 No.2（2022）