MISSION NET ZERO: Carbon Neutrality Initiatives at MHI Group toward a Sustainable, Safe, Secure and Comfortable Society

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While the common goal of reducing CO_2 emissions to Net Zero by around 2050 is shared by countries around the world, Mitsubishi Heavy Industries, Ltd. (MHI) Group has declared its "MISSION NET ZERO" to reduce the group's CO_2 emissions and those of its customers who use our products to virtually zero by the year 2040. We have divided the energy social system into the "supply side" and the "use side", and have defined the direction we should aim in these areas as "Energy Transition" and "Smart Infrastructure", respectively. In addition, we are working to develop technologies and businesses that will contribute to a "carbon-neutral society of the future" through technological development based on open innovation, collaboration and co-creation across industries rather than efforts made by our company alone, in addition to conventional product development.

1. Introduction

Since the Industrial Revolution in Europe in the 18th century, human civilization has developed in leaps and bounds using fossil fuels. Modern society is supported by energy, much of which is provided by fossil fuels such as coal, oil and natural gas. While the expanded use of fossil fuels has brought great benefits to humankind, it has also caused numerous problems. One of these is environmental problems, which include local problems such as smog and region-wide problems such as acid rain. Today, in the 21st century, the problems have expanded to a global scale. Climate change, as typified by global warming, is believed to be mainly caused by greenhouse gases emitted by humans. In terms of human activities, the main source of greenhouse gas emissions is the use of fossil fuels. The composition of this problem was internationally recognized at COP3 in 1997 in the form of the Kyoto Protocol. After long discussions, the Paris Agreement was adopted at COP21 in 2015, which set "efforts to keep the global average temperature increase well below 2°C above pre-industrial revolution levels and to limit it to 1.5°C" as a common global goal. In response to this, countries have been required to set their own greenhouse gas reduction targets. In 2018, the IPCC's Special Report on Global Warming of 1.5 °C was published, which recognized the need to reduce global CO_2 emissions to Net Zero around 2050 in order to limit the temperature increase to less than 1.5°C, and "Net zero CO_2" or "carbon neutrality" was once again shared as a common goal worldwide. After that, around the time of COP26 in 2021, countries around the world declared their commitment to carbon neutrality by around 2050 or similar, which is still fresh in our memories.

As mentioned at the beginning, modern society operates by consuming energy, the main source of which is fossil fuels. In other words, the consumption of fossil fuels and resulting CO_2 emissions is a prerequisite for modern society. Aiming for carbon neutrality means fundamentally reconsidering this prerequisite, and can be said to be a major paradigm shift. This paradigm shift means a drastic change in the socio-economic system that has been built over a long period of time since the Industrial Revolution, and in particular, the energy social infrastructure is under pressure for major changes.

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Since its foundation, MHI Group has been extensively involved in the development of energy infrastructure, and even today, most of our business areas contribute to our customers and society by creating, transporting, storing, and consuming energy. Therefore, in the paradigm shift toward carbon neutrality, it is the social responsibility of our group to actively and proactively work toward achieving that goal. As an expression of this commitment, MHI Group declared "MISSION NET ZERO" in October 2021, which set a target to achieve Net Zero CO_2 emissions by 2040 for both our group's CO_2 emissions (Scopes 1 and 2) and our customers' CO_2 emissions from the use of our group's products (Scope 3 reductions plus the contribution to reductions by Carbon dioxide Capture, Utilization and Storage (CCUS)).

Table 1 shows the CO_2 emission reduction targets in "MISSION NET ZERO" and **Figure 1** shows the roadmap toward "MISSION NET ZERO". The reason for setting the deadline at 2040 rather than 2050, which is generally adopted, is that in order for our customers and society as a whole to achieve carbon neutrality, the renewal of the social infrastructure that supports them must be done well before, and we set 10 years as a rough estimate of the period in which we should complete our role. This is an extremely challenging target, but we believe that this is one of our responsibilities as a company that supports social infrastructure, and that it is essential for the future development of our business to lead the creation of a market in a new paradigm.

This report outlines our group's approach to achieving carbon neutrality and provides a bird's-eye view of our initiatives in Energy Transition (supply side of energy) and Smart Infrastructure (use side of energy).

Table 1 CO_2 emissions reduction targets in MISSION NET ZERO

Target Year	Reduce CO_2 emissions across MHI Group Scope 1 and 2	Reduce CO_2 emissions across MHI's value chain Scope 3 + reductions from CCUS
2030	-50% (compared to 2014)	-50% (compared to 2019)
2040	Net Zero	Net Zero

Scope 1 and 2: The calculation standard is based on the GHG Protocol.
Scope 3: The calculation standard is based on the GHG Protocol. However, we also account for reductions achieved by CCUS as an MHI original index.
GHG: Greenhouse Gas
CCUS: Carbon dioxide Capture, Utilization, and Storage

* CO_2 emissions account for 99% of our GHG emissions, so our goal is simply set as reduction of CO_2 emissions.

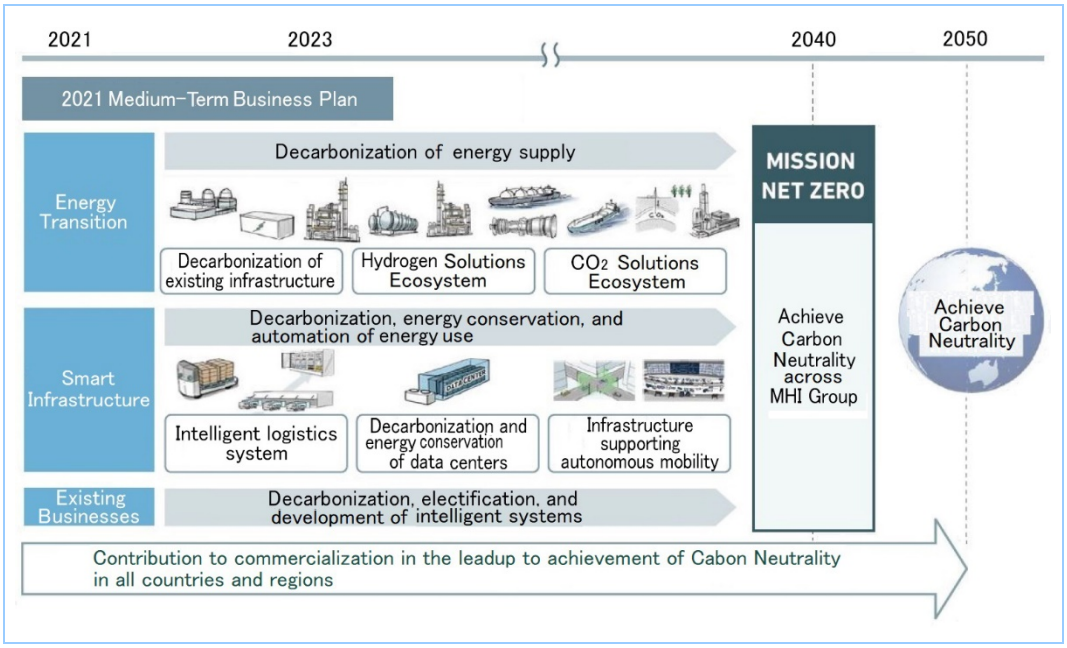

Figure 1 Roadmap toward MISSION NET ZERO

2. Approach to carbon neutrality

Carbon neutrality means a state of practically zero CO_2 emissions mainly from human economic and social activities, achieved by reducing the emissions, and in some way absorbing (recovering) the remaining un-reduced emissions. The scope on which the emission and recovery calculations are based varies, and carbon neutrality has been declared at different levels: national/regional (e.g., Japan and EU), municipality, and corporate. The important point here is that it is impossible for any individual player to achieve carbon neutrality on its own, regardless of which level it belongs to. Energy is distributed to every corner of society from production to consumption through supply chains in which many players participate. The energy supply chains are interrelated, traded in oil and electricity markets, and the supply side and the use side (and the distribution between them) are linked by an extremely complex global network. To dare to simplify, in order to achieve carbon neutrality, there must be an "energy supply contributing to carbon neutrality" that is sufficient to make the achievement possible, and at the same time, there must be an "energy use contributing to carbon neutrality". Furthermore, a trading system that can link these two and prove that the energy is carbon-neutral must be established.

This principle offers several implications for a carbon-neutral worldview. The first is that "the paths to carbon neutrality are diverse". For example, on a country-by-country basis, the measures toward carbon neutrality should differ between countries that produce abundant fossil fuels and countries that have abundant renewable energy sources. Also, the technical challenges and the degree of economic difficulty in achieving carbon neutrality for companies will also differ depending on the country where they are located. The second is that "the establishment of economic rationality is a requisite for achieving carbon neutrality". Although it may seem obvious, most measures toward carbon neutrality require additional costs to be paid in some form or another. Since the energy system is based on a trade between the supply side and the use side, the additional costs are borne by someone participating in such trade, but they must be kept within a range that is acceptable to society as a whole, and at the same time, they must be fairly distributed (shared). The other is that "carbon-neutral energy systems require stability". As of October 2022, the surge in energy prices originating in Europe, partly due to Russia's invasion of Ukraine, has led to inflation around the world. This is by no means an accidental event, but rather partly due to European political blunders to prematurely phase out coal-fired and nuclear power generation and consequently increase dependence on Russian gas. To achieve carbon neutrality, it is inevitable to reduce dependence on fossil fuels and to transform the existing energy system, but it is important to secure a balance so as not to undermine the stability of the overall system or create economic disadvantages.

Based on the premise described above, MHI Group aims to "contribute to building a stable energy social system while meeting the wide-ranging needs of its customers and controlling the increase in social costs". To achieve this, we divided the energy social system roughly into the "supply side" and the "use side", and defined the direction and approach we should aim for in each area as "Energy Transition" and "Smart Infrastructure". The following chapters provide an overview of each area.

3. Our group's initiatives

3.1 Energy Transition (energy supply side)

The Energy Transition mainly refers to the overall initiatives to decarbonize the energy supply system centered on fossil fuels. Our group defines the Energy Transition as "decarbonization of existing infrastructure", "realization of hydrogen ecosystems", and "realization of CO_2 ecosystems", and are promoting new business and technological developments in each of these areas.

The "decarbonization of existing infrastructure" reduces CO_2 emissions while utilizing existing energy social infrastructure such as thermal and nuclear power plants, thereby suppressing the additional social cost of introducing new infrastructure and contributing to a stable energy supply. While the introduction of renewable energies is increasing in society as a whole, natural energies such as wind and solar have low CO_2 emissions over their lifecycle, but their output

fluctuations are a major issue. It is possible to suppress the fluctuations and provide backup for short periods of time and small capacities by using storage batteries, but from the perspective of overall grid stability, storage batteries have their limitations and need to be supplemented by other methods. Therefore, MHI Group promotes the development and social implementation of technologies for gas turbines and engines capable of hydrogen co-firing or single-fuel hydrogen firing, and ammonia co-firing for coal-fired power generation, for example, thereby aiming to reduce CO_2 emissions and at the same time maximizing the use of existing infrastructure to absorb fluctuations in renewable energy. We are also working to reduce CO_2 emissions to practically zero by installing CO_2 capture equipment in thermal power plants and industrial plants. In particular, in the "hard-to-abate" industries, i.e., steel and cement, it is difficult to reduce CO_2 emissions by greening electricity (i.e., converting to renewable energy) due to their product manufacturing processes. Therefore, we aim to expand the application of our CO_2 capture technology to contribute to the achievement of carbon neutrality in a wide range of industries. In the steel industry, where MHI Group also produces products, we are developing future technologies to reduce CO_2 emissions themselves, such as a direct reduction process using hydrogen.

Nuclear power is a carbon-free, large-scale stable power source that does not emit CO_2 during operation and can generate electricity stably regardless of weather conditions. In addition, recently there has been a rapid increase in interest in energy security, and expectations for nuclear power, which ensures a high degree of energy security, are rising worldwide. To achieve carbon neutrality, we will support existing nuclear power plants, including not only pressurized water reactors (PWRs) but also boiling water reactors (BWRs), to restart operations and to install accident management system, and will ensure safe and stable operation thereafter in order to improve the safety of nuclear power plants. In addition, we will make steady progress in our initiatives toward the early establishment of a fuel cycle. We will also promote the development and design of innovative light water reactors (next-generation light water reactors) that achieve the world's highest level of safety for social implementation in the mid-2030s. Furthermore, in response to the diversifying needs of society in the future, we will also develop compact light water reactors as distributed power sources, high-temperature gas reactors for stable mass hydrogen production, fast reactors for effective use of resources and for reducing the volume and toxicity of high-level radioactive waste, and micro reactors as portable power sources for remote islands and disaster areas. In the medium to long term, we intend to take up the challenge of putting fusion reactors, our dream permanent energy source into practical use.

The other two of the three pillars, "realization of hydrogen ecosystems" and "realization of CO_2 ecosystems" are to build the value chain necessary to realize the "decarbonization of existing infrastructure". The "realization of hydrogen ecosystems" builds upstream supply chains for hydrogen and ammonia needed in thermal power plants and steel plants, etc., while the "realization of CO_2 ecosystems" builds downstream supply chains for transporting, storing, and reusing CO_2 captured from various emission sources. We use the term "ecosystem" because we recognize that it is necessary not only to demonstrate a single supply chain, but also to create markets and build networks through collaboration with a wide variety of players, including customers and partner companies, in consideration of the fact that the energy social infrastructure consists of complex supply- and use-side networks as mentioned above.

The "realization of hydrogen ecosystems" is primarily aimed at building a large-scale hydrogen supply network for hydrogen consumption at power plants, etc. For this purpose, we are developing technologies for the production of blue hydrogen and ammonia, which are produced from natural gas, and green hydrogen and ammonia, which are produced by water electrolysis using renewable energy, as well as transportation technologies, etc.

To demonstrate the decarbonization of existing infrastructure through building hydrogen ecosystems, we are constructing the "Takasago Hydrogen Park" at Takasago Machinery Works of Mitsubishi Heavy Industries, Ltd. (located in Takasago City, Hyogo Prefecture), which is scheduled to begin operations in fiscal 2023. The Takasago Machinery Works has operated a combined cycle power plant as a demonstration facility since 1997, and is responsible for supplying electricity to the local community, and thus the "Takasago Hydrogen Park" will demonstrate the decarbonization of existing infrastructure through fuel conversion.

The "realization of CO_2 ecosystems" denotes an attempt to build a value chain primarily aimed at collecting, transporting, and appropriately storing or reusing the captured CO_2. Various concepts are currently being proposed and studied around the world to determine what kind of chain will be built, but the chains are roughly classified into two types: “CCS (Carbon Capture and Storage) to finally store the captured CO_2“ and “CCU (Carbon Capture and Utilization) to finally utilize the captured CO_2”. The storage (CCS) mainly uses depleted oil and gas fields as the final storage site, but it is necessary to develop technologies to economically transport the captured CO_2, store it underground, and prove that it is stored reliably. Mainly in Europe and North America, projects to demonstrate CCS in the country and the region are being planned, and we are considering participating in some of these projects. For the utilization (CCU), processes have been proposed to convert the captured CO_2 back into fuel or into valuable materials such as recycled plastics, but most of them are still in the research and development stage before commercialization. Furthermore, there are many issues to be addressed in terms of designing the system, such as how to certify CO_2 reductions during the life cycle. Currently, we are focusing on several promising technologies and determining their feasibility. For example, direct air capture (DAC), which captures CO_2 from the air, is a technology that enables a carbon recycling process without sticking to artificially emitted CO_2, but because its cost of capturing CO_2 is currently very high, we are working to develop and demonstrate this technology as a future technology. In addition to these technologies, MHI Group is also developing and demonstrating a digital platform called CO_2NNEX^{TM}, which visualizes and links CO_2 emissions and demand (take-back as CCS or reuse as CCU) to establish trade and ensure traceability. We will contribute to the creation and expansion of markets, and ultimately to the achievement of carbon neutrality for society as a whole, by providing the technology that will serve as the basis for trading CO_2, for which no market currently exists.

3.2 Smart Infrastructure (energy use side)

The world’s population is expected to reach nine billion between 2040 and 2060. This population growth will occur mainly in emerging countries and will be accompanied by an increase in the scale of economic activities. In order to achieve carbon neutrality in this process, changes in the "way energy is used", including changes in people's behavior, will be required. Not only in emerging countries but also in developed countries, a major shift in socioeconomic systems is creating a polarization in which the population is concentrating in large cities and decreasing in rural areas, and an era of disparities in the universality of utilities such as electricity, gas, and water, public transportation services, and food supply is beginning. The Internet and the services that make use of it continue to expand. A data society has been built in which the world is connected in every possible way, and the foundation has begun to be organized to realize process visualization from production to consumption and automated and autonomous mechanical systems through the accelerated speed of information sharing and the processing of vast amounts of data. Furthermore, in the mobility, logistics, and industrial sectors, the trend toward decarbonization is accelerating "electrification", and the world is moving toward an era of pursuing optimization through automation and autonomy using data and digital technology. All these trends are linked to an increase in electricity consumption, which is predicted to more than triple by 2050 compared to today. In the future, an important issue of how to use precious energy resources (electricity) efficiently and carefully on the use side will arise.

We believe that a challenge that our group should address is to make social systems smart and pursue efficiency, optimization, and sustainability on the use side in the coming age when the use for energy and food is expected to increase dramatically, while taking the global environment into consideration. As a means to achieve this, we are promoting technological development and participating in new business sectors with the major themes in "decarbonization", "energy saving", "manpower reduction", "autonomous operation", and "digital intelligence".

As an initiative in the mobility sector, MHI Group is building infrastructure for the realization of a Mobility as a Service (MaaS) society. One example is the provision of comprehensive environmental test equipment for realizing "autonomous driving". In collaboration with partners in Japan and overseas, we are considering providing everything from test equipment to actual testing services and homologation support. In addition, as the EV market accelerates and

urbanization progresses at the same time, multi-story parking garages and other facilities will serve as recharging bases. We are also developing and building next-generation MaaS service bases that will serve as energy storage systems. By supporting these changes in the mobility sector on the social infrastructure side, we will contribute to the development of various mobility services that provide safety and security.

In the logistics sector, we are promoting the provision of "intelligent logistics systems". By combining high-performance AGF (Automated Guided Forklift) and other equipment, we are working on smooth coordination between people and various logistics equipment to build more efficient and safer automated logistics systems. In addition, we aim to achieve significant energy saving and decarbonization by taking advantage of our product lineup that includes air conditioning and refrigeration equipment such as natural refrigerant chillers to optimize the total operation of logistics equipment, air conditioning and refrigeration equipment, and electric power equipment.

The industrial sector faces the urgent challenge of the "decarbonization of factories". Many factories require not only electricity but also heat, and have conventionally used fossil fuels as their energy source. In line with the trend toward decarbonization, it will be necessary in the future to build utility systems that pursue economic efficiency and stability while promoting electrification or utilizing decarbonized power generation with renewable energy, hydrogen, ammonia, etc. After declaring "MISSION NET ZERO", our group has been promoting the decarbonization of our plants in order to achieve carbon neutrality in Scopes 1 and 2. As a first step, we have been promoting the realization of a "carbon neutral factory" in Mihara Machinery Works of Mitsubishi Heavy Industries, Ltd. (Mihara City, Hiroshima Prefecture) by completely eliminating 10,000 tons of CO_2 emissions per year from each plant there by the end of fiscal 2023. We plan to work with the electric utility to replace the existing power supply with solar power generation using the PPA method, and to use the Mihara Machinery Works as a development field for MHI Group's proprietary technologies to achieve carbon neutrality, such as heat source electrification and fuel conversion. Thus, we will achieve carbon neutral factories by implementing carbon neutral solutions in a challenging and rational manner.

Finally, we are also promoting the construction of "data center" infrastructure, which will be an important social infrastructure for the next generation. In the case of hyperscale data centers, it is expected that the data capacity per building will be enormous. In order to support the construction of an optimal and highly reliable data center that combines the reduction of power consumption, the enhancement of server cooling efficiency, and the establishment of an integrated operation system, we have been providing high-performance air conditioning and refrigeration systems, power generation systems, and energy management systems. In addition to hyperscale data centers, micro-edge data centers are expected to accelerate in the future. The micro-edge data center infrastructure, in conjunction with the hyperscale data center infrastructure, will enable large volumes of data processing and low latency, and will realize automatic and autonomous operation of mechanical systems, as well as remote control and operation. Our group aims to optimize the operation of data centers through next-generation cooling systems, decarbonized power generation systems, and integrated control.

As described above, MHI Group has a product base related to various industrial and lifestyle fields, and by combining intelligent technologies for mechanical systems with technologies for improving and optimizing energy efficiency, we will realize Smart Infrastructure and contribute to building sustainable social systems.

4. Conclusion

The achievement of carbon neutrality is an issue that needs to be addressed by society as a whole, and as described in this report, changes on the energy supply side (Energy Transition) and on the use side (Smart Infrastructure) must be pursued in parallel. However, the road ahead is not yet clear, and it is difficult to predict which technologies and products will become mainstream. Startup companies aiming to establish innovative technologies are emerging in various fields. Technology and business development based on unconventional approaches, such as open innovation with such startup companies, will also be required. In addition, in order to transform the structure of the energy social infrastructure that is related to both supply and use, collaboration and

co-creation across industries are required rather than one company working alone. Our group, which has a diverse product lineup and has provided products and services to a wide range of industries, has the potential to contribute to many of society's needs in this changing environment. For this purpose, it is necessary to envision a "future carbon-neutral society", steadily develop the necessary technologies, and at the same time, carry out a rapid and flexible business development cycle. This will pave the way for the MHI Group to make a new contribution to society.

CO_2NNEX^{TM} is a registered trademark of Mitsubishi Heavy Industries, Ltd. in Japan.