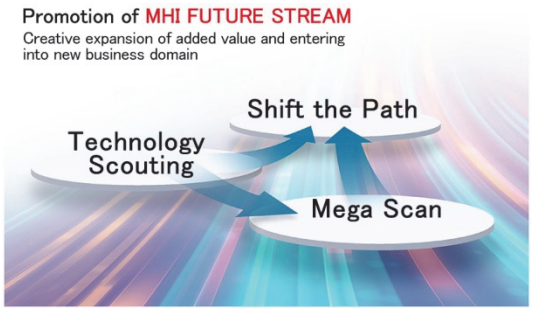
MHI FUTURE STREAM: Indicating MHI Group's Direction



YO AKIYAMA[*1]　　TAKAAKI FURUYA[*2]

To continue to contribute to society and humanity through the provision of machine systems, it is necessary for Mitsubishi Heavy Industries (MHI) Group to be a company that can sustainably grow with the capability of responding to rapid changes in the social agenda, people's values, technological innovation, etc.

MHI FUTURE STREAM is an activity for setting MHI Group's business direction according to several possible scenarios that are formulated based on the big picture of changes in the political, economic, social, and technological situations surrounding our business from a medium- to long-term perspective. With regard to the three approaches of "Mega Scan", "Shift the Path" and "Technology Scouting", which were described as components of MHI FUTURE STREAM in previous Technical Review [(1)], this report describes the notable megatrends, the direction of our group's business shift theretoward, and the activities of Yokohama Hardtech Hub, which was newly inaugurated as a co-creation platform.

1. Introduction

Since its founding, MHI Group has contributed to the progress of society through the manufacture of machine systems that make up social infrastructure. Under such circumstances, in recent years, complicated social agendas, the diversification of people's values, technological innovations such as digitization, functional materials, and biotechnology, as well changes in people's behavior due to the COVID-19 catastrophe, have been superimposed, and the needs and values surrounding social infrastructure have been changing uncertainly and discontinuously.

MHI group will continue to be a machine system manufacturer that contributes to society. However, in order to continue to contribute to and provide value to the stakeholders surrounding us, our group needs to draw a picture of the future society we are aiming for, reaffirm the role we should play, and continue to make changes theretoward.

MHI FUTURE STREAM is an activity to discover the direction in which our group's business should go.

2. MHI FUTURE STREAM looks toward future society and encourages business shifts

Three approaches are taken in MHI FUTURE STREAM: "Mega Scan", "Shift the Path" and "Technology Scouting" (**Figure 1**).

*1　Manager, Business Intelligence & Innovation Department, Technology Strategy Office, Head Office, Mitsubishi Heavy Industries, Ltd.

*2　Senior Fellow, Technology Strategy Office, Head Office, Mitsubishi Heavy Industries, Ltd.

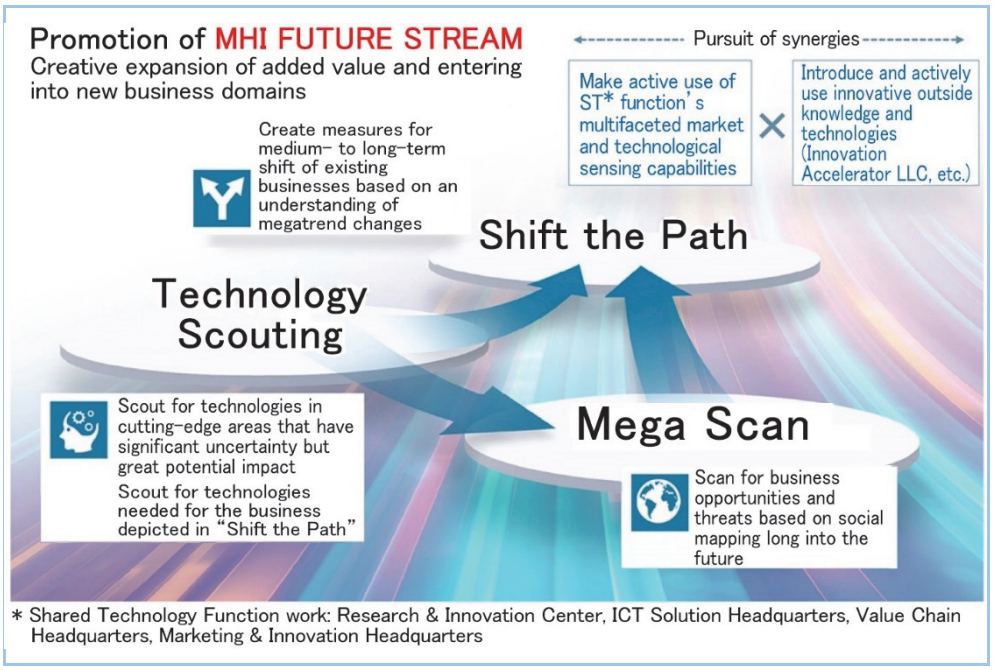


Figure 1 Three approaches of MHI FUTURE STREAM

In "Mega Scan", society 10 to 20 years in the future is predicted from a broad, comprehensive perspective, and based on the obtained image, possible change pattern scenarios are formulated considering wide-ranging possibilities in markets and technologies to suggest possible business opportunities. Through this approach, many dialogues are held with experts and innovators both inside and outside our companies, and insight into the future and vision are created with multiple perspectives in terms of markets and technologies. Especially in recent years, major movements that may affect the future society occurred at the same time, such as the social agenda including sustainable growth with a view to preserving the global environment with regard to climate change, etc., and utilizing limited resources, cross-border regulations starting from U.S.-China friction, etc., the acceleration of technological innovation including digital and biological technologies, changes of people's behavior triggered by the COVID-19 catastrophe, and supply chain vulnerabilities exposed against the background of the globalized economy. "Mega Scan" does not consider these changes as a set of single phenomena, but gives insight into the overall picture of these changes.

"Shift the Path" generates innovation hypotheses of market and technology based on the insights and perspectives of "Mega Scan" and "explores" the business opportunities found from them. "Shift the Path" deals with themes that are difficult to sprout and nurture in the current business functions, such as new businesses that are not related to existing businesses and business opportunities that cross multiple businesses. The agile business development team, which is led by the shared technology function and also includes external partners such as venture companies, conducts verification through prototyping and trials, and hands the fruit over to the "exploitation" process (**Figure 2**).

"Technology Scouting" has two key concepts. One is a disruptive technology that has the potential to have a significant impact on the medium- to long-term insight and vision obtained in "Mega Scan". The other pertains to a technology needed to realize the innovation hypotheses generated through "Shift the Path". These technologies are created together with external partners.

By taking these three approaches alternately, we will draw a picture of the future society and determine the direction of the business shift of our group, which is a supplier of machine systems that make up social infrastructure.

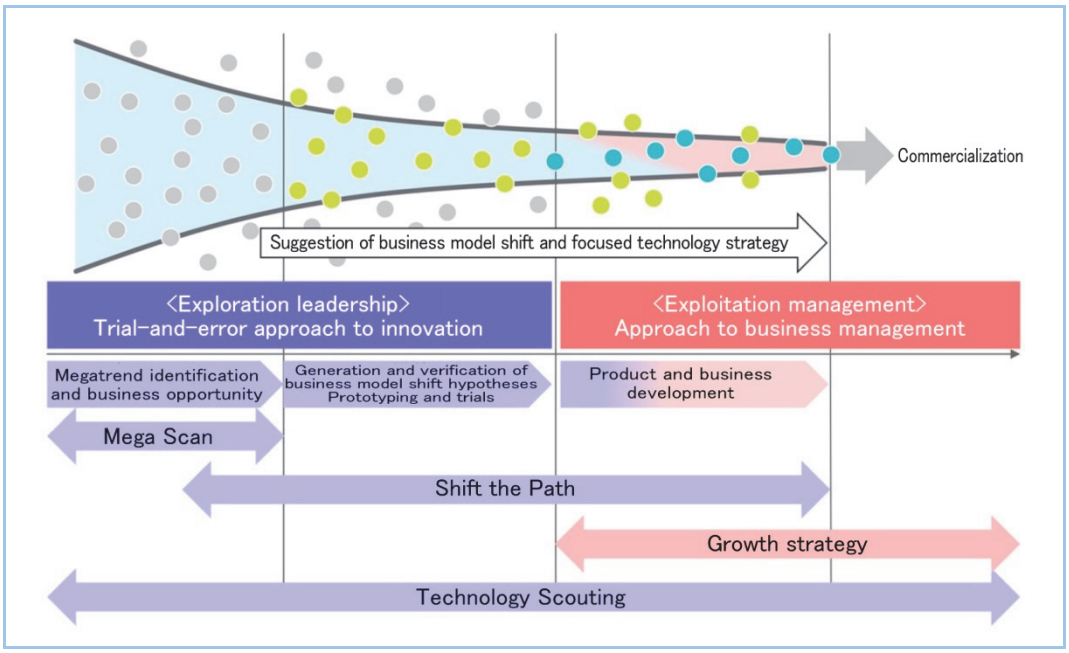


Figure 2 From MFS, business model shift/new business conception to development of growth strategy (Blue: led by Shared Technology Function, Red: led by Business Function)

3. Advancement of machine systems and relationship between nature, humans, and machines

This chapter describes the direction of the advancement of machine systems to look toward the future society centering on them. Machine systems have changed discontinuously along with technological innovation. The invention of external combustion engines promoted the mechanization of factories and freed humans from hard physical labor and repetitive work. The invention of internal combustion engines gave humans the freedom to move and carry things through the advancement of moving vehicles. Now, with the progress of power electronics technology against the background of innovative materials and microfabrication technology, machine systems are advancing from internal or external combustion engine drive to electric drive (or hybrid drive). The electrification of machine systems improves environmental friendliness, maintainability, controllability, functions, and performance, as well as changes in the form of machine systems due to miniaturization and increased design freedom brought by functional consolidation and increase rotational speed. This electrification of machine systems is considered to be essential for a future decarbonized society.

At the same time as the electrification described above, the intelligence evolution of machine systems is accelerating against the background of the advancement of digital technology. The intelligent evolution of machine systems described here do not simply refer to machine systems that are autonomized or automated for obtaining accuracy, speed, and sustainable durability, but are defined as machine systems that collaborate and coexist with humans while coordinating themselves with the judgment of humans based on their knowledge of business or operation and ethical sense of safety, security, etc.

In the past, the automation of machine systems has progressed in the form of dividing the work with humans while automating the repetitive work that was performed by humans. However, the recent advancement of AI technology has made it possible to extract features quantity from information such as vision, and its application has expanded. The operation of machine systems has changed from a planned type where humans input behavior patterns one by one in advance to a prediction/learning type that uses past operation data, and machine systems have been advancing so as to take a form where they accumulate the knowledge of skilled humans and coexist with humans. As a result, the functions and performance of machine systems have been improved not only in terms of their long PDCA cycles such as hardware modifications, but also in terms of their short OODA cycles in software enhancements*.

(* PDCA: Plan-Do-Check-Action (improvement), OODA: Observe-Orient-Decide-Act)

For collaboration and coexistence between machine systems and humans, it is necessary to reconsider not only the value and role of machines, but also the humans, organizations, and decision-making that incorporate the machines. Machines are usually better than humans in terms of speed, accuracy, and repeatability. However, blindly relying on the increasingly complex operation of machines poses the risk of malfunctions and the inability to deal with emergent or exceptional events. In order to become familiar with the use of a machine, humans perform many simulations and tests to understand its operation. It is necessary to have a mechanism to accumulate these understandings as organizational knowledge. Especially for applications related to human safety and security, it is necessary to define the roles of humans and machines in light of not only business and operation knowledge, but also values and ethics for labor (**Figure 3**).

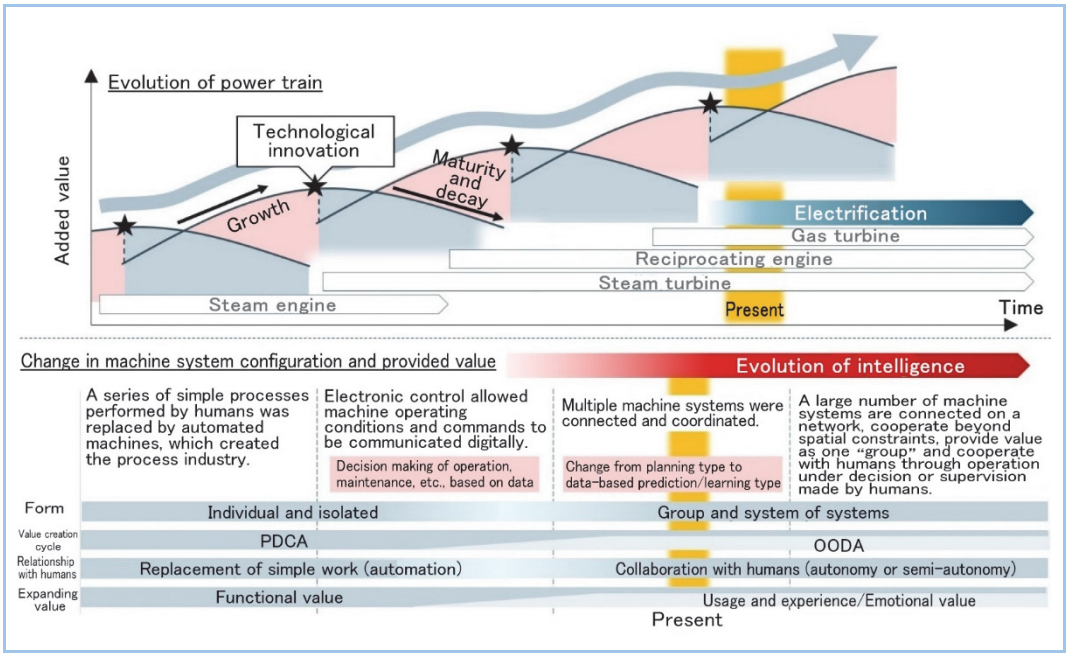


Figure 3 Evolution of machine systems and electrification/intelligence evolution

Machine systems are integrated with digital technology, and their forms change. In recent years, the range of use of intelligent machine systems has expanded not only to large-scale production and supply equipment such as factories and plants, but also to consuming and demanding sides. It is expected that machine system functions will be divided in order to flexibly meet the diverse needs of individuals, etc., and interconnected machines will work together to provide value as a group.

Such progress in machine intelligence changes the relationship between machines and humans, evolves to be closer to humans, and also changes the relationship between humans and nature. They will no longer be just tools, but partners for building symbiotic relationships between humans and nature. It is expected that as human augmentation technology, such as AR (Augmented Reality) and VR (Virtual Reality), and sensor technology advance, scientific understanding of medical/health and the substance metabolism mechanism of biological/natural environment ecosystems will advance, the substance metabolism processes of plants, microorganisms, animals, humans, and the natural environment and the functions of machine systems will be complemented gradually, and symbiotic evolution will occur while guaranteeing the finiteness of earth resources.

4. Changes in social infrastructure needs and provided value

4.1 Changes in social infrastructure for a decarbonized society

As mentioned in the previous chapter, machine systems continued to change their appearance due to technological innovation. At the same time, however, the value they provide changed in response to changes in social needs according to the stage of economic development, which resulted in changes in human livelihoods and the industrial structure.

Toward improvement in people's living standards while responding to the increasing demand for energy and industrial goods during postwar reconstruction and economic growth, the need for the development of large-scale energy and industrial infrastructure to prevent environmental pollution and the transportation infrastructure responsible for the transportation of people and goods linked to economic growth grew significantly. Our group has contributed to the progress of global society by supplying machine systems such as energy/environmental plants and ships/aircraft in response to the needs of society.

In recent years, the need for decarbonization against the background of climate change has become a major trend throughout the world. Toward the realization of carbon neutrality, our group is working on the development of new machine systems based on three directions (**Figure 4**): "Reduction" of CO_2 emissions by improving machine performance and operational efficiency, "No Emission" of CO_2 by using renewable energy, electrification, and manufacturing/using carbon-free fuel, etc., and "Utilization" of CO_2 by capture/fixing emitted carbon and generating valuable resources.

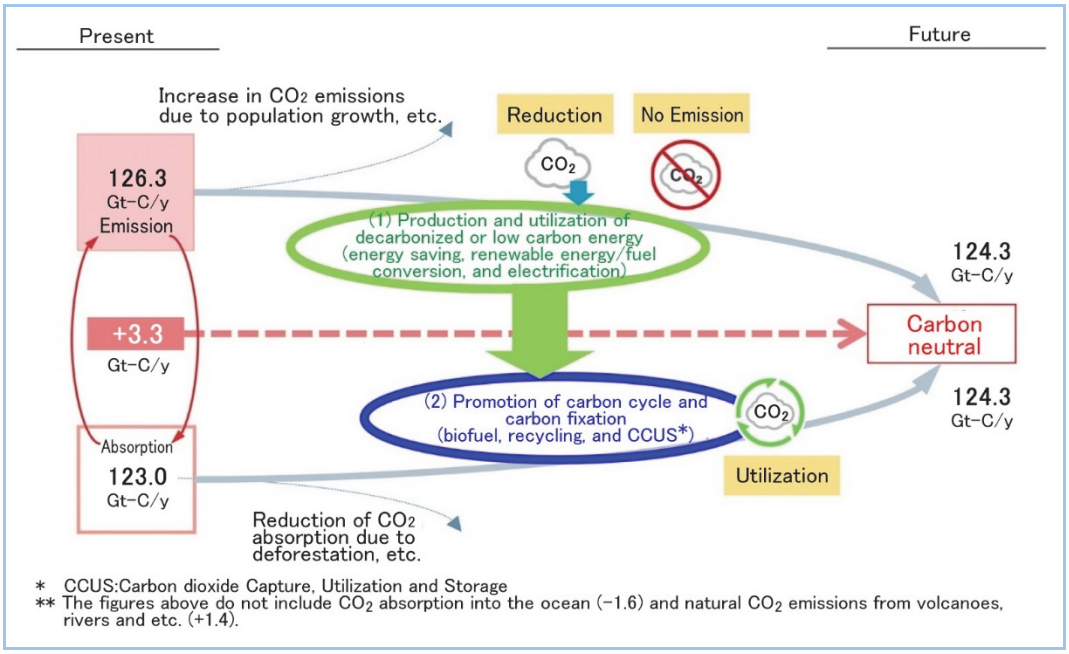


Figure 4 Directions of efforts toward carbon neutrality (created based on reference (2))

Specifically, we are working on, in addition to the "reduction" of CO_2 emissions by improving the efficiency of conventional equipment, the use of hydrogen and ammonia for "no emission" of CO_2 and carbon capture and storage/conversion for the "utilization" of CO_2 in the energy field, electrification and "defossil" fuel utilization in the mobility field, and conversion to carbon-free fuel in the industrial field for large-scale demand such as ironmaking (**Figure 5**).

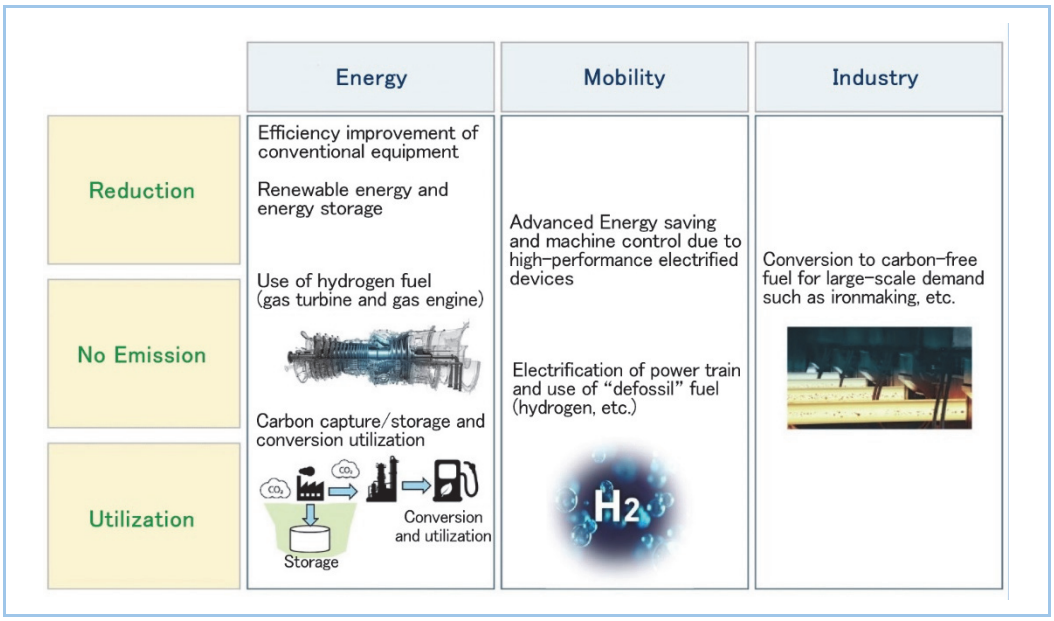


Figure 5 Examples of approaches in energy, mobility, and industrial fields toward carbon neutrality

4.2 Exploration of integrated solutions for sustainable growth

While awareness of climate change issues has increased and taking approaches toward a carbon-free society has become an urgent task worldwide, approaches toward a circulating society that effectively utilizes and conserves the finite resources of the earth and toward a society that coexists with nature including diversified organisms have been actively taken. These approaches for a future sustainable society depend on diverse local cultures and values and are interconnected. Therefore, rather than independent solutions, integrated solutions are needed. For example, the problem of marine plastics, the impact of which on the ecosystem is problematic, also includes various social issues in terms of the overall plastic material flow, such as the mass consumption of exhaustible resources, increased greenhouse gases due to incineration and landfill site shortages, so a well-balanced and integrated solution is required, such as reducing, recycling, reuse, and energy recovery in anticipation of an increase in the use of biomass plastics such as polyethylene and polypropylene (**Figure 6**).

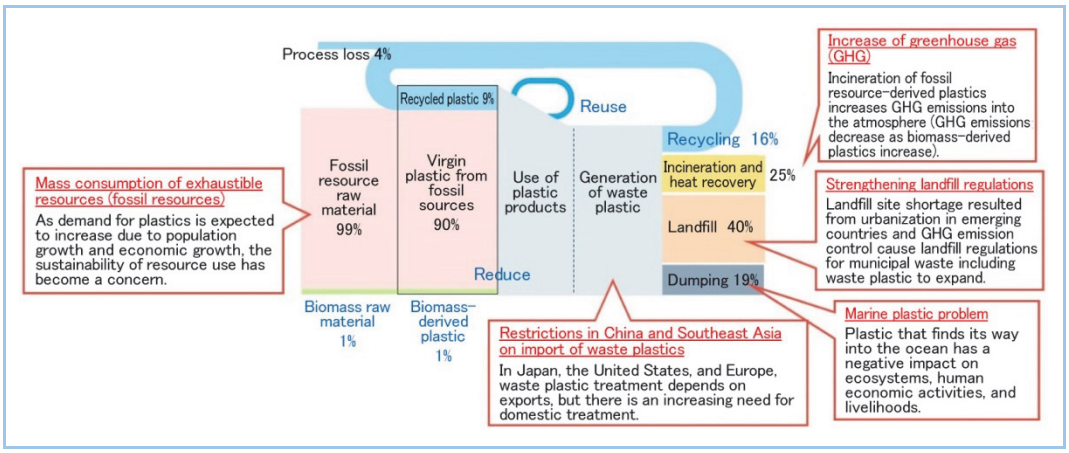


Figure 6 Social issues related to plastic material flow (entire world, 2016) (created based on reference (3))

In the field of mobility such as automobiles, the assessment of environmental load has progressed from that for a single vehicle (Tank to Wheel) to that up to energy resources (Well to Wheel). In addition, the assessment of environmental load of the entire value chain (Life Cycle Assessment) from the mining and development of automotive materials and fuels to manufacturing, disposal and recycling of those products is attracting attention. Furthermore, against the background of progressing digital technology, various means of information transmission have been developed

and communication without physical movement is becoming possible, so it is expected that the existence of mobility infrastructure in society in general will change significantly.

In order to respond to such a change, it is necessary to develop not only decarbonization solutions for products themselves, but also products and services that consider their impact that tends to be invisible for business activities. In response to these complex social needs, our group is focusing on "life" as a business region in which the scientific understanding of the material metabolism mechanism of nature and life has progressed in the medium to long term and the equipment industry will be developed through innovations in digital and biological technologies.

Figure 7 shows the result of a rough calculation of the breakdown of greenhouse gas emissions by field with reference to the existing materials released by institutions. Through an overview of greenhouse gas emissions conducted in this manner, not only can energy systems such as power generation and transportation systems be seen, but also can various approaches to decarbonization in agriculture and livestock fields.

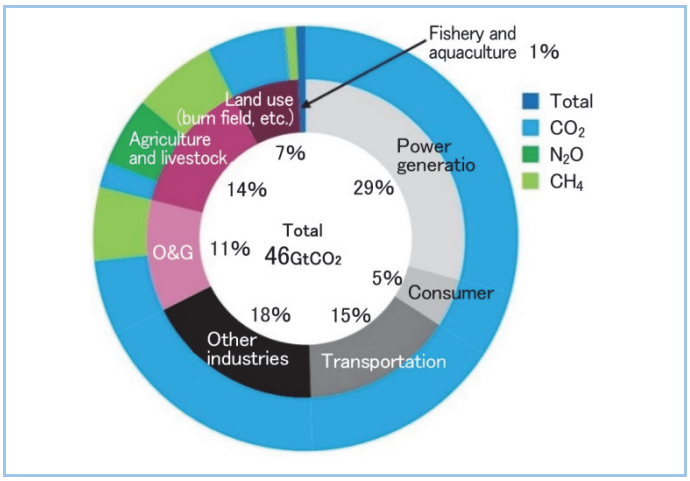


Figure 7 Breakdown of greenhouse gas emissions (2012, rough calculation based on references (4) to (7))

Such approaches not only reduce greenhouse gas emissions in a certain industry itself, but also have ripple effects on adjacent regions. For example, efficient agriculture using plant factories, etc., increases the absorption of greenhouse gas and brings about the diversification and conservation of the ecosystem due to the planting of trees in the areas gained by reducing agricultural lands. It also reduces food loss and provides a stable supply of food against climate change due to the realization of food production and supply in which supply and demand are integrated, and contributes to the reduction of greenhouse gas emissions during transportation. For another example, cellular agriculture, such as cultured meat production, which is being developed against the background of advances in biotechnology, realizes a stable supply of food against epidemic infections and reduces greenhouse gas emissions such as CO_2 and methane derived from livestock. In this way, various means can be considered. By incorporating the equipment industry in these life regions into the cycle of local production for local consumption, it is possible to contribute simultaneously to the realization of not only a carbon-free society, but also a circulating society and a society that coexists with nature.

Aiming at the realization of a decarbonized, circulating, and coexisting-with-nature society, our group will capture the entire flow of substances and energy including areas that were previously invisible, and explore approaches that take advantage of the characteristics of our group, which handles various machine systems for social infrastructure.

5. For creating innovations and initiating changes

There is no doubt that the role of achieving reliable manufacturing through division of labor and efficient production that our group has played will continue to be important. On the other hand, as mentioned in the previous chapters, the business environment has undergone major changes, and our group is required to evolve constantly in response to social needs. In order to respond to these changes, it is necessary not only to "exploit" conventional efficiency, reliability, and accuracy, but also to "explore" based on a wide range of knowledge and insight obtained by an overview or long-

term observation, or by prototyping and trial based on a hypothesis. Therefore, MHI FUTURE STREAM strengthens an agile prototyping and trial system in which a small team works independently, without exchanging opinions or division of labor with various stakeholders of our group or experts in different industries.

Specifically, the shared technology function strengthens proposal-based research in which the creators themselves verify their created idea as a product or business hypothesis in a short period of time and perform prototyping and trial. It also works on efforts to accelerate ties with venture companies at the newly opened Yokohama Hardtech Hub (YHH) in Honmoku, Yokohama, in addition to joint research it has been carrying out with outside researchers and collaborative projects with venture companies.

YHH advocates “environment and energy”, “next-generation mobility”, “intelligence evolution and electrification of machine” and “next-generation agriculture & food” as regions that will form future social infrastructure, and builds a platform for the support of and co-creation with ventures of the “seed” or “early” stage without presupposing collaboration with our company. YHH focuses on venture companies that take on the challenge of “Hardtech,” which will be the core of future machine system advancement, in a technological area where digital technological innovations such as AI (Artificial Intelligence) and IoT (Internet of Things) are combined with innovations of physical technologies such as quantum, material design, microfabrication, and biological technologies, and repeated prototyping and verification are important. Aiming to create machine systems that meet future social needs, YHH has the largest facilities in Japan for prototyping and practical verification.

In the future, by having entities within our group participate in YHH as a member of the ventures, we will realize and review the future image found in “Mega Scan” materialize the business opportunities found in “Shift the Path” and co-create technological innovation in “Technology Scouting” as well as ingrain into the company not only “waterfall-type exploitation” work streamlined by division of labor, but also “agile-type exploitation” work that improves the success rate by taking the initiative and quickly conducting prototyping and trials on a wide network. As a result, MHI FUTURE STREAM will evolve so as to connect the process of exploration and exploitation. We believe that this approach can improve technological innovation that is rapidly changing due to advanced specialization, as well as business judgment abilities that respond to diversifying social needs. This can also provide a place to foster the development management ability to quickly repeat failures and improvements and human resource development of an entrepreneurial spirit that allows for recruiting colleagues beyond the framework of the current organization, in order to take on the challenge of realizing a new society (**Figure 8**).

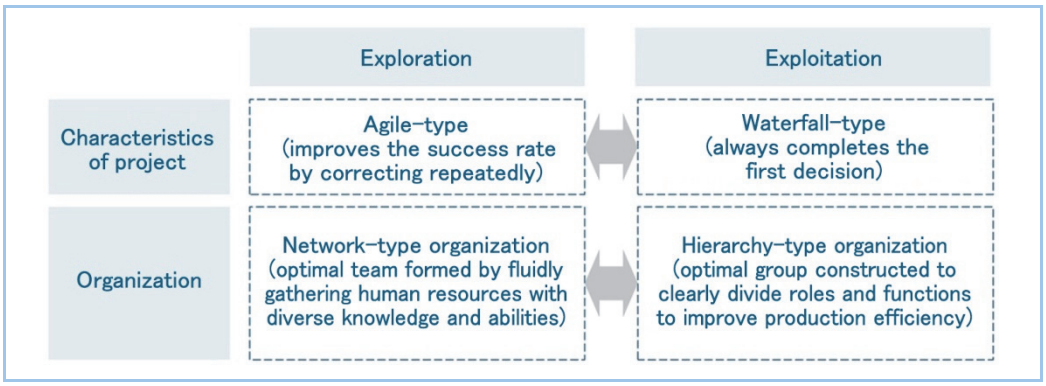


Figure 8 Characteristics of exploration and exploitation

6. Conclusion

MHI FUTURE STREAM overviews social issues, technological advancement, and the associated relationships between humans, nature, and machine systems, and discovers the direction in which our business should proceed from a medium- to long-term perspective. We believe that the future vision that our group should aim for is to contribute, through these approaches, to environmental adaptation and symbiotic evolution through technological innovation including

machine systems, while considering other ecosystems and minimizing impact, as a resident of the earth.

In the future, MHI FUTURE STREAM will become more important for confronting the uncertainty of the business environment surrounding our group and contributing to the sustainable growth of a society in harmony with nature. Our group will not be limited to the conventional framework of business areas, but will be working on exploration and co-creation with external partners in various areas to continue to evolve.

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