MITSUBISHI HEAVY INDUSTRIES | MISSION NET ZERO

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MITSUBISHI HEAVY INDUSTRIES

Mitsubishi Heavy Industries Group

Carbon Neutrality Handbook

MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

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MHI Group's
Carbon Neutrality Declaration

Mitsubishi Heavy Industries (MHI) Group made our 2040 Carbon Neutrality Declaration, MISSION NET ZERO, on October 29, 2021. We are striving to help contribute to CO_2 reduction through our products, technologies, and services, and by cooperating with our partners around the world in order to contribute to the achievement of global Net Zero with new solutions and innovations.

We refer to our commitment to achieve Carbon Neutrality as MISSION NET ZERO. The goals of this commitment are shown in Table 1. The first goal is to reduce the Group's CO_2 emissions (Scopes 1 and 2) by 50% by 2030 (compared to 2014 levels) and achieve Net Zero by 2040. This is the amount of CO_2 emissions reduction from the Group's plants and other facilities resulting from production activities. MHI will work on decarbonizing its factories by implementing the technologies MHI has developed in its own facilities and further improving energy conservation. The second goal is to reduce CO_2 emissions not only within the Group but also throughout the entire value chain, upstream and downstream, by 50% by 2030 (compared to 2019 levels) and to Net Zero by 2040. MHI's targets are ten years ahead of those set by the governments of Japan and other major developed countries, which are aiming to achieve Net Zero by 2050. As MHI contributes to the building of a sustainable society, MHI will help to bend the cost curve of the Energy Transition by introducing innovative technologies and providing affordable, reliable solutions.

Target Year	Reduce CO_2 emissions across MHI Group Scope 1&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

Table 1 2040 carbon neutrality declaration

What is Carbon Neutrality/Net Zero?

Carbon neutral means "reducing the total amount of CO_2 emissions minus the amount of CO_2 absorbed and removed to zero." In other words, after reducing CO_2 emissions as much as possible, the remaining emissions "absorbed" through afforestation and recycling, or "removed" by storing them underground, to achieve the Net Zero. The concept of carbon neutrality is illustrated in Figure 1.

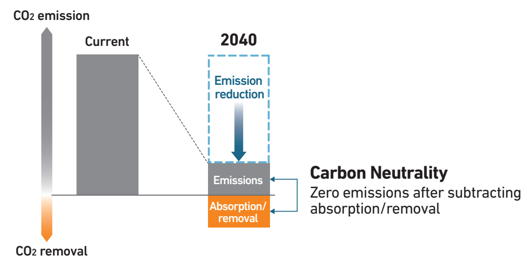


Figure 1 Carbon neutrality

What are Scopes 1, 2, and 3?

The definitions of Scopes 1, 2, and 3 CO_2 emissions as defined by the GHG Protocol* are shown in Figure 2. Scope 1 is the direct emission of CO_2 by the Group itself, which is mainly generated by fuel combustion. For example, when the heat source required for production facilities is provided by an on-site boiler, the CO_2 emitted as boiler exhaust gas is the target of Scope 1 reductions.
Scope 2 represents indirect emissions connected to the use of electricity, heat, and steam supplied by other companies. These emissions mainly arise from the consumption of electricity. For example, when electricity purchased from an electric power company is used in a building or production facility, the CO_2 emissions generated during the electricity generation process are included in this scope. Scope 3 is the emissions of other companies located up- and downstream of MHI Group. The upstream emissions include CO_2 generated during the production and transportation of raw materials, while the downstream emissions include CO_2 generated during the operation and disposal of MHI Group's products, such as power generation equipment MHI has delivered.

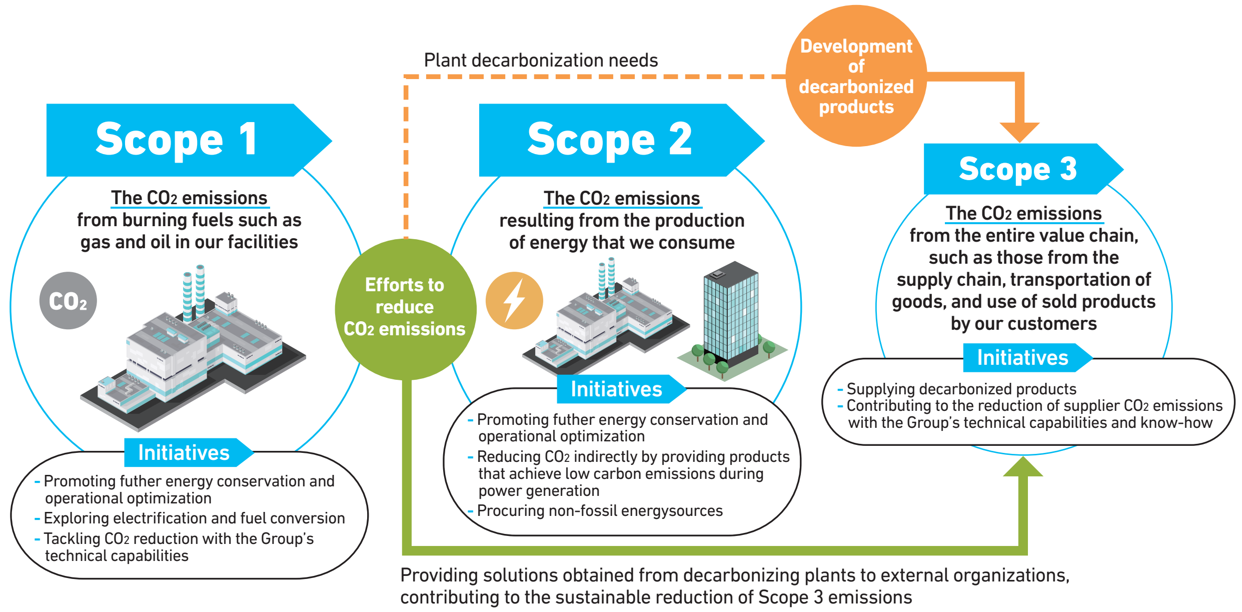


Figure 2 CO_2 emission reduction scopes

GHG Greenhouse gas

*GHG Protocol:

The GHG Protocol is a set of internationally-recommended standards for the calculation and reporting of greenhouse gas (GHG) emissions. The standard was developed under the leadership of the World Resources Institute (WRI), a U.S. environmental think tank, and the World Business Council for Sustainable Development (WBCSD), with the involvement of national government agencies.

The Colors of Hydrogen

Producing hydrogen may produce CO_2 in some cases, depending on the raw materials and production method used. The use of the color-coding (shown in Table 2) to distinguish between these different types of hydrogen is becoming increasingly popular.
Gray hydrogen is produced from fuels such as natural gas using steam reformation. Since CO_2 is also generated and released into the atmosphere at the same time, its use must be curbed to prevent global warming.
Blue hydrogen is hydrogen obtained from fuels such as natural gas using steam reformation. The resulting CO_2 is captured and stored as soon as it is generated, making this a carbon-free source of hydrogen.
However, this means that a location in which the captured carbon can be stored must be secured.
Turquoise hydrogen is produced using a process called methane pyrolysis, which directly splits methane into hydrogen and carbon. The process does not emit CO_2 and produces solid carbon as a byproduct, which can be used as a raw material for tires and other products and is a valuable resource.
Green hydrogen is hydrogen that is generated from water electrolysis powered by renewable energy.
Purple hydrogen is obtained by direct methane decomposition and high-temperature steam electrolysis using high-temperature heat and electricity from nuclear power.
Blue, turquoise, green, and purple hydrogen are considered carbon-free, because they do not emit CO_2 into the atmosphere. Ammonia is also similarly color-coded according to the color of the raw hydrogen used in its production.
On the other hand, there is also a widespread idea to compare and evaluate low-carbon hydrogen based on the amount of CO_2 released in the hydrogen value chain, regardless of the color of hydrogen.

Type of hydrogen	Energy source	Hydrogen production process
Gray hydrogen	Fossil fuels, etc.	CH_4, etc. → steam reforming → H_2 + CO_2 → atmospheric release
Blue hydrogen	Fossil fuels, etc.	CH_4, etc. → steam reforming → H_2 + CO_2 → capture/storage
Turquoise hydrogen	Combustion and waste heat, etc., Electricity	CH_4 → direct decomposition → H_2 + C → storage and effective utilaization, etc.
Green hydrogen	Electricity (renewable energy)	H_2O → electrolysis → H_2
Purple hydrogen	Heat (nuclear power), Electricity	CH_4, etc. → direct decomposition → H_2 + C → effective utilization H_2O → High-temperature water electrolysis, etc. → H_2

Table 2 Color-coding of hydrogen

MHI Group's

Value Chain for Realizing Carbon Neutrality

MHI Group's roadmap to achieving our goal of Carbon Neutrality by 2040 is shown in Figure 3. For Scopes 1 and 2, MHI aims to achieve zero CO_2 emissions by 2040 through energy conservation, installation of in-house technologies, and introduction of decarbonized electricity. For Scope 3, MHI will reduce CO_2 emissions through fuel conversion, energy conservation, and electrification, but since it is difficult to achieve zero emissions right away, MHI will aim to achieve zero emissions by 2040 by combining these methods with CO_2 Capture Utilization and Storage (CCUS). Although not included in the definition of Scope 3 + CCUS, the nuclear and biomass power plants we provide do not emit CO_2 during operation, and we will contribute to the reduction of CO_2 emissions by increasing the amount of these plants installed and their operating rates.
Compared to Scopes 1 and 2, which amounted to about 700,000 tons of CO_2 emissions in 2019, Scope 3 emissions totaled 1.5 billion tons, which is 2,000 times more than that. This is because the use of power generation equipment and other products is the main source of CO_2 emissions. Approximately 70% of these emissions are associated with the operation of thermal power plants.
In order to achieve Net Zero, the top priority is to promote the Energy Transition, i.e., conversion to carbon-free fuels that do not produce CO_2 when burned.
MHI Group's value chain for the achievement of Carbon Neutrality is shown in Figure 4.
First, MHI needs to develop products that can use decarbonizing (including carbon neutral) energy while decarbonize existing infrastructure. MHI will continue to promote decarbonization that builds on the central pillar of energy solutions such as carbon-free power generation, biomass power generation, and gasification technology. In addition, with the goal of maximizing the use of nuclear power as a stable large-scale carbon-free power source, MHI will promote the use of existing nuclear power plants that are currently offline, as well as the commercialization of advanced light water reactors (SRZ-1200) by the mid-2030s, in addition to developing small reactors, high-temperature gas reactors, fast reactors, and micro reactors to meet the diverse needs of the future.
Second, MHI needs to decarbonize energy upstream in the value chain. MHI is proceeding with the construction of a hydrogen solutions ecosystem by switching from conventional fossil fuels to supply chains based on hydrogen and ammonia.
Third, for industrial sectors that are difficult to decarbonize, MHI will build a CO_2 ecosystem with products, technologies, and services related to CCUS, from capture, transportation, and storage of emitted CO_2 to utilization.

CCUS Carbon dioxide Capture, Utilization, and Storage

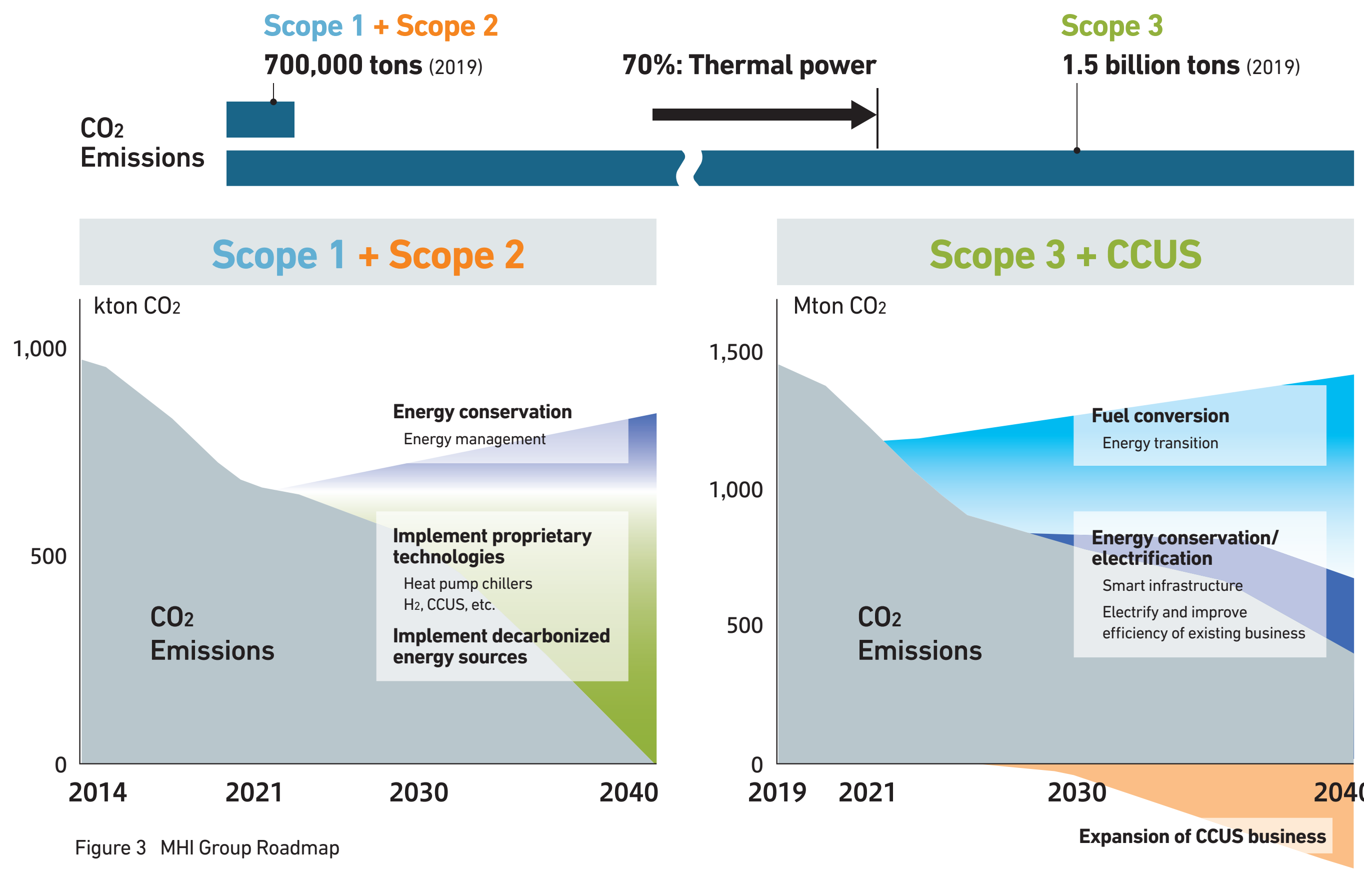


Figure 3 MHI Group Roadmap

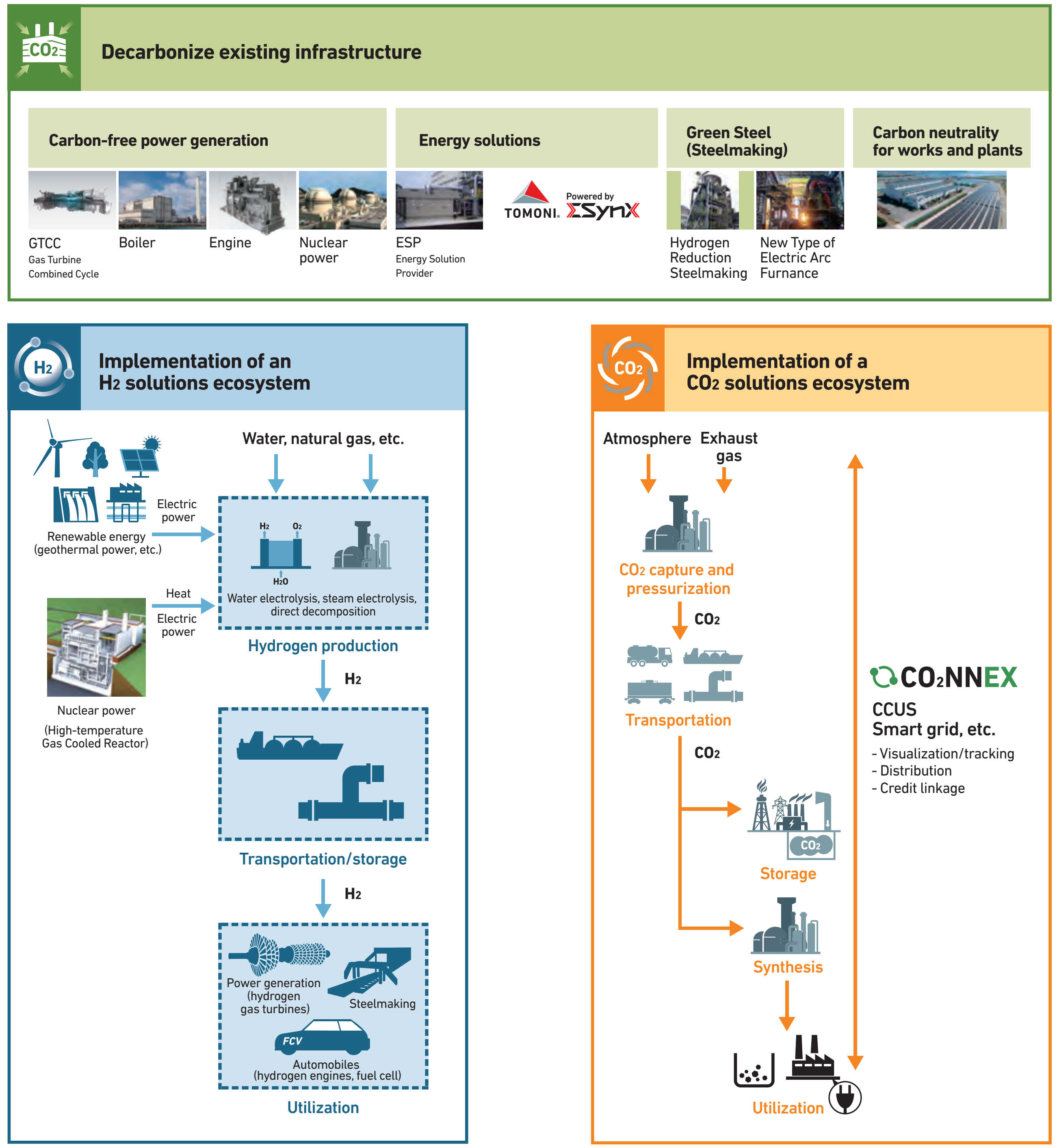


Figure 4 MHI Group's value chain for the achievement of Carbon Neutrality

MHI Group's

Carbon Neutrality Roadmap

Table 3 shows MHI Group's roadmap toward achieving Carbon Neutrality. MHI Group will promote the decarbonization of existing infrastructure and the implementation of a hydrogen and CO_2 solutions ecosystem. Please find a detailed description of the roadmap on the following pages.

MISSION NET ZERO
MHI Group

2010	2020	2030	2040	2050
		Reduction of CO_2 emissions by 50%	Carbon Neutrality	Carbon Neutrality in many countries

Decarbonize existing infrastructure

Carbon-free power generation	Decarbonize thermal power Transition to hydrogen/ammonia fuel	Hydrogen co-firing/100% firing gas turbines	Hydrogen co-firing / 100% firing gas turbines	Large-frame gas turbines: commercialization of 30-50% mixed hydrogen firing; Takasago Hydrogen Park; Large-frame gas turbines: validation of 30% mixed hydrogen firing; Small and medium-sized gas turbines: validation of 100% hydrogen firing; Small and medium-sized gas turbines: commercialization of 100% hydrogen firing; Large-frame gas turbines: commercialization of 100% hydrogen firing
		Boiler ammonia combustion		Boiler ammonia combustion; Small and medium-sized gas turbines: commercialization of 100% ammonia firing; Boilers: commercialization of ammonia firing
		Hydrogen engines		Hydrogen engines
	CO_2 capture technology utilization GTCC and CCS			GTCC and CCS
	Nuclear power		Restart of existing nuclear power plants	Advanced LWRs with enhanced safety (SRZ-1200); SMRs, Fast reactors, Micro reactors; Fusion reactors
Biomass power, Gasification	Decarbonization using biomass SAF conversion		Biomass co-fired boilers	Bio jet fuel; Nagasaki Carbon Neutral Park
Energy solutions TOMONI. Powered by ΣSynX	Decarbonization of the industrial sector Energy Solution Provider		Domestic industrial in-house power generation solutions (fuel conversions and retrofits)	Heat energy supply business, operation and maintenance services
	Transitional fuels LNG supply chain businesses		Feasibility study for southeast Asia	Business participation in Southeast Asia
Renewable energy	Geothermal power		Geothermal power	
Green Steel (Steelmaking)	Hydrogen reduction steelmaking		HYFOR (Direct reduction of pulverized ore) SMELTER (New type smelting furnace)	→ Commercialization
	Electric arc furnace		Fusion and Quantum EAF (new type electric furnace)	→ Commercial operation with renewable energy
	Blast furnace/direct reduction furnace and CCUS		CO_2 recovery system (KM CDR Process™) CO_2 recycling (LanzaTech technology)	→ Commercialization
Carbon neutrality for work	Visualization & Implementation of CO_2 reduction		CO_2 reduction for MHI's factory & plants Providing MHI's solutions for custmor	Mihara Advanced Carbon Neutrality Project → Execution of CO_2 reduction measures

Implementation of an H_2 solutions ecosystem

Carbon-free fuel production	CO_2-free fuel production equipment and technology Hydrogen production	Turquoise hydrogen		In-house development of turquoise hydrogen technology; Investment in Monolith in U.S. → Increased capacity
		Green hydrogen	In-house development of next-generation water electrolysis technologies SOEC	→ Increased capacity; Investment in HydrogenPro (Norway); Investment in Electric Hydrogen (U.S.); In-house development of next-generation water electrolysis technologies AEM → Increased capacity
		Purple hydrogen	Development of hydrogen production technology using heat from high-temperature gas cooled reactors	High-temperature gas cooled reactors → Application of CO_2-free hydrogen production technology
Carbon-free fuel supply chain	CO_2-free fuel supply chain construction Hydrogen and ammonia business		Ammonia carriers Compressors for ammonia plant Hydrogen-rich compressors	Liquid hydrogen booster pump for hydrogen stations; Takasago Hydrogen Park; Australian green hydrogen and ammonia business; U.S. Advanced Clean Energy Storage Project; Germany green hydrogen project; U.K. industrial cluster decarbonization project; Japan hydrogen carrier supply chain

Implementation of a CO_2 solutions ecosystem

CCUS value chain	Products	CO_2 capture technology (Advanced/KM CDR Process™) LCO_2 carriers CO_2 compressors	→ Increased capacity; New recovery technology; Ammonia and LCO_2 multi gas carriers
	Solution and service business		Recovery services (CaaS); CO_2NNEX Project; End-to-End carbon capture, transformation and storage (CCS) solution; Marine transportation service

Table 3 MHI Group's Carbon Neutrality Roadmap

Carbon-free power generation

1 Transition to hydrogen/ammonia fuel

Since the 1970s, we have been working on gas turbines that handle hydrogen-rich off-gas from such sources as oil refineries and steel mills. Since 2015, we have been developing state-of-the-art hydrogen combustion technology, utilizing a grant from the New Energy and Industrial Technology Development Organization (NEDO), a national research and development institution. In 2018, MHI achieved stable combustion of fuel containing 30 vol% hydrogen at 1,600°C using a J-series gas turbine combustor. In 2022, a 50vol% hydrogen co-firing combusion test was successfully conducted. In 2023, 30vol% hydrogen co-firing was achieved at the state-of-the-art 1650°C-class JAC-series gas turbine validation facility. MHI is currently proceeding towards the development of 100% hydrogen firing combustion technology by 2025. We are planning to conduct validation testing of 30vol% or more hydrogen firing in large-frame gas turbines in the lead-up to commercialization in 2025 and expect to commercialize 100% hydrogen firing after 2030. In addition, we are targeting commercialization of mixed hydrogen firing in small to medium-sized gas turbines in the early 2030s or thereafter. Figure 5, 6 shows an image of a hydrogen gas turbine and a photograph of a dedicated hydrogen combustor. Ammonia is significantly easier for carriers to handle than hydrogen and also has a role to play in the creation of a hydrogen-based society in Japan. In addition to developing technology to separate hydrogen from ammonia using waste heat from gas turbines, MHI is also developing a 40 MW-class gas turbine system that directly uses 100% ammonia as fuel, aiming for commercialization and operation of the first commercial model in 2025. Ammonia also can be used directly in coal-fired boilers, and holds promise as a means to decarbonize coal-fired thermal power. In order to meet the various needs in boilers, MHI is developing an ammonia burner that reduces the generation of NOx emissions in multiple combustion systems. By FY2028, MHI will demonstrate ammonia combustion in coal-fired boilers and aim for early commercialization.

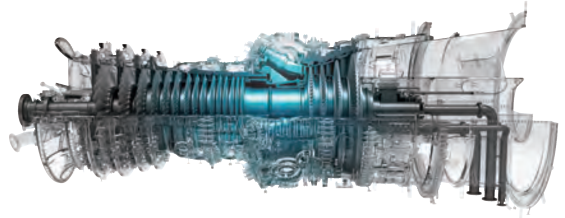


Figure 5 Digital mockup of a hydrogen gas turbine

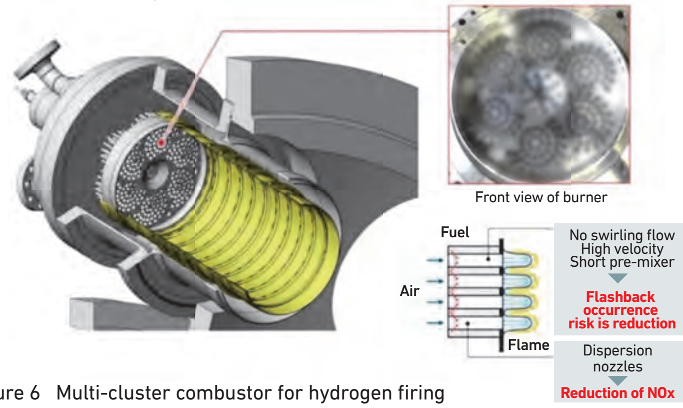


Figure 6 Multi-cluster combustor for hydrogen firing

Initiative to Realize Dacarbonized Society:

"Takasago Hydrogen Park" and "Nagasaki Carbon Neutral Park" (Figure 7-1, Figure 7-2)

Aiming for early commercialization of hydrogen gas turbines, Takasago Hydrogen Park, the world's first integrated demonstration facility for hydrogen production and power generation, is under construction at Takasago Machinery Works, where the development, design, manufacturing, and validation of hydrogen gas turbines will be based. Preparations were made to start demonstration of hydrogen production, storage and hydrogen combustion technology in gas turbines, and 30vol% hydrogen co-firing tests were successfully conducted in 2023. In addition to employing a water electrolysis system, the hydrogen production facility will sequentially test and validate next-generation hydrogen production technologies, such as turquoise hydrogen, which is produced by the thermal decomposition of methane into hydrogen and solid carbon. The use of this demonstration facility is expected to contribute greatly to the full-scale popularization of hydrogen and the commercialization of hydrogen power generation.

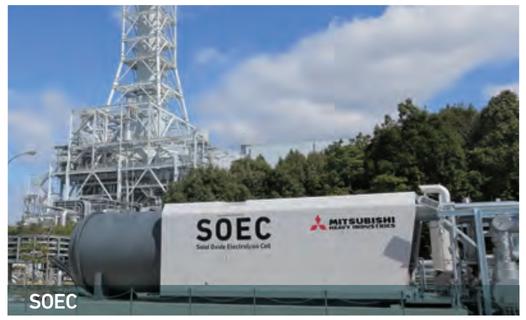
Figure 7-1 Takasago Hydrogen Park

Figure 7-2 Nagasaki Carbon Neutral Park

Large-capacity hydrogen production and hydrogen gas turbine combined-cycle (GTCC) system in one integrated demonstration facility (a world first)

Hydrogen production equipment

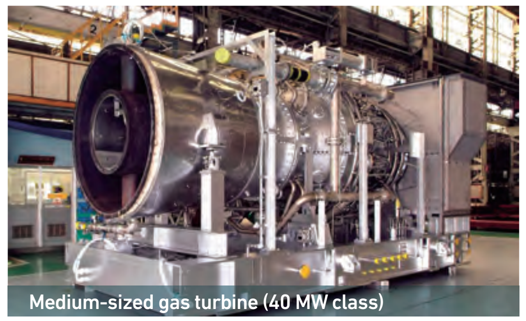
Water electrolysis unit (5 MW class)



SOEC

Proof-of-concept power generation equipment

Large-frame gas turbine (450 MW class)



Medium-sized gas turbine (40 MW class)

2 GTCC and CCS

Engineering Solutions - with its CO_2 Capture and Storage (CCS) technology, which can contribute to implementing a CO_2 solutions ecosystem - and Energy Systems will collaborate to provide power generation systems which provide maximum reduction of CO_2 emissions by combining high-efficiency power islands - such as GTCC - with CCS systems. MHI received orders for basic designs for CO_2 capture for gas turbine power plants in Alberta, Canada, and for GTCC power plants and CO_2 capture plants in Scotland. We are contributing to achieving global Net Zero by supporting the introduction of commercial-scale CCS.

GTCC Gas Turbine Combined Cycle **CCS** Carbon dioxide Capture and Storage

MHIET

[Achieved stable combustion of 100% hydrogen and installed a hydrogen engine generator set and hydrogen supply facility for in-house evaluation]

Mitsubishi Heavy Industries Engine & Turbocharger (MHIET) in the Logistics, Thermal & Drive Systems (LT&D) Domain has been developing hydrogen engines utilizing technical knowledge obtained through the development of existing diesel and gas engines.
Since FY2019, collaborative research on hydrogen engine combustion with the National Institute of Advanced Industrial Science and Technology (AIST) has been ongoing, and a single-cylinder hydrogen engine modified from MHIET's reciprocating gas engine was tested at AIST Fukushima Renewable Energy Laboratory (Koriyama City, Fukushima Prefecture).
The conditions that ensure stable combustion with hydrogen-only firing were determined by modifying hydrogen fuel supply, ignition, intake air valve closing timing, excess air ratio, and other parameters for optimum combustion. Converting the test results, maximum outputs of 340 kW for a 6-cylinder engine equivalent and 920 kW for a 16-cylinder engine equivalent were achieved.
For commercialization, the knowledge gained from the testing was utilized to develop a 6-cylinder 100% hydrogen engine with 500kW output and integrated it into a generator set. The hydrogen engine generator set as well as hydrogen supply facility have been installed within its Sagamihara Plant. The technical evaluation of the hydrogen engine generator set will start in FY2024.
A thorough performance of the newly developed engine will be evaluated, including combustion, output and reliability.

Figure 8 A hydrogen engine installed at the AIST Fukushima Renewable Energy Laboratory

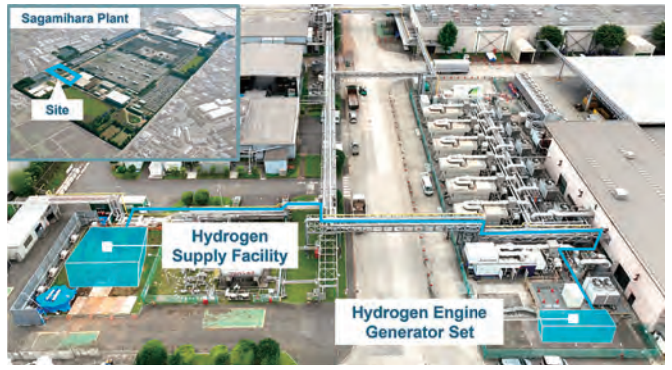


Figure 9 Installation site in Sagamihara Plant (Starting in FY2024)

Safety system of the generator set will be closely monitored as hydrogen requires very strict care in handling.
Reciprocating engines have the unique structure that can burn a variety of fuels. Hydrogen engine generator sets are considered as a promising technology in energy transition that can bring about carbon neutrality of distributed power systems because they emit zero CO_2 while responding to power needs. MHIET endeavors to help achieve carbon neutral society through the marketing of fully validated hydrogen-fueled engine products to the world.

MHIET

[Biogas power and biodiesel]

Biogas power generation is a form of power generation that uses biogas produced through the fermentation of organic waste such as sewage, leftovers, and livestock manure. Therefore, biogas power generation can help prevent global warming, reduce waste, promote waste recycling, and increase renewable energy supply and is considered to be effective in environmental conservation and addressing electricity shortages.
Many are calling for biogas to replace fossil fuels worldwide as a new source of energy, and various research and development efforts are underway. At biogas plants in Japan, waste is digested in an anaerobic environment of approximately 35-55°C after sorting and conditioning, producing gas similar to that results from human digestion. After 20 days to 1 month of fermentation, the gas is extracted. The chemical composition of biogas is mainly methane (CH_4) (approximately 60%) and carbon dioxide (CO_2) (approximately 40%). Although biogas contains hydrogen sulfide and other corrosive components and siloxane compounds that can seriously damage the engine and need to be removed to a certain level before the gas is supplied to the engine, a standard gas engine designed to use gas distributed via pipeline in Japan (13A) can run on biogas with some modifications.
MHIET has delivered a total of five 300 to 600 kW-class biogas engine power generation systems to food recycling and purification facilities in Japan, and all have been operating stably.
Biodiesel fuel (BDF) is a fuel for use in diesel engines that is usually produced by special chemical processing of biologically derived oils (such as palm oil and rapeseed oil) or waste cooking oil. BDF is a fuel that holds promise as an alternative to fossil fuels. Typical BDFs are fatty acid methyl esters (FAME), which are obtained by methyl esterification of raw materials, and hydrotreated vegetable oil (HVO), which goes through hydrogenation, a process similar to sustainable aviation fuel (SAF). Both have different fuel properties than diesel fuel in terms of density, viscosity, and calorific value.
FAME is generally used by blending with diesel fuel at a ratio of a few to several dozen percent, whereas HVO can be used without blending and as a drop-in fuel. For details of sustainable aviation fuel (SAF), please see "4. Transition to biomass/SAF fuel".
In some countries, it is normal for FAME to be sold as diesel fuel after premixing (max. 5-7%) as a part of environmental protection efforts. FAME is characterized by its tendency to degrade more easily than diesel fuel, and the higher the concentration, the more restrictions may apply to how it is used, stored, and by when it must be used.
Contrastingly, HVO, a next-generation BDF that has recently been attracting attention, boasts a strong resistance to degradation.For both industrial and marine engines, MHIET has approved use of EN 15940 compliant HVO with or without blending with diesel fuel. Also, evaluations of engines for industrial vehicles are ongoing.
In addition, MHIET is validating the use of high-density FAME for the purpose of reducing impact on the environment.

3 Nuclear power

MHI has built all 24 pressurized water reactor (PWR) plants in Japan since Mihama Unit 1 started operation in 1970. In addition to construction and maintenance of PWR plants, MHI also provides services in almost all areas of nuclear energy, including nuclear fuel fabrication, intermediate storage of spent fuel (in casks), fuel cycle facilities, and fast reactor development. Nuclear power is a carbon-free, large-scale, stable power source that emits no CO_2 during operation and can generate electricity stably regardless of weather conditions. In addition, with the recent rapid increase in interest in energy security together with the high utility of nuclear power from the perspective of a secure energy supply, expectations for nuclear power are rising worldwide. In the lead-up to achieving of Carbon Neutrality in 2050, MHI will first strive to improve the safety of nuclear power plants by supporting the restart of existing nuclear power plants, including not only the PWRs that we built but also boiling water reactors (BWRs). We will also achieve safe and stable operation after these restarts, while also steadily advancing efforts to complete the nuclear fuel cycle. Furthermore, MHI is promoting the development and design of advanced light water reactors (SRZ-1200), which will achieve the world's highest level of safety, in order to commercialize them in the mid-2030s. In addition, in response to the diversifying needs of society in the future, with the support of the Japanese government, MHI is developing compact LWRs as distributed power sources, high temperature gas-cooled reactors (HTGRs) for high-volume, stable hydrogen production, fast reactors for effective use of resources and for reducing the volume and hazard level of high-level radioactive waste, and micro reactors as portable power sources for remote islands as well as after natural disasters. In the long-term, MHI will also take on the challenge of commercializing a fusion reactor, a perpetual energy source.

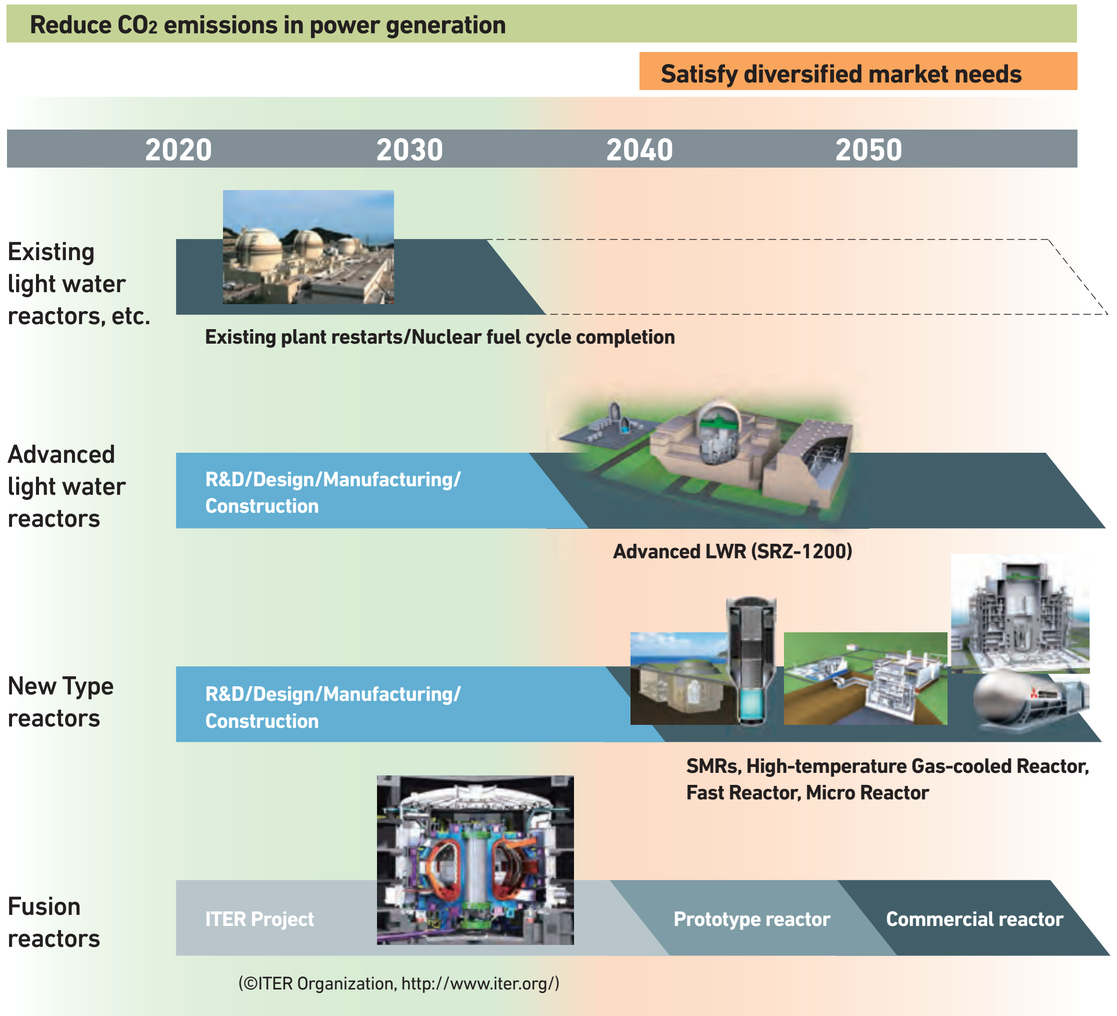


Figure 10 Nuclear Energy Roadmap Toward Carbon Neutrality

Advanced light water reactors (SRZ-1200)

Based on the recognition that new nuclear power plants must be built to ensure the continuous use of nuclear energy, we are developing advanced light water reactors (SRZ-1200) with enhanced safety features based on proven technologies, aiming to bring them to market in the 2030s. Advanced light water reactors (SRZ-1200), with enhanced resistance to all types of natural disasters and utilizing the redundant and diversified safety measures, improves plant safety. MHI will introduce latest technology for melting core countermeasures, and as company's proprietary system for preventing the release of radioactive materials, the first of its kind in the world, to achieve world-class safety. In addition, the power output adjustment function will be enhanced compared to that of conventional reactors to ensure operability that can flexibly respond to changes in the amount of renewable energy generated and other factors. MHI is working with PWR4 Electric Power Company (Kansai Electric Power, Kyushu Electric Power, Shikoku Electric Power, Hokkaido Electric Power) on the basic design of a standard plant for early practical use, and plan to conduct demonstration tests, etc. with the aim of obtaining data for licensing, with the support of the government. MHI through implementation of the advanced light water reactors (SRZ-1200), will contribute to both Carbon Neutrality and a stable energy supply in the future.

SMRs

In addition, we will promote the development of small, modular reactors (SMRs) for small-scale grids to meet the diversified needs of society in the future by utilizing the technology we have developed during the development of advanced light water reactors (SRZ-1200). MHI's SMRs will achieve a high level of safety by adopting innovative technologies, such as integrating the main components within the reactor vessel to create an integrated reactor that, in principle, eliminates the possibility of loss of reactor coolant caused by rupture of piping. The power output is expected to be 300 MW, and development will be pursued with the aim of bringing this type of reactor to market around 2040.

Fast reactors

In Japan, the basic policy is to promote the nuclear fuel cycle, in which spent fuel is reprocessed and the plutonium recovered from the reprocessed fuel is effectively utilized, in order to use resources efficiently and reduce the volume and hazard level of high-level radioactive waste. MHI has been promoting research and development for practical use of fast reactors, based on its central role in the experimental fast reactor "Joyo" and the prototype reactor "Monju." In addition, the "Fast Reactor Roadmap," officially adopted by the Cabinet Meeting on Nuclear Energy in 2018 sets the goal of starting operation of a domestic demonstration reactor by 2050. MHI was selected as a core company for the development of a demonstration reactor in Japan in 2023. During the development of demonstration reactors in Japan, it will be important to utilize the framework of international collaboration to promote efficient development. In January 2022, MHI concluded a memorandum of understanding with TerraPower in the U.S. regarding collaboration on the development of the Natrium reactor, in addition to our existing efforts to develop fast reactor technology in collaboration with Japan and France.
As the leading company for fast reactors, MHI will continue to study fast reactor technology while utilizing the framework of international cooperation while working toward the implementation of a demonstration reactor by 2050.

Micro reactors

Micro reactors are being developed for use as portable, multipurpose reactors for applications such as power supply for isolated islands, remote areas, and after natural disasters. This MHI proprietary all-solid-state reactor employs an innovative safety concept that eliminates coolant leakage into the environment and the associated factors that can cause accidents. MHI also aims to achieve a maintenance-free reactor that can be operated remotely and autonomously, eliminating the need for fuel replacement in the long term.

Fusion reactors

Fusion energy, considered by many to be the energy source of the future, has the potential to contribute to solving the world's energy problems and combating global warming.
MHI is involved in the ITER project, an international project for the development of nuclear fusion and the DEMO reactor development project, which aims to validate power generation from nuclear fusion and is engaged in research and development for the practical use of fusion energy.
In the ITER project, in which seven countries around the world (Japan, Europe, Russia, the U.S., China, South Korea, and India) are participating, MHI is in charge of manufacturing toroidal field coils and diverters, which are the main components of a fusion reactor. Toroidal field coils must meet extremely strict manufacturing tolerance requirements, and by utilizing our technological capabilities cultivated through the design and manufacture of nuclear power equipment, MHI was the first company in the world to manufacture and ship them, earning high praise from the ITER Organization.
MHI will continue to take on the challenge of developing and commercializing fusion reactors to make this futuristic energy source a reality by utilizing our technological capabilities cultivated through the manufacture of nuclear power products.

Biomass

4 Transition to biomass/SAF fuel

Biomass is a green alternative energy source that will help decarbonize power generation and jet fuel. MHI will propose fuel conversions contributing to Carbon Neutrality which will be achieved through technologies such as biomass mixed and single-fuel firing in thermal power plants and biomass gasification for the production of sustainable aviation fuel (SAF). SAF is a sustainable type of aviation fuel that is expected to reduce CO_2 emissions compared to conventional jet fuel and is expected to become a very important tool in the move toward decarbonization.
Figure 11 shows the exterior of the bio jet fuel pilot plant. SAF synthesized from wood biomass at this facility was used to fuel a Japan Airlines flight between Haneda Airport and New Chitose Airport, the world's first passenger flight to use this type of fuel. This project was implemented through the joint efforts of SAF producers and users with a view to establishing of a domestic SAF supply chain in Japan and promoting the widespread utilization of this fuel.
In addition to SAF production by biomass gasification, we are also studying a carbon-neutral SAF production method using (1) green hydrogen in the hydrogen ecosystem and (2) CO_2 from a CO_2 recovery system introduced in the CO_2 ecosystem. Specifically, as shown in the figure 12, CO_2 and H_2-dominated gases are converted to H_2 and CO-dominated gases by a reverse shift reaction, and fuel synthesis is carried out by the FT method (Fischer-Tropsch method).

SAF Sustainable Aviation Fuel

As described in Section 10 - **Green steelmaking (decarbonization of the steelmaking process)**, Primetals Technologies Ltd. (PT), an MHI Group company, is a shareholder in LanzaTech, a U.S.-based biotech company developing technology for the fermentation of carbon waste gases into chemical products and SAF (LanzaJet). CO_2 is first captured from industrial gases, including those from steel mills (blast furnace/direct reduction furnace). In a bio-reactor, propriety microbes convert the CO_2 and H_2 into ethanol or other higher alcohols, which are later converted into SAF applying the LanzaJet process.

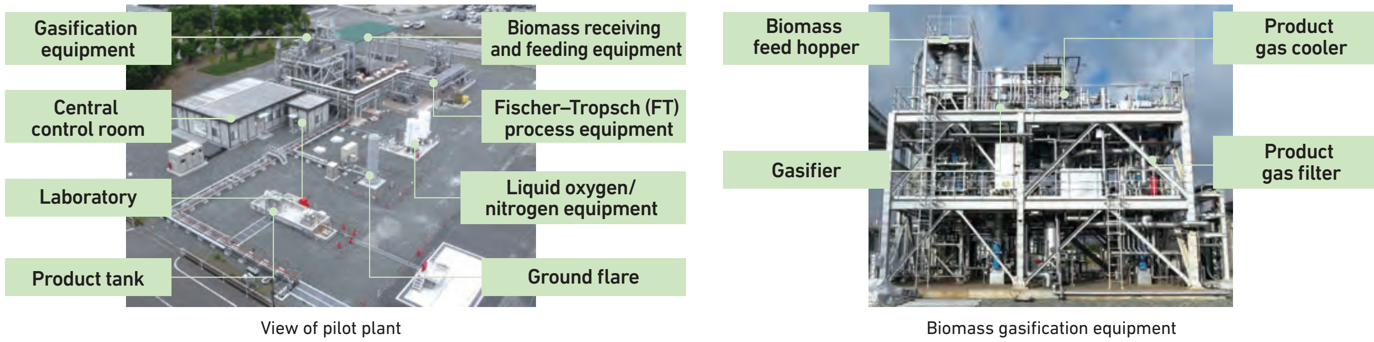


Figure 11 Bio jet fuel production facility

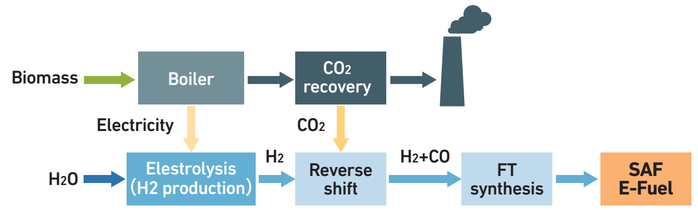


Figure 12 SAF flow

MHIRJ

Providing engineering services to ZeroAvia

MHI RJ Aviation Group (MHIRJ), an MHI Group company, has begun working with ZeroAvia on the integration of their propulsion technology onto regional aircraft.
ZeroAvia, the leader in developing zero-emission solutions for commercial aviation, has made a substantial leap forward in plans to deliver hydrogen-electric engines for regional jets, thanks to an expanded agreement with MHIRJ.
As part of the collaboration, MHIRJ will provide engineering services, integrated aircraft operations, and its industry-renowned experience as an OEM manufacturer to support the certification of ZeroAvia's hydrogen-electric powertrain for retrofit onto airframes in the regional jet market. ZeroAvia's plans to certify its ZA600, 600 kW powertrain for smaller, 10-20 seat aircraft are already well underway, with entry into service planned for 2025. Concurrently, the company is working on ZA2000, a 2-5 MW modular powertrain which targets support for 40-80 seat turboprops by 2027. The ZA2000RJ powertrain will expand this technology to enable passengers to fly in zero-emission regional jets as early as the late 2020s.

ZEROAVIA

Figure 13 First practical zero emission aviation powertrain (U.S. and U.K../ZeroAvia)

Efforts to achieve utilization of 100% SAF

The CRJ Series of aircraft has already been certified to use fuel with 50% SAF content. MHIRJ recognizes that SAF is an important key to decarbonizing aviation and is working with industry partners to ensure that our aircraft will be able to utilize 100% SAF.

CRJ Canadair Regional Jet

Energy solutions

5 Energy solution provider (Figure 14)

Industries such as petrochemicals, paper, steel, and cement account for about a quarter of CO_2 emissions in Japan. These sectors face complex, wide-ranging challenges with regards to in-house power generation systems. This includes balancing needs for a stable supply of essential electricity and steam to facilities that need them, with those for improving the efficiency of existing facilities (energy conservation), decarbonization, and economic viability. MHI has the largest market share in Japanese in-house power generation equipment for industrial use, and we provide energy solutions for all aspects of in-house power generation which can satisfy individual customer needs while effectively utilizing existing equipment and solving a variety of issues.

MHI continues to offer a comprehensive range of sustainable solutions for this sector. Short-term solutions include: retrofitting/upgrading in-house power generation systems to improve efficiency/operability or convert to different fuels, energy use optimization through digital solutions such as TOMONI. Mid- to long-term solutions include fuel conversions of existing facilities or the installation of new equipment both using hydrogen/ammonia (decarbonization). In addition, MHI will also engage for energy solution provider, which is a comprehensive energy service that includes services such as operations optimization, business engineering support for optimized maintenance and stable procurement of power and steam in order to efficiently utilize power generation facilities. MHI will be a one-stop shop providing not only conventional energy/electricity conservation and cost-cutting services but also options for the decarbonization of existing plants, operation optimization using TOMONI*, utilization of surplus electricity, and energy optimization including maintenance services. As the company with the largest share in the Japanese domestic industrial energy market, MHI has a duty to contribute to the decarbonization of Japan's industrial sector, and we are seeking to strengthen and expand this business. MHI will also implement initiatives that leverage our distributed power technologies to work towards decarbonization in the industrial sector. Particular attention is being paid to data centers, which are an indispensable part of the infrastructure required for our increasingly digital lifestyles. Large quantities of electricity are consumed in order to continuously provide convenient digital services 24 hours a day, 365 days a year. This makes data centers a prime target for decarbonization. Singapore is known as a suitable location for data centers, and as part of its efforts to decarbonize, the country is in need of new, environmentally-friendly, high-performance facilities. MHI is currently working on a joint study with Keppel Data Centres to operate data centers using green power generated by our gas turbines. MHI will support the digitalization of society by designing and supplying sustainable, highly reliable power generation equipment for this industry. In addition, MHI will contribute to the decarbonization of ports and industrial complexes, where large industries gather and emit large amounts of CO_2 (Carbon Neutral Ports).

* TOMONI® is a suite of intelligent solutions that accelerates decarbonization with power plant design, O&M and system knowledge, together with strong customer and partner collaborations. TOMONI leverages advanced controls, artificial intelligence and machine learning with multi-layered cybersecurity to make energy systems smarter, more profitable and ultimately more autonomous on the road to a sustainable future.

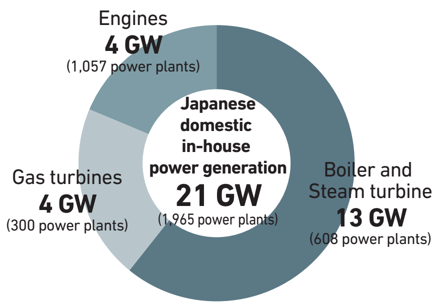
- Many companies operating in industrial sectors (including petrochemicals, steelmaking, iron and steel, and cement), which account for about 1/4 of Japan's CO_2 emissions, operate their own power generation facilities, many of which use boilers to supply electricity, heat, and steam.
- The challenge here is that switching from boilers to renewable sources of electricity alone is not enough to supply the heat and steam used in factories.

No.1 market share in Japanese domestic in-house power generation systems

Expertise in complex processes that incl. supply of heat and steam

Maintain existing electricity, heat, and steam supply systems, and provide diverse decarbonization solutions
- **Fuel conversion to natural gas and replacement with gas turbines**
- **Additionally, conversion to hydrogen and other decarbonized fuels**

Capacity of Japanese domestic in-house thermal power facilities*



* Source: Survey of Electric Power Statistics (FY2020), Japan Agency for Natural Resources and Energy (number of in-house power plants and output)

CO_2 reductions for in-house power generation (example)

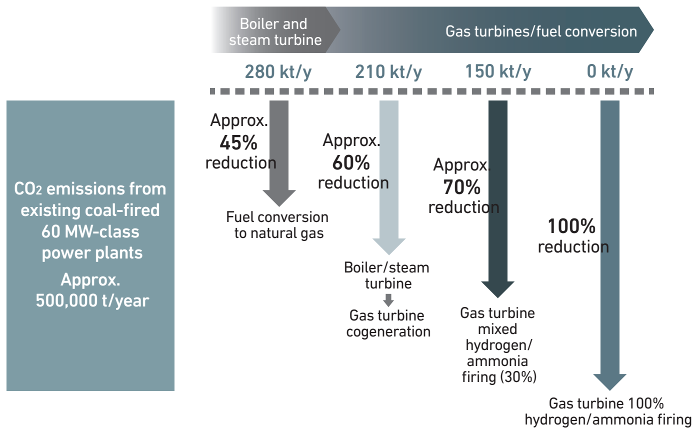
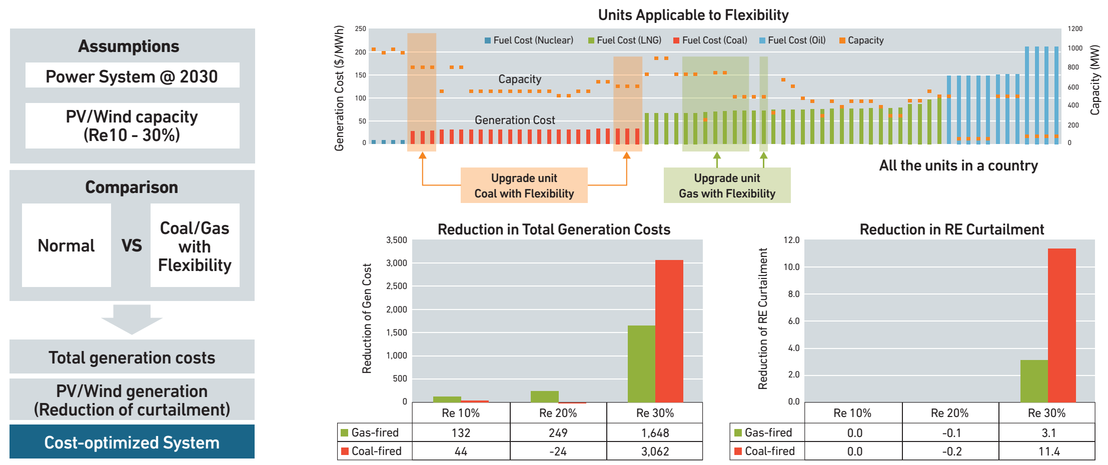


Figure 14 Decarbonization of Japanese domestic in-house industrial power generation

Selection for decarbonization technology by power systems simulation

The selection of technologies to decarbonize the power generation sector will have to be carried out assuming operating conditions that take into account the impact of the implementation of renewable energy and carbon pricing, rather than simply comparing average cost.

In response to this challenge, MHI has built a model that simulates region-specific power generation facilities and the transmission networks that link them. This model is equipped with the ability to, in light of market rules, determine what types of power generation are best supplied from which locations in order to supply the amount of electricity needed in the future. This capability supports the selection of the best technologies from the earliest stages of energy resource planning, enabling the pursuit of high operational and economic efficiency as well as investment risk management while meeting decarbonization goals. These analyses are comprised of two main types, one that considers operational optimization based on the assumption of existing facilities, including retrofits, and a second that considers the composition of new and old technologies to meet long-term demand. MHI has accumulated a robust track record in analyses targeting regions other than Europe and the U.S. – where such modeling first gained prominence – and we are able to make proposals targeting a wide range of regions both within and outside of Japan.



Reduction in Total Generation Costs

	Re 10%	Re 20%	Re 30%
Gas-fired	132	249	1,648
Coal-fired	44	-24	3,062

Reduction in RE Curtailment

	Re 10%	Re 20%	Re 30%
Gas-fired	0.0	-0.1	3.1
Coal-fired	0.0	-0.2	11.4

Figure 15 Example of evaluation of existing facility retrofit using simulation of power generation system

6 LNG supply chain business (Figure 16)

Coal-fired thermal plants are low-cost and are widely used in developing countries in Southeast Asia and other regions. As a result, rapid decarbonization in such regions could hinder economic development. Therefore, liquified natural gas (LNG), which emits less than half the CO_2 per kWh of coal, is expected to be used as a transitional fuel for power generation in the preliminary stage of decarbonization. MHI will promote the construction of an LNG supply chain (gas to power) in order to help meet these needs.
In the future, MHI will expand from LNG to hydrogen and ammonia value chains, thereby contributing to phased decarbonization while maintaining maximum economic efficiency and sustainability.

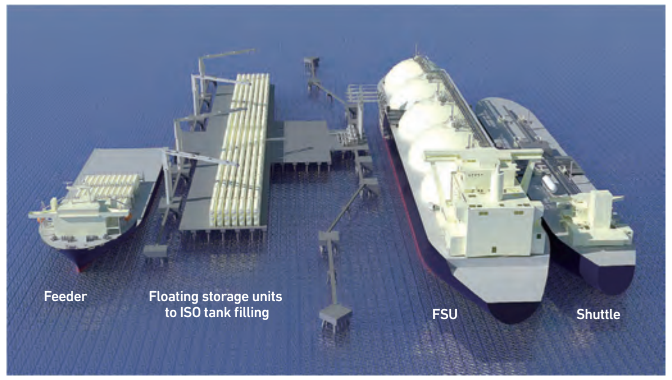


Figure 16 Gas to power

Renewable energy

7 Geothermal power

Geothermal power uses heat energy from magma trapped beneath the earth's surface. CO_2 emissions into the atmosphere are extremely low, making this power generation method effective in preventing global warming. Heat energy exists in large quantities within the earth and, while it is a form of renewable energy, it is not affected by weather conditions, making geothermal power comparable to thermal power in terms of availability. MHI has supplied our flash cycle geothermal power turbines to 13 countries around the world, totaling more than 100 units with a combined output of more than 3 GW. Since the requirements for geothermal power vary from site to site, MHI also supplies binary power generation systems (Turboden ORC) that can generate power even from low-temperature heat sources, enabling them to precisely meet a wide range of customer needs. By implementing geothermal power, MHI will contribute to a sustainable energy mix on a global scale.

Carbon-Free Fuel Production

MHI's Turquoise hydrogen production technology

8 Turquoise hydrogen

Characteristics of turquoise hydrogen

The fluidized bed system has been selected as the reactor type for methane pyrolysis, and the continuous pressurized fluidized bed test equipment shown in Figure 18 has been constructed to accelerate the development. A fluidized bed reactor and a heater are installed in the pressure vessel, and a catalyst supply and by-product carbon discharge mechanism are also provided to carry out continuous methane pyrolysis reaction test. Representative test results are shown in Figure 19. Continuous operation under high temperature pressure has been successfully achieved. Figure 20 shows the road map for the future. We aim to commercialize it around 2030. In-house development of turquoise hydrogen for high-capacity and low-cost hydrogen production. Turquoise hydrogen production technology by methane pyrolysis is a technology which decomposes natural gas into solid carbon and gaseous hydrogen under high temperature, and it is a technology which has been used for the production of carbon materials such as carbon black which is an industrial material until now. In MHI, the fuel utilization of hydrogen produced simultaneously was noticed, and the reaction form which can produce hydrogen much more efficiently than the system using electric power such as plasma was found. Figure 17 shows the outline of the turquoise hydrogen production technology. A natural gas infrastructure has already been established, and decarbonization is realized by adding a turquoise hydrogen production plant between the supply line of this natural gas infrastructure and the consumer or upstream of the consumer's consumption equipment. Taking Gast Turbine power plant as an example, it is possible to convert it to Hydrogen Gas Turbine by simply replacing the combustion system. Since by-product carbon is a solid, it can be fixed and stored more easily than CO_2 which becomes a gas at room temperature and atmospheric pressure. By the combination with turquoise hydrogen, drastic reduction of carbon and decarbonization of the existing thermal power plant: zero CO_2 emission power generation can be achieved. The fluidized bed system has been selected as the reactor type for methane pyrolysis, and the continuous pressurized fluidized bed test equipment shown in Figure 18 has been constructed to accelerate the development. A fluidized bed reactor and a heater are installed in the pressure vessel, and a catalyst supply and by-product carbon discharge mechanism are also provided to carry out continuous methane pyrolysis reaction test. Representative test results are shown in Figure 19. Continuous operation under high temperature pressure has been successfully achieved. Figure 20 shows the road map for the future. MHI is aim to commercialize it around 2030.

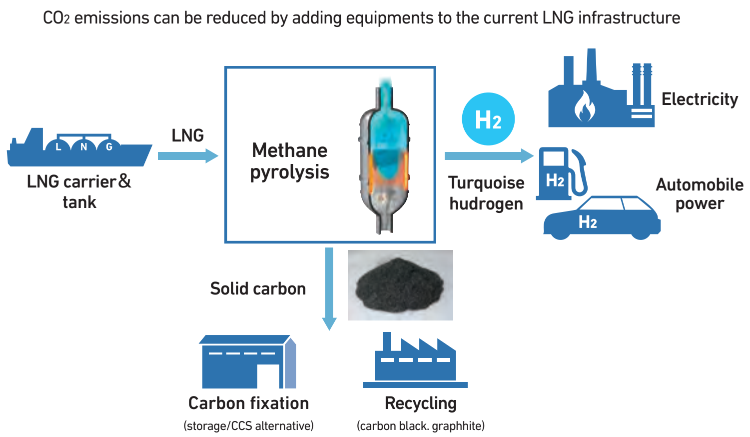


Figure 17 Outline of the turquoise hydrogen production technology

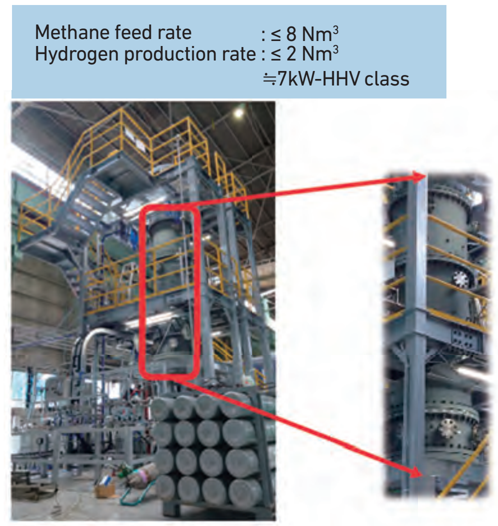


Figure 18 Continuous pressurized fluidized bed test equipment

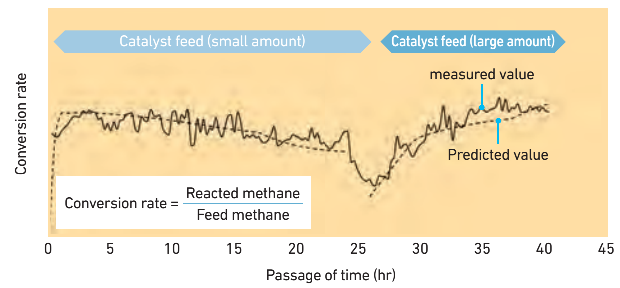


Figure 19 Test results

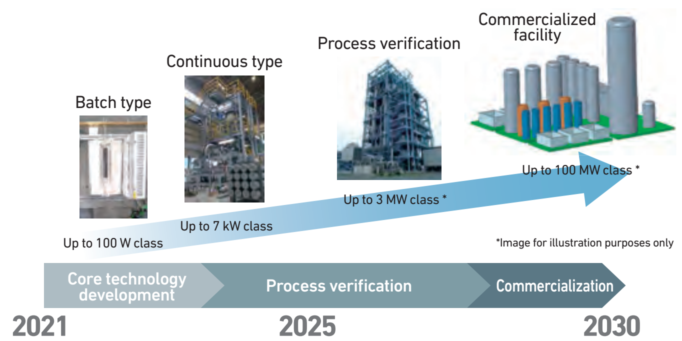


Figure 20 Development roadmap

Example of capital investment (Monolith Inc.)

Through our subsidiary, Mitsubishi Heavy Industries America, Inc. (MHIA), which is headquartered in the U.S., MHI Group has invested in Monolith, Inc., a company that has developed an innovative technology for the plasma pyrolysis of natural gas, which uses renewable energy-derived electricity to extract hydrogen and solid carbon from methane with significantly reduced CO_2 emissions compared to other methods. Monolith's process is shown in Figure 21. MHI aims to strengthen and diversify the hydrogen value chain as one of the innovative alternative technologies in our Group's Energy Transition (decarbonization of energy supply) initiatives.

In 2014, the Group successfully verified that the production of 700 tons/year of carbon black is possible at a demonstration facility built in California. Currently, a 14,000 ton/year production plant is in operation in Nebraska (see Figure 22), and plans are underway to build a commercial plant with a carbon black production capacity of 180,000 tons/year.

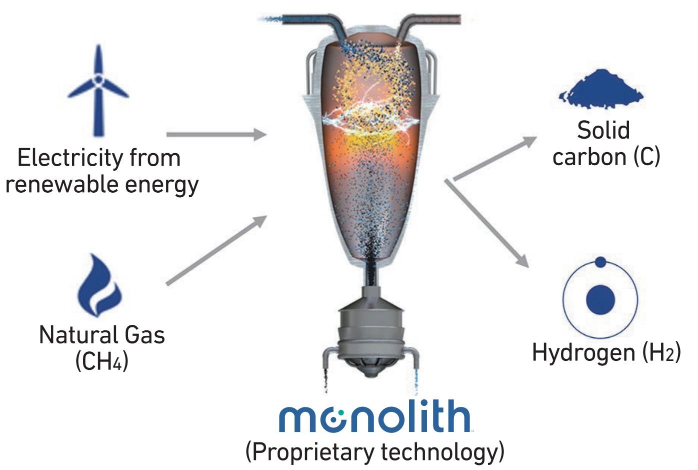


Figure 21 Monolith process

Figure 22 Production plant in operation in Nebraska, U.S., with 14,000 tons/year capacity

Raw material	How to produce	CO_2 emission	MHI related technology
Water	Electrolysis Water — Alkaline water electrolysis(AEL) / Proton Exchange Membrane water electrolysis (PEM) / Anion Exchange Membrane water electrolysis (AEM); Steam — Solid oxide electrolytic device(SOEC)	No1)	AEM, SOEC, AEL (HydrogenPro)
	Photocatalysis (artificial photosynthesis)	No	
Hydrocarbon compound	Natural gas — Modification(SMR/ATR)	Yes2)	Turquoise hydrogen (Methane pyrolysis)
	Natural gas — Pyrolysis (methane pyrolysis)	No3)	
	Coal — Gasification	Yes2)	Coal gasification(IGCC)
	Biogas (Grasses, trees, waste, etc.) — Gasification	Yes4)	SAF Production
Hydrogen carrier	Methylcyclohexane — Decarbonation reaction; Ammonia — Cracking	No1)	Ammonia cracking (Ammonia cracking cycle gas turbine system)
By-product gas	Water + Salt — Soda electrolysis	No1)	Diffusion combustor for gas turbine
	Oil — Petroleum refinery related (naphtha cracking, etc.)	Yes2)	
	Coal — Coke production(COG、BFG、LDG)	Yes2)	

1) Depend on the power source and heat source, 2) CCS is necessary for decarbonization, 3) Depend on the heat source, 4) If CCS is used, it is negative emission.

Table 4 Hydrogen production technology

MHI's Green hydrogen production technology

9 Green hydrogen

MHI is working on the development of three kinds of hydrogen production technologies focusing on the use of hydrogen in power generation: high pressure, high efficiency, large capacity Solid Oxide Electrolysis Cell (SOEC), Anion Exchange Membrane water electrolysis (AEM), and turquoise hydrogen production by methane pyrolysis. In addition, the synthetic fuel production technology development using these electrolysis equipment is also being developed. Figure 23 shows a roadmap for technology development toward decarbonized power generation. The comprehensive long-term validation of these elemental technologies is carried out at Takasago Hydrogen Park, and the elemental technology development is carried out at Nagasaki Carbon Neutral Park.

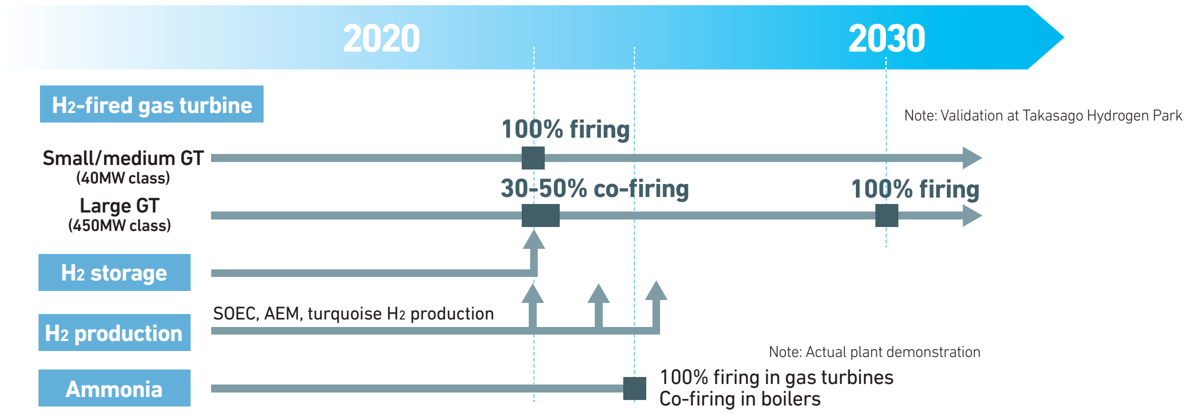
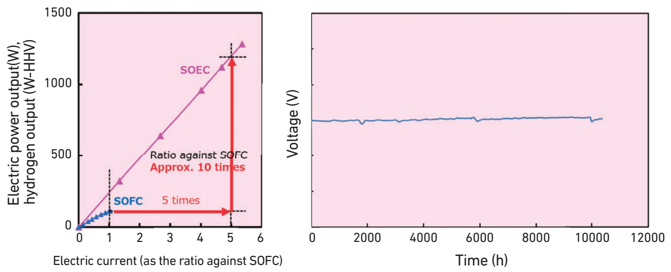


Figure 23 Roadmap of Technology Development for Decarbonized Power Generation

High-Pressure, High-Efficiency, High-Capacity Solid Electrolyte Steam Electrolysis (SOEC: Solid Oxide Electrolysis Cell)

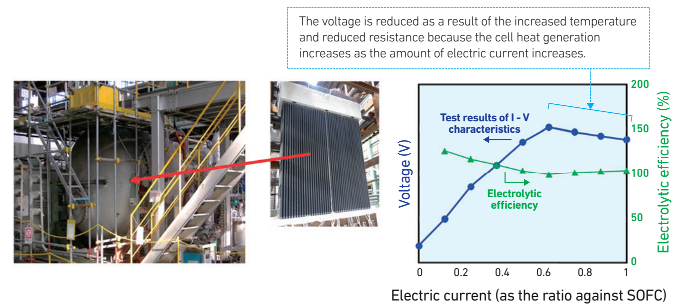
SOEC can produce hydrogen by electrolysis of water vapor with high efficiency which is overwhelming other systems. MHI succeeded in the development of cylindrical SOEC made of all ceramics by original technology. The performance is shown in Figure 24. Hydrogen production exceeding 1kW and stable operation exceeding 10,000 hours are realized with 1cell stack. In addition, a cartridge operation consisting of several hundred cells shown in Figure 25 was carried out, and hydrogen production of 0.1MW-HHV and 30Nm^3/h was achieved. At present, a test equipment with four cartridges as shown in Figure 26 is under construction in Takasago Hydrogen Park. Figure 27 shows the future development roadmap. In the future, several MW class system will be developed and validation operation will be carried out in Takasago Hydrogen Park, and commercialization acceleration will be promoted.



(a) Confirmation of cell stack electrolytic characteristics

(b) Durability test

Figure 24 Test results



(a) Cartridge and test equipment

(b) Confirmation of cartridge electrolytic characteristics

Figure 25 Test equipment with four cartridges

Figure 26 SOEC (Takasago Hydrogen Park)

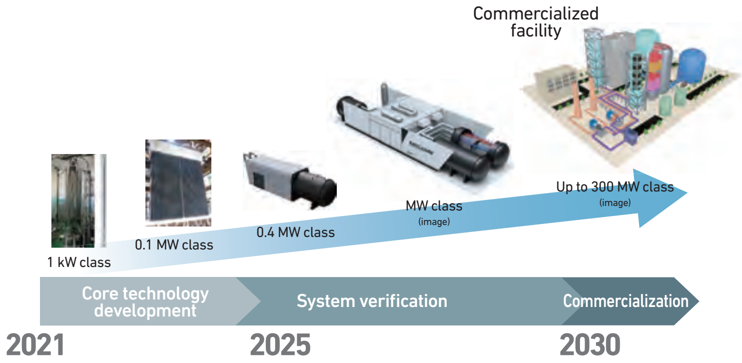


Figure 27 Development roadmap

Anion Exchange Membrane(AEM)water electrolysis

MHI is making use of its experience in PEFC and PEM electrolysis to develop an AEM electrolyzer that is expected to be more compact and more efficient in comparison with the alkaline electrolysis. Figure 28 shows a prospectus, and Figure 29 shows a kW-scale electrolysis device under development. Development is being promoted along the road map shown in Figure 30.

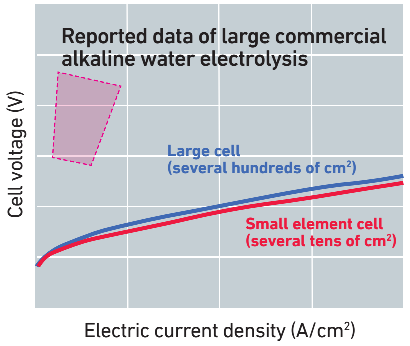


Figure 28 Development prospectus

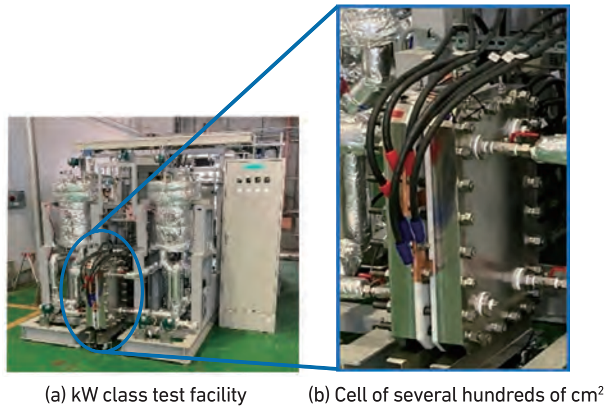


Figure 29 Electrolysis device (kW-scale)

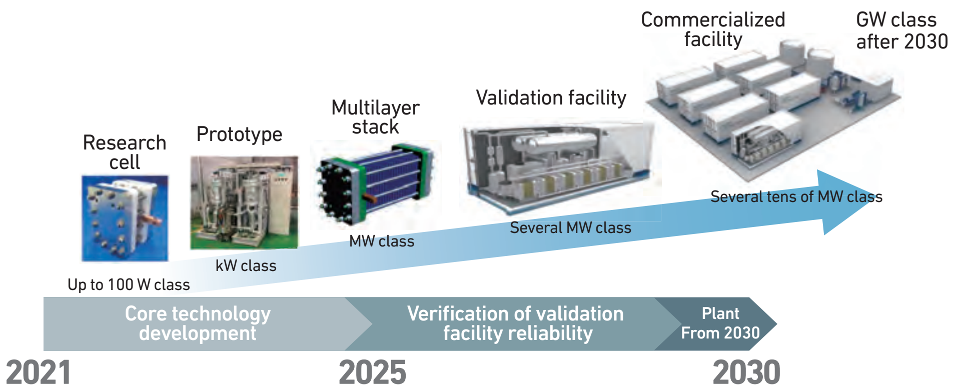


Figure 30 Development roadmap

Example of capital investment

HydrogenPro ASA

MHI has invested in HydrogenPro, which develops and produces electrolysis equipment of 5 MW class (hydrogen production capacity 2.4 tons/day). The unit was installed at Takasago Hydrogen Park, and produced hydrogen is used for hydrogen co-firing test of the gas turbine to validate long-term reliability test and accelerate the development of the hydrogen gas turbine. In addition, 220MW capacity was delivered to the Advanced Clean Energy Storage Project in Utah, U.S.

Figure 31 HydrogenPro water electrolysis system

Electric Hydrogen Inc.

Through MHIA, MHI has invested in Electric Hydrogen (EH2), EH2 plans to accelerate commercialization by producing large capacity (100 MW-class) clean hydrogen systems for industrial and infrastructure applications.

ELECTRIC HYDROGEN

PEM Proton Exchange Membrane

Green Steel

10 Green steelmaking (decarbonization of the steelmaking process)

Currently, the steel industry emits about 9% of the world's CO_2. The blast furnace steelmaking process is the largest contributor, emitting approximately 2.0 tons of CO_2 per ton of steel. In the mid- to long-term, the steelmaking process is expected to consolidate into the following three processes to achieve Net Zero green steel:

- **Hydrogen direct reduction ironmaking: Direct reduction ironmaking using green hydrogen (replacing natural gas) as the reducing gas**
- **Renewable energy use: Melting and smelting of steel scrap and direct reduced iron (DRI/hot briquetted iron [HBI]) using electric arc furnaces (EAF) and other technologies**
- **Blast furnace/direct reduction furnace + CCUS: Capture, store, and reuse of CO_2 emitted from blast furnaces and natural gas direct reduction furnaces**

Primetals Technologies Ltd. (PT) is a leading provider of green steel solutions to decarbonize the steelmaking process, covering all three of these steelmaking processes.

[Hydrogen reduction ironmaking]

MIDREX Process: PT is a licensee of the MIDREX direct reduction ironmaking process which produces DRI/HBI from iron ore pellet feed. PT has worked with MIDREX to deliver numerous natural gas-based reduction plants. In recent years, the MIDREX process has become capable of fully replacing natural gas with green hydrogen, and PT is in discussions with customers to transition to hydrogen reduction iron, including options to gradually increase the hydrogen input to match the availability of hydrogen.

HYFOR Process: PT is developing a hydrogen-based fine ore direct reduction (HYFOR) process that allows direct feeding of all grades of (fine) iron ore without further processing. The process is based on horizontal fluidized bed technology, uses hydrogen as the reducing gas, has low process temperatures, is highly efficient, and does not require iron ore pelletizing equipment. A pilot plant has been operational since 2021, and based on the good results obtained there, construction of an industrial prototype plant is under consideration.

HyREX Process: PT developed a direct reduction ironmaking process (Finored) using sinter feed ore with a grain size up to 8 mm as feedstock in the late 1990s. They already delivered two natural gas-based commercial plants in the early 2000s. In recent years, PT has been developing a HyREX process that will use hydrogen (up to 100%).

Smelter (new smelter): One of PT's strategic innovations for the utilization of low-grade iron ore, this new type of smelter is an electric furnace that operates in a reducing atmosphere using short arc discharge from electrodes to melt and smelt reduced ore (DRI). It will be used to convert DRI/HBI from the above direct reduction ironmaking process into molten metal (green hot metal) instead of using conventional blast furnaces.

Figure 32 Hydrogen-based fine ore direct reduction (HYFOR) pilot plant

[Utilization of renewable energy]

Steel scrap recycling and melting can be achieved with renewable energy to achieve the smallest carbon footprint possible. PT's new EAF Quantum electric arc furnace is the most energy-efficient electric arc furnace available today. It can efficiently preheat scrap by exposing it to the furnace's exhaust gas prior to charging and melting. Also, steel scrap (not iron) is in limited supply and contains impurities, which limits the production of high-grade steel. However, Fusion EAF, developed by PT, is a highly flexible electric furnace that can change the mixing ratio of steel scrap, DRI/HBI, and hot metal according to the desired quality of the final product. In addition, the recent trend toward larger electric arc furnaces has resulted in furnaces which consume a large amount of power (up to around 300 MW), so it is essential to minimize grid disruptions and maximize power efficiency. PT proposes Active Power Feeder, a solution suitable for building power supply systems for large electric arc furnaces (high voltage/large capacity) with minimal reactive power and a greatly improved power factor.

Figure 33 New electric furnace (Quantum EAF)

[Blast furnace/direct reduction furnace + CCUS]

Even if the percentage of blast furnace process use decreases and hydrogen reduction steelmaking is implemented, a certain percentage of blast furnaces is expected to remain even after 2050. Therefore, CCUS from blast furnace-based steel mill off-gas will be necessary.
PT will work with MHI Engineering Solutions to apply its CCS technology (KM CDR Process™) to the steel industry. While deploying CCS first, PT plans to commercialize CCUS by around 2030 in combination with CO_2 recycling using bio-fermentation technology.
For CO_2 capture and utilization (CCU), we are partnering with LanzaTech, a U.S. biotechnology company that has developed a proprietary bio-fermentation process to convert carbon in exhaust gas into bioethanol, biofuels, and other products. PT has had a minor stake in LanzaTech since 2014 and is working with them on a proof-of-concept project for a commercial-scale CO_2 fermentation plant for a Belgian customer's blast furnace process, which is scheduled to be operational in 2022. In the medium term, we also aim to apply the exhaust gas from the steelmaking process to the production of sustainable aviation fuel (SAF) through CO_2/H_2 fermentation. (See p.15)

Achieving carbon neutrality for works and plants

11 Visualization of CO_2 reduction measures

Visualization of priorities for CO_2 reduction measures; the "MAC Curve"

To achieve carbon neutrality, utilizing the "MAC Curve", a roadmap for carbon neutrality in other words, is effective in order to reduce CO_2 emissions from plants, etc. MAC stands for "Marginal Abatement Cost." The MAC Curve is a bar graph to visualize CO_2 reduction measures in terms of reduction benefits and costs. Creating a MAC Curve starts with calculating the amount of energy consumed by each facility in the works and plants. We then consider ways to decarbonize each facility. Figure 34 shows an example of the MAC Curve for a plant toward carbon neutrality. Each bar on the graph represents an individual measure. Measures with lower cost per unit are depicted with lower bar heights, and measures with high reduction effectiveness are shown with wider bars. In the bottom figure, the green section indicates measures that can reduce both cost and CO_2, suggesting priority actions to be addressed. The initiatives in the blue section can reduce CO_2, but due to higher costs and time requirements, they should be carefully considered for the future or following new technology development. Creating a MAC Curve allows for a clear understanding of the CO_2 reduction amount and required costs for each measure at a glance. This makes it easier to set goals for CO_2 reduction, and the visualization helps prioritize measures to focus on. MHI designed the MAC Curves first and foremost for our works and plants. MHI has expertise in estimating the amount of CO_2 emissions per facility, formulating measures for energy-saving and carbon neutrality and identifying which measures need to be implemented first. Therefore MHI can propose solutions to visualize CO_2 emissions that suit your plant facilities.

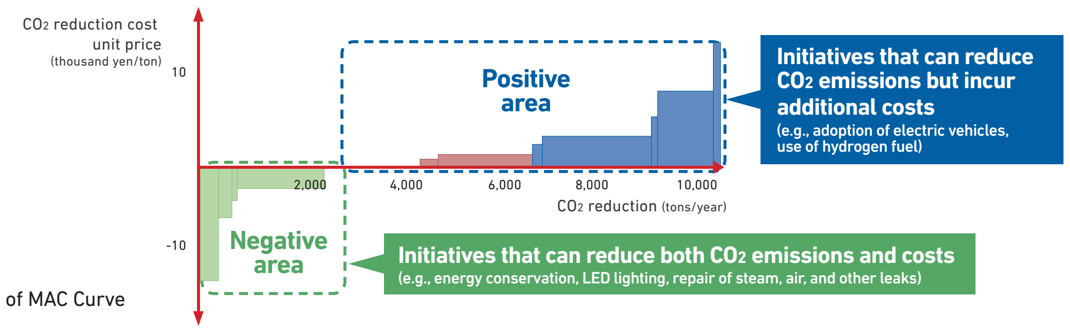


Figure 34
Typical bar chart of MAC Curve

Steps toward carbon neutrality at works and plants

To achieve carbon neutrality at works and plants, we calculate the amount of energy at first that each process and operation truly requires. Secondary, we have to make concrete efforts to save and effectively utilize finite energy. Finally, we consider the viability of using non-fossil energy sources such as renewable energy. There are numerous methods available for reducing CO_2 emissions. Many of these methods require investment or additional costs. However, it is most important to minimize the amount of energy required, and thereby achieve both cost reductions and CO_2 emission reductions.

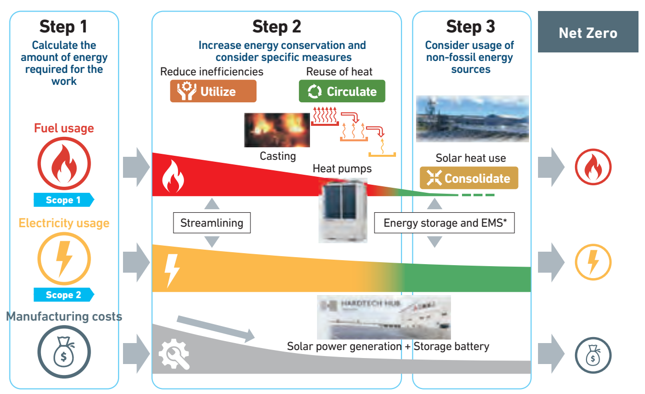


Figure 35 Steps toward carbon neutrality at works and plants

*EMS: Energy Management System (management system for efficient use of energy in plants)

12 Mihara Advanced Carbon Neutrality Project

Project overview

To demonstrate a practical implementation of measures for energy-saving & decarbonization, and provide our customers with a tangible vision, Mihara Machinery Works (Mihara City, Hiroshima Prefecture) is striving to become a net-zero CO_2 emission plant.Mihara Machinery Works has evolved to become a leading producer of paper converting machinery (corrugated cardboard manufacturing equipment) and new transportation systems. Embracing the theme of "becoming a plant that emits minimal CO_2," it is undergoing a transformation. To make the plant carbon-neutral, MHI began by ascertaining its current state. As a result of our decarbonization efforts since June 2022 to achieve net-zero CO_2 emissions by the end of FY2023, CO_2 emissions are expected to be reduced by 97.8% (compared to FY2021).

Figure 36 Solar power plant in Mihara Machinery Works Wadaoki Plant

Four processes toward net-zero CO_2 emissions

At Mihara Machinery Works, MHI is working toward carbon neutrality based on the following four processes.

- **Energy conservation and operational optimization for Scope 1 and 2: Reducing energy consumption that is the most crucial aspect to prioritize.** (Partially realized already)
- **Utilization of current technology for Scope 1: Reducing CO_2 emissions by introducing high-efficiency measures and facilities, such as heat pumps and electrification** (Under consideration)
- **Solutions through new products and technologies for Scope 1: Developing the new products and technologies to address challenging CO_2 emission sources** (Under consideration)
- **Introduction of renewable energy Scope 2: Introducing the non-fossil energy; a 16.8 MWp solar power plant has been installed at the Wadaoki Plant** (Completed)

The results of achievements through these processes, not only has MHI gained practical know-how in reducing CO_2 emissions, but MHI has also high feasibility of achieving MISSION NET ZERO (carbon neutrality by 2040).
Through our products and services, MHI can supply a more concrete vision of carbon neutrality combined with individual measures and specific unique solutions.

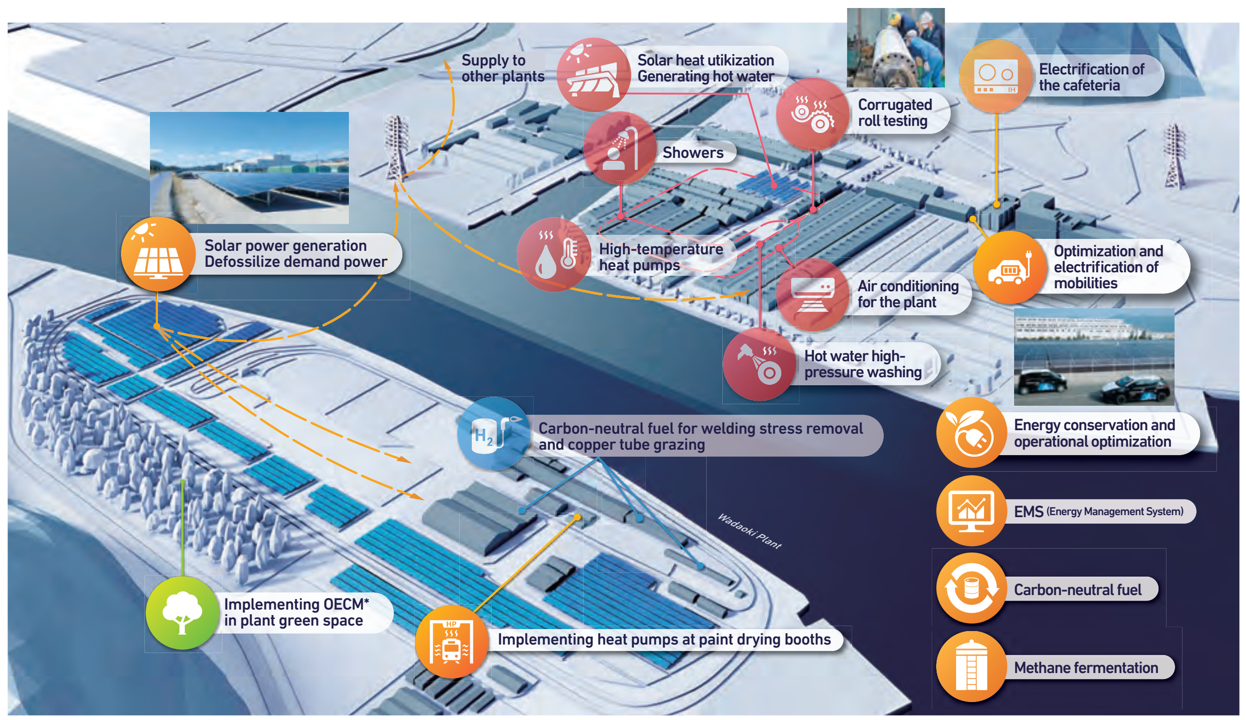
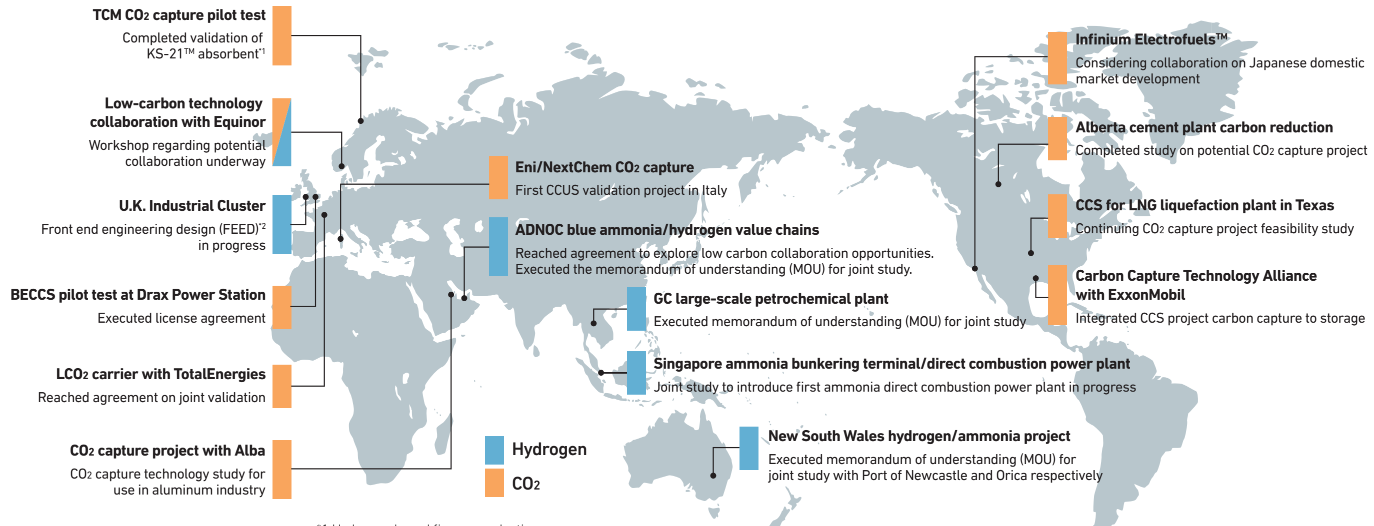


Figure 37 Mihara carbon neutral plant (image)

* OECM: Other Effective area-based Conservation Measures

The implementation of a hydrogen solutions ecosystem requires an approach that goes beyond simply using hydrogen. It comprises the creation of a complete value chain that covers the production, storage, and transportation of this resource. To this end, MHI Group is working to increase the feasibility of the hydrogen ecosystem by publicly communicating the achievability and potential of hydrogen technologies to our stakeholders, including customers, shareholders, and partners as well as society as a whole. Figures 38 and 39 show maps displaying hydrogen and CO_2 capture projects in which we are participating around the world. Energy Systems is currently pursuing collaboration with external parties by participating in business development in leading regions. We are working toward commercialization of these technologies by leveraging the strengths of MHI Group's core products related to the production and supply of carbon-free fuels such as hydrogen and ammonia, which are located upstream in the value chain of our product lines.



*1 Hydrogen-based fine-ore reduction
*2 Front end engineering design: A precursor to EPC during which technical issues and cost estimates are considered

Figure 38 Project development map (hydrogen and CO_2 projects around the world)

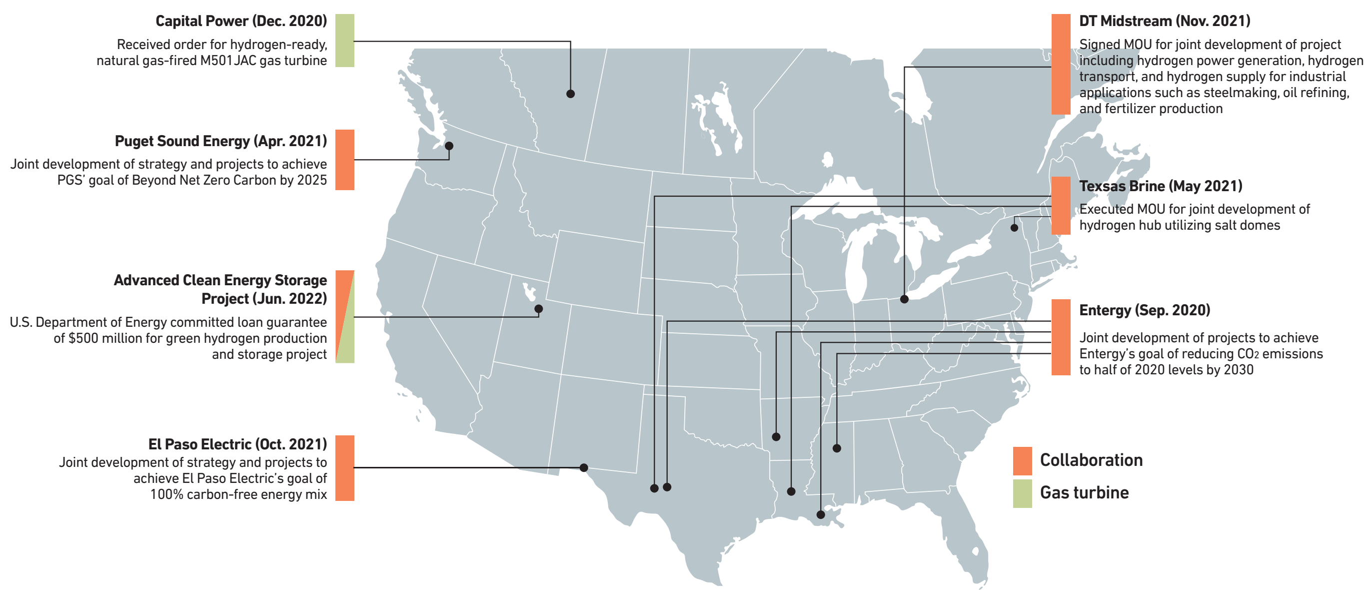
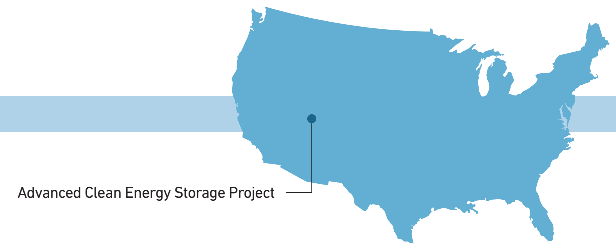


Figure 39 Project development map (hydrogen projects in the U.S.)

Carbon-free fuel supply chain projects

Hydrogen and ammonia supply projects

U.S. Green hydrogen project (Figures 40 and 41)



The Advanced Clean Energy Storage Project in the U.S. aims to store hydrogen produced by water electrolysis using renewable energy in underground salt domes in Utah and to utilize the hydrogen to generate power. MHI is working with Chevron, the co-developer and operator of the salt domes, to develop one of the world's largest green hydrogen hubs using 100% renewable energy.

The storage facility will use a 220 MW water electrolysis unit to produce up to 100 tons of hydrogen per day.

The hydrogen produced and stored here will be supplied to an 840 MW-class GTCC power plant (Intermountain Power Plant Renewal Project), which is being constructed by Intermountain Power Agency, a power generating cooperative in Utah, with MHI M501JAC gas turbines at its core. The plant will start operation in 2025 with a 30vol% hydrogen mixture and is expected to operate with 100% hydrogen by 2045.

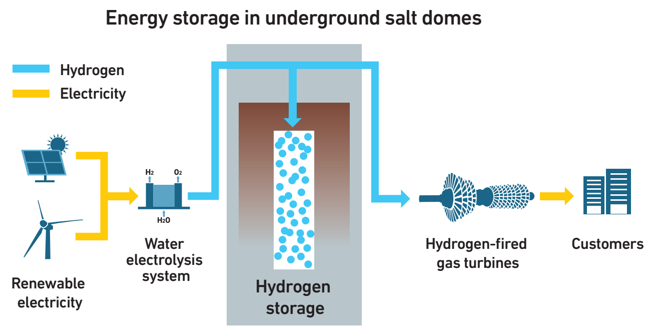
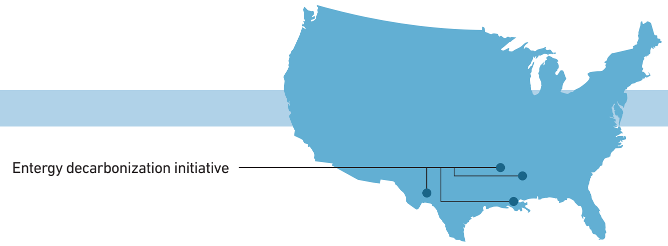


Figure 40 Diagram of the Advanced Clean Energy Storage Project

Figure 41 Illustration of hydrogen production and storage plant

U.S. Collaboration with Entergy (Figure 42)



In September 2020, MHI signed an MOU with Entergy, agreeing to collaborate on the decarbonization of their fleet in four southern U.S. states (Arkansas, Louisiana, Mississippi, and Texas). MHI will work with Entergy on a comprehensive range of projects, including the development of hydrogen-ready GTCC power plants, the production, storage, and transportation of green hydrogen, and the consideration of utility-scale battery storage systems.

Figure 42 Signing of MOU with Entergy

U.K. Hydrogen fuel conversion project (Figure 43)

MHI is participating in a project that aims to decarbonize the Humber Industrial Cluster, which is located in the Humber region on the east coast of the U.K. and is the country's largest industrial cluster. Under this plan, 14 companies and organizations in the global decarbonization industry, including Equinor, aim to achieve virtually zero CO_2 emissions in the industrial cluster by 2040 utilizing hydrogen produced from natural gas together with CO_2 capture and removal technologies. MHI will be involved in technical and project feasibility studies regarding the conversion of a natural gas-fired GTCC facility (Saltend Power Station, the region's main power source) to fire hydrogen.

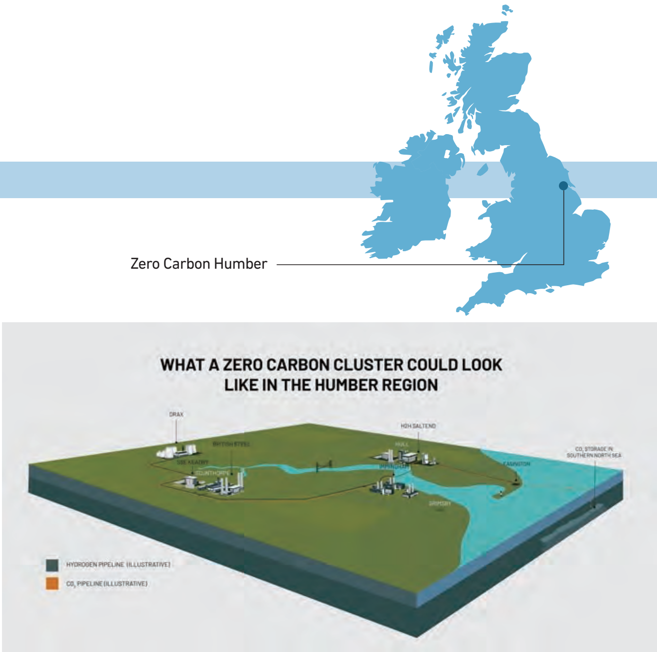


Figure 43 Zero Carbon Humber

Japan Hydrogen carrier supply chain (Figure 44)

Renewable energy resources are not readily available in Japan, and there are limited sites for CO_2 storage. As such, there are currently considerations underway regarding the shipment of hydrogen produced in areas with ample renewable energy resources and/or CO_2 storage sites to Japan. Various methods of transportation are being considered, including liquid hydrogen; methylcyclohexane (MCH), a liquid obtained by combining hydrogen with toluene; ammonia produced by combining atmospheric nitrogen with hydrogen; and methane, which can be obtained by reacting captured CO_2 with hydrogen. Energy Systems is developing hydrogen utilization technologies, particularly gas turbines, which can accommodate the various hydrogen carriers being contemplated in Japan.

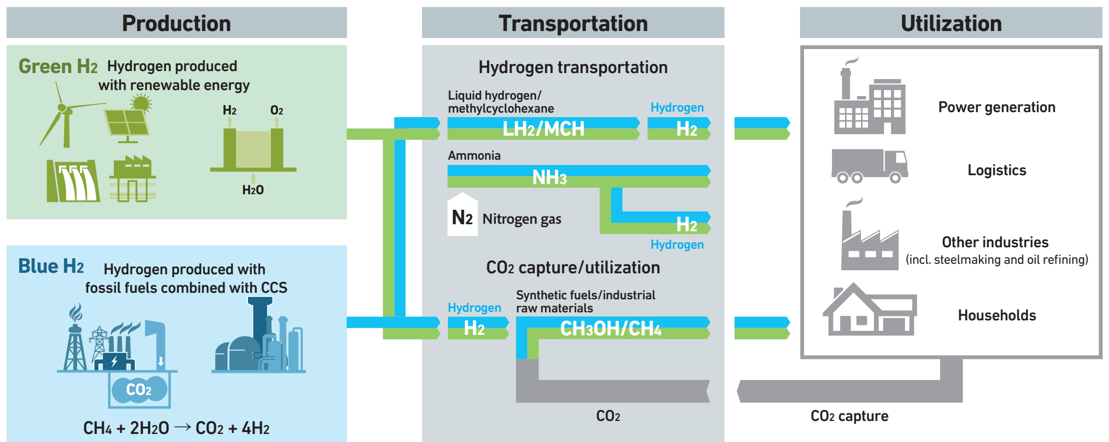


Figure 44 Hydrogen carrier supply chain

Japan Achieved stable combustion of co-firing hydrogen in gas engines for cogeneration systems

Toho Gas Co., Ltd. and MHIET collaborated on a demonstration test of natural gas and hydrogen dual fuel combustion in an existing MHIET's 450kW-class gas engine model for use in cogeneration systems, achieving rated output with 35 vol% hydrogen. This was the first successful test of its kind in Japan.

The test was conducted at the Toho Gas Technical Research Institute (Tokai City, Aichi Prefecture) with the aim of understanding how to achieve stable combustion of the fuels without major modifications to existing systems. Abnormal combustion events such as backfire, engine knocking, and preignition are an issue with dual fuel combustion, but stable combustion was verified by adjusting the air-fuel ratio and other parameters.

Furthermore, MHIET confirmed stable combustion of hydrogen admixture through a testing of a single cylinder gas engine whose original model has 5.75MW output for use in cogeneration systems. The test achieved stable combustion with up to 50 vol% hydrogen admixture without losing the rated output. The testing additionally revealed that the cogeneration system that generates power and steam is likely to satisfy CO_2 emission coefficient of 0.27kg- CO_2/kWh without recovering energy for hot water. The emission level is set as the standard for natural gas-fired power generation system during transitional period by EU taxonomy for sustainable activities. In preparation for targeted commercialization in FY2025, MHIET will finalize specifications of auxiliary equipment to be installed together with the engine and control systems of all related equipment. MHIET aims at contributing to low carbonization of distributed gas engine power generation system for wide variety of industries.

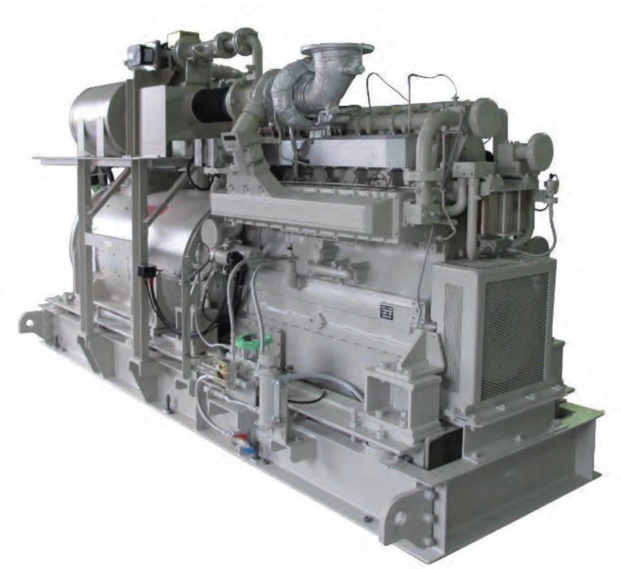


Figure 45 450kW gas engine (GS6R2)

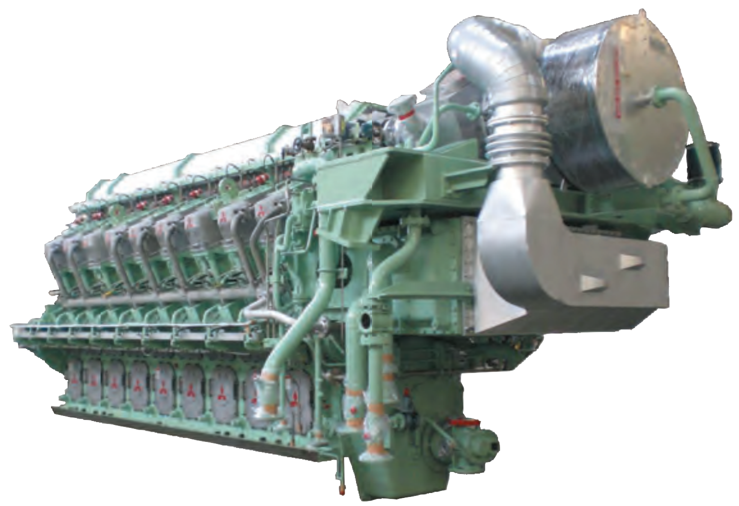


Figure 46 5.75MW gas engine (KU)

Japan Hydrogen production utilizing high-temperature heat from nuclear power plants (HTGRs)

A high-temperature gas-cooled reactor (HTGR) is a nuclear reactor capable of producing heat at much higher temperatures (approx. 950°C) than light water reactors (approx. 300°C) by using highly heat-resistant graphite (moderator) and silicon carbide (SiC) ceramic materials (fuel coating) as core and fuel components as well as chemically stable helium gas as coolant for nuclear heat extraction. This type of reactor has superior safety features, such as the ability to naturally dissipate heat from the outer surface of the reactor core in the event of an accident, and inherent safety features that prevent the core from melting down.
MHI will contribute to the decarbonization of industry by developing a high-temperature gas-cooled reactor (HTGR) that can achieve stable, high-volume production of hydrogen utilizing high core temperatures.

Participation in the Demonstration Program for Hydrogen Production Using the High-Temperature Engineering Test Reactor (Figure 47)

In April 2022, MHI and the Japan Atomic Energy Agency (JAEA) jointly launched a demonstration program for hydrogen production technology utilizing an HTGR, aiming for commercialization in the early 2030s.
In this project, MHI plans to connect a new hydrogen production facility to the High-Temperature Engineering Test Reactor (HTTR) owned by JAEA, and to demonstrate that hydrogen can be produced stably by utilizing high-temperature heat obtained from an HTGR.

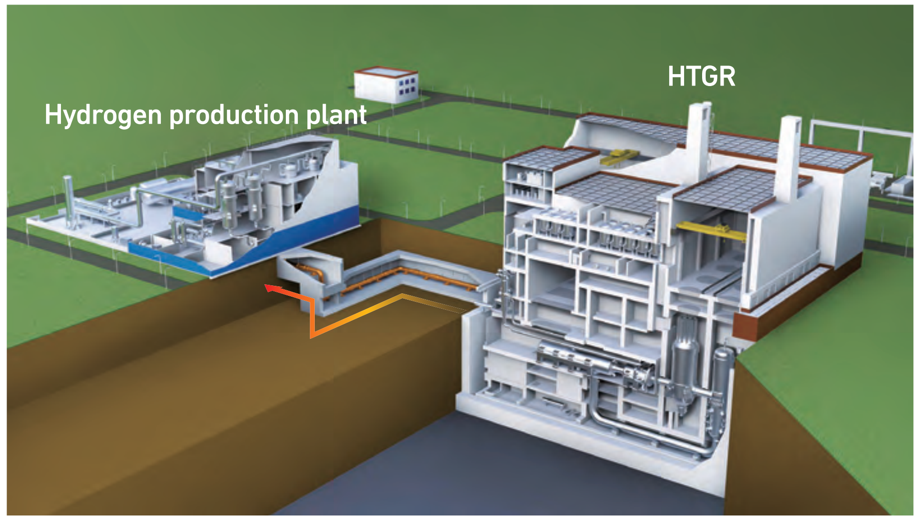


Figure 47 High Temperature Gas Reactor - Hydrogen Production Plant (diagram)

Selected as core company for development of HTGR demonstration reactor

In July 2023, MHI was selected as a core company responsible for the development of a state-sponsored HTGR demonstration reactor. As a core company, MHI will promote the development of HTGR demonstration reactors, and will work together on R & D, design, and construction for the national goal of starting the operation of demonstration reactors in the 2030s.

Japan Hydrogen compressor (Figure 48)

As the demand for hydrogen expands over a wide range of areas, including hydrogen power generation, fuel for vehicles, and household heating, there will be an increasing number of scenarios where hydrogen will be handled in large volumes. Pressure boosting is needed in hydrogen production, transportation, storage, and utilization processes, and compressors with a high pressure ratio which can efficiently boost the pressure of large volumes of hydrogen are a key component for achieving a hydrogen-based society. Hydrogen is the lightest gas on earth (with a molecular weight of 2 u) and is therefore difficult to compress. It is necessary to increase the impeller speed (high peripheral speed) as much as possible in order to efficiently boost pressure. Additionally, hydrogen embrittles materials it comes into contact with (hydrogen embrittlement), so hydrogen compressors require advanced technology including materials that can withstand embrittlement and the ability to achieve high peripheral speeds at the same time.
MHI's centrifugal hydrogen compressors use a high peripheral speed impeller to boost hydrogen pressure, thereby increasing the pressure ratio per casing. This makes the equipment compact and lightweight, and reduces the time required for maintenance. Continuous operation for long periods of time is also possible.
Based on our experience manufacturing more than 2,600 compressors throughout our history, MHI offers compressors that boost the pressure of hydrogen-rich gases using high-speed centrifugal compressor technology. To handle hydrogen of even higher purity, MHI is working to provide ultra-high-speed compressors.

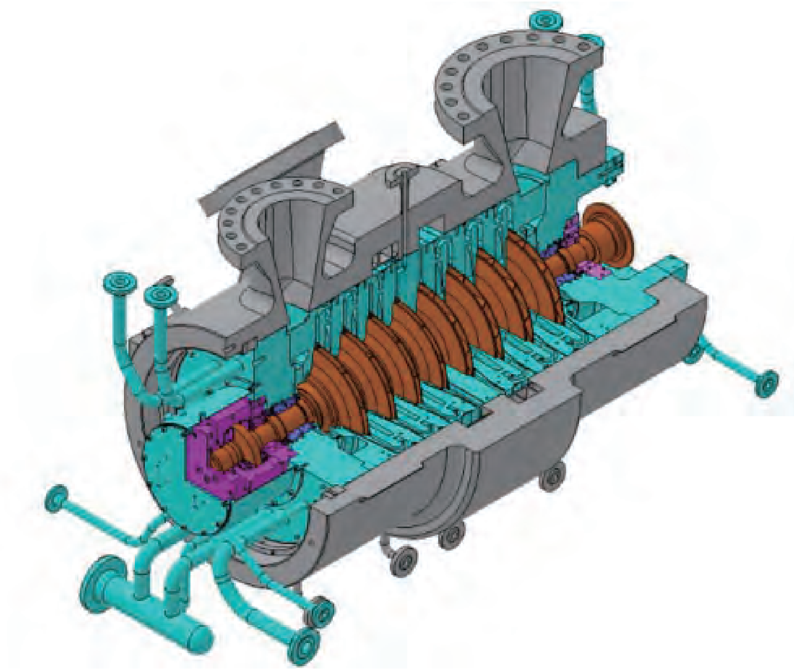


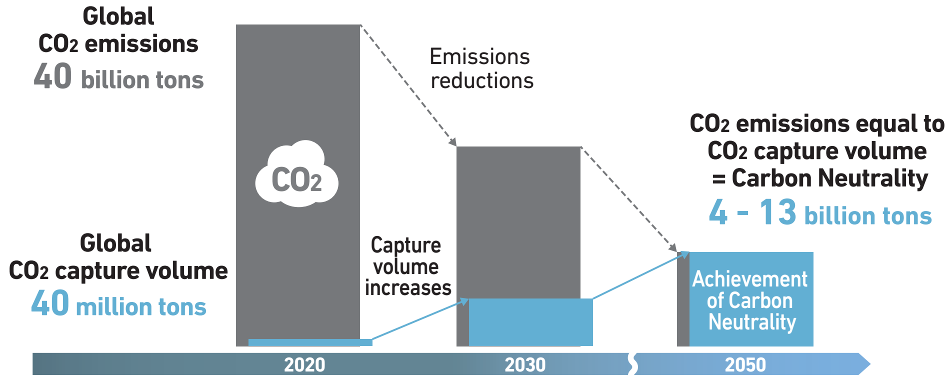
Figure 48 Hydrogen compressor

Japan **Liquid hydrogen pressure booster pump for hydrogen fueling stations** (Figure 49)

The implementation of fuel cell vehicles (FCVs) is expected to expand as the transportation sector decarbonizes. Efforts are being made to promote the use of FCV, and it is expected that the introduction of commercial vehicles such as FC trucks will be expanded to take advantage of FCV, such as long running distances and short filling times. Hydrogen fueling stations will need to be developed to supply hydrogen to these vehicles in the future. According to the Basic Hydrogen Strategy prepared by the Japan Ministry of Economy, Trade and Industry (METI), 1000 hydrogen fueling stations are planned for construction in Japan by 2030. Correspondingly, demand is expected to increase for liquid hydrogen pressure booster pumps, which can reduce energy consumption as well as save space and reduce capital expenses and running costs compared to the current compressor booster type equipment.
MHI has developed a new 90 MPa-class ultra-high-pressure liquid hydrogen pressure booster pump for use in hydrogen fueling stations. This high-pressure liquid hydrogen pressure booster pump has a reciprocating pump structure and is motor-driven (inverter-controlled for easy flow control) with explosion-proof specifications that prevent it from becoming a source of ignition even in flammable atmospheres. In order to handle liquid hydrogen, which is a cryogenic fluid that easily vaporizes, the pump is of the submerged type with a vacuum-insulated container in the suction section.
Furthermore, the pressure of the liquid hydrogen pressure booster pump has been increased to 90 MPa from 40 MPa, enabling more hydrogen fuel to be filled into FCVs in a shorter time. Currently, A long-term durability test is currently being conducted at a test site of FirstElement Fuel in the U.S., with the aim of commercialization around 2024.
MHI will contribute to the implementation of an environmentally-friendly hydrogen-based society by developing new solutions based on our cryogenic technologies acquired during the development of launch vehicles and marine-use LNG equipment.

Figure 49 Liquid hydrogen pressure booster pump for hydrogen fueling stations

In order to reduce the world's CO_2 emissions from the estimated 40 billion tons per year as of 2020 to Net Zero by 2050, in addition to the various reduction efforts currently being pursued, steps must be taken to capture around 4 to 13 billion tons of CO_2 emissions per year.



* MHI summary based on major reports (incl. McKinsey 1.5°C scenario, IEA Net Zero by 2050, IEA SDS, and IPCC)

Figure 50 Scenario for global achievement of Carbon Neutrality

The Paris Agreement, which was reached at COP21, included two main targets, the 2°C target – the goal to keep the global average temperature increase well below 2°C beyond pre-industrial levels – and the 1.5°C target – which seeks to limit the increase to 1.5°C. Each of these targets includes a carbon budget, or the total cumulative amount of CO_2 allowed to be emitted. The carbon budget under the 1.5°C target (i.e., emissions from the present until a 1.5°C increase is reached) is 400 to 500 billion tons, while the carbon budget for the 2°C target is estimated to be 1,150 to 1,350 billion tons. If CO_2 emissions proceed at the rate of 40 billion tons per year, the 1.5°C target will be reached in 10 years, and the 2°C target in 30 years.
CCUS is a concept that aims to reduce CO_2 emissions by 4.3 to 13 billion tons per year in order to reach Net Zero by 2050 by actively capturing and processing CO_2 in parallel with reducing CO_2 emissions. CCUS stands for CO_2 capture, utilization and storage. MHI will contribute to increasing the blue bars signifying CO_2 capture volumes as shown in Figure 50 with our CCUS and CO_2 solutions ecosystem initiatives.
CCUS will see a full-scale commercial launch around 2025. Large-scale CCUS projects have been announced in the U.K., Europe, the U.S., and Canada, where there are already mechanisms in place to encourage companies to invest in this technology. These systems include: subsidies for initial investment, operations, and CO_2 utilization such as recycled carbon fuels; regulated fees for CO_2 transport and storage; tax credits for CO_2 sequestration; and relatively high carbon pricing and carbon border adjustment mechanisms.
In 2023 in Japan, Independent Administrative Agency (JOGMEC Act) selected seven CCS projects, the design of public support mechanisms and dispensation under subsidy programs – such as the Green Innovation Fund – began to gain momentum, and full-scale feasibility studies on CCS and CCU are expected to get underway in the near future. It was stated in the interim report of the Long-Term CCS Roadmap that commercial CCS will start using storage within Japan by 2030.

The Breeze Concept

At MHI, we call our CCUS business concept the Breeze Concept, because we want to leave a world that still has cool breezes for our children in the 22nd century and beyond by keeping the rise in global temperatures as low as possible. Our motto for the Breeze Concept is "Solving CO_2 for Good." The Breeze Concept's vision is to pursue all possible methods to decrease CO_2 emissions today in all related areas, including technology, business, and social contributions, for the common cause shared by all the countries of the world.

Figure 51 The Breeze Concept mission statement

CO_2NTAIN, CO_2NNECT, CO_2NVERT

Within the Breeze Concept, we have selected three main areas of focus: **CO_2NTAIN**, **CO_2NNECT**, and **CO_2NVERT**. **CO_2NTAIN** refers to CO_2 capture and storage. **CO_2NNECT** refers to connections between participants (including MHI) in the CCUS value and supply chains, which are still in the planning phase. MHI has expertise related to engineering of LCO_2 carriers, compressors, liquefaction equipment, gas tanks, and port facilities. MHI is also working on CO_2NNEX, a platform that will digitally connect all links in the CCUS value chain. In the CO_2NNECT area, MHI will not limit ourselves to the simple supply of equipment and technologies. We will provide solutions services such as CO_2 capture, aggregation, transportation, demand and supply matching as well as intermediate and final storage as CCUS businesses in their own right. **CO_2NVERT** refers to the utilization CO_2. We will find value in CO_2, which is considered a nuisance to the recycling industry, and commercially distribute it. CO_2's value includes use as a raw material in carbon recycling, the environmental value produced by certified emissions reductions such as carbon credits, and the monetary effects of subsidies and carbon pricing schemes which provide incentives for emissions reductions and penalties for emissions. In addition to MHI's in-house carbon recycling technologies such as those for fertilizer, dimethyl carbonate, and methanol production, we are investing in startups that are developing new technological areas such as synthetic fuel (e-Fuel) production and the manufacture of chemical products using microalgae. Furthermore, through CO_2NNEX, MHI will contribute to the utilization of CO_2 and the expansion of CCUS by efficiently connecting the CO_2 demand with supply. MHI is also working to use CO_2NNEX to convert CO_2 into a valuable commodity by linking emissions reductions with carbon credits and also by providing quantitative evidence of the environmental contributions of CCUS with reliable data and relaying this to certification organizations.

In addition to existing CO_2 capture technology, MHI started demonstration tests for CO_2 capture technologies able to be applied to new types of exhaust gases. We will also develop technologies for long-distance mass transportation of liquefied CO_2 (LCO_2), thereby becoming a leader in the implementation of a CCUS value chain using these technologies. In addition, digital verification of the application of CO_2NNEX to actual CCS/CCU/CCUS systems has been underway since 2022. The aim of this effort is to implement a complete platform for the commercial launch of real CCUS systems. In the CCUS solutions and services area, MHI will explore ways to engage in CCUS beyond simple systems manufacturing by partnering with leading companies active in transportation, storage, and utilization and by creating our own services.

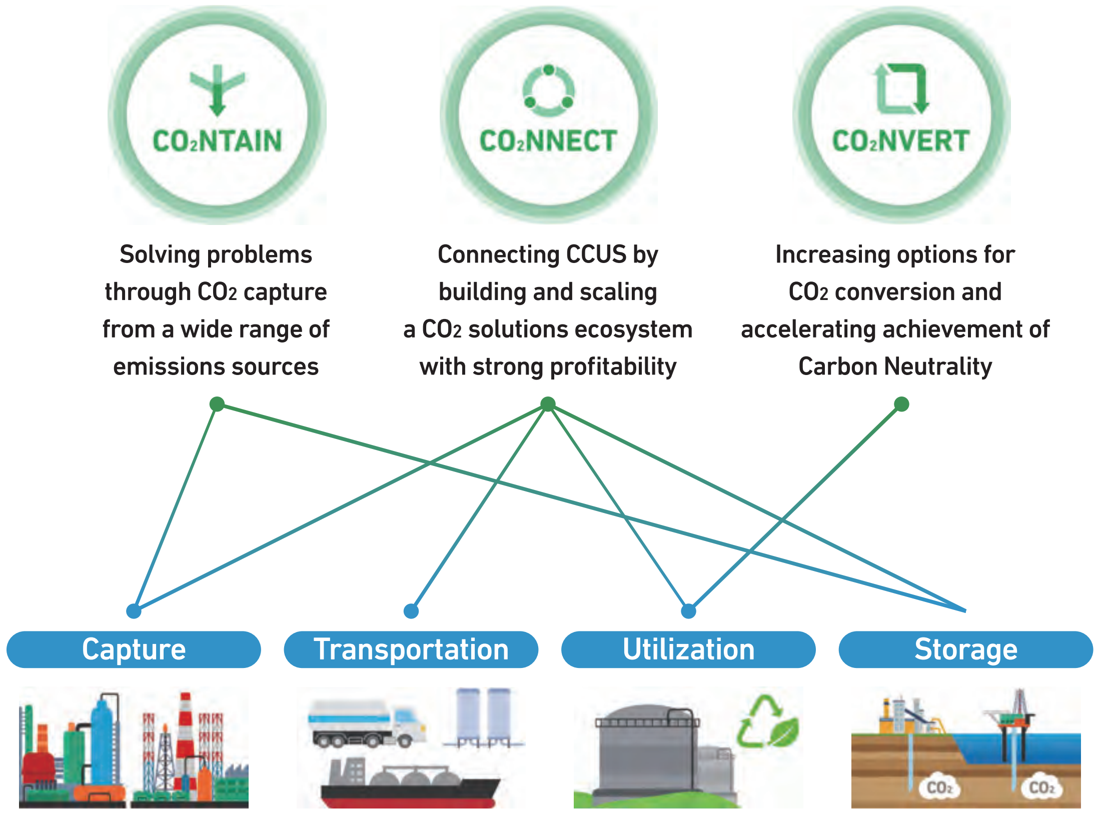


Figure 52 MHI's CCUS business areas

CO_2 capture systems (CO_2NTAIN)

CO_2 is captured from three major sources. The first is the CO_2 produced during the extraction of oil and natural gas. Second is CO_2 emitted during chemical manufacturing processes. The third is CO_2 contained in the exhaust gas generated when fossil fuels or fuels containing carbon components are burned. Since the 1990s, MHI has a proven track record in CO_2 capture from the second and third type of exhaust gases, and as of 2022, we have the world's largest share of CO_2 capture systems in commercial operation by volume. MHI's technologies for CO_2 capture are summarized in Table 5 below. Our strength lies in chemical absorption method technology.

Technology*	Characteristics	Development Status	Companies
Chemical (Liquid) Absorption	• CO_2 is dissolved into a liquid absorbent, separated from other exhaust gases, and absorbed through a reaction with absorbent components • Suitable for separation from combustion exhaust gas • Proven track record at high volumes (5,000 tons per day) • Amine-based solvents are frequently used	■ Commercially ready. Absorbent development, reductionof equipment costs (CAP/OPEX), and expansion of technology application scope are areas of focus.	MHI, Shell, Fluor, Aker, Carbon Clean, Toshiba
Solid Adsorption	• CO_2 is adsorbed onto a solid adsorbent's surface or through pores • After adsorption, CO_2 is desorbed (released) by heat or pressure • Some well-known adsorbents include activated carbon and zeolite, which are also used on the International Space Station	■ Commercially ready. Increasing equipment size, material development, energy consumption reduction, and expansion of technology application scope are areas of focus.	Air Liquide, Air Products, Svante, CO_2 Solutions
Membrane Separation	• CO_2 is separated from other gases using osmotic pressure • Suitable for separation from high pressure/concentration gases (Not suitable for capturing CO_2 from exhaust gas)	■ Commercially ready for natural gas separation. ■ Many new technologies, such as polymeric membranes, are still in the preliminary testing stage. Material development is an area of focus.	Air Liquide MTE

Table 5 CO_2 capture technologies

* MHI internal comparison of the commercialization status of three main CO_2 capture technologies

The KM CDR Process™, developed jointly with Kansai Electric Power Co., can reduce energy consumption by 30% compared to existing technologies. The process uses a proprietary amine-based CO_2 absorbing solution, KS-1™, which provides excellent CO_2 absorption and separation efficiency.
This contributes to lower operating costs for customers' CO_2 recovery equipment. In addition, the newly developed Advanced KM CDR Process™ and KS-21™ absorbent further improve CO_2 absorption and separation efficiency compared to KS-1™ and also reduce degradation of CO_2 absorbent during operation. MHI is thus working tirelessly to improve our CO_2 capture technology.
The KM CDR Process™, which uses the chemical absorption method, consists of a plant shown in Figure 53 below.
The exhaust gas from the left side of the diagram is cooled and enters the absorption tower in the center, where it comes into contact with the amine-based CO_2 absorption solution, which absorbs the CO_2. The amine CO_2 absorbent containing CO_2 is heated in the regeneration tower on the right side of the figure to separate (regenerate) the CO_2.
The separated CO_2 is removed from the top of the regeneration column, compressed, and transported to the next process. The purity of the CO_2 extracted is almost 100%, and the CO_2 recovery rate from the flue gas can exceed 99% depending on the equipment used.

https://www.mhi.com/news/211019.html

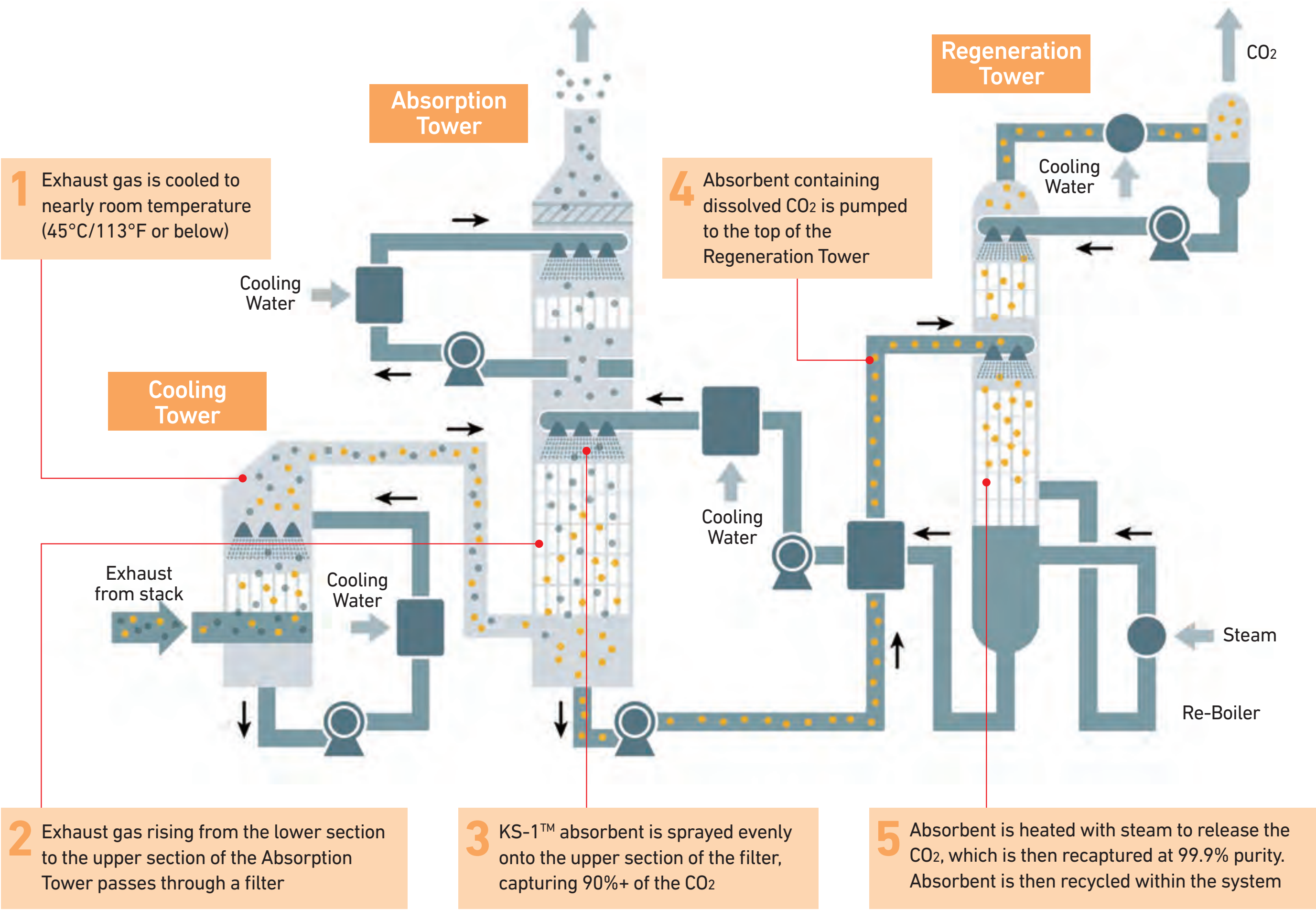


Figure 53 KM CDR Process™ plant configuration

MHI's specialty in CO_2 capture from flue gas is not limited to thermal power plants, as shown in Figure 54 below. MHI is expanding the application of our technology to a wide variety of emissions sources. These include waste incineration facilities, LNG production facilities, steel mills, cement plants, chemical plants, and ships. These are called hard-to-abate industries, because CO_2 emissions will inevitably remain despite efforts to reduce or eliminate them through fuel conversions. The degree of difficulty differs for each emissions source and depends on various conditions such as trace constituents in the exhaust gas, exhaust gas temperature, and space available for installation. The amount of CO_2 recovered also varies from ultra-large scale (several tens of thousands of tons per day) to very small scale (several hundred kilograms per day). MHI continues to develop comprehensive recovery technologies while keeping an eye on marketability.

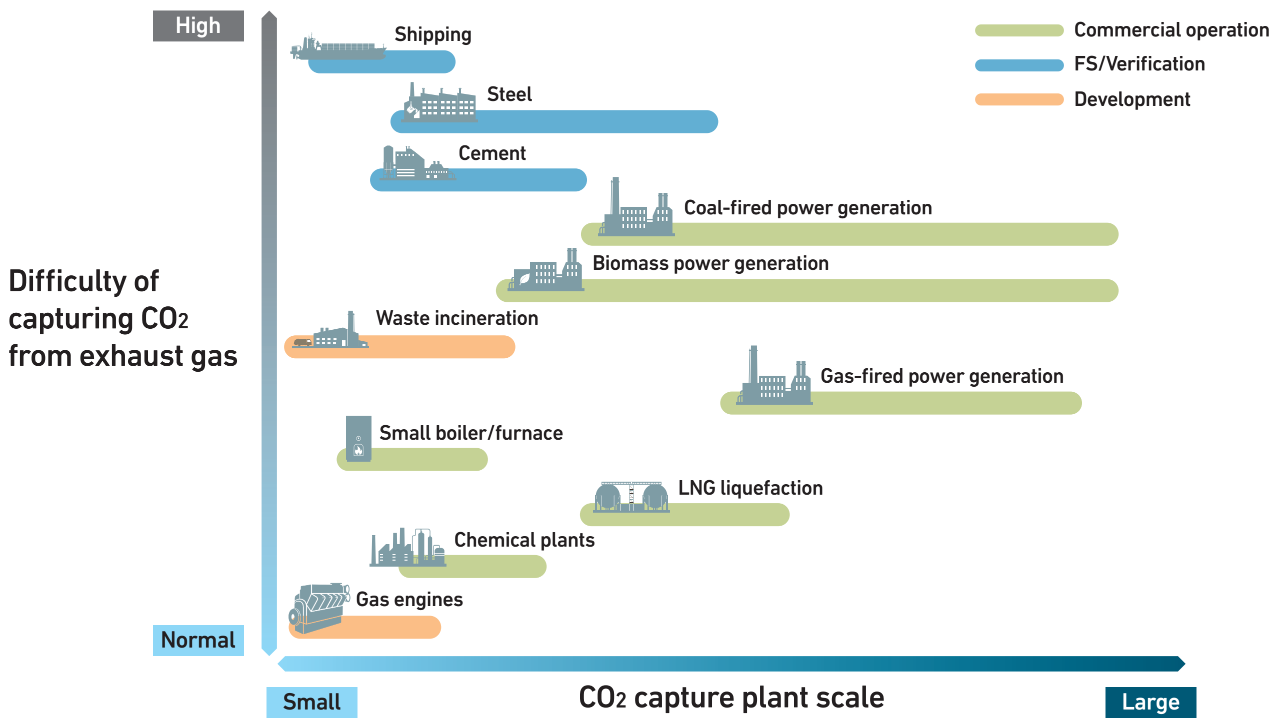


Figure 54 Various CO_2 emission sources MHI is considering for CO_2 capture application

Liquefied CO_2 (LCO_2) carriers

CCUS will require the transport of large amounts of CO_2. For example, at Humber CCS in the U.K. plans to transport up to 28 million tons of CO_2 per year through a pipeline to a storage site. Pipelines are the most common method of CCS transport currently being planned worldwide. While CO_2 pipelines themselves are not as numerous as natural gas pipelines, as of 2022, the U.S. already has approximately 8,000 km of CO_2 pipelines, and more are slated for construction. That said, several hundred kilometers of pipeline in a single supply chain is considered to be the limit from an economic standpoint.
However, in many cases, it is difficult to acquire land for pipeline construction, which may cause environmental pollution, and flexible transfer routes often cannot be selected.
Small amounts of CO_2 will still be transported by truck or rail. They will be transported in high-pressure gas tanks or LCO_2 tanks. Dry ice will be transported in containers. The volume of these truck and rail shipments will be limited, ranging from a few tons to several dozen tons. Contrastingly, it would be very difficult for trucks or railroads to transport all of the millions to tens of millions of tons of CO_2 per year that will be generated by CCUS.

Therefore, large carrier ships, such as those currently used in the transport of primary energy, will be needed to transport large amounts of CO_2 over long distances such as a few thousands of kilometers. Currently in Europe, LCO_2 carriers with capacities in the 1,000 to 2,000 ton range are used to transport CO_2 for use in food. MHI assumes that the demand for large LCO_2 carriers of the same size as those used to transport primary energy is likely to increase in the future. CO_2 aggregated by pipeline in areas with high emissions will be liquefied at ports and transported by LCO_2 carriers to storage sites for underground injection, or transported to industrial complexes where it will be recycled.
MHI is developing liquefied CO_2 handling technology that can tranport large amounts of LCO_2 at low cost. In addition, in November 2023, we built one demonstration ship for transporting liquefied CO_2, which will be used for the "CCUS R&D and Demonstration Related Project / Large-scale CCUS Demonstration in Tomakomai / Demonstration Project on CO_2 Transportation" (the demonstration projects) being conducted by Japan's New Energy and Industrial Technology Development Organization (NEDO).

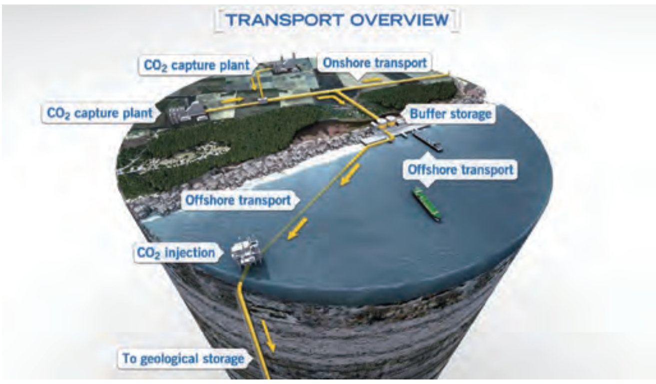
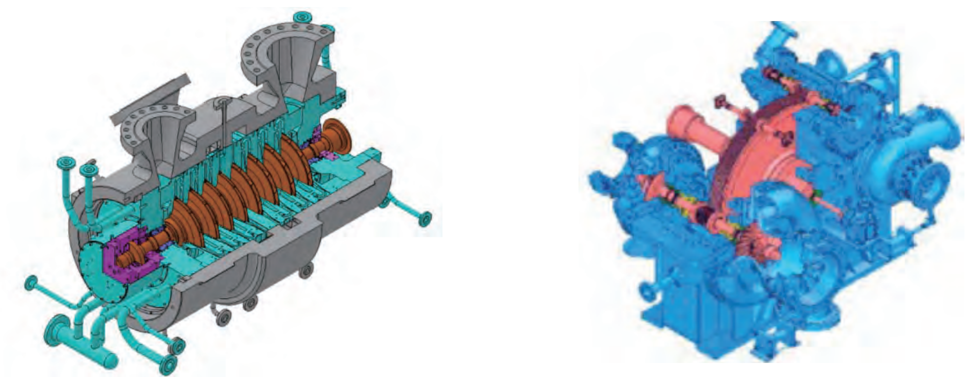


Figure 55 Over view of CO_2 transportation
Source: "Fact Sheet: Transporting CO_2," Global CCS Institute

Figure 56 "EXCOOL", a demonstration test ship for LCO_2 transport

CO_2 compressors

CO_2 gas must be efficiently pressurized in order to transport it from the various industrial facilities where it is collected via pipelines to storage sites. Mitsubishi Heavy Industries Compressor Corporation (MCO) has single-shaft, multi-stage CO_2 compressors as well as geared models, which offers optimal solutions tailored to the capacity, application, and storage site.
Single-shaft, multi-stage compressors are designed to hold multiple impellers in a single casing and are suitable for high-pressure applications. High boss ratio impellers and strong damping seals are applied to achieve stability of the rotating shaft (rotor) under high pressure.
Geared compressors optimize the rotation speed of each impeller and intermediate coolers in each stage for high efficiency. Based on the experience of delivering one of the world's largest geared compressors to the Petra Nova Carbon Capture Project in the U.S. in 2017, MHI is working on compact, modular versions of this compressor and peripheral equipment in order to minimize on-site installation workdays and to reduce plant construction time.



Single-shaft, multi-stage model

Geared model

Figure 57 CO_2 compressor

CO_2NNEX

CO_2NNEX is MHI's proprietary digital platform, on which the CCUS Smart Grid will be built. The system will use a variety of IT technologies, including IoT to connect CO_2 smart meters; blockchain technology to provide proof of environmental value in a tamper-proof manner; traceability technology to track CO_2 sources, transportation routes, and usage; and API technology to enable credit authentication and integration with other systems. MHI is developing this system in collaboration with IBM, which has a great deal of experience in similar IT infrastructure.
The amount of CO_2 in circulation will increase more than 100-fold by 2040, and small- and large-scale CCS, CCU, and CCUS chains will be built to meet this demand. All of these are primarily aimed at contributing to the environment with CO_2 reductions, and will require tracking and quantitative proof of CO_2 capture, transport, utilization, and storage.

We believe that the CCS/CCU/CCUS chains will be linked to each other to maximize the value of CO_2 and to correctly transfer environmental value to distant locations. Captured CO_2 will sometimes be sold and other times stored at the cost of the emitter. CO_2 absorbed directly from the atmosphere through direct air capture (DAC) and that captured from biomass boilers – when properly sequestered – will increase the carbon budget itself and be carbon negative, thus increasing the value of the CO_2, which will be traded at a higher price than that from others sources. CO_2NNEX will also become a marketplace for the purchase and sale of CO_2 of different values, which will ultimately improve the cost efficiency of the entire CO_2 solutions ecosystem by correctly adjusting supply and demand.

Figure 58 CO_2NNEX concept illustration and PR video

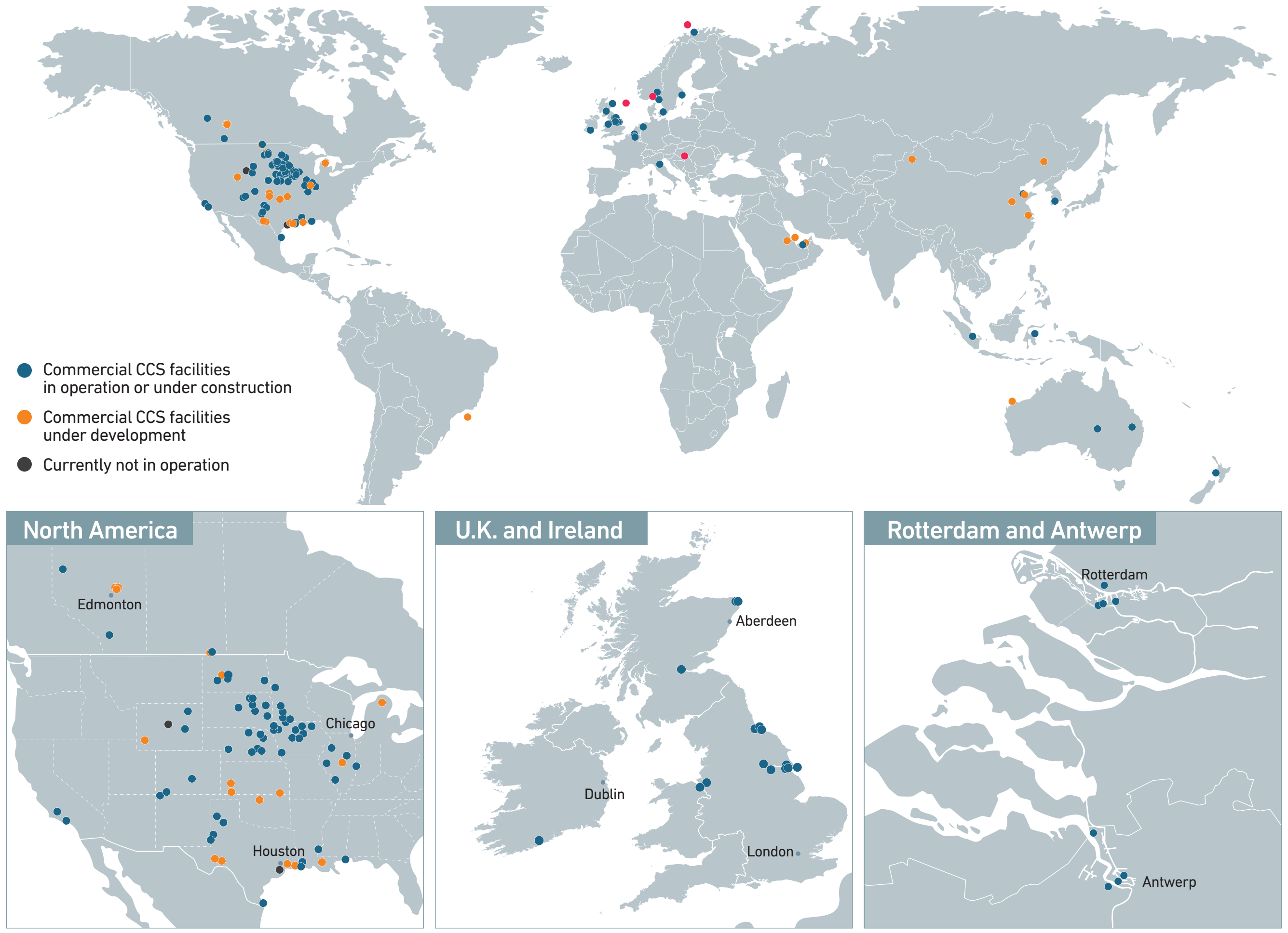


Figure 59 Map of large-scale CCS projects Sourse: "Global Status of CCS in 2021," Global CCS Institute

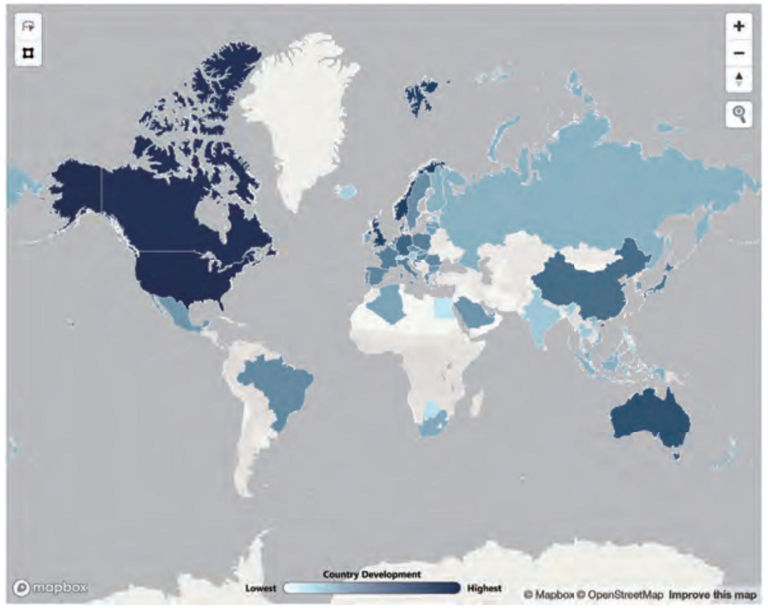


Figure 60 Institutional readiness for CCS implementation
Source: CCS Readiness index, Global CCS Institute

CO_2NVERT CO_2 utilization technology

MHI is strengthening its cooperation with startups in the field of CO_2 utilization. By combining MHI Group's CO_2 capture technology and value chain solutions with startup CO_2 utilization technology solutions, MHI is aiming for the realization of a CO_2 ecosystem.

Infinium (Electrofuels™)

Through MHIA, MHI is investing in California, U.S.-based Infinium. Infinium's Electrofuels™ is a revolutionary technology that generates clean fuel from CO_2 and renewable energy. This proprietary technology enables fuels for airplanes, ships, trucks, and other vehicles to be replaced with carbon-neutral fuels. By boosting its relationship with Infinium, MHI aims to strengthen and diversify its expansion into the field of CO_2 capture and utilization amid the energy transition (the conversion to low environmental-impact energy sources).

Cemvita (using CO_2 in biotechnology)

Through MHIA, MHI has invested in Cemvita Inc. (Cemvita), a Houston-based startup that utilizes innovative synthetic biology to decarbonize heavy industries such as chemical manufacturing, mining, and oil and gas. Cemvita provides innovative CO_2 utilization solutions through biotechnology for heavy industries. Its bio-manufacturing platform mitigates emissions from traditionally energy-intensive chemical and catalytic conversion processes by operating under ambient temperature and pressure. Additionally, this same technology can turn polymer production into a low-carbon activity by utilizing CO_2 as a feedstock, a crucial step in building a circular carbon economy.