2023

Transition Whitepaper 2023

AN MUFG PERSPECTIVE ON
ENERGY TRANSITION IN JAPAN:
WHERE WE ARE AND WHERE WE ARE HEADED

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Preface

The critical role financial institutions play in helping the global community achieve carbon neutrality prompted MUFG to publish our first Transition Whitepaper in October 2022, showcasing emissions reduction initiatives taken by Japan's leading public and private institutions. It emphasized that (i) individual countries' paths to carbon neutrality will differ depending on geographical characteristics, the structure of industries that cause greenhouse gas (GHG) emissions, and unique energy composition; and (ii) a holistic economic perspective is essential when considering reductions in carbon emissions from industrial sectors, given their interdependence.

Carbon neutrality has consistently been a hot topic in my conversations with MUFG stakeholders and CEO peers throughout the year since we published our whitepaper. In these conversations, I have often used a mountaineering analogy: Although each route of ascension depends on one's unique starting point of national and regional circumstances, a common goal among all ascendants, regardless of route, is to reach the same summit of net-zero GHG emissions in 2050.

Around the time our whitepaper was published, major advanced economies – including the United States, the European Union, and Japan – updated their carbon neutral policies and their pathways, where available. This new MUFG Transition Whitepaper 2023 touches on the policies of major nations and regions, analyzes their starting points, and presents technologies needed for Japan to progress on its pathway – including specific efforts of industrial players – with a strong focus on power and heat.

Now that Japan has stirred from its pandemic dormancy, I myself have been eager to increase face-to-face human interactions, domestically and abroad. I sense a consensus emerging that meeting in person promotes mutual understanding – which is the key to promoting a just and orderly transition to a carbon-neutral future. This includes listening to stakeholders carefully and challenging them respectfully. This is what MUFG has done in discussions with various stakeholders since the release of our first transition whitepaper last year, and I have faith in the effectiveness of our common-engagement approach to customers, shareholders, communities, and other stakeholders.

MUFG draws understanding from our relationships with customers in a wide range of industries and through our strong global network. By assimilating content of our discussions with this cross-industry customer base and global network – and making connections among various parties' points-of-view – MUFG will continue our commitment to deepen mutual understanding on carbon neutrality, fulfill our responsibility to create cross-sector global consensus, and work toward promoting a just and orderly transition into a carbon-neutral society.

Mitsubishi UFJ Financial Group, Inc.

President & Group CEO

Hironori Kamezawa

Acknowledgement

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Contents

Table of Figures

Executive Summary

As countries and companies around the world act to reduce their greenhouse gas emissions, the journey toward carbon neutrality is well underway. Meanwhile, the world is in a transition phase from a linear economy, built on take-make-waste approaches, to a circular economy focused on reuse, recycling and recovery. Over the next few years, global efforts to mitigate and adapt to warming will come together with fundamental changes toward true sustainability, creating both socioeconomic risks and opportunities. The plans and decisions taken now will define both the pace of progress and the world's ultimate success in achieving the carbon neutrality goal of a sustainable society.

As the third largest country by GDP, Japan will have a significant role to play in the coming transition. Through the efforts of its citizens, companies, and policymakers, it can contribute both to reducing domestic emissions and shaping the carbon neutrality agenda in Asia and beyond. Stakeholders across the economy have a role to play, supported by financial institutions as originators and facilitators of capital.

This whitepaper discusses the role financial institutions can play in the context of the challenges ahead. Building on MUFG's Transition Whitepaper 2022, it sets out our unique perspective on the factors that will define the transition, and highlights how technologies and systems may evolve. In the spirit of our "whole of economy transition," this whitepaper builds on government commitments and insights gained through our client engagements, including those in high-emitting sectors. We focus on seven technologies mainly relevant to emissions reduction in electricity and heat that will move the Japanese economy toward carbon neutrality, alongside the structural and regulatory conditions that will support effective change. MUFG committed to achieve Net Zero in our finance portfolio by 2050, and this can be achieved only through emissions reduction in real economy. Based on MUFG's theory of change: "our clients' emissions reductions are our emissions reductions," we are committed to constructive and continuous dialogue with our stakeholders, creating opportunities for mutual understanding and economic progress to achieve sustainability. With our corporate purpose of "committed to empowering a brighter future," we reassert this commitment to creating a sustainable future.

The whitepaper consists of seven chapters:

1. MUFG's engagement philosophy for energy transition and whitepaper objective

New policies around the globe signal an accelerating shift from setting climate targets to funding and implementation, amid a pace of innovation not seen in decades. Still, $100-150 trillion must be unlocked globally by 2050 to align the global economy with credible pathways to carbon neutrality.

Each country will take a nuanced approach, and there is no single winning strategy that can be applied globally. Japan's carbon neutrality strategy differs from those in the US and Europe, but no two economies will take the same approach given the different context.

Japan is on the verge of economic and industrial climate mobilization, the vision for which is contained in its Green Transformation (GX) Basic Policy, published in February 2023. GX earmarks JPY150 trillion (approx. $1.1 trillion) of public-private financing for the transition over the next 10 years, with Japan's 22 sectors and technological activities included. Industrial companies are primarily responsible for development and deployment of lower- or zero-emitting technologies. This whitepaper outlines a technology development status and roll-out the Japanese government's strategy. Our Transition Whitepaper 2022 discussed the energy transition as a high priority to accelerate other sectors' journeys and reasons for Japan requiring a diversified approach to carbon neutrality. Building on these findings, our Transition Whitepaper 2023 focuses on carbon neutral path for electricity and "whole of economy transition strategy" for energy. In this whitepaper, MUFG aims to help international partners and stakeholders understand a sub-set of the technology options associated with Japan's transition—and the opportunities they create.

The GX Basic Policy is just a beginning; it provides technology options suitable for Japan to achieve 2030 targets and the level of investment expected. Discussions on details of incentives and enablers are under way. As one of the largest banks in the world and the largest in Japan, MUFG is committed to contributing to global climate action by building momentum for new capital flows toward carbon neutrality solutions in Japan, Asia, and the rest of the world. Our engagement philosophy is to "encourage and enable" our clients' transitions and by doing so, contributing to creating new markets for innovative technologies to accelerate further transition in the real economy. We listen to our clients, respectfully challenge their plans, and assess their business viability.

2. Progress in carbon neutrality as a first step of journey towards sustainable society

The world is shifting towards a sustainable society, and the whole of economy transition to carbon neutrality needs to reflect this dynamic process of industrial and societal change including other sustainable components including circular economy. As disclosure of Scope 1-3 emissions of goods has become mainstream, companies need to periodically review and adjust their emissions profiles, with consideration of "interdependency" among sectors horizontally through value chains and vertically through electricity, heat, and carbon sharing systems, to optimize a circular loop for the whole of the economy.

Though countries share the same goals of alignment with the Paris Agreement, the starting points and constraints vary significantly. As a result, while there is a broad similarity in the overall direction, comparing various policies reveals distinct approaches tailored to local conditions. These differences are evident in specific strategies, such as the selection of technologies, the acceleration of technology value chain development through goal setting and regulatory frameworks, support for demand creation, and the mitigation of financing uncertainty. To highlight these differences in the policy frameworks and approaches to GHG emissions reduction, this whitepaper classifies low-emissions technologies into the following three categories:

- **Long list**: A universally common set of technologies for deployment (integrated list of 167 technologies that could be deployed by 2035)
- **Middle list**: Technologies accepted or recognized by policy documents of each country for deployment with reasoning (giving a clear signal on the direction of the energy transition)
- **Short list**: Technologies in the middle list that will receive deployment support, or committed for support within roadmaps, and other forms of incentives or regulations

Climate policies in countries and regions, such as the US, Europe, China, and ASEAN, have a clear connection between ambition and supported technologies (the "middle list") with differences in implementation approaches in their regulations. However, they vary in their structures. Europe uses both "carrots" and "sticks"—sticks including tighter regulation on disclosure. The US, on the other hand, uses a market-based approach to encourage companies with a wide range of technology options with minimum eligibility requirements. Meanwhile, Japan's approach is characterized by its emphasis on practical effectiveness rooted in viability assessments of specific technologies. The Japanese government's approach is first to publish intensive plans developed in collaboration with the private sector, outlined in the government roadmaps for various sectors and a list of technologies requiring development and deployment ("short list"). This divergence in planning philosophy between Japan and the EU/US underscores the increased importance of communicating Japan's roadmap to carbon neutrality to authorities and stakeholders outside Japan. This whitepaper will list the technologies Japan requires, considering its unique geographical and infrastructural characteristics, while also highlighting their vital role.

The GX Basic Policy partially serves as the middle list and provides some information on those technologies. However, it needs supplementary information on rationale behind the choices of the technologies to further enhance the predictability of financing opportunities for GX technologies. This whitepaper considers technologies in the middle list as “positive technologies” supported by the Japanese government, and elaborates on how these technologies will enable the country’s carbon neutrality to contribute to the global conversation.

3. Contextual differences in pathways to carbon neutrality for each country

The technologies that will work best in a national context will be contingent on the most promising pathway to carbon neutrality driven by the energy needs and differences in industrial compositions and local conditions in each country. While emissions by sector vary from country to country, most economic sectors are connected through their shared dependency on electricity and heat. However, planning the decarbonization of electricity and heat production across an economy is complex, and the need for considering circular use of resources and CO_2 adds further complication.

The International Energy Agency (IEA) recognizes a common set of levers for reducing energy-related emissions that are applicable globally. These include 1) Behavior change and avoided demand, 2) Energy efficiency, 3) Hydrogen-based fuels, 4) Electrification, 5) Bioenergy, 6) Wind and solar, 7) Other fuel shifts, and 8) CCUS. Countries will need similar technologies that focus on reducing emissions from electricity and heat in their journeys toward carbon neutrality. However, the exact approach to applying these levers differs influenced by various factors such as availability of natural resources and existing energy infrastructure and assets.

Each country’s pathway to reducing emissions from electricity and heat is driven by the overall cost of deploying and integrating new renewable capacity. The impacts of a country’s natural resources and existing energy infrastructure will be reflected in overall costs (energy production costs (also referred to as levelized cost of energy), system costs, and decommissioning costs). While the production costs of renewables will decline with technological and operational maturity and scale-up, system costs will rise with the need for additional backup power supply, enhanced transmission, distribution, and storage. There will be cost trade-offs, and taking a comprehensive approach is important to balance impacts and costs.

When aiming to maximize the adoption of renewable energy across various countries and regions, there are two pillars as articulated below:

- **Pillar 1 [Domestic renewables]**: Maximizing domestic renewable energy deployment and usage, while fostering CO_2-free power generation. The level of renewable energy deployment will be driven by total costs relative to existing solutions in each region, including energy production costs, system costs, and decommissioning costs. While average production costs for renewable energy may decline as the market grow, high system costs may overtake those reductions in the cost.
- **Pillar 2 [Importing foreign renewables]**: Enabling international renewable utilization by importing either directly in a form of electricity via grid connection or converted to appropriate carriers for transportation for emissions reductions beyond Pillar 1.

Pillar 2 may result in building a global value chain for renewable energy, and renewables costs and grid connectivity of countries and regions may become critical factors. These two factors can further categorize countries into four types:

1. **Lower cost, higher connectivity countries** (such as Brazil, China, Denmark, India, and the US) can generate renewable electricity and deliver it widely via power transmission. The countries have accessible renewables potential and sources of demand. This connectivity sets up some countries to be net exporters of electricity.
2. **Lower cost, lower connectivity regions** (such as Argentina, Australia, Chile, and Mexico) can generate renewable electricity cost-effectively but currently lack the ability to export globally. They are likely to be exporters of hydrogen-based and biogenic fuels.
3. **Higher cost, higher connectivity regions** (such as France and the UK) are not able to generate renewable energy as cost-effectively as other regions. However, their grid capacities may enable access to renewables elsewhere.
4. **Higher cost, lower connectivity regions** (such as Japan, Vietnam, and South Korea) are not able to generate renewable energy as cost-effectively as other regions. Nor are they able to access renewables from other regions via the grid. Low-carbon fuel imports offer a solution.

Japan, where Pillar 1 has already reached a certain level, ranks third in the world in installed solar and wind capacity and ranks first when viewed through the lens of available usable land. Since capacity is already installed in readily accessible locations, it is now necessary to install wind and solar in less suitable locations, including rooftops and the deep sea. The overall cost of renewable energy becomes high, and at that point, maximizing adoption through international trade becomes essential. This is the reason why Japan has expanded into engaging with Pillar 2 in parallel. However, the grid system in Japan, unlike that of Europe, is isolated and cannot be connected to other countries to enable electricity import (category 4). This requires Japan to seek for alternative methods to import renewables in a form such as hydrogen, while continuing to make innovation in renewable energy technology to augment Pillar 1.

Japan's strategic priorities reflect building a global renewable energy value chain at scale. MUFG recognizes the value that can be delivered through an approach that delivers global climate results through economic collaboration and shared development. In particular, economic collaboration and development can bring together developed and developing economies in a shared mission. To achieve global decarbonization, each country should maximize its domestic renewables potential while supporting global efforts to develop renewables value chains.

4. Outlining Japan's Pathway to Carbon Neutrality

The Japanese government has pledged to reach a 46% reduction in greenhouse gas emissions by 2030 and carbon neutrality by 2050. Reflecting the Japanese government's "S+3E principles" (Safety + Energy security + Economic efficiency + Environmental sustainability) with energy security as the highest priority among others, the GX Basic Policy leverages Japan's unique position as a highly industrialized island to deliver nationwide emissions reductions through centralized planning. A package of 22 sector roadmaps developed based on viability testing of specific technologies─both existing and innovative─through public-private collaboration will be achieved by optimizing combinations of technologies for implementation with incentives and financial support to establish necessary infrastructure. From energy perspective, these incentives create opportunities while acknowledging the country's relatively higher renewables costs, switching costs, and lower grid connectivity.

Japan plans to utilize seven "positive technologies" relevant for electricity and heat for high-emitting sectors that will play a critical role in moving the country toward meeting its carbon neutrality target. These are elements of two pillars; it is expected to scale Pillar 1 or domestic renewables (mainly solar and wind) to make up 50-60% of the energy mix by 2050, accompanied by thermal energy paired with CCUS and nuclear (30-40%). Under Pillar 2, hydrogen-based and biogenic fuels, particularly hydrogen and ammonia, will account for 10% of the energy mix by 2050.

Within Pillar 2 alternatives, three solutions are uniquely critical for Japan to achieve carbon neutrality: mono-firing/co-firing of hydrogen-based and biogenic fuels, marine shipping of H_2 and CO_2, and e-methane to create an energy carrier. While mostly similar to other country's pathways, Japan's diverges through the application of these three technologies:

- **Mono-firing/co-firing of hydrogen-based and biogenic fuels**: As Japan not being connected to an international grid, renewables need to be augmented with flexible power to ensure a stable power supply. The country is committed to mono-firing as a long-term solution and co-firing as transitional solution by replacing fossil fuels in thermal plants with hydrogen/ammonia either completely or partially. The cost of repurposing infrastructure should be relatively low, which would contribute to minimizing the cost of operating a stable power system.
- **Marine shipping technologies and services for liquified H_2 and CO_2**: Marine shipping of gas (such as hydrogen fuel and captured carbon) may be a potential option for Japan to establish a global supply chain. Hydrogen that is manufactured overseas can be directly shipped to Japan or converted to carriers such as ammonia and then shipped. Some of the captured CO_2 in Japan may also be transported by sea, due to long distances between capture and storage sites. Japan intends to further reduce emissions from industries and the power sector through CCUS.
- **E-methane**: Captured CO_2 can be a useful resource that can be transformed into synthetic fuels, such as e-methane to replace fossil fuels. This process, known as methanation, benefits households/industries that cannot be easily shifted to be electrified. For Japan, where energy resources are scarce, such usage of CO_2 will contribute to self-sufficiency.

These solutions allow Japan to advance technological innovations and scale the global value chain for both H_2 and CO_2. The value chain will also contribute to effective utilization of H_2 and CO_2 in industries through CCU and potentially result in lower GHG emissions.

Historically, Japan's distinct energy needs have served as a catalyst for global energy innovation, such as in the development of the global liquified natural gas (LNG) supply chain. The alternative represents Japan's commitment to develop a new global energy supply chain built on carbon neutrality. It represents an important early signal of demand for hydrogen-based and biogenic fuels—a commitment that can encourage financial support, innovation, and scaling at each point in the supply chain.

Key considerations could influence the deployment timeline. Technology can develop at faster- or slower-than-expected speeds. In addition, deployment could be inhibited by local dynamics, such as sensitivities around land usage. Geopolitics can shift, as is evidenced today by the growing demand for LNG and the rising focus on extending the operational life of nuclear plants globally.

5. Japan's Positive technologies

The GX Basic Policy covers both existing and innovative technologies for the 22 sectors. Among those, seven positive technologies highlighted in this chapter will play a critical role in supporting Japan's energy transition for electricity and heat (mainly on supply side) that need significant innovation. Those technologies can be sorted by the two pillars:

- **Pillar 1**: Technologies that enable the expansion of domestic renewable energy generation and usage with other domestic means to balance energy supply and demand, specifically (1) wind, (2) solar, (3) power transmission and distribution (4) nuclear, and (5) industrial electrification.
- **Pillar 2**: Technologies and infrastructure that enable Japan to access global renewable energy sources and carbon storage sites globally. Within this pillar, Japan will utilize (6) hydrogen-based and biogenic fuels such as hydrogen and ammonia, and (7) CCUS.

The viability of Pillar 2 Japan is pursuing may be affected by the progress to be made alongside three solutions: hydrogen-based fuels for mono-firing and co-firing, marine shipping of fuels and CO_2, and e-methane. Seven technologies listed in this chapter are highlighted as they are reflecting unique situation of Japan. They are supplemented with other technologies such as geothermal, hydro power, biomass energy, energy savings, fuel switching, demand-side measures, etc. Listed under the GX Basic Policy.

Concerted efforts of government roadmaps, private industry commitments, and policy support to align public and private sector initiatives will create a credible pathway toward implementation.

6. Supporting sustainable growth through cross-industry collaboration

Carbon neutrality is a critical piece of a broader sustainability ecosystem. Pathways to carbon neutrality must consider, in addition to other aspects, including circularity, to be in line with overall sustainability. To deploy and disseminate the positive technologies, two steps are required: 1) market creation and maturation through government funding, and then 2) private sector's independence from government support achieved by the ability to pass on costs to end users. Japanese government has earmarked JPY20 trillion for early-stage technology investment through GX Economic Transition Bonds for 1), and has established mid-to-long-term cost (reduction) targets for each technology coupled with introducing carbon pricing for 2). However, energy costs are relatively high in Japan compared to the rest of the world, and it is not clear which energy sources will have a cost advantage in future. Each technology presents its own cost curve, which may become further complicated due to demand for alternatives (e.g., hydrogen-based, biogenic, and synthetic fuels) to replace fossil fuels-based feedstock. Japan needs to further improve its overall productivity and raises income level to pass on costs to end users.

Japan, which has always faced energy supply and land constraints, has focused on developing energy-saving technologies as well as finding effective use of energy using recovered heat. One example is waste to energy solution, by improving recovery rate of waste heat for reutilization and eliminates the need for landfill sites, which are scarce due to land limitation. Another example is waste utilization in the cement industry. The industry accepts a wide range of wastes and by-products and utilizes approximately 26.2 million tons annually or approximately 5% of the total waste generated in Japan. In addition, Japanese companies have a history of not only working to reduce their own emissions but also contributing to CO_2 emissions reductions (avoided emissions) by developing energy efficient products. Japanese government's Green Innovation Fund takes these country-specific aspects into consideration and encourages the development of new innovative technologies to achieve the country's emissions reduction target for 2030 while maintaining the economic growth.

The development and introduction of new energy supply technologies and refinement of energy-saving and demand technologies to effectively recover waste heat and materials will accelerate Japan's journey toward carbon neutrality, as well as supporting the international community in its efforts to do the same where appropriate. These collaborative efforts through value chains may need to be deepened and expanded to shift toward a more circular and sustainable economy.

7. MUFG's role in fostering a sustainable society

Swift deployment of emissions reduction technologies is urgently needed to achieve carbon neutrality by 2050. The GX Basic Policy laid out the action plan until 2030 with roadmaps for Japan. It will further polish its design to minimize the social/financial cost associated with a whole-of-economy transition. By harnessing the seven promising technologies discussed in this whitepaper while continuing to improve energy efficiency and scale renewable energy, Japan can progress toward its carbon neutrality ambition.

As a commercial bank actively and directly lending in the primary market to clients across the industries, MUFG has a role to facilitate a whole of economy transition in Japan. Our objective is to actively support all stakeholders involved in the journey toward carbon neutrality. In this sense, commercial banks have an outsized role and responsibility to finance the Net Zero/carbon neutrality transition, especially in countries where the primary market plays a key role in corporate finance.

For the effective deployment of the technologies, many of which are still in the development stage and require substantial capital mobilization, we are committed to providing the necessary funding to viable business opportunities to ensure the safety and soundness of our operations. To achieve this, we need a credible transition that combines three elements as below:

- **Legitimization**
  Framework to encourage the private sector to respond to climate change by establishing legally-binding regulations and rules. Legitimization will foster awareness in terms of selection of technologies required in the near term for the purpose of longer-term emission reductions and will increase awareness and predictability among stakeholders.

- **Incentivization**
  Mechanisms to attract external capital by providing incentives, including the use of public funds for the deployment and roll out of new technologies that contribute to carbon neutrality.

- **Evidence with integrity**
  Mechanisms to regularly monitor and report company's commitments to carbon neutrality based on transparent evidence of its own emissions reductions (or avoided emissions, if appropriate) and in the deployment and roll out of new technologies. This allows banks to monitor the progress of emissions reduction, which in turn will reduce banks' financed emissions.

The path to technology commercialization is not linear; in the early stages of the market creation phase, commitment to ascent technologies entails significantly more risk. Funding tailored to technological readiness is needed at each stage. Private and public partnership will be key to unlocking technological potential. While government can de-risk early-stage development, financial institutions will provide funding during the market scale-up and market maturity phases. To achieve the ambitions in the Paris Agreement, it will be critical for government, industry, and financial institutions to work in concert.

MUFG continues to play an active role in building a mutual understanding between Japan and the rest of the world regarding Japan's carbon neutrality commitment and pathway with detailed insights with deployment timelines in the real economy to enhance their predictability. We will also support a whole of economy transition in line with national and sectoral pathways, as well as the pathways developed by individual companies in Japan, Asia, and globally, along with continued checking of their credibility through our transition plan assessment lens of legitimization, incentivization, and evidence with integrity including by seeking evidence of progress and promoting reporting and transparency.

Financial institutions have a critical role to play in supporting the global energy transition by providing new money. MUFG is dedicated to collaborating across sectors and industries to enable this global transition.

With policies in place in Japan and globally, the world's attention shifts toward tangible climate action—and the financing required to enable it. MUFG will play an active role in these activities in Japan, Asia, and globally though our capability to provide new finance to corporates and projects. In our whitepaper 2022, we outlined that we would engage proactively in the formation and implementation of Japan's strategy. Meanwhile, our engagement with clients has allowed us to develop our "transition plan assessment lens." MUFG's role naturally sits between the Japanese government and global industry, as a bridge to the finance industry in line with the government's priorities.

With these evolving landscapes, MUFG recognizes the importance of engaging with high-emitting sectors and supporting their transitions through the provision of financial solutions. Financial institutions, especially banks, have the critical role to play in supporting the global energy transition by providing new money in the rollout of the clean technologies. MUFG is committed to collaborating across sectors and industries to enable this global transition.

1. MUFG's engagement philosophy for energy transition

MUFG's engagement for the energy transition

The transition to a sustainable society requires collaboration between the financial industry and actors in the real economy, as well as cross-sectoral collaboration. We hope to connect relevant stakeholders so they can act with us to support the journey, and the whitepaper is a manifestation of this thinking. As industries take steps and implement new technologies, and governments establish climate policies and mobilize capital, financial institutions can facilitate dialogue and lay the groundwork for cross-sector collaboration and public-private partnership.

The technologies and strategies discussed in this whitepaper reflect MUFG's commitment to achieving Net Zero emissions in our finance portfolio by 2050, and our conviction that we cannot do this alone. In the spirit of our "whole of economy transition," the whitepaper builds on government commitments and insights gained through our client engagements, including those in high-emitting sectors. Through these conversations, we are working with our clients, based on MUFG's theory of change: "our clients' emissions reductions are our emissions reductions." Indeed, pursuing sustainability on our own balance sheet without considering real-economy implications is against our corporate purpose: "committed to empowering a brighter future." As companies develop and commercialize technologies, they are also pursuing their own emission reduction strategies towards the sustainable society, and our role is to support them with financial solutions.

The energy transition is the highest priority and requires action by both corporates and governments (i.e. through policy support). At the same time, the world is seeing a shift from a linear economy, built on take-make-waste approaches, to a circular economy focused on "reuse" and "recycle". The whole-of-economy transition reflects these dynamics of optimizing resources, including energy and heat but also carbon, where appropriate.

The world cannot create a sustainable society without a comprehensive strategy reflecting the regional differences. To minimize the impact on the real economy and individual livelihoods, the world will need to continue to trade in resources such as minerals, materials, energy, and water, and this should be conducted with the idea of developing circular supply chains.

Industrial companies are primarily responsible for the development, commercialization, and implementation of lower- or zero-emitting technologies. These technologies rollout may benefit from forward-looking pathways that align parties and track progress against carbon neutrality goals. The pathways can serve as critical bridges between national government commitments and financial incentives from both the public and private sectors.

Realizing a national commitment requires government and industry to take a unified and consistent approach. This begins with laying the groundwork for the transition, which includes setting targets providing incentives, reducing green premiums through policies, and de-risking financing to achieve the pathways envisaged in the government's roadmaps in case of Japan.

MUFG's longstanding relationships with our corporate clients provide opportunities to share mutual learning, identify areas for cross-sector partnership, and collaborate on transition planning and advances in technology and policy. Our engagement philosophy is to "encourage and enable" our clients' transitions and by doing so, contributing to creating new opportunities for innovative technologies to accelerate further transition in the real economy. We listen to our clients, respectfully challenge their plans, and assess the viability of their approaches. Indeed, this engagement informed the contents of this whitepaper. We believe our clients' strategies that are summarized here are ambitious and achievable given the technologies and strategies at hand.

Contents and objectives of this Transition Whitepaper 2023

This whitepaper outlines a technology development and roll-out strategy to achieve Japan's carbon neutrality, with resulting financing opportunities in Japan. It presents our ongoing review of the macro situation in Japan and plans for technologies to support carbon neutrality in line with the Japanese government's "Green Transformation Policy" (GX Policy).

Building on our Transition Whitepaper 2022 on Japan's transition strategy, published in October 2022,[1] MUFG will consider, among others, "legitimization," "incentivization" and "evidence with integrity" when it comes to assessing the "business viability" of new technologies development and deployment. In this whitepaper, we discuss why Japan requires a diversified approach to carbon neutrality in various industrial sectors.

MUFG's many interactions with clients have provided insights into how Japan's highest-emitting sectors will transition to carbon neutrality (Figure 1.1). Our clients have helped us develop a comprehensive view of Japan's "whole economy transition strategy," which is largely reflected in the country's GX Basic Policy published in February 2023. In this whitepaper, MUFG aims to help international partners and stakeholders understand a subset of the technology options associated with Japan's transition—and the opportunities they create. However, the GX Basic Policy is evolving; it laid down the foundation of Japan's path to carbon neutrality by providing technology options suitable for Japan to achieve targets set out for 2030 and the level of investment expected. The Japanese government has developed a comprehensive list of technologies, supported by a dedicated legislative program. Discussions on details of incentives and enablers are under way, leveraging Japan's research, development, and technology capabilities.

As one of the largest banks in the world and the largest in Japan, we are committed to contributing to global climate action by building momentum for new capital flows toward carbon neutrality solutions, at home and globally. As Japan rolls out action on climate change, MUFG will serve as a bridge between international and Japanese industry, based on three core objectives:

1. Build global awareness of Japan's carbon neutrality ambitions. We aim to inform stakeholders around the world about Japan's emissions reduction pathway and technological needs, as well as opportunities for collaboration through emerging supply chains.
2. Contribute to global understanding of the activities and technology options required and implemented under the GX Basic policy to achieve Japan's ambition. By enhancing global understanding, we aim to improve financing predictability for stakeholders, clarify timelines for implementation and commercialization of technologies, and shed light on potential trends in adoption.
3. Highlight MUFG's commitment to Japan's carbon neutrality ambition, and the bank's role in supporting climate goals and industrial players, both in Japan and abroad. We engage in continuous dialogue with our clients to ensure mutual understanding of the latest advances and thinking on carbon neutrality strategies.

Each country will take a nuanced approach, and there is no single winning strategy that can be applied globally. Japan's carbon neutrality strategy differs from those in the US and Europe, but no two economies will take the same approach given the different context. Japan's diversified approach includes renewable energy, nuclear power, and the development of technology and global supply chain infrastructure for low-carbon fuels such as ammonia and hydrogen, as discussed in this whitepaper. These initiatives include new technologies such as the repurposing of coal-fired power plants (for co-

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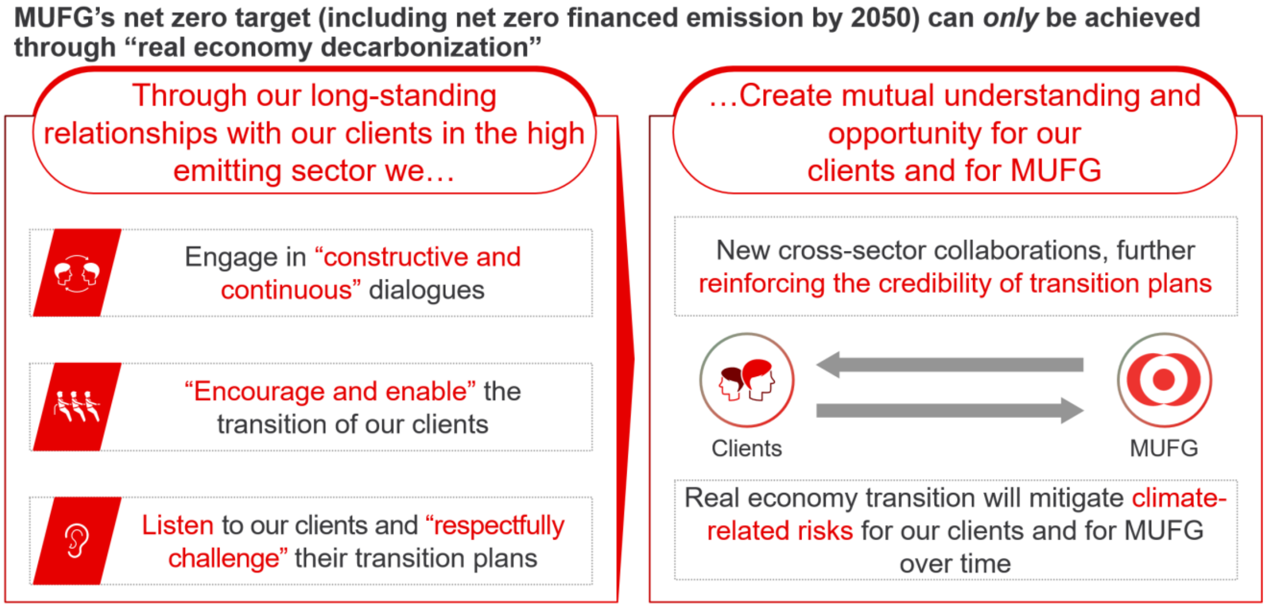
[1] https://www.mufg.jp/dam/csr/report/transition/wp2022.pdf

firing) and the ramp up of carbon capture, utilization, and storage (CCUS). MUFG believes that financing these transition technologies will align the Japanese economy with the country's Paris Agreement target, serving as a critical enabler of Japan's carbon neutrality.

Figure 1.1 Deep engagement informs MUFG's view on how transition strategies and new technologies align with the Japan's carbon neutrality ambition



MUFG's Transition Whitepaper 2022 (see In Focus) identified the distinctive characteristics that shape a country's transition pathway. We recognize that the energy transition must be a high priority to accelerate other sectors' emissions reduction journeys. It is vital to take a forward-looking approach to understand transition pathways and strategies within each emitting sector.

Through proactive engagement with clients and policy makers, MUFG is translating its commitment into tangible strategies for real-economy carbon neutrality in line with Japan's GX Basic Policy. As the world's attention shifts from planning to tangible actions, and the financing required, MUFG will continue to play an active role in Japan, Asia, and the rest of the world.

In focus: MUFG Transition Whitepaper 2022

The objective of our first Transition Whitepaper was to build understanding of the unique characteristics each country's economy and sector profile, and how these impact decarbonization solutions. The paper defined the characteristics that shape Japan's (and possibly Asia's) transition pathway, along with the key considerations to guide how MUFG engages with clients on their transition plans.

There are four major drivers that shape country- and sector-specific pathways to carbon neutrality (Figure 1.2).

1) Sources of emissions: emission reduction levers should match the energy sources and emissions profile of the country or sector.

   Emissions sources: Sources of emissions drive the pathways to reduce them. In Japan, electricity, heat, and industry account for nearly 70% of total emissions, compared with 45% in the US and under 35% in the UK and France. Meanwhile, transportation emissions in those other countries are nearly double those of Japan.

   National profile: National decarbonization levers should align with the country's energy characteristics. Though Japan has the highest solar PV flat-land density of any country, it has limited space for further development using today's technologies. The resulting high installed costs for variable renewable energy (e.g., wind and solar) impacts how they can be deployed as decarbonization levers.

2) Connectivity with other regions via pipelines or electricity grids: Regional power grid and pipeline infrastructure play a role in shaping a country's climate strategy. A lack of power grid and pipeline connectivity reduces options for reliable, low-carbon electricity and necessitates pathways that prioritize stable, low-carbon power and storage.

   Electricity grid: The electricity grid plays a significant role in the expansion of wind and solar capacity deployment. A strong grid can provide access to and manage the variable output from wind and solar resources. The fact that Japan's grid is not connected with the rest of the world gives limited options in terms of generating low-carbon electricity with security and affordability.

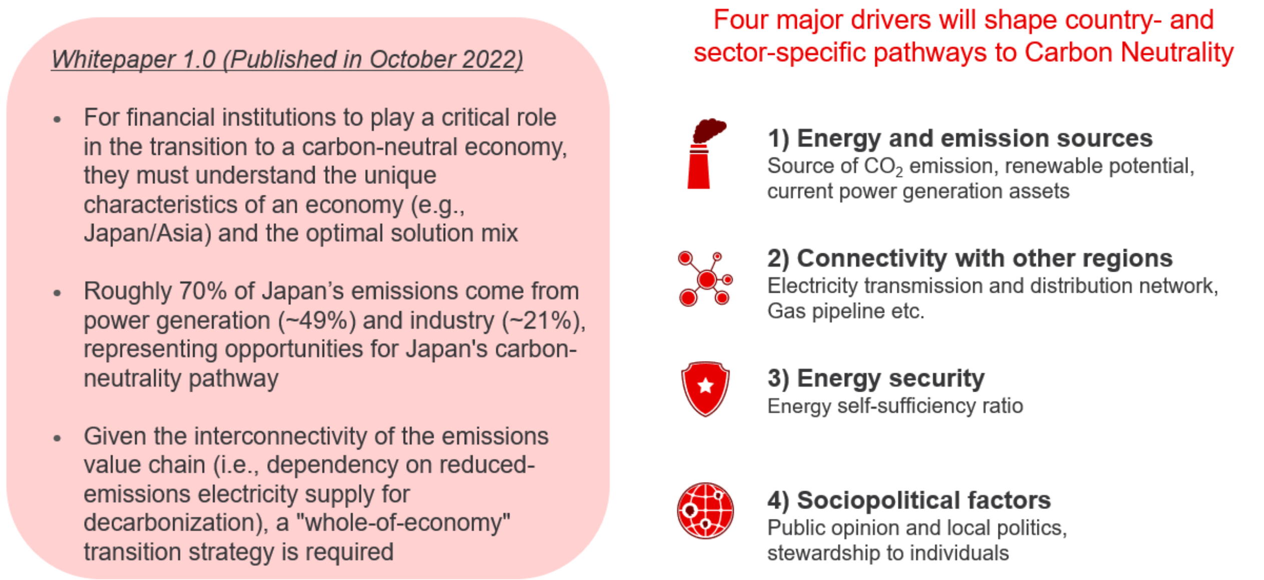
   Pipeline infrastructure: Pipelines support the energy transition by providing a seamless means of transporting alternative energy fuels. Low-carbon fuels, such as hydrogen and its derivatives, can be transported using some natural gas pipelines.

3) Energy security: Carbon abatement approaches must be aligned with energy security objectives. Increased connectivity with or dependence on other countries can have impacts on a country's energy security position.

   As of 2017, Japan could only meet 9.6% of its national energy demand using domestic sources. Japan has diversified its supply of fossil fuels via a global supply chain.

4) Sociopolitical factors: Public opinion is an important factor in transition pathway design and can be leveraged to support execution. Japan has a strong culture of environmental stewardship, influencing actions on energy efficiency, recycling, and energy demand reduction. Concepts such as "Mottainai" have been promoted to help reduce demand for non-domestic resources in Japan and other countries. While public opinion on nuclear power is mixed, the government announced plans in 2022 to restart plants and assess the development of next-generation reactors.

Figure 1.2 MUFG contributed to the global conversation on transition plan/finance and carbon neutral strategy via its Transition Whitepaper 1.0



Whitepaper 1.0 discussed the need for a whole-of-economy transition, prioritizing energy**.** The paper featured six leading companies from high-emitting sectors (power, iron & steel, chemical, paper, glass, and cement), summarizing how each plan to pursue its carbon neutral goal. It highlighted how Japan's approach can be a blueprint for ASEAN countries.

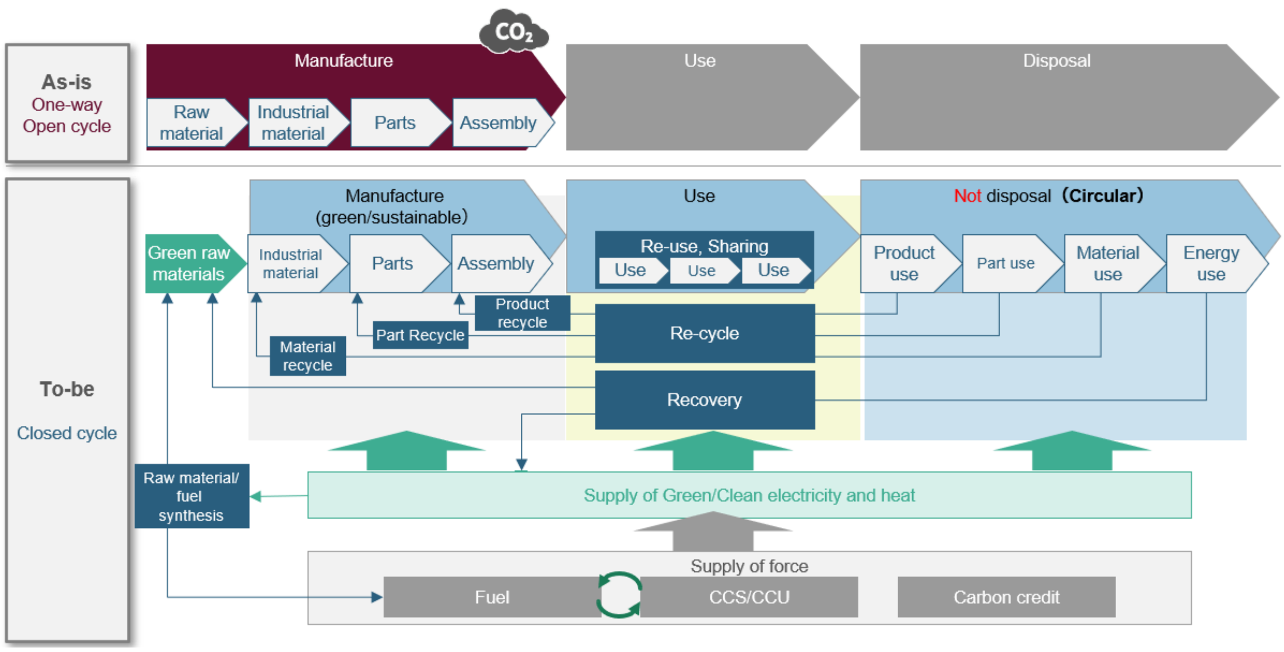
2. Progress in carbon neutrality as a first step of journey towards sustainable society

What is a sustainable society in terms of goods and energy?

A sustainable society consists of different elements and its meaning may vary among stakeholders. In goods and energy, for example, a sustainable society needs to strive for circularity, among other things, promoting the efficient utilization of resources to minimize the burden on the environment, including in goods. Renewable and clean energy sources are the driving force behind these activities, aiming to achieve carbon neutrality in energy consumption.

The whole of economy transition to carbon neutrality reflects this dynamic process of industrial and societal change over a long-term horizon (Figure 2.1). A circular economy is certainly part of the dynamic. However, new processes are required across the economy. Increasing recyclability, for example, may need new processes that utilize recycled materials to create new products, in addition to enhancing waste collection. To minimize environmental impacts, integrating management of the disposal process in the manufacturing process at a basic material level may be effective. Thus, the transition to carbon neutrality requires not only reductions in current emissions but also controlling new emissions through transitions in the energy system and goods manufacturing through a circular economy. As disclosure of Scope 1-3 emissions of goods has become mainstream, companies need to periodically review and adjust their emissions profiles. Such review and adjustment should consider "interdependency" among sectors horizontally through value chains and vertically through electricity, heat, and carbon sharing systems, optimally creating a circular loop for the whole of the economy.

Figure 2.1 Transition to a sustainable society



In the process of these transformations, transitioning toward a circular society that leverages clean energy, there remains room for improvement in efficient material utilization. This is because, even as circular processes progress, material depletion can still occur within processes, and the need for new materials rises alongside population growth. In the next step, the focus will be on synthesizing imported raw materials and fuels to advance carbon recycling. Hydrogen, required for this synthesis will be generated using clean energy. While effectively utilizing carbon through such processes, carbon that cannot be efficiently recycled will either be stored in geological formations or become a target for other viable means to reduce carbon emissions.

The transition toward a sustainable society, with a focus on goods And energy, is consistent across nations. Countries have set the same goals: to reduce greenhouse gas (GHG) emissions in alignment with the Paris Agreement and achieve carbon neutral societies.

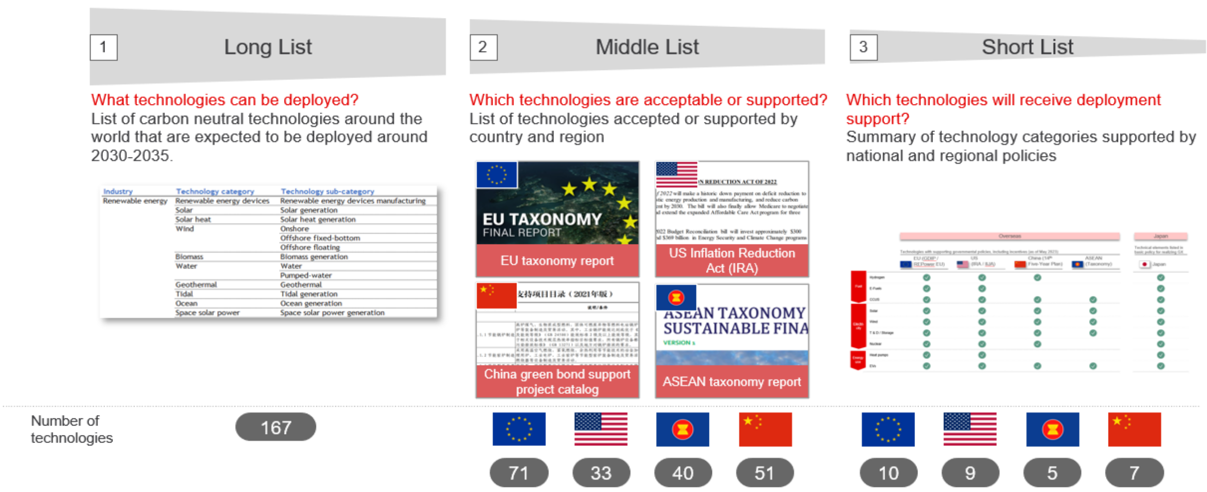
Approach to reducing GHG emissions

While the ultimate goal remains the same, the starting points and constraints vary significantly among different jurisdictions. As a result, while there is a broad similarity in the overall direction, comparing various policies reveals distinct approaches tailored to local conditions. These differences are evident in specific strategies, such as the selection of technologies, the acceleration of technology value chain development through goal setting and regulatory frameworks, support for demand creation, and the mitigation of financing uncertainty.

To highlight differences in the policy frameworks and approaches to GHG emissions reduction, this whitepaper classifies low-emissions technologies into the following three categories (Figure 2.2):

- **Long list:** Technologies that could be deployed: Integrated list of 167 technologies that could be deployed by 2035, based on information gathered from experts and policy documents in each country.
- **Middle list:** Technologies accepted or supported (Positive technologies): Technologies listed or contemplated in policy documents of each country or region that are eligible for support or may be acceptable for deployment. The list provides a clear signal on the direction of the energy transition in these jurisdictions. In this whitepaper, we refer to seven technologies in this group as “Positive technologies.”
- **Short list:** Technologies that will receive deployment support (part of Positive technologies): Technology categories in the middle list for which jurisdictions provide financial support, commitment within roadmaps, and other forms of incentives or regulations. The Government of Japan has made budget allocations and roadmaps. The short-listed technologies are deemed indispensable, warranting efforts to scale them, even at substantial cost. In this whitepaper, technologies in this group are also included in the list of “Positive technologies.”

Figure 2.2 Comparison of technologies towards GHG emission reduction supported by peer economies[2]



[2] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en, https://www.congress.gov/bill/117th-congress/house-bill/5376/text, http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/4342400/2021091617180089879.pdf, https://asean.org/wp-content/uploads/2023/03/ASEAN-Taxonomy-Version-2.pdf.

Climate policies in the US, Europe, China, and ASEAN have a clear connection between ambition and supported technologies (the "middle list"). However, they vary in their structures**.** For instance, in Europe, much of the emphasis is on the need to secure affordable energy and reduce dependency on fossil fuels from abroad. It applies regulations and the drafting process to narrow down its selection of technologies. This is reflected in the EU Taxonomy where eligibility requirements are clearly defined, with emission thresholds to direct both companies and investors to what the EU considers green active entities and reduce emissions on a lifecycle-base (the "middle list"). The US also uses regulation such as the Inflation Reduction Act (IRA) to highlight industries the government considers important (the "middle list"), together with incentive schemes (the "short list"). There are few emission thresholds and instead the IRA lists a significant number of eligibility criteria to obtain incentives.

Approaches in implementing regulations differ

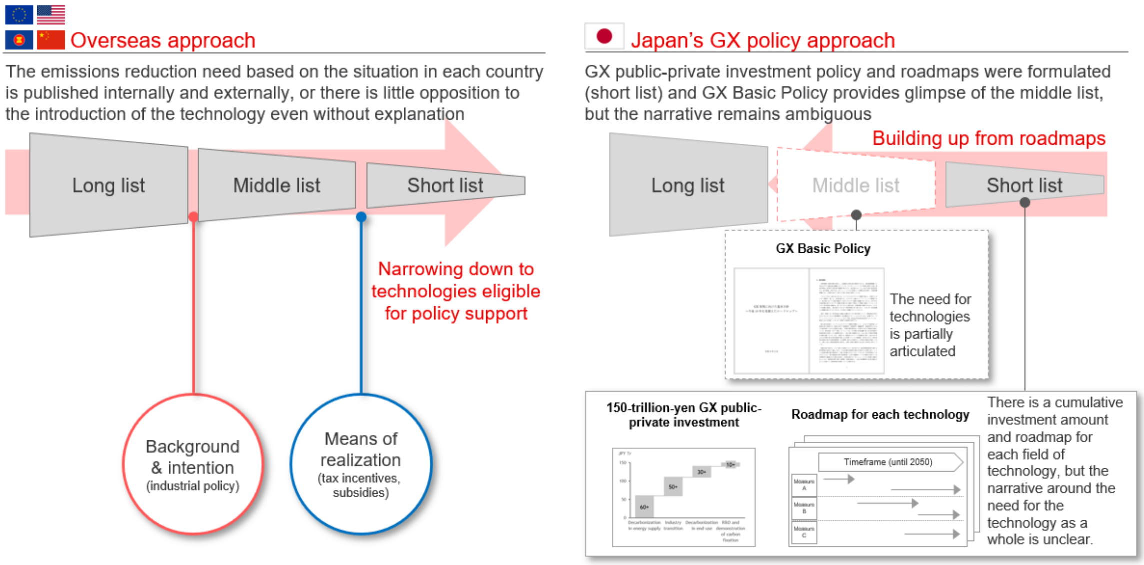
Europe uses both "carrots" and "sticks"—sticks including tighter regulation on disclosure, for example through the Sustainable Finance Disclosure Regulation for asset managers, Green Asset Ratio for banks, and Corporate Sustainability Reporting Directive for companies. These enable it to be transparent on EU-taxonomy eligible investments and/or emissions levels. Carrots are offered through regulations such as REPowerEU and ongoing discussion on the Green Deal Industrial Plan. The US, on the other hand, uses a market-based approach to encourage companies with a wide range of technology options with minimum eligibility requirements. Incentives are offered to support new industries, reflecting the country's abundant domestic renewable energy potential and infrastructure related to fossil fuels including carbon capture and storage (CCS). Furthermore, IRA incentives have spurred domestic clean energy projects leveraging a range of technologies.[3]

Meanwhile, Japan's approach is characterized by its emphasis on practical effectiveness rooted in viability assessments of specific technologies (Figure 2.3). This stands in contrast to the EU and US approaches, which are focused on identifying technologies from a long list for policy support. The Japanese government's approach is first to publish intensive plans developed in collaboration with the private sector, outlined in the government roadmaps for various sectors and a list of technologies requiring development and deployment ("short list"). This divergence in planning philosophy between Japan and the EU/US underscores the increased importance of communicating Japan's roadmap to carbon neutrality to authorities and stakeholders outside Japan. This whitepaper will list the technologies Japan requires, considering its unique geographical and infrastructural characteristics, while also highlighting their vital role. The Government of Japan has made budget allocations and roadmaps for focus areas. "Shortlist" technologies are deemed indispensable, warranting efforts to scale them, even at substantial expense. In this whitepaper, technologies in this group are also included as "Positive technologies."

The short-listed technologies envisioned by the EU and US governments are technologies listed for implementation in the roadmap for Japan. To provide incentives for and prioritize "shortlist" technologies, Japan published its Basic Policy for GX Realization (GX Basic Policy) in February 2023. This presents roadmaps for 22 sectors alongside rationales for their selection and approximate breakdown of JPY150 trillion of public-private funding to support their deployment by 2035 (Figure 2.4). The Japanese government has initiated intensive discussions with stakeholders to decide the details of government support and incentive schemes ("short list") from April 2023 for gradually implementation from April 2024 onwards. Japan needs a combination of technologies identified in the 22 roadmaps, due to limited natural resources and renewable potential, amid constraints on power grid/pipeline connectivity. While maximizing renewable energy and optimizing other factors, Japan needs to further articulate this narrative and its rationale to further enhance the predictability of financing opportunities for GX technologies.

[3] https://cleanpower.org/investing-in-america/

Figure 2.3 Framework for communicating technology choices for achieving carbon neutrality

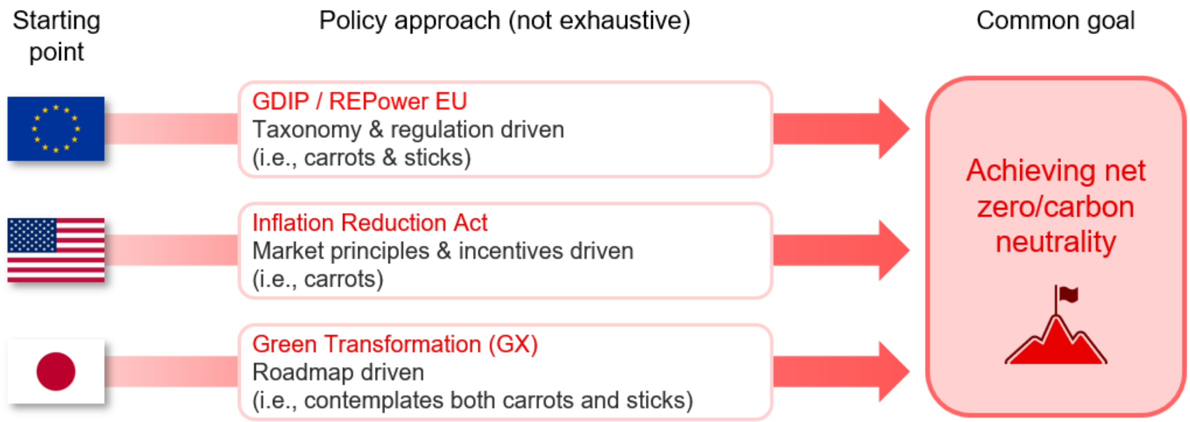


Across countries, public-private investment will be critical for innovation and establishment of infrastructure for technology deployment and scale-up to drive cost reductions, commercial-scale testing, and supply chain formation. In the GX Basic Policy, the Japanese government establishes sector-specific roadmaps for driving JPY150 trillion of transition funding (JPY20 trillion public and JPY130 trillion private) and discusses the following:

- Regulation, support for companies, and integrated investment promotion
- Carbon pricing mechanisms
- Introduction of new financial instruments
- International expansion

The GX Policy calls for supplemental explanation of Positive technologies since it is based on building roadmaps through public-private collaboration and is still evolving. On the other hand, the advantage of Japan's approach lies in its ensured feasibility, which becomes a crucial perspective when demonstrating a commitment to achieving carbon neutrality. This presents an opportunity for MUFG to elaborate on how Positive technologies will enable Japan's carbon neutrality. Our hope is that by contributing to the global conversation, we can shed light on issues and contribute to the global conversation.

Figure 2.4 Jurisdiction-specific policies towards the common goal



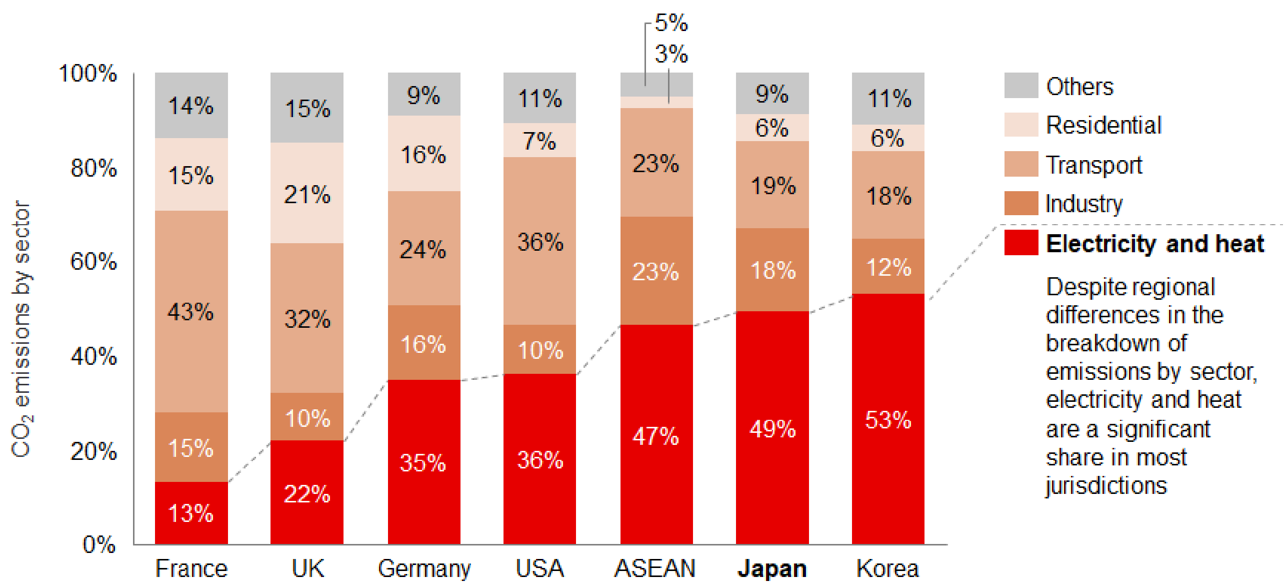
3. Contextual differences in pathways to carbon neutrality for each country

The technologies that will work best in a national context will be contingent on the most promising pathway to carbon neutrality, taking into account geographic, emissions, socioeconomic, resource, policy, and technological factors. A useful way to explore these differences is to focus on the potential evolution of carbon neutrality pathways in each region.

Carbon neutrality pathways

Each country can identify its own carbon neutrality pathway according to its individual emissions profile. However, electricity and heat stand out as being significant sources of emissions almost everywhere, and particularly in Asian countries (Figure 3.1).

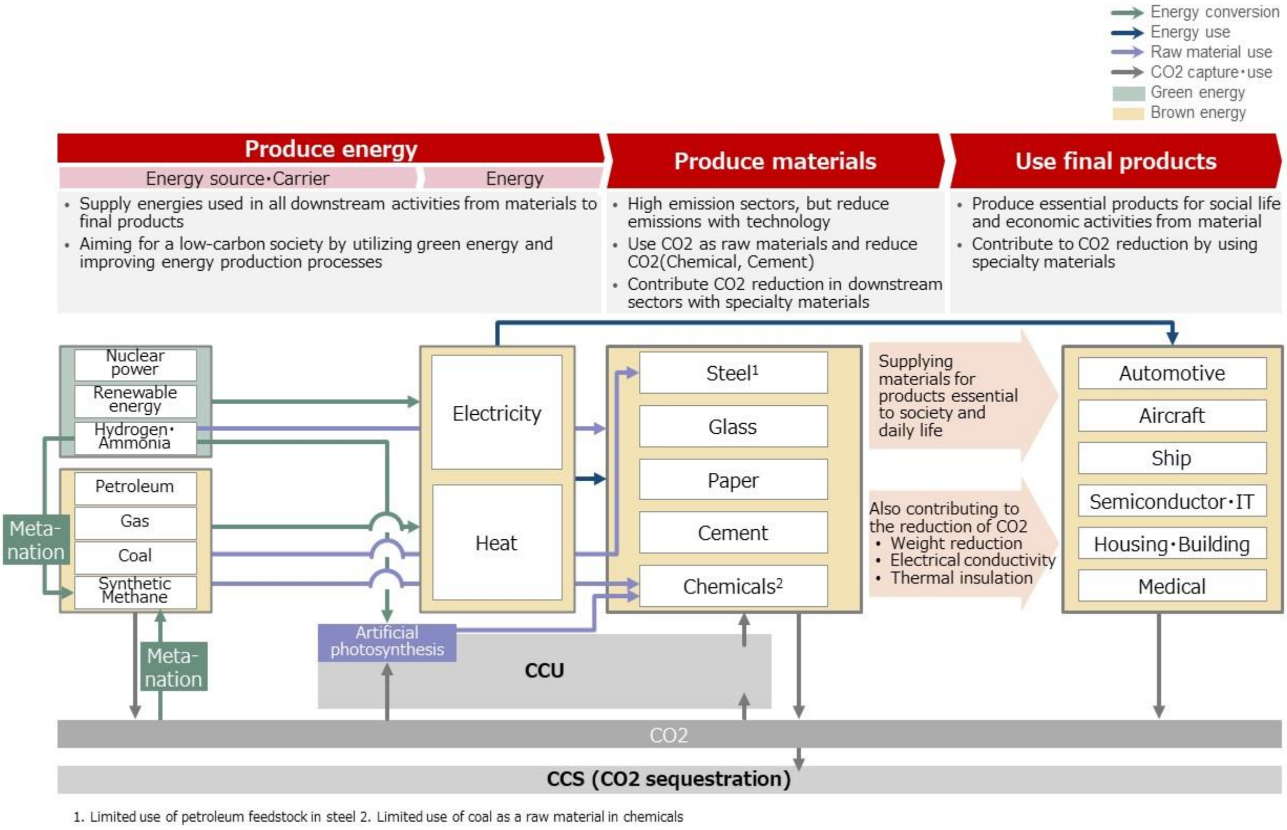
Figure 3.1 CO_2 Emissions by sector in 2020[4]



Most economic sectors are connected through their shared dependency on electricity and heat. Therefore, the timing and direction of activities to achieve carbon neutrality in electricity and heat affect the timing and direction of carbon neutrality in downstream sectors (Figure 3.2). However, planning the decarbonization of electricity and heat production across an economy is complex, requiring solutions across sectors. At the same time, combining efforts to reduce emissions from other sectors by effectively using carbon in a circular manner and carbon capture storage (CCS) can amplify emissions reductions through industrial value chains.

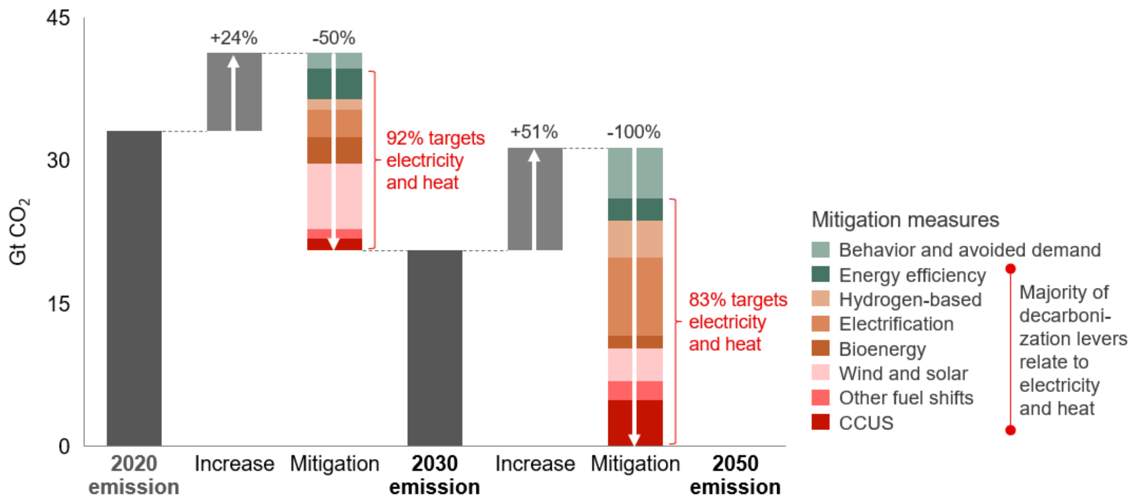
[4] IEA World Energy Balance 2022: Countries & Regions - IEA

Figure 3.2 Interdependencies between the energy sector and key industries[5]



While emissions by sector vary from country to country, the IEA's report "Net Zero by 2050," published in 2021, recognizes a common set of decarbonization levers that are applicable globally—with a shared impact on electricity and heat in particular (Figure 3.3). These include: 1) Behavior change and avoided demand, 2) Energy efficiency, 3) Hydrogen-based fuels, 4) Electrification, 5) Bioenergy, 6) Wind and solar, 7) Other fuel shifts, and 8) CCUS. This whitepaper focuses on electricity and heat because their decarbonization has the most impact on society as a whole.

Figure 3.3 IEA roadmap to Net Zero by 2050 decarbonization levers[6]



[5] https://www.mufg.jp/dam/csr/report/transition/wp2022.pdf

[6] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050, License: CC BY 4.0

Emissions reductions in electricity and heat will require acceleration in the deployment of renewable energy, restarting nuclear energy, electrification, and alternative technologies, such as hydrogen-based fuels and CCUS. In the IEA's Net Zero Emissions by 2050 Scenario, the following measures deliver global emissions reductions[7]:

- Renewable energy will drive nearly 90% of electricity generation, amounting to 64,506 TWh out of 73,231TWh in 2050. Renewable capacity will need to expand from 3,278GW in 2021 to 10,349GW by 2030 and 27,304GW in 2050, driven primarily by increases in solar and wind power.
- Nuclear energy will account for around 10% of the share of electricity generation, with an expectation of a rise from 413GW (or 3,890TWh) in 2021 to 535GW (or 3,896TWh) in 2030 and then 871GW (or 5,810TWh) in 2050.
- Electrification will account for 20% of emissions reduction through direct use of low-emissions electricity in place of fossil fuels.
- Emerging low-carbon fuels and emissions-reduction technologies (e.g., hydrogen and hydrogen-based fuels, bioenergy, and CCUS) are: (1) a source of flexibility to balance variable renewables output, especially for smaller or unconnected grids; (2) solutions in high-emitting industries such as cement and steel.

Despite some commonalities in approaches, regional characteristics necessitate different combinations of measures in line with specific national considerations (e.g., to support energy security, employment, population health or safety, to address intermittency of renewable energy sources, or to achieve economic stability).

Diversity of approaches to electricity and heat supply

The Japanese government has outlined the necessity of balancing Safety, Energy Security, Economic efficiency, and Environment when pursuing decarbonization of energy, known as the "S+3E principle." In addition to regional characteristics and these S+3E principles, key factors impacting national choices on potential pathways are:

- Natural resources (e.g., availability of land or shoreline for solar and wind capacity, amount of wind or solar radiation), and the availability of technologies that can harness these resources.
- Existing energy infrastructure and assets; for example, the ease with which a country can support new generation capacity (e.g., renewable assets) and switch from existing capacity (e.g., fossil fuel assets). This ease is commonly derived from the share of fossil fuel usage, the age of assets, the availability of electricity from other countries, and the potential for carbon capture and storage.

Influenced by these factors, each country's pathway to reducing emissions from electricity and heat is driven by the overall cost of deploying and integrating new renewable capacity. The impacts of a country's natural resources and existing energy infrastructure will be reflected in overall costs, which can be defined as the sum of the following (Figure 3.4):

1) Energy production costs, also referred to as levelized cost of energy (LCOE).
2) System costs, which reflect the cost of transmission, distribution, and backup power supply. These depend on power supply flexibility from other countries, backup facilities, and the quality of power

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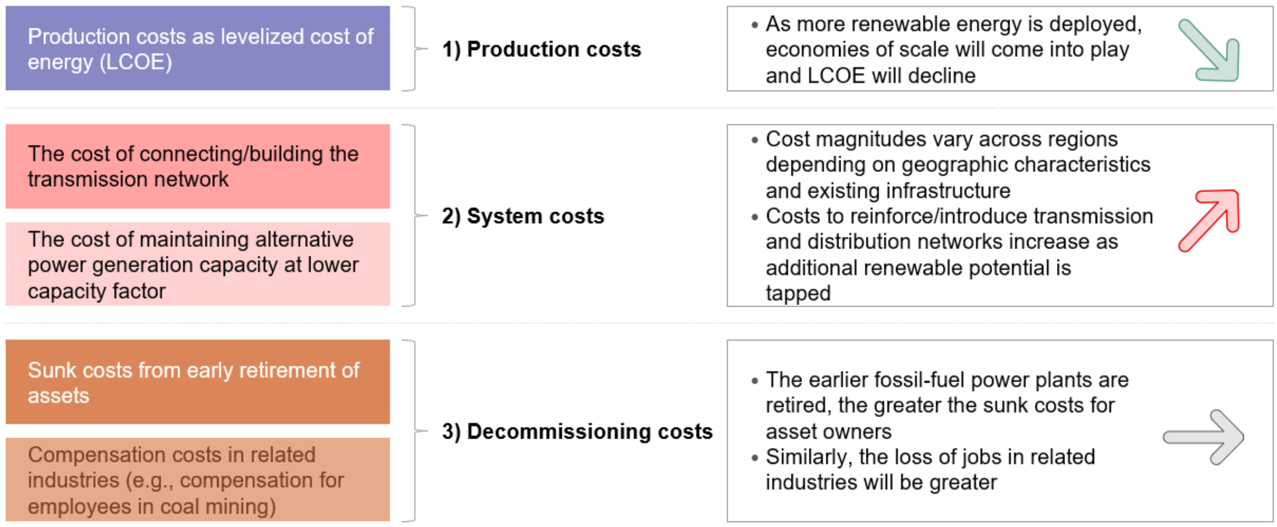
[7] IEA (2022), World Energy Outlook 2022, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

transmission and distribution networks. They also include costs associated with new infrastructure (e.g., financing to expand and strengthen transmission and distribution systems to connect renewables) and alternative power supply (e.g., storage technologies and flexible lower-emission power sources to absorb the variability of renewable energy).

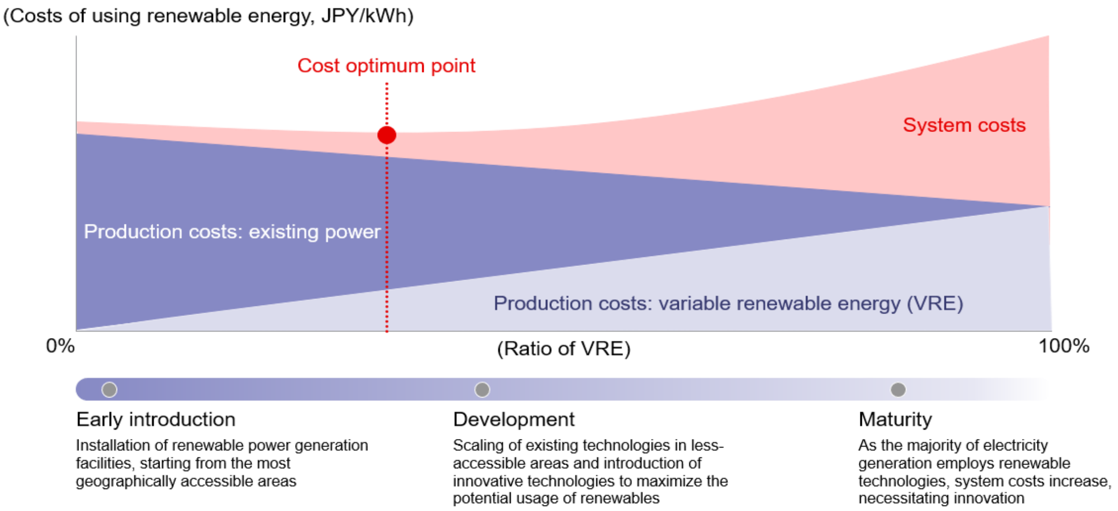
3) Decommissioning costs, which reflect the costs associated with switching away from thermal power, including the sunk costs from early retirement of assets and the transition costs (e.g., providing compensation for lost employment in coal mining).

Figure 3.4 Costs associated with new energy deployment



While the LCOE of renewable energy will decline with technological and operational maturity and scale-up, system costs will rise with the need for additional backup power supply, enhanced transmission, distribution, and storage. There will be cost trade-offs. Renewable energy sources such as solar and wind are variable renewable energy (VRE) and are subject to natural fluctuations in generation. The existing system can absorb only a certain excess of VRE. As a result, as more renewable energy is introduced, more system costs will be incurred after a certain scale of capacity deployment, including for the securing of alternative backup power sources and development of the power transmission and distribution network to ensure system stability (Figure 3.5). It is therefore important to take a comprehensive approach that balances impact and costs.

Figure 3.5 Production costs and system costs in VRE introduction phases (illustrative)[8]



Total costs manifest as the marginal abatement costs of carbon, ultimately driving a country's suite of decarbonization solutions (Figure 3.5). Similar technologies have different marginal abatement cost curves based on the stage and availability of the technology being deployed. In crafting a national approach, countries will tend to first maximize cost saving opportunities (where the abatement cost is negative) and proceed with the next lowest-cost solutions to the right of their abatement curves. Costs can also be dynamic, as in the case of renewables, which are featured at several points along the cost curve. As maturity increases and more renewable capacity is added, total costs can be higher than in the early phases, reflecting the fact that system costs and production costs also increase. Countries will need to balance cost benefits and emissions reduction benefits in their decarbonization pathways.

When aiming to maximize the adoption of renewable energy across various countries and regions, there are two pillars. The first involves maximizing the adoption of renewable energy within each country or region. The second entails importing renewable energy from overseas to fulfill the growing energy demand of each country or region. This strategy is defined in this whitepaper as the "two pillar strategy" for applying low-carbon technologies while controlling costs. The strategy aims to ensure cost-effective implementation across technologies while positioning renewables and electrification as key measures:

- **Pillar 1 [Domestic renewables]:** Maximizing domestic renewable energy deployment and usage. Simultaneously, CO_2-free power generation such as nuclear is fostered to move energy production toward carbon neutrality.
- **Pillar 2 [Importing foreign renewables]:** Importing overseas renewables either directly in a form of electricity via grid connection or converted into appropriate carriers for transportation for emissions reductions beyond what can be achieved by maximization of domestic renewables, contributing to the creation of a global market.

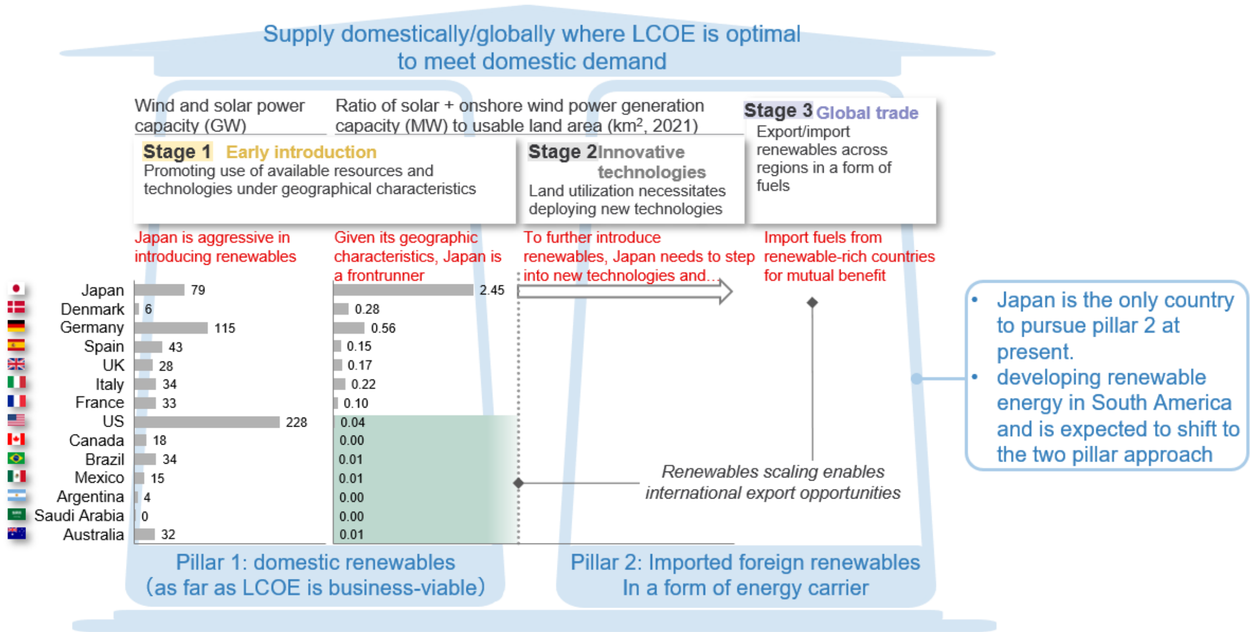
Implementation of the two pillars typically occurs in three stages (Figure 3.6):

- **Stage 1) Early introduction:** Countries in the first stage maximize renewable energy production by scaling deployment of existing technologies. This allows them to leverage cost declines where land availability and renewable potential are not a constraint.

[8] Matsuo Y. Re-Defining System LCOE: Costs and Values of Power Sources. Energies. 2022; 15(18):6845. https://doi.org/10.3390/en15186845

- **Stage 2) Development and innovation:** After renewables are deployed in easily accessible locations, costs may rise, leading to a requirement for innovation, in Japan's case probably in floating offshore wind and perovskite solar.
- **Stage 3) Global trade:** In the final stage, countries look to leverage international trade. Renewable energy can be used to produce hydrogen-based and biogenic fuels, which can be transported from the location of production to the location of demand.

Figure 3.6 Stages of typical transition pathways[9]



Within Pillar 1 (maximizing domestic renewables), average levelized costs have generally declined due to economies of scale, but high system costs in some regions still outweigh reductions in the cost of renewables. Within Pillar 2 (importing foreign renewables), an array of alternative technologies can balance energy supply and demand domestically, enable international renewable utilization, and reduce emissions of existing fuels. In short, the country-driven context will impact each nation's optimal portfolio. Considering this viewpoint, jurisdictions may initially concentrate their efforts on Pillar 1, while also indicating the potential to shift towards Pillar 2 when reaching a certain stage.

Japan, where Pillar 1 has already reached a certain level, ranks third in the world in installed solar and wind capacity and ranks first when viewed through the lens of available usable land. Since capacity is already installed in readily accessible locations, it is now necessary to install wind and solar in less suitable locations, including rooftops and the deep sea. The cost of absorbing renewable energy variability becomes high after a certain scale of capacity deployment. At that point, maximizing adoption through international trade becomes essential, signifying that countries have already progressed to the stage of engaging with Pillar 2. Furthermore, continual innovation in renewable energy technology may augment the adoption of renewable energy in Pillar 1. Such increases in renewable energy adoption should not be discussed solely in terms of each country or region's potential for adoption, as the economic rationality based on LCOE is also a crucial aspect.

[9] FAO, IRENA. Suitable land for renewables is defined as land area of each country, excluding forests, land and water, and buildings (roads, waste disposal sites, etc.)

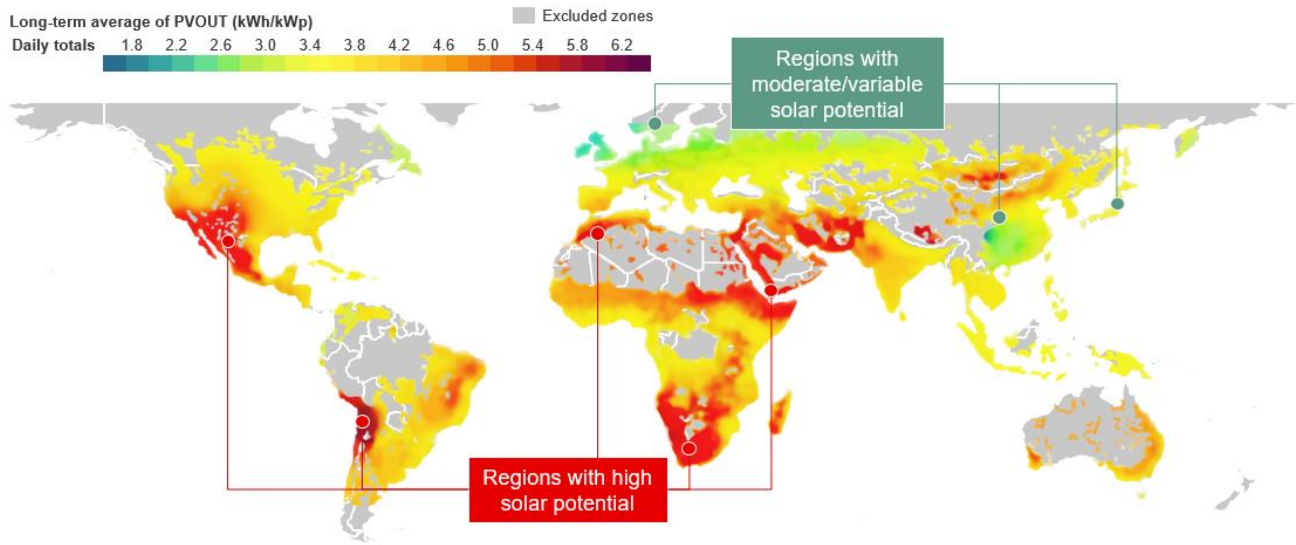
From this perspective come various economic drivers for Pillar 1 and 2, specifically impacting LCOE for renewable energy and opportunities in global trade:

- Pillar 1:
  1. Drivers impacting renewable energy production costs (LCOE) – Solar
  2. Drivers impacting renewable energy production costs (LCOE) – Wind
  3. Drivers impacting system costs
- Pillar 2: Role of alternative technologies

Pillar 1: Drivers impacting renewable energy production costs (LCOE) – Solar

Solar potential and installation capacity varies widely across the globe, with geographic factors that can be indexed to local solar radiation conditions (Figure 3.7). Some regions, such as parts of Africa, the Middle East, and the Americas, have higher solar potential. Northern Europe, East Asia, and Southeast Asia have more moderate potential.

Figure 3.7 Global solar potential[10]



Taking into account other factors, including average air temperature, terrain, albedo (surface reflection potential), and shading, there are still significant variations in solar generation potential between regions (Table 3-1).

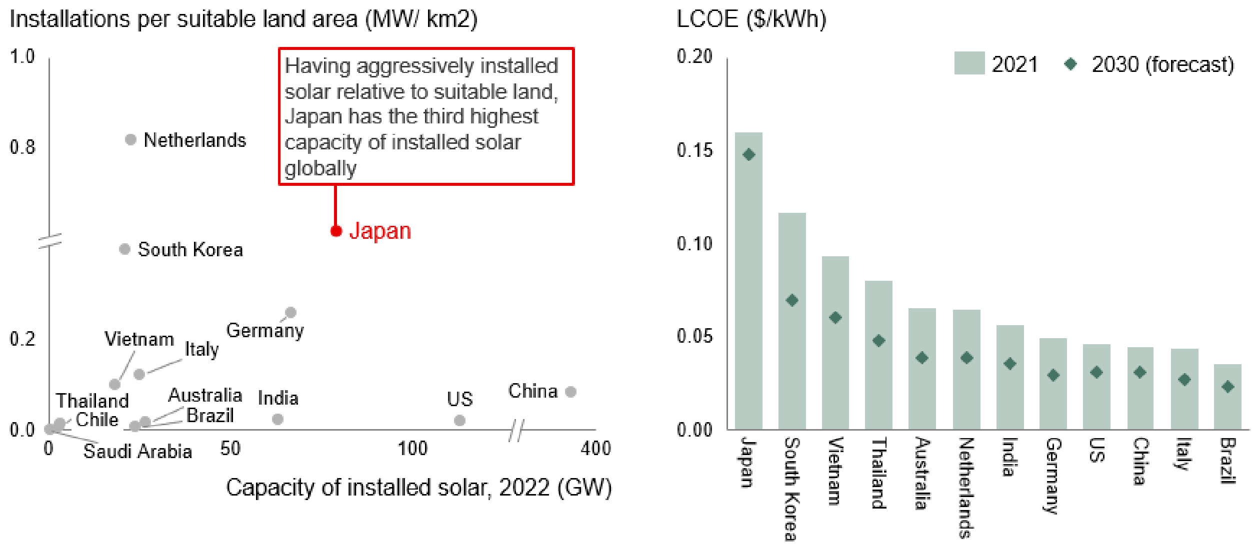
In addition to solar potential, suitable flat land is required for solar installation. As mentioned above, Japan has reached a certain level within Pillar 1, installing a large amount of solar relative to available land (Figure 3.8). Further installations will require access to new sites and new technologies (e.g., perovskite solar), suggesting the cost of installation in Japan will be higher than in other regions.

[10] Land suitable for solar installation is based on ratio of flat land, terrain, proximity to population/industrial areas, and forest coverage. Source: 2020. The World Bank. Global Solar Atlas 2.0, Solar resource data: Solargis (https://solargis.com/maps-and-gis-data/download/world)

Table 3-1 Solar resource and characteristics, by country

	US	Japan	Germany	France	UK
Installed solar capacity (2022, GW)[11]	113	79	67	17	14
Specific solar yield (kWh/kWp)[12]	2.61	3.45	2.96	3.39	4.36
Land area (km^2)[13]	9,630,000	380,000	380,000	540,000	240,000
Land area suitable for solar (km^2, % of total land area)[14]	5,330,000 (55%)	130,000 (34%)	260,000 (68%)	440,000 (81%)	210,000 (88%)
Installed solar capacity per suitable land area (MW/km^2)	0.02	0.62	0.26	0.04	0.07

Figure 3.8 Comparison of installed solar capacity, suitable land, and LCOEs by country[15]



In Japan's Sixth Basic Energy Plan, solar power is targeted to account for 14-16% of energy production by 2030 and drive the growth of renewables to 50-60% of the energy mix. In addition to the Feed-in Tariff (FIT) program, launched in 2012, the Japanese government has stated its support for development and mass production of next generational solar by FY2030, and perovskite in particular, in the GX Basic Policy roadmap.

Pillar 1: Drivers impacting renewable energy production costs (LCOE) – Wind

Wind power potential, which is calculated based on mean wind speeds, similarly varies substantially around the globe (Figure 3.9). While there is significant offshore wind power potential globally, much

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[11] https://pxweb.irena.org/pxweb/en/IRENASTAT/

[12] kWp is the maximum output in kilowatts that the PV system can produce. https://www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Country-Rankings

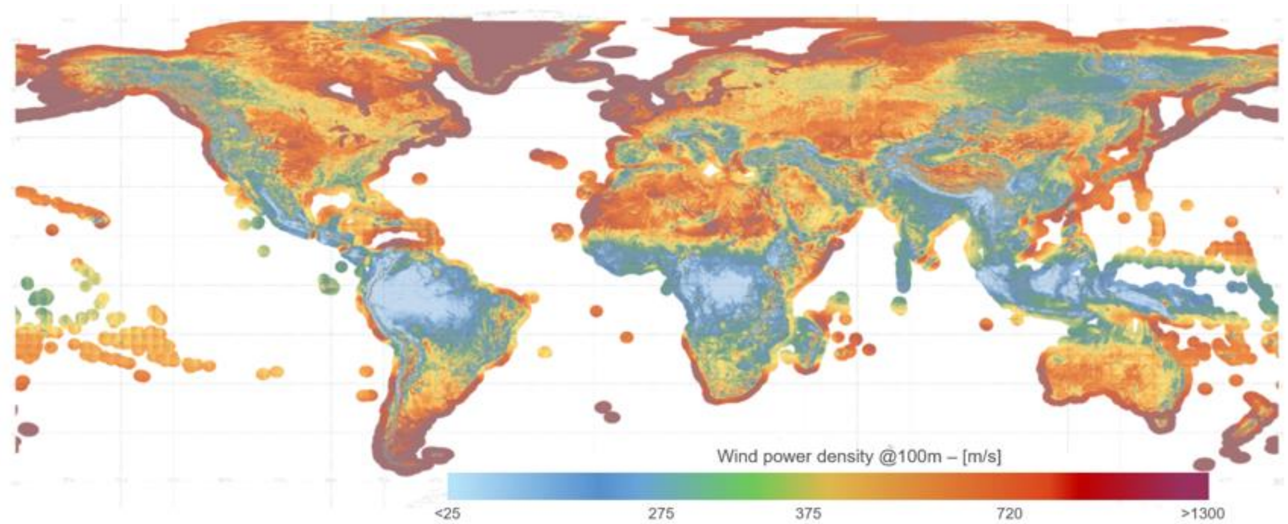
[13] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/025_01_00.pdf

[14] Land suitable for solar installation is based on ratio of flat land, terrain, proximity to population/industrial areas, and forest coverage. Source: 2020. The World Bank. Global Solar Atlas 2.0, Solar resource data: Solargis (https://solargis.com/maps-and-gis-data/download/world)

[15] Ibid.

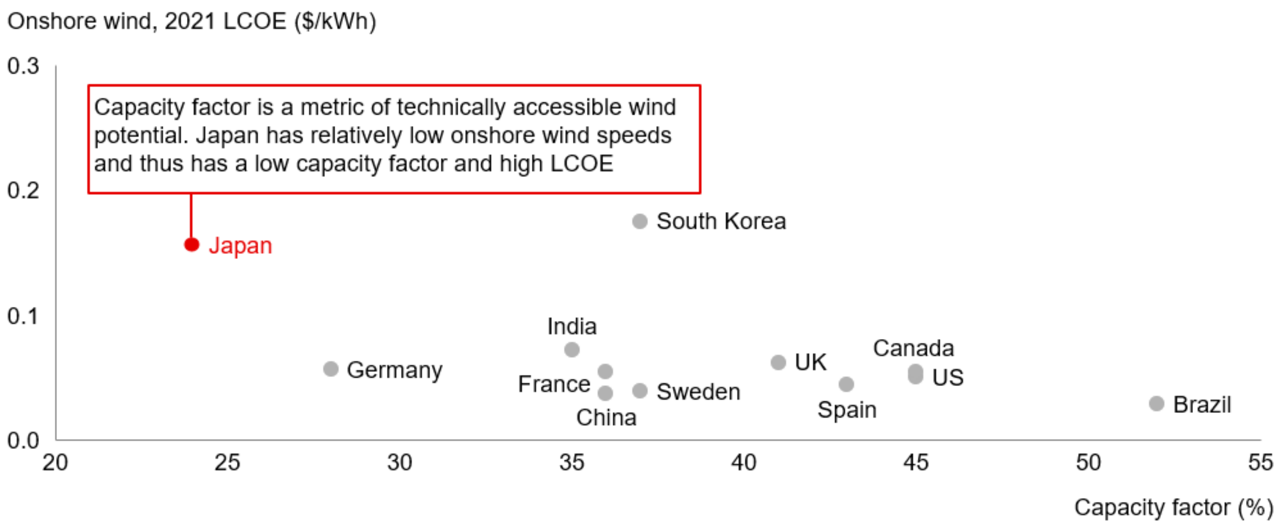
of it is located in deep waters, which are inaccessible for current offshore wind turbine technologies. Wind potential accessible using commercially-ready technologies (onshore or offshore in waters of <50-70m) is unevenly distributed globally, but is largely in North America, Northern Europe, and China. As a result, the development of both onshore and offshore wind could be the key to reaching higher levels of total potential. Some countries with high offshore wind potential can access technologies available today, due to shallower coastal waters. Others with deeper waters will be able to tap into this potential only in the future.

Figure 3.9 Global wind potential[16]



There are a wide range of costs involved in installing wind capacity, due to significant variability of terrain types, market maturity, infrastructure availability, and land permitting requirements (Figure 3.10). Countries with high levels of wind installation have reduced costs over time, while less mature markets face higher costs.

Figure 3.10 Wind LCOEs by country[17]



Offshore wind costs will additionally be driven by the type of installation, which is influenced by water depths and the cost of grid connectivity. In general, floating offshore costs will not be prohibitive for

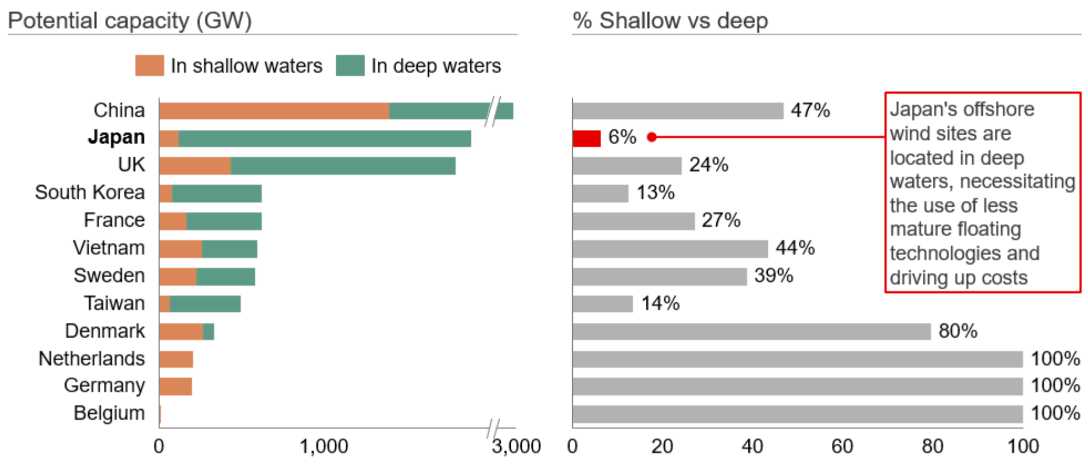
[16] https://datacatalog.worldbank.org/search/dataset/0039490

[17] 2021 IRENA Renewable Cost Database, GWEC Offshore Wind Technical Potential, GWEC Offshore Wind Technical Potential

development or installation, as evidenced by ongoing offshore wind auctions.[18] However, they are forecast to be initially higher than fixed bottom costs.

In Japan, where Pillar 1 has been implemented to a certain level, wind is expected to account for 6% of the energy mix in 2030.[19] Since only a tiny share of Japan's waters are shallow, floating wind power will necessary, which will result in high LCOE (Figure 3.11).

Figure 3.11 Offshore wind potential[20]



Pillar 1: Drivers impacting system costs

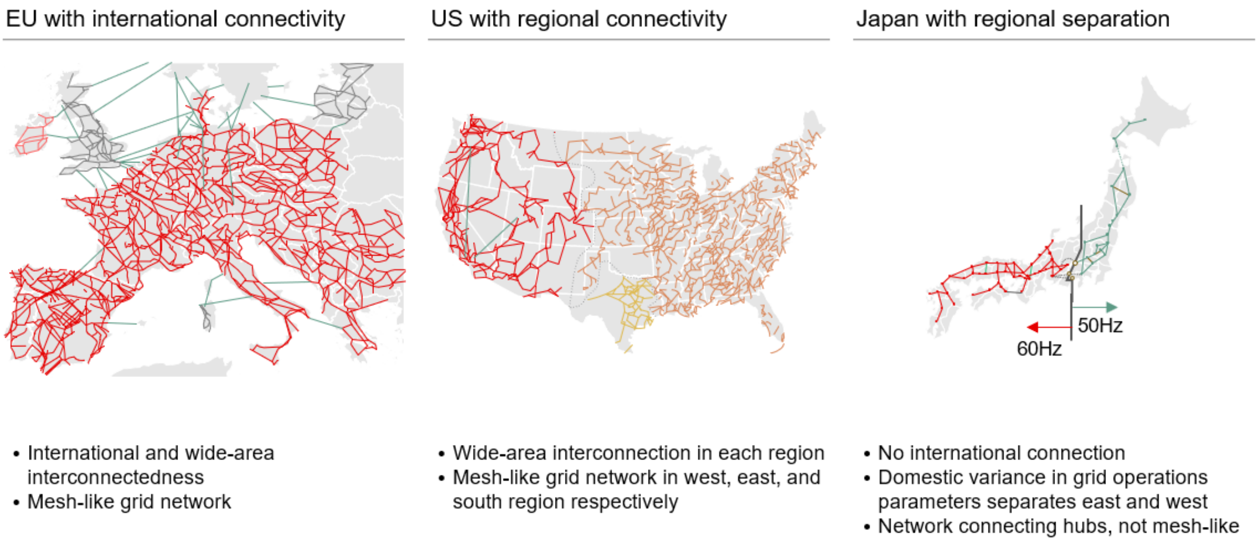
Energy transmission grids are a key factor in a country's ability to access renewables in the presence of nuclear and/or CO_2-free power sources. The transmission and distribution of electricity connects electricity generation to sources of demand. Grid capacity reflects the level to which any generation source can deliver electricity to demand. Grid size varies from country to country, with some grids more broadly connected as wide-area synchronous grids (Figure 3.12). The larger and denser the grid, the more it can meet growing demand for new power generation. Similarly, a larger grid can meet energy loads with a wider variety of generating types. Mesh-like grid networks enable wide-area interconnection, including internationally, while hub-based networks confine transmission and are less suited to fluctuations in supply and demand.

[18] The Japanese offshore wind power auction is a process where businesses bid to be selected as operators for generating power in government-designated sea areas. This has already been carried out up to Round 2. https://www.meti.go.jp/press/2022/12/20221228001/20221228001.html

[19] https://www.enecho.meti.go.jp/category/saving_and_new/saiene/community/dl/05_01.pdf

[20] https://gwec.net/discover-the-potential-for-offshore-wind-around-the-world/; Data for ten countries with highest installed wind capacity for each technology and Japan sourced from Renewable Energy Statistics

Figure 3.12 Comparison of grid connections (bulk power system), by jurisdiction[21]



To connect to a transmission grid, the starting points are different for each country. Islands, as well as other remote locations, face more complexity. Connecting new sources of renewable power generation via transmission grids is a preferred option where the grid infrastructure exists and where the geography permits connectivity. The EU has a wide, mesh-like network capable of international transmission based on cross-border energy supply and demand fluctuations. In the EU, the total energy exchanged between countries in 2021 was 429 TWh, or 15% of total energy generation.[22] In the US, regional grid networks are independent from one another, limiting domestic connectivity. Each regional grid is mesh-like and enables sufficiently wide connection to absorb renewables fluctuations.

As an island, Japan faces cost and national security barriers to international interconnection. It also has variations in grid operating frequency (50 Hz and 60 Hz). Regional fragmentation via a hub-based network further challenges domestic grid expansion. These characteristics necessitate additional infrastructure to absorb the variability of renewable energy within a smaller grid (beyond domestic renewable energy, e.g., a transmission and distribution network expansion and lower-emission thermal power).

Across the globe, further development of power grids is required to ensure variable renewables can be carried at optimal levels. To balance variable electricity supply and demand, grid operators and regulators should prioritize grid expansion and capacity balancing, for example, by introducing new ancillary service products (e.g., frequency response) or by planning for more flexible capacity in both the short and long terms. Each of these approaches adds costs.

A core principle of power generation is that the amount of electricity produced (supply) and used (demand) must be the same at the same time. If there is an imbalance between supply and demand, the quality (frequency) of electricity will be disrupted, potentially resulting in a power failure. To stabilize and provide a reliable power system, it is necessary to constantly adjust supply and accurately forecast demand.

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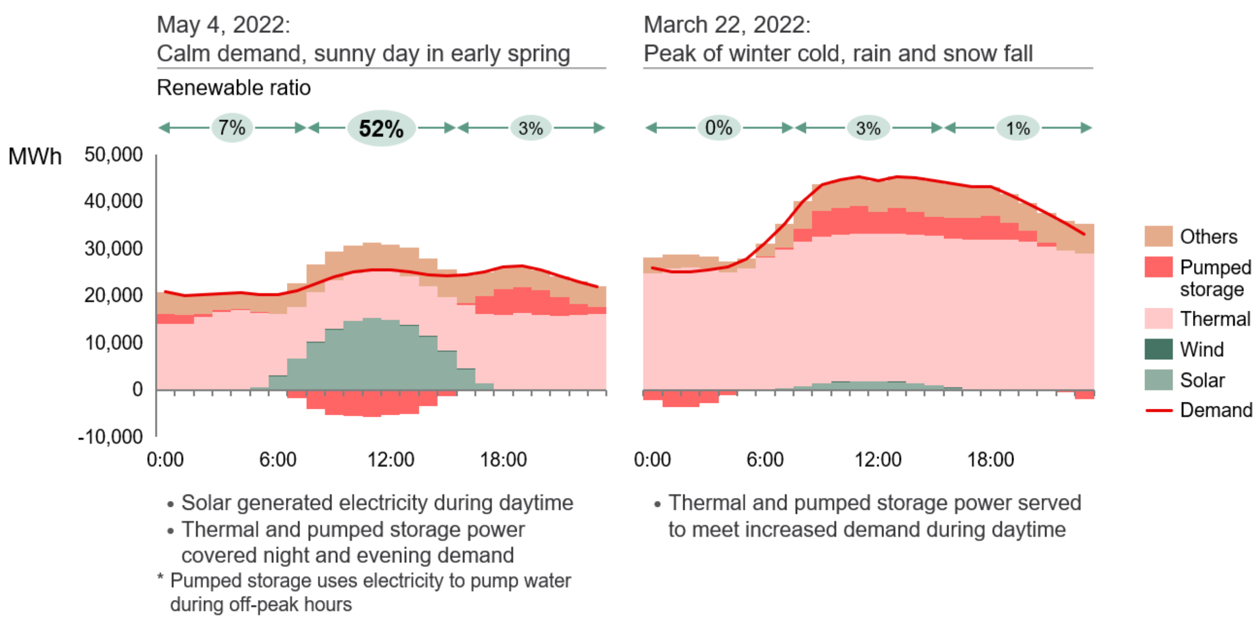
[21] https://www.entsoe.eu/data/map/, https://atlas.eia.gov/pages/energy-maps, https://www.hitachi.com/rev/archive/2021/r2021_03/04/index.html

[22] https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2021_web.pdf

In focus: Need for diversified power sources for stable supply

The need to maintain flexible power supply can be clearly seen from demand response on two days in Tokyo (Figure 3.13). On March 22, 2022, bad weather with an unusually low temperature forecast of 4.7 to 5.6 degrees Celsius boosted demand for both heating and electricity. However, the amount of solar power generation was low due to insufficient sunlight. As a result, thermal power (non-renewable) sources accounted for 70-80% of total power generation throughout the day. By contrast, on a sunny day (May 4, 2022), significant sunlight was generated during the daytime while almost no electricity was generated in the early morning and night. Therefore, during the day, the operating rate of thermal power generation facilities was reduced, while during the morning and night it rose to 70-80% of total power generation.

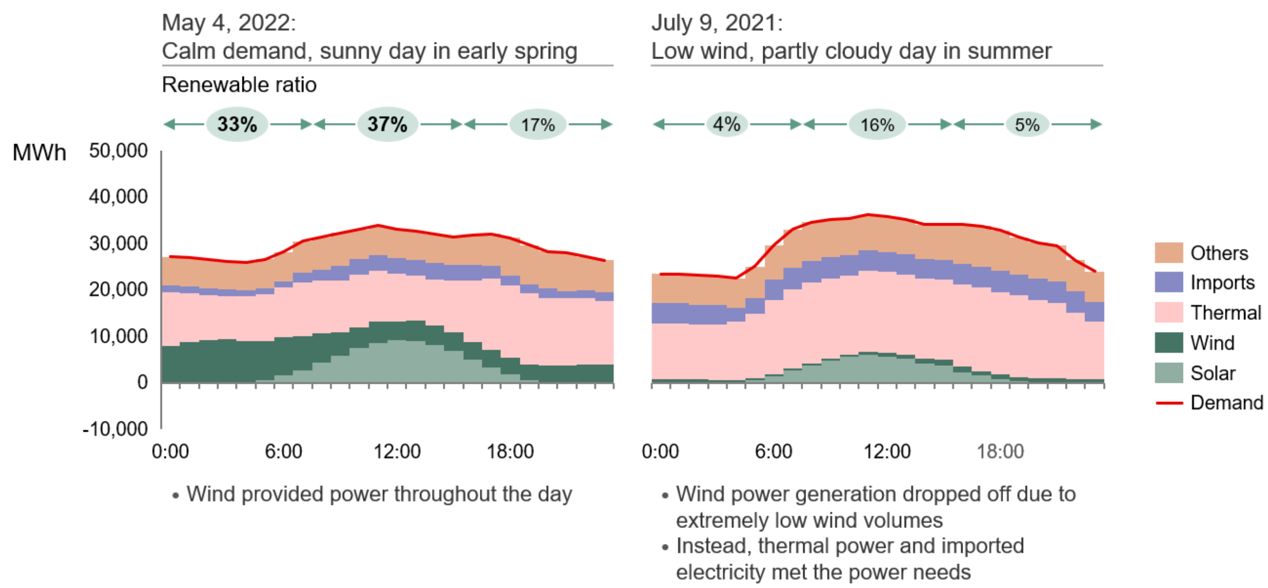
Figure 3.13 Tokyo Electric Power Company (TEPCO)'s supply adjustment[23]



Similar volatility in power generation is seen in wind, despite its relatively consistent output compared to that of solar. As shown in (Figure 3.14), UK wind speeds were sufficient to provide power consistently through the day, reducing the need for thermal power supply in May 2022. The year before, in summer 2021, the UK experienced lower-than-average wind speeds, so utilities relied on increased thermal power and electricity imports to meet demand. Low levels of wind generation in 2021, in conjunction with regulatory constraints, soaring wholesale gas prices, and other regional characteristics, put substantial stress on energy suppliers.

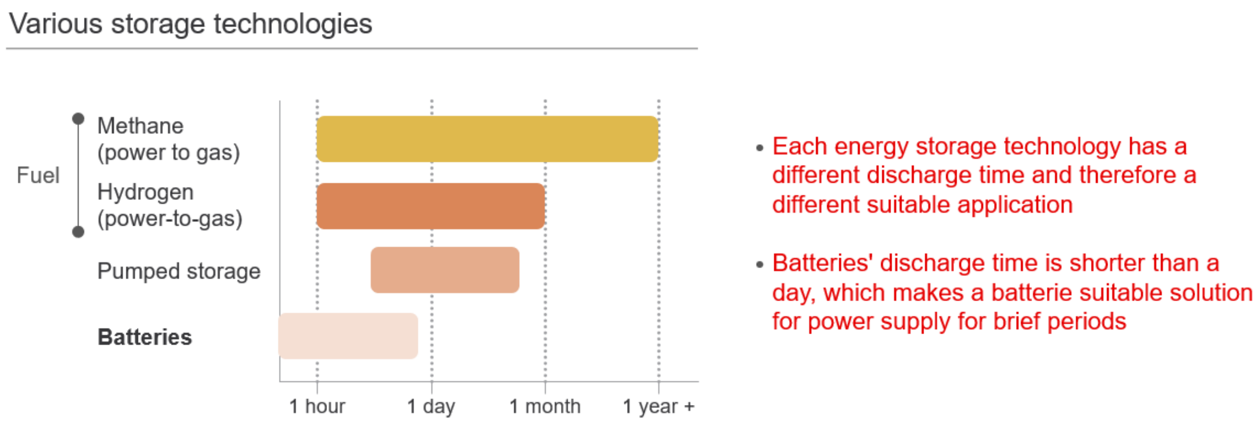
[23] https://www.occto.or.jp/oshirase/sonotaoshirase/2016/170106_juyojisseki.html

Figure 3.14 Fluctuation in wind power generation in the UK[24]



Flexible power sources with output control are therefore important to absorb the fluctuation in renewables. While storage can offer a temporary solution, facilities have a range of discharge times (Figure 3.15). Storage alone cannot adequately cover power shortages for extended durations. Specifically in battery storage, repeated recharge and discharges result in battery degradation. Therefore, fluctuations in renewable energy are difficult to manage with batteries alone.

Figure 3.15 Discharge time by storage technology[25]

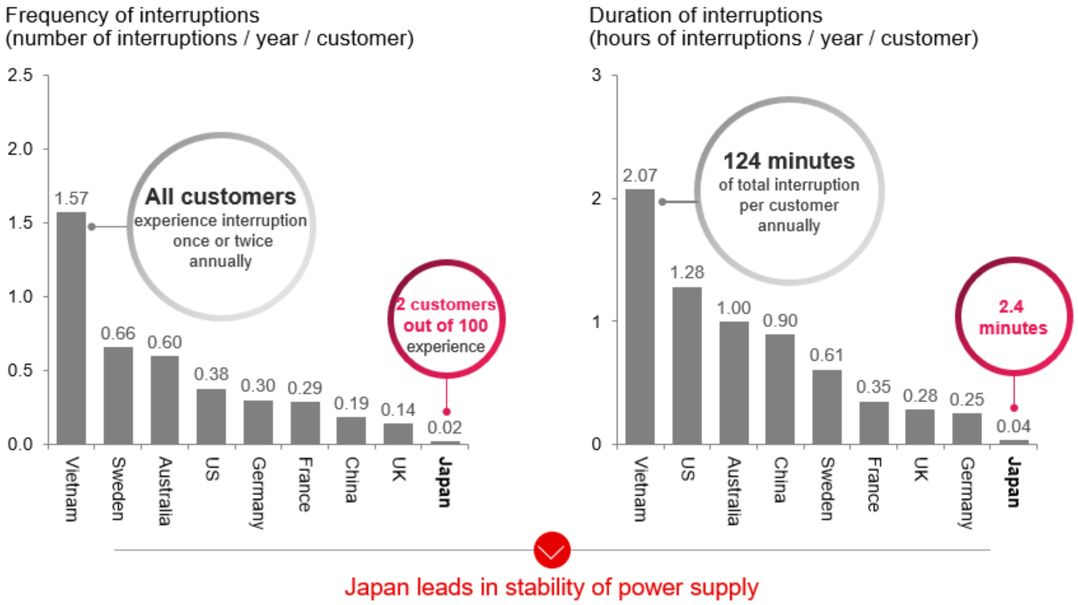


Historically, to ensure stable power, Japan has used diversified power sources (including thermal, nuclear, and pumped storage), maintenance of its grid network, and demand management. The low number of power interruptions in Japan relative to other countries, in particular relative to countries in Southeast Asia, demonstrates the value and security of this multi-layered approach (Figure 3.16). A higher reliance on variable energy sources without adequate risk mitigation, including peaking capacity or backup power sources, could lead to greater grid instability.

[24] https://data.nationalgrideso.com/carbon-intensity1/historic-generation-mix/r/historic_gb_generation_mix

[25] Power to Gas: The Case for Hydrogen White Paper; California Hydrogen Business Council: Los Angeles, CA, USA, 2015.

Figure 3.16 Electricity system interruptions by country, 2020[26]



Pillar 2: Alternative technologies

Pillar 2 entails advancing the development of renewable energy overseas and importing converted renewable energy in a form such as hydrogen, when demand for renewable energy cannot be met solely by domestic renewable energy production in Pillar 1. The utilization of imported energy carriers involves, for instance, hydrogen-based thermal power generation, furnaces powered by hydrogen combustion for industrial heat sources, and hydrogen fuel cells for transportation modes such as trucks. Thus, hydrogen manufactured overseas are expected to replace fossil fuels in process heat applications in various industries beyond power generation. Hydrogen-based and biogenic fuels will also provide increased domestic energy reliability and stability through their roles as storage solutions, as well as increased integration between the power and gas grids due to their roles in both grids. This stability will provide clean baseload power, which can be leveraged to maximize the deployment of renewables under Pillar 1. Transporting fuels requires significant infrastructure (with its associated operational risks and costs), but offers the ability to connect any two points on the globe.

The urgency of near-term carbon reductions may further drive country-by-country variations in approach. Effective use of hydrogen-based and biogenic fuels through transition technologies, including partial application, may result in immediate emissions reductions.

For instance, in countries like Japan that rely on imported fossil fuels, transitioning to hydrogen-based and biogenic fuels converted from renewable sources for their own decarbonization efforts can contribute to decarbonization of international markets. Japan can also engage in discussions on international standards for hydrogen-based and biogenic fuels and their long-term application.

Hydrogen-based and biogenic fuels are not a silver bullet; there are trade-offs such as energy loss and value chain emissions. There are also greater energy losses involved in converting renewable electricity to fuels and then converting fuels back to electricity. Depending on the specific fuel and production method, up to 50-80% of the original energy can be lost in the conversion processes,

[26] Frequency and duration of interruptions are index values SAIFI and SAIDI, respectively. SAIFI measures the average number of power outages per customer; SAIDI measures the average duration of power outages. https://databank.worldbank.org/reports.aspx?source=3001

compared to the typical 10-20% losses in direct electricity transmission and distribution.[27] Current research aims to curb these losses. Beyond energy losses, there are emissions associated with some transportation methods. For example, maritime shipping, which is largely powered by heavy fuel oil, currently accounts for 3% of global emissions. To the extent that the sector transitions to hydrogen-based and biogenic fuels, associated emissions could decline.

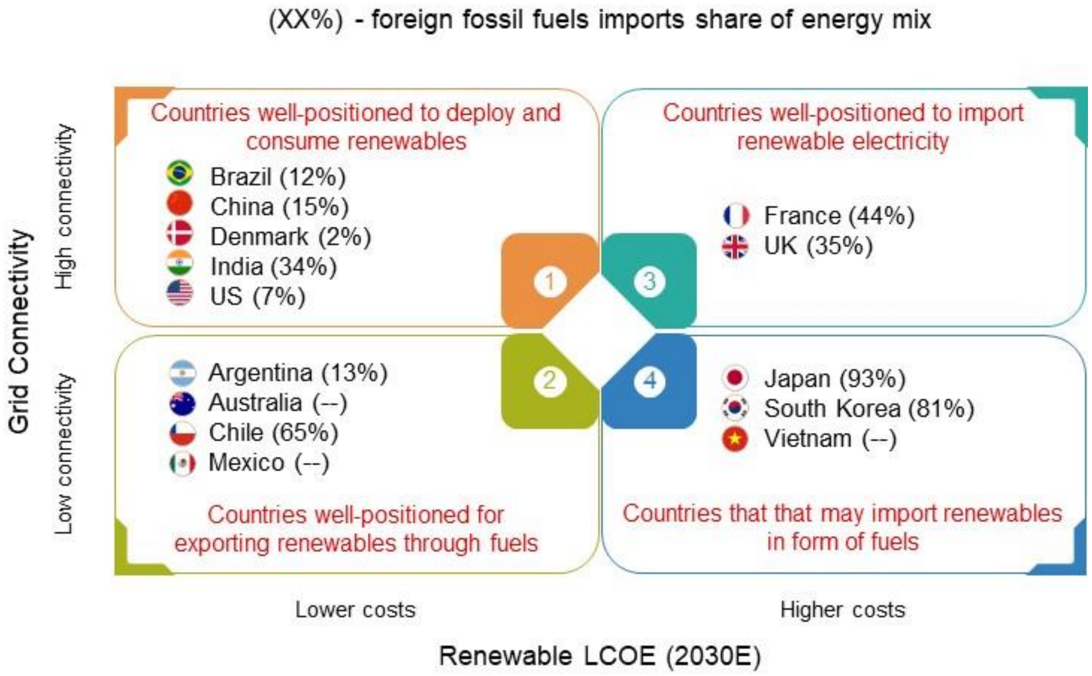
In summary, each country should consider the trade-offs in reducing emissions in electricity and heat. A holistic value chain view is optimal as countries leverage renewables and hydrogen-based and biogenic fuels in their carbon neutrality pathways.

Opportunities for global collaboration driven by commonalities and differences

Technology pathways vary across countries, creating opportunities for truly global solutions. In assessing their technological potential, taking into account nuclear and other CO_2-free power sources, countries and regions can maximize renewables in two ways:

- Renewables costs: Costs of increasing deployment of renewables
- Connectivity: Size and nature of the grid and connectivity to other countries, which can be used to represent a country's system costs.

Figure 3.17 Framework of technology pathways based on connectivity and costs[28]



Note: Higher costs = solar PV and onshore wind 2030 LCOE >=$ 0.035/kWh, Lower costs = solar PV and onshore wind 2030 LCOE <$ 0.035/kWh, High connectivity = Average planned grid capacity across nation's grids >= 175 GW, Low connectivity = Average planned grid capacity across nation's grids <175 GW

[27] ACS Sustainable Chem. Eng. 2017, 5, 11, 10231–10239 https://pubs.acs.org/doi/full/10.1021/acssuschemeng.7b02219

[28] IRENA 2021 Renewable LCOEs, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8, https://data.worldbank.org/indicator/EG.IMP.CONS.ZS

These two factors result in four categories of countries (Figure 3.17):

1. **Lower cost, higher connectivity countries** (such as Brazil, China, Denmark, India, and the US) can generate renewable electricity and deliver it widely via power transmission. Additional power grid opportunities are now also a key focus. The countries have accessible renewables potential and sources of demand. Additionally, countries with high cross-border connectivity can develop low-cost renewables while avoiding extensive grid financing (in the short term) by importing and exporting electricity supplied through wide-area interconnection. This connectivity sets up some countries to be net exporters of electricity even while being net importers of energy for industrial purposes (primarily natural gas).[29]

2. **Lower cost, lower connectivity regions** (such as Argentina, Australia, Chile, and Mexico) can generate renewable electricity cost-effectively but currently lack the ability to export globally. They are likely to be exporters of hydrogen-based and biogenic fuels, as they will choose to convert some of their low-cost renewable power into fuels to address growing global demand. Alternatively, they may seek to move further downstream, for example producing lower carbon steel or other commodities.[30]

3. **Higher cost, higher connectivity regions** (such as France and the UK) are not able to generate renewable energy as cost-effectively as other regions. However, their grid capacities may enable access to renewables elsewhere. For example, France benefits from The North Seas Energy Cooperation, which will facilitate sharing up to 300GW of offshore wind capacity developed in the North Sea across partner countries.[31] Although countries in this category will not need hydrogen-based and biogenic fuels to replace their electricity sources, they may still require imports of these fuels for portions of their energy mix that cannot be electrified.

4. **Higher cost, lower connectivity regions** (such as Japan, Vietnam, and South Korea) are not able to generate renewable energy as cost-effectively as other regions. Nor are they able to access renewables from other regions via the grid. Low-carbon fuel imports offer a solution. Advances in renewable technologies such as floating offshore wind could serve as an additional option for some countries. The evolution of key cost trade-offs will shape strategies.

Taken together, these variations create potential synergies across countries and the opportunity to build a global value chain for renewable energy. Just as the global trade of legacy energy commodities has increased energy access and reliability, a global trade in hydrogen-based and biogenic fuels could maximize renewable energy deployment.

What will it take to enable this global collaboration?

Country-specific policies can support domestic emission reductions while bolstering global collaboration. Policy instruments, such as those that establish targets, support demand creation, mitigate financing risks, promote knowledge sharing, and establish regulatory frameworks, can facilitate development of the global value chain at the pace required for the energy transition. Examples across the US, Europe, and Asia demonstrate approaches relevant to their context:

- The US Inflation Reduction Act (IRA) provides incentives to reduce costs across a range of energy technologies. Specifically, these incentives accelerate the deployment of high renewable

[29] https://eepublicdownloads.entsoe.eu/clean-documents/Publications/Statistics/Factsheet/entsoe_sfs2021_web.pdf

[30] https://energia.gob.cl/sites/default/files/documentos/green_h2_strategy_chile.pdf

[31] https://www.bundesregierung.de/breg-en/news/north-sea-summit-article-2185814

potential and carbon sequestration capacity and create opportunities to export excess production to other countries in forms such as green and blue hydrogen.

- The UK's Powering Up Britain policy outlines an energy transition plan aimed at a Net Zero economy by 2050. This includes a combination of renewable energy, nuclear power, and fossil fuels with CCUS, supported by technology-specific incentives. Notably, it includes up to GBP20 billion for funding the early deployment of CCUS value chains, and targets 10GW of low-carbon hydrogen production by 2030. The policy also encourages a breadth of decarbonization solutions relevant to the UK's regional context—such as tidal energy.
- In a regional collaboration, the four North Sea states of Belgium, Denmark, Germany, and the Netherlands' Esbjerg Declaration creates a joint target of 65GW offshore wind production by 2030, and large-scale onshore and offshore production of green hydrogen with a 20GW production capacity by 2030, proposing the North Sea as the Green Power Plant of Europe.
- In 2022, the Government of Japan published its Green Transformation (GX) policy with a detailed plan in the subsequent Basic Policy for GX Realization (GX Basic Policy) in 2023. A key pillar of this policy is to support the broader energy transition in Asia as both a lender and technology exporter.

Building a global value chain at scale is an urgent priority, but will take time. It depends on infrastructure development at a macro level, and innovative technology development at a micro level. Many lower-emissions technologies are under development and targeted for commercialization by the late 2020s.[32] As a result, countries will assess interim solutions that can ensure energy security while supporting progress toward carbon neutrality and lowering emissions in the short term, while long-term solutions are developed.[33]

Japan's strategic priorities reflect this global renewable energy value chain. MUFG recognizes the value that can be delivered through an approach that delivers global climate results through economic collaboration and shared development. In particular, economic collaboration and development can bring together developed and developing economies in a shared mission. To achieve global decarbonization, each country should maximize its domestic renewables potential while supporting global efforts to develop renewables value chains.

[32] https://www.meti.go.jp/press/2022/02/20230210002/20230210002.html

[33] IEA (2020), Aligning investment and innovation in heavy industries to accelerate the transition to net-zero emissions, IEA, Paris https://www.iea.org/commentaries/aligning-investment-and-innovation-in-heavy-industries-to-accelerate-the-transition-to-net-zero-emissions

4. Outlining Japan's Pathway to Carbon Neutrality

Japan's ongoing efforts toward carbon neutrality

Japan has become "among the most energy-efficient economies in the world" with its continuing efforts to develop energy saving technologies, according to the IEA.[34] Where possible, the country has installed renewable generation capacity, backed by policy support such as the Feed-in-Tariff (FIT) system introduced in 2012. The FIT system sets fixed prices for energy supplied to the grid from renewable sources, resulting in the third largest installed solar PV capacity globally and the sixth largest installed renewable energy capacity.[35]

The next area of significant opportunity is floating offshore wind. Although the technology is economically unfeasible to deploy at scale today, it has significant potential and is being promoted. Looking to potential next steps, it is useful again to consider possibilities across two pillars, focusing on domestic renewables and imported alternatives.

Japan's Green Transformation (GX) Basic Policy

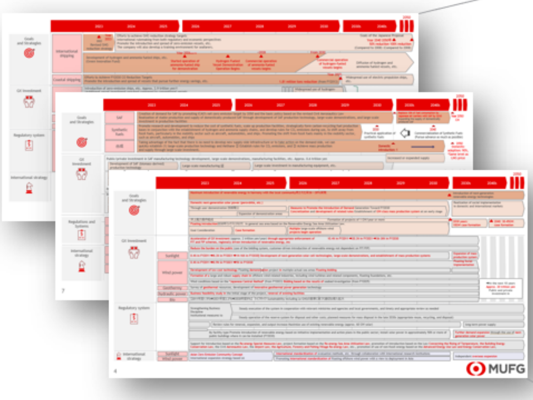
In the GX, Japan lays out an ambitious plan to move toward the 1.5 degrees Celsius target under the Paris Agreement, despite challenges including high renewables costs, delays in restarting nuclear facilities, constraints in connectivity, and geographical characteristics. The government's "strong determination to take a nationwide approach to climate change" dovetails with a sense of urgency around energy security and stability globally. The determination inspires the policy's core framing:

- **Climate ambition:** The strategic aim of the GX Basic Policy is to deliver Japan's international commitment of a 46% reduction in greenhouse gas emissions by 2030 and carbon neutrality by 2050. The GX Basic Policy serves a dual purpose—climate change measures and economic sustainability by ensuring the competitiveness of companies and the nation as a whole.
- **S+3E principles (Safety + Energy security + Economic efficiency + Environmental sustainability):** These are the foundational energy principles developed by the Japanese government in 2014. Putting security first, the GX Basic Policy inherits the spirit of the S+3E principles and leverages Japan's unique position as a highly industrialized island to deliver nationwide emissions reductions through centralized planning. To do this, a package of individual roadmaps for the 22 sectors will be achieved by optimizing combinations of technologies for implementation (Figure 4.1).

[34] IEA (2021), Japan 2021, IEA, Paris https://www.iea.org/reports/japan-2021, License: CC BY 4.0

[35] https://www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Country-Rankings

Figure 4.1 22 sectorial roadmaps in GX Basic Policy[36]



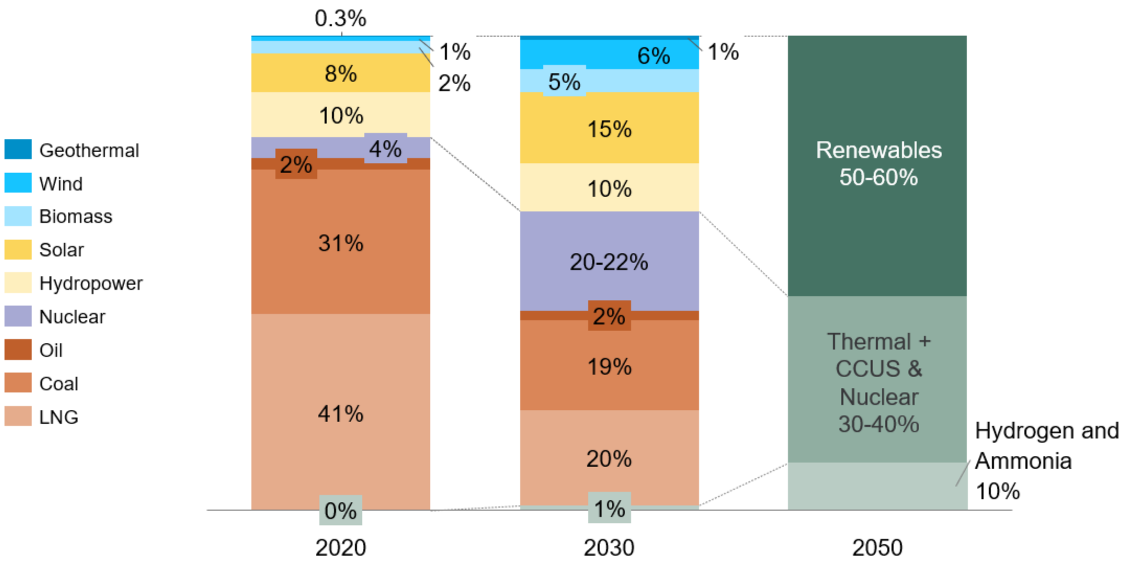
Roadmaps cover 22 of Japan's key emitting sectors

Topics in the GX Policy	
1.	Hydrogen and ammonia
2.	Storage battery
3.	Iron and steel
4.	Chemicals
5.	Cement
6.	Paper
7.	Automobile
8.	Resource recycling
9.	Housing and buildings
10.	Digital
11.	Aviation
12.	Maritime sector
13.	Biotech manufacturing
14.	Renewable energy
15.	Grid networks
16.	Nuclear
17.	Transportation
18.	Infrastructure
19.	Carbon recycled fuels
20.	CCS
21.	Food, agriculture, forestry, and fisheries
22.	Community

Japan's future energy mix, as envisaged by the GX policy, will be based on the two-pillar strategy for applying low-carbon technologies while controlling cost. Japan plans to scale Pillar 1, namely renewables (mainly solar and wind) to make up 50-60% of the energy mix by 2050, accompanied by thermal energy paired with CCUS and nuclear (30-40%). Under Pillar 2, hydrogen-based and biogenic fuels, particularly hydrogen and ammonia, will account for 10% of the energy mix (Figure 4.2). Pillar 2 and related initiatives are also necessary to support demand growth for energy, given Japan's lack of fossil-fuel resources. Furthermore, replacing fossil fuels with hydrogen-based and biogenic fuels, converted from overseas renewable energy sources in thermal plants, as well as thermal paired with CCUS, will serve to decarbonize backup power—enabling energy stability and maximal renewable deployment. This holds significant relevance for Japan, an industrialized nation, as it greatly contributes to mitigating the critical issue of power shortages.

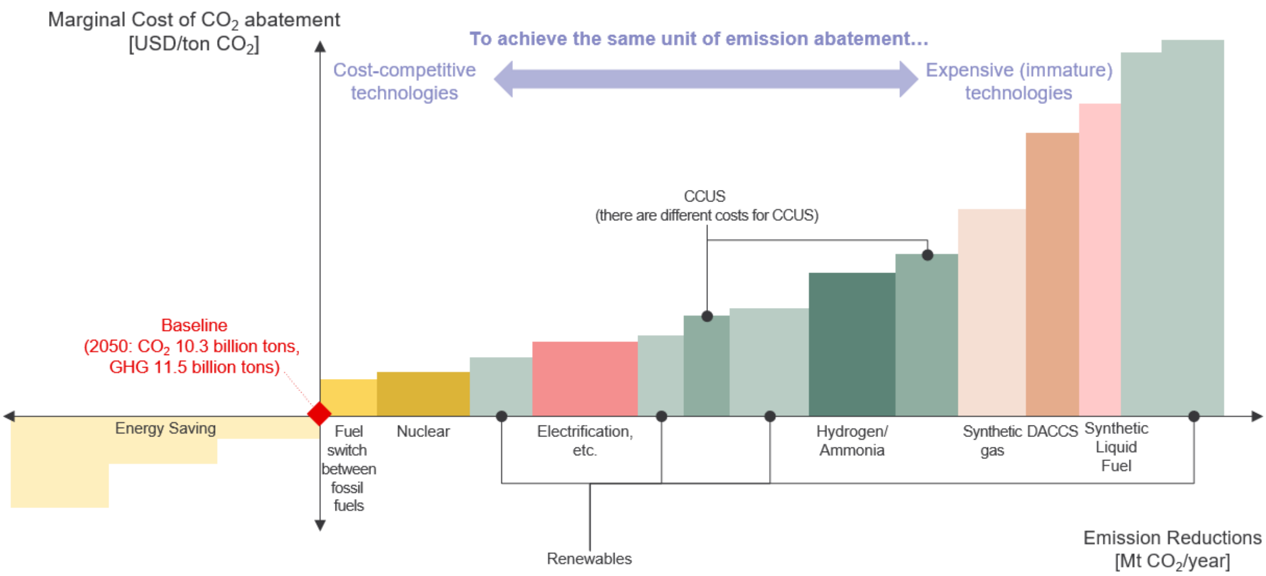
[36] https://www.meti.go.jp/press/2022/02/20230210002/20230210002.html
https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/ELECCAP_2023_cycle2.px/

Figure 4.2 Government of Japan's projected energy mix in 2030 and 2050[37]



Furthermore, this energy mix is underpinned by Japan's consideration of the marginal cost of CO_2 abatement (Figure 4.3). Generally, technologies with lower maturity levels incur higher costs to develop and implement. Consequently, it is economically advantageous to prioritize technologies with lower costs per unit of CO_2 emission reduction (i.e., favorable cost-benefit) as the starting point.

Figure 4.3 Japan's marginal abatement costs by energy-related technology (illustrative)[38]



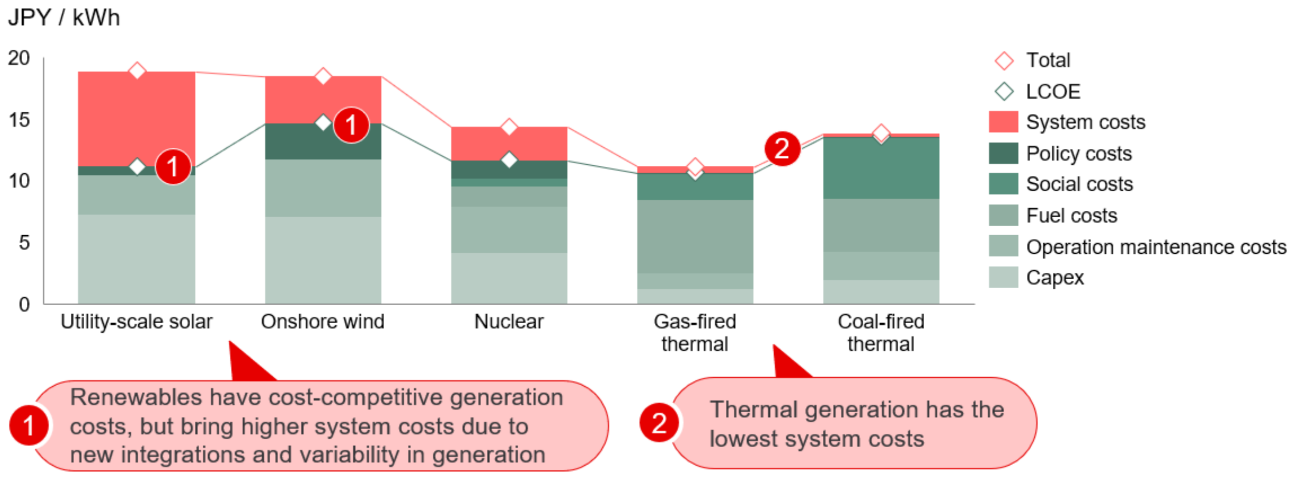
In addition, when incorporating renewable energy, system costs are also considered (Figure 4.4). Although certain renewable energy sources have seen their LCOE decrease to levels comparable to thermal power generation due to recent technological advancements, the costs associated with

[37] 2020 results are estimated based on OCCTO compiled off-transmission power.
https://www.enecho.meti.go.jp/category/saving_and_new/saiene/community/dl/05_01.pdf
https://www.occto.or.jp/system/gijutsu/kouri_ippan_renkei.html

[38] https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/043/043_005.pdf

integrating them into the transmission and distribution systems are substantial. This leads to the total cost of renewables often surpassing that of thermal power by a significant margin.

Figure 4.4 Breakdown of costs by type of energy[39]



Pillar 1: Further enhancement of domestic renewable energy generation

To achieve the Japanese government's ambition of achieving a 50-60% renewable energy ratio in 2050, combining proven technologies with investment in R&D for new sources of energy will be required. New technologies include perovskite solar cells and floating offshore wind in deep sea locations. Along with the expansion of existing technologies, it is necessary to significantly enhance power transmission and distribution, as well as battery storage infrastructure, together with further electrification on the demand side, where applicable. The Japanese government's listed technologies include those we refer to as "Positive technologies." The GX Basic Policy covers an extensive list of technologies, and it is a mix of existing and innovative technologies for the 22 sectors (see Figure 4.1). Some technologies are specifically mentioned, but many are mentioned in broad categories, such as hydrogen, energy savings, fuel switching, etc. In this whitepaper, technologies under development or undergoing improvement, mainly related to electricity and heat for high-emitting industrial sectors, will be explained.

Electricity

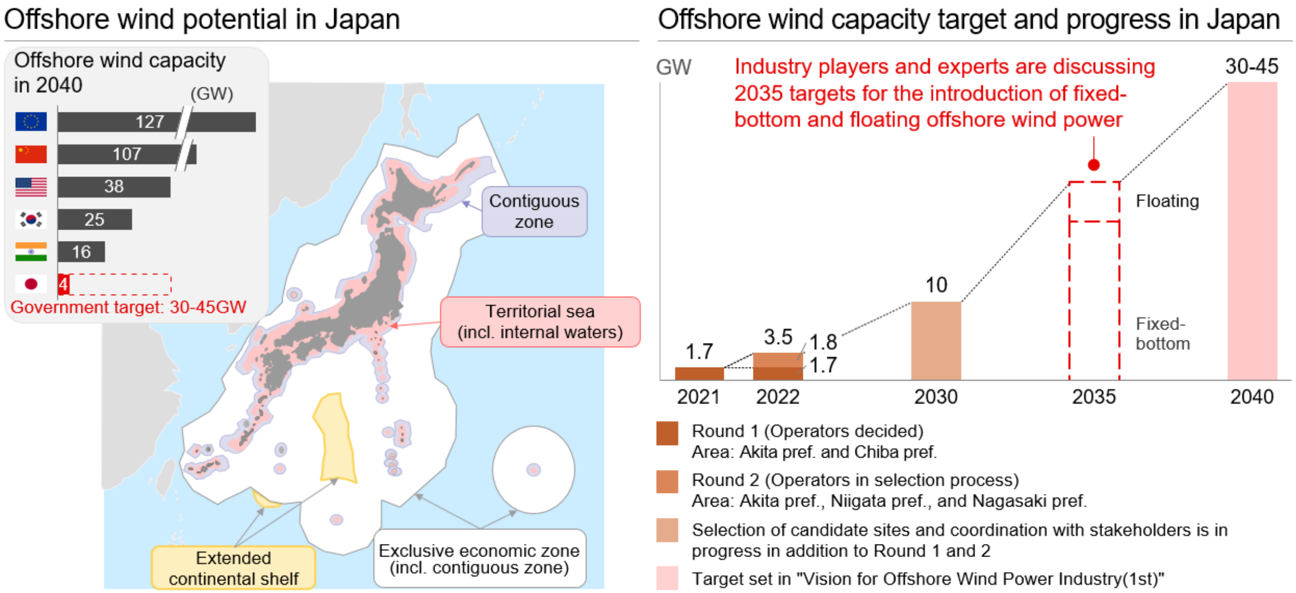
The government aims for these to account for more than a third of Japan's electricity generation capacity by 2030.

- **Positive technology 1**: Wind represents less than 1% of the energy mix today, but its share is expected to rise through expansion of onshore wind and introduction of offshore wind (Figure 4.5). In Japan, there are very few shallow water areas suitable for fixed-bottom installations (only 6% of offshore waters). To achieve the target of offshore wind capacity of 30-45GW by 2040, the country is promoting the deployment of shallow-water fixed-bottom and has initiated auctions for a generating capacity of 3.5GW. Floating turbine systems capable of operating in deep waters hold potential for further harnessing offshore wind capacity for subsequent development. With ongoing technical improvement, this technology is also being de-risked through development

[39] https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/cost_wg/2021/data/08_05.pdf

projects around the world. Overall, wind should account for 6% of the electricity supply (~36 GW[40]) by 2030 in Japan, with accelerating growth to follow.

Figure 4.5 Japan's offshore wind expansion plan[41]



- **Positive technology 2**: Solar is set to nearly double its share of the energy mix, reaching 15% by 2030 from 8% in 2020. Silicon photovoltaics (PV) have been installed mainly on flat land. New sites might include rooftops, parking lots, and transportation rights of way, as well as other parts of Japan's built environment. In addition, it will be important to develop and scale production of the emerging perovskite solar cell technology.

A combination of enabling technologies can support renewables penetration. One key challenge is to maintain grid stability and ensure an adequate level of baseload power, thereby managing the variable output associated with renewable electricity generation.

- **Positive technology 3**: Power transmission and distribution must be further developed to build robust electricity markets. As indicated in the Master Plan of Nationwide Power Transmission Networks (Master Plan), JPY6-7 trillion is earmarked to be invested.

- **Positive technology 4**: Nuclear power contributes to CO_2-free electricity supply stability and security, which is especially important in Japan, where energy self-sufficiency is low. Since the Fukushima accident in 2011, confidence in nuclear has declined and operations at several reactors have been halted. Japan has been restarting nuclear power plants and has considered the possibility of supporting the development of next-generation reactors. As a CO_2-free baseload power source, nuclear has the potential to address variable renewables growth. It also has potential to contribute to thermal decarbonization through the development and deployment of high temperature reactors.

[40] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/028_05_00.pdf

[41] IEA (2019), Offshore Wind Outlook 2019, IEA, Paris https://www.iea.org/reports/offshore-wind-outlook-2019, License: CC BY 4.0
https://www1.kaiho.mlit.go.jp/ryokai/ryokai_setsuzoku.html
https://www.meti.go.jp/shingikai/energy_environment/yojo_furyoku/pdf/001_04_01.pdf
https://www.meti.go.jp/shingikai/energy_environment/yojo_furyoku/sangyo_kento/001.html
meti.go.jp/shingikai/sankoshin/green_innovation/green_power/pdf/004_04_00.pdf

Industry electrification

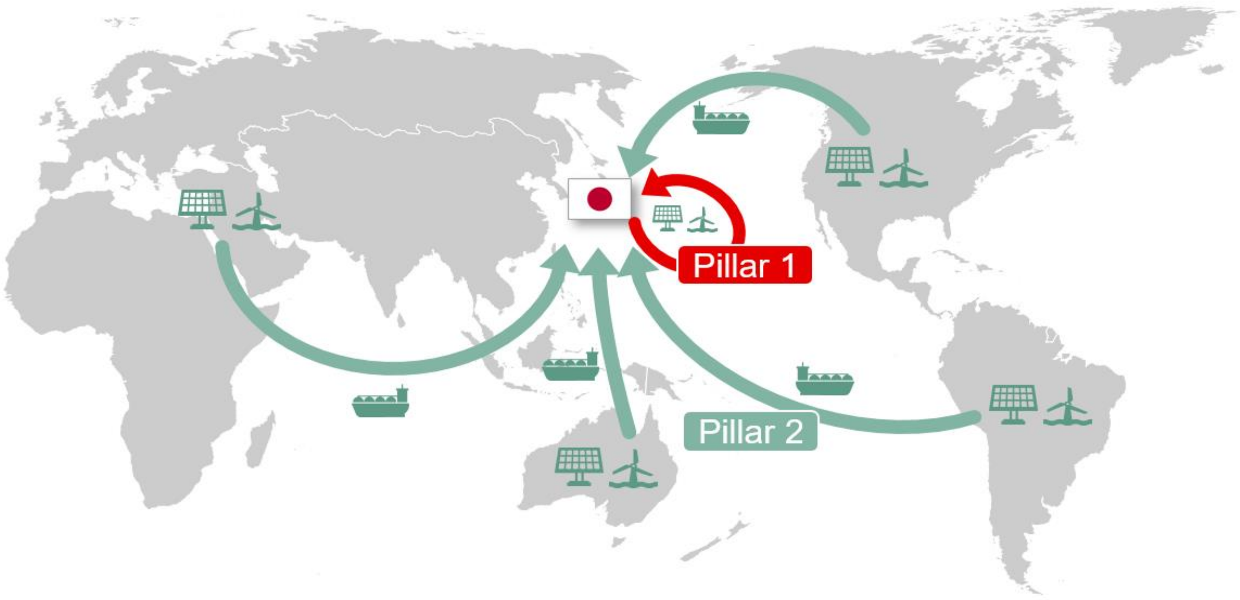
As in electricity generation, fossil fuels such as coal and gas are key heat sources for materials-based industries. Indeed, natural gas dominates both the industrial and the domestic heating supply. For decades, Japan has strived to improve energy efficiency across the economy, including through waste heat recovery. However, the country's path to carbon neutrality will require alternative technologies. Renewable heat is nascent in Japan, comprising only about 6% of overall heat consumption.[42] Electrification, as well as fuel conversion, present new opportunities.

- **Positive technology 5**: Industrial electrification can therefore reduce the emissions associated with the use of heat in industrial purposes. It is seen as one of the primary options to replace conventional boilers and less efficient compressors. Currently, heat pumps are mainly deployed in lower temperature ranges (below 200 degrees Celsius), including in residential, commercial, machinery manufacturing, chemical petroleum, textile, and food & beverage use cases. Technical advancement is needed for usage at higher temperatures. Still, there are new solutions under development, such as producing large-scale, high-quality steels using electric arc furnaces, which are currently produce by blast furnaces. There are additional efforts underway to further reduce electricity needs through the use of waste heat. Fuel replacement, such as with hydrogen, ammonia, e-methane, and other hydrogen-based and biogenic fuels is under consideration for reducing emissions from heat generation at higher temperatures.

Pillar 2: Leveraging global renewable energy

In addition to generating renewable energy domestically, Japan plans to develop pathways to import fuels from renewable energy produced outside Japan. By doing so, Japan can import renewable energy carriers in the form of hydrogen and ammonia to directly replace thermal power generation and industrial heat sources. Imported fuels such as hydrogen and ammonia will account for 10% of energy mix by 2050 and will be used in mono-firing power plants as a complement to renewables, the output of which often fluctuate (Pillar 2) (Figure 4.6).

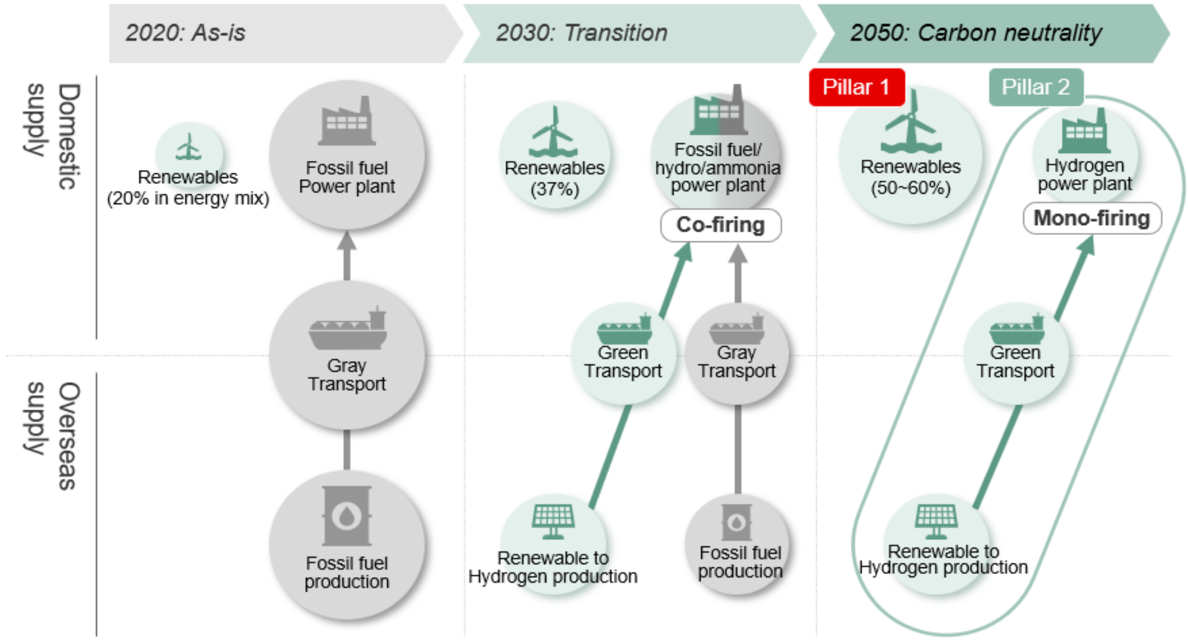
Figure 4.6 Integrated global vision for scaling Japan's renewable energy deployment



[42] IEA (2022), Renewables 2022, IEA, Paris https://www.iea.org/reports/renewables-2022, License: CC BY 4.0

- **Positive technology 6**: Hydrogen-based and biogenic fuels can play a role in reducing emissions. The Japanese government is aiming to reduce emissions in the thermal power and industrial sectors through fuel switching from fossil fuels to hydrogen-based and biogenic fuels (Figure 4.7). Existing thermal power infrastructure can be used for this transition. Co-firing ammonia in thermal power plants is already viable. Hydrogen and ammonia mono-firing will likely be deployed by the 2030s, raising the prospect of zero-emissions thermal power generation. This target is in line with industry commitments that will drive demand for these fuels. Hydrogen-based and biogenic fuels can also be used as "hydrogen carriers" for multiple applications, including feedstock replacement for basic chemicals (see Positive technology 7) and reduction agents in steelmaking.

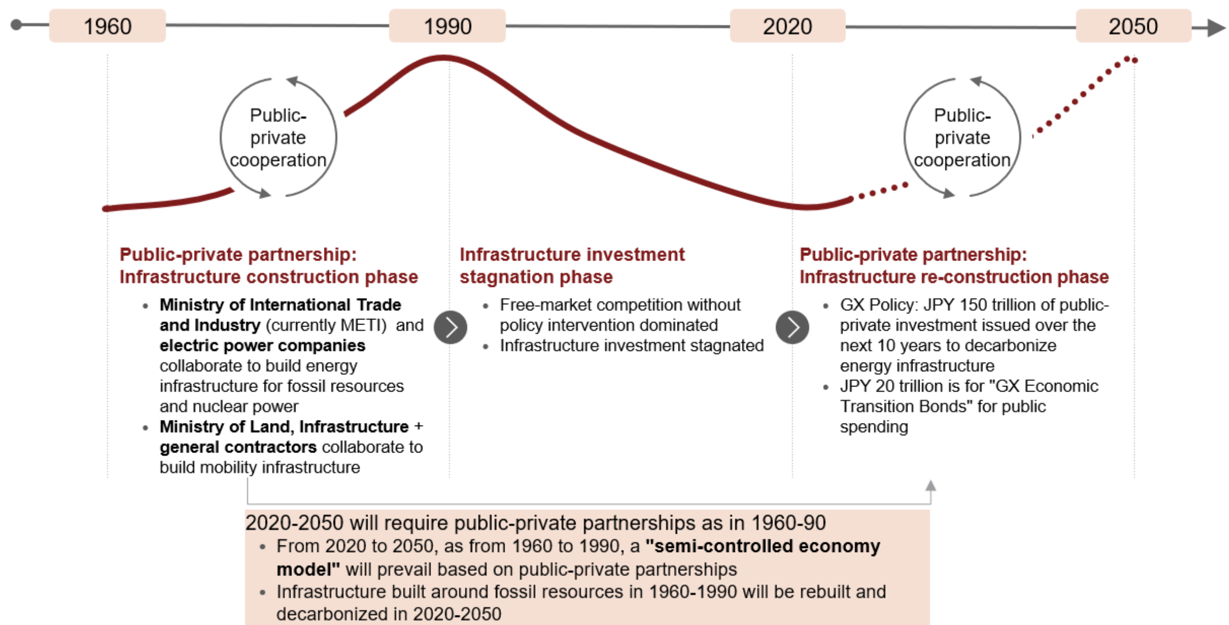
Figure 4.7 Japan's strategy for hydrogen-based and biogenic fuels



In focus: Japan's history of energy innovation: The LNG and nuclear industries

Creating a new value chain for hydrogen-based fuels is a challenge for Japan. However, historically, the Japanese government and industry have played a key role in the creation and development of the global liquefied natural gas (LNG) market as well as promoting nuclear as an advanced energy technology (Figure 4.8). In the 1960s, the government set the goal of reducing its dependence on foreign oil imports and stabilizing its energy supply. This led to a series of initiatives to diversify its energy portfolio. Government interventions such as regulatory frameworks for LNG infrastructure and subsidies for companies involved in the construction of LNG terminals, carriers, and related facilities supported the project. Internationally, Japan cooperated with its regional partners, for example to start imports from Southeast Asia. Private players responded by building out supply chain infrastructure. Japan quickly emerged as the predominant source of demand in the global LNG market, achieved through private sector engagement.

Figure 4.8 Japan's public-private partnership economic cycle[43]



In parallel, the country stimulated new LNG supply through financial and technological efforts (Figure 4.9). The country's lenders, investors, and trading companies, backed by the government through organizations such as Japan Bank of International Cooperation (JBIC) and Nippon Export and Investment Insurance (NEXI), actively participated in supporting new LNG projects globally via loans, financing mechanisms, purchase commitments, and other services, leading to diversified supply locations (Figure 4.10). Additionally, Japanese industrial players have been instrumental in designing and implementing new technologies to support the growth of the LNG market. From the 1980s onwards, Japan led the LNG vessel construction industry and built a substantial fleet. Companies such as Toshiba, Itochu, and IHI have played a critical role in developing innovative technologies for liquefaction and transport. Today, Japan continues to lead in designing and pioneering development of advanced LNG technologies.

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[43] https://www.enecho.meti.go.jp/en/category/special/article/detail_178.html

IEA (2019), LNG Market Trends and Their Implications, IEA, Paris https://www.iea.org/reports/lng-market-trends-and-their-implications, License: CC BY 4.0

Figure 4.9 LNG development trajectory in Japan[44]

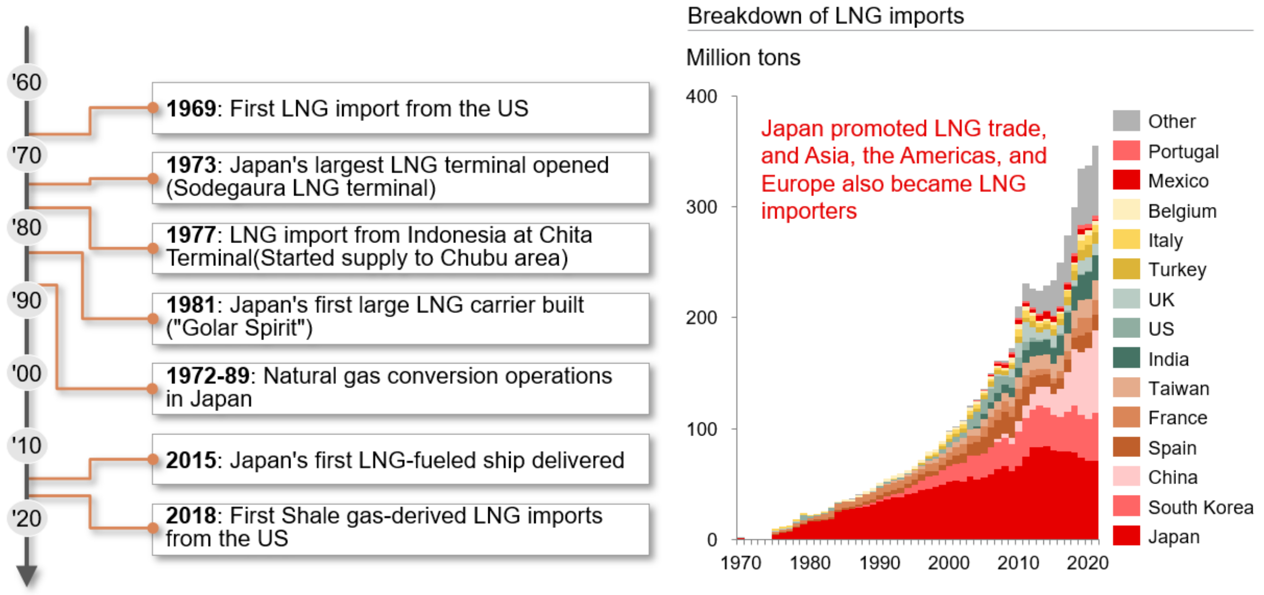
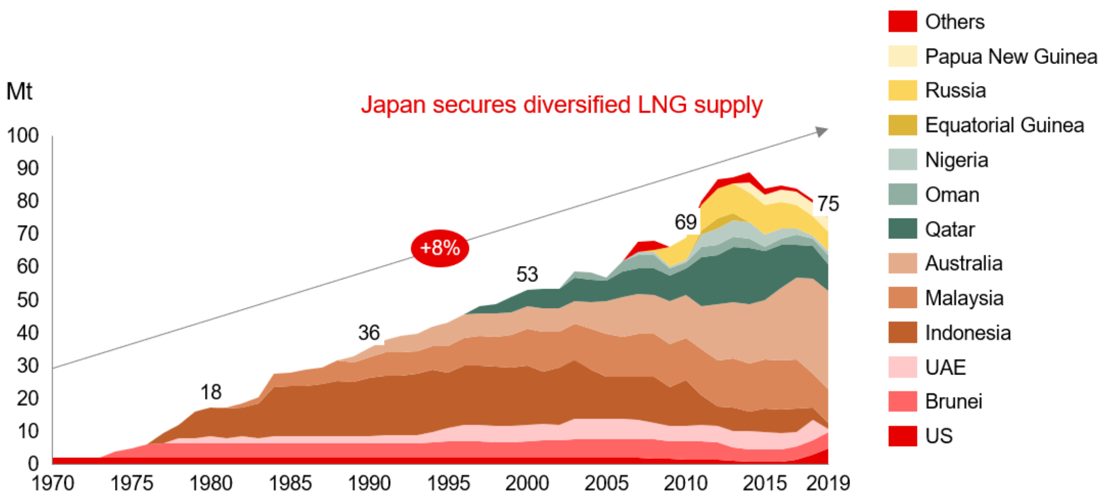


Figure 4.10 Japan's diversified LNG supply[45]

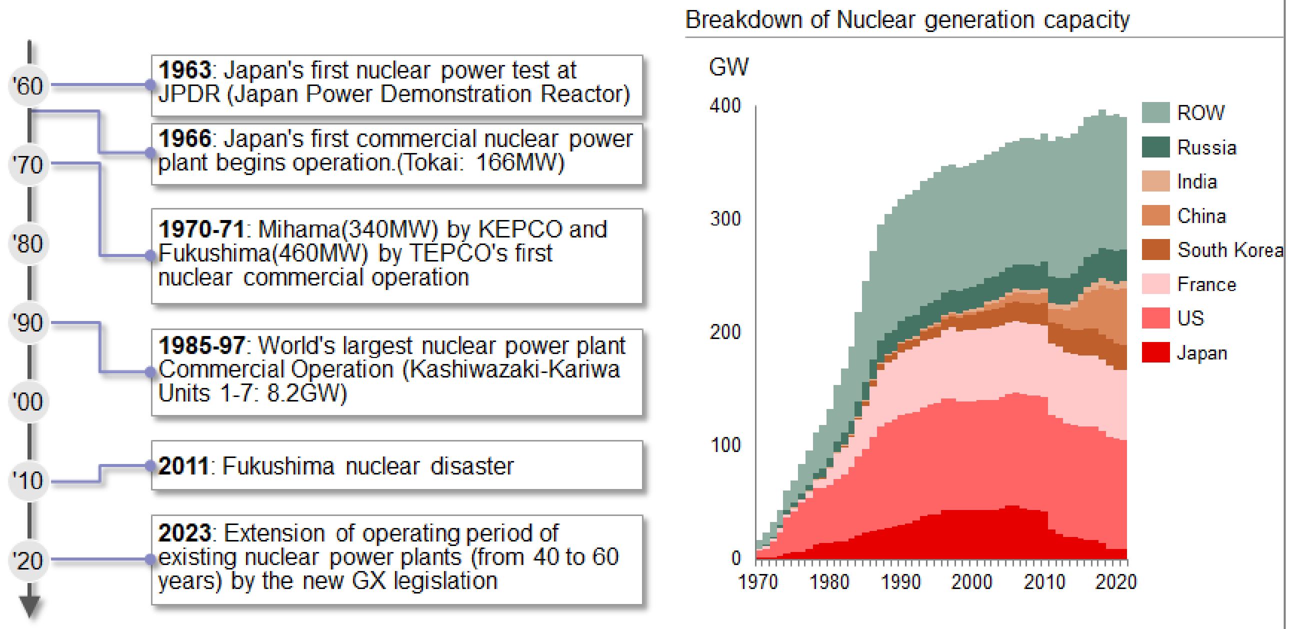


Similarly, Japan was one of the earliest movers to develop and deploy nuclear power generation technologies. Research on nuclear power generation began in the 1950s, which was followed by power generation tests and plant commissioning in the 1960s. Since then, Japan has become a global leader in developing nuclear power technologies and building and operating nuclear power plants (Figure 4.11).

44 Ministry of Economy, Trade and Industry, CEDIGAZ database

45 CEDIGAZ database

Figure 4.11 Nuclear development trajectory in Japan[46]



The establishment of a global LNG supply chain has implications beyond LNG and presents a pathway for hydrogen-based and biogenic fuels. Similarly, Japan's nuclear experience shows its domestic knowhow in developing new energy sources.

Beyond hydrogen-based and biogenic fuels, a range of solutions will be used to manage emissions from hard-to-abate sectors. To achieve its plan for 2050, the Japanese government envisages a CO_2 supply chain enabled by CO_2 capture, utilization, and storage (CCUS) and transported by sea.

- **Positive technology 7**: CCUS can reduce residual emissions in the thermal power sector and hard-to-abate industries, such as steel, chemicals, cement, and other materials industries. The captured CO_2 is typically liquefied and transported to storage or usage locations. For storage, the Japanese government is supporting the development of domestic sites. Storage facilities are also abundant in Australia and Southeast Asia, where CO_2 could remain for long periods of time. In parallel with storage, carbon utilization or recycling (CCU) can be applied to manufacture minerals, chemicals, and materials.

These seven technologies are broadly reflective of the decarbonization levers being supported globally (Figure 4.12).

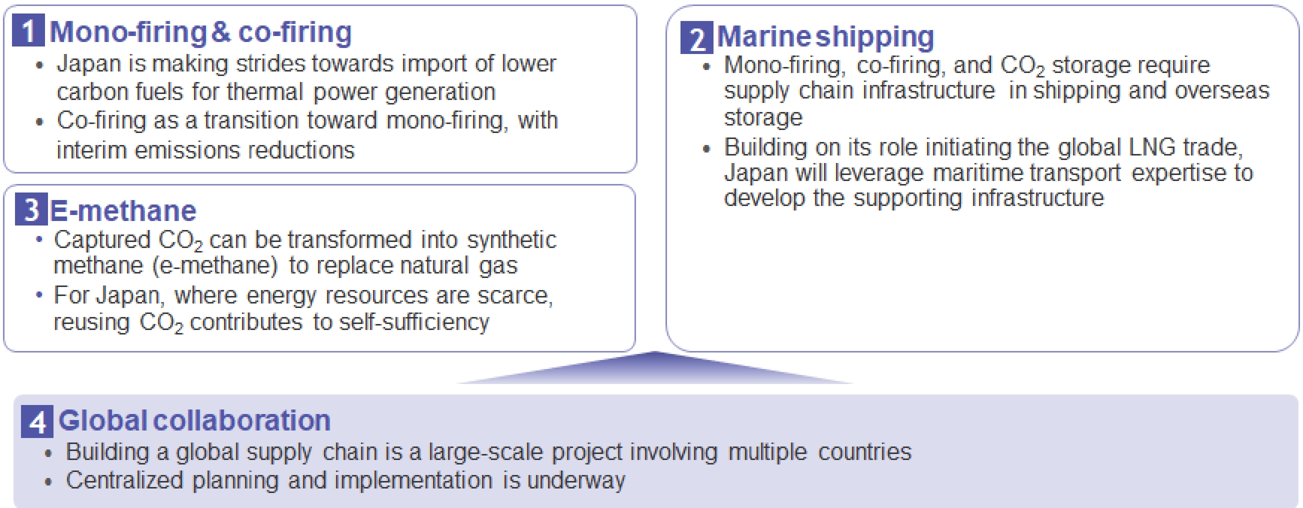
[46] NUCLEAR POWER REACTORS IN THE WORLD 2022 Edition, © IAEA, 2022, page 92, https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-2-42_web.pdf; https://world-nuclear.org/information-library/country-profiles/countries-g-n.aspx .

Figure 4.12 Technologies with supporting governmental policies in Japan and globally, as of May 2023

	EU (GDIP / REPower EU)	US (IRA / IIJA)	ASEAN (Taxonomy)	China (14th Five-Year Plan)	Japan (GX Basic Policy)
Hydrogen	✓	✓		✓	✓
E-fuels	✓	✓			✓
CCUS	✓	✓	✓	✓	✓
Solar	✓	✓	✓	✓	✓
Wind	✓	✓	✓	✓	✓
Power transmission and distribution	✓	✓	✓	✓	✓
Nuclear	✓	✓		✓	✓
Electrification	✓	✓			✓
EVs	✓	✓	✓	✓	✓

New activities are under development in Japan to develop Pillar 2 technologies (Figure 4.13). These include use of imported low-carbon fuels for power generation, shipping to facilitate transportation, production of e-methane and global collaboration networks. Development in these areas may provide learnings for partners outside Japan.

Figure 4.13 New activities to support Japan's carbon neutrality ambition[47]



Viability verification through Japan government's approach

Japan has adopted a roadmap-driven approach that focuses on viability testing of specific technologies through public-private collaboration, rather than identifying technologies for policy support, as is commonly seen in other countries. Technologies with high priority in this viability verification process are treated as "Positive technologies." Viability testing in Japan includes verification through demonstration projects using the government's "Green Innovation Fund" (equivalent to Europe's Green Innovation Fund), in addition to individual companies' R&D efforts. In this context, we will present notable technologies as case studies.

[47] METI; Company websites

In focus: Technolgy development to actual deployment: case of hydrogen and ammonia technologies in the power sector (see 5.6 for details)

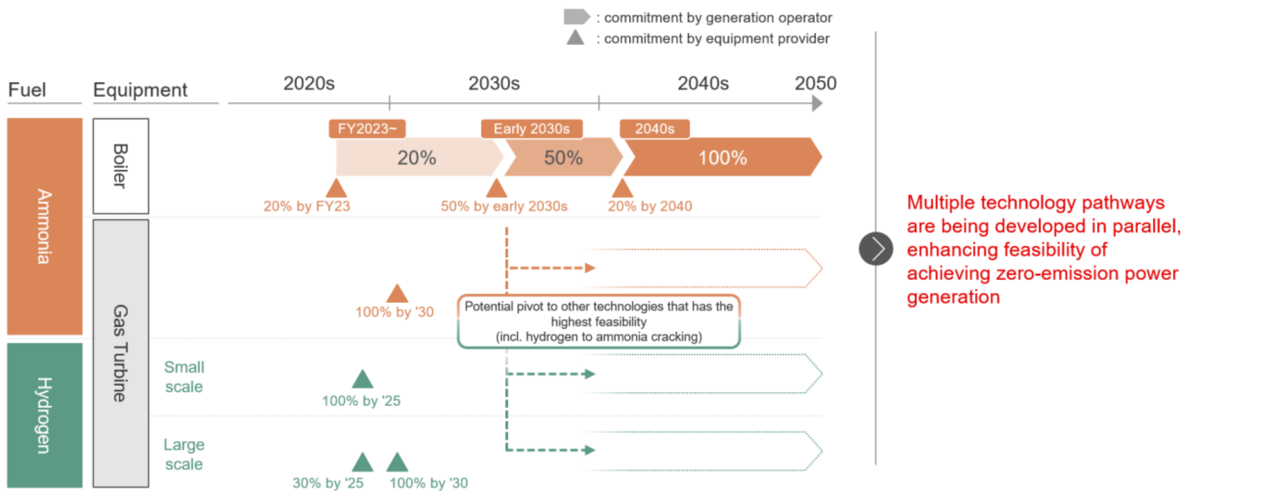
When developiong technologies, there is an imperative to ascertain that the technologies not only reduce direct emissions, but also contribute to reducing lifecycle emissions, especially when fuel switching occurs. Furthermore, the new technologies need to go through sufficient testing to secure safe operation. For containing lifecycle emissions, some economies introduce CO_2 emissions thresholds to direct the private sector to align with their targets to meet the Paris Agreement. This is the case in the EU, where the Taxonomy requires gas-fired power plants of 270 g-CO_2-e /kWh (direct emissions) up to 2035, and 100g-CO_2-e/kWh (life cycle) after 2035 to be recognized as sustainable activities. The 270 g-CO_2-e /kWh threshold can be achieved with either (30% to) 50% hydrogen co-firing,[48] which is currently at demonstration phase with large-scale turbines, or around 66% ammonia co-firing. While the ultimate goal is to develop hydrogen and ammonia mono-firing gas turbines, and they are within a reach at a small scale (Figure 4.14), there remains challenges such as reducing emissions in the hydrogen and ammonia supply chains.

For safe operation at commercial scale, a player such as JERA has provided its power plant in Hekinan for demonstration of fuel switching to ammonia. Together with manufacturers, JERA is working on solutions to meet safety standards that address challenges such as toxicity of fuel (ammonia) and development of de-nitration equipment to handle NOx emissions for commercial application.

Economic viability is important for commercialization. This encompasses emissions intensity, energy efficiency, scale, fuel prices, technology maturity, and safety issues. Having multiple alternatives for new technologies using hydrogen and ammonia will further strengthen project viability. A supply chain for ammonia, for instance, can be used for hydrogen supply by converting ammonia to hydrogen. To facilitate a pivot to better options for carbon neutrality, multiple technologies are being concurrently developed by domestic equipment manufacturers, with Mitsubishi Heavy Industries (MHI) at the forefront.

To realize early deployment of fuel switching in large-scale thermal power plants, the Japanese government and companies plan to accelerate the development of renewable energy outside Japan and import hydrogen and ammonia from renewable energy outside Japan.

Figure 4.14 Technology development for switching to hydrogen/ammonia firing power plants[49]



[48] Thresholds can be achieved with as little as 30% mixed burning, depending on the equipment.

[49] https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/029_05_00.pdf; https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/029_04_00.pdf

5. Japan's Positive technologies

As noted in chapter 4, the GX Basic Policy covers both existing and innovative technologies for the 22 sectors. Among those, seven positive technologies highlighted in this chapter will play a critical role in supporting Japan's energy transition for electricity and heat (mainly on the supply side): wind power, solar, power transmission & distribution, nuclear, industrial electrification, hydrogen-based and biogenic fuels, and CCUS. The viability of Pillar 2 that Japan is pursuing may be affected by the progress made alongside three solutions: hydrogen-based fuels for mono-firing and co-firing, marine shipping of fuels and CO_2, and e-methane. Seven technologies listed in this chapter are highlighted as they are reflecting unique situation of Japan. They are supplemented with other technologies such as geothermal, hydro power, biomass energy, energy savings, fuel switching, demand-side measures, etc. listed under the GX Basic Policy.

5.1 Positive technology: Wind power

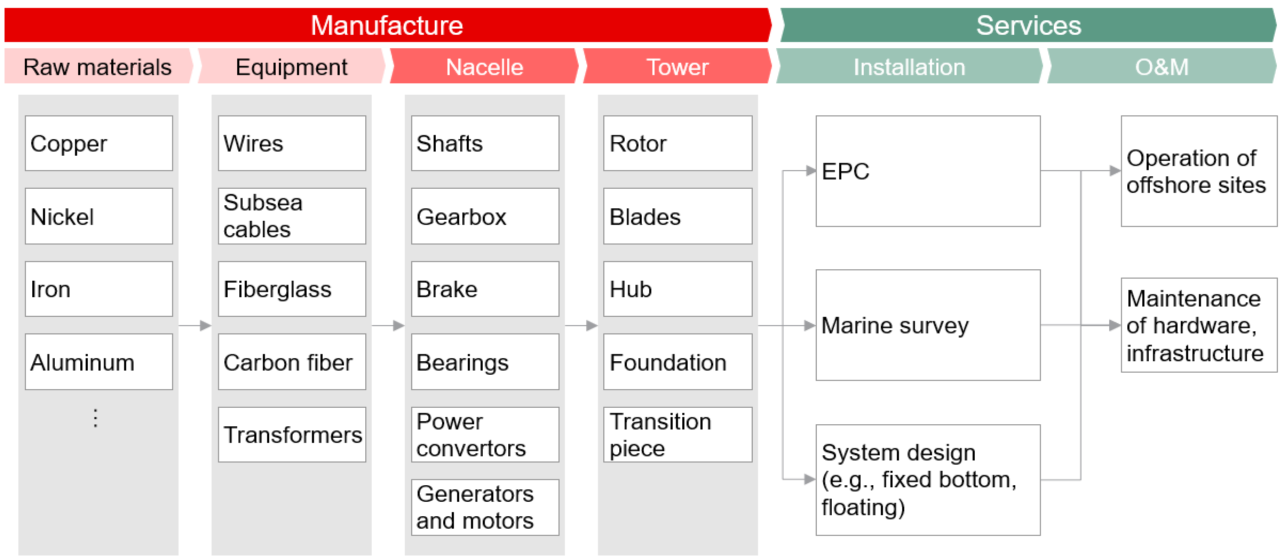
5.1.1 The role of wind power in a carbon neutral society

Wind power is expected to play an important role in Japan's journey towards carbon neutrality, with both onshore and offshore contributing to the renewable energy of 50% in Japan's energy mix in 2050. Offshore wind installations can either be fixed (to the seabed) or floating, in which the turbine is installed on a moored structure. Onshore is the most mature technology, followed by fixed offshore and floating offshore. Installation costs increase in that order. As noted in chapter 4, only 6% of shallow water is suitable for fixed offshore technologies, making floating offshore the preferred option in many instances if the technology in Japan achieves commercialization. Japan's offshore wind potential is due to its outsized exclusive economic zone, where the country could install generation capacity.

5.1.2 The offshore wind supply chain

The wind power supply chain consists of manufacturing of power generation equipment and services relating to installation and generation (Figure 5.1). To date, just a few floating offshore wind turbines have been installed, and the technology is still maturing. Both legs of the supply chain need to be developed and strengthened.

Figure 5.1 The offshore wind power generation supply chain



A sufficient, economically feasible supply of offshore wind can be secured through commercialization and scaling up. This means continuing to develop manufacturing technology and promoting domestic business in high-potential sectors, taking into account energy security considerations.

The GX Basic Policy and Vision for Offshore Wind Power Industry (1st) targets full-scale project planning in the late 2020s, followed by projects totaling 10GW in 2030 and 30-45GW by 2040.[50] In this context, renewable energy will be a major theme for the Green Innovation Fund (GI Fund). Additionally, GX aims to increase domestic procurement of wind power equipment to 60% by 2040.

5.1.3 The need to build a wind power generation supply chain in Japan

The offshore wind supply chain is broadly divided into manufacturing and generation, and there are seven major technologies (Figure 5.2).

Figure 5.2 Detailed list of positive technologies

Not exhaustive

Supply chain segment	#	Technology	Necessity in Japan	Leading players
Wind turbine manufacturing	1	Turbine assembly	• Need to secure domestic wind industry is to foster wind generation in Japan and leverage domestic employment - Japan aims to achieve a 60% domestic procurement ratio of offshore wind power (by 2040) through public-private partnership. - Offshore wind turbines consist of 20,000 parts which is as large as automobiles (10,000-30,000), and the economic ripple effect and employment creation effect of new industry development are extremely large • Also need to a highly competitive supply chain with aspirations of expanding into Asia.	GE, Vestas, Siemens Gamesa
	2	Nacelle parts		Yasukawa, Meiden, NTN, NKS
	3	Tower		Nippon steel engineering, MODEC, Hitachi zosen
	4	Foundation		Toyo construction, Kajima, Shimizu
	5	Electrical equipment		Furukawa
Wind power generation	6	Fixed bottom turbines	• Need to leverage Japan's offshore wind energy potential to further introduce renewables • Japan aims to scale wind power generation six-fold by 2030	Tokyo Electric Power, Power Development
	7	Floating turbines	• Need to tap into floating technologies that are suitable in deep waters to capture the majority of available wind potential	JERA, Tokyo Electric Power , Mitsubishi Corp.

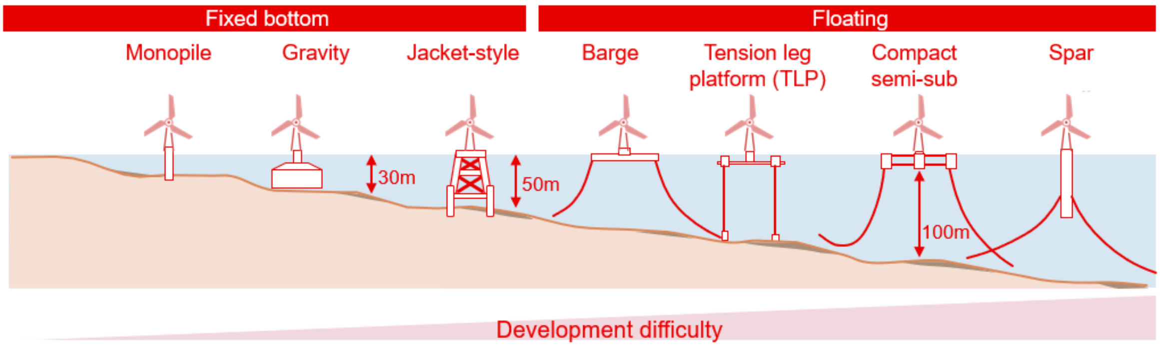
As stakeholders consider their options for wind energy, they need to in parallel plan for the manufacturing that supports it, the potential for wind power in Japan, government policy, corporate initiatives, and alignment with the international community and global trends.

5.1.3.1 Power generation

Japan's Sixth Strategic Energy Plan targets 6% wind power by 2030. Broadly, it targets the share of renewable energy at 50 to 60% by 2050, from the current level of around 20%. Japan has already made significant progress installing renewable energy facilities for solar and onshore wind. Given the country's extensive coastline, offshore wind has great potential. Japan is surrounded by large areas of deep water (50m or deeper) – but just 6% of domestic waters is shallow enough to accommodate fixed bottom wind, so there is a significant geographic impetus for floating technologies (Figure 5.3).

[50] https://www.mlit.go.jp/kowan/content/001390489.pdf

Figure 5.3 Types of offshore wind turbines[51]



Pros	• Low cost • Low maintenance	• Low inspection • Low maintenance	• Suitable at relatively deep water	• Simple construction • Low cost	• Compact • Motion contained	• Motion contained	• Simple construction • Low cost
Cons	• Pollution during installation • Specific ground conditions required	• Complex construction	• Complex construction • High cost	• Storm safety and resilience unverified	• High cost	• High cost • Complex construction	• Difficult installation

To promote offshore wind in Japan, the government has established a public-private council working group and is looking to strengthen the competitiveness of the offshore industry, as well as support development projects through the GI Fund. The public-private council has launched the Japanese Central System, a government-led project planning scheme for selecting targets of feasibility for study.[52] This forms the basis for projects to be developed using domestic resources. In 2023, three areas in Hokkaido were selected as study areas.[53]

Four companies, MODEC (floating wind moorings), Toyo Construction (mooring platforms), Furukawa Electric Co. (cables, etc.), and JERA (design conditions and turbines) are working together to develop floating offshore wind technologies. Meanwhile Toda Corporation has installed and operates the first domestic floating offshore turbine.[54] JERA is participating in international offshore wind projects and using acquired knowledge to develop projects in Japan.

Wind power is being developed in many major economies. EU has capitalized on its shallow coastal waters and existing offshore wind technologies, maximizing the deployment of offshore wind across the EU sea basins. Countries including Germany, Denmark, and the Netherlands are rolling out capabilities. The EU's current installed capacity is ~16GW and it has targeted 60 GW of capacity by 2030 (with the sum of national goals targeting roughly 110GW in the same period). By 2050, the EU expects total offshore wind capacity of between 250 and 500 GW.

With nearly 60,000 miles of coastline, the contiguous US has significant offshore wind potential, and new policies have sought to foster and grow the industry. Still, amid policy challenges, offshore wind technology only produces 0.04 GW of power.[55] Looking ahead, the Department of Energy has announced that the permitting pipeline has over 40 GW of potential. The recent Federal-State

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[51] https://www.meti.go.jp/shingikai/sankoshin/green_innovation/green_power/pdf/001_04_00.pdf

[52] Inefficiencies arise in planning offshore wind projects as multiple operators conduct duplicate surveys in the same areas and results in a burden on local fisheries as they adjust their operations. To resolve these issues, the government's takes initiative from the initial stages of project planning, with JOGMEC taking the lead in conducting the research necessary to consider the offshore wind business, and the results are utilized by operators.

[53] https://www.meti.go.jp/press/2022/01/20230113005/20230113005.html

[54] https://www.toda.co.jp/business/ecology/special/windmill_02.html

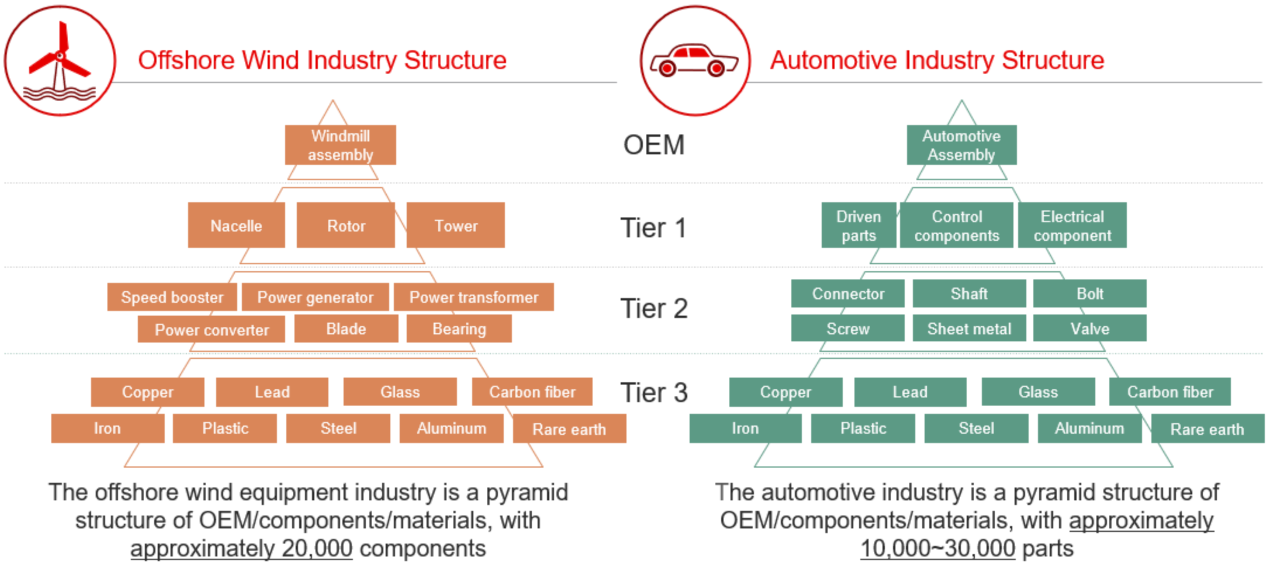
[55] https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php

Offshore Wind Partnership marks an effort to deploy 30 GW of offshore wind energy by 2030 and sets the nation on a pathway to 110 GW or more by 2050.

5.1.3.2 Installation

To promote large-scale offshore wind, a foundational manufacturing system is required. Installations are comprised of as many as 20,000 components (on a par with autos) and require a wide range of manufacturing skills, so there is significant potential economic upside (Figure 5.4).

Figure 5.4 Industry structure of offshore wind[56]



The Japanese government is developing measures to support the domestic industry. In addition to setting a goal of 60% domestic procurement, it aims to lower the cost of fixed bottom power generation to JPY8-9/kWh by 2030-2035. It will achieve this by streamlining systems and developing human resources. The government is assessing skills needs and working with industry and academia to develop mechanisms for skills development. Safety reviews are being expedited by the Electricity Business Act and consolidated screening process by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and Ministry of Economy, Trade and Industry (METI).

In June 2023, METI and MLIT launched the Floating Industry Strategy Study Group, consisting of experts, industry associations, power generation companies, and floating body manufacturers.[57] The study group is focused on fostering the growth of floating offshore wind technology, which is poised to contribute significantly to achieving the 30-45 GW target by 2040 set out in Vision for Offshore Wind Power Industry (1st). The study group aims to compile the second version of the vision report through public-private discussion.

Southeast Asia is close to Japan in terms of climate and hydrographical conditions (Figure 5.5). Through international cooperation and standardization, the government is looking to help deploy offshore wind across Asia. Discussions on international standards are underway.

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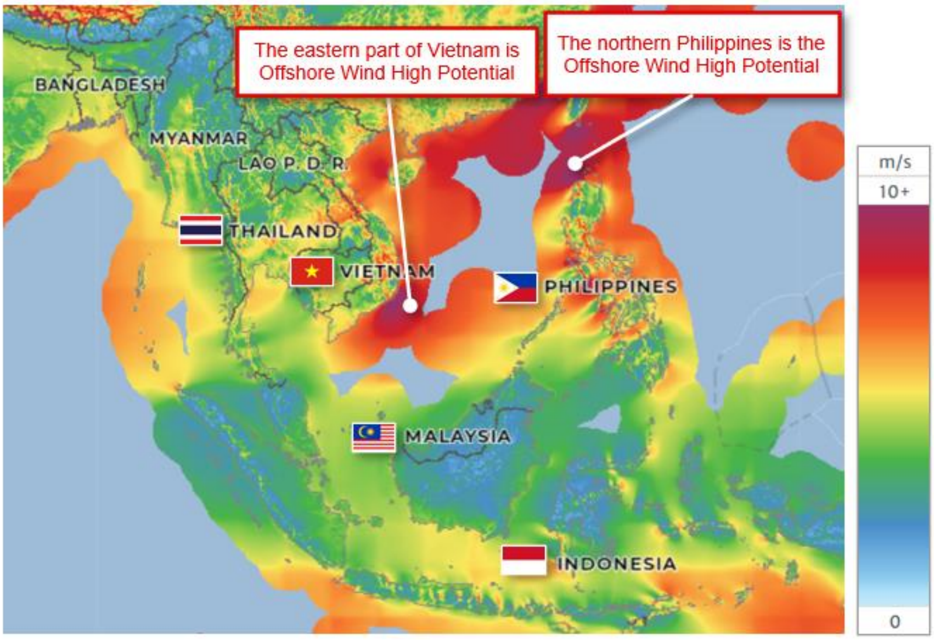
[56] https://www.nedo.go.jp/fuusha/doc/20140324_01.pdf and https://www.pref.fukushima.lg.jp/uploaded/attachment/128710.pdf

[57] https://www.mlit.go.jp/report/press/content/001616114.pdf and https://www.meti.go.jp/press/2023/06/20230623003/20230623003.html

Figure 5.5 Potential for offshore wind in Southeast Asia[58]



Internationally, there is progress being made in many countries, and particularly those with extensive coastlines. In the UK, the Department for Business, Energy, and Industrial Strategy (BEIS), Offshore Wind Industry Council (OWIC), Offshore Wind Growth Partnership (OWGP) and Offshore Renewable Energy (ORE) Catapult are collaborating to grow the wind industry, which provides Japan with a valuable comparator for promoting the offshore wind power industry.

[58] https://datacatalog.worldbank.org/search/dataset/0039490

5.2 Positive Technology in Japan: Solar

5.2.1 Solar power in a carbon neutral society

In Japan, there has been substantial support for solar photovoltaics (PV) following the Great East Japan Earthquake in 2011. The FIT program, launched in 2012, set the purchasing price for solar PV at JPY40/kWh, significantly higher than other renewables, and offered a purchasing agreement for one to two decades.[59] While global prices for solar PV have been falling, the FIT purchasing price in Japan has also declined to around JPY10/kWh. During this time, the installed capacity of solar PV in Japan has grown over tenfold compared to before FIT introduction.[60]

Thanks to policy support and maturing technology, solar PV installations have progressed considerably. Yet for extensive further deployment, new technological developments in power generation are necessary (Figure 5.6). Currently, silicon-based panels account for 95% of the global market.[61] Other technologies do not yet match silicon in terms of durability and power generation efficiency. As we expand the installation of solar PV systems onto buildings, mobility infrastructure, IoT devices, and others, there is a need for flexible, lightweight solutions. Perovskite technology is expected to meet these requirements (Figure 5.7).

Figure 5.6 Characteristics of different types of solar cells[62]

	Inorganic		Hybrid		Organic	
	Silicon	Compound thin film	**Perovskite**	Silicon & Perovskite tandem	Dye-sensitized type	Organic thin film
	Currently dominant technology with market share >95%	Commercialized but room for cost reduction	Major technology to expand solar application to buildings etc.	Further development in efficiency from perovskite	Challenge in durability	Challenge in durability
Efficiency (highest module)	26.7% (Kaneka)	19.0% (Solar frontier)	17.9% (Panasonic)	n.a.	n.a.	11.7% (ZAE Bayern)
Shape/weight	Various form available, not flexible	Thin, light	Flexible, light	Flexible, light	Flexible, small	Flexible, light
Application	Solar power farm, roof	Roof, building material	Building, material, IoT	Solar power farm, roof	Building, material, IoT	Building, material, IoT
Technological maturity	Commercialized in 1960s	Commercialized in 2000s	R&D/early commercialization	R&D/early commercialization	Commercialized in 2000s	Commercialized in 2010s

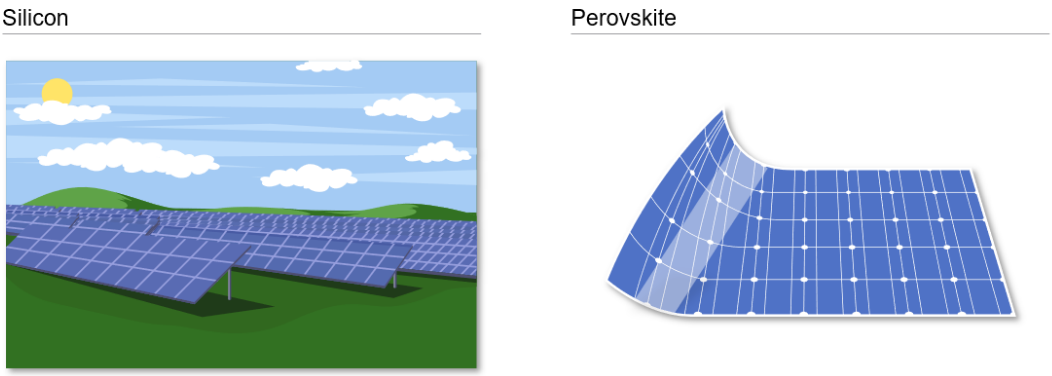
59 https://www.enecho.meti.go.jp/category/saving_and_new/saiene/kaitori/kakaku.html#h24

60 https://www.meti.go.jp/shingikai/santeii/pdf/082_01_00.pdf

61 https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics

62 https://www.nrel.gov/pv/cell-efficiency.html; https://www.meti.go.jp/shingikai/sankoshin/green_innovation/green_power/pdf/003_04_00.pdf; https://www.nedo.go.jp/content/100544817.pdf

Figure 5.7 Illustration of silicon and perovskite solar

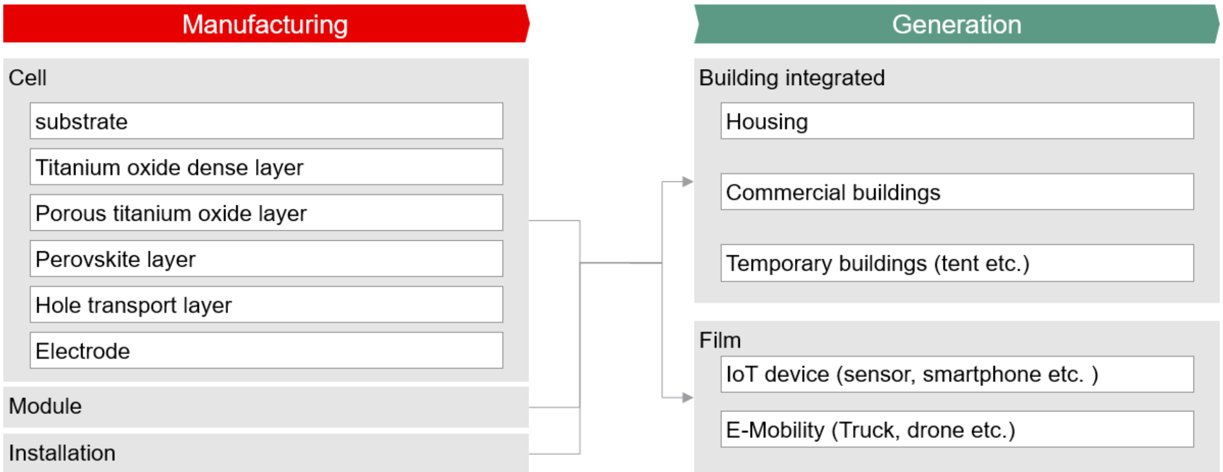


Solar is expected to play an increasingly important role as the share of renewables in the energy mix rises. Currently accounting for about 8% of energy production, it will reach 14-16% by 2030 if the government target is reached.

5.2.2 Solar power supply chain

The solar power supply chain consists of upstream manufacturing and downstream power generation (Figure 5.8).

Figure 5.8 Solar supply chain



Japan's GX Basic Policy states that solar power, and perovskite in particular, is a leading renewable energy technology. The GX calls for expanded installation in locations including public facilities, housing, factories and warehouses, airports, and railways. In the perovskite supply chain, development is necessary in power generation and manufacturing. In power generation, government subsidies will provide support. Meanwhile falling equipment and installation costs will spur private sector investment. Meanwhile, several technical challenges must be overcome, and large-scale manufacturing is necessary for commercialization.

5.2.3 The need to build a solar supply chain in Japan

There are two supply chain categories for solar power, and seven positive technologies in Japan (Figure 5.9). Potential market participants will consider local conditions in Japan, government policies, corporate initiatives, and alignment with the international community and global trends.

Figure 5.9 Detailed list of solar power technologies

Not exhaustive

Supply chain segment	#	Technology	Necessity in Japan	Leading players
Manufacturing solar cells (#1-7 are technologies in a case of perovskite)	1	Substrate	• Need to address technical challenges such as durability, generation efficiency, and design and establish mass production system that can supply next-generation solar infrastructure to sufficient level	Toshiba, Panasonic, Sekisui Chemical
	2	Layers (Titanium oxide dense, porous titanium oxide, perovskite layer, hole transport, etc.)		
	3	Electrode		
	4	Module		
Solar power generation (Application)	5	Housing and buildings	• Need for technology that enables solar PV introduction in untapped locations such as building, mobility infrastructure, and IoT devices - Silicon PV has been effectively deployed in suitable land areas	Owners of buildings, infrastructure and consumer goods
	6	IoT devices (sensor, smartphone etc.)		
	7	E-Mobility (Truck, drone etc.)		

5.2.3.1 Power generation

Japan's Sixth Basic Energy Plan aims for 14 to 16% solar power by 2030, as it increases the share of renewable energy in its energy mix to 50 to 60% by 2050.[63] Japan is already making progress installing solar equipment. Indeed, the amount of solar power generated in Japan is third globally after the US and China. Still, Japan's mountainous topography makes solar installation challenging; flat landscapes are preferred to capture the sun's rays. Stakeholders thus are required to find new installation options. This may, for instance, comprise installing integrated solar cells into residential and business buildings or using a special film that can be affixed to IoT devices.

Japan's GX Basic Policy cites the necessity of investment in perovskite initiatives and solar installations for buildings, mobility, and other applications. In addition, it promotes adoption within the FIT system through relaxed requirements and bidding exemptions. This would mean some housing complexes can receive support, subsidies, and reduced taxes.

Installation of building-integrated solar panels is already underway. AGC is developing panels that reflect building colors and design features (see the AGC case study). Kaneka, jointly developed with Taisei Corporation, also installed ones on railings on the roofs of its factories and on skylights and sell them to customers.[64] Globally, authorities in Europe and the US support the expansion of solar power, albeit with less focus on buildings.

5.2.3.2 Manufacturing

Japanese players led the market in the 1970s, backed by the Japanese government. Now China has a significant presence in the global market, of which majority is silicon PV (Figure 5.10). Perovskite is a new technology originated in Japan. However, it still needs to be refined in the context of an effective and cost-efficient supply chain. If that can be achieved, Japan has an opportunity to reestablish market leadership in solar, which would also contribute to Japan's energy security.

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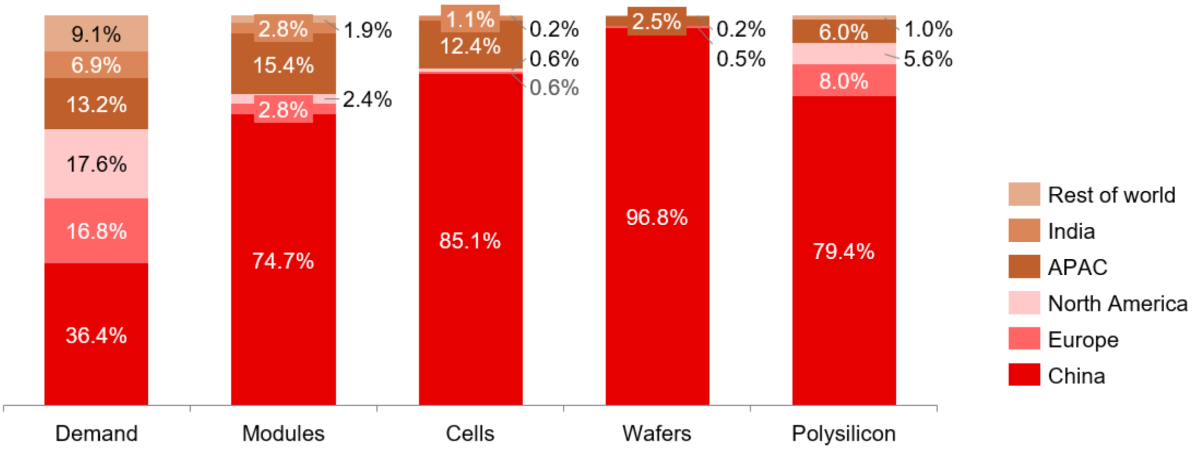
[63] Japan's Sixth Basic Energy Plan does not set a target for solar alone in 2050 energy mix.

[64] https://bipv-re-mieruka.jp/bipv.html

Figure 5.10 Solar PV manufacturing capacity by country and region, 2021[65]



Japanese demand for silicon PV is expected to be moderate going forward, while supply and demand of perovskite is likely to grow. For perovskite to reach its potential, however, service life and durability are challenges. Perovskite has strengths such as flexibility and transparency; however, it often exhibits lower durability and shorter lifespan compared to silicon PV.[66] Moreover, the production process for perovskite sheets is still in its infancy in Japan, compared with overseas. To get there, production lines must be built, and building-integrated standards must be met for power generation and products. Producers must improve efficiency and reduce costs, creating standardized solutions for the construction industry.

The Japanese government's roadmap for next-generation solar power aims for pilots in FY2023 and after, demand generation in FY2026, and GW-scale mass production in FY2030. The government provides financial support through the GI Fund, which backs projects to increase size (over 900 cm^2), reduce power generation costs (below JPY20/kWh), and improve conversion efficiency and durability of perovskite.[67] Individual underlying technologies and manufacturing processes are being developed to achieve performance and cost levels comparable to those of existing technologies.

In response to government support, private companies are also accelerating the development of next-generation solar technologies. Their research into solutions such as crystal structures, material compositions, and analytical evaluation techniques to control degradation, are in line with targets in the GI Fund's support for perovskite. These research and development efforts are yielding results. A joint project by industry, government, and academia has achieved a perovskite service life of 20 years,[68] on a par with silicon, albeit without commercial roll out. Sekisui Chemical Co. is working on technology to achieve uniform processing of materials in a rolled sheet, known as roll-to-roll.

The development of these new types of solar panels is also underway in Europe and the US. In the EU, a public-private platform has been created for the joint development of basic and manufacturing technologies. In the US, government research organizations such as the National Renewable Energy Laboratory have led the way in launching the US Manufacturing of Advanced Perovskites (US-MAP), a joint public-private consortium for the development of basic and manufacturing technologies and evaluation methods.[69] The US long-term strategy assumes a significant fall in the cost of solar power.[70]

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65 IEA, Solar PV manufacturing capacity by country and region, 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/solar-pv-manufacturing-capacity-by-country-and-region-2021, IEA. License: CC BY 4.0

66 https://unit.aist.go.jp/rpd-envene/PV/ja/results/2019/oral/T1.pdf

67 https://green-innovation.nedo.go.jp/project/next-generation-solar-cells/

68 https://www.cell.com/cell-reports-physical-science/fulltext/S2666-3864(21)00370-2

69 https://www.meti.go.jp/shingikai/sankoshin/green_innovation/green_power/pdf/001_06_00.pdf

70 https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf

AGC Case study: Developing building-integrated solar by a Japanese player

AGC

AGC is a global materials solutions provider with offices in Japan/Asia, Europe, and the Americas. In its main business areas of glass, electronics, chemical and ceramics/other, the company uses materials and technologies developed over its more than 110 years of history, and with the strengths of its customer base and production technology. AGC has declared net zero carbon emissions by 2050, and as an interim target, will reduce its GHG emissions 30% and GHG emissions per sales unit 50% (total Scope 1 & 2, compared to 2019) by 2030. Furthermore, the company has stated that it will contribute to reducing global GHG emissions through their products. This case study is an overview of their contribution to decarbonization through the supply of products related to solar power.

Building-integrated photovoltaics (BIPV)

In the past, solar power panels were installed mainly on flat land. While Japan has promoted the installation of mega solar farms on its mountainous terrain, as discussed in this chapter, flat land suitable for solar power is already largely in use. Furthermore, there are concerns about their environmental impact and safety, as natural disasters, such as flooding due to heavy rain, have increased in recent years, and some local governments are regulating development over a certain scale, creating challenges for securing locations to install solar panels. Installing solar panels on buildings is better for securing space for installations. Rooftop panels are the most common type of solar cell installed on buildings. However, most building roofs are not spacious, and are often already used for other purposes such as heliports and rooftop green spaces, making it impossible to install solar cells in addition to wind pressure regulations relevant to most high-rises.

Based on these characteristics of Japan, AGC is working to develop and sell SUNJOULE, a building-integrated photovoltaic glass that enables other remaining spaces such as walls and windows to generate electricity. SUNJOULE is a laminated glass that incorporates photovoltaic functionality by sealing a solar cell between two sheets of building material glass. Highly transparent glass is placed in front of the cell to increase the efficiency of power generation, and proven laminated glass production technology is used to achieve high durability as a building material. It is possible to choose between two types of sealed cells: one-sided cells that generate electricity from sunlight on one-sided surfaces such as facades, spandrels and canopies, and double-sided cells for surfaces that receive sunlight from both sides such as fences and balustrades. SUNJOULE can also increase functionality such as heat shielding and insulation through its multi-layered structure. AGC's strength is that, in addition to providing integrated services from architectural design to installation, it is able to apply knowledge accumulated over many years regarding the exterior of entire buildings to installation of BIPV. It can provide solutions that combine aesthetics (appearance) and practical benefits (power generation). With an extensive track record in the design and construction of facades and windows, in addition to proposing highly reliable solar power systems, they can also give engineering proposals such as intensity calculations, power generation simulations and thermal fracture calculations at the design stage for each property, leading to more efficient solar power generation.

Example of SUNJOULE installation (AGC Kashima Factory Administration Office)

(left) SUNJOULE made ZEB possible
(right) Inside view of SUDARE module which retains good transparency of window

AGC is also developing products that achieve even higher design quality. Until now, the color of the solar panel itself has been changed, but the company is now developing coating technology for solar panels. With a wide variety of colors, “Artlite Active” has made it possible for BIPV to be used extensively while maintaining the high-quality design of buildings and is already starting to be sold in the European market.

“Artlite Active” a BIPV glass panel

5.3 Positive technology in Japan: Power transmission and distribution

5.3.1 The role of power transmission and distribution in a carbon neutral society

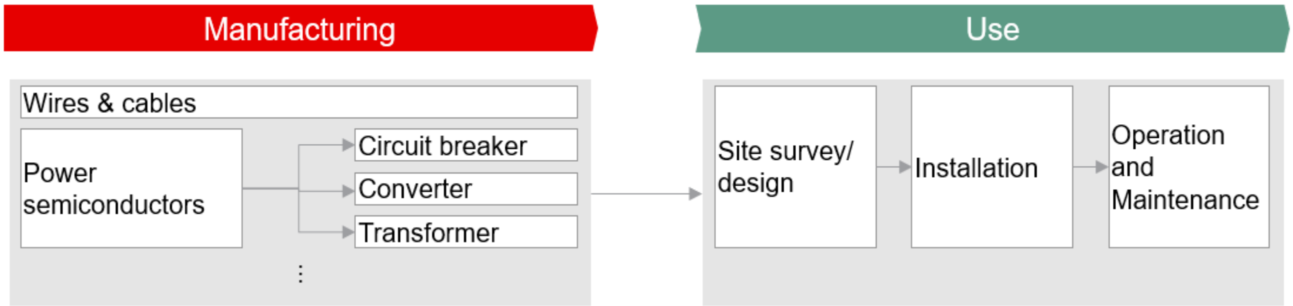
Japan's renewable energy generation capacity is expected to expand up to 2050. However, there will be fluctuations in supply depending on weather conditions in different regions and at different times. A strategic approach to power transmission and distribution, connecting power generators and consumers, can help stakeholders manage this challenge.

The preferred approach reflects that fact that there are two key types of transmission and distribution; distributed, used when power generation and customers are in proximity, and centralized, for when demand and generation are distant, as is often the case with offshore wind. The latter approach is even more important when there are significant regional disparities in the generation of renewable energy.

5.3.2 The power transmission and distribution supply chain

The power transmission and distribution supply chain consist of two elements: upstream hardware manufacturing and downstream use (Figure 5.11). As renewable energy increases, further demands will be put on both.

Figure 5.11 Overview of the entire power transmission and distribution supply chain



There is a strong case for funding to improve the efficiency of power transmission and distribution upstream, and to promote the installation of technology and its efficiency in downstream operations. The Japanese government announced a long-term policy for the wide-area grid ("Master Plan") in 2023, in which it heralded projects for interconnected line reinforcement and underground line reinforcement. Meanwhile the government's GI Fund has provided more than JPY30 billion of funding to improve conversion efficiency in power semiconductors, the core technology for power transmission and distribution.

To support growth of the power transmission and distribution supply chain, it will be necessary to identify downstream applications and technical requirements that will stimulate demand for power transmission and distribution.

5.3.3 The need to expand the power transmission and distribution supply chain

The transmission and distribution supply chain can be split into manufacturing and use segments, across which the following technologies are positive technologies in Japan (Figure 5.12).

Figure 5.12 Detailed list of power transmission and distribution technology

Not exhaustive

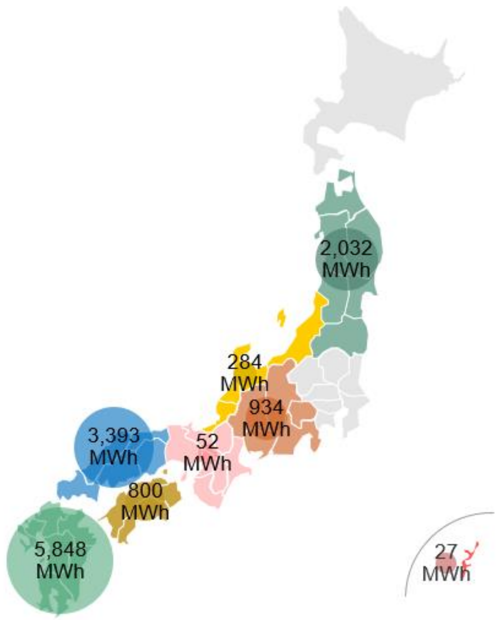
Supply chain segment	#	Positive technology	Necessity in Japan	Leading players
Manufacturing of power transmission & distribution systems	1	Wires & cables	• In Japan, where long-distance transmission with different standard exists in the east and west regions, HVDC is suitable. • HVDC requires power semiconductors to be incorporated into various components and perform complex controls.	Mitsubishi Electric, Denso, Toshiba, Rohm, Hitachi (Hitachi ABB Power Grid)
	2	Power semiconductor		
	3	Other components (Converter, transformer, circuit breaker, etc.)		
Use of power transmission & distribution systems	4	Use	• Increase in renewable energy capacity such as floating offshore wind, which are distant from demand areas, necessities high-efficiency transmission and distribution • Also, output fluctuation of renewables calls for remand response through transmission and distribution	Power transmission and distribution business operator such as TEPCO Powe Grid and Kansai Transmission and Distribution

Power transmission and distribution enable the interconnection of domestic power, contributing to the integration of fluctuating renewable energy generation across the country and ensuring a stable power supply. Moving forward, stakeholders will need to take into account a variety of economic, geographic and policy factors in building out supply chains.

5.3.3.1 Operation

The output of renewable energy sources such as solar and wind power fluctuates due to weather conditions. Furthermore, Japan's power transmission and distribution network is fragmented, with different standards for eastern and western Japan. There is therefore room to strengthen interconnectivity between the regions. In addition, there are regional variations in renewable energy potential and generation capacity. Due to shortfalls in infrastructure to transfer power, some regions that have a surplus of renewable energy, including Kyushu, Chugoku, and Tohoku, have limited output instead of supplying it to other regions (Figure 5.14). So, there is still untapped potential in domestic renewable energy resources.

Figure 5.13 Maximum output control by region in Japan in 2023[71]

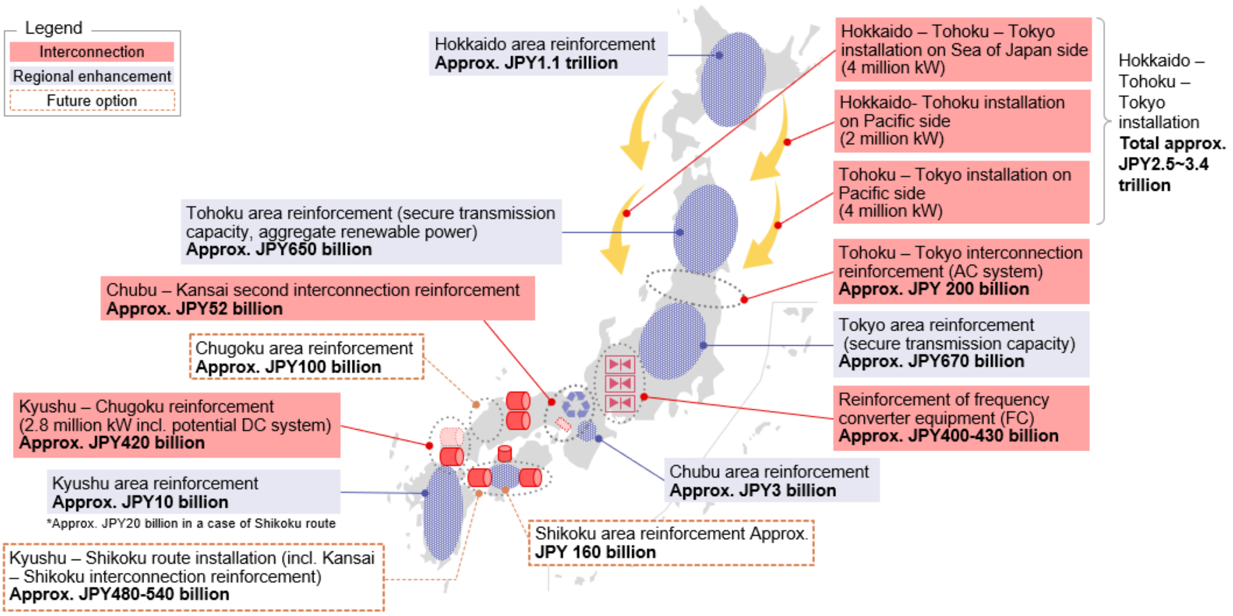


[71] http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/energy/electrical-japan/curtailment/

A transmission and distribution network are necessary to transport surplus renewable energy from regions with excess production to regions with shortages. There are two types of flows in a circuit: direct current (DC) and altering current (AC). In DC, electrical charge flows in one direction while in AC it changes direction periodically. For more efficient transmission of electricity over long distances, DC has better efficiency. Among potential approaches, High Voltage Direct Current (HVDC) is a preferred option, due to its transmission efficiency and suitability for grid interconnection at different frequencies. HVDC works for renewable energy in Japan because DC has a cost advantage over AC for distances over 50 km in submarine lines and 800 km in overhead lines.[72]

In the Master Plan, the government announces projects and backing for interconnected line reinforcement and underground line reinforcement. For interconnected lines, HVDC will connect between Tokyo, which is a major demand center, and Hokkaido and Tohoku in the northern part of Japan. There will also be a new line between Shikoku and Kyushu in the southern part of the country. In addition, the plan indicates the need for about JPY2 trillion of investment in regional enhancement, focusing on Hokkaido, Tohoku, and Tokyo (Figure 5.14).

Figure 5.14 Overview of the Master Plan[73]



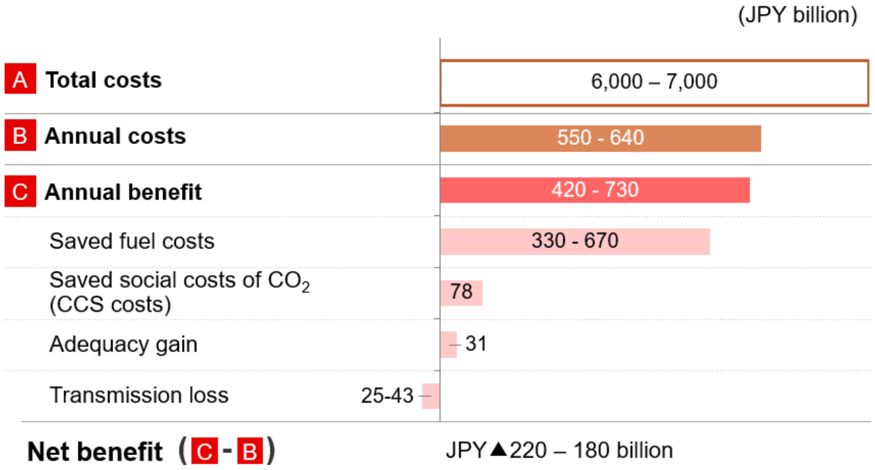
The government is also looking at cost-sharing for the development of power transmission and distribution networks. The cost of interregional interconnector facilities is in principle borne by the regions at both ends. Under the current system, regions with large amounts of renewable energy generation that can afford to supply electricity to other regions are required to bear the cost of building interconnectors, making it difficult to reach a consensus on how to share the costs. To resolve the issue, the government's Subcommittee on the Establishment of Sustainable Power System is discussing the details of a national coordination scheme, under which the cost of facilities will be borne by demand regions and the entire nation, since the entire nation will benefit from lower electricity prices and reduced CO_2 emissions. The cost of interconnector reinforcement will also be borne by the nation. Based on the Master Plan and the national coordination scheme, the GX roadmap states that a new grid will be in place by the 2030s. However, it will be difficult for the private

[72] https://www.meti.go.jp/shingikai/energy_environment/chokyori_kaitei/pdf/001_05_00.pdf

[73] https://www.occto.or.jp/kouikikeitou/chokihoushin/files/chokihoushin_23_01_03.pdf

sector to bear the burden alone, suggesting government involvement will be required.[74] Under the Master Plan's base scenario, there will be net benefits of JPY420-730 billion per year against annual costs of JPY550-640 billion (total commitment of JPY6-7 trillion) (Figure 5.15).[75] Although there may be transmission losses, the net benefits would be significant due to the optimized use of renewable energy. These would be manifested in reductions in fossil-fuel costs for thermal power generation, lower CO_2 (carbon capture and storage costs), and greater adequacy (lower costs for securing reserve power sources), which can be further cut through domestic power supply flexibility.

Figure 5.15 The impact of reinforcing an interconnected system[76]



Away from Japan, there are similar initiatives to strengthen power transmission and distribution networks. In the US, the IIJA has allocated $1.2 trillion in infrastructure retrofit funds for several industries. In 2022, the US Department of Energy launched the "Building a Better Grid" initiative, which allocates $12.5 billion from the IIJA to improve the reliability of the transmission grid. Furthermore, the IRA allocates $5 billion in direct financing for the construction, modification, and restart of generation and transmission facilities, and $76 million for high-voltage interstate power lines. In the EU, the investment required to achieve the objectives of the European Green Deal and REPowerEU is estimated to be EUR80 billion/year over the next 30 years for internal grid infrastructure, and EUR1.3billion/year in 2025-2030 for cross-border transmission.[77]

5.3.3.2 Manufacturing

HVDC can make fast connections over long distances and at different frequencies. In Japan, with different frequencies in eastern and western regions of the country, HVDC and power semiconductors that combine efficiency, economy, durability, and large-scale production are needed to enhance interconnection.[78] Power semiconductors are used in converters and transformers to convert between alternating current and direct current and to control voltage, current, and frequency (Figure 5.16).

[74] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/pdf/055_05_00.pdf

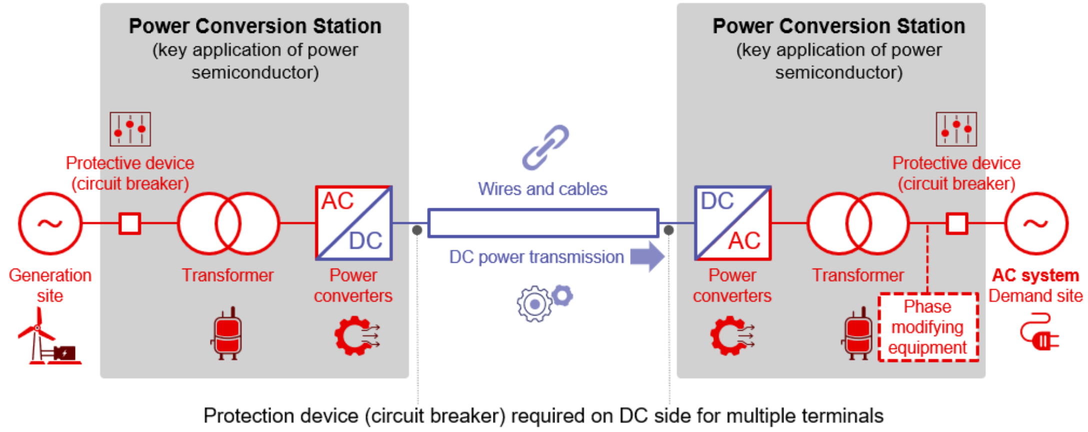
[75] https://www.occto.or.jp/kouikikeitou/chokihoushin/files/chokihoushin_23_01_03.pdf

[76] The costs and benefits are rounded numbers. https://www.occto.or.jp/kouikikeitou/chokihoushin/files/chokihoushin_23_01_01.pdf

[77] https://energy.ec.europa.eu/topics/funding-and-financing/investors-dialogue-energy/working-groups/working-group-2-transmission-and-distribution-wg2_en

[78] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/pdf/055_05_00.pdf

Figure 5.16 HVDC Structure[79]



Currently, silicon(Si)-based power semiconductors, which offer high-speed operation and high-temperature capability, dominate the market. Next-generation power semiconductors will offer enhanced durability and switching characteristics. The Japanese government supports private companies working on power semiconductor manufacturing through the GI Fund. The support aims to achieve improved performance, such as reducing transmission losses and switching technology for stable transmission. This would be achieved through the development of manufacturing technology for next-generation power semiconductors using alternative materials.[80] More specifically, JPY30.5 billion is available to pursue a goal of reducing power converter loss by 50% or more. The Japanese government is also promoting power semiconductor cost reductions to the equivalent level of conventional Si power semiconductors.[81]

In the private sector, Rohm, Toshiba, and Denso will proceed with development from FY2020 to FY2030. Hitachi's group company, Hitachi ABB Power Grids, provides end-to-end services, from the manufacture of transmission and distribution hardware to maintenance. The company is working to increase HVDC capacity and voltage. Mitsubishi Electric is also developing and demonstrating ways to strengthen the resilience of the entire power system, including HVDC (see Mitsubishi Electric case study).

In the US, there is growing government support for the development and manufacture of a high-performance HVDC system. The US CHIPS and Science Act passed in 2022 provides $52.7 billion for research, development, manufacturing, and workforce development, prompting companies such as Micron and Qualcomm to announce additional investments.[82]

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79 https://www.meti.go.jp/shingikai/energy_environment/chokyori_kaitei/pdf/001_05_00.pdf

80 Materials such as silicon carbide (SiC) and gallium nitride (GaN), which allows better durability, heat-resisting, efficiency in conversion etc., are expected to replace silicon-based devices to a certain level. https://www.nedo.go.jp/koubo/IT2_100182.html

81 https://www.nedo.go.jp/content/100942452.pdf

82 https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/

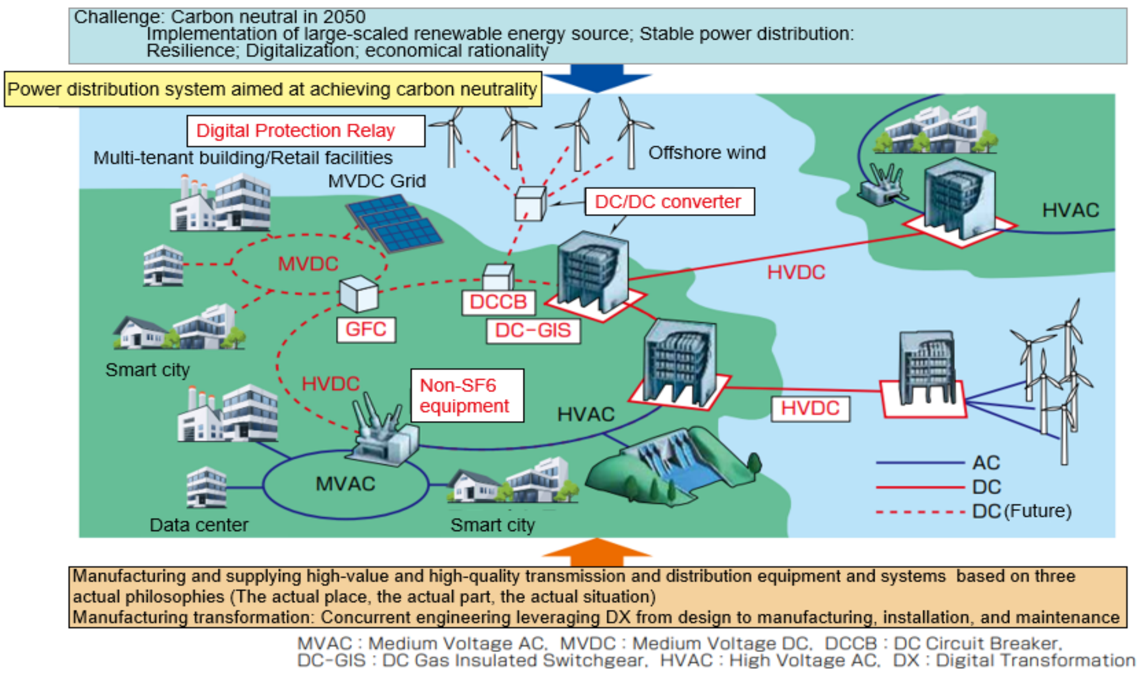
Case study of a Japanese power distribution provider

Mitsubishi Electric is a major Japanese electronics manufacturer that manufactures and sells heavy electrical systems, industrial mechatronics, information and telecommunication systems, electronic devices, and household appliances. The company operates in more than 30 countries in the Americas, Asia Pacific, Europe, and the Middle East, in addition to all over Japan. In its initiative “Sustainability Management” of Corporate Strategy published in 2023, Mitsubishi Electric aims for Net Zero greenhouse gas emissions in the entire value chain by FY2050 and Net Zero greenhouse gas emissions from factories and offices by FY2030, which is a mid-term goal. In “Environmental plan 2023,” a three-year plan of initiatives for environment, Mitsubishi Electric sets KPIs and targets from viewpoint of "environmental contribution through products and services," "Reduction of the environmental impact of our business activities," and "Pursuing business innovation." This case study will focus on electricity transmission and distribution from the perspective of decarbonizing customers through the supply of Mitsubishi Electric's products and services.

Strengthening the Resilience of the Power Distribution System through the Development of Transmission and Distribution Equipment

In the introduction of renewable energy such as solar and wind, whose output varies greatly depending on weather conditions, there is an urgent need to establish a power distribution system that can maintain a stable power supply. Mitsubishi Electric is promoting the development of various technologies based on its accumulated technologies related to conventional power transmission and distribution equipment to contribute to resilience of the electric power distribution system. In the future, a resilient power distribution system will be realized by supplying equipment such as a power conversion system, de-SF6 equipment, DCCB, and DERMS system, while a complicated power system configuration is expected in which high- and medium-voltage DC systems (HVDC, MVDC) are connected and interconnected with conventional high- and medium-voltage AC systems (HVAC, MVAC).

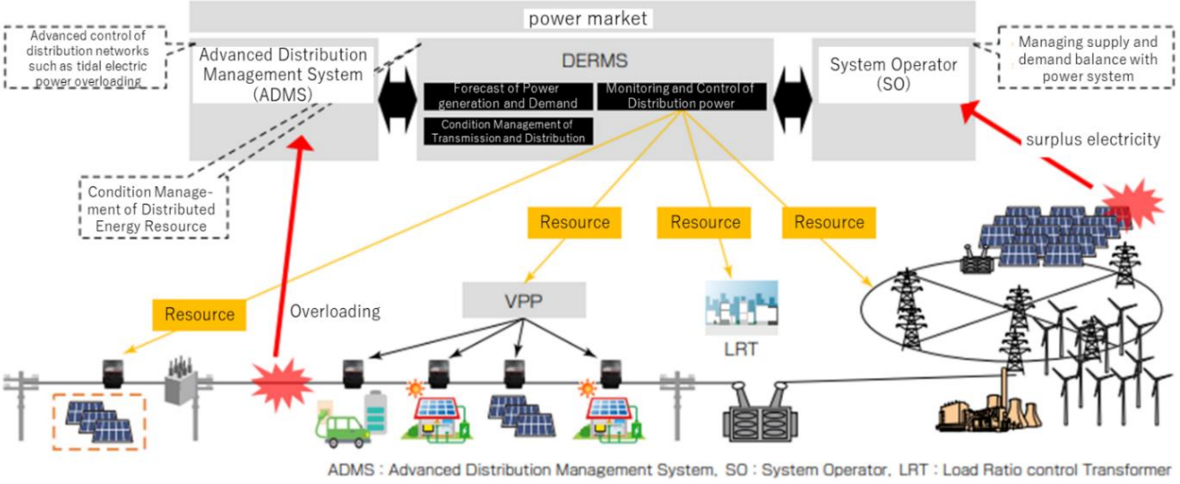
Resilient Power Distribution System toward carbon neutrality



The following is an overview of specific technologies and Mitsubishi Electric's initiatives:

- **HVDC** is a system that can transmit large amounts of power over long distances with reduced transmission losses and is expected to be introduced especially for offshore wind power. Mitsubishi Electric has been using its own power semiconductors and other equipment to develop the systems since 2000, when it delivered equipment for a direct-current interconnection facility to enhance the interconnection between Shikoku and Honshu. Mitsubishi Electric has installed an HVDC demonstration building with a capacity of 50 MW in its own factory, verification experiments have been conducted since 2018, and the validation of a DC power transmission system has been completed.
- **DCCB (DC circuit breaker)** is a device designed to isolate only the sections where accidents occur, such as overhead line disconnectors, in order to prevent the spread of damage to surrounding equipment. Mitsubishi Electric has already demonstrated high-speed interruption of DC currents up to 16kA and is continuing to develop DCCB that can be applied to actual systems up to 525 kV class. To further strengthen its development capabilities, the company acquired Scibreak in February 2023 which has world-class technology for DCCB.
- **Non-SF6 (Sulfur hexafluoride gas) equipment** is an alternative to traditional gas circuit breakers or gas insulated switchgears that have been using SF6, which provides high insulation performance but has environmental concerns due to the greenhouse effect it produces. Mitsubishi Electric is collaborating with Siemens Energy Global to develop devices that utilize dry air (clean air, gas mixture of oxygen and nitrogen) as a substitute for SF6.
- **DC/DC converter** is an electronic circuit/device that converts DC power from one voltage level to another. Mitsubishi Electric has developed a "DC Multi-Voltage System" for medium- and low-voltage DC distribution systems up to 750V, applying silicon carbide power semiconductor devices. As of November 17, 2022 (according to Mitsubishi Electric's research), it achieves the industry's highest power conversion efficiency. Compared to conventional systems, the power losses at converters are reduced by 45%, while the volume of the converter panel is reduced by 20% and the weight is reduced by 36%, enabling space-saving installations. Additionally, it can reduce distribution losses by 20%. Mitsubishi Electric is validating the effectiveness and stability of the system in the ZEB (Net Zero Energy Building) project called "SUSTIE."
- **DERMS (Distributed Energy Resource Management Systems)** is a system that connects a large amount of power to an existing distribution network and controls it in real time while reducing capital expenditures. This system contributes to both the expansion of the introduction of renewable energy and the stable supply of electricity. in August 2021, Mitsubishi Electric acquired the British company Smarter Gird Solutions (SGS) to expand its DERMS business in Europe and the United States. The company plans to strengthen its product capabilities by combining the technologies cultivated in the domestic market with the advanced technologies of SGS.

Image of DERMs



5.4 Positive technology in Japan: Nuclear power

5.4.1 The role of nuclear power in a carbon neutral society

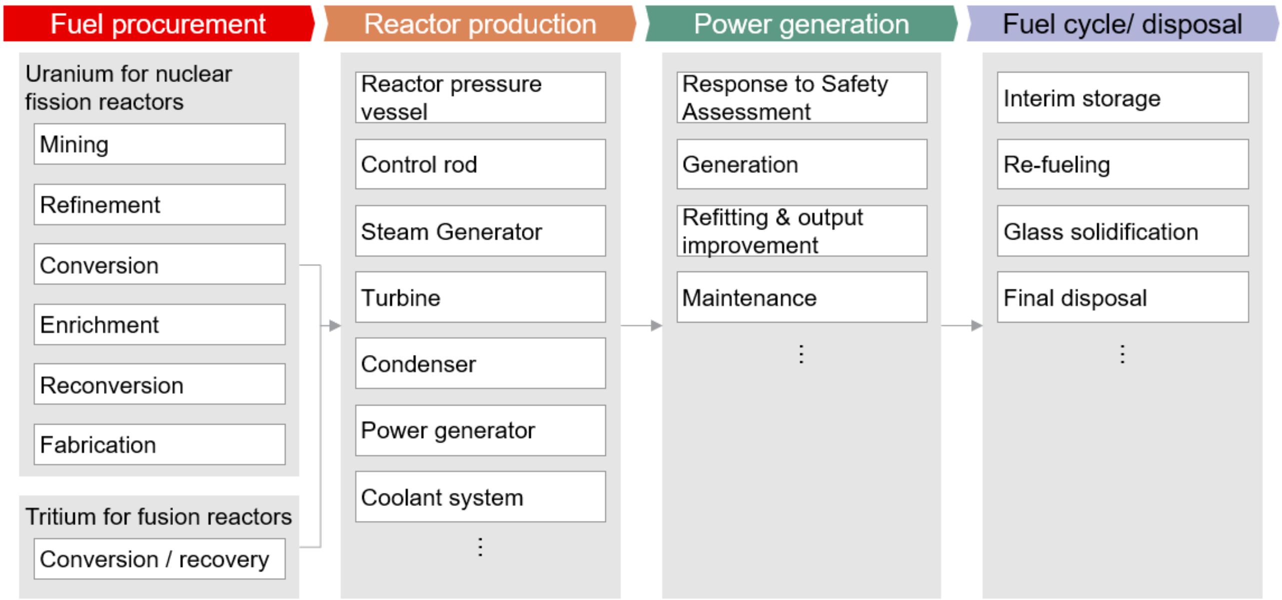
Nuclear power generation leverages nuclear fuel to generate heat, which is used to make electricity. It is an attractive option across three dimensions:

1. **CO_2-free**: In principle, nuclear power does not emit CO_2 when generating electricity.
2. **Stable supply**: Nuclear provides a stable supply of electricity regardless of season, weather, or time of day.
3. **Economic potential**: Nuclear incurs generally lower generation costs than thermal power and renewable energy. For example, in Japan, the cost of nuclear power generation is JPY11.5/kWh, compared with JPY12.5/kWh for coal-fired power, JPY12.9/kWh for solar (commercial), JPY25.9/kWh for offshore wind, and JPY19.8 /kWh for onshore wind in 2020.[83][84]

5.4.2 Japan's nuclear power supply chain and nuclear energy policy

The nuclear supply chain consists of four elements: fuel procurement, reactor production, power generation, and fuel cycle/disposal (Figure 5.17).

Figure 5.17 Overview of the nuclear supply chain



The quest for an advanced power generation system is focused in Japan on safety while achieving superior efficiency and economic viability. To achieve these aims, the country requires continuous

[83] Estimates include not only costs directly related to power generation, but also future costs such as decommissioning costs, nuclear fuel cycle costs (including final disposal of radioactive waste), accident response costs (including compensation for damages and decontamination), and policy costs (power source location subsidies, research and development, etc.). Sensitivity analysis estimated an increase in nuclear LCOE of approximately JPY 1 /kWh when nuclear power plant-related costs (decommissioning costs, compensation, fuel recycling costs) increase.
https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/cost_wg/pdf/cost_wg_20210908_01.pdf

[84] When using renewable energy, the system costs are high because transmission and distribution systems often need to be upgraded to compensate for load fluctuations with other power sources. See Chapter 4 for details.

technological advancement and developments through the supply chain, including in nuclear fuel cycle.

In 2022, the Japanese government announced four major pillars of Japan's nuclear energy policy[85]:

- **Resumption of operations**

  Since the accident at TEPCO's Fukushima Daiichi (Unit 1) Nuclear Power Station in 2011, fewer nuclear power plants have been in operation. To ensure step-by-step resumption of operations, the government is reforming the operating structure of power suppliers and deepening local understanding through regional dialogue.

- **Extension of operation of existing reactors**

  Some nuclear power plants are reaching their maximum age for operation, even while they are not operational. When the GX Decarbonized Power Supply Promotion Bill was passed into law, a maximum of 60 years operation (40 years of normal operation plus 20 years of extended operation, extended shutdown deduced) was set.[86] It is intended to extend the operational period of reactors that meet standards set by the Nuclear Regulation Authority.

- **Development of next-generation reactors**

  Based on the premise of ensuring safety and deepening the understanding of the local community, the government aims to develop and construct next-generation nuclear reactors with built-in safety mechanisms that are also more efficient. Their introduction is planned as existing plants are decommissioned.

- **Promotion of the fuel cycle**

  The government has outlined a policy to promote the establishment of domestic processing facilities and other necessary infrastructure to enable nuclear fuel reprocessing. Efforts are being made to facilitate knowledge sharing and develop mechanisms for funding.

The optimization of Japan's nuclear power value chain is based on the goal of maximizing usage of fuel already in Japan. This will mean restarting existing nuclear power plants and considering means to secure clean, stable, and economic energy supply capacity through next-generation reactors. Furthermore, nuclear manufacturing infrastructure must be strengthened to provide a stable domestic supply of reactors and peripheral solutions. In addition, assuming that nuclear energy will be utilized over the medium to long term, the development of a nuclear fuel reprocessing and disposal system will ensure the effective use of resources and safety after use.

5.4.3 The need to establish a nuclear power supply chain

There are four supply chain segments for nuclear power, and several technologies considered under Japan's policy (Figure 5.18).

[85] https://www.cas.go.jp/jp/seisaku/gx_jikkou_kaigi/dai2/siryou1.pdff

[86] Green Transformation Decarbonization Electricity Act was amended in May 2023, stipulates the deduction of extended shutdown periods after the implementation of new regulations for reactor operation extensions, effectively allowing operation for more than 60 years. https://www.meti.go.jp/press/2022/02/20230228005/20230228005.html

Figure 5.18 Nuclear power technology list

Not exhaustive

Supply chain segment		#	Technology	Necessity in Japan	Leading players
Fuel production		1	Nuclear fuel	• Need to utilized currently secured fuels from energy security perspectives	Mitsubishi Nuclear Fuel, Global Nuclear Fuel-Japan Co., Nuclear Fuel Industries, Japan Nuclear Fuel Limited
Reactor production	Existing	2	Boiling water reactors	• Needed to utilize power generation assets which assure high technical maturity, relatively low cost	Hitachi, Toshiba
		3	Pressurized water reactors		Mitsubishi Heavy Industries
	Next gene-ration	4	Light water reactors	• Needed to realized - Increased safety - Faster response to power demand fluctuations - Hydrogen production - Lower fuel disposal cost etc.	Mitsubishi Heavy Industries, Framatome
		5	Small modular/ compact/micro reactors		Mitsubishi Heavy Industries, IHI, JGC, Hitachi GE, Nuscale, Rolls-Royce
		6	High-temperature gas-cooled reactors		Mitsubishi Heavy Industries
		7	Fast reactors		Mitsubishi Heavy Industries, Hitachi GE
		9	Fusion reactors		ITER International Fusion Energy Organization
Power generation		10	Generation	• Need for clean, stable and economical power supply to complement renewable power, output of which fluctuates	Major electric power companies, such as Tokyo, Kansai, Tohoku, etc.
Fuel cycle/ disposal		11	Fuel cycle	• Need to utilize residual energy in used fuel after power generation and to lower toxic level by fuel recycle	Japan Nuclear Fuel Limited
		12	Disposal	• Need to store waste for a long period of time in a stable way without health and environmental impacts	Municipalities of final disposal site (solidification is currently outsourced to foreign players)

The necessity of nuclear power generation in Japan, with its low energy self-sufficiency rate, is discussed in a sequence of sections: securing nuclear fuel, utilizing existing and next-generation reactors for power generation, manufacturing nuclear power plants, and addressing energy efficiency and the fuel cycle/final disposal of waste from a hazardousness standpoint.

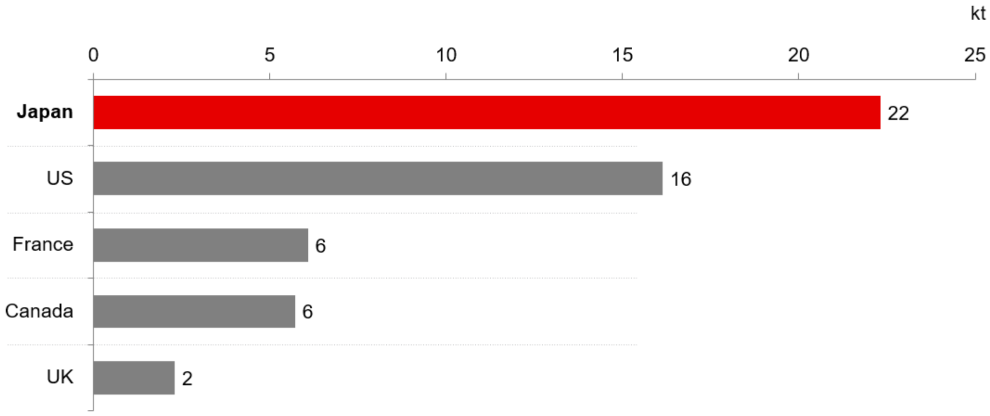
5.4.3.1 Fuel supply

Japan has minimal domestic uranium ore reserves, so it often imports enriched uranium. Uranium ore is mined in countries including Kazakhstan and Canada, and then converted and reconverted in countries such as France, Canada, the US, and Russia.

With many nuclear power plants out of operation, there is an abundant domestic inventory of nuclear fuel, totaling 22 kt that may take part of Japan’s energy security (Figure 5.19). Japanese companies supplying fuel include Mitsubishi Nuclear Fuel, Global Nuclear Fuel-Japan Co., and Nuclear Fuel Industries, are responsible for shaping and processing to meet all domestic demand. Japan Nuclear Fuel Limited (JNFL) has a large capacity of uranium enrichment and is planning to expand to 1,500 ton-separate work units (SWU)/year.[87] Having these players within the country contributes to energy security in Japan. 1,500 ton-SWU/year is equal to the amount needed by 12 one-million-kW reactors for one year, with the remainder requiring imports.

[87] https://www.jnfl.co.jp/en/business/uran/

Figure 5.19 Enriched Uranium Inventories in major nuclear holding counties as of 2021[88]

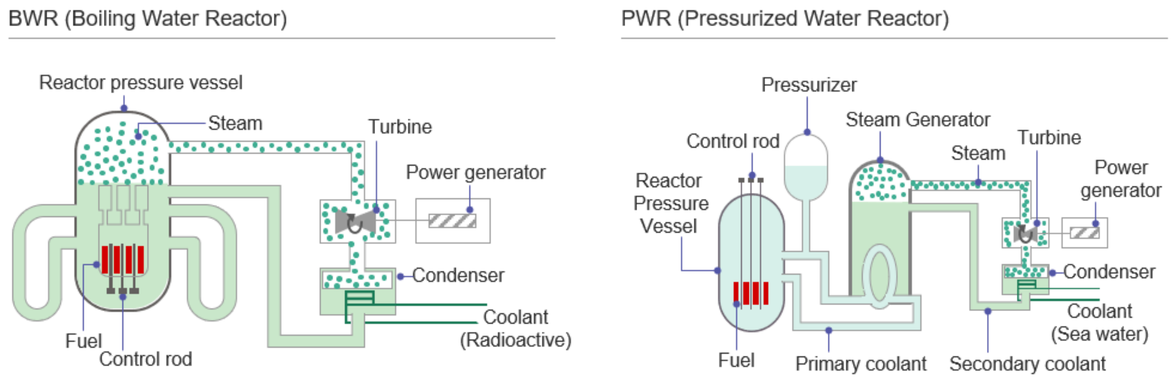


5.4.3.2 Power generation

Japan will maximize its use of renewable energy, but also needs other stable and clean power sources, offsetting unpredictable renewable supply. This is where nuclear reactors can play a role, either through established or next-generation technologies. Established technologies (Figure 5.20):

- **Boiling water reactor (BWR)**: A method that generates electricity by directly turning a turbine with steam generated by a nuclear reactor. BWR has a simple structure, but the simplicity also poses the challenge of contamination of the power turbine with radioactive materials. There are currently 17 operable BWRs in Japan.[89]
- **Pressurized water reactor (PWR)**: High-temperature, high-pressure water produced in the reactor is transmitted to a steam generator, which boils water that is not in contact with radioactive materials and uses the steam produced to power a turbine. The structure is more complex than that of a BWR and is able to contain radioactive materials more easily. There are currently 16 operable PWRs in Japan.[90]

Figure 5.20 Structure of BWR and PWR[91]



Next generation technologies (Figure 5.21):

88 https://www.nra.go.jp/data/000390996.pdf
89 https://www.world-nuclear.org/country/default.aspx/Japan
90 https://www.world-nuclear.org/country/default.aspx/Japan
91 https://www.fepc.or.jp/smp/enterprise/hatsuden/nuclear/genshiro/index.html

- **Innovative light water reactor**：This combines the PWR structure with resistance to natural hazards (e.g., earthquake resistance, tsunami resistance, etc.). It is also equipped with a core catcher, the world's most advanced molten core countermeasure, and a radioactive material release prevention system, which reduces the amount of radioactive material released outside the containment vessel. The system significantly improves safety while ensuring economic efficiency. Furthermore, it is superior in terms of feasibility because it complies with current regulatory standards and is already in the practical application stage. Its primary role is expected to be as a regulating power source in the context of renewable energy.

- **Small modular reactor (SMR) /compact nuclear reactor/micro reactor (portable reactor)**：In the SMR being developed by MHI and NuScale, the steam generator is built into the reactor vessel to reduce size. The size is smaller and power generation capacity at ~300,000kW (SMR) is generally lower than existing types (>1 million kW). It is expected to be used for small-scale grid and distributed power generation. Natural circulation cooling eliminates the need for coolant pumps, reducing potential pipeline rupture.

- **High-temperature gas-cooled reactor**：Nuclear heat at ultra-high temperatures (900 degrees Celsius or higher) can be used for industry demands such as hydrogen production. Only two units exist globally, one of which is in Japan.[92]

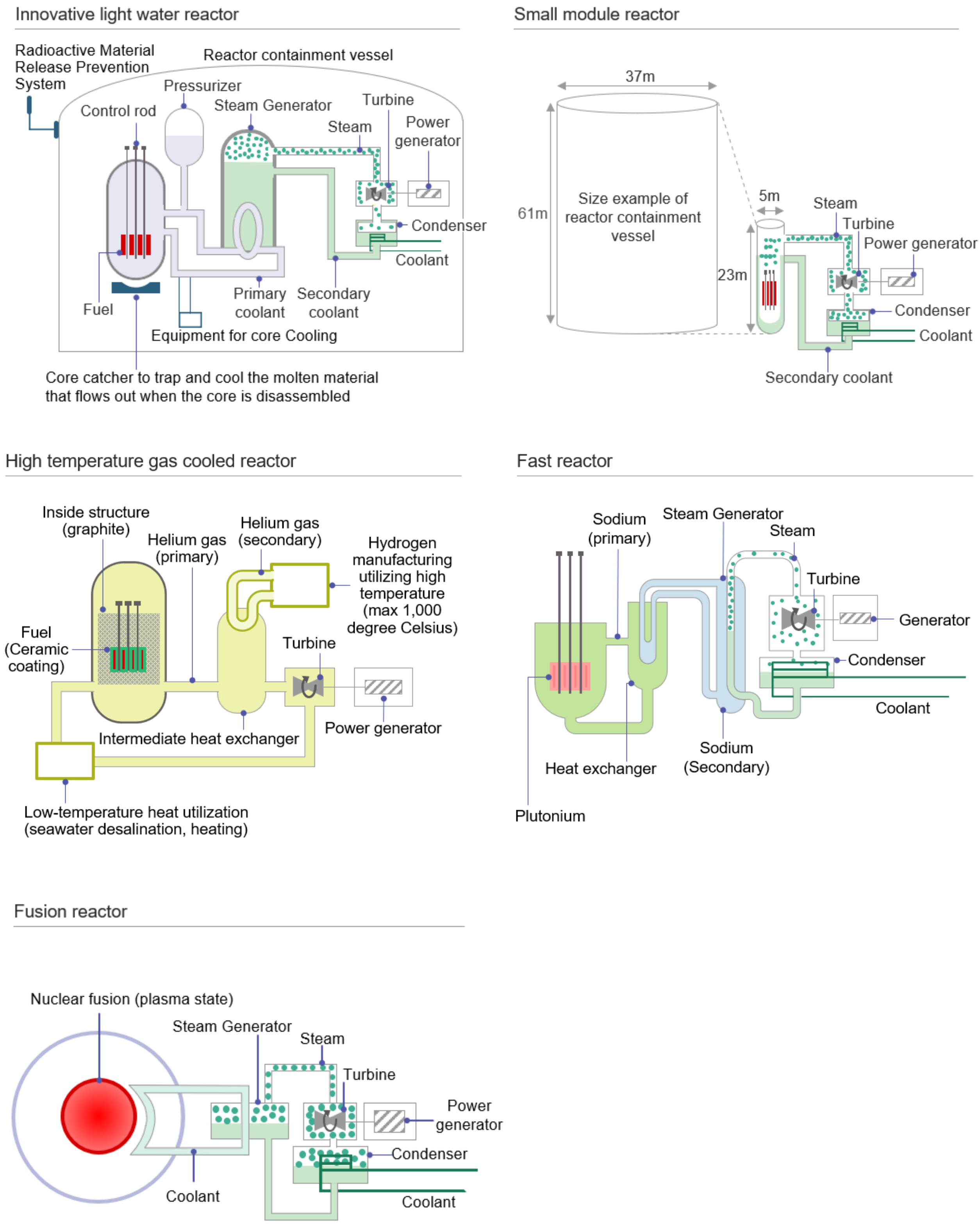
- **Fast reactor**：Fast reactors generate electricity by causing a reaction at high speed using plutonium. This process also generates fissile plutonium from uranium 238, which is less prone to fission and not very suitable for power generation. The heat generated by fission reaction is transferred through highly conductive sodium to boil water and then spin turbines. Fast reactors are an important technology for Japan, which has few natural resources, because the establishment of a fuel cycle enables the effective use of resources and decrease the level of toxicity of disposals.

- **Fusion reactor**： A fusion reactor operates by creating and maintaining a plasma state. In this state, high temperatures and pressure cause light atomic nuclei, like hydrogen isotopes, to collide with enough energy to fuse together. Fusion, unlike nuclear fission, is not only safer with minimal production of radioactive waste, but also holds great promise due to its use of materials like seawater that are not subject to resource depletion concerns. Momentum for the development of nuclear fusion is growing worldwide.

Next-generation nuclear reactors are emerging technologies that require significant investment and time. Nevertheless, the development of these next-generation reactors is being pursued in various countries because they offer benefits such as improved safety, greater flexibility in meeting electricity demand, hydrogen production potential, and reduced toxicity and disposal costs for spent fuel. Alongside operating existing reactors, Japan is focusing on demonstrating viability.

[92] High Temperature Engineering Test Reactor (HTTR) in Ibaraki prefecture is the first and only high temperature gas cooled reactor in Japan. It restarted operation in 2021.

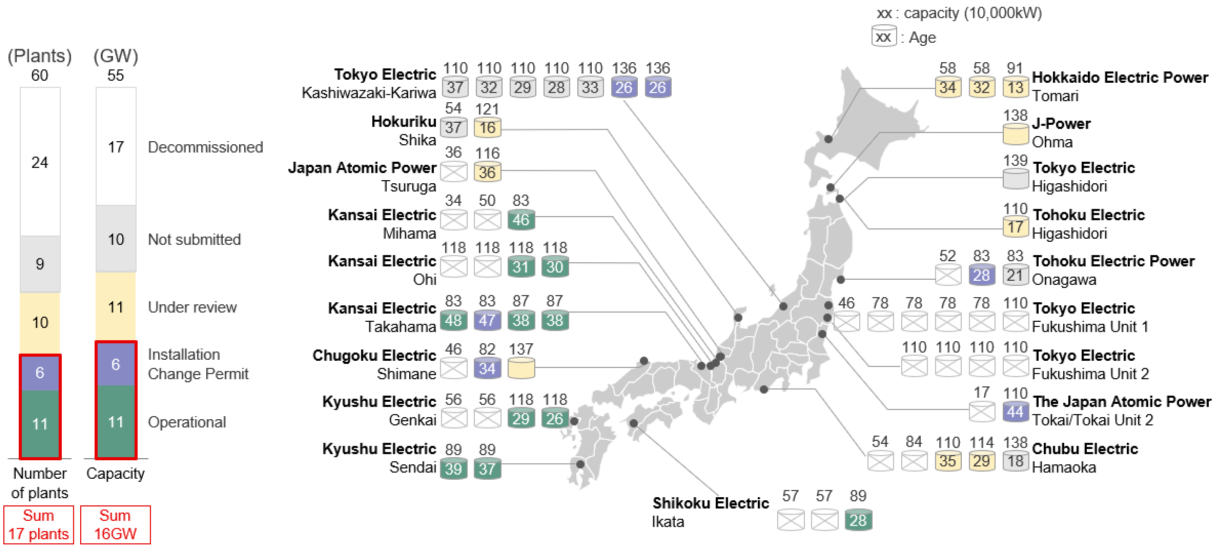
Figure 5.21 Next generation technologies[93]



93 https://www.jaea.go.jp/04/sefard/faq/#newmaterials

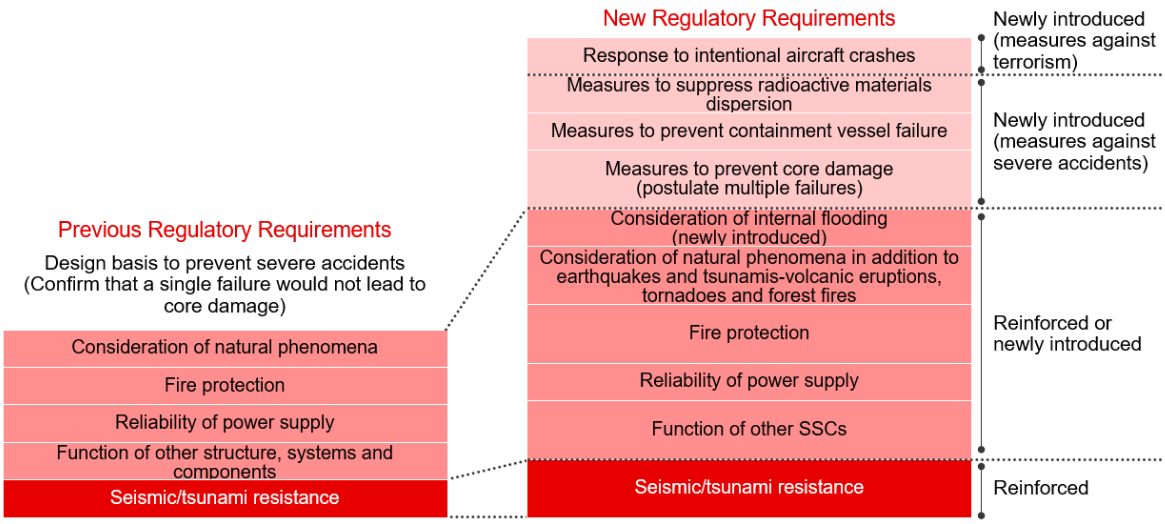
The Japanese government has a policy of using nuclear in its power supply mix, through both existing and next-generation reactors. Among existing reactors, there are a significant number that have not been in operation since the 2010s (Figure 5.22).

Figure 5.22 Nuclear Reactor Operation in Japan as of August 2, 2023[94]



In 2013, the Nuclear Regulatory Authority (NRA), an independent regulatory agency, established new regulatory standards that included countermeasures against terrorism and severe accidents to further ensure the safety of nuclear power plants (Figure 5.23). The NRA said, "Close attention was given to several considerations during the draft preparation—most importantly lessons learned from the Fukushima Daiichi (Unit 1) accident, IAEA safety standards and guidelines, and international best practice."[95]

Figure 5.23 Previous and current safety requirements[96]



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94 https://www.enecho.meti.go.jp/category/electricity_and_gas/nuclear/001/pdf/001_02_001.pdf

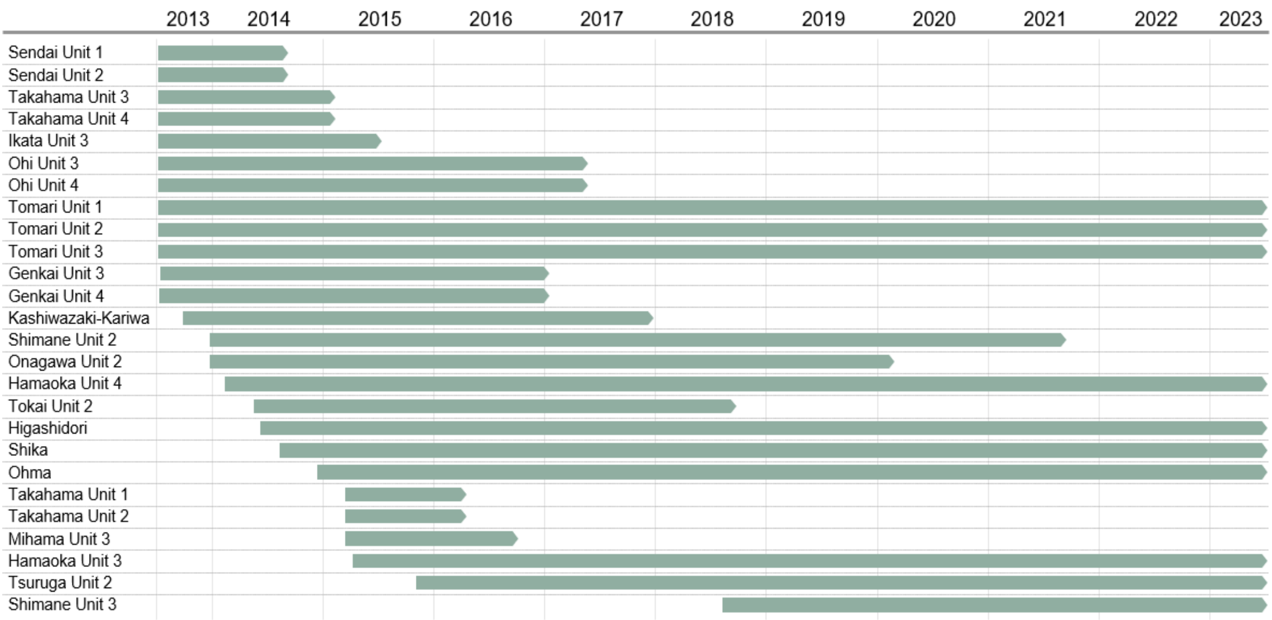
95 https://www.nra.go.jp/data/000067120.pdf

96 https://www.nra.go.jp/data/000067212.pdf

To ensure the implementation of new standards and even higher levels of safety, power companies operating nuclear power plants have allocated new expenditure to safety measures. According to METI's announcement, as of 2021, for the 27 reactors at 16 nuclear power plants that have submitted applications to the NRA, an average of JPY200 billion per reactor was estimated for additional safety measures to comply with the new standards. This would amount to a total cost of over JPY5 trillion.[97]

For some nuclear power plants, compliance assessments have taken nearly a decade (Figure 5.24). Throughout this process, utility players have accumulated knowledge aligned with the new safety criteria. In addition, NRA in 2022 stated that its policy for future reviews will be "expeditious and rigorous."[98] Simultaneously, the government is taking the lead in moving toward safe nuclear by reforming operating structures and deepening local understanding. These steps are designed to achieve the 20-22% share of nuclear in power source composition in 2030 set out in the Sixth Basic Energy Plan, and a 30-40% share in 2050, together with thermal power plus CCUS.

Figure 5.24 Review period for new safety standards, as of May 5, 2023[99]



Both power generation operators and plant manufacturers are moving toward operating existing nuclear power plants. Kansai Electric power resumed the operation of Takahama Unit 1 (Takahama-cho, Fukui Prefecture), which was over 40 years old then, in July 2023. The three major domestic plant manufacturers have also positioned for the restart of reactors (see Kansai Electric power case study).

Development of next-generation reactors is also in progress, mainly driven by Japan's major plant manufacturers. Moreover, Japanese players are participating in development projects in Japan and abroad. For example, Toshiba and Mitsubishi Heavy Industries (MHI) are participating in International Thermonuclear Experimental Reactor (ITER), a joint European, US-Japan-Russia-China-Korea-India fusion reactor development project. Hitachi is developing the BWRX-300, a small light water reactor, with GE Hitachi, and MHI is developing a sodium fast reactor with TerraPower of the US.

97 https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/cost_wg/2021/data/08_05.pdf

98 https://www.nra.go.jp/data/000405149.pdf

99 https://www.genanshin.jp/facility/map/

Electricity utilities have clarified their policies on the use of next-generation reactors. For example, Kansai Electric Power, Shikoku Electric Power, Hokkaido Electric Power, and Kyushu Electric Power are working with MHI to commercialize innovative light water reactors by the mid-2030s (see MHI case study).[100]

[100] https://www.mhi.com/jp/news/220929.html

Case study: The resumption of nuclear power operations by a Japanese utility

Kansai Electric Power is one of Japan's major electric utilities supplying electricity in the Kansai region of Japan. The company has offered a variety of services on top of its core energy business, such as telecommunications, lifestyle and business solutions that support people's daily lives, the economy and industries. Nuclear power and LNG are the primary power sources that each account for 26% of Kansai Electric Power's energy mix, followed by coal at 16%. Kansai Electric Power is pursuing carbon neutrality by 2050 throughout its business activities, as declared in the "Zero Carbon Vision 2050." The company has also stated that it will "keep the top spot for the amount of zero-carbon power generation in Japan" and "halve CO_2 emissions associated with power generation in FY2025, compared to FY2013." Nuclear power is one of the pillars of zero-carbon power generation. Kansai Electric Power has utilized nuclear power since it began to commercialize operation in 1970 This case study overviews Kansai Electric Power's efforts to restart existing nuclear reactors.

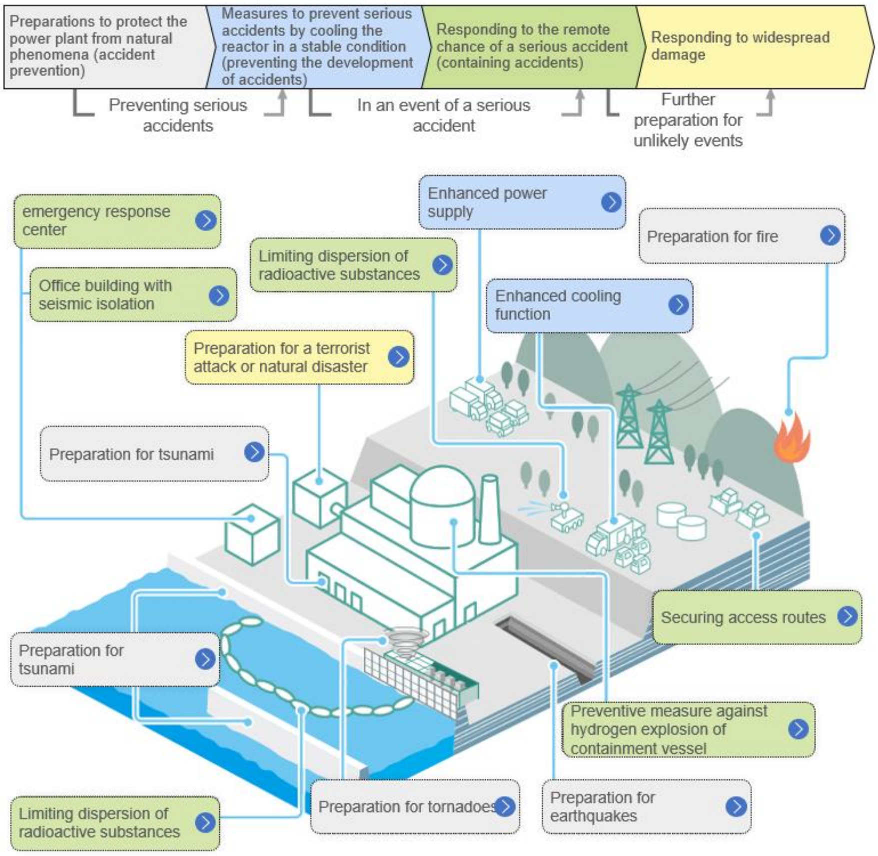
Restart of existing reactors

Kansai Electric Power has seven nuclear power plants, excluding those shut down, five of which are in operation. In its "Zero Carbon Roadmap," the company plans to restart seven plants by 2025, including Units 1 and 2 of Takahama nuclear power station, which have been idle for 12 years. Those units started commercial operations in 1974 and 1975, respectively. Despite surpassing the previous maximum operating period of 40 years, necessary measures to ensure safety have been confirmed to be feasible. Since December 2014, special inspections of targeted equipment such as reactor pressure vessels and containment vessels have been conducted, and it has been confirmed that there are no issues even for an operating period of up to 60 years. In April 2015, Kansai Electric Power submitted an application for an extension of the operating period, and after undergoing a review by the Nuclear Regulation Authority, in June 2016, they obtained approval for the extension of the operating period.

Safety measures

Kansai Electric Power has diligently implemented measures to comply with new regulatory standards and continually pursue uncompromising safety enhancements (voluntary efforts). For example, at the Takahama power plant, the company has divided risks into four phases and taken various measures to minimize their impact at each phase. In the initial phase, equipment tailored to specific risks, such as seismic activity, tsunami, tornadoes, and fires, has been introduced. Additionally, a mechanism has been established to prevent major accidents by strengthening the power supply and cooling functions in case the reactor is affected. In the event of a major accident, measures to prevent the release of radioactive substances and prevent hydrogen explosions have also been implemented to enhance accident prevention. Furthermore, measures to address intentional aircraft collisions (terrorism) from a non-natural disaster risk perspective have also been taken.

Safety measures at Takahama Nuclear Power Station



Dialogue with stakeholders

Kansai Electric Power also engages in dialogue with regulatory authorities, such as the Nuclear Regulatory Authority, and communicates its efforts towards safety improvement. For example, in April 2022, the company not only presented its own initiatives regarding new regulatory standards, nuclear regulatory inspections, and the safety enhancement evaluation reporting system, but also shared its understanding of challenges in rule operations and proposed improvements. This facilitated discussions aimed at achieving more efficient system operation.

Kansai Electric Power also maintains a dialogue with the host communities of its nuclear power plants. For instance, in preparation for the expiration of the 40-year operating period for Units 3 and 4 at the Takahama power station in 2025, they submitted a "prior understanding request" to Fukui Prefecture and the town of Takahama for equipment replacements such as a steam generator to enhance reliability, based on a safety agreement. They have explicitly stated their commitment to continue providing detailed explanations to the residents of Takahama town regarding the operation of the nuclear power plant beyond 40 years.

Case study: Developing next-generation reactors by a Japanese equipment provider

MITSUBISHI HEAVY INDUSTRIES

In the "MISSION NET ZERO," MHI Group declared its commitment to reducing the Group's CO_2 emission by 50% by 2030 and achieving Net Zero of Scope 1/2/3 by 2040. "Decarbonize existing infrastructure," "implement an H2 solutions ecosystem," and "implement a CO_2 solutions ecosystem" are three pillars to achieve these goals. CCUS is involved in all three pillars, especially in the CO_2 solutions ecosystem. This case study focuses on advanced (next-generation) reactors as a part of decarbonizing existing infrastructure. MHI has built all 24 pressurized water reactor (PWR) plants in Japan since Mihama Unit 1 (in Mihama-cho, Mikata-gun, Fukui Prefecture) started operation in 1970. MHI also provides services in almost all areas of nuclear energy, including fuel cycle facilities, advanced (next-generation) reactors and nuclear decommissioning, from the perspective of waste fuel recycling and safety and efficiency improvements, which is unique to Japan's low energy self-sufficiency rate.

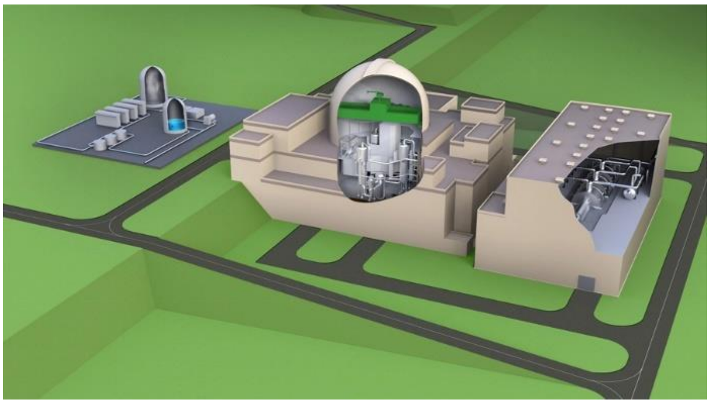
Advanced (next-generation) reactors

MHI promotes early commercialization of advanced LWRs (SRZ-1200) with the world's highest level of safety to contribute to carbon neutrality and a stable energy supply. In addition, in response to the diversifying needs of society in the future, MHI is developing compact LWR, high-temperature gas-cooled reactors (HTGRs), and fast reactors. MHI will also take up the challenge of commercializing a fusion reactor, a perpetual energy source.

Advanced LWRs

MHI is promoting the development of advanced LWRs, SRZ-1200, which means Supreme Safety/Sustainability, Resilient light water reactor with zero carbon. As the name suggests, the SRZ-1200 is based on existing PWR technology with innovative technologies to achieve the world's highest level of safety while ensuring economic efficiency and significantly reducing CO_2 emissions compared to thermal power generation. Specifically, the addition of a core catcher, the world's most advanced safety measure to catch molten core material, and a unique system that reduces the radioactivity release outside the containment vessel, minimizes the impact of natural disasters such as earthquake and tsunami or severe accidents, and events like large-scale aircraft collision, terrorist attack and activation of passive safety systems when losing power. In addition, functions to adjust the power output are enhanced to be flexible for output change and power system stability, and another capacity is set to produce and supply hydrogen using surplus power, making it a baseload power source and a source of hydrogen when renewable energy is introduced. MHI has already completed about 80% of the basic design of the standard plant and is currently conducting full-scale demonstration tests using national projects to acquire additional data for licensing purposes. Going forward, MHI will proceed with individual plants' basic and detailed designs, aiming for commercialization in the mid-2030s.

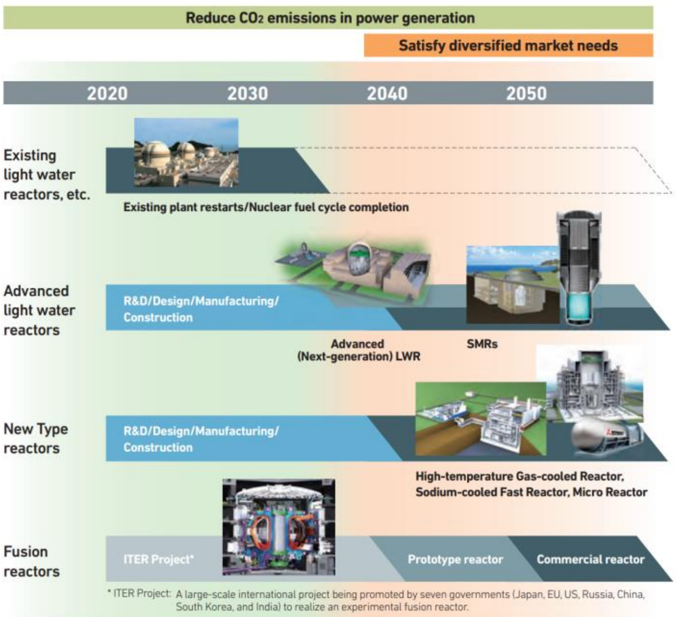
Digital mockup of SRZ-1200



Other reactors

In addition, MHI promotes the development of small, modular reactors (SMRs) to meet the diversified needs of society in the future by utilizing the technology acquired during the development of advanced LWRs. SMR, an integrated reactor incorporating steam generators and other components within the reactor vessel, is compact, and the initial introduction cost is low. It is also suitable for reactors for small-scale grids and mobile power sources for nuclear-powered ships. In addition, the underground placement of reactors with passive nuclear safety systems, which do not require intervention from active components, enhances resilience in events such as an aircraft collision. Using a double containment shell ensures safety and security by confining radioactive materials. However, SMRs are still at an earlier stage of development than advanced LWRs and have much room for technological advancement, requiring technology demonstration tests and regulatory standards that match the reactor type. In addition, MHI is also working on next-generation technologies such as high-temperature gas-cooled reactors (HTGRs) and fast reactors in parallel, aiming for demonstration and commercialization starting around 2040.

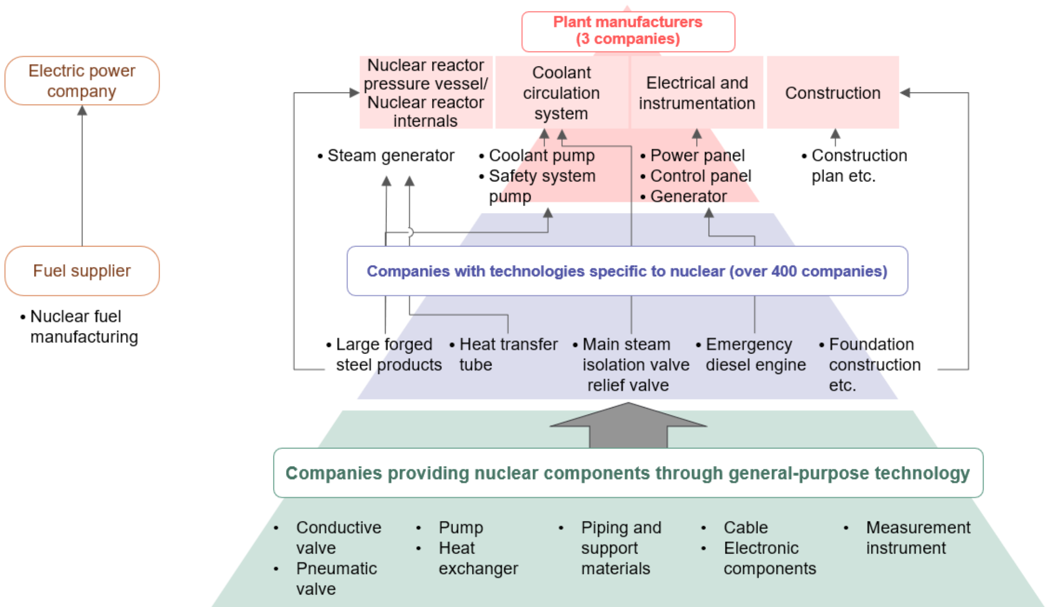
Reactor development timeline



5.4.3.3 Reactor production

Nuclear power plants require more than 10 million components per unit and the Japanese supply chain consists of more than 400 players, operating under three major plant manufacturers, Mitsubishi Heavy Industries, Toshiba, and Hitachi (Figure 5.25). The domestic supply chain fulfills over 90% of nuclear needs.

Figure 5.25 Major players in Japan's nuclear industry (not exhaustive, as of 2020)[101]

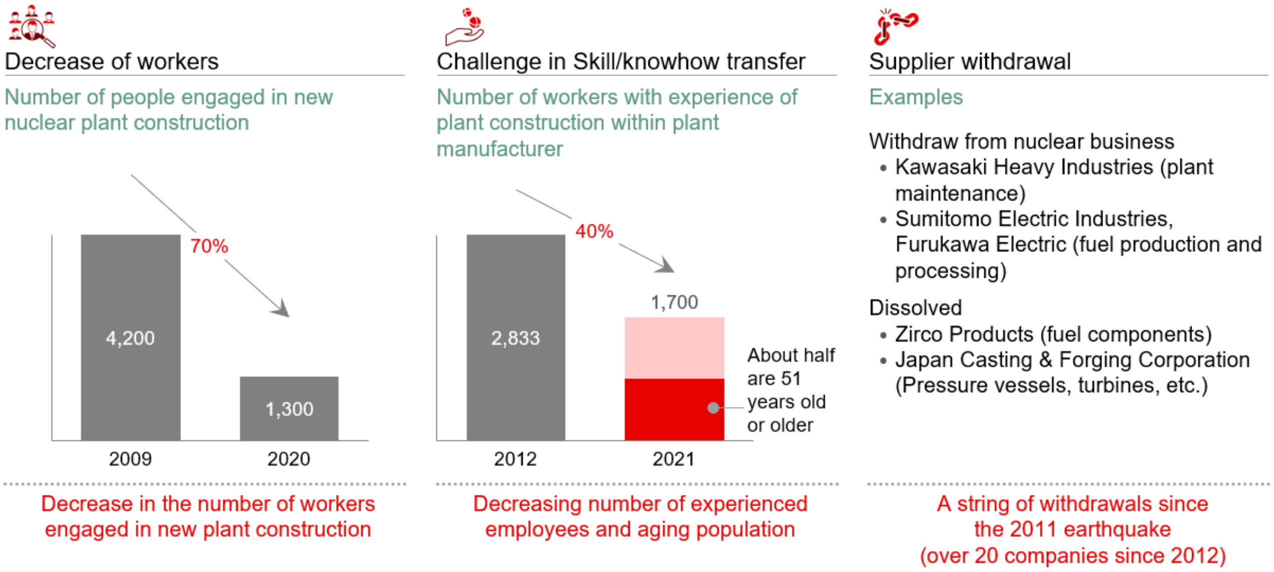


The nuclear industry has a large presence in the economy. OEM, primary supply, and secondary supply serve demand worth about JPY1.5 trillion and employ more than 30,000 people.[102] Most of the nuclear industrial base is concentrated in Japan, and from the viewpoint of energy security, it is effective to maintain and strengthen domestic supply chains.

In recent years, as the construction of new nuclear power plants has halted, some companies have either withdrawn from the sector or reduced hiring. Given that development, design and construction of a next-generation reactors require deep knowledge, skills, and innovation capabilities, a domestic supply chain is important for the future of the industry (Figure 5.26).

[101] https://www.meti.go.jp/shingikai/Figure 5.26enecho/denryoku_gas/genshiryoku/kakushinro_wg/pdf/001_08_00.pdf
[102] http://www.aec.go.jp/jicst/NC/iinkai/teirei/siryo2022/siryo13/3_haifu.pdf

Figure 5.26 Challenges faced by Japan's nuclear industry[103]



To maintain domestic capabilities, the Japanese government has taken steps. These include human resource development, technology advancement, business succession support, and the fostering of international collaboration among industry, government, and academic stakeholders. The government is actively promoting Japan's nuclear power industry while assisting companies in pursuing opportunities abroad (Figure 5.27).

Figure 5.27 Government support to maintain and strengthen the nuclear industry of Japan[104][105]

Scale of Japan's Nuclear-related manufacturing

Curriculum building
- Curriculum standardization of nuclear-related skills in Advanced Nuclear Energy Consortium for Future Society

Horizontal cooperation for HR development
- Information sharing among member companies and Nuclear Human Resource Development Network

Technical and business succession support

Successor matching
- M&A specialists by government-affiliated financial institutions to match companies without successors with companies that wish to take over their businesses

Complementing technical succession through digital technology
- Introduction of digital technology through a subsidy from METI's "Nuclear Industry Infrastructure Enhancement Project

International Cooperation

Cooperation among manufacturers
- Forming teams of Japanese manufacturers participating in each next-generation reactor
- Information sharing among manufacturers

Finance Support
- The Japan Bank for International Cooperation and Nippon Export and Investment Insurance provide loans

Information sharing and export support
- Japan Atomic Energy Industries Association, Japan External Trade Organization, and Japan External Trade Organization share information and support for exporters

Support for standards, equipment, and R&D
- The following support through METI's subsidy
  - Compliance with overseas standards
  - Equipment repair
  - R&D of equipment and materials

5.4.3.4 Fuel cycle/ disposal

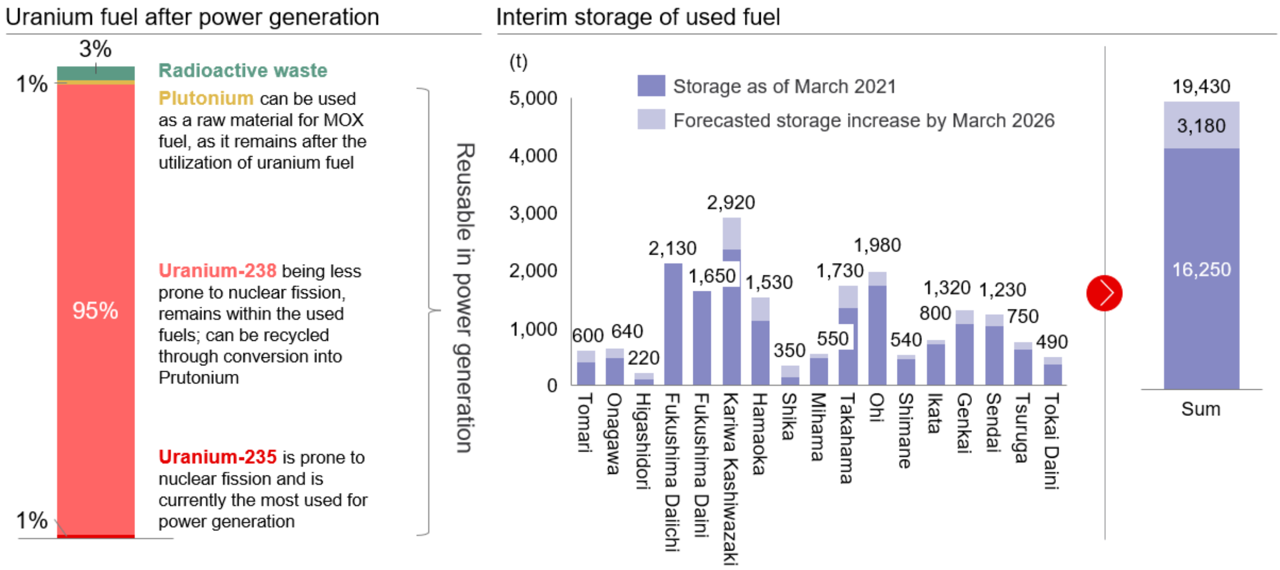
After the uranium-235 is used, more than 90% if spent fuel can be reused. Through cycling spent fuel, the energy resource is effectively utilized as well as the toxicity of nuclear fuel is reduced that lead to reducing burden of final disposal. Fast reactors will further improve effective energy usage and

[103] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/kakushinro_wg/pdf/006_03_00.pdf
[104] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/kakushinro_wg/pdf/006_03_00.pdf
[105] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/pdf/036_01_00.pdf

reduced toxicity. To establish such fuel cycle would help improve domestic self-sufficiency in nuclear fuel and, ultimately, energy self-sufficiency.

The challenge is to establish fuel cycles with intermediate storage facilities, at an early stage and to gain public understanding of decisions related to the final disposal site. (Figure 5.28). Efforts are required to improve the stability, reliability, operability, and maintainability of fuel recycling and final disposal.

Figure 5.28 Interim storage of spent fuel in Japan[106]



The Japanese government promotes both fuel cycle and final disposal. In 2015, the Action Plan for Spent Fuel Countermeasures called on the public and private sectors to work together to expand spent fuel storage capacity, as well as “establish a council between the government and business operators” and “request business operators to formulate a spent fuel countermeasure promotion plan.” Specific initiatives include JNFL’s reprocessing plant and MOX fuel processing plant in Rokkasho village (Aomori Prefecture), which is scheduled to begin operations in 2024. With recycling capacity in short supply in nuclear-hosting countries, further recycling facilities will be required (Figure 5.29).

[106] http://www.aec.go.jp/jicst/NC/about/hakusho/index2022.htm and https://www.jaero.or.jp/sogo/detail/cat-02-08.html https://www.kepco.co.jp/corporate/profile/community/wakasa/ew/k_topics/62k_topics.html

Figure 5.29 Worldwide trends in fuel cycle[107]

Reprocessing

Extracting reusable uranium and plutonium from spent fuel

Company Name	Location	Commencement of operations	Processing Capacity (t/year)
Sellafield	Cambria (Northwest England)	1994 (Closed in 2018)	900
		1964 (Closed in 2022)	1,000
Mayak	Chelyabinsk (Southwest Russia)	1977	400
ORANO	La Arg (Northwest France)	1966	1,700
JNFL	Aomori prefecture (Tohoku area) Rokkasho Village	Scheduled for FY2024	800

Total 2,100t/year

*Operated for commercial use

Re-fueling (= MOX fueling)

Mixing plutonium with uranium to create new fuel

Company Name	Location	Commencement of operations	Processing Capacity (t/year)
FBFC International	Dessel	1960 (closed in 2015)	200
ORANO	Bagnon Lesere (Southeastern France)	1965.	195
Mayark (cigarette brand)	Chelyabinsk (Southwest Russia)	1977	400
Nuclear power Mechanism	Tokai Village, Ibaraki Prefecture	1988	4.5[1]
JNFL	Aomori prefecture (Tohoku area) Rokkasho Village	Scheduled for FY2024	130

Total 595t/year

*Operated for commercial use

Fuel recycling capacity is inadequate worldwide and spent fuel is waiting to be recycled

Today the dominant method for the treatment of high-level radioactive waste is glass solidification, whereby the fuel is immobilized in glass form. Spent fuel generated in Japan is currently converted to solid glass in the UK and France, and then returned to Japan for storage (Figure 5.30). Kamoenai Village and Suttu Town (both in Hokkaido) are candidates to be final disposal sites and the literature survey is under way.

Figure 5.30 Current Waste Disposal Cycle[108]

Radioactive Waste Flow in Japan

Spent fuel	Japanese utilities store used fuel • Currently holds nearly 20,000 tons
Glass solidification	Radioactive waste solidified into a stable form at reprocessing plants in the UK and France and returned to Japan • Radioactive liquid waste and glass are melted, hardened, and packed in a cylindrical container.
Storage	Waste is cooled and stored at the high-Level Radioactive Waste Storage and Management Center in Rokkasho Village for 30 to 50 years final disposal.

Glass Solidified Radioactive Waste Storage Facility

Location	Rokkasho Village, Aomori Prefecture
Capacity	Glass solidification 2,880 (nearly 1,800 stored as of 2018)
Commencement of operations	1995
Safety consideration	Surrounded by reinforced concrete walls about 1.5 to 2 m thick, radiation shielding

107 http://www.aec.go.jp/jicst/NC/about/hakusho/hakusho2022/index_pdf01.htm

108 https://www.jnfl.co.jp/ja/business/about/hlw/summary/

5.5 Positive Technology in Japan: Industrial electrification

5.5.1 The role of industry electrification in a carbon neutral society

Domestic renewable energy generation such as solar and wind is expanding in Japan. Using green electricity for industrial processes where technically and economically viable, will contribute to CO_2 emissions reductions. The technology for industry electrification is contingent on heating needs:

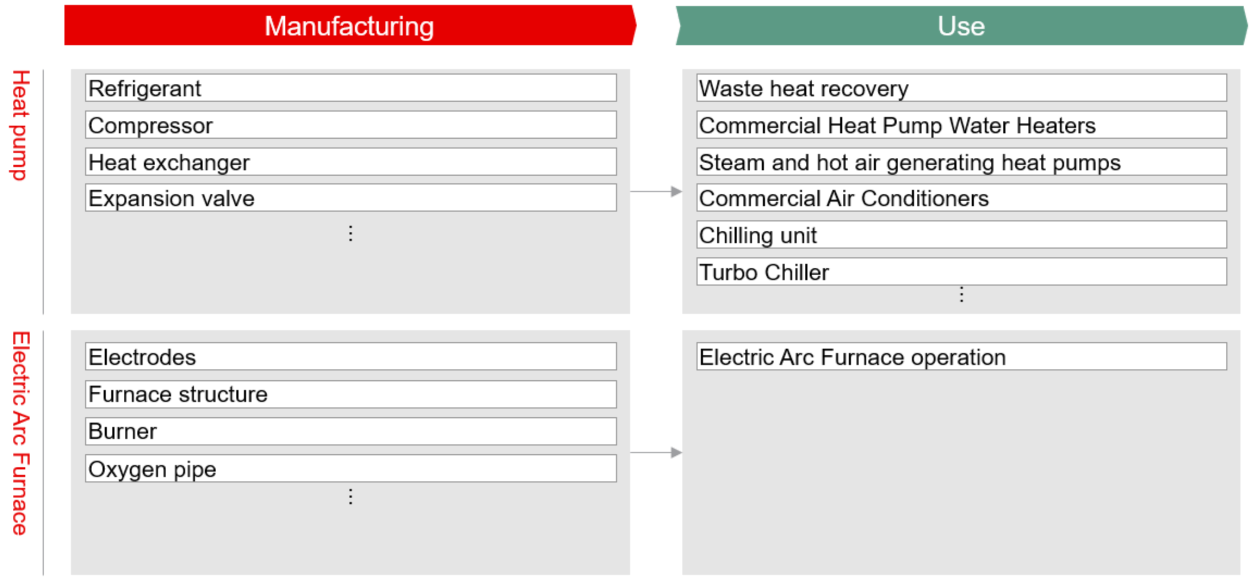
Heat needs under 200 degrees Celsius: Equipment with integrated heat pumps to generate heat using electricity.

Heat needs over 200 degrees Celsius: Different technologies are applied even within the steel industry, where emissions are particularly high. Possible options include conversion to electric arc furnaces (EAFs), as well as Hydrogen injection into BF and hydrogen direct reduction of iron.

5.5.2 The industrial electrification supply chain

The supply chain for both heat pumps and EAFs is broadly split into equipment manufacturing and usage (Figure 5.31).

Figure 5.31 Overall image of the industrial electrification supply chain



To build an electrification supply chain, financing and research are required in both manufacturing (equipment providers) and usage (process industries). In addition, performance improvements through technological innovation and cost reductions will be necessary. Meanwhile, stakeholders must make decisions relating to replacement of equipment and operational efficiencies for the long term.

5.5.3 The need to build an industrial electrification supply chain

There are two major supply chain segments for both heat pumps and EAFs, relating to manufacture and use, and the following technologies are positive technologies for Japan (Figure5.32).

Figure 5.32 Detailed list of industry electrification technology

Not exhaustive

Supply chain segment	#	Positive technology	Necessity in Japan	Leading players
Heap pump manufacturing	1	Refrigerant	• Need to expand the range of temperatures that can be handled by heat pumps while currently, the majority of heat pumps are used at temperatures below 100 degrees Celsius • In addition, it is necessary to introduce new types of refrigerants to minimize the impact on the ozone layer when using heat pumps.	Mitsubishi Electric, Mayekawa, Daikin, Mitsubishi Heavy Industries Thermal Systems, Toshiba Carrier
	2	Compressor		
	3	Other main components (Heat exchanger, expansion valve, etc.)		
Heap pump use	4	Waste heat recovery	• Need to decarbonize industry heat demands, of which more than half is the temperature range below 200 degrees Celsius • Since this temperature range is within the scope of heat pump application, CO_2 emission reductions can be expected from the introduction of heat pumps.	Machinery, Automobile, Chemical, food and beverage, pulp and paper industries
	5	Commercial and Industrial application (Commercial water heaters/air conditioners, Steam and hot air generator, Chilling unit, Turbo chiller, etc.)		
Electric arc furnace (EAF) manufacturing	6	Electrodes	• Need to assure efficiency and capability to supply high-grade steel, which is conventionally produced by the blast furnace process, in EAF process • Need for electric furnace equipment itself to be solved through further research and development.	Nippon Steel Engineering, Nakanihon Ro Kogyo
	7	Furnace structure		
	8	Other main components (Burner, Oxygen pipe, etc.)		
EAF use	9	Use	• Need to decarbonize steel making process, which is high-emitting and high-temperature zone above 1,000 degrees Celsius through use of EAF in addition to hydrogen injection into BF and hydrogen direct reduction of iron.	Nippon Steel, JFE Steel, Kobe Steel
Other equipment for industrial electrification	10	Manufacturing and Use	• Other industrial-specific technologies for electrification. GX Basic Policy mentions electrification in chemical, cement, pulp & paper, aviation, shipping sector as examples for electrification	Various players

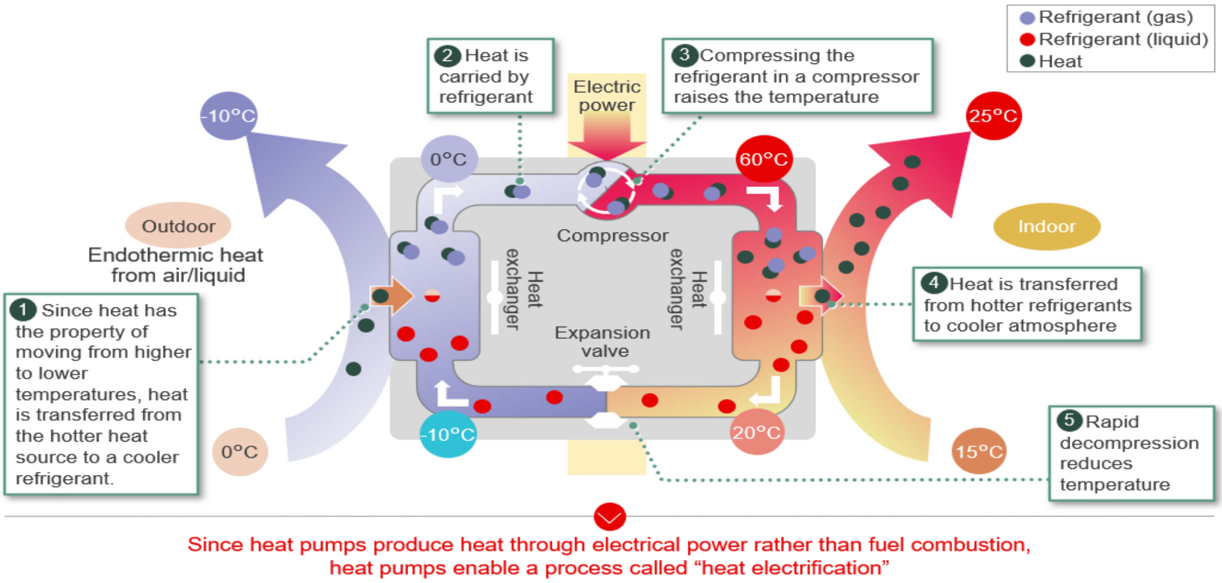
Manufacturers and users of heat pumps and EAFs will consider technologies based on four key parameters: conditions in Japan, government policies, Japanese businesses initiatives, and global trends.

5.5.3.1 Heat pumps

5.5.3.1.1 Usage

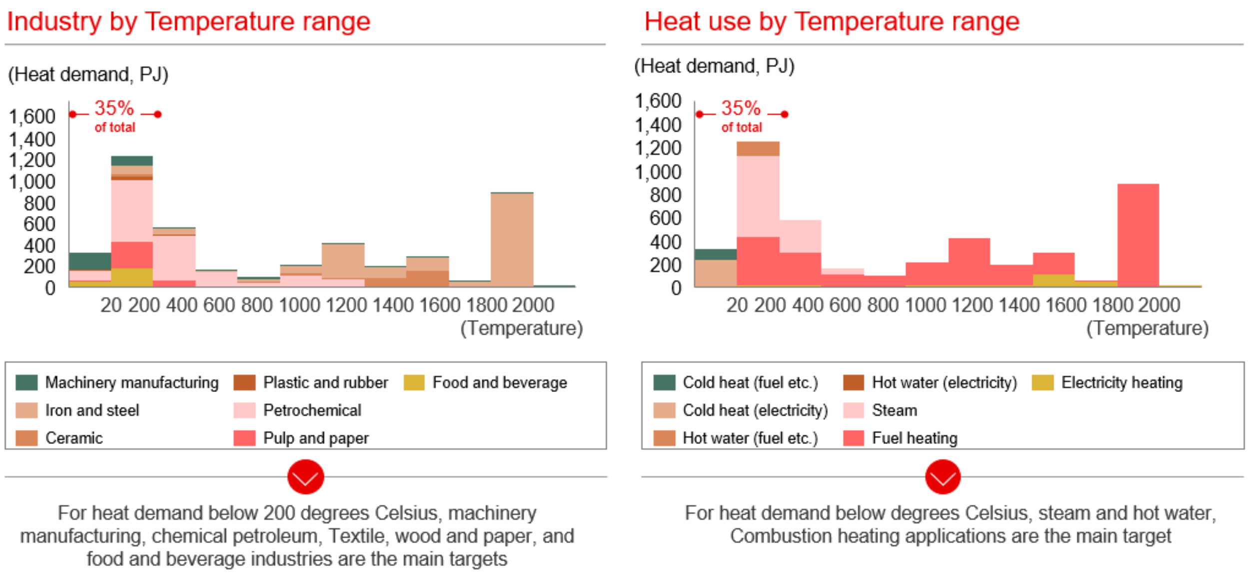
Heat pumps are built into equipment to provide either cooling or heating energy. They are most often used in buildings and process industries. They extract heat from the atmosphere/liquid, amplify, and transfer through a process of compressing and decompressing refrigerants (Figure 5.33).

Figure 5.33 Heat pump mechanisms[109]



In Japan, there is significant demand for heat under 200 degrees Celsius, which represents about 35% of total heat demand (Figure 5.34). This is from industries including machinery manufacturing, chemical petroleum, textiles, wood and paper, and food and beverages. Use of heat pumps can cut CO_2 emissions in these industries and in domestic situations.

Figure 5.34 Breakdown of heat demand by industrial sector[110]



Use of heat pumps is progressing for temperatures of 100 degrees Celsius and below, where the technology is relatively mature and required efficiency is much lower than in the production of higher temperatures. Common use cases include air conditioners, low-temperature chilling units, and turbo chillers. Indeed, Japanese manufacturers such as Toshiba Carrier and JCI/JCI Hitachi Air Conditioning have captured a large share in different product categories of global market.[111] At higher temperatures, there is still significant room for innovation (Figure 5.35).

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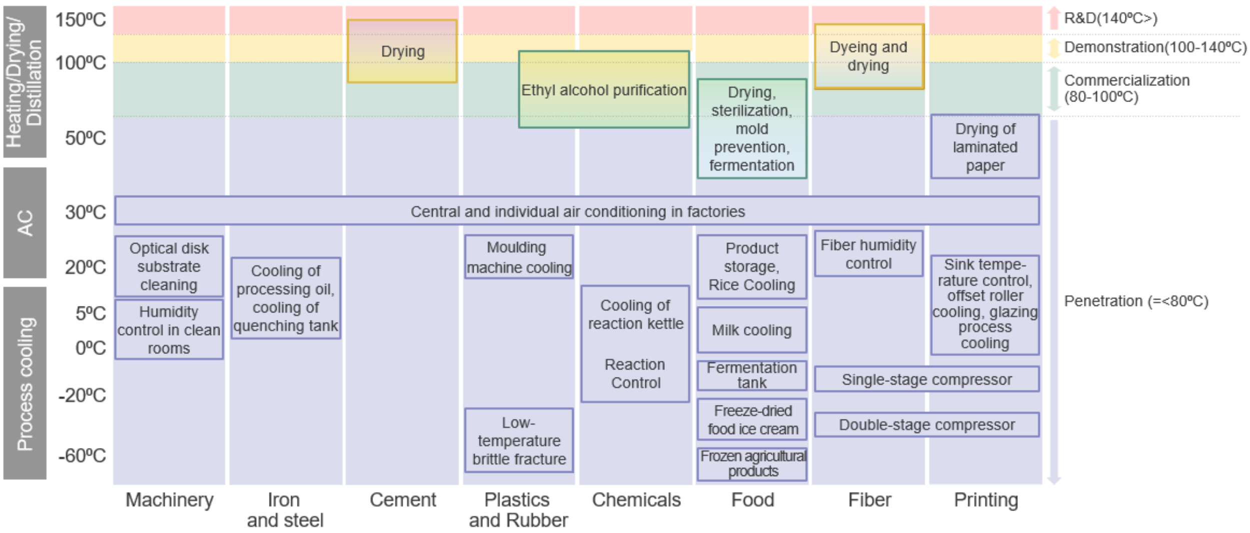
[109] https://www.hptcj.or.jp/study/tabid/102/Default.aspx

[110] https://www.hptcj.or.jp/Portals/0/data0/press_topics/2020NewsRelease/news_release_siryo.pdf

[111] Company website

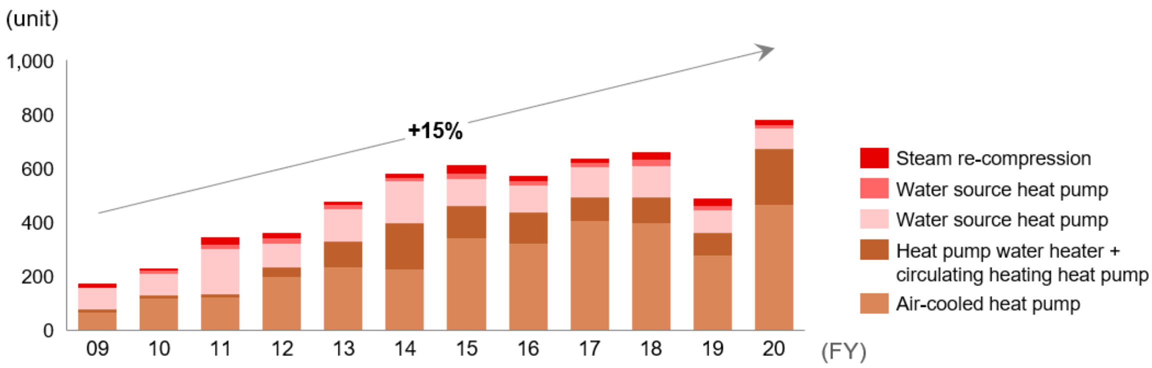
Figure 5.35 Heat pump use by temperature range (not exhaustive)[112]



In its clean energy strategy, the Japanese government presents heat pumps as one way to decarbonize manufacturing processes, and JPY0.5 trillion of public-private investment is forecast to be required by 2030.[113] In addition, the Ministry of the Environment and Economy, Trade and Industry provides subsidies for equipment and construction costs.[114]

In recent years, industrial heat pumps have been increasingly used (Figure 5.36). Examples of their use includes cleaning, drying, and concentrated distillation processes in the machinery, electrical and electronics, food and beverage, chemicals, and oil industries. For example, chemical manufacturer Daicel adopted heat pump technology for the compression and reuse of low-temperature steam, which it traditionally discarded. Through lower energy use, CO_2 emissions were reduced by 40%.[115]

Figure 5.36 Installation of industrial heat pumps in Japan[116]



The adoption of heat pumps, including for residential use, is forecast to continue to grow at double digit rates globally.[117] Furthermore, numerous government policies recognize electrification as a critical lever for decarbonization.

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[112] https://sangyo-hp.jeh-center.org/heatpump_factory.html

[113] https://www.env.go.jp/council/content/i_01/000060962.pdf

[114] https://www.enecho.meti.go.jp/appli/public_offer/2020/20210120_002.html

[115] https://www.jeh-center.org/emonoden_video_HP0617.html?_anch_=

[116] https://www.jeh-center.org/asset/00032/20211028IHP_hokoku/IHP_hokoku_2021.10.pdf

[117] IEA (2023), Global heat pump sales continue double-digit growth, IEA, Paris https://www.iea.org/commentaries/global-heat-pump-sales-continue-double-digit-growth, License: CC BY 4.0

5.5.3.1.2 Heat pump manufacturing

Major commercial and industrial electric heat pump products include waste heat recovery, commercial water heaters, steam and hot air generators, commercial air conditioning, chilling units, and centrifugal chillers. Major players in Japan aim to internally produce core components such as compressors, which significantly improve heat pump performance. Additionally, individual manufacturers have strengths in different areas. For example, Mayekawa has a high domestic market share in steam and hot air generation, Toshiba Carrier in waste heat recovery and chilling units, MHI Thermal Systems in centrifugal chillers, and Mitsubishi Electric in water heaters, among other areas.

To maximize their decarbonization impact, heat pumps need to produce higher temperatures. This will largely mean enhancing the functionality of compressors and heat exchangers. Manufacturers focusing on this goal include Mayekawa, MHI Thermal Systems, and KOBELCO Compressors, all of which are conducting research and development for practical applications.

Compliance with international rules for raw materials, particularly refrigerants, is important in heat pump manufacturing. The 2016 Kigali Amendment to the Montreal Protocol aims to curb ozone depletion through stricter regulations for refrigerants and indicates timelines for phase-out. There is a growing movement in Japan to reconcile these concerns for the environment while optimizing heat pump performance. For example, Mitsubishi Electric is focusing on developing and selling products that utilize new types of refrigerants (see the Mitsubishi Electric case study).

Both Europe and the US have implemented policy incentives for heat pumps and for regulating the use of conventional refrigerants. Legislation includes the Fluorinated Gases Regulation (F-Gas) in the EU and the SNAP Program in the US.[118] [119] The EU has launched an EU Heat Pump Action Plan and has set a target of installing at least 30 million new heat pumps by 2030, adding to the 20 million currently in use. At present, 70% of the energy supplied to heating and cooling comes from fossil fuels, but heat pumps are three to five times more efficient than conventional boilers. The European Green Deal and REPowerEU call for the doubling of the current deployment rate in buildings and faster deployment of large district heating and cooling network heat pumps. Given limited domestic manufacturing capacity, imports will be required. The Green Deal Industrial Plan (GDIP) will also seek to phase out stand-alone boilers by 2029.

The US will invest heavily in the creation of heat pumps, seeking to meet its domestic demand and eventually become an exporter to global markets. The US Energy Information Administration reports that 17.5 million heat pumps are utilized currently. With the assistance of the IRA, the US is positioned to add at least 7 million heat pumps by 2030, but with individual states creating their own targets, that number is expected to rise. The IRA has carved out individual tax credits for residential installation. The policy also intends to promote the US as an exporter of the technology, providing federal income tax credits for manufacture and development.

Heat pumps are promising technologies for industries. However, potential barriers need to be removed, including a lack of skilled engineers on the demand side and speedier roll out by manufacturers.

[118] The F-Gas regulation has established criteria for Global Warming Potential by item and has gradually expanded the number of prohibited items for sale since its enactment in 2006.

[119] The Significant New Alternatives Policy of US aims to identify and evaluate alternative substances for ozone-depleting substances. It assesses the risks posed to human health and the environment by both existing and new substitutes. SNAP publishes lists of approved substances and actively encourages the use of these acceptable alternatives.

Case study: Heat pump manufacturing by a Japanese company

Mitsubishi Electric is a major Japanese electronics manufacturer that manufactures and sells heavy electrical systems, industrial mechatronics, information and telecommunication systems, electronic devices, and household appliances. The company operates in more than 30 countries in the Americas, Asia Pacific, Europe, and the Middle East, in addition to all over Japan. In its initiative "Sustainability Management" of Corporate Strategy published in 2023, Mitsubishi Electric aims for Net Zero greenhouse gas emissions in the entire value chain by FY2050 and Net Zero greenhouse gas emissions from factories and offices by FY2030, which is a mid-term goal. In "Environmental plan 2023," a three-year plan of initiatives for environment, Mitsubishi Electric sets KPIs and targets from viewpoint of "environmental contribution through products and services," "Reduction of the environmental impact of our business activities," and "Pursuing business innovation." This case study will focus on electricity transmission and distribution from the perspective of decarbonizing customers through the supply of Mitsubishi Electric's products and services.

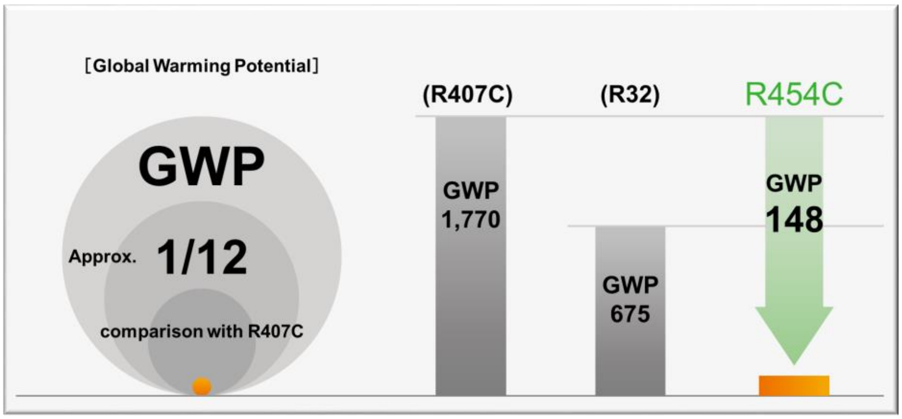
Industrial Heat Pumps

Mitsubishi Electric is developing new products that reduce the environmental impact of its existing products by using refrigerants with low GWP (Global Warming Potential: a numerical value that measures the global warming effect of other gases based on CO_2), while also considering safety and efficiency. For example, Mitsubishi Electric has conventionally utilized an alternative CFC refrigerant called R407C, but it has also been utilizing R32, which has a GWP of approx. 1/3 of R407C. In recent years, the company has also been working to produce products that incorporate heat pumps using R454C, which has even lower GWP. In selecting a refrigerant, Mitsubishi Electric decided to use R454C refrigerant based on the following four conditions: 1) GWP less than 700[120], 2) 70 degrees Celsius hot water output, which is required for industrial applications, 3) potential for use in regions as cold as -25 degrees Celsius, and 4) refrigerant is safe and only slightly combustible.

In addition to changing refrigerants, Mitsubishi Electric is also working to improve its energy consumption efficiency, in terms of SCOP (Seasonal Coefficient of Performance). Compared to conventional equipment, the SCOP has been improved 3.55 to 3.57, while keeping its cost lower than conventional ones so as to secure a competitive advantage by promoting the practical application of new technology for social implementation.

[120] GWP700 is a level consistent with the US standards
EPA Proposes Rule to Advance Transition to Safer, More Efficient Heating and Cooling Technologies | US EPA

Comparison of GWP of each refrigerant



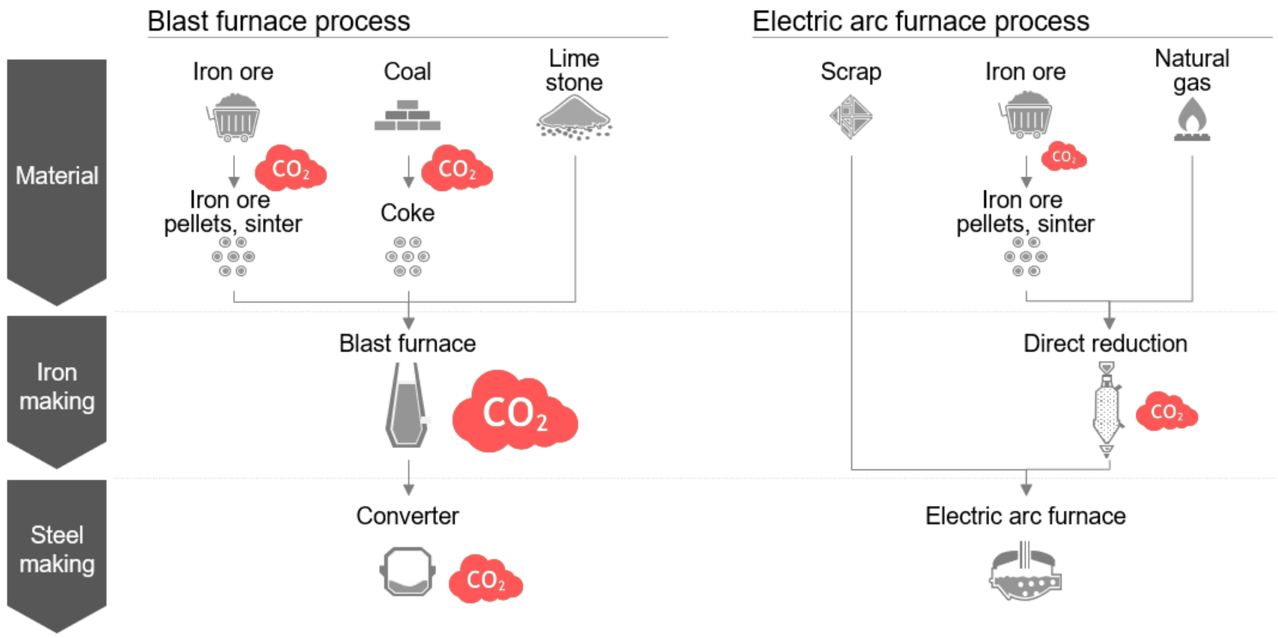
Products that utilize R454C refrigerant include, for example, air conditioning chiller systems. While R454C refrigerant has a low GWP and can reduce environmental load, it also has a characteristic that reduces its ability to provide cold heat, and because it is a low-pressure refrigerant, the pressure in the device drops to nearly atmospheric pressure when operated at -25 degrees Celsius outside air. In order to address these technical challenges, the heating capacity of existing models was secured by increasing the size and speed of the compressor, and the control of the compressor and other components was optimized for commercialization. Additionally, noise caused by these measures and the amount of frosting during low ambient air temperature operation are mitigated. These R&D efforts have resulted in the R454C being incorporated into new air conditioning chiller systems and circulating heating systems, which are already on the market and being used in a wide range of areas, including industry and residential applications.

Looking at refrigerant development for applications other than heat pumps, Mitsubishi Electric also introduced R290, a natural refrigerant, in Europe and will introduce 454B, an ultra-low GWP refrigerant, in the US market in 2024. In addition to strengthening the development of new refrigerants, it is building a system to develop products tailored to local needs through R&D centers in Europe, the Americas, China, and Asia.

5.5.3.2 Electric Arc Furnaces (EAFs)

EAF are used to convert scrap iron into steel (Figure 5.37). However, the iron scrap needed for the electric arc furnace process is not inexhaustible. Thus, it is necessary to establish an operating technology for EAFs using reduced iron as feedstock, which has low iron content. However, the iron needs to be of a high level of purity. Therefore, the transition from blast furnaces to EAF will be difficult. Further technological advances in the removal and detoxification of impurities are needed for the production of high-performance steel products such as sheets, rods, and wires.

Figure 5.37 Blast furnace process and Electric arc furnace process[121]



Steel accounts for 37% of Japan's industrial sector CO_2 emissions. Crude steel production in Japan is dominated by the blast furnace method. Blast furnace hydrogen reduction, reduced iron production with hydrogen, and the use of electric arc furnaces are effective in reducing CO_2 emissions. Based on the availability of steel scrap, a productive combination of technologies is required.

The Japanese government's GX Basic Policy sets a goal to increase the supply of green steel to 10 million tons by 2030, achieve internationally competitive electricity prices, and continue to expand global markets through international rulemaking. This should be achieved while promoting the conversion of fuel and raw materials, including switching to EAFs. Relevant measures include the Energy Conservation Act and GX support based on structural reforms. Through these measures, CO_2 emissions from steelmaking are projected to fall by 30% from their 2013 level by 2030. The GX Basic Policy envisages JPY3 trillion of funding over 10 years to convert production systems, including funding for assets including electric arc furnace equipment, electric power infrastructure, and scrap yards.

Consistent with government policy, major steel manufacturers such as Nippon Steel and JFE Steel are looking at switching to EAFs. Japanese steelmakers often produce products that require extremely high purity, such as electromagnetic steel sheets for automobiles. The companies are developing large-scale EAFs capable of high-quality outputs and making efforts to commercialize (See Nippon Steel case study).

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[121] https://www.meti.go.jp/shingikai/sankoshin/seizo_sangyo/pdf/011_03_01.pdf; https://www.steel.org/steel-technology/steel-production/

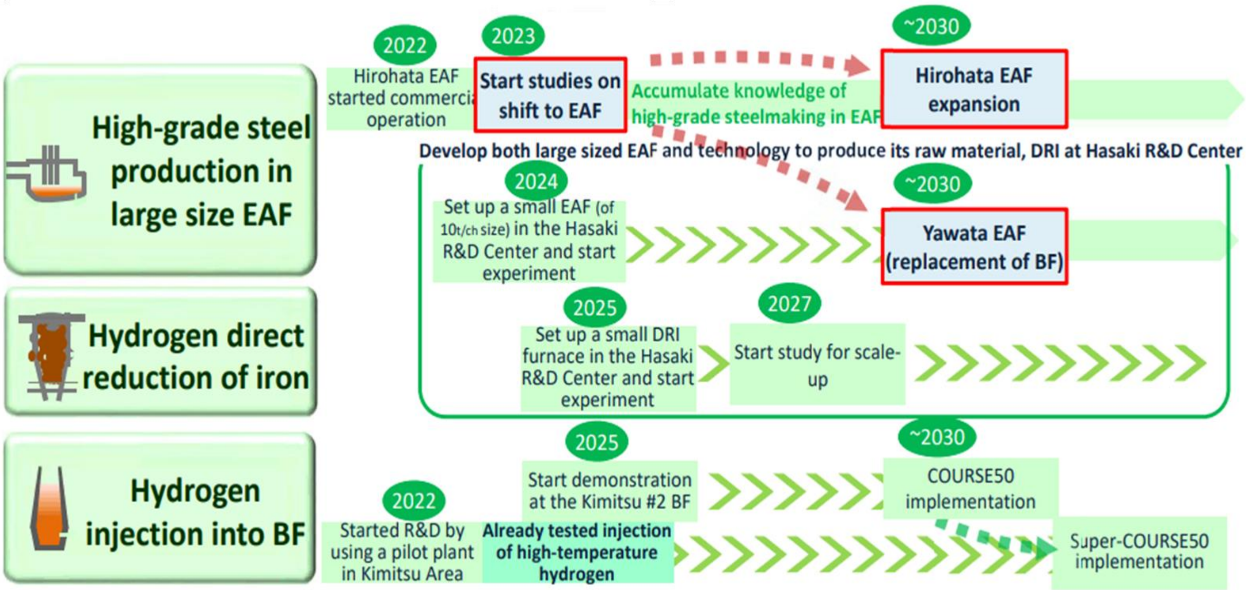
Outside Japan, similar trends are playing out. For example, the British company Liberty Steel Group will invest about JPY50 billion to install two EAFs at its Czech Republic steelworks, starting operations in 2025. The new furnaces will reduce steelwork CO_2 emissions by 80% or more. The Swedish company SSAB has also announced its expansion into EAFs. Each steel manufacturer, however, will need to secure high-quality steel scrap and high-quality reduced iron with fewer impurities.

Case study: Introducing electric arc furnaces by a Japanese company

NIPPON STEEL

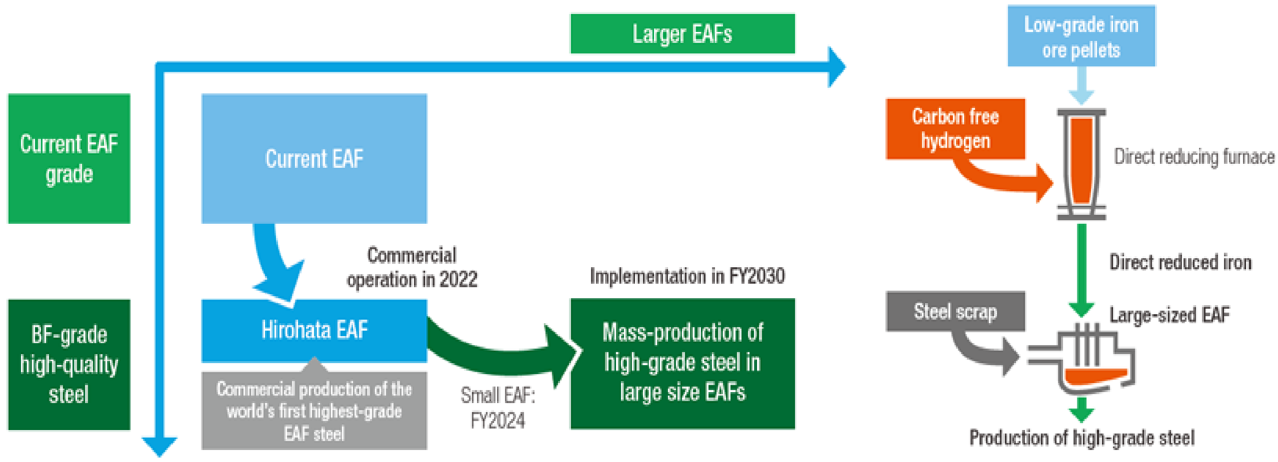
Nippon Steel Corporation is Japan's largest steelmaker and one of the world's leading steel producers, with manufacturing in Japan and more than 15 countries around the world. In its Carbon Neutral Vision 2050, the company commits to reduce its Scope 1 and Scope 2 CO_2 emissions by 30% in 2030 compared with 102 million tons a year in 2013, and to become carbon neutral in 2050. In addition, the company sets a target for a 30% reduction in CO_2 emissions in 2030 compared with the 2013 baseline for its consolidated crude steelmaking companies with blast furnaces (BF) and electric arc furnaces (EAF) in Japan and abroad. To achieve this target, Nippon Steel advances initiatives to produce high-grade steel in large EAF as a pillar along with the use of hydrogen (Hydrogen injection into BF and hydrogen direct reduction). This case study gives an overview of Nippon Steel's initiatives for using EAF.

Roadmap of major initiatives



High-grade steel production in large size EAF

A BF is a technology used for smelting iron ore (Fe_2O_3) to pig iron (Fe), while an EAF uses reduced iron for manufacturing. Nippon Steel is committed to replacing the BF in the Kyushu Works Yawata Area with EAF in 2030, maintaining an annual crude steel production capacity of about 4 million tons and starting to produce high-grade steel. Nippon Steel plans to minimize CO_2 emissions using hydrogen direct reduction (H-DR) technology (see the case study on hydrogen/bio-based fuel for details), iron scrap and carbon-free electricity in the EAF.



Nippon Steel has already built new EAFs in Japan and overseas. At Setouchi Works Hirohata Area, commercial operation of an EAF commenced in October 2022, achieving the world's first integrated manufacturing and supply of high-grade electrical steel in EAF. 122 AM/NS Calvert in the US (a 50/50 joint venture between Nippon Steel and ArcelorMittal) also works toward EAF operation in 2024. High-value-added products such as Third Generation AHSS (980MPa or higher) and IF steel (deep drawing steel sheets for auto car exteriors) are expected to be produced in the integrated EAF process.

The company aims to manufacture high-grade steel in a large EAF by 2030. The first plan is to install a small EAF (10 tons) at Hasaki Research and Development Center (Kamisu City, Ibaraki Prefecture), and start testing in FY2024. Furthermore, a full-scale study to replace a BF currently in operation with an EAF at Kyushu Works Yawata Area was announced in May 2023. In addition, there is another plan for installing a second EAF in the Setouchi Works Hirohata Area, where an EAF is currently operating.

To reduce CO_2 emissions as fast as possible, in addition to hydrogen injection into BF, Nippon Steel has studied a full-scale transition and expansion of the EAF process for early commercialization regardless of the availability of an external hydrogen supply system. Iron scrap supply, impurities and production efficiency are key challenges. In particular used iron scrap contains copper and other impurities, and the manufacturing process is prone to mix nitrogen. For this reason, there are restrictions on the quality and items that can be manufactured using conventional EAF. In terms of productivity, the smelting of iron scrap and other materials can be time-consuming—lower productivity is an issue for smelting and direct iron reduction in a large EAF.

To address these issues, Nippon Steel is developing technology to detoxify toxic elements in the EAF process, which, if realized, would reduce impurities to the level of materials of BF process. Regarding productivity, the company is working to increase the size of the EAF, considering standardization with other existing facilities. Specifically, since the BOF has a capacity of 300 tons, the company is conducting a demonstration test to introduce EAF in the equivalent size. Introducing a large-sized EAF requires a large amount of green power, so cross-sector collaboration with electric power companies is essential.

[122] It is a smart material used as an iron core of electrical equipment. It must have few impurities, as it is coated with an insulating film and needs to pass magnetic flux efficiently.

5.6 Positive Technology in Japan: Hydrogen-based and biogenic fuels

5.6.1 The role of hydrogen-based and biogenic fuels in a carbon neutral society

The key industrial emitters of CO_2 vary from region to region and country to country. However, in most geographies, the share of CO_2 emissions relating to heat and electricity is high: 49% in Japan and 47% in ASEAN.[123] Therefore, reduction of fossil fuels in the production of heat and electricity is a common global lever to achieve carbon neutrality by 2050.

Hydrogen-based and biogenic fuels, which emit low (or zero) levels of CO_2, are attracting attention as an effective decarbonization technology for heat and power, as well as a new means of storage (or "carrier"), transport, and use of clean power from renewable energy sources and nuclear. There are a wide variety hydrogen-based and biogenic fuels, including hydrogen, ammonia, biofuels, and synthetic fuels. Away from heat and power, these are expected to be deployed as substitutes for raw materials and reductants in industries such as steel and chemicals (referred to as hydrogen-based and biogenic fuels in this whitepaper though they are not used as fuels).[124]

- **Hydrogen**: Hydrogen is described in different ways depending on the production method[125]. Green hydrogen is produced by the electrolysis of water from renewable energy sources; blue hydrogen is produced by capturing and storing CO_2 in the process of extracting hydrogen from natural gas or coal; pink hydrogen is produced by the electrolysis of water from nuclear power generation; and turquoise hydrogen is produced by direct thermal decomposition of natural gas (CH_4) to produce hydrogen (H) and solid carbon (C).
- **Ammonia**: Ammonia is produced by heating a mixture of hydrogen and nitrogen gases at high temperature and pressure.
- **Biofuels**: Biofuels are produced from a wide variety of feedstock, including vegetable oil, waste cooking oil, plant materials such as sugarcane and rice, and waste materials such as sludge and sewage.
- **Synthetic fuels**: Synthetic fuels are produced from hydrogen and CO_2 and include e-methane as a gaseous fuel and e-methanol as a liquid fuel.[126]

5.6.2 The hydrogen-based and biogenic fuel supply chain

The hydrogen-based and biogenic fuel supply chains consist of three components: Upstream production, midstream transportation, and downstream demand/utilization (Figure 5.38). Since multiple technologies are expected to be deployed in these areas, the supply chains that connect them are composed of diverse combinations.

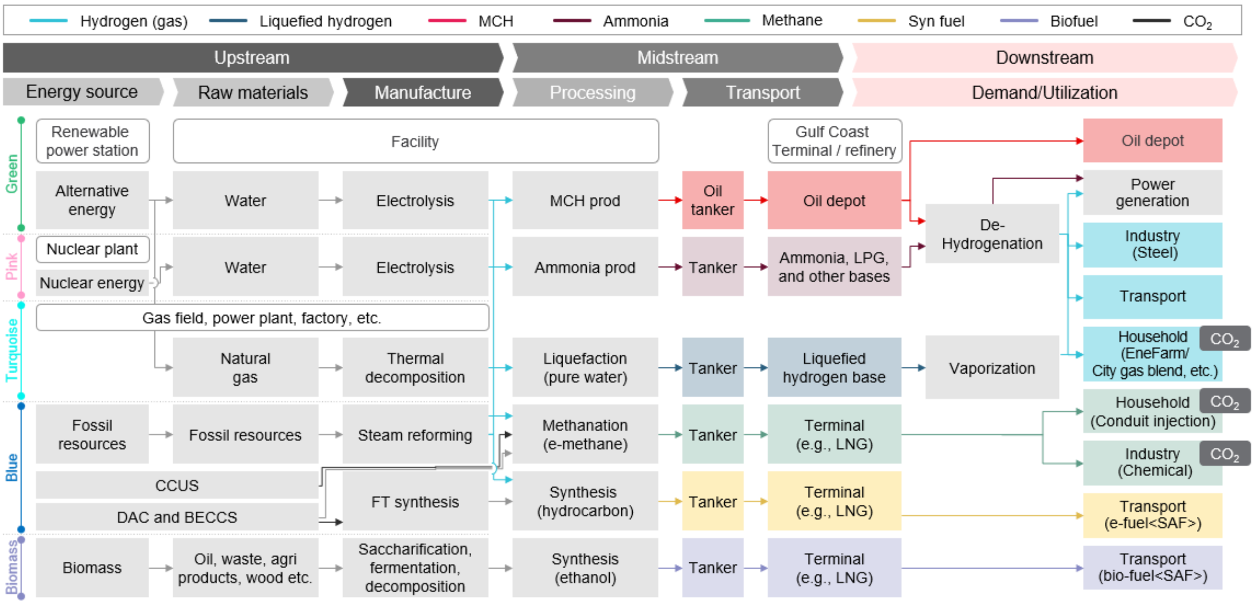
[123] https://www.iea.org/data-and-statistics/data-product/global-energy-and-climate-model-2022-key-input-data

[124] A variety of materials produced by CCU exist to replace raw materials and reducing agents. Products manufactured by CCU technologies other than hydrogen, ammonia, biofuels, and synthetic fuels are covered in the CCUS section

[125] For simplicity, this whitepaper uses color code to distinguish different types of hydrogen; however, there are various ways in differentiating hydrogen and not limited to the color code mentioned in this section.

[126] Synthetic fuels are considered one of the applications of CCU as they are produced using CO_2 as one of the raw materials. Other applications of CCU, such as the production of chemicals and cement, are discussed within the section on CCUS (Carbon Capture, Utilization, and Storage).

Figure 5.38 The hydrogen-based and biogenic fuel supply chain



For deployment of hydrogen-based and biogenic fuels in Japan, each element of the supply chain must be developed from upstream to downstream in an end-to-end and integrated manner. A holistic approach will also enable Japan to optimally develop its power and gas grid infrastructure. This requires collaboration among regulators and companies that straddle the supply chain. In addition, since supply chains cross national borders, public-private collaboration is required, both within Japan and internationally.

In Japan, the Basic Hydrogen Strategy outlines a plan to invest JPY15 trillion in the public and private sectors over the next 15 years to build a large-scale hydrogen supply chain. As part of this effort, a scheme will be introduced to support early developers of low-carbon hydrogen and ammonia[127] supply chains (first movers) for 15 to 20 years. This will narrow the price difference between hydrogen and ammonia and fossil fuels—an important step in de-risking imports and production. A critical next step from a regulatory perspective will be to enable cost-effective transmission and distribution of hydrogen-based and biogenic fuels, and to ensure effective integration of hydrogen- and bio-based fuels in the power and heating markets.

To establish a hydrogen-based and biogenic fuel supply chain, it is necessary to identify downstream applications (power generation, industry, transportation) and stimulate demand. Upstream fuel production and downstream demand/utilization can be connected after identifying transportation technology in the midstream. Furthermore, in upstream manufacturing, some resource development is required to determine where and how to secure and procure supply.

5.6.3 The need to establish a hydrogen-based and biogenic fuel supply chain in Japan

There are three supply chain segments for hydrogen-based and biogenic fuels, and dozens of positive technologies (Figure 5.39).

[127] Basic Hydrogen Strategy defines low-carbon hydrogen as hydrogen produced with a Well to Production Gate CO_2 emission of 3.4 kg-CO_2-e or less per 1 kg of hydrogen, on a provisional basis. Similarly, low-carbon ammonia is defined as one produced with a Gate to Gate (including hydrogen production) CO_2 emission of 0.84 kgCO_2-e/kg-NH3 or less per 1 kg of ammonia.

Figure 5.39 Positive technologies for hydrogen-based and biogenic fuels

Not exhaustive

Supply chain segments	#	Positive technology	Necessity in Japan	Leading players
Production	1	Green hydrogen	• Need to ensure efficient and inexpensive hydrogen supply domestically and internationally - Electrolyzer technology SOEC under development while AEC and PEM commercialized • Necessary to secure diverse supply sources for energy security	Asahi Kasei, Hitachi Zosen, Kawasaki Heavy Industries, Toshiba, Toray, Tokuyama, Nippon Shokubai
	2	Blue hydrogen		
	3	Turquoise hydrogen		
	4	Pink hydrogen		
Transport & storage	5	Ammonia carrier	• Demand sites away from production sites • Need for large scale and efficient maritime transport	JERA, NYK Line, MOL
	6	Liquefied hydrogen carrier		KHI
	7	MCH carrier		ENEOS
	8	e-Methane carrier		Osaka gas, Tokyo gas, Toho gas
	9	Other hydrogen carrier		—
	10	Hydrogen terminal	• Need for updated port infrastructure/storage for large-scale fuel imports	KHI, IHI
	11	Ammonia terminal		
Demand/ Utilization	12	Hydrogen mono-/co-firing thermal power generation	• Need for flexible power supply to support introduction of renewables • Existing thermal power plants can be re-purposed to replace fossil fuels with hydrogen or ammonia partially (co-firing) and fully (mono-firing)	MHI, IHI/GE
	13	Ammonia mono-/co-firing thermal power generation		JERA, MHI, IHI/GE
	14	Naphtha cracking furnace ammonia combustion	• Need for emission reduction at high-emitting sectors (petrochemical complexes, cement manufacturing, and steel making) by replacing raw material/fuels (methane, coal) with ammonia/hydrogen	Mitsui Chemicals, Maruzen Petrochemical, Toyo Engineering, Sojitz Machinery
	15	Ammonia co-firing in cement manufacturing		Mitsubishi UBE Cement Corporation
	16	Hydrogen injection into Blast furnace		Nippon Steel, JFE Steel, Kobe Steel
	17	Hydrogen direct reduction		
	18	Shipboard combustion engines	• Need for decarbonized supply chain process including long-haul marine transportation for island nations like Japan • Fuels such as e-methanol or ammonia are expected to replace fossil fuels	IHI
	19	Sustainable aviation fuel (SAF)	• Need for decarbonization in mobility sector by replacing fossil fuels with SAF	JAL, ANA
	20	City gas methanation	• Need for utilizing CO2 as resource in countries with low fuel self-sufficiency • Methanation also allows to utilize current LNG supply infrastructure with relatively small capex	IHI, INPEX, Tokyo Gas, Mitsubishi Corporation, Osaka Gas, Toho Gas

5.6.3.1 Utilization/demand

5.6.3.1.1 Utilization/demand: Power generation sector

Japan currently relies on coal- and gas-fired thermal power generation for approximately 70% of its energy mix. Hydrogen/ammonia mono-/co-firing technologies for thermal power plants are required to decarbonize the power generation sector and achieve stable supply.

Hydrogen- and ammonia-fired power plants can operate flexibly with excellent load-following capability. This means they can absorb output fluctuations in solar and wind power. Put another way, the deployment of hydrogen and ammonia-fired power generation will play a role in maximizing the use of global renewable energy in Japan, a country with a small land area and an electricity grid that is not connected to other countries.

Government and industry are working toward harmonized goals for the deployment of hydrogen/ammonia mono-/co-firing technologies (Figure 5.40). In the government's Sixth Basic Energy Plan, it is assumed that hydrogen and ammonia will provide about 1% of the energy mix in FY2030, and 10% in 2050. The Basic Strategy for Hydrogen aims to reduce the price of hydrogen to

JPY 30/Nm^3 in 2030 and JPY 20/Nm^3 in 2050, to boost production to 30 million tons per annum by 2050, and to supply the hydrogen and ammonia needed.

The government will support the private sector. In the Basic Strategy for Hydrogen, the government outlines its intention to support the closing of price gaps and establishment of supply chains. It plans to bridge the gap between the cost recovery and stable revenue for hydrogen and ammonia providers and the current price of fossil fuels. Additionally, infrastructure development support will be provided to foster the clustering of hydrogen and ammonia industries, taking into account optimal placement across the country. The specific design of these schemes is expected to be formulated by around 2024. Thereafter, the government plans to provide medium- to long-term support to sustain the efforts of private players in the sector.

The Basic Strategy for Hydrogen includes plans to support the development of hydrogen/ammonia mono-/co-firing through the GI Fund. It will also regulate electricity retailers to supply 44% or more of electricity from non-fossil power sources by 2030 under the Advanced Electricity Utilities Act and introduce fixed-cost support for hydrogen/ammonia-fired power generation through the Auction for Decarbonized Power Sources. This will mean promoting hydrogen/ammonia utilization in the power generation sector through regulation and support as a single package.[128]

In response to the government commitment and de-risking measures, private players are promoting R&D, demonstration, and commercialization. Mitsubishi Heavy Industries, a power generation equipment manufacturer, for example, is engaged in full-scale development of gas turbine and boiler technologies for hydrogen and ammonia-fired power generation. Major players are developing multiple technologies in parallel as there is no single winning technology in mono-firing:

- **Gas Turbine Technology**: Hydrogen and ammonia mono-firing of small and medium-sized gas turbines is targeted for commercialization from 2025, while large gas turbines are targeted for commercialization up to 30% of hydrogen combustion in 2025 and hydrogen mono-firing in 2030.
- **Boiler Technology**: High-mixture technology (>50%) is being developed for commercial operation in the early 2030s.

Similarly, IHI and General Electric will conduct a demonstration of 2MW scale mono-firing aiming to market in by 2027 while at the same time develop 380 MW-scale mono-firing to market in 2030. IHI has also managed to suppress NOx emissions from ammonia combustion.[129]

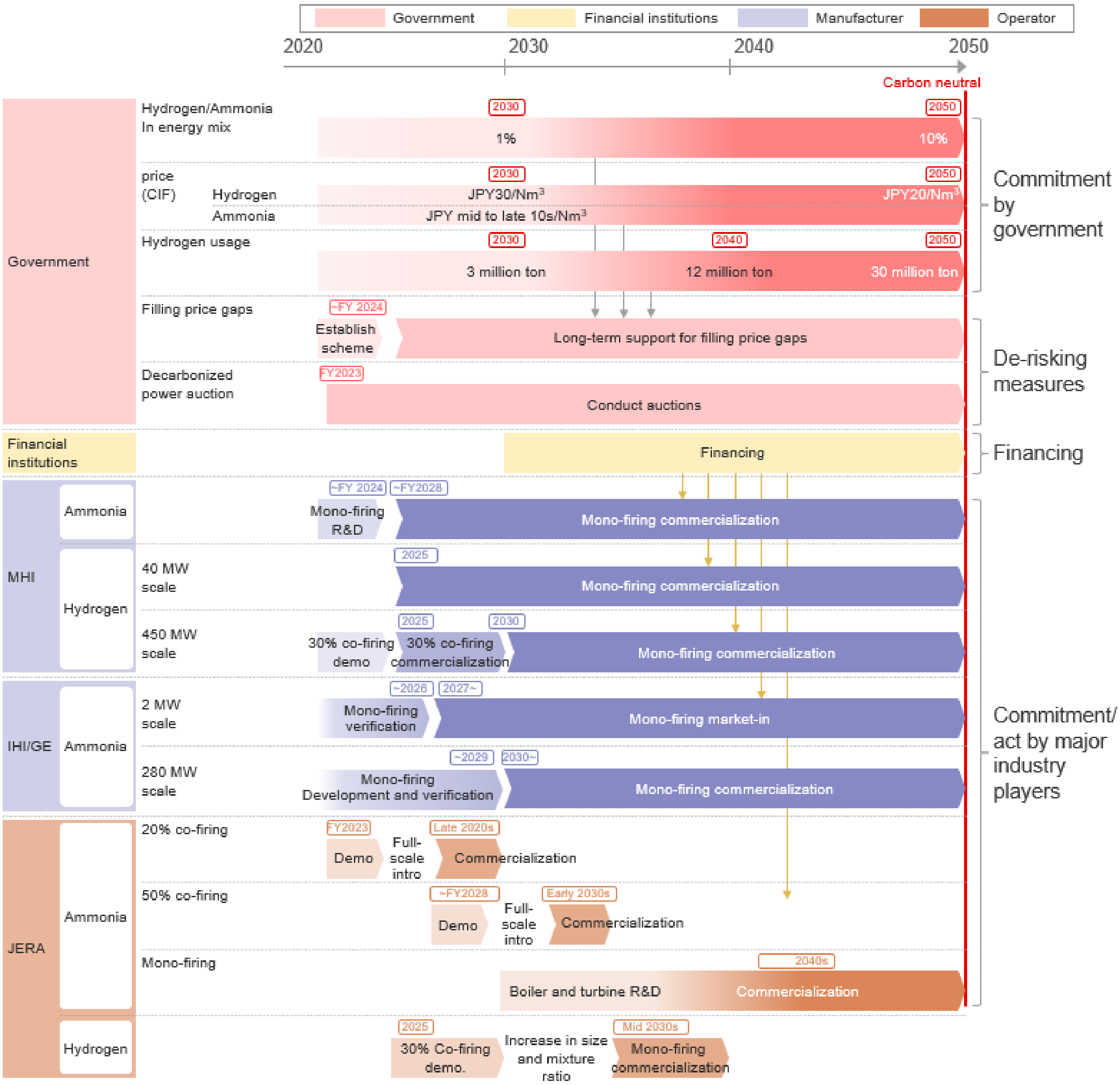
Power generators are also making commitments, in its "JERA Zero Emissions 2050 Japanese Roadmap,"the power generation operator JERA announced a commitment to start large-scaled mono-firing of hydrogen and ammonia in the 2040s.

- **Ammonia co-firing**: Hekinan Thermal Power Station Unit 4 (1GW) will start demonstration tests at a co-firing ratio of 20% in FY2023, aiming for commercial operation in the late 2020s. Unit 5 (1GW) will conduct high co-firing tests at a co-firing ratio of 50% or higher by FY2028, aiming for commercial operation in the early 2030s.**Hydrogen co-firing**: Demonstration tests with a firing ratio of 30% will be conducted in the 2020s, followed by technological development for further expansion of the firing ratio and larger scale operation, with the goal of commercial operation of mono-firing plants in the mid-2030s.

[128] https://www.occto.or.jp/soukaihoka/hyougiinkai/2022/files/2022_4_houkoku_1.pdf

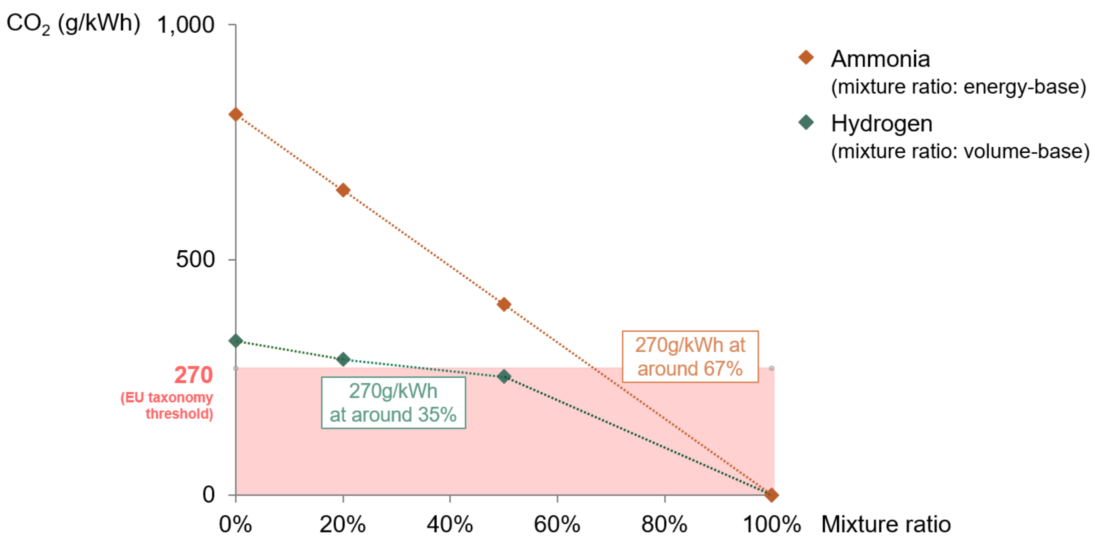
[129] https://www.ihi.co.jp/en/technology/techinfo/contents_no/__icsFiles/afieldfile/2023/06/17/afc79cb8b1ff3aad7af5fde6306e991c.pdf

Figure 5.40 Public-private roadmap for fuel conversion in thermal power generation in Japan



As mentioned in Chapter 4 (see In Focus: Technology development to actual deployment: Case study of hydrogen and ammonia technologies in the power sector), Japan's policy of advancing the decarbonization of thermal power generation broadly aligns with the objectives set out by the EU (Figure 5.41). In Japan, progress to develop hydrogen mono-firing gas turbine is being made toward achieving zero direct emissions. By realizing hydrogen mono-firing, small-sized gas turbines will achieve commercialization of zero direct emissions from 2025 onwards. Large gas turbines are on track for zero emissions by 2030, according to MHI's roadmap. With an eye to realize mono-firing of ammonia at repurposed boilers, Japanese players such as JERA are working on establishing an ammonia supply chain. Demonstration and further R&D is taking place at JERA's Hekinan power plant for the repurposing of boilers of coal-fired power plants. At the same time, preemptive measures are being taken in case a pivot is required, due to potential technical challenges or other factors in ammonia mono-firing within a boiler. The ammonia supply chain established specifically for ammonia mono-firing in boilers can also be utilized for ammonia mono-firing in turbines or for converting ammonia to hydrogen (cracking), enabling hydrogen mono-firing. To facilitate a pivot, multiple technologies are being concurrently developed by domestic equipment manufacturers, with Mitsubishi Heavy Industries (MHI) at the forefront. While there are challenges such as toxicity of fuel (ammonia) and handling of NOx emission, they are managed through safety standards and the technological development of denitration equipment.

Figure 5.41 CO_2 reduction by hydrogen/ammonia firing[130]



To realize the early deployment of mono-/co-firing in large-scale thermal power plants, the Japanese government and companies plan to accelerate the development of renewable energy overseas and import hydrogen and ammonia from renewable energy overseas.

[130] Based on CO_2 emission of 810g/kWh of USC according to Ministry of the Environment. The same proportion of CO_2 emissions is also reduced when ammonia is co-fired on a calorie basis. Based on MHI's estimation for large-scaled gas turbine. Mixture ratios that achieve 270g/kWh is estimated based on preceding and subsequent data points.
https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/029_05_00.pdf
https://www.enecho.meti.go.jp/about/whitepaper/2021/html/3-8-4.html https://www.env.go.jp/content/900497779.pdf

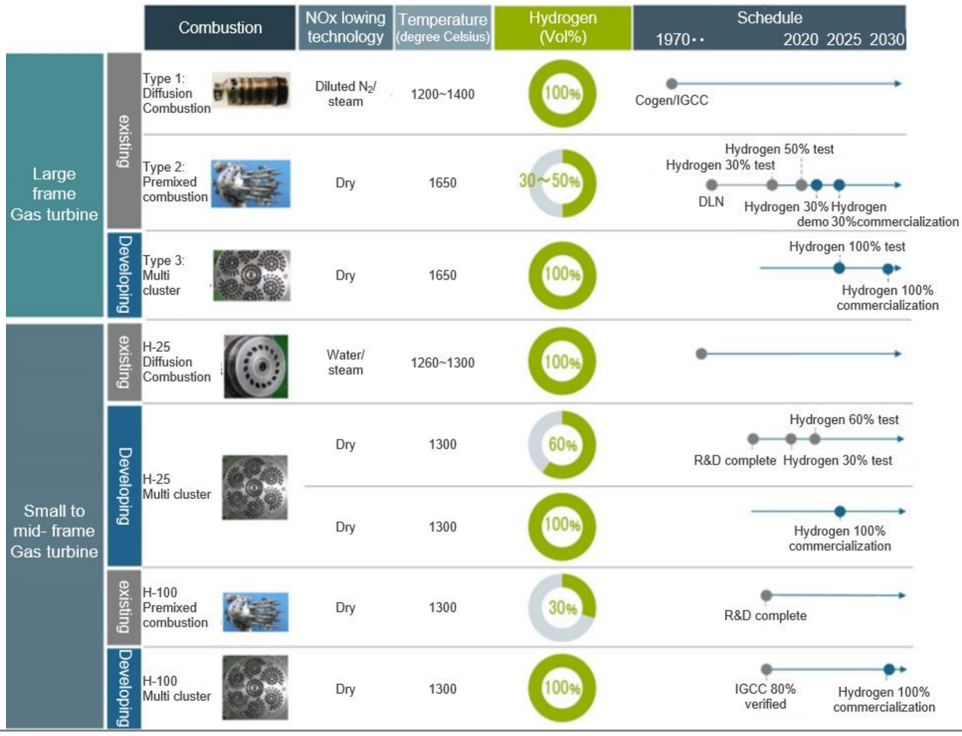
Case study: Japanese company's power plant repurposing

Mitsubishi Heavy Industries (MHI) is an engineering and manufacturing company covering energy, plant & infrastructure, logistics, thermal & drive systems, aviation, defense & space. In the "MISSION NET ZERO," MHI Group declared their commitment to reducing the Group's CO_2 emission by 50% by 2030 and achieving Net Zero of Scope 1/2/3 by 2040. "Decarbonize existing infrastructure," "Build of a hydrogen solutions ecosystem," and "Build of a CO_2 solutions ecosystem" are three pillars to achieve these goals. This case study focuses on the development of hydrogen and ammonia utilization in gas turbines and boilers, one aspect of decarbonizing existing infrastructure.

Hydrogen-fired gas turbine power generation

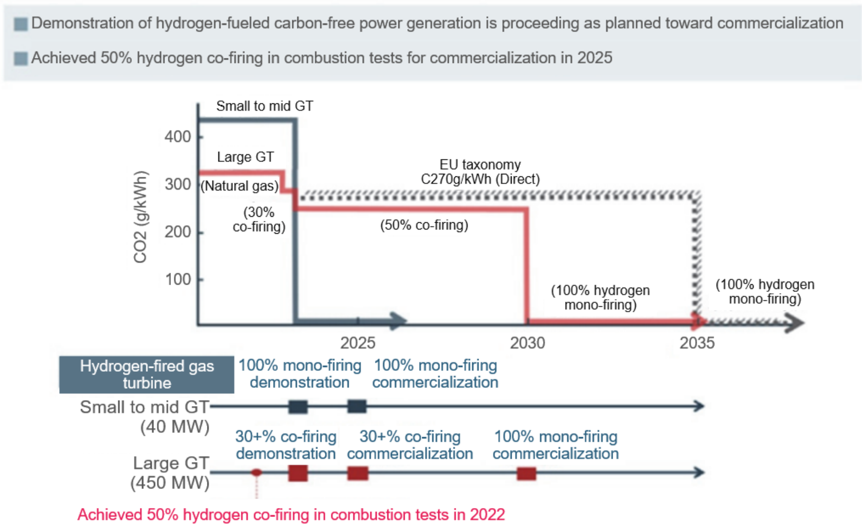
MHI has worked with a multitude of gas turbines with various fuel sources including hydrogen since the 1970s. It has been developing technology for firing hydrogen in large-frame gas turbines as projects supported by NEDO since 2015. Through these projects, the prospects for achieving 100% hydrogen combustion in small to medium-sized gas turbine tests in addition to hydrogen co-firing tests up to 50vol% are promoted, and they are continuing development with the goal of commercialization from 2025 onwards. They aim to apply the expertise and knowledge gained from small- and mid-sized turbines to large ones and commercialize them by 2030 when the hydrogen supply is expected to ramp up. To prepare for commercialization, demonstrations using actual gas turbines as well as upstream activities such as hydrogen production will be conducted at MHI's Takasago Hydrogen Park.

Development roadmap for hydrogen gas turbine combustors



It will be possible to achieve the level of CO_2 emissions required by the EU taxonomy (270g/kWh (direct emission threshold) from 2023-2035, 0g/kWh (MHI's assumed direct emissions corresponding to the life cycle emission lower than 100g/kWh threshold) from 2035) through hydrogen co- and mono-firing. MHI is continuing to develop technologies that will contribute to global carbon neutrality while keeping a watchful eye on international trends and standards.

Current state of hydrogen-fired gas turbine development and EU taxonomy target levels



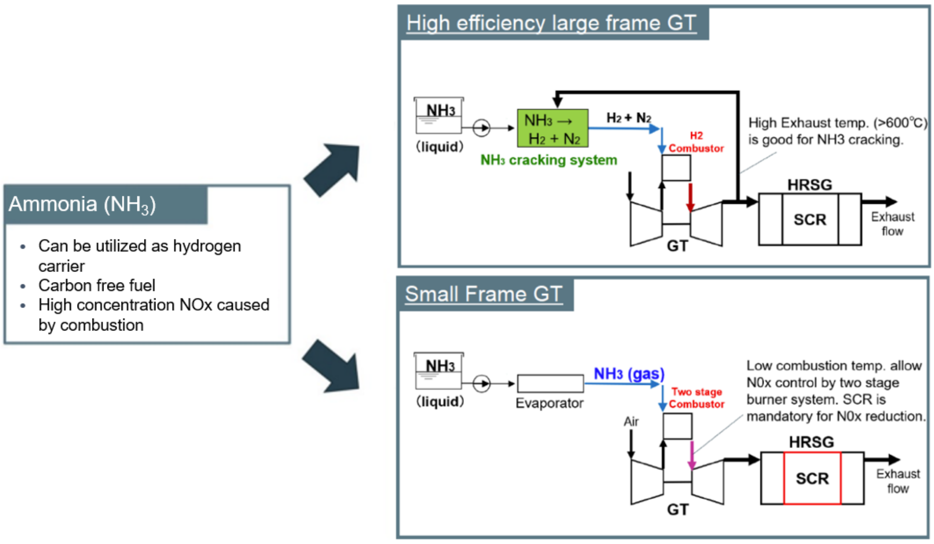
Furthermore, MHI is conducting demonstrations of hydrogen co-firing abroad. In 2022, at the McDonough-Atkinson power plant in the US, MHI, along with Georgia Power and the Electric Power Research Institute, achieved 20% volume-based hydrogen co-firing at a high-efficiency, large-scale GTCC power plant. CO_2 emissions were reduced approximately 7%. In the Intermountain Power Plant project in Utah, their GTCC plant is to move to 30% hydrogen co-firing in 2025 and hydrogen mono-firing by 2045, and MHI has already received order of the GTCC plant equipment.

<u>Ammonia-fired gas turbine power generation</u>

There are challenges in mass transportation and storage of hydrogen, and the use of ammonia is considered an effective means to realize a hydrogen society in Japan, which relies on imports for the majority of its energy needs.

Among carriers for transporting and storing hydrogen, ammonia has a higher hydrogen density per volume than liquid hydrogen or methylcyclohexane, and can transport and store hydrogen efficiently. In addition, ammonia has an advantage in handling because it can be diverted from existing transportation and storage infrastructures. Furthermore, it can be directly combusted as a carbon-free fuel, and its early introduction into GTCC is expected to lead to its use as a carbon-free fuel in the future. MHI is currently working on the development of a gas turbine system using ammonia, and will further expand the lineup of carbon-free power generation systems.

Gas turbine system using ammonia



As the speed of direct ammonia firing is approximately that of methane (the main component of natural gas), unstable firing and the release of large amount of nitrogen oxide (NOx) are challenges. MHI aims to build a gas turbine system by combining the development of combustors that reduce NOx emission and highly efficient denitrification equipment and put it to practical use around 2025.

Ammonia-fired boiler power generation

MHI is developing different technological methods for high-ratio ammonia co-firing to meet the diverse needs of their customers. In the NEDO project for establishing a supply chain of ammonia for fuel, they will develop an ammonia firing burner by 2024 through combustion tests with full-scale burner equivalent to actual equipment. At the same time, they are working together with JERA on a master plan and feasibility study for the demonstration of actual ammonia co-firing boilers and are aiming for the validation of over 50% ammonia co-firing in a circular firing system and an opposed firing system.

Case study: Use of hydrogen-based and biogenic fuels in power plants

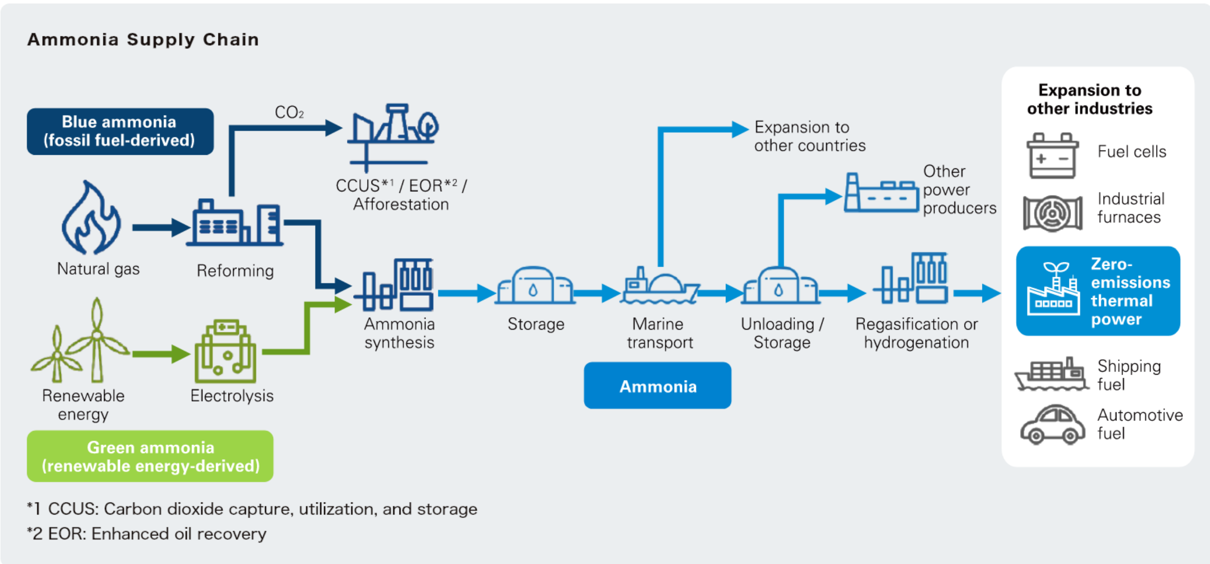
JERA is Japan's largest electric power company, providing approx. 30% of the country's electricity. Based on a comprehensive alliance with Tokyo Electric Power Company and Chubu Electric Power Company, JERA has a unified value chain from upstream and procurement of fuel to power generation and wholesale sales of electricity/gas and is one of the largest fuel handling companies in the world. JERA has set a goal of achieving zero CO_2 emissions from its domestic and overseas operations by 2050. The company intends to achieve this goal through "zero-emission thermal power generation" that does not emit CO_2 during power generation by promoting the use of renewable energy and green fuels. This case study will focus on JERA's efforts toward zero-emission thermal power.

Mono-firing/co-firing

Value chain owned and strengthened by JERA

JERA participates in a series of business activities in the value chain from upstream fuel development, transportation and storage to power generation and sales. The company is now considering expanding its business domain with an eye to selling green fuel not only for electric power but also for other applications (e.g., transportation fuel).

JERA's ammonia supply chain



Demonstration of ammonia co-firing at Hekinan Power Plant

Hekinan Power Plant is JERA's coal-fired power plant located in Aichi Prefecture, Japan, where units 1-5, with outputs ranging from 700-1,000 MW, are currently in operation. At present, coal mainly from Australia and Indonesia is used for power generation. However, over the past 15 years, advanced efforts have been made to reduce CO_2 emissions by co-firing coal with "woody biomass" and a substance called "sewage sludge carbonized fuel," which is produced by sanitizing digested sewage sludge. In addition to these efforts, a 20% ammonia co-firing demonstration will be conducted at unit 4.

The project is supported by NEDO as "Development of Carbon Recycling and Next Generation Thermal Power Generation Technology / R&D and Demonstration of Ammonia Co-firing Thermal Power Generation Technology," with an estimated project scale of JPY 45.2 billion and support amount of JPY 27.9 billion. In addition to JERA, IHI, an equipment supplier, is collaborating in this project. The demonstration project period began in June 2021, and the goal is to generate electricity by converting 20% of the fuel (calorific value ratio) to ammonia after repurposing unit 4 (output: 1,000 MW). The 20% ammonia co-firing at the actual plant is scheduled to last about two months from late 2023 to early the following year. Preliminary combustion tests are being conducted in unit 5 of the same plant from October 2021 for the burner design, and the design and mechanical work for unit 4 will be conducted based on the results of these tests. The amount of ammonia used is expected to be 30,000 to 40,000 tons, and JERA is in the process of building a supply network. For example, an ammonia purchase agreement for Hekinan unit 4 was recently signed between JERA and Mitsui & Co. Mitsui, which has been handling ammonia for about 50 years and currently handles about 700,000 tons per year mainly in Asia, plans to start supplying ammonia to Hekinan with future for clean ammonia supply.

Hekinan Power Plant

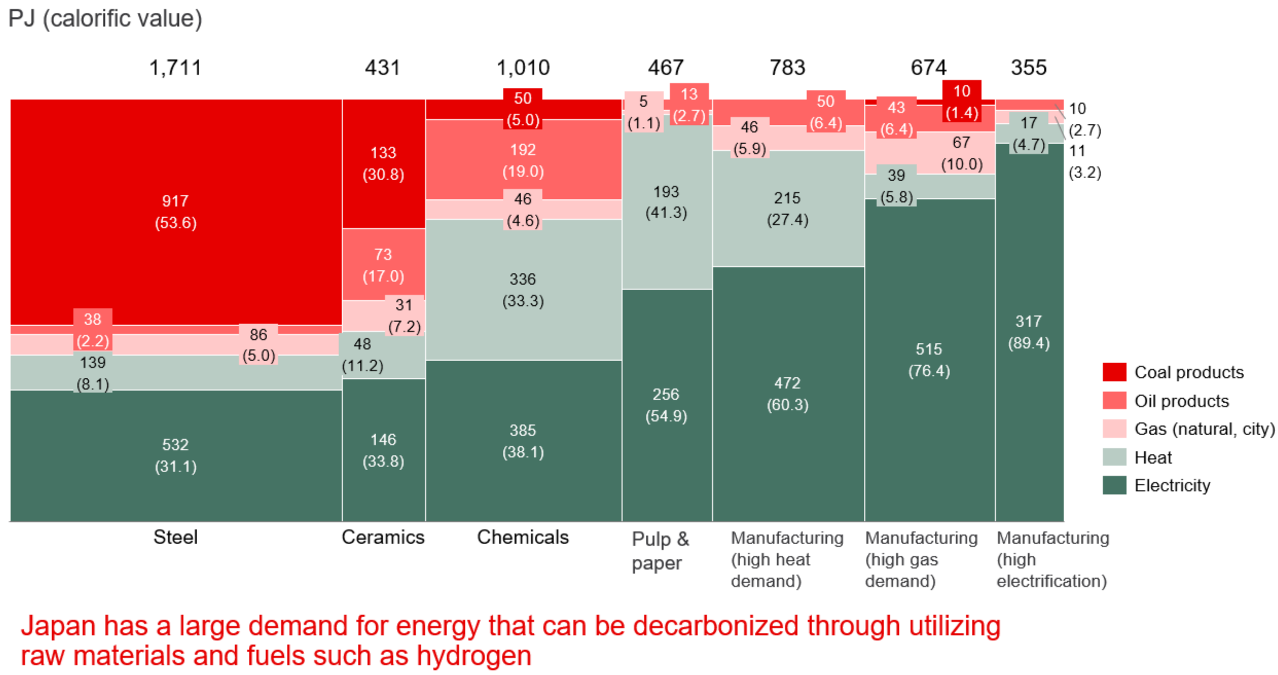
Furthermore, looking ahead, the 20% co-firing experiment at the Hekinan unit 4 power plant in FY2024 is a step toward higher mixture rates and mono-firing in the future. High mixture of more than 50% will take place in 2028 under the assistance of the GI Fund, and will be carried out up to commercialization in the 2030s.

The combination of the above two initiatives will enable the development of other power plants in Japan and the export of technology to ASEAN countries, thus playing an important role in bringing the experiment closer to the realization of zero emissions not only in Japan but also in the wider ASEAN region.

5.6.3.1.2 Utilization/demand: Industrial sector

Four materials industries account for about 80% of Japan's industrial CO_2 emissions (steel: 40%, chemical: 14%, ceramic: 8%, paper/pulp: 5%).[131] Therefore, decarbonization in Japan's key materials industries is a high priority. Process industries in general need to decarbonize the large amounts of heat and electricity used in their manufacturing processes, while the steel and chemical industries need to convert from using fossil fuels for producing materials used in these industries (Figure 5.42).

Figure 5.42 Japan's Energy Demand by Manufacturing Sector[132]



Electrification, such as through high-power heat pumps, is one of the main means of decarbonizing heat in process industries below 200 degrees Celsius, while globally up to 400 degrees Celsius is under development. When the temperature range of manufacturing process heat sources in process industries is above 200 degrees Celsius, electrification by heat pumps or other means are currently less efficient (Figure 5.43).

Fuel conversion is a cost competitive alternative to achieve decarbonization of high-temperature processes while maintaining existing production facilities and operations. This approach could maximize the use of advanced heat energy transfer technology between industries and large-scale manufacturing facilities, often maintained by Japanese companies in industrial clusters. In coastal areas, industrial complexes achieve reduced transportation costs and shorter lead times by involving different players in the import of raw materials, production of intermediate goods, and production of final goods within adjacent regions. Due to these interdependencies, any changes in production methods can have an impact on an entire region. Therefore, the introduction of hydrogen-based and biogenic fuels or materials at one production site creates significant potential to contribute to a reduced carbon footprint at other sites.

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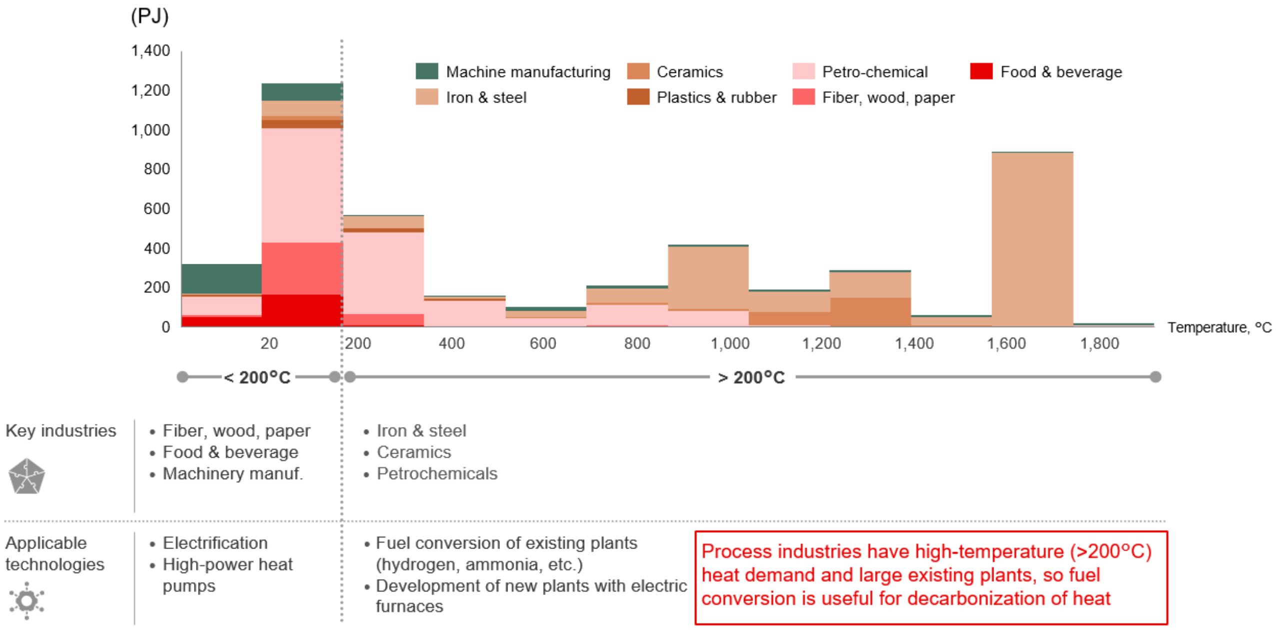
[131] https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/ondanka_wg/pdf/003_03_00.pdf

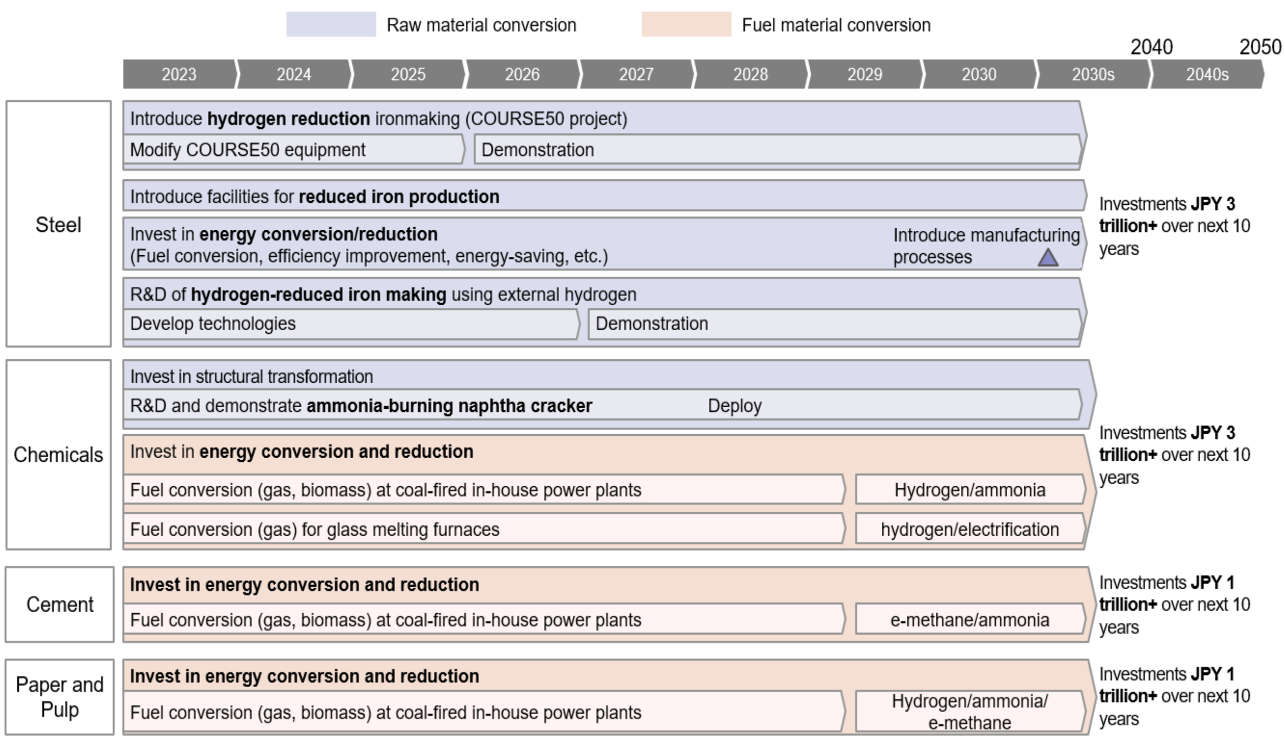
[132] https://www.enecho.meti.go.jp/about/whitepaper/2022/html/

Figure 5.43 Heat demand and applied decarbonization instruments by temperature zone in Japanese industrial sectors



Fuel and material conversion and for steel/chemical/cement/paper pulp is clearly stated in the GX roadmaps (Figure 5.44).

Figure 5.44 Raw material and fuel conversion in Basic Policy for Realization of GX in the materials industry (excerpts of the part relating to the use of hydrogen-based and biogenic fuels)[133]



133 https://www.meti.go.jp/press/2022/02/20230210002/20230210002_3.pdf
GX investments are totals that include other themes within the industry.

Iron and Steel

Japanese iron and steel industries are pursuing combinations of technologies: Electric Arc Furnaces (EAF), hydrogen injection into Blast Furnaces (BF), and hydrogen direct reduction as mentioned in section 5.4. Further progress will be required to meet the world's steel needs, and scrap recycling alone will be insufficient. Most likely, steelmaking by iron ore reduction will be necessary. The Japanese government, in its GX Basic Policy, has set a target of producing 10 million tons of green steel by 2030, and has a policy of mobilizing JPY3 trillion in public and private investment over the next 10 years for a decarbonization transformation centered on the use of hydrogen in the steel industry.

- Hydrogen injection into BF：Blast furnaces emit CO_2 while reducing and dissolving iron ore (Fe_2O_3) into pig iron (Fe) using coking coal. Hydrogen injection into BF is an ironmaking process that reduces the use of coking coal by blowing in hydrogen and replacing part of the CO_2 emissions with water.
- Direct hydrogen reduction：An ironmaking process that uses hydrogen to reduce iron ore in solid form and then transfers it to blast furnaces and electric arc furnaces for melting.

With regard to Hydrogen injection into BF, Nippon Steel plans to start demonstration tests on actual equipment in FY2025 and to further reduce CO_2 emissions by 2050 by using external hydrogen. In addition, on the production of reduced iron using hydrogen, the company plans to start demonstration tests in a test furnace from 2025, and to introduce the technology by 2050.

Chemicals

The chemicals industry is the second largest emitter of CO_2 in Japanese industry after steel. The GX Basic Policy aims to reduce fossil fuel used in naphtha crackers, which produce basic chemicals from naphtha refined from crude oil, by replacing with it low-carbon feedstock to produce greener chemicals. The plan is to reach processing capacity of 2.5 million tons by 2050.[134] Two key products will be green methanol, which is a pivotal feedstock for high-end plastics and building materials, and low-carbon ammonia for the fertilizer industry.[135]

Cement

The GX Basic Policy proposes fuel conversion of captive coal-fired power generation, which is used for combined heat and power generation for the cement manufacturing process.[136] In addition, there are moves to convert the use of coal to ammonia in the calcination process, in which materials such as limestone are mixed and then heated at high temperatures. For example, in April 2023, Mitsubishi UBE Cement was the first company in the world to announce the start of ammonia co-firing at actual equipment level in cement production. Going forward, the company aims to increase the co-firing rate to 30%.[137]

Pulp & Paper

The Japanese government's GX Basic Policy proposes fuel conversion of in-house coal-fired power generation, which is used for combined heat and power generation for the paper manufacturing process. It also proposes the upgrading of boilers that recover black liquor, a kind of biofuel generated in the paper manufacturing process. The biogenic emissions from pulp and paper plants can enable domestic production of low-carbon methanol and kerosene as local renewables capacity increases.

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134 GX is also promoting decarbonization of raw materials in the chemical industry. For example, there is a possibility of carbon recycling to utilize CO_2 captured and separated by CCUS, which is explained in the next section of CCUS

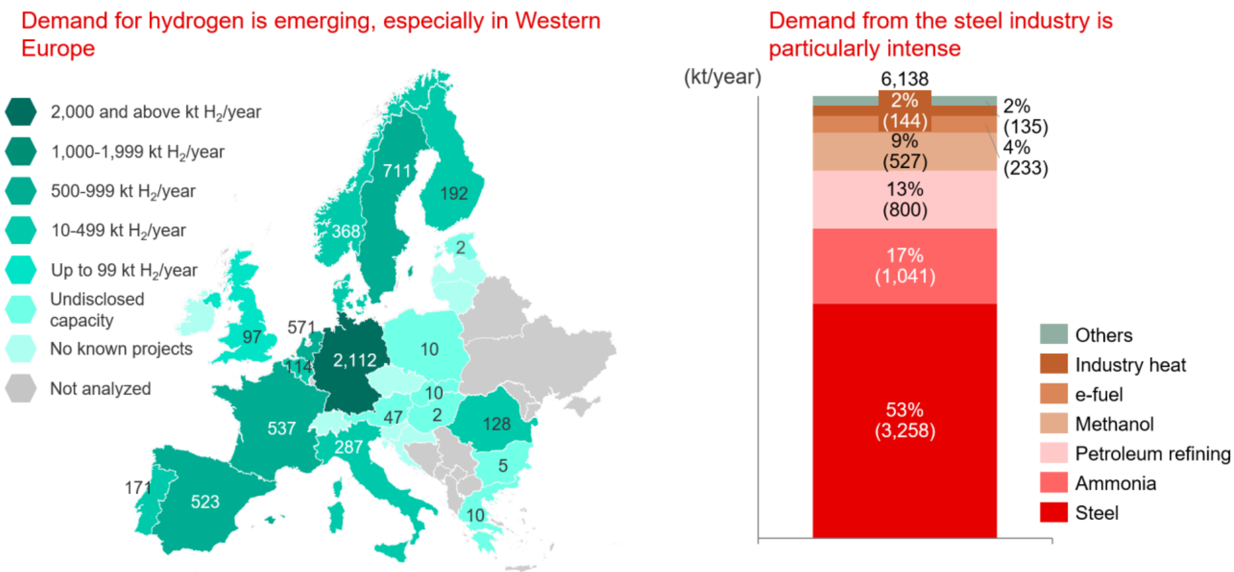
135 One of the key usages of ammonia is currently fertilizer https://www.enecho.meti.go.jp/about/whitepaper/2021/html/3-8-4.html

136 Decarbonization of raw materials is also an important theme, as in the chemical industry, explained in the CCUS

137 https://www.mu-cc.com/en/information/20230405_03.html

Hydrogen use in industrial sectors is also expected to grow in Europe. It is assumed that more than half of hydrogen demand in the European industrial sector in 2030 will be from the steel industry (Figure 5.45). Major European steel players (Arcelor Mittal, ThyssenKrupp, Salzgitter, Voestalpine, SSAB) are planning to further utilize hydrogen in the steelmaking process, in line with Japanese companies. Hydrogen is also being used in the decarbonization of heat in the industrial sector and in petrochemicals.

Figure 5.45 Projected European industrial sector hydrogen demand in 2030[138]



Regions around the world are actively engaged in promoting the development and adoption of low-carbon fuels, but are taking differing approaches. EU policies support the uptake of these fuels through stimulating demand, with established targets for imports and the use of fuels in transport. Fit for 55 and REPowerEUmandate 20 Mtpa of green hydrogen usage by 2030, with the expectation that half will be imported. Supply is expected to come from such locations as the Middle East, South America, and North and South Africa. Transport and heavy industry are the main use cases; for instance, Fit for 55 includes specific regulation packages that establish binding targets for the share of renewable fuels and emissions in the transportation sector, including road transport (2.6% e-fuel by 2030), aviation (5% e-fuel by 2035), and maritime shipping (75% emissions reduction by 2050) where green hydrogen through e-fuels production plays a key role. These targets mobilize end users to invest in technologies that can utilize low-carbon fuels while simultaneously encouraging suppliers by establishing demand.

By contrast, in the US, the low-carbon fuel market development is predominantly supported by stimulating new supply. Due to an abundance of renewable potential, as well as a desire to build domestic energy security, create infrastructure jobs, and aggregate production and use sites, the US is focused on producing low-carbon fuels as a means of supplying a growing domestic low-carbon fuels market (Figure 5.46). As a part of the US federal government's incentive scheme, IRA offers substantial tax incentives for producing hydrogen with low-carbon emissions, thereby improving the cost competitiveness of green and blue hydrogen compared to fossil-derived gray hydrogen. Consequently, green and blue hydrogen utilized for ammonia, methanol, and oil refining, particularly near hydrogen hubs, are anticipated to reach cost competitiveness with gray hydrogen from 2030 onwards.[139]

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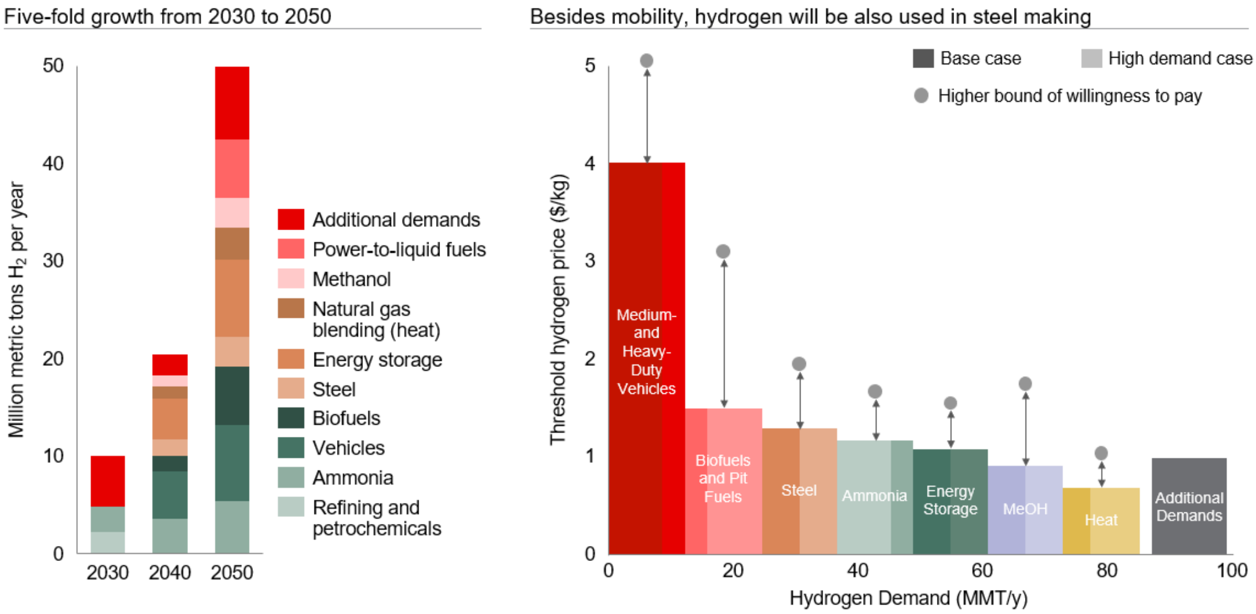
[138] https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/031_05_00.pdf

[139] BCG hydrogen demand model

Figure 5.46 US DOE domestic hydrogen demand forecast[140]



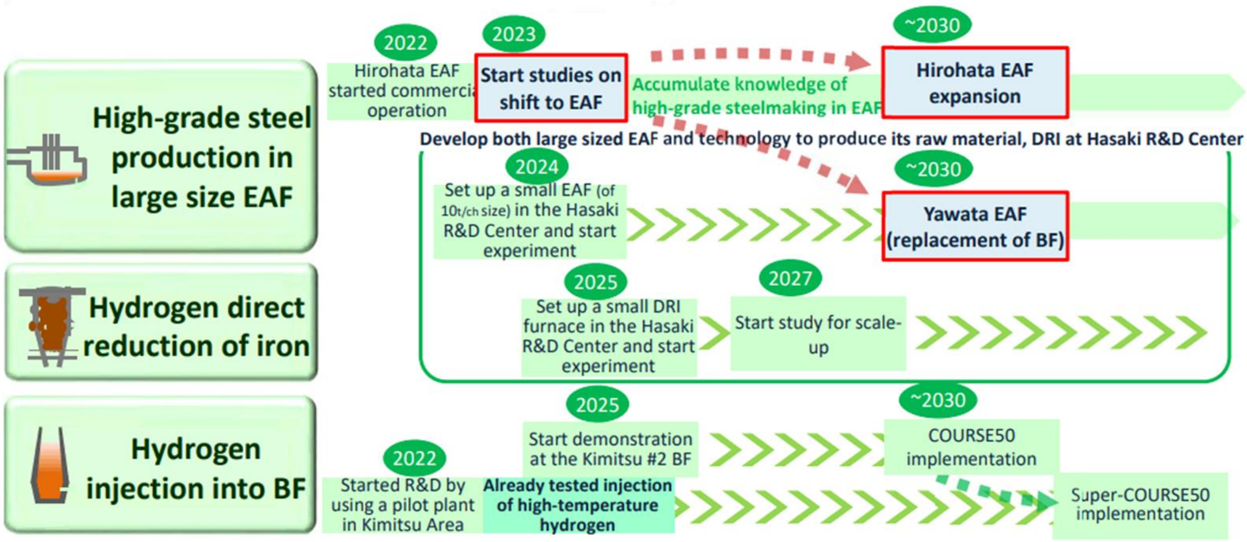
[140] https://www.energy.gov/eere/fuelcells/articles/doe-hydrogen-and-fuel-cell-remarks-fuel-cell-expo

Case Study: Hydrogen utilization in the steel industry

NIPPON STEEL

Nippon Steel Corporation is Japan's largest steelmaker and one of the world's leading steel producers with manufacturing bases in Japan and more than 15 countries around the world. In its Carbon Neutral Vision 2050, the company commits to reduce its Scope 1 and Scope 2 CO_2 emissions by 30% in 2030 compared with 102 million tons a year in 2013 and to become carbon neutral in 2050. In addition, the company sets a target for a 30% reduction in CO_2 emissions in 2030 compared with the 2013 baseline for its consolidated crude steelmaking companies with blast furnaces (BF) and electric arc furnaces (EAF) in Japan and abroad, by combining hydrogen injection into BF, manufacturing of reduced iron using hydrogen, application of large-sized EAF and carbon-offsetting initiatives such as CCUS. Hydrogen is used as a reducing agent instead of fuel in hydrogen injection into BF and manufacturing of reduced iron using hydrogen.

Roadmap of major initiatives

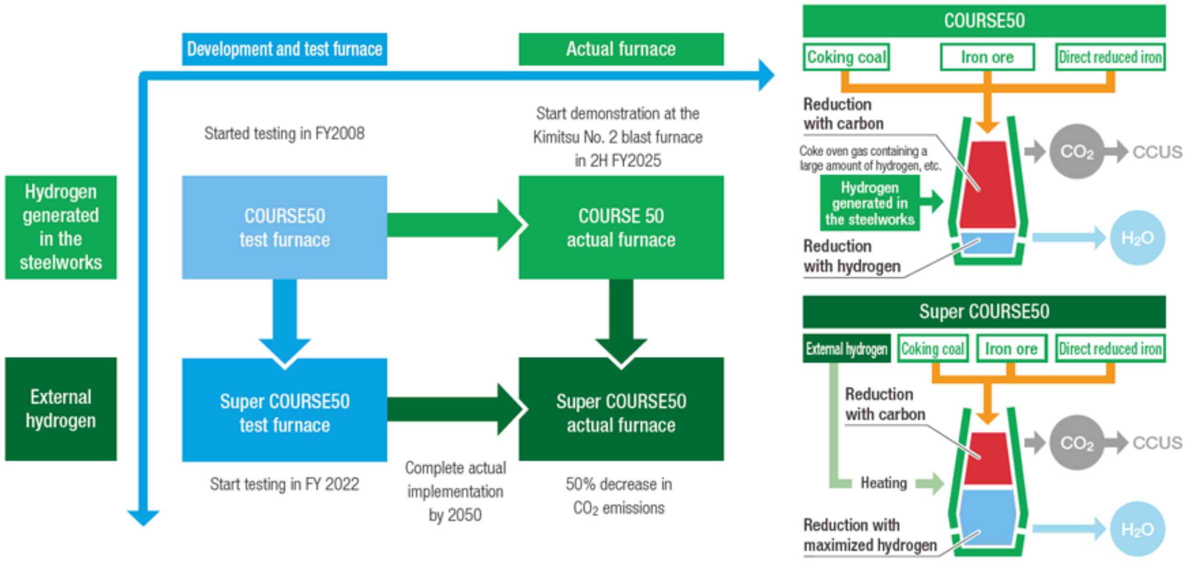


Hydrogen injection into BF

Currently, coking coal is used to reduce and dissolve iron ore (Fe_2O_3) into pig iron (Fe) while emitting CO_2 at the same time. By injecting hydrogen into a BF, the amount of coking coal can be reduced, and CO_2 emissions can be partially replaced with water (H_2O) emissions. COURSE50,[141] using hydrogen generated inside steel mills) started in 2008, and SuperCOURSE50, using outsourced hydrogen injection, is also underway for further CO_2 emission reductions. Both COURSE50 and SuperCOURSE50 are combined with CCUS to manage the remaining CO_2 emissions.

COURSE50 is a project supported by NEDO, in which Japan's three BF steelmakers (Nippon Steel, JFE Steel, and Kobe Steel) and Nippon Steel Engineering are engaged in large-scale joint development. Government support has started for research and development of these large-scale projects, with "hydrogen generated inside steel mills" receiving a JPY 14 billion subsidy (business scale of JPY 35.3 billion) and "outsourced hydrogen usage + utilization of CO_2 from the BF exhaust gas" receiving JPY 121.4 billion (business scale of JPY 291.8 billion) under the Green Innovation Fund.

[141] CO_2 Ultimate Reduction System for Cool Earth 50 (COURSE50) Project



Nippon Steel is working on hydrogen injection into BF in its East Japan Works Kimitsu Area (Chiba Prefecture), the company's core steel mill. In February 2023, Nippon Steel announced the actual demonstration test of hydrogen-rich gas injection technology using hydrogen generated inside the steel mills (COURSE50). The company will start using the demonstration facility in preparation for the demonstration test in January 2026. Using the actual BF of 4,500m^3 which is close to the final target and an unprecedented scale in the world, the company aims for a 10% CO_2 emissions reduction + 20% reduction with CCUS. In addition, the company plans an actual implementation of 1 – 2 units by FY2030 and targets to complete the implementation of Super COURSE50 by FY2050, projecting a more than 50% reduction in CO_2 emissions.

As hydrogen injection into BF is a new technology, SuperCOURSE50 has technical challenges. The first one is to ensure high temperatures. Since reduction with hydrogen is endothermic, the injection of preheated hydrogen is needed in addition to hot air in the conventional BF process (over 1,300℃) to supply heat. Nippon Steel is currently developing a technology to inject a large amount of hot flammable gas into BF. The second challenge is the need to ensure ventilation. By substituting hydrogen for solid coke, the iron ores adhere to each other, making the reducing gas less permeable. For this reason, the use of coke is still needed, and a combination with CCUS is required to offset CO_2 emissions. The third challenge is the need to scale up the experimental BF (12m^3, 30t/day) by three hundred times to the size of the actual BF (5,000m^3, 1,000t/day). Same as COURSE50, scaling up of SuperCOURSE50 also needs verification. Since SuperCOURSE50 requires outsourced hydrogen, a stable and cost-effective procurement of outsourced hydrogen is needed. Hydrogen must be procured at JPY8/Nm3 to keep the manufacturing cost on par with current cokes.[142]

Hydrogen direct reduction of iron

Reducing iron ore to pig iron without dissolution is called direct reduction, whereas the current process using natural gas (CH_4) exhausts reduced iron (Fe), CO_2, and H_2O. Using 100% hydrogen instead of natural gas to theoretically eliminate CO_2 emissions is a 100% hydrogen-fueled direct reduction process.

[142] Estimation by The Japan Iron and Steel Federation

Hydrogen direct reduction of iron is also supported by NEDO; JPY 34.5 billion is subsidized by the Green Innovation Fund Projects (business scale of JPY 72.4 billion). Hydrogen direct reduction of iron is in progress at Nippon Steel Hasaki R&D Center (Kamisu, Ibaraki Pref) and JFE Steel East Japan Works Chiba Area, in collaboration with JFE Steel and The Japan Research and Development Center for Metals (JRCM).

The technology is still in its experimental phase; tests using a small-scale test shaft furnace (1t/hour) are scheduled at Hasaki R&D Center in FY2025, followed by a scaling-up demonstration in FY2027 aiming for a 50% or more CO_2 reduction compared with the current BF process, and a complete implementation of 100% hydrogen direct reduction of iron by 2050.

Same as hydrogen injection into BF, hydrogen direct reduction of iron also has technical issues. Since hydrogen reduction is endothermic, heating is required. Nippon Steel is currently developing a technology to inject a large amount of hot flammable gas. In addition, the powdering of raw material pellets and sticking of produced iron pellets occur at the shaft furnace when reducing pellets, which allows only high-purity iron ore raw materials (10% of commercially available ores) to be used for the process. The company is developing an operating technology to overcome the constraints on raw materials.

Since direct reduction also uses outsourced hydrogen, a stable and cost-efficient procurement of outsourced hydrogen is required here as well.

While both hydrogen injection into BF and hydrogen direct reduction of iron require further development, concrete actions have been taken toward the implementation of target technologies including the identification of technical issues and financing, and key milestones have been achieved with solid technical prospects for demonstration tests.

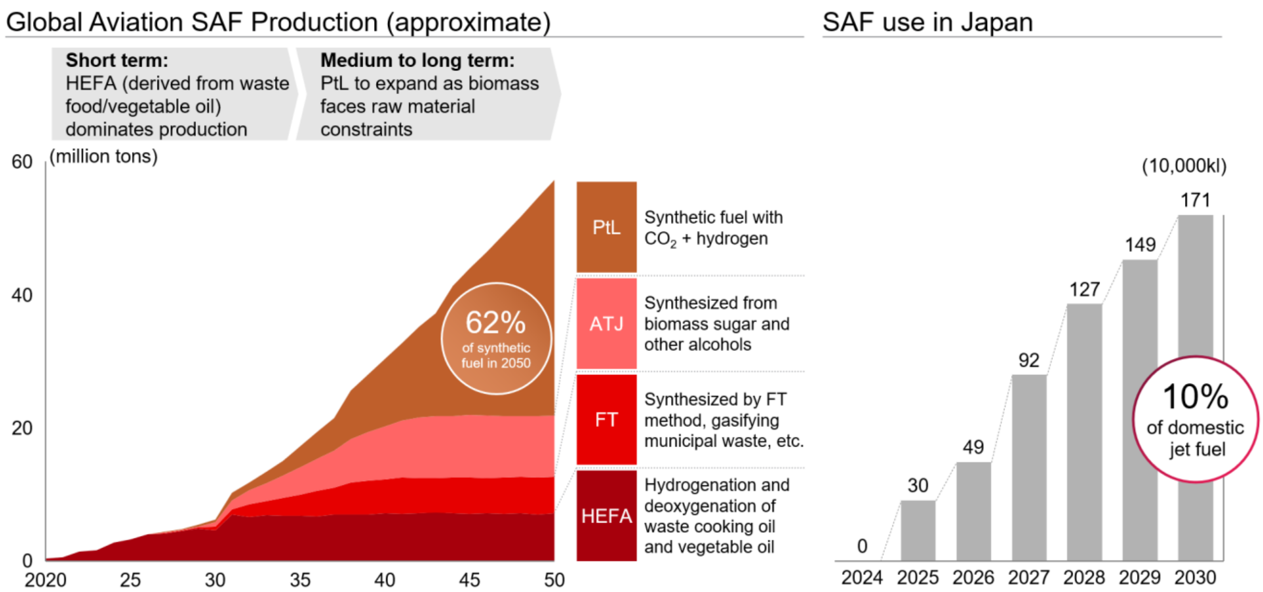
5.6.3.1.3 Utilization/demand: Mobility sector

Among transportation sectors, the decarbonization of international aviation and shipping, which are key to Japan's human and logistics connections, are high priorities. Electrification is generally not cost competitive, so hydrogen-based and biogenic fuels are the best current alternatives to fossil fuels, especially for large and long-distance international flights and ocean-going vessels, which are difficult to electrify.

In the aviation sector, the International Civil Aviation Organization (ICAO) in 2022 set a target of Net Zero carbon emissions by 2050 for global aviation. As short to mid-term measures, ICAO lists four main streams: technology, operations, sustainable aviation fuels (SAF), and Net Zeroinitiatives[143] ICAO also has published a SAF deployment scenario for 2050 (Figure 5.47). Biofuels (HEFA/FT/ATC), which are technologically mature and cost competitive in the short term, and synthetic fuels (PtL), which will expand in supply in the medium to long term, are expected to be introduced. The efforts of the Japanese government and Japanese companies in relation to SAF are in line with those of the international community.

In Japan, the Ministry of Economy, Trade, and Industry's "Public-Private Consultative Meeting to Promote the Introduction of Sustainable Aviation Fuel" has indicated that 10% of jet fuel consumption should be replaced by SAF by 2030. The government is considering regulation that would require oil distributors to introduce SAF for fueling international flights and a subsidy support scheme for the establishment of an SAF supply chain.

Figure 5.47 Global (ICAO Global SAF Adoption Scenarios to 2050) and Japan's SAF introduction outlook[144]



Japan Airlines (JAL) has announced a commitment to replace 1% of its total fuel loadings with SAF in FY2025 and 10% in FY2030 and estimates that it will need to secure 400,000-500,000 kl of SAF to achieve its goal. As part of these efforts, JAL is investing in US-based Fulcrum BioEnergy, Inc., which produces SAF from general waste. The investment is being made jointly with the Overseas

143 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO%20ENV%20Report%202022%20F4.pdf

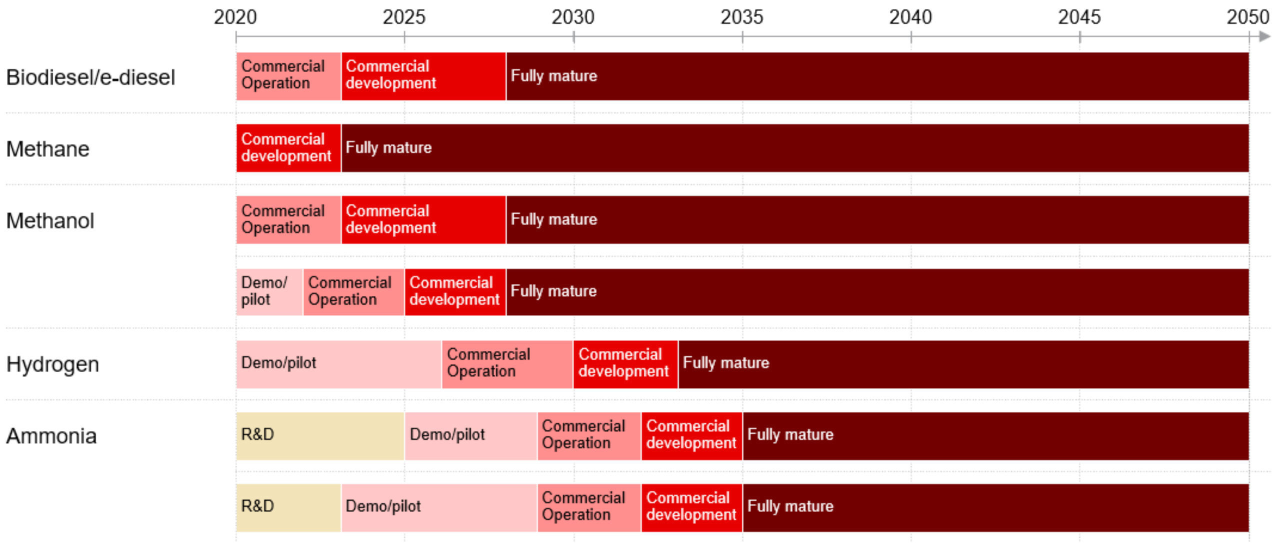
144 https://www.icao.int/Meetings/Stocktaking2021/Pages/default.aspx and https://www.meti.go.jp/shingikai/energy_environment/saf/pdf/003_07_00.pdf

Transportation and Urban Development Business Support Organization, Inc., and Marubeni Corporation (see JAL case study).

Securing a stable supply of SAF is often an issue, and Oji HD is conducting a demonstration project to supply bioethanol (one of the raw materials for SAF) from woody biomass, a new feedstock, to establish manufacturing technology and supply to the domestic market (see Oji HD case study).

In marine transportation, the International Maritime Organization (IMO) has published a forecast of the technological maturity of international shipping fuels for the year 2050 (Figure 5.48). Methanol- and methane-fueled vessels will be commercialized and mature in the 2020s, and hydrogen- and ammonia-fueled vessels are expected to be commercialized by the mid-2030s. The use of these new fuel vessels is expected to rise to meet the IMO's emissions reduction targets of at least 50% by 2050 from 2008 levels. Recent decisions to include emissions from international maritime transport in the EU Emissions Trading System[145] encourage the shipping industry to expedite the commercialization of new-fuel vessels.

Figure 5.48 IMO Forecast of readiness and availability of candidate fuel marine internal combustion engine technologies[146]



Nippon Yusen (NYK) is working on a project to develop ammonia-fueled ammonia carriers to reduce CO_2 emissions over their lifecycle. The timeline is for completion of domestic vessels in 2024 and ocean-going vessels in 2026 (See NYK case study).

[145] For the shipping sector, the Paris Agreement only covers reduction targets and measures relating to domestic maritime transport. The reduction of emissions from international maritime transport have been discussed at the IMO. In April 2023, the EU adopted maritime transport in its emissions trading system (EU-ETS) in which owners/operators of over 5,000 gross ton of ships regardless of jurisdiction of the flags will be required to purchase emissions allowances equivalent to (i) 100% CO_2 emissions when ships are at berth in EU ports and all emissions from voyages within the EU, and (ii) 50% of the CO_2 emissions from voyages starting or ending at EU ports.

[146] https://wwwcdn.imo.org/localresources/en/MediaCentre/WhatsNew/Documents/MEPC80.INF10.pdf

Case Study: SAF utilization in aviation

Japan Airlines (JAL), Japan's leading full-service carrier and member of the oneworld alliance, aims to achieve Net Zero emissions in 2050 under a 1.5 degrees Celsius scenario and a 10% reduction in total emissions in FY2030 compared to FY2019. The pillars for achieving this goal include upgrading to more fuel-efficient aircraft, devising new operations, and utilizing SAF (Sustainable Aviation Fuel). This case study introduces various initiatives related to the use of SAF.

Use of SAF

SAF is a fuel that significantly reduces CO_2 emissions throughout its lifecycle, from the production and collection of raw materials to manufacturing and combustion, compared to conventional fuels. It is used in mixture with traditional fossil fuels. The feedstock for SAF includes biomass, used cooking oil, vegetable oil, and garbage. In the future, growth in SAF may be derived from exhaust gases and atmospheric CO_2. In line with emission reduction targets by CORSIA, JAL has set a target of replacing 1% of its total fuel consumption with SAF by FY2025 and 10% by FY2030.

Challenges and collaboration in industry

In October 2021, JAL developed and disseminated a "Joint Report" with ANA, a competing full-service carrier in Japan. The report examines the utility and requirements of SAF, summarizes the current status of the fuel's production, distribution, and utilization, and considers the impact on other countries and future generations, which are the key topics in the Japanese aviation industry. JAL and ANA then presented their commitment to infrastructure investment and collaboration with all sectors involved in air transportation.

In March 2022, JAL and 15 other companies established ACT FOR SKY, a voluntary organization for the commercialization of domestically produced SAF, to identify issues and disseminate information across industries for the utilization of SAF. Furthermore, the Public-Private Council for the Promotion of SAF Introduction has foster collaboration between industry and the public sector. Since April 2022, the Ministry of Economy, Trade and Industry, Ministry of Land, Infrastructure, Transport and Tourism, and other government agencies and aviation players have repeatedly discussed technical and economic issues for SAF introduction based on the GX Basic Policy. In May 2023, an interim report was released on the regulatory aspects of setting SAF supply and usage targets, as well as on government support policies such as tax incentives and subsidies for the supply of SAF.

JAL's own efforts

JAL is investing in manufacturers to secure SAF. In September 2018, JAL, the Overseas Transportation and Urban Development Business Support Organization, Inc., and Marubeni Corporation, jointly acquired shares of US company Fulcrum BioEnergy, Inc. Fulcrum BioEnergy is developing a process to manufacture SAF from general waste that would otherwise be sent to the landfill. Using SAF supplied by the company, JAL plans to reduce CO_2 emissions on its flights to North America.

In March 2023, ANA and ITOCHU established a contract with ITOCHU Corporation for the procurement of SAF in Japan. The latter has been procuring SAF manufactured by Neste OYJ of Finland. A part of the procured SAF is already in use on flights to and from Central Japan International Airport. The SAF procured under this contract will also be used at Haneda and Narita airports in the future.

With these SAF procurement efforts, the introduction of energy-efficient aircraft, and carbon offsetting, a sustainable charter flight with fuel-based net-zero CO_2 emissions operated between Tokyo and Okinawa in November 2022. JAL intends to continue expanding the use of SAF in the future, in conjunction will support securing SAF supply.

Case Study: SAF production by a large paper manufacturer

OJI HOLDINGS

Oji Holdings Corporation (Oji HD) is the largest Japanese paper manufacturer offering a wide range of businesses from its origins in paper manufacturing to Household and Industrial Materials, Functional Materials, Forest Resources and Environment Marketing Business, and Printing and Communications media business. Oji HD is a global company with over 100 production sites and sales offices in Japan and overseas. It owns forests totaling 188,000 ha in Japan and 385,000 ha in six countries overseas (of which 256,000 ha are production forests) and has publicly announced its Purpose: Grow and manage the sustainable forest, develop and deliver the products from renewable forest, and Oji will bring this world a brighter future filled with hope. Under its Environmental Vision 2050, the company aims to reduce greenhouse gas (GHG) emissions to virtually zero by 2050, with an interim target of 70% GHG emissions in FY2030 compared to FY2018. Oji HD focuses on reducing GHG emissions and increasing the forest's ability to absorb CO_2 to achieve these goals. In addition to improving energy efficiency, switching fuels of coal-firing boilers, renewable energy generation, and using wood and black liquor are promoted to reach net zero. In addition, the company is seeking new business opportunities toward a carbon-neutral society. This case study focuses on bioethanol production from woody biomass as one of these opportunities.

Bioethanol production for possible use as SAF

In preparation for a carbon-neutral society by 2050, there is a possibility that the momentum to produce from biomass what was previously made from petroleum will accelerate, but at the same time, there are issues such as competition with the food supply. Woody biomass is a representative example of inedible biomass that exists in large quantities on the earth. Oji HD is developing new wood-derived materials using its own production forests, with a particular focus on ethanol, which can be used as a fuel and in the manufacture of basic chemicals, and on sugar solutions, which are a key raw material for Biomanufacturing.

Woody biomass is an alternative source of replacing fossil fuels in transportation, industry, and power generation, while effectively using residual lumber and forest thinnings that cannot be used for lumber production. It also uses liquid wastes, a byproduct of pulp and paper manufacturing. For ethanol, the company was selected for NEDO's "Comprehensive development and demonstration project for cellulosic ethanol production systems" until 2018 with ENEOS and has accumulated technological knowhow.

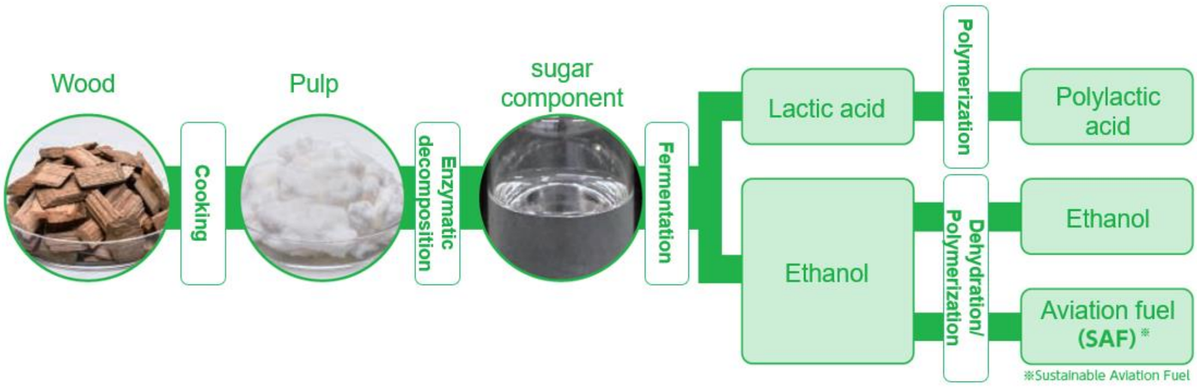
While ethanol derived from woody biomass can avoid competition with food, unlike ethanol derived from sugarcane or corn, it is challenging to decompose the raw material, resulting in high production costs. Oji HD is trying to address this by integrating pulping technology that can fully utilize the oil (lignin) contained in wood as biomass energy, and a process that reuses the enzymes needed to break down the pulp and the yeast needed to convert it into ethanol.[147]

In May 2023, Oji HD installed a pilot production facility for producing bioethanol from woody biomass and sugar solution at the Oji Paper Yonago mill (Yonago City, Tottori Prefecture). Its operation, expected in the second half of FY2024, will produce up to 1,000 kl/year (equivalent to 820 t/year) of

[147] https://www.eneos.co.jp/company/rd/hommoku_insight/2019/202001_06.html

ethanol. The production of 6,000 tons/year of wood chips and 3,000 tons/year of wood pulp as raw materials for ethanol production is also expected. The company will expand its facilities to produce 100,000 kl/year of ethanol in 2030.[148]

Woody biomass utilization process



Oji HD envisions this ethanol from woody biomass as a source of next-generation sustainable aviation fuel (SAF). While waste cooking oil, crops, and crop residues are often used as raw materials for producing SAF, production from the inedible wood fiber is an alternative option to avoid competition for food crops.

Oji HD owns 573,000 hectares of forests in Japan and overseas, of which 432,000 are for sustainable timber production, and 141,000 are for environmental conservation and biodiversity in watersheds. The "Environmental Action Program 2030" set by Oji HD aims to expand production forests overseas from the current 250,000 to 400,000. Wood grown in production forests can be used not only as a raw material for papermaking but also as a raw material for new wood-derived materials under development as biomass fuel. The company plans to further increase the supply of biomass fuel in the future, in conjunction with efforts to increase the production of fuel chips from unused wood resources in Japan.

148 News Release-Oji Group installs pilot wood-derived ethanol/sugar solution equipment (ojiholdings.co.jp)

5.6.3.2 Fuel transportation

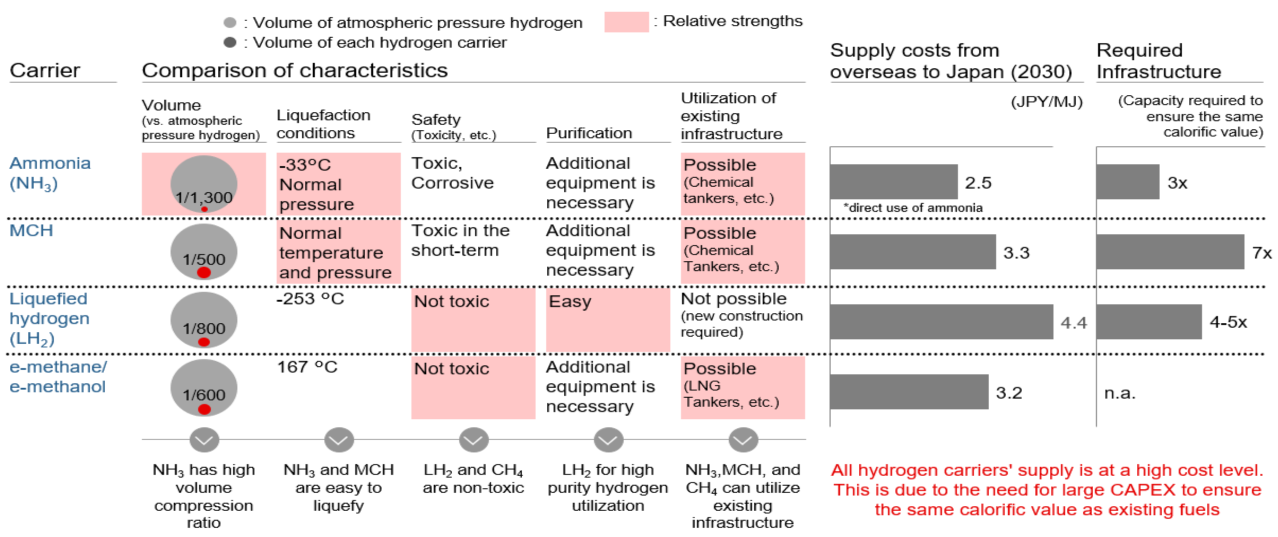
Japan's large-scale hydrogen supply chain will cross borders in the years before 2030, amid upstream fuel production overseas and downstream demand/utilization in Japan. Marine transportation technology (carriers) will be necessary for midstream fuel transportation connecting upstream and downstream.

There are four major potential hydrogen carrier technologies: Ammonia, Methylcyclohexane (MCH), Liquefied Hydrogen, and e-methane/e-methanol.

- **Ammonia**: Hydrogen can be converted and transported as ammonia and then cracked back to hydrogen if not used directly in an ammonia application such as feedstock for fertilizer production.
- **MCH**: Hydrogen can be transported at room temperature and pressure by adding a medium such as toluene or benzyl toluene. Existing transportation and cargo handling infrastructure such as tanks can be utilized.
- **Liquified Hydrogen**: Hydrogen is liquified and transported. Depending on the application, the hydrogen is either re-gasified and injected in the local gas/H_2 pipeline or trucked/railed/barged as liquid H_2 to the end user. Liquified H_2 is stored at -253 degrees Celsius. Long-term storage is not cost effective due to boil-off issues.
- **e-methane (synthetic fuel)**[149]: Hydrogen and CO_2 are synthesized and transported at -167 degrees Celsius. Existing transportation and cargo handling infrastructure such as LNG tankers can be used.

Each carrier has different technical characteristics, and the economic rationale varies depending on the use at the demand location. Whichever hydrogen carrier becomes the mainstream, there will be costs associated with building infrastructure and transportation (Figure 5.49). Japan will aim for deployment of diverse technologies rather than narrowing down to a single hydrogen carrier technology.

Figure 5.49 Major carrier characteristics/cost comparison[150]



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[149] Biofuels can be converted to methane/methanol and transported, but methane/methanol as a transport carrier is often synthetic.

[150] In a case where ammonia is converted to hydrogen through ammonia cracking, there are additional costs.
https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/20230104_1.pdf
https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/002_01_00.pdf

In contrast to Japan, Europe, and the US can produce hydrogen within their own countries or in surrounding regions. Pipelines will be the primary means of transportation. Still, the broader aims are similar in Japan, Europe, and the US.

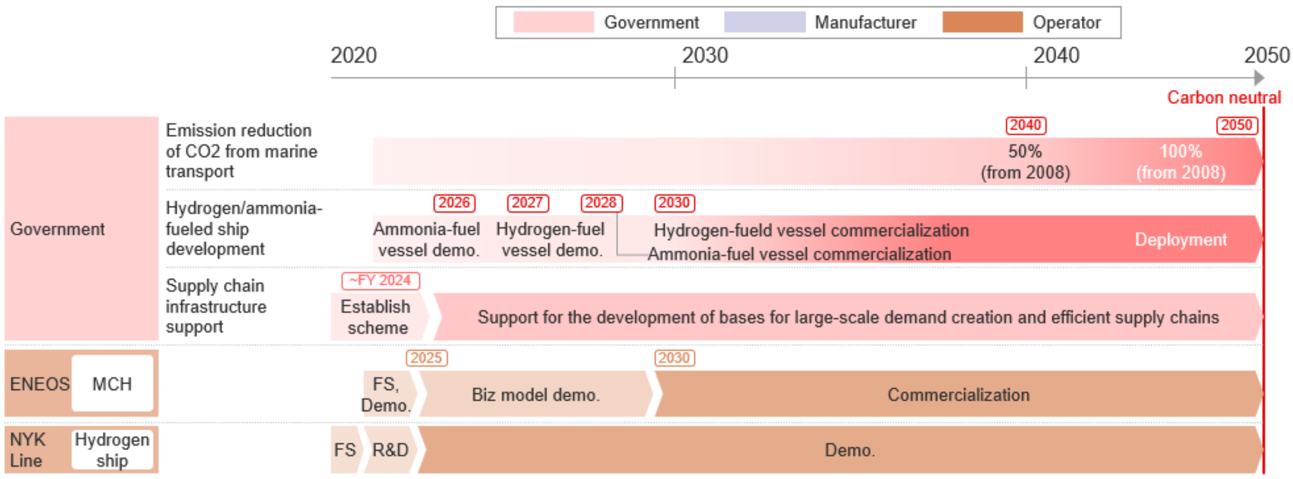
In shipping, Japan aims to switch from heavy fuel oil to ammonia or synthetic methane. By promoting decarbonization through hydrogen-based and biogenic fuels, in parallel with the development of hydrogen carriers, Japan will achieve emissions reductions across Scopes 1,2, and 3. In 2023, IMO adopted a revised strategy which targets Net Zero close to 2050 and reduction of at least 40% by 2030 from 2008 levels.[151]

The GX Basic Policy targets demonstration of ammonia- and hydrogen-fueled ships in 2026 and 2027 and commercialization by 2028 and 2030 or later respectively (Figure 5.50).

Shipbuilders and shipping operators are working to create transportation networks for hydrogen-based and biogenic fuels in line with these policies. In addition, the Japanese government's offer of compensation for the price difference between hydrogen and fossil fuels is intended to lower the selling price, so subsidies are provided for the supply chain, including transportation before that point. ENEOS is developing renewable hydrogen production, MCH production, transport, and dehydrogenation in Australia. It plans to evaluate feasibility in 2025 and proceed to commercialization in 2030 (see ENEOS case study).

In transportation, the NYK is focusing on MCH and ammonia carriers, the former already in operation and the latter to start operation in the late 2020s, aiming for 20% commercial operation of ammonia at JERA's Hekinan thermal power plant (see NYK case study).

Figure 5.50 Public-private roadmap for establishing fuel transportation in Japan



[151] https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx

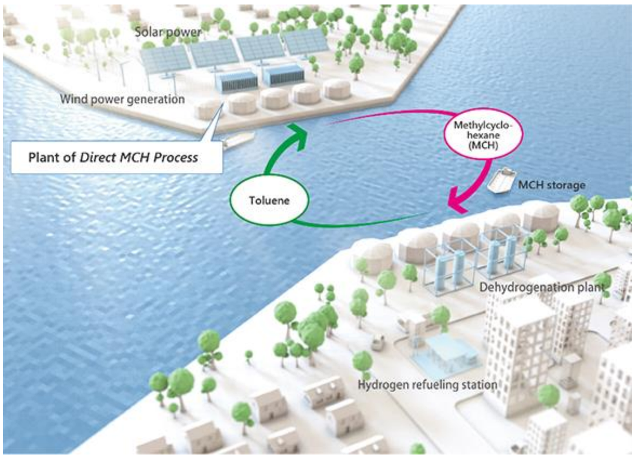
Case study: Marine transportation of MCH

ENEOS Group is engaged in the energy business, from upstream oil development to oil refining and sales and the metals business, from development of non-ferrous metal resources to the manufacturing and sales of non-ferrous metal products. ENEOS Group announced its Carbon Neutrality Plan in May 2023, sharing its long-term vision of taking on the challenge of both a stable supply of energy and materials and achieving a carbon neutral society. In order to achieve this, they aim to reduce company greenhouse gas (GHG) emissions through optimizing their manufacturing and businesses and CCS and natural absorption, as well as contributing to reducing GHG in wider society by the energy transition to hydrogen and carbon-neutral fuels and promoting a circular economy. This case study focuses on ENEOS' MCH business in relation to hydrogen supply.

MCH

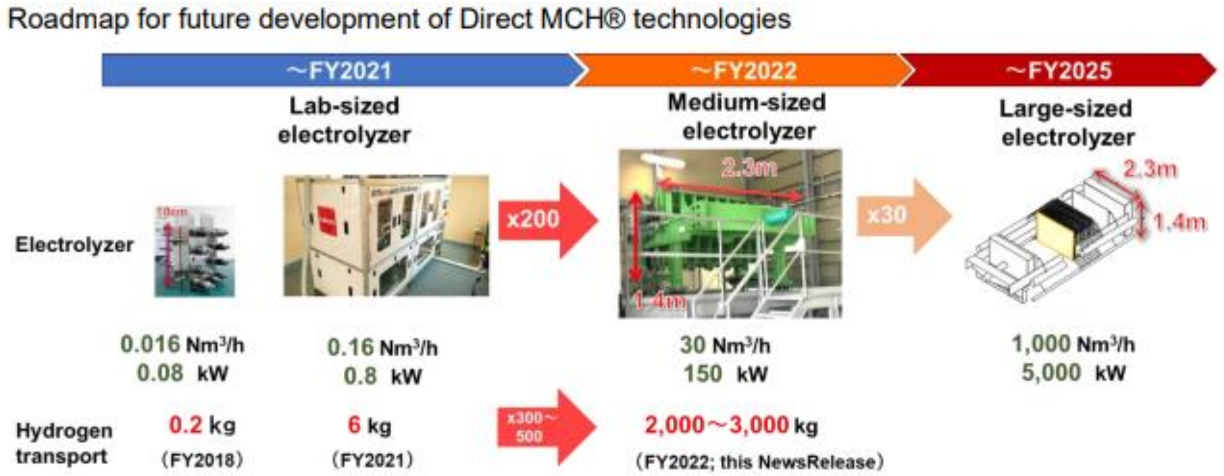
For Japan, securing a stable and economical source of hydrogen is important, and to this end, ENEOS is collaborating with local businesses in Australia, Southeast Asia, and the Middle East. In countries with cost-competitive sources of renewable energy, competition for a stake in green hydrogen is increasing. Therefore, it is important for Japanese companies like ENEOS with supply chain technology and knowhow to lead upstream development of hydrogen sources.

ENEOS is focusing on Methylcyclohexane (MCH) as a hydrogen carrier. MCH is composed of liquid made by the chemical reaction of hydrogen to toluene. MCH contains over 500 times more hydrogen by volume than hydrogen gas, so it can carry hydrogen more efficiently. In addition, MCH is a liquid with petroleum-like characteristics, so it can be used in existing petroleum infrastructure. From the transported MCH, hydrogen and toluene are extracted at demand sites such as Japan and toluene can be reused for another transport.



In conventional storage and transportation of hydrogen, hydrogen generated from water electrolysis was stored in tanks, and needed to be temporarily converted to MCH (a type of organic hydride) for transport. In 2019, through a joint project by four institutions: ENEOS, the University of Tokyo, Chiyoda Corporation, and Queensland University of Technology (Australia), the world's first technology verification of low-cost production of MCH by Direct MCH® in Australia and hydrogen extraction in Japan has been successfully completed. This will simplify the manufacturing process, including the MCH manufacturing plant and hydrogen tanks, and significantly reduce manufacturing costs.

A demonstration using Direct MCH® has already begun. ENEOS constructed a demonstration plant in Brisbane, Australia, to produce MCH. The 150-kilowatt-scale medium-sized electrolyzer (approximately 200 times larger than the electrolyzer used in the previous demonstration), which ENEOS recently succeeded in developing the technology for, consists of stacked electrodes with a surface area of 3 square meters. The electrolyzer increases efficiency in MCH production with electrodes that are nearly the largest used industrially. The demonstration plant will produce green MCH by combining the medium-sized electrolyzer with a 250-kilowatt solar power system in Queensland, which is ideal for solar power generation. With the aim of maximizing production efficiency, the plant will confirm the durability of the electrolyzer under subtropical conditions as well as develop optimal operation and control technologies for it when plant operation is adjusted to match fluctuations in solar power during the approximately eight-month-long demonstration period from February to September 2023. ENEOS will use the knowledge gained from this demonstration plant to develop a larger-sized 5 megawatt-scale electrolyzer (more than 30 times larger than the medium-sized electrolyzer used in this demonstration plant) for commercialization by FY2025.



In addition, ENEOS is involved in developing standards to further promote the use of hydrogen. ENEOS was selected to undertake the "Technology Development Project for Establishing a Competitive Hydrogen Supply Chain / Technology Development for Establishing a Large-Scale Hydrogen Supply Chain." ENEOS is investigating the properties of hydrogen for a wide range of industrial fuel applications, along with JERA, which is conducting an impact assessment of aromatic compounds in power generation applications. Both companies plan to investigate industry standardization of hydrogen properties for each application and compile them to create a hydrogen quality standards system.

Case study: Marine transportation of hydrogen carriers

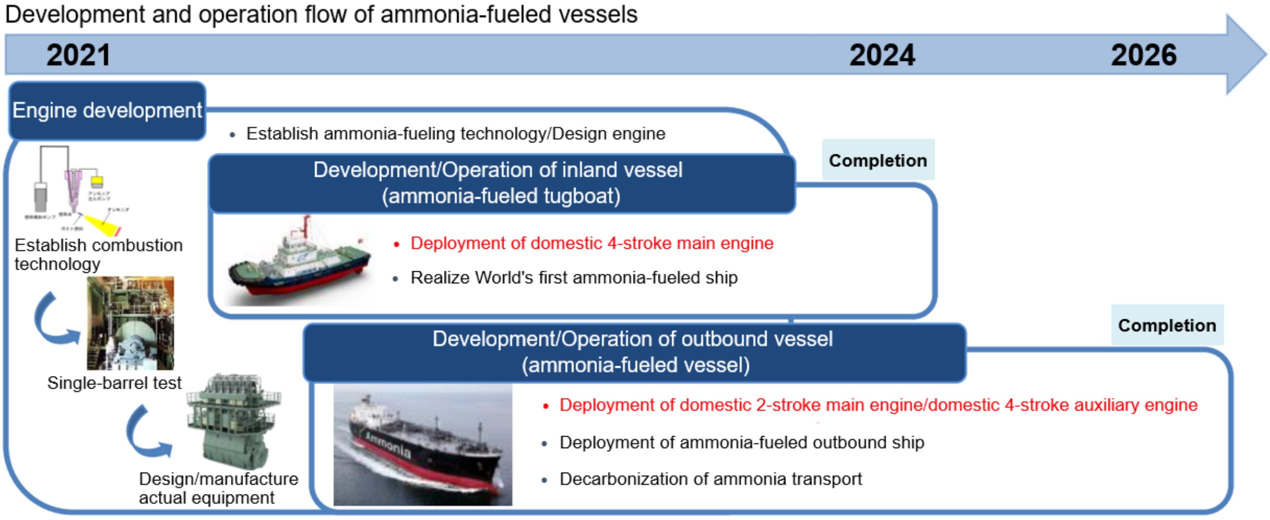
NYK is Japan's largest player in marine transportation, and has been expanding its activities as a comprehensive global logistics enterprise. With a fleet of over 800 vessels, including bulk carriers, car carriers, oil tankers, and LNG carriers, NYK has set a goal of achieving net-zero emissions by 2050. To achieve this target, NYK has identified research and deployment for hardware and fuel conversion, optimal operation, implementation of energy-saving technologies, and use of biofuels as key decarbonization levers. As a leading company in international transportation, NYK is committed to developing cutting-edge technologies to meet IMO reduction targets and regional regulations such as EU-ETS. This case study will focus on NYK's efforts to establish a supply chain for Japan's imports of hydrogen, ammonia, and other next-generation fuels.

<u>Next generation energy carriers</u>

In order to transport hydrogen at high volume overseas, hydrogen is first liquefied into carriers such as ammonia, MCH, liquefied hydrogen, and e-methane to compress its volume such that it is suitable for transport by large vessels. It is also necessary to develop tanks and other infrastructure at the ports to receive these vessels. NYK is specifically involved in both ammonia and MCH transport as well as development of zero-emission ships that run on low environmental load marine fuels, such as ammonia or hydrogen.

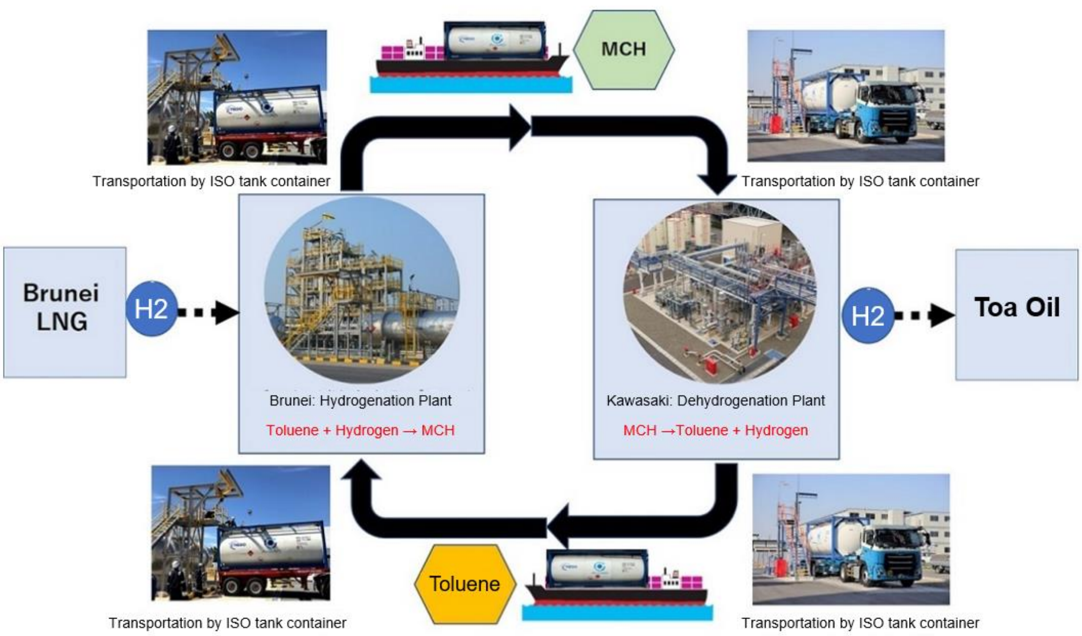
Ammonia Carrier

In 2022, NYK and JERA jointly signed a memorandum of understanding to study the transport of fuel ammonia to the Hekinan Thermal Power Plant, where JERA aims to begin using fuel ammonia in commercial operations in the late 2020s. The MOU stipulates the following: 1) development of an ammonia carrier, 2) establishment of a system for transporting and receiving fuel ammonia, 3) implementation of a propulsion engine using ammonia as fuel, and 4) study on how to approach related parties to formulate rules regarding ammonia.



MCH Transport

NYK is a member of The Next Generation Hydrogen Energy Chain Technology Research Partnership (other members: Chiyoda Corporation, Mitsubishi Corporation, and Mitsui & Co., Ltd.). The partnership is transporting MCH as part of the world's first international hydrogen demonstration experiment and has achieved stable operations in 2020. In this project, MCH will be produced from toluene and hydrogen in Brunei, transported by sea to Japan, and separated back into toluene and hydrogen. The hydrogen will be used in Japan, while the toluene will be returned to Brunei and reused to produce MCH.



Given the successful track record of this partnership, the partnership has signed an agreement with ENEOS Corporation to supply hydrogen produced in Brunei for use in its refinery decarbonization trials.

Ammonia-fueled vessel project utilizing the Japanese government's Green Innovation Fund

NYK is currently working on a project to develop ammonia-fueled vessels. The Green Innovation Fund's "Development of Ships with Domestic Ammonia Fuel Engines" project has received a total of JPY8.4 billion (with a total project size of JPY12.3 billion) for two initiatives: (1) developing an ammonia-fueled tugboat for coastal use and (2) developing an ammonia-fueled transport vessel for ocean-going operations. NYK is the lead sponsor, with additional participation from IHI Power Systems, Japan Engine Corporation, Nippon Shipyard, and Nippon Kaiji Kyokai. Engine development is scheduled to begin in 2021, with the aim of completing construction of the domestic vessel in 2024 and the ocean-going vessel by 2026.

Given the timeline needed for the development of ammonia-fueled vessels, NYK is also working on interim solutions ahead of other industry players. For example, in October 2020, NYK completed the development of LNG-fueled ships that can also make use of a range of alternate fuels such as bio-fuel and e-methane. Additionally, NYK is developing LNG-fueled ships that can be readily converted to use ammonia as fuel in the future and completed the conceptual design in 2022 in collaboration with MTI (NYK's subsidiary focused on technology R&D) and Elomatic Oy (a Finnish ship technology consulting company). NYK will proceed with the actual design with the shipyard and marine manufacturers, reflecting the results obtained in the concept design.

5.6.3.3 Fuel manufacturing

5.6.3.3.1 Fuel manufacturing: Hydrogen/ammonia manufacturing

There are three main production technologies for green hydrogen, used in hydrogen-based and biogenic fuels:

- **Alkaline Electrolysis Cell (AEC)** electrolyzes water using a strong alkaline solution of potassium hydroxide. The technology is mature, with advantages that include large-scale production and long service life. Still, a significant physical area is required for installation of equipment and there is vulnerability to fluctuations in the renewable energy output.
- **Proton Exchange Membrane (PEM)** electrolyzes pure water using rare metals such as titanium and platinum for the cathode and anode. In PEM, the hydrogen produced does not require purification and is flexible with respect to fluctuating power consumption, but the cost is high due to the use of rare metals. Although further improvements in efficiency are still in the development stage, the technology has been put to practical use over the past decade.
- **Solid Oxide Electrolyzer Cell (SOEC)** electrolyzes steam at 800-1,000 degrees Celsius (the heat source is assumed to be nuclear power plants or fuel cells). SOEC potentially can achieve higher electrolysis efficiency than AEC or PEM, but it is still in the research and development phase, with commercialization most likely in the 2030s.

Types of sustainable hydrogen and ammonia include green from renewable energy, blue from fossil resources plus CCS, pink from nuclear power, and turquoise from direct thermal cracking of natural gas. The carbon intensity of these various types varies depending on the production method.

From the perspective of resource availability and cost competitiveness, it is necessary to establish an international supply chain that utilizes not only domestic fuel production but also abundant overseas energy resources such as renewables. When establishing the supply chain, Japan should promote deployment of diverse hydrogen and ammonia production technologies, rather than a single technology. This will strengthen energy security and promote stable procurement through risk diversification.

To stabilize the supply of low-carbon fuel, Japan has set targets in its Basic Strategy for Hydrogen of 3 million tons per year in 2030, 12 million tons per year in 2040, and 20 million tons per year in 2050. As for hydrogen supply costs (CIF basis), the target is JPY30/Nm^3 (about JPY 334/kg) in 2030 and JPY20/Nm^3 (about JPY 222/kg) in 2050. Hydrogen with CO_2 emissions of 3.4 kg-CO_2e or less is recognized as low-carbon hydrogen. For ammonia supply costs (CIF basis), the target is in the upper JPY10/Nm^3 in 2030 in terms of hydrogen.

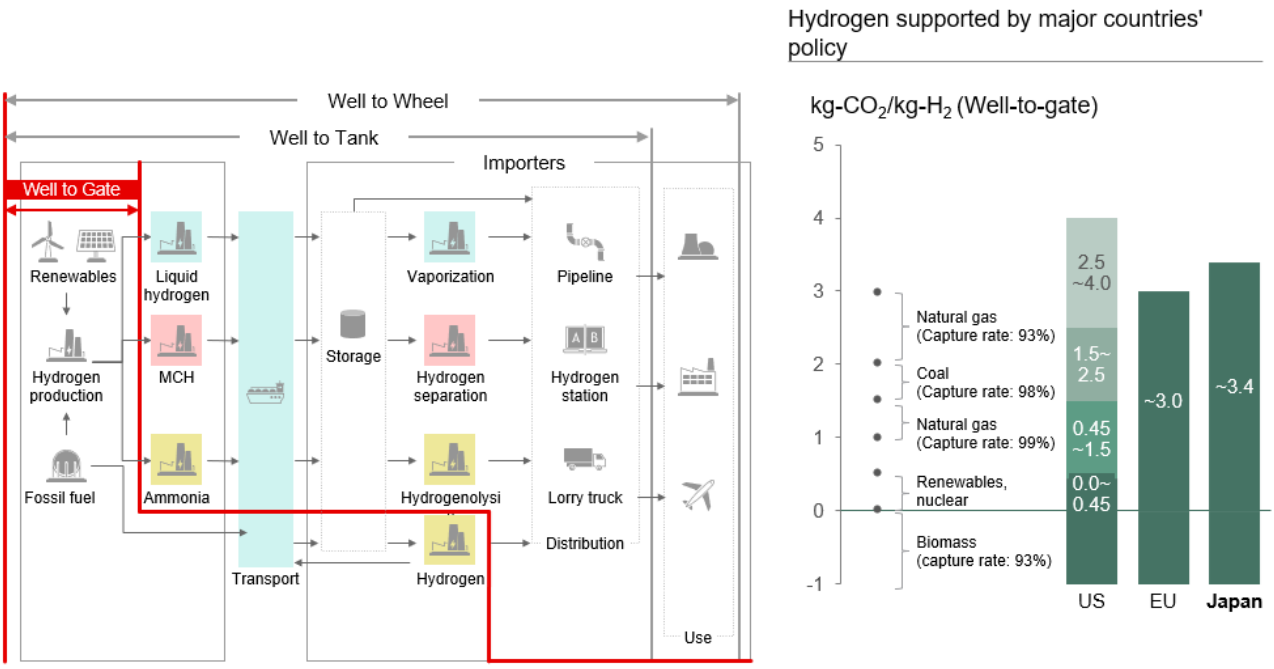
It is common in the EU, the US, and Japan to selectively support the production of low-emission hydrogen by setting thresholds based on CO_2 emissions, without specifically limiting the production methods for hydrogen. Also, these three countries have set thresholds at similar levels (Figure 5.51).

The low-carbon standard for hydrogen, in accordance with the International Partnership for a Hydrogen Economy (IPHE) calculation method, from well to production gate for 1kg of hydrogen production is set at 3.4kg-CO_2-e or less. The standard for gate-to-gate CO_2 emissions for 1kg of ammonia production is 0.84 kg-CO_2-e/kg-NH_3 or less. Similarly, the EU sets a threshold for hydrogen production of 3 t-CO_2/t-H_2 (reduction of 73.4% from grey hydrogen).

The US IRA promotes hydrogen production technologies with different incentives for different emissions thresholds. Specifically, a production tax credit (PTC) is weighted according to CO_2

emissions per kilogram of hydrogen produced (kg-H_2), with four levels: 1) 0.0-0.45 kg CO_2-e: \$3.0, 2) 0.45-1.5 kg CO_2-e: \$1.0, 3) 1.5-2.5 kg CO_2-e: \$0.75, and 4) 2.5-4.0 kg CO_2-e: \$0.6.

Figure 5.51 CO_2 emission threshold of policy-supported hydrogen production [152]



5.6.3.3.2 Fuel manufacturing: Synthetic fuels

Synthetic fuels are a type of hydrogen-based fuel produced by synthesizing hydrogen and CO_2 and include, but not limited to, e-methane as a gaseous fuel and e-methanol as a liquid fuel. Especially since e-methane has similar chemical compositions with those of natural gas, it can effectively utilize existing gas infrastructure, including pipes, storage tanks, tankers, and heat and power supply facilities such as boilers and turbines.

Japan has spent more than a decade and JPY1 trillion to develop its gas infrastructure in pursuit of both environmental gains and a stable energy supply. [153] Plans were made in 1972 to switch to natural gas, which emits zero sulfur oxide (SOx) and 30-40% less nitrogen oxide (NOx) than coal or oil and has higher calorific content and better energy efficiency. Natural gas, however, differs in calorie and composition from conventional city gas, which necessitates adjustment of gas appliances. Therefore, Japanese gas companies implemented a nationwide natural gas conversion operation. It took 16 years from 1975 to 1990 for Osaka Gas to complete this project. Up to 3,000 people worked on natural gas conversion, with a cumulative total of 4.4 million units converted and a total of 2,300 units of equipment converted. As a result, energy efficiency per unit was improved by a factor of 2.4 (from 18.8 MJ/m3 to 46 MJ/M3).

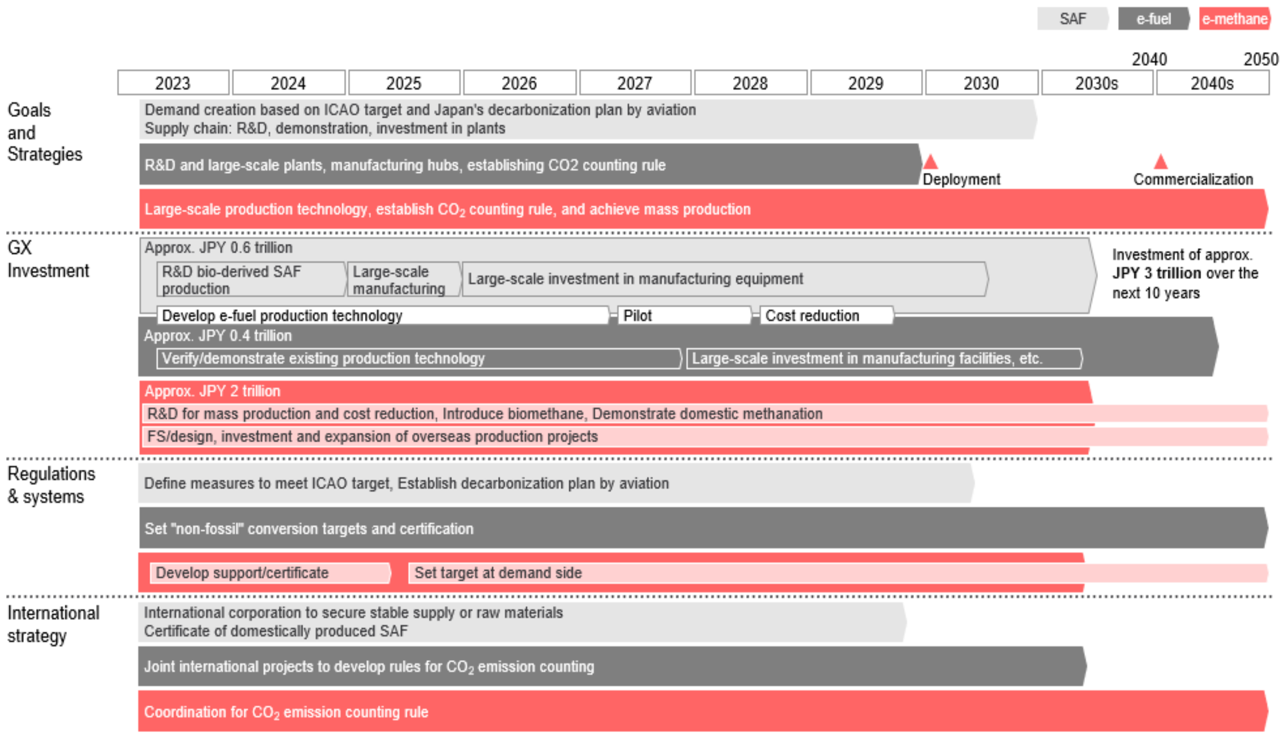
The calorific value of hydrogen, at approximately 12.8 MJ/m3, is about one-third that of natural gas. Therefore, the aforementioned task of rebuilding new infrastructure will be necessary, requiring

[152] IEA (2023), Towards hydrogen definitions based on their emissions intensity, IEA, Paris https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity, License: CC BY 4.0
https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/031_04_00.pdf
[153] https://www.gas.or.jp/kankyo/taisaku/toshigas/

several decades and financial commitments of several trillion yen. Therefore, e-methane, which has a high compatibility with existing infrastructure such as gas pipelines and gas appliances and offers the potential for early deployment and economic viability, will probably be needed in Japan.

In the GX Basic Policy, the Japanese government lays out a roadmap for promotion of carbon-recycling fuels, including e-methane. It plans to (1) establish large-scale production technology, (2) establish rules for CO_2 emissions, and (3) realize mass production and supply through large-scale financing commitments (Figure 5.52). In line with the roadmap, the government is discussing the introduction of financial incentives for e-methane through the Working Group to Study Gas Business System.[154]

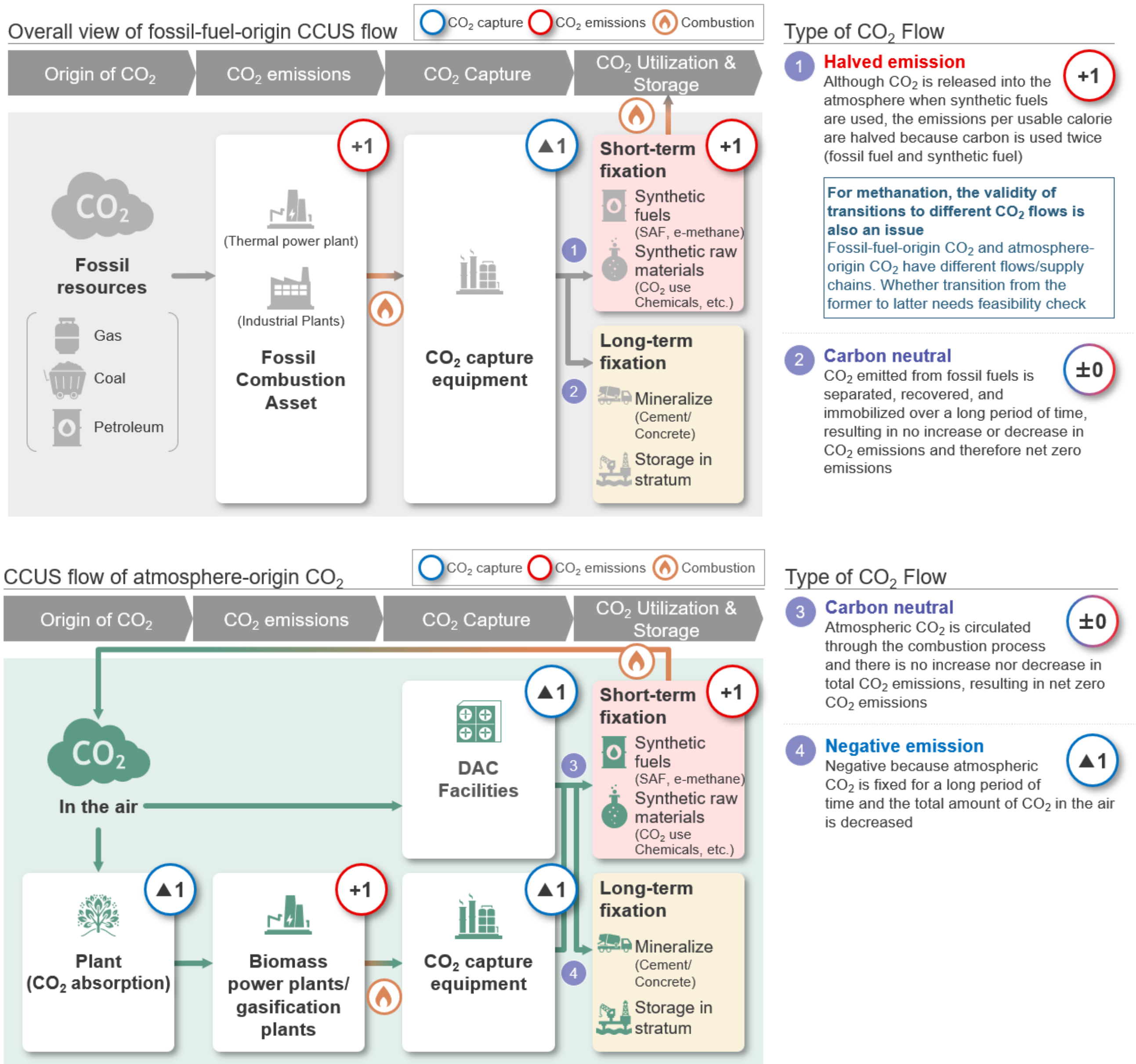
Figure 5.52 Roadmap for carbon recycling in GX Basic Policy (excerpt) [155]



There are two primary origins of CO_2: fossil-derived and bio- and atmospheric-derived. Fossil-derived CO_2 is often emitted from thermal power plants and industrial plants. Bio- and atmospheric-derived CO_2 is mainly captured at biomass power generation (BECC), direct air capture (DAC), and biomass and biofuels (Figure 5.53).

[154] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/gas_jigyo_wg/index.html
[155] https://www.meti.go.jp/press/2022/02/20230210002/20230210002.html

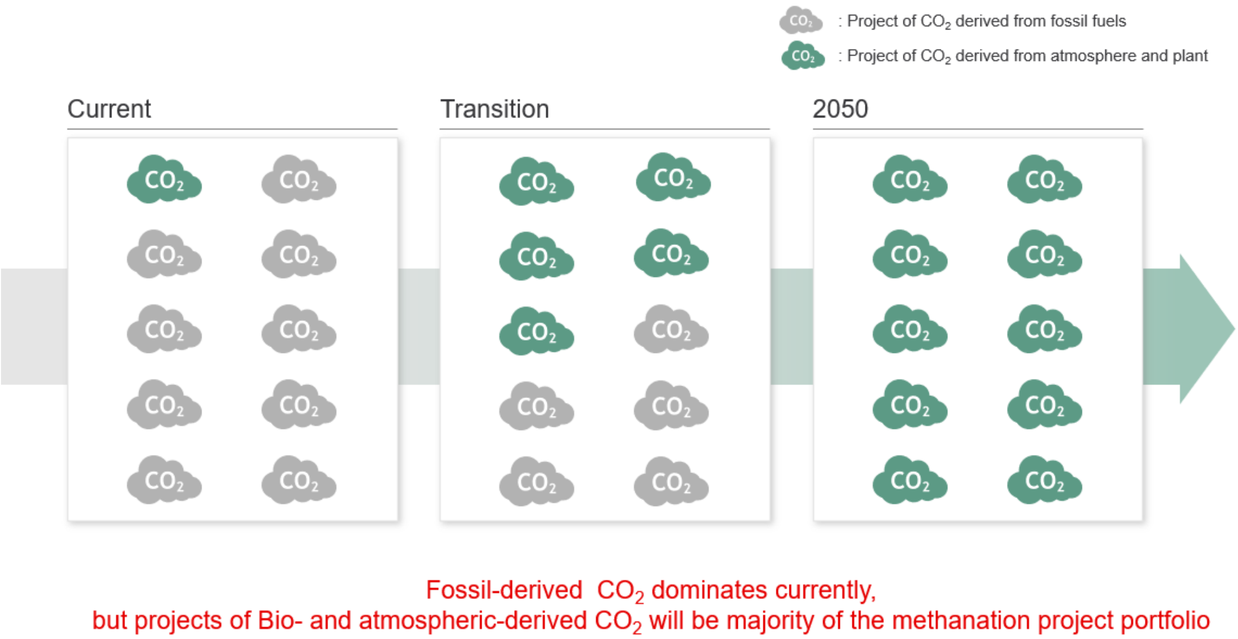
Figure 5.53 Flow of fossil-derived CO_2 and bio- and atmospheric-derived CO_2



In Japan, the direction in CO_2 resource utilization is to build fossil-derived CO_2 flows in the short term and bio- and atmospheric-origin CO_2 flows in the medium to long term. From the standpoint of economic viability of the process from CO_2 capture to utilization, as well as the energy efficiency of procuring large quantities of CO_2, it makes sense in the short term to utilize fossil-derived CO_2 with high concentrations. The resourceful use of fossil-derived CO_2 can reduce CO_2 emissions from usage of fossil fuels, making it a useful emissions reduction measure in the transition period.

We anticipate a gradual switch from fossil-derived CO_2 to bio- and atmospheric-derived CO_2 (Figure 5.54). This will be supported by technological development to enable stable procurement of bio- and atmospheric-derived CO_2 over the medium to long term. The use of bio- and atmospheric-origin CO_2 resources will also contribute to the creation of a carbon neutral society by 2050, since carbon neutrality can be achieved for the entire flow.

Figure 5.54 Transition of CO_2 sources



In Europe, the Renewable Energy Directive classifies origins of CO_2 resources.[156] It indicates that fossil-derived CO_2 for power generation will be recognized as a CO_2 resource until 2035, while fossil-derived CO_2 from industries other than power generation will be recognized as a CO_2 resource until 2040. CO_2 from bio- and atmospheric sources will be continuously recognized as a CO_2 resource. This is consistent with the direction of travel in Japan.

Since international rules for CO_2 counting are still being developed, the Japanese government and Japanese companies should actively participate in collaborative drafting efforts. They should also promote technology and business development relating to CO_2 resource utilization.

[156] https://energy.ec.europa.eu/system/files/2023-02/C_2023_1086_1_EN_ACT_part1_v5.pdf

Case study: E-methane supply by a Japanese company

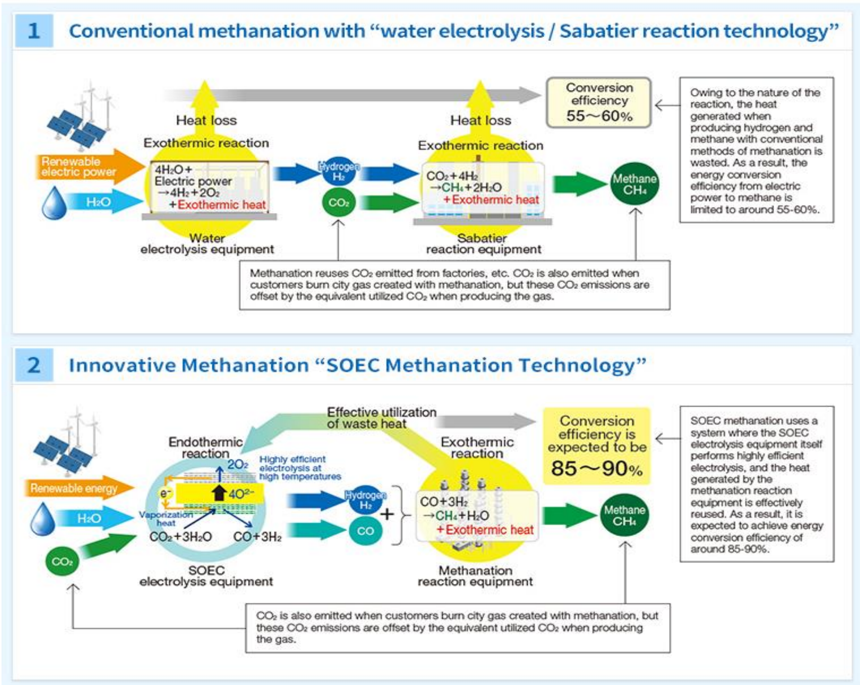
OSAKA GAS

Osaka Gas is one of Japan's leading gas companies and is committed to becoming carbon neutral by 2050. It has an interim goal of contributing 5 million kW to the diffusion of renewable energy by 2030, achieving a renewable energy ratio of approximately 50% in its domestic power business, alongside 10 million tons of CO_2 emissions reductions. Renewable energy and methanation are expected to be the primary means.

Methanation

Osaka Gas is working on R&D and building an overseas supply chain, aiming to introduce synthetic methane equivalent to 1% of gas sales volume by 2030 and 90% by 2050, and to achieve a price of JPY40-50/Nm3, which is equivalent to the current LNG price. In R&D, in addition to the existing Sabatier reaction, the company is working on innovative technologies such as SOEC and bio (e-methane production by biological reaction using biogas from sewage treatment plants). SOEC methanation technology uses renewable energy to electrolyze water and CO_2 with electrolysis equipment to generate hydrogen and carbon monoxide, which are then used to synthesize methane through a catalytic reaction, eliminating the need to procure hydrogen as a feedstock. In addition, electrolysis at high temperatures (approx. 700-800 degrees Celsius) can reduce the amount of renewable electricity required. Furthermore, since the waste heat from methane synthesis can be effectively utilized, it has the potential to achieve the world's highest energy conversion efficiency of approximately 85-90% compared to conventional methanation (approx. 55-60%) and is expected to significantly reduce the cost of synthetic methane production, of which renewable electricity and other resources account for a large proportion.

Comparison between conventional methanation and innovational methanation (SOEC Methanation)

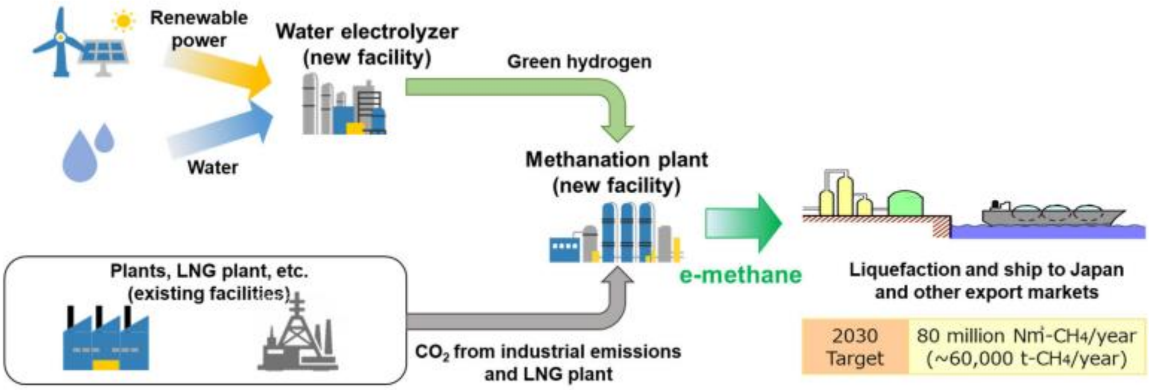


SOEC Methanation has been adopted by NEDO as an "innovative technology development for synthetic methane production". The project aims to establish SOEC methanation technology in

FY2030, with Osaka Gas, which has metal-supported SOEC technology[157] and gas synthesis catalyst and process technology, as the lead company, in collaboration with the National Institute of Advanced Industrial Science and Technology, which has world-class advanced fundamental technologies relating to SOEC and gas synthesis. Toshiba Energy Systems & Solutions Corporation, which has the technology to develop SOEC hydrogen production technology and large-scale electrolysis facilities, and universities with the world's most advanced research capabilities, are expected to participate in the project to bring together their technical capabilities in SOEC methanation and promote technological innovation. In addition, a lab-scale test (synthetic methane production scale of 0.1 Nm3/h, equivalent to two ordinary households) is scheduled to be conducted from FY2022 to FY2024, a bench-scale test (10 Nm3/h class, or 200 households) from FY2025 to FY27, and a pilot-scale test (400 Nm3/h class, or 10,000 households) from FY2028 to FY2030.

In addition to technological development and demonstration in Japan, Osaka Gas is conducting studies on multiple methanation projects in Australia, North America, South America, the Middle East, and Southeast Asia, where renewable energy is widely available. For example, in Australia, Osaka Gas collaborates with Santos, an Australian energy company operated in Australia, Papua New Guinea, Timor-Leste, and North America. In the project, e-methane is produced from CO_2 recovered from industrial exhaust gas and natural gas liquefaction plants, and green hydrogen is produced by electrolyzing water with renewable energy, which is liquefied at Santos and third-party LNG facilities for export to Japan and other countries. The scale of the e-methane production plant is expected to be 10,000 Nm^3/h class. The project is scheduled for detailed study from April 2023, with the basic design in 2024, the investment decision in 2025, and e-methane export in 2030 (approx. 60,000 tons/year). The company is also considering the use of CO_2 captured from the air (DAC) in the future.

Collaboration with Santos, Australia



In cooperation with Tokyo Gas, Toho Gas, and Mitsubishi Corporation, Osaka Gas is currently studying the export of e-methane produced in the US to Japan, with a target year of 2030. Louisiana and Texas have infrastructure such as connections to other regions via hydrogen and CO_2 pipelines, extensive solar and wind power generation capacity, a well-developed power grid network, and the existing Cameron LNG facility (export base). Four Japanese companies and overseas partners will produce e-methane in the US. Mitsubishi Corporation will liquefy and transport it, and gas suppliers will supply a total of 180 million Nm3/year (of which 60 million Nm^3/year will be supplied by Osaka Gas) in Japan by 2030. Negotiations and agreement on CO_2 counting rules between the U.S. and Japan are necessary for the realization of this project, as well as policy support for businesses. The companies are now working together to secure governmental support.

[157] A technology suitable for low cost and scale-up, which reduces the amount of special ceramics used in SOEC by about 10%.

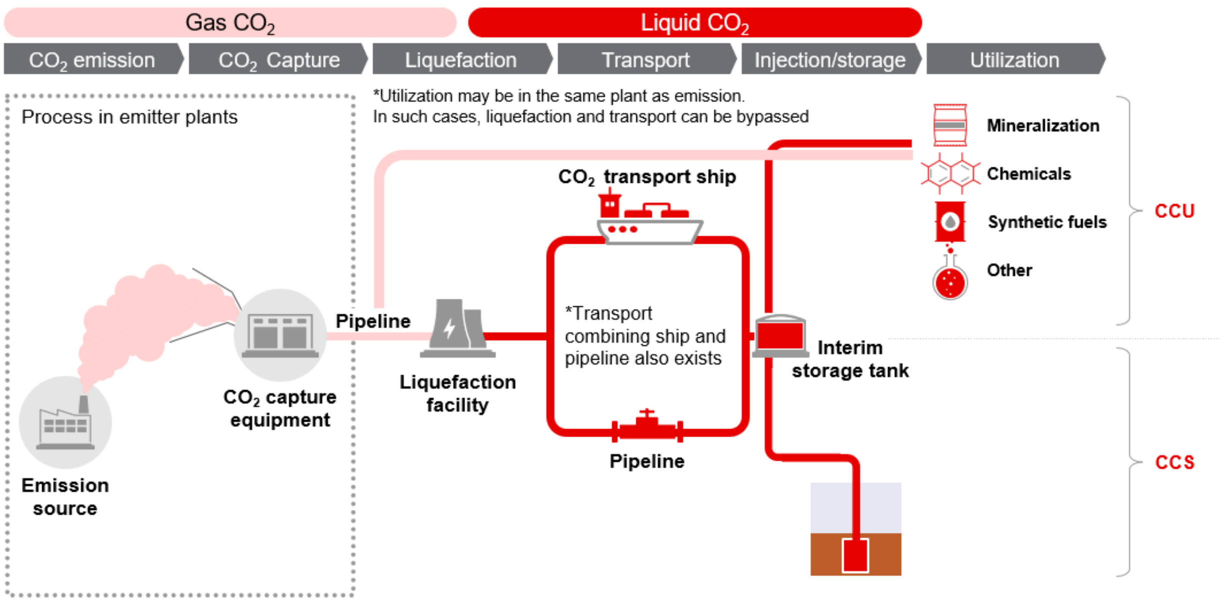
5.7 Positive Technology in Japan: CCUS

5.7.1 The role of CCUS in a carbon neutral society

To decarbonize heat and electricity, Japan will maximize the use of renewables and pursue fuel/material conversion to hydrogen-based and biogenic fuels. In that context, carbon capture, usage and storage (CCUS) are required to accelerate both CO_2 emissions abatement in high-emissions industries and negative emissions through storing carbon captured by direct air capture or captured from combustion of bioenergy. CCUS is broadly divided into two categories (Figure 5.55):

- **CCU** : This technology utilizes CO_2 to produce synthetic fuels, chemicals, cement, and agricultural products.[158] Because CO_2 emitted from industries is a finite resource, capturing and recycling it is an effective circular economy application. Some industries have been ahead of the curve in promoting CCU. Various players are undertaking R&D with a view to future commercialization.
- **CCS**: In industry and electrical power production, CO_2 can be captured and stored, so that it is not released into the atmosphere. Methods for CO_2 capture include chemical or physical absorption and separation by membranes. Long-term and stable storage is necessary, so that the gas never escapes. In the past, injection into oil/gas fields, known as EOR/EGR, was the predominant method of achieving this, but other storage locations, such as deep saline water and depleted oil and gas reservoirs, are becoming mainstream methods.[159]

Figure 5.55 Flow of CCS and CCU (Not exhaustive)



Japan aims to maximize the usage of renewables (both domestic and imported in a form of fuel) to reduce CO_2 emissions. However, there are three key reasons for adoption of CCUS:

- **1) Infrastructure constraints:** CCUS can be an effective tool for facilities located in areas where it is difficult to build hydrogen-based and biogenic fuel infrastructure, such as ports, or electrification infrastructure with large-scale renewable energy.

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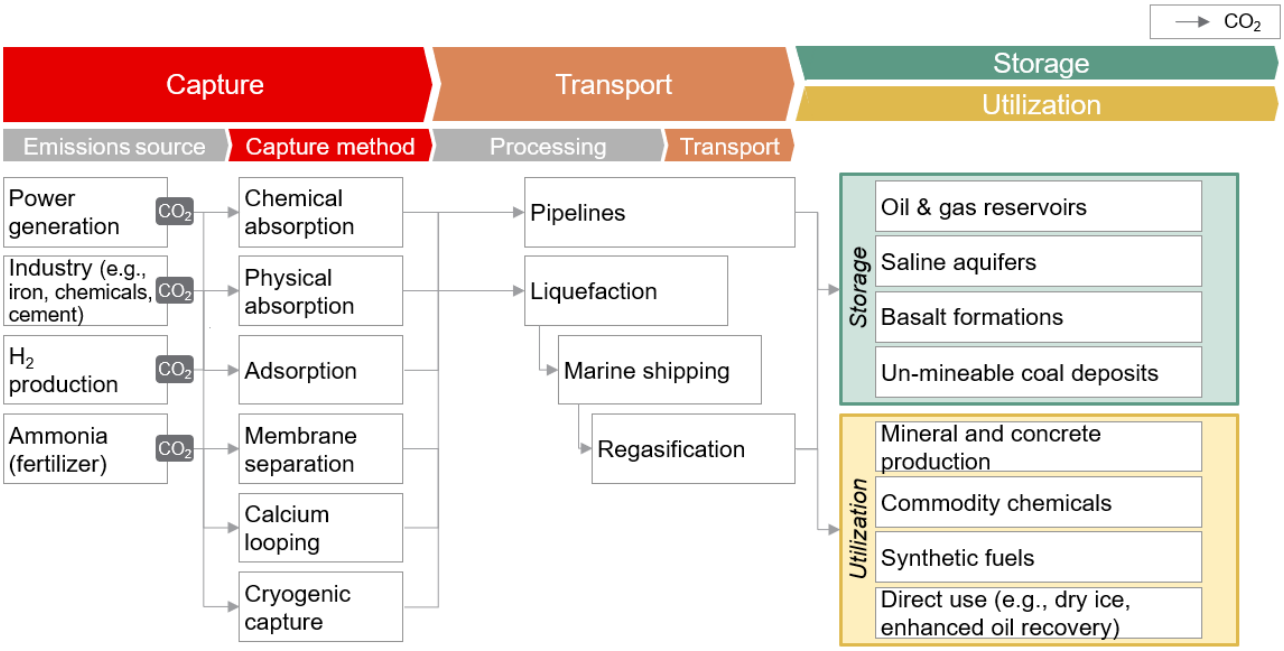
[158] Synthetic fuels are discussed in the section of hydrogen-based and biogenic fuels.
[159] https://www.globalccsinstitute.com/resources/global-status-of-ccs-2022/

- **2) Technological availability:** The required technologies for emissions reduction vary depending on the industry and processes involved, and when multiple options are available, their level of maturity also varies. Among options such as fuel switching to next-generation fuels, electrification, CCU, and CCS, the effective emission reduction approach should be chosen based on the availability of the technology and other factors.
- **3) Lower funding requirements:** Since power generation and process industry facilities are typically operational for 30-40 years, a significant amount of capital would be required to replace assets in implement hydrogen-based and biogenic conversion and electrification, especially in newer facilities. Carbon capture, conversely, be added relatively simply, helping to reduce the cost of emissions reduction while utilizing existing assets.

5.7.2 CCUS supply chain

The CCUS supply chain consists of four elements: upstream CO_2 capture, midstream CO_2 transport, downstream CO_2 storage, and CO_2 utilization (Figure 5.56).

Figure 5.56 CCUS supply chain overview



Given the original purpose of CCUS, which is to reduce CO_2 emissions, the supply chain itself must avoid emitting large amounts of CO_2. From this perspective, there is a need to connect each supply chain element end to end, including, for example, hydrogen-based and biogenic fuels. Since collection, transportation, storage, and utilization are expected to be handled by different players in different countries, cooperation between countries and players will be required. Also, some CCS supply chains could transition to CCU in some industries. This is because CCU can generate new monetary value by using CO_2 as a resource, while CCS incurs a storage cost.

Japan's Basic Policy for the Realization of GX, published in February 2023, states the need for the early establishment of a CCUS value chain, as well as for the agreement of targets and development plans for CCUS by 2025. The policy says the CCUS value chain will require funding of JPY4 trillion over the next 10 years. However, to achieve the CCS target of storing 120 to 240 million tons/year (10-20% of Japan's emissions) for example, further commitment of several tens of trillions of yen is expected to be required. As for synthetic fuels, also known as carbon-recycled fuels, the government acknowledges challenges on the supply side, such as establishing manufacturing capacity and developing CO_2 counting rules.[160] [161] It also indicates the funding of JPY3 trillion over the next 10 years, separate from the establishment of the CCUS value chain.

In establishing a CCUS value chain, it is first necessary to identify use cases in the areas where CO_2 capture is needed (power generation and industries). Then stakeholders need to secure reservoirs as destinations for industries that prioritize CO_2 storage in the short term. Since CO_2 capture and storage sites are not necessarily adjacent, it would be necessary to establish low-carbon CO_2 transport technology.

In sectors where CO_2 can be effectively utilized as a resource, downstream technologies and production systems that use CO_2 as a raw material need to be developed. In the case of rapid CCU technology development and rising demand for CCU products, demand for CO_2 as a resource may also rise and the CCS value chain can be converted to a CCU value chain.

5.7.3 The need to establish a CCUS supply chain in Japan

The CCUS supply chain requires 14 technologies in four supply chain segments: upstream CO_2 capture, midstream CO_2 transport, downstream CO_2 storage, and CO_2 utilization (Figure5.57).

Figure 5.57 CCUS technologies

Not exhaustive

Supply chain segment	#	Positive technology	Necessity in Japan	Leading players
CO_2 capture	1	Chemical absorption	• Need for complementary measure to decarbonize hard-to-abate sectors, in addition to electrification and fuel conversion	MHI, Nippon steel engineering, Toshiba
	2	Physical absorption		
	3	Adsorption		
	4	Membrane separation		
	5	Other (Direct air capture)	• Though not mentioned in the GX Basic Policy, there are few on-going demonstration projects	—
CO_2 transport	6	Marine transport vessels	• Need to transport CO_2 to overseas where storage potential is greater than in Japan	Shipbuilder: Mitsubishi shipbuilding, Kawasaki Operator: NYK Line, Mitsui O.S.K.
	7	Pipeline	• Need for domestic CO_2 transport (relatively short distance)	Nippon Steel Pipeline & Engineering
CO_2 storage	8	Oil & gas reservoirs	• Need for stable and sufficient storage to prevent CO_2 to be released to atmosphere - Southeast Asia and Australia, where the storage potential is greater than in Japan are also candidate location	ENEOS, INPEX
	9	Saline aquifers		
	10	Basalt formations		
	11	Un-mineable coal deposits		
CO_2 utilization	12	Mineralization	• Need to utilize CO_2 to the maximum extent due to scarcity in natural resources in Japan	Mitsubishi UBE Cement, Kajima Construction, Taiheiyo Cement, Sumitomo Osaka Cement
	13	Chemicals		Mitsubishi Chemical, Asahi kasei
	14	Synthetic fuel		Osaka gas, Tokyo Gas
	15	Other (Biogenic carbon, etc.)		—

[160] Fuels and chemicals have the largest portion of VC investment in CCU. IEA, Venture Capital investments in CCU start-ups, 2015-2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/venture-capital-investments-in-ccu-start-ups-2015-2021, IEA. Licence: CC BY 4.0

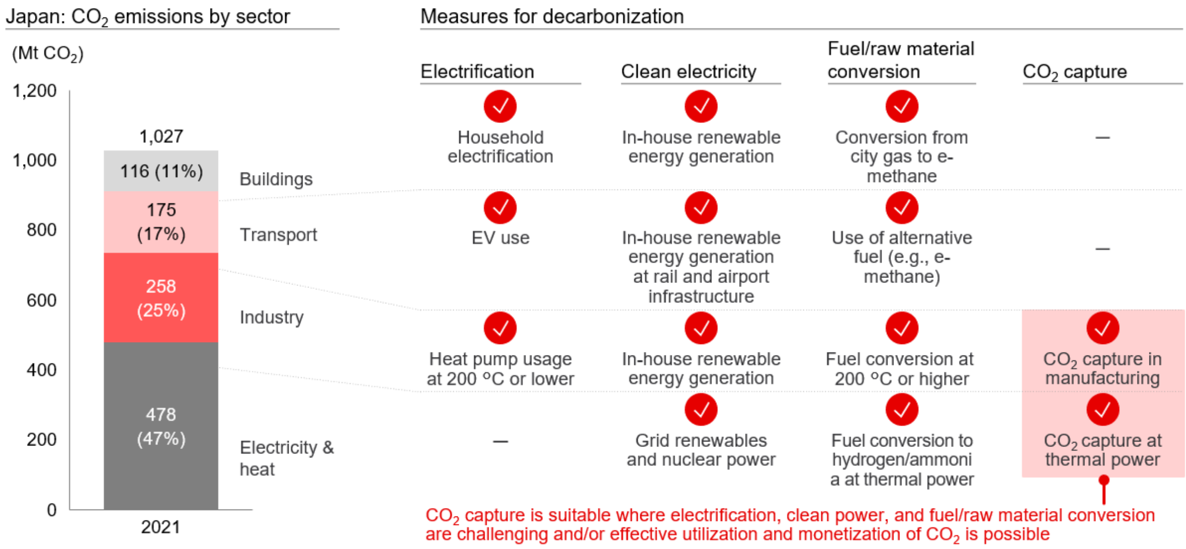
[161] Rules are beginning to be debated as to which countries should be given credit for the capture of CO_2 during the production of synthetic fuels. Further discussion in hydrogen-based and biogenic fuel section.

5.7.3.1 CO_2 capture

CO_2 capture will be led by industries with high CO_2 emissions and where electrification, clean power, and conversion of material/fuel are challenging from the viewpoint of infrastructure constraints and technology maturity (Figure 5.58).

- **CO_2 capture in the industrial sector:** Where the heat/steam/heated water temperature is below 200 degrees Celsius, electrification by heat pumps achieves the clean transformation of in-house coal fired power plants. Above 200 degrees Celsius, it will mainly be conversion to hydrogen-based and biogenic fuels. Meanwhile, CO_2 capture is an option where electrification and fuel conversion are not applicable and where the long-term fixation of CO_2 (CCS) or product manufacturing from CO_2 is possible.
- **CO_2 capture in the power generation sector:** CO_2 capture will be implemented where other solutions, such as conversion to nuclear, hydrogen or ammonia, are not readily available.

Figure 5.58 Japan's CO_2 emissions by sector and major decarbonization instruments



The Japanese government expects thermal power generation plus CCUS and nuclear power to account for 30-40% of the power mix in 2050, creating flexible power for baseload supply and fluctuation adjustment. Also, the government has established a CCS Long-Term Roadmap Study Group to set volume targets for CCS and develop the project environment. [162] [163] The first CCS project is expected to be operational by 2030, with full-scale projects developed after. The target is to reduce the cost of capture from the current JPY4,000/ton to the JPY2,000/ton by 2030 and to below JPY1,000 /ton by 2050.[164] Furthermore, the government's Study Group for Establishing a Roadmap to Promote Transition Finance in the Economy, Trade and Industry Sector has established targets for CO_2 capture.[165] These include targets for large-scale CCUS commercialization of CO_2 capture from blast furnaces in the steel industry by 2040, the production of basic chemicals from biomass in the chemical

[162] https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/index.html

[163] These include cost reduction measures, public understanding, law enactment for CCS projects, and relevant laws and regulations related to exporting CO_2 for storing overseas storage sites.

[164] https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/20230310_report.html

[165] https://www.meti.go.jp/shingikai/energy_environment/transition_finance_suishin/index.html

industry by the late 2020s, and CCUS of exhaust gas from production processes also in the chemical industry by around 2030.

Meanwhile, the private sector has already taken steps. Indeed, Mitsubishi Heavy Industries has a 70% share of the global market for CO_2 capture facilities (Figure 5.59), having been involved in large-scale projects including Petra Nova (coal power generation) and NextDecade (LNG liquefaction) in the US, Drax (biomass power generation) in the UK, and Lehigh Cement (cement) in Canada.

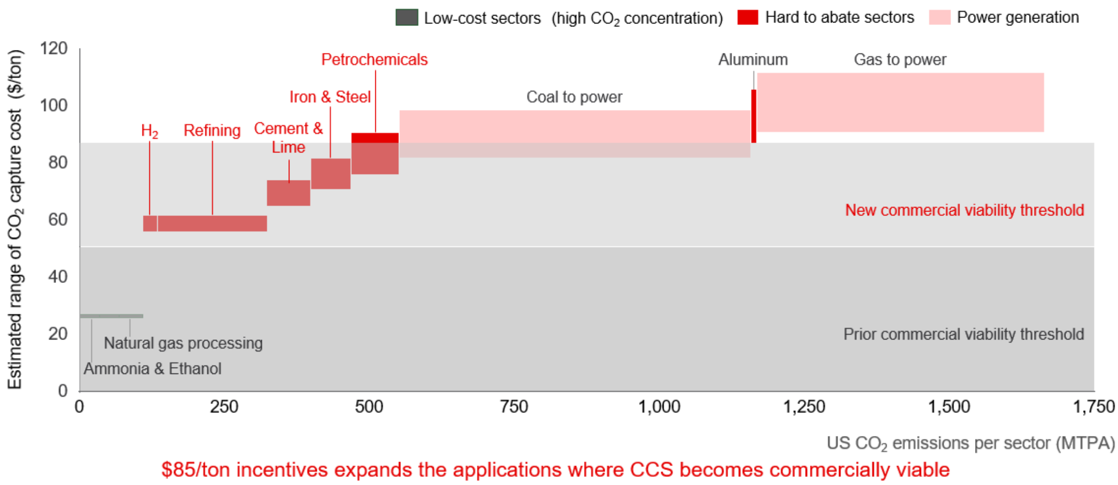
Projects backed by the Japanese government's GI Fund include those operated by Chiyoda Corporation, Denso, Showa Denko, Sumitomo Chemical, Air Water, and Toho Gas. From a methodological perspective, the amine method (chemical absorption) is currently the mainstay of many companies, including Mitsubishi Heavy Industries. In addition, companies are working on new capture technologies including so-called physical absorption and membrane separation.

Figure 5.59 Share of CO_2 Capture Equipment[166]

1	Mitsubishi Heavy Industry (73%)	Japan	• Design, pilot, demonstrate, and supply licenses • Projects: Petra Nova (US); Drax (UK), NextDecade(U.S.), Lehigh Cement (Canada), etc.
2	Cansolv (22%) (Acquired by Shell in 2008)	Canada	• Participates in multiple CCS projects in Europe as Shell • Projects: Northern Lights (Norway), Acorn CCS / Northern Endurance(UK), and Porthos (Netherland) with partnership with other players
3	Carbon Clean (2%)	UK	• Participates in 49 projects in Europe/India/U.S./Japan • Projects: Cemex (Germany), Pacific Cement (Japan), Tata Steel (India), etc.
4	Nippon steel engineering (2%)	Japan	• Collaborates with non steel makers • Projects: Siam Cement Group (Thailand), Air Water Carbonic Acid (Japan), Sumitomo Joint Power Company (Japan)
5	FLUOR (1%)	US	• Focus on CCS projects at power plants in the US • Projects: California Resources Corporation (US), Minnkota Power Cooperative (US)

Japan is not alone in providing incentive schemes for CCUS. The US IRA expands the tax credit from \$50/t to \$85/t. This has the potential to make some previously unprofitable sources of low-concentration CO_2 capture economical, including in the steel and cement industries and some thermal power generation scenarios (Figure 5.60).

Figure 5.60 US IRA tax credits for CCS[167]



[166] Website of each of the companies

[167] https://www.bcg.com/publications/2023/gaining-edge-in-clean-tech

Case study of Carbon capture systems manufactured by a Japanese company

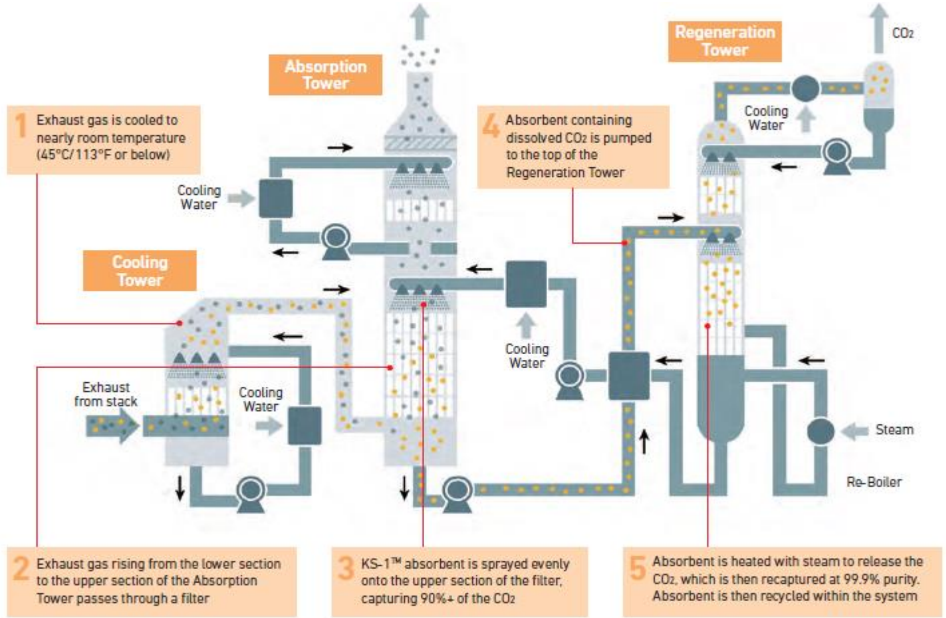
Mitsubishi Heavy Industries (MHI) is an engineering and manufacturing company covering energy, plant & infrastructure, logistics, thermal & drive systems, aviation, defense & space. In the "MISSION NET ZERO," MHI Group declared its commitment to reducing the Group's CO_2 emission by 50% by 2030 and achieving Net Zero of Scope 1/2/3 by 2040. "Decarbonize existing infrastructure," "Build a hydrogen solutions ecosystem," and "Build a CO_2 solutions ecosystem" are three pillars to achieve these goals. CCUS is involved in all three pillars, especially in the CO_2 solutions ecosystem. This case study focuses on the CO_2 capture systems within MHI's CCUS-related businesses.

<u>CO_2 capture systems</u>

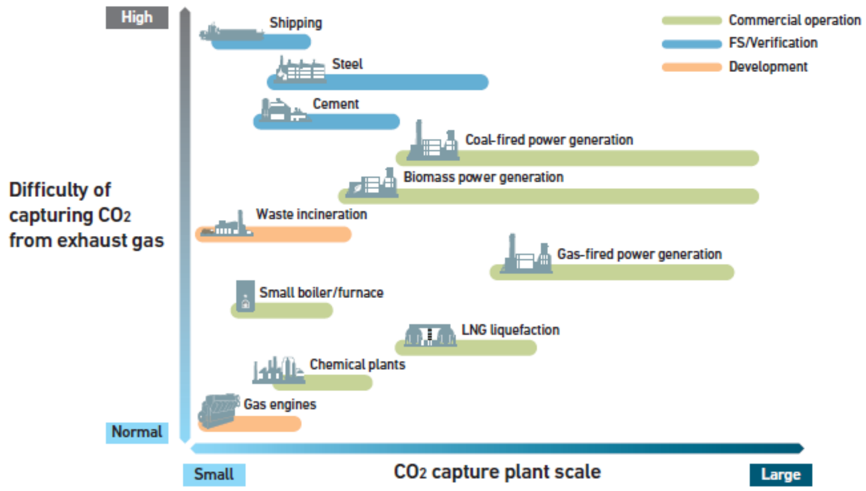
Since the 1990s, MHI has commercialized technologies to capture CO_2 emitted during chemical manufacturing processes, as well as CO_2 contained in exhaust gases generated when fossil fuels or fuels containing carbon components are burned. As of 2022, MHI has the world's largest share of CO_2 capture systems in commercial operation by volume. Currently, there are three major CO_2 capture methods in commercial use: chemical absorption (CO_2 is dissolved in a liquid absorbent, separated, and absorbed through a reaction with absorbent components), solid adsorption (CO_2 molecules are adsorbed onto a solid adsorbent's surface or through pores), and membrane separation (high temperature/concentration gases are separated by osmotic pressure). MHI's strength lies in chemical absorption technology.

For example, "the KM CDR Process^{TM}," developed jointly with Kansai Electric Power Co., can capture more than 90% of the CO_2 contained in gases (purity of more than 99.9% by volume), and its unique energy-saving regeneration system reduces steam consumption. The process uses a proprietary amine-based CO_2 absorbing solutions, "KS-1TM" and "KS-21TM," which provide excellent CO_2 absorption and prevents corrosion and degradation compared to other amine solutions. The exhaust gas on the left side of the diagram below is cooled and enters the absorption tower in the center, where it comes into contact with the amine-based solution that absorbs the CO_2. The amine CO_2 absorbent containing CO_2 is heated in the regeneration tower on the right 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.

KM CDR Process™ plant configuration



CO_2 capture from flue gas, as shown in the diagram above, is not limited to thermal power plants and can be applied to a wide variety of emissions sources. These include waste incineration facilities, LNG production facilities, steel mills, cement plants, chemical plants, and ships. 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 ranges from ultra-large-scale recovery (several tens of thousands of tons per day) to very small-scale recovery (several hundred kilograms per day). Thus, MHI continues to develop comprehensive recovery technologies while keeping an eye on marketability.



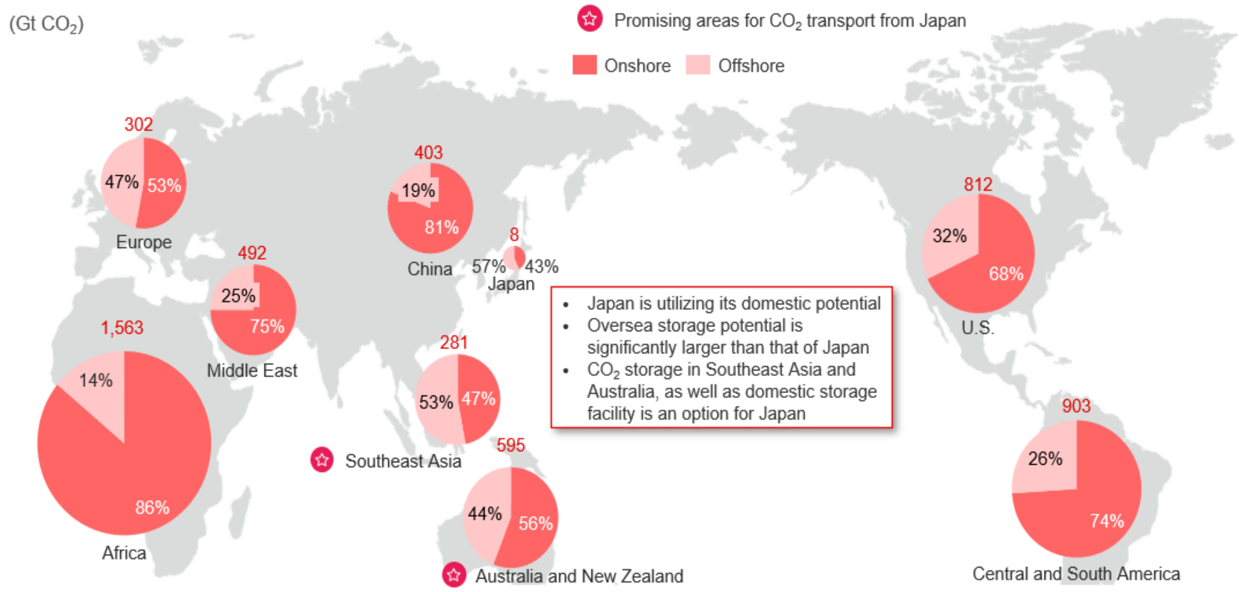
A small CO_2 capture system is in actual operation. For example, a compact CO_2 capture system with a capacity of 0.3 tons/day was installed at a 7,000-kW class biomass power plant in Hiroshima City and launched in 2022, becoming the first system to go into commercial operation. It has a footprint of only 5m long by 2m wide, and its modular configuration with a compact and versatile design enables rapid truck transport from the manufacturing plant to the site and quick and easy installation. MHI will continue to provide equipment and solutions for diverse CO_2 capture as an all-in-one service, such as equipment operation support services utilizing its unique remote monitoring system.

5.7.3.2 CO_2 Storage

CO_2 recovered in the electrical power and industrial sectors requires long-term stable storage. Underground storage requires a shielding layer, an impermeable geological formation. In Japan, the Hokkaido, Tohoku, Kanto, Chugoku, and Kyushu regions have been selected for large-scale projects and are moving toward starting operations.

In addition, CO_2 captured in Japan may be shipped to storage overseas, the locations of which are unevenly distributed (Figure 5.61). Storage potential in Southeast Asia and Australia is significantly larger than in Japan. Cross-national CCS is an option but may be more expensive. The optimal approach is likely to be to use a mix of storage sites in Japan and overseas (see ENEOS case study).

Figure 5.61 CO_2 Storage Potential of Major Regions[168]



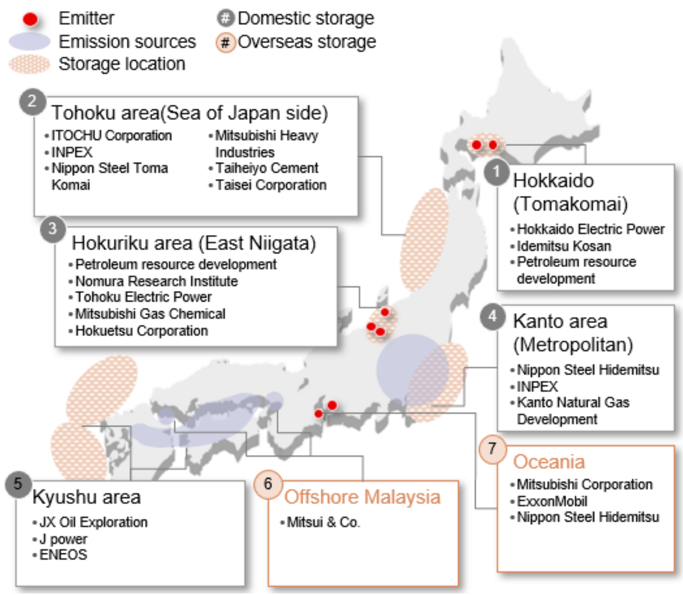
In the Japanese government's CCS Long-Term Roadmap Study Group, the government aims to achieve its CO_2 storage target of approximately 120 to 240 million tons per year by 2050, with a goal of securing sites for 6 to 12 million tons of annual CO_2 storage by 2030.[169] The country is currently supporting seven storage projects in Japan and abroad under the advanced CCS demonstration program (Figure 5.62). Japan aims to reduce storage costs from the current JPY6,000/ton to JPY5,400/ton.

[168] IEA (2021), The world has vast capacity to store CO_2: Net Zero means we'll need it, IEA, Paris https://www.iea.org/commentaries/the-world-has-vast-capacity-to-store-co2-net-zero-means-we-ll-need-it

[169] https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/20230310_report.html

Figure 5.62 Advanced CCS projects[170]

Location of advanced CCS project



Summary of advanced CCS projects to receivepolicy support

#	Expected storage amount (10kt/year)	CO_2 emission	Transportation means
1	150	Refinery and power plant in Tomakomai	Pipeline
2	200	Wide coverage of the entire country (Steel mills, cement plants and local emitters at potential storage sites)	Ship (domestic)
3	150	Chemical, paper, and power plants in Niigata	Pipeline
4	100	Multiple industries including steel in metropolitan area	Pipeline
5	300	Covers Setouchi and Kyushu (Refineries and thermal power plants in western Japan)	Ship (domestic)
6	200	Multiple industries including chemical and petroleum refining in the Kinki and Kyushu regions, etc.	Ship (Overseas)
7	200	Multiple industries including steel in Chubu (Nagoya, Yokkaichi)	Ship (Overseas)

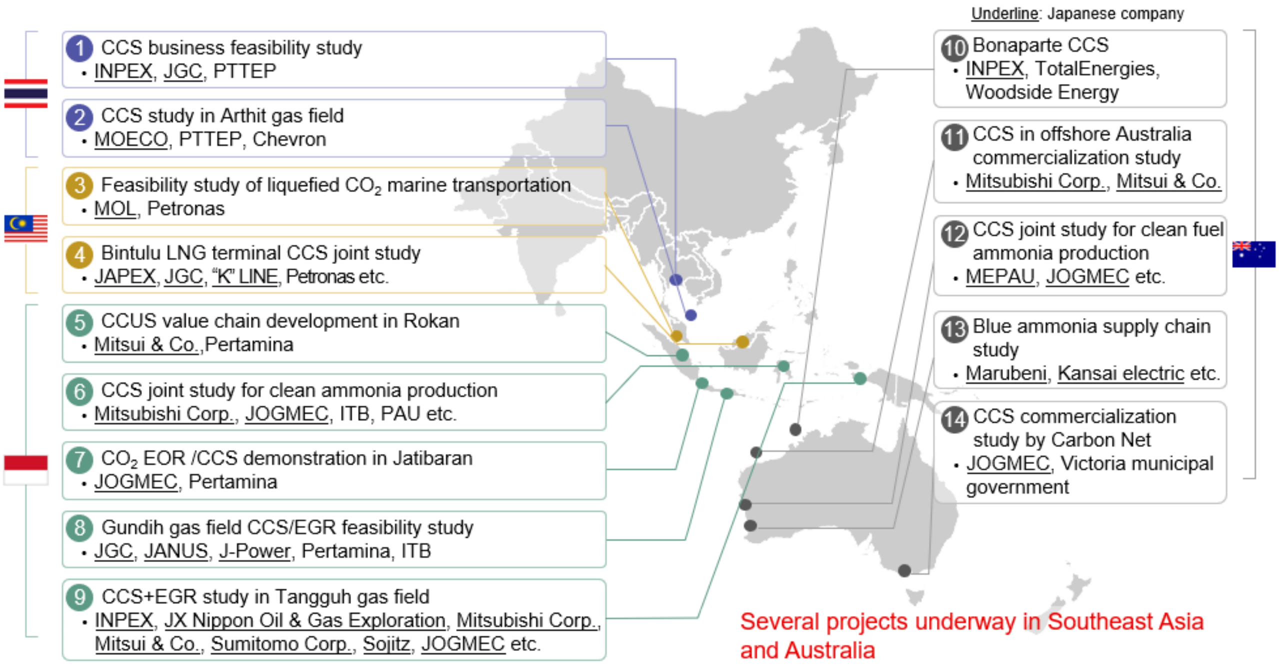
The Japanese government is also initiating and participating in the Asia CCUS Network Forum, which aims to develop an environment and share knowledge for CCUS utilization throughout Asia. In addition to the 10 ASEAN countries, Japan, the US, and Australia are participating, and Japan and the US are acting as a bridge to ensure international collaboration outside Asia.[171] A roadmap has also been established, with plans to create a cross-national CCS pilot project in ASEAN in FY2025, with a view to establishing a network in FY2030.

On the corporate side, participation in CCUS projects is becoming more common, particularly in the Asia-Pacific region (Figure 5.63). Specific studies for commercialization are being conducted in the form of joint projects among Japanese and local companies.

[170] https://www.jogmec.go.jp/news/release/news_01_00034.html

[171] https://www.env.go.jp/content/900440498.pdf

Figure 5.63 Examples of Japanese companies in CCUS projects in the Asia-Pacific region[172]



Carbon storage is also covered by policy support in Europe and the US. The EU Taxonomy has established standards for offshore and underground storage, including storage sites and the implementation of leak detection and monitoring plans. The US IRA provides a tax credit.

Cross-national CCS is also being promoted in Europe. The Northern Lights project in Norway is the world's first open-source cross-border transportation and storage project. It was established through a collaboration between the Norwegian government, Equinor, Shell and Total. Northern Lights promotes the use of storage capacity by companies in the region from the perspective that storage potential should be available to companies throughout Europe. The Porthos project in the Netherlands similarly accepts CO_2 emitted in other countries.

[172] https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/jisshi_kento/pdf/004_05_02.pdf

Case Study of CCS by Japanese Companies

ENEOS

ENEOS Group is engaged in the energy business, from upstream oil development to oil refining and sales and the metals business, from development of non-ferrous metal resources to the manufacturing and sales of non-ferrous metal products. ENEOS Group announced its Carbon Neutrality Plan in May 2023, sharing its long-term vision of taking on the challenge of both a stable supply of energy and materials and achieving a carbon neutral society. In order to achieve this, they aim to reduce company greenhouse gas (GHG) emissions through optimizing their manufacturing and businesses and CCS and natural absorption, as well as contributing to reducing GHG in wider society by the energy transition to hydrogen and carbon-neutral fuels and promoting a circular economy. This case study focuses on ENEOS' MCH business in relation to hydrogen supply.

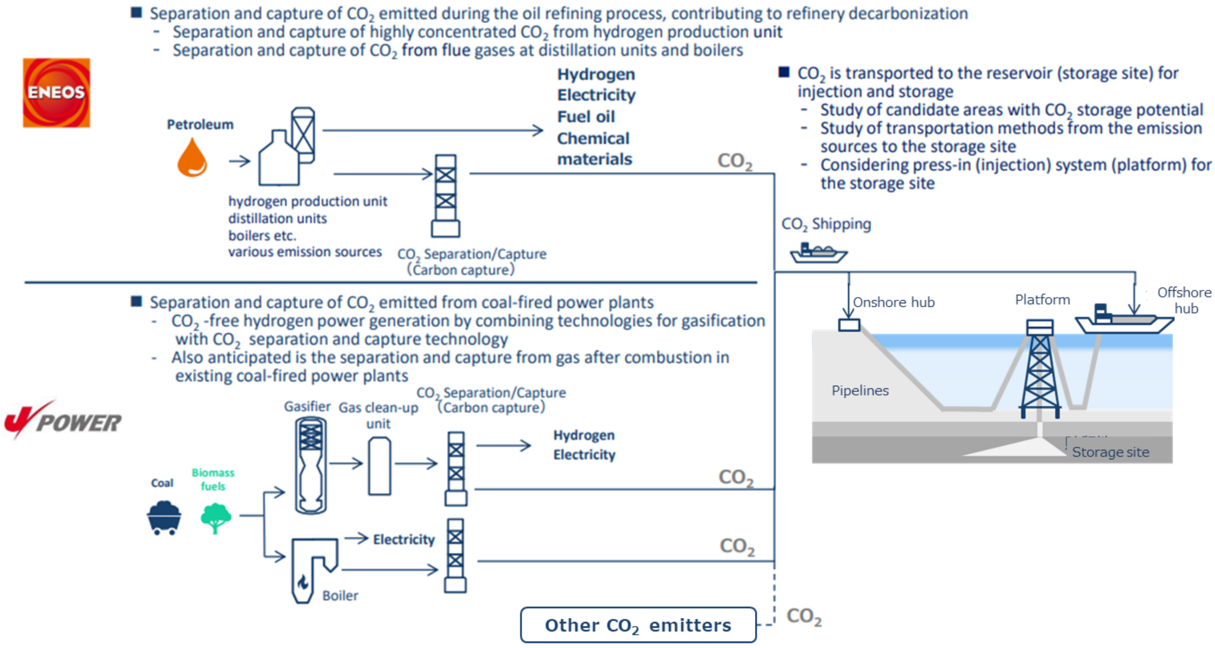
CCS

ENEOS Group has two companies, ENEOS, which is a large CO_2 emitter and JX Nippon Oil & Gas Exploration Corporation, which possesses CO_2 storage technology. The Group is actively working on CCS to reduce its CO_2 emissions. The ENEOS Group Carbon Neutrality Plan aims to implement CCS at a scale of 3 million tons/year in 2030 and 11 million tons/year in 2040 to reduce the company's GHG emissions. Furthermore, their goal is not only CCS for their own emissions but also monetizing by building Japan's largest CCS value chain by 2040 and storing other companies' CO_2 (4-10 million tons/year).

In 2016, in the state of Texas in the US, ENEOS Group commercialized CCS that injects CO_2 captured from exhaust gas of thermal power stations into the ground and has acquired a certain amount of technology and expertise related to geological evaluation and CO_2 injection.

In Japan, they are currently collaborating with J-POWER as announced in 2022. They aim to combine J-POWER's hydrogen power generation, which utilizes biomass gasification technology and captures CO_2 in the same process, and ENEOS' underground CO_2 storage technology to implement CCS by FY 20230. Through this work, they can achieve a stable energy supply while contributing to achieving Japan's reduction target for GHG emissions in addition to CO_2-free hydrogen power generation.

Process of collaborative CCS with J-POWER



They are currently investigating the storage of CO_2 emitted from ENEOS oil refineries in both eastern and western Japan utilizing this domestic and global expertise. For example, their CCS project on the northern to western coast of Kyushu (offshore saline aquifer) was recently chosen as a role model project that receives support from JOGMEC.[173] The project includes three companies, ENEOS, JX Nippon Oil & Gas Exploration Corporation, and J-POWER, through which they aim to capture, transport CO_2 emitted from ENEOS oil refineries and J-POWER thermal power stations in western Japan, and then store 3 million tons/year of CO_2 in the northern to western coast of Kyushu. They are currently conducting business research on domestic CCS storage with the goal of beginning CO_2 injection in FY 2030. In addition, through acquisition of shares in Japan Drilling Co., which owns offshore drilling technology, in February 2023, ENEOS Group is moving to obtain the expertise needed to cover the entire CCS value chain. As a future prospect, the group aims to investigate the creation of global carbon credits in cooperation with the government and to verify BECCS and DACCS, which will utilize the CCS value chain built through the aforementioned investigation.

[173] Projects that could be used as models and address large-scale operations and cost reductions are positioned as advanced CCS projects and the entire value chain, from CO_2 separation and capture to transport and storage, is supported in an integrated manner.

5.7.3.3 CO_2 Transport

CO_2 capture sites, which are predominantly industrial areas and power plants, are not necessarily near storage sites. Therefore, efficient CO_2 transport from the capture site to the storage site is one of the requirements for CCS to be viable. In Europe and the US, in advanced use cases, both pipelines and short-to-medium-distance CO_2 transport ships are used. Japan is exploring both domestic and international storage to ensure adequate storage capacity. Domestically, as in Europe, short-distance pipeline transport within CCS hubs and short-to medium-distance CO_2 ocean carriers are envisioned, but long-distance ocean transport will be required to transport CO_2 to overseas storage sites. In order to transport CO_2 efficiently and in large volumes by sea, liquefaction of CO_2 is effective, which reduces the volume to 1/500. However, carrier technology for liquefied CO_2 is still in its infancy, and the development of port and other facilities is necessary.

The current cost of shipping 50 MtCO_2/year over 1,100 km is estimated at JPY9,300/ton. The government's CCS Long-Term Roadmap Study Group has set a target of reducing the cost by 30% or more to JPY6,000 /ton by 2050. Combined with the costs of capture and storage, the government is targeting a cost reduction of about 40% from the current level by 2050. For advanced CCS projects, the Japan Organization for Metals and Energy Security (JOGMEC) selected seven projects as model cases JOGMEC has already provided support for joint research and technical studies into CCS projects and site surveys suitable for CCS, for example in Australia and in Japan (Niigata Prefecture) respectively. The company is supporting research into CO_2 sequestration during LNG mining and a demonstration of CO_2 injection into depleted gas fields.[174]

The technical development of large CO_2 carriers is a challenge in terms of factors such as temperature and pressure management and tank development. In Japan, Mitsubishi Heavy Industries Group is working on development of carriers, and plans to proceed to commercialization in 2025, installation of onboard CO_2 capture facilities in 2030, and transportation to offshore CO_2 injection facilities (see the Mitsubishi Heavy Industries case study on transporting CO_2).

In the shipping industry, major players such as NYK and Mitsui O.S.K. Lines (MOL) are looking for the opportunities to start CO_2 shipping operations (see NYK case study).

In Europe and the US, pipelines are often the main means of transportation. However, in projects such as the Northern Lights, which deploys CO_2 transportation vessels and pipelines, the need for innovation in operation and design when deploying CO_2 vessels has been clearly communicated.[175]

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[174] https://www.jogmec.go.jp/carbonneutral/carbonneutral_01_00011.html

[175] https://norlights.com/news/what-it-takes-to-ship-co2/

Case study of CO_2 transportation ship development by a Japanese company

MITSUBISHI HEAVY INDUSTRIES

Mitsubishi Heavy Industries (MHI) is an engineering and manufacturing company covering energy, plant & infrastructure, logistics, thermal & drive systems, aviation, defense & space. In the "MISSION NET ZERO," MHI Group declared its commitment to reducing the Group's CO_2 emission by 50% by 2030 and achieving Net Zero of Scope 1/2/3 by 2040. "Decarbonize existing infrastructure," "Build a hydrogen solutions ecosystem," and "Build a CO_2 solutions ecosystem" are three pillars to achieve these goals. This case study focuses on the development of CO_2 transport ships, one aspect of the CO_2 ecosystem.

Liquefied CO_2 carriers (LCO_2 carriers)

In the CO_2 ecosystem, MHI Group provides solutions to optimize the overall value chain from land to ship. Because cost-optimal pressure differs for each device, optimizing the overall value chain is required. As Japan is an island nation, maritime transport is often necessary even domestically, and as it is also expected that CO_2 will be transported to storage areas abroad, liquefied CO_2 (LCO_2) carriers are considered particularly important in the value chain. Mitsubishi Shipbuilding, a part of MHI group, is building an LCO_2 carrier for Japanese national demonstration project and utilizing its experience to strengthen the Group’s strategic energy transformation business as well as develop necessary technologies to build a CCUS value chain. For example, they are currently investigating various technologies such as liquefied CO_2 handling that will improve economy.[176] Mitsubishi Shipbuilding (MHI at that time) began developing an LCO_2 carrier in-house in 2000, and has continued to participate in projects of high public interest, such as the 2004 IEA Study and the NEDO project in 2008-2011. They have also entered a large number of partnerships with private companies and have issued 16 press releases since 2020.

[176] For example, by developing ships that can transport LPG from oil-producing countries to Japan along with ammonia, a next-gen decarbonized fuel, they will be less likely to operate with empty cargo, improving economy.

Mitsubishi Shipbuilding is working to accumulate knowledge and create more advanced technologies through collaboration with global players. For example, in 2021, they began collaborative research on LCO_2 carriers with the French company TotalEnergies. TotalEnergies plays a leading role in the CCUS value chain market, and in addition to working as partners in proactive technological development to achieve a decarbonized society through LCO_2 carriers, they also aim to build the CCUS value chain market.

In addition, they announced a contract in 2022 for a large-scale project constructing the world's first demonstration test ship for the transportation of liquefied CO_2 intended for CCUS. Mitsubishi Shipbuilding contributed as shipbuilding player in NEDO's "Technology Development and Testing Project to Establish Technology for the Large-scale Transport of CO_2 by Ships." The Engineering Advancement Association of Japan, one of the contractors, will charter the ship from the shipowner, Sanyu Kisen, and will install and operate the LCO_2 tank system, which is R&D equipment. As subcontractors of the Engineering Advancement Association of Japan, Kawasaki Kisen, Nippon Gas Line and Ochanomizu University are entrusted with the R&D for pressure control and safety of the LCO_2 transported by the ship and preparation of demonstration test plans, and they are working to develop and test technologies to transport CO_2 safely and at low cost.

Mitsubishi Shipbuilding plans to continue expanding the use of their technology through collaboration with multiple partner companies in the future. For example, in 2023 Mitsubishi Shipbuilding began discussing joint-study on ocean-going LCO_2 carriers with Nihon Shipyard. They aim to complete construction at Nihon Shipyard from 2027 onward, leveraging the mutually complementary advantages of both companies: Mitsubishi Shipbuilding's expertise and advanced gas-handling technology cultivated through construction of liquid gas carriers (liquefied petroleum gas/LPG and liquefied natural gas/LNG) and Nihon Shipyard's abundant experience in constructing various types of ships and advanced shipbuilding technologies.

Case study of CO_2 transportation ship operation by a Japanese company

NYK is Japan's largest player in marine transportation, and has been expanding its activities as a comprehensive global logistics enterprise. With a fleet of over 800 vessels, including bulk carriers, car carriers, oil tankers, and LNG carriers, NYK has set a goal of achieving net-zero emissions by 2050. To achieve this target, NYK has identified research and deployment for hardware and fuel conversion, optimal operation, implementation of energy-saving technologies, and use of biofuels as key decarbonization levers. As a leading company in international transportation, NYK is committed to developing cutting-edge technologies to meet IMO reduction targets and regional regulations such as EU-ETS. This case study focuses on CO_2 carriers for CCS.

CO_2 Carrier

CO_2 is transported via ship after liquefaction in order to enable large-scale transport, but there are challenges of temperature and pressure control during liquefaction and in port facilities, stability of CO_2 on board, and establishment of injection technology at the storage site. NYK is working on several projects to operate CO_2 carriers.

Knutsen NYK Carbon Carriers AS <KNCC>

In 2022, NYK will establish Knutsen NYK Carbon Carriers AS (KNCC, investment ratio: NYK 50%, Knutsen Group 50%) as a joint venture with Knutsen Group, a major Norwegian shipowner, to develop a liquefied CO_2 marine transportation and storage business. The jointly developed LCO_2-EP tank system (elevated pressure) transports liquefied CO_2 at ambient temperatures (0-10 degrees Celsius) and under high pressure (35-45 bar), thus enabling the CCUS value chain. The LCO_2-EP tank system concept aims to reduce costs throughout the value chain and uses larger vessels than those that transport liquefied CO_2 under medium pressure. NYK and the Knutsen Group have a joint business relationship through Knutsen NYK Offshore Tankers (KNOT), one of the world's leading shuttle tanker operators. KNCC aims to provide customers with advanced transportation technology, including loading and unloading of liquefied CO_2 onshore and offshore.

In June 2023, the LCO_2-EP tank system received General Approval for Ship Application from DNV, the Norwegian classification society. This enables KNCC to fit the cargo tank system capable of transporting and storing liquefied CO_2 at ambient temperature on newly built vessels and retrofit the systems on existing vessels.

provided by KNCC

Mitsubishi Shipbuilding Corporation

In 2021, NYK and Mitsubishi Shipbuilding agreed to jointly develop CO_2 transport technology using large vessels, for which global demand is expected to grow. Mitsubishi Shipbuilding is part of the MHI Group, which possesses diverse technologies in the CCUS value chain. Mitsubishi Shipbuilding has accumulated advanced gas handling technologies through construction of liquefied gas carriers (LPG/LNG/LNG carriers). Combined with NYK's extensive knowledge of operating a wide variety of vessels as a system integrator, the company is working to quickly realize the operation of not only small and medium-sized vessels, but also large LCO_2 carriers. Furthermore, NYK expects to use this project as a stepping stone for future participation in the CCUS value chain.

In 2022, NYK and Mitsubishi Shipbuilding received Approval in Principle (AiP)[177] from Nippon Kaiji Kyokai. The design of the cargo tank system is highly dependent on the temperature and pressure conditions of the liquefied CO_2 gas. The size of the system and hull is therefore an important consideration for the future mass transportation of liquefied CO_2 gas. To address these issues, NYK and Mitsubishi Shipbuilding have confirmed the feasibility and compliance with regulations and standards for cargo tank systems and hull sections for both medium and large vessels, considering a range of tank pressure settings. The acquisition of the AiP is a major milestone towards the future demonstration and commercialization of large vessels.

Provided by Mitsubishi Shipbuilding

[177] Indicates that the certification body has reviewed the basic design and approved it as satisfying the technical requirements and safety criteria.

5.7.3.4 Utilization

CO_2 Utilization is an effective means to realize carbon neutrality and resource utilization, given the scarcity of natural resources in Japan. Some Japanese industries are developing technologies to take the lead. There are also examples of industries looking at storage in the short to medium term that are also considering CCU and CCS in parallel, due to the cost of capture and transportation itself. In addition to e-fuel, hydrogen-based and biogenic fuels, CO_2 can be used for synthetic raw materials, minerals, agriculture, forestry, and fisheries (Figure 5.64).

Figure 5.64 CO_2 Utilization[178]

Mode of use	Direct use		Indirect use			
CO_2 utilization product	**Carbon dioxide gas, dry ice** • Food and beverage • Medical use	**Agriculture and biological** • Greenhouses	**Mineralization** • Concrete • Cement • Carbonate	**Chemicals** • Methanol & derivatives • Urea • Olefins & polymers • Artificial photosynthesis	**Synthetic fuels** • Liquid fuel • Methanol • SAF • Gaseous fuel • Methane	**Other** • CO_2 based animal and fish meal
Anticipated go-to-market timeline	The market is already established and will continue to be stable. Demand is expected, but will not expand significantly in the future	Small-scale decentralized but fast social implementation, with steady commercialization toward 2030	CO_2 absorbing concrete is getting technically mature. Could be a short-term recipient of CO_2	Expected to expand massively after 2030 as a means of decarbonizing Scope 3	Technology development /demonstration is underway and expected to expand in the medium term in conjunction with the establishment of a biomass/hydrogen supply chain	In the basic research stage with the aim of commercialization in 2050

In addition to carbon-recycled fuels, the GX Basic Policy set targets for chemicals and cement. In the chemicals industry, the goal is to establish carbon-recycling manufacturing process no later than 2030. In cement, the target is to increase production of carbon-recycled cement to 2 million tons by 2030 and 18 million tons by 2050.[179]

Progress is being made. Mitsubishi Chemical is developing olefin production using artificial photosynthesis, and Mitsubishi UBE Cement is conducting demonstrations to establish cement production using CO_2 as a raw material (see Mitsubishi Chemical and Mitsubishi UBE Cement case studies).

The number of companies globally engaging in CCU is rising, with projects in China, the US, Denmark, and Portugal, and these are consistent with those in Japan. In the US according to the IRA, CO_2 use is tax deductible at a maximum of $60/t ($130/t maximum for direct air capture), although the amount is smaller than for storage. In Europe, thresholds have been set for CO_2 emissions from vehicles that use e-fuel, and CCU is being promoted.

178 https://www.env.go.jp/earth/brochureJ/ccus_brochure_0212_1_J.pdf
179 https://www.meti.go.jp/press/2022/02/20230210002/20230210002_3.pdf

Case study of raw material production using CO_2 by a Japanese company

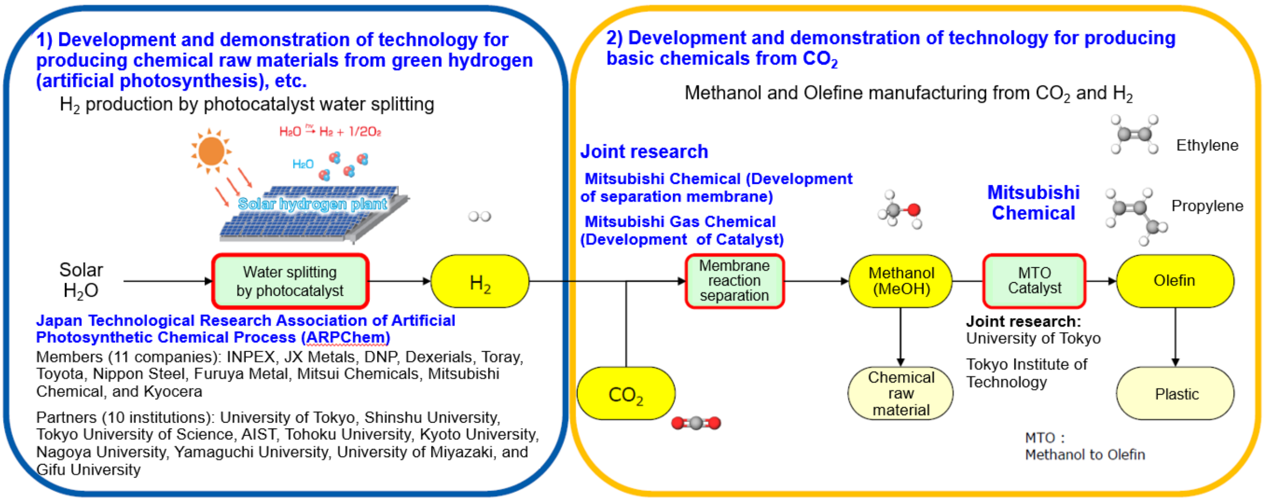
Mitsubishi Chemical Corporation

Mitsubishi Chemical Corporation is Japan's largest diversified chemicals company. Mitsubishi Chemical has stated a goal of group-wide carbon neutrality as of 2050, with a halfway point of 32% emissions in 2030 compared to 2019. To achieve this target, the company is making efforts to reduce emissions in various areas, focusing on purchased electricity, in-house power generation, and processes. Of these, the process that can contribute to reducing emissions is the development of artificial photosynthesis technology which combines hydrogen production using the photocatalyst and chemical production using hydrogen and CO_2.

Commercialization and development of chemical raw material production by artificial photosynthesis

This technology produces olefin, a raw material for plastics, from hydrogen obtained through photocatalytic water splitting using sunlight and CO_2 through multiple reactions. By providing chemical raw materials from CO_2, this technology is expected to either contribute to lower CO_2 emissions from plastics and other chemical products, or to reduce negative CO_2 emissions. The process can be broadly divided into two stages: 1) green hydrogen (artificial photosynthesis) and 2) production of basic chemicals from hydrogen and CO_2. The latter can be further broken down into two stages: methanol production from hydrogen and CO_2, and olefin production from methanol.

Leading Japanese companies, universities and research organization have joined this project where they are starting from the development of various underlying technologies. An expected JPY42.8 billion, 30.3 billion of which will come from public funds, will be used for R&D by 2030. Mitsubishi Chemical, as a leader, oversees the entire R&D process, and leads the development of green hydrogen (artificial photosynthesis) and olefin production from methanol.



Green hydrogen (artificial photosynthesis)

Reducing the cost of hydrogen production, which accounts for the majority of the cost of producing olefin from CO_2 and hydrogen, is the biggest challenge for large-scale commercialization. Japan Technological Research Association of Artificial Photosynthetic Chemical Process (ARPChem), a technology association of 11 Japanese companies for the production of low-cost green hydrogen production, is jointly working with 10 universities and research organizations to reduce the cost of green hydrogen production through artificial photosynthesis technology. Photocatalytic water splitting is a technology that splits water into hydrogen and oxygen without electricity by exposing catalysts in sheet form submerged in water to sunlight. Energy conversion efficiency, which measures the efficiency of hydrogen production from solar energy, is one KPI, and research is underway with the goal of achieving energy conversion efficiency of 4% in 2024 and 10% in 2030 and demonstrating its use in outdoor areas covering tens of thousands of square meters using photocatalytic sheets that can be produced with a large enough area for significant reductions in cost. In terms of hydrogen production costs, their target is set at JPY20 /Nm^3 or below. Additionally, it is necessary to safely and efficiently separate hydrogen and oxygen during photocatalytic water splitting since mixed hydrogen and oxygen gases are prone to explosion, so they are simultaneously developing not only high-performance separation membranes (membranes that separate the hydrogen from mixed gases) but also highly safe separation modules.

In 2021, ARPChem's pilot demonstration of the world's first $100m^2$-scale solar hydrogen production was a success, and they are now working to increase the scale, such as demonstrating safety and durability in an environment equivalent to approximately a year outdoors.

ARPChem aims to start large-scale production in the 2040s, increase market share, and license the technology to other companies and overseas in 2050.

Methanol production from hydrogen and CO_2

Technology for the production of methanol from hydrogen and CO_2 itself already exists, but the conventional technology has the problem of a reaction efficiency of 30-40% and large amounts of unreacted materials that must be recycled. Mitsubishi Chemical is working with Mitsubishi Gas Chemical Company to jointly develop a new membrane-based reactive separation process, aiming to improve the yield of this technology. They expect to license the process in 2032 and sell separation membranes after commercialization.

Olefin production from methanol

In current olefin production, byproducts are created, so the current challenge is producing large amounts of just olefin. To do this, Mitsubishi Chemical aims to establish a production technology that produces the desired olefin at a ratio that meets demand through an MTO (Methanol to Olefin) reaction that uses a special catalyst. In addition, after establishing technology to eliminate CO_2 emissions during production, a catalytic process technology that leads to the construction of a full-scale plant with a capacity of over 10,000 tons/year will be demonstrated in a large pilot test facility. Production costs will be reduced by 20% compared to current olefin production, which uses a technology that uses CO_2 and H_2 as raw materials. In the future, after commercialization in 2035, they also aim to license the process and sell the catalyst in addition to producing olefin.

Case study of cement production using CO_2 by a Japanese company

UBE三菱セメント株式会社 MUCC Mitsubishi UBE Cement Corporation

Mitsubishi UBE Cement Corporation (MUCC) is a leader in Japan's cement industry and supplies basic materials for social infrastructure development all over Japan. MUCC is committed to becoming carbon neutral by 2050 as MUCC group. In the Medium-Term Management Strategy, "Infinity with Will 2025 ~MUCC Sustainable Plan 1st STEP~," MUCC has set a goal of reducing CO_2 emissions by 40% by 2030 compared to 2013 levels. The plan calls for the early realization of energy conversion (fuel conversion in cement production and shift to fossil-free energy for firing and electricity) and the early commercialization of CCU Business. The former includes a recent announcement of the world's first attempt to start ammonia co-firing with coal in cement production as mentioned in Section 5.6.3.1.2. This case study overviews CO_2 capture and carbon-recycled products in cement production.

<u>CO_2 capture and carbon recycled products in cement production</u>

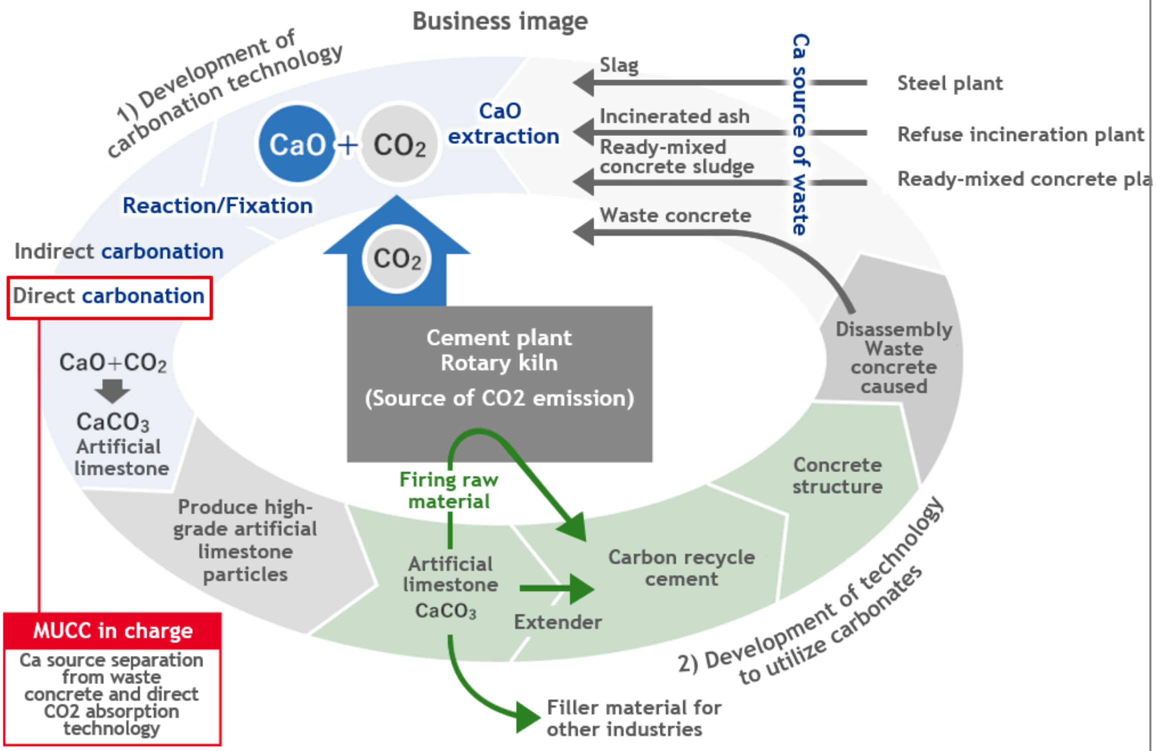
In cement production, raw materials containing calcium carbonate ($CaCO_3$), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Al_2O_3) are processed at high temperatures between 1,400 to 1,500 degrees Celsius to detoxify them, enabling effective use of a large amount of waste and by-products to contribute to building a "recycling-based society." On the other hand, since limestone is the primary raw material and thermal energy is required for high-temperature processing, a large amount of CO_2 is also emitted. Therefore, CO_2 capture and fixation are essential in addition to energy conservation. MUCC has positioned introducing CO_2 capture technology, establishing a CCU business scheme by 2030, and widening CO_2 application by 2050 as essential measures.

First, MUCC is considering introducing CO_2 capture technology unique to cement plants from overseas that efficiently captures limestone-derived CO_2. An inspection tour for the pilot plant was conducted, and a detailed study is underway to commercialize the direct utilization of CO_2 captured through this technology. In addition, MUCC is under a demonstration stage of its CO_2 separation and capture technology that recovers kiln exhaust gases from the Kyushu Plant Kurosaki District as a CO_2 capture technology, including thermal energy-derived. In this demonstration, energy-efficient solid amine sorbents were used for CO_2 capture.

Regarding CO_2 utilization, the basic technology is being developed to establish CO_2 fixation and utilization technologies using a recycled concrete aggregate from used concrete. This technology produces limestone by reaction and fixation of calcium oxide (CaO) derived from used concrete and CO_2 captured at MUCC plants. Green Innovation Fund/NEDO were used to develop a technology to separate calcium powder for CO_2 fixation from used concrete and efficiently absorb CO_2 directly. MUCC plans to proceed with supplementary experiments to establish the technology and to prepare for demonstration tests.

In addition, MUCC is pursuing demonstration tests and other activities that promote research and development of CO_2 fixation and utilization technologies using wastes and by-products other than used concrete. The company can thereby identify issues and study solutions in anticipation of implementation while considering a community-based business model for carbon recycling to promote social implementation smoothly.

Concrete forming process using waste and CO_2



6. Supporting sustainable growth through cross-industry collaboration

In this whitepaper, we have highlighted positive technologies in energy supply (solar and wind), transmission and distribution; nuclear power; industrial electrification; hydrogen-based and biogenic fuels; and CCUS — technologies that will significantly advance Japan toward carbon neutrality in the energy eco-system. Some of these technologies also support circularity; for example, in producing synthetic fuels from CO_2 emissions. Meanwhile, the integration of these different technologies will accelerate the shift toward a sustainable society.

To deploy and rollout these technologies, two steps are required: 1) market creation and maturation through government funding, and then 2) a sustainable business case for private sector, achieved by the ability to pass on associated costs to end users.

1) Market creation and maturation through government funding

In the early stages of deploying and rolling out of new technologies, the private sector alone cannot bear the necessary funding required, given that the cost of introducing new technologies is usually high. Therefore, the government are encouraged to provide early-stage funding to creating a new market.

2) Private sector business case through passing on the associated costs

Once the technology matures and is widely used, companies can break away from government support and legitimately pass on the associated costs to customers. The Japanese government is aiming to build the market through "investment promotion measures that integrate regulation and support." It has earmarked JPY20 trillion for early-stage technology investment through the GX Economic Transition Bonds and carbon pricing and has set mid-to-long-term cost (reduction) targets for each technology.

Energy costs are and will continue to be relatively high in Japan, and it is not clear which energy sources will have a cost advantage in the future (Figure 6.1 and Figure 6.2). Each technology presents its own cost curve, which may become further complicated due to the demand for alternatives (e.g., hydrogen and synthetic fuels) to replace fossil fuel-based feedstock:

- **Hydrogen:** The goal is to reduce the cost of hydrogen, which is currently high at JPY50/Nm^3, to JPY30/Nm^3 in 2030 and JPY20/Nm^3 in 2050. The cost of importing hydrogen, including marine transportation costs, is inevitably higher than the cost of overseas green hydrogen production, where cheaper renewable energy can be obtained locally. In addition, the Japanese government's hydrogen cost target is calculated on a CIF basis (delivered on board) and does not include the price of pipelines, tanks, and equipment for hydrogen utilization, so there is a high level of uncertainty about the future cost trajectory.

- **Renewable energy:** The current cost of renewable energy in Japan is approximately JPY20/kWh, and it is expected to fall to JPY8/kWh. However, even this will be relatively high compared with the current cost of renewable energy in Europe. The fact that these costs do not include the expenditure associated with responding to supply-demand fluctuations, such as the installation of transmission and distribution facility/network and storage batteries, means there is uncertainty as to the future evolution of costs.

- **Fossil fuel (oil/coal/gas) + CCS:** The cost of fossil resources is expected to rise with the introduction of carbon pricing or CCS, but the outlook for institutional design and technology development trends is unclear and highly uncertain.

- **Synthetic fuels (e.g., SAF, e-methane, and other e-fuels for feedstock application):** Given unpredictable hydrogen and CO_2 procurement costs, there is a high degree of uncertainty.

Figure 6.1 The cost of energy in Japan[180]

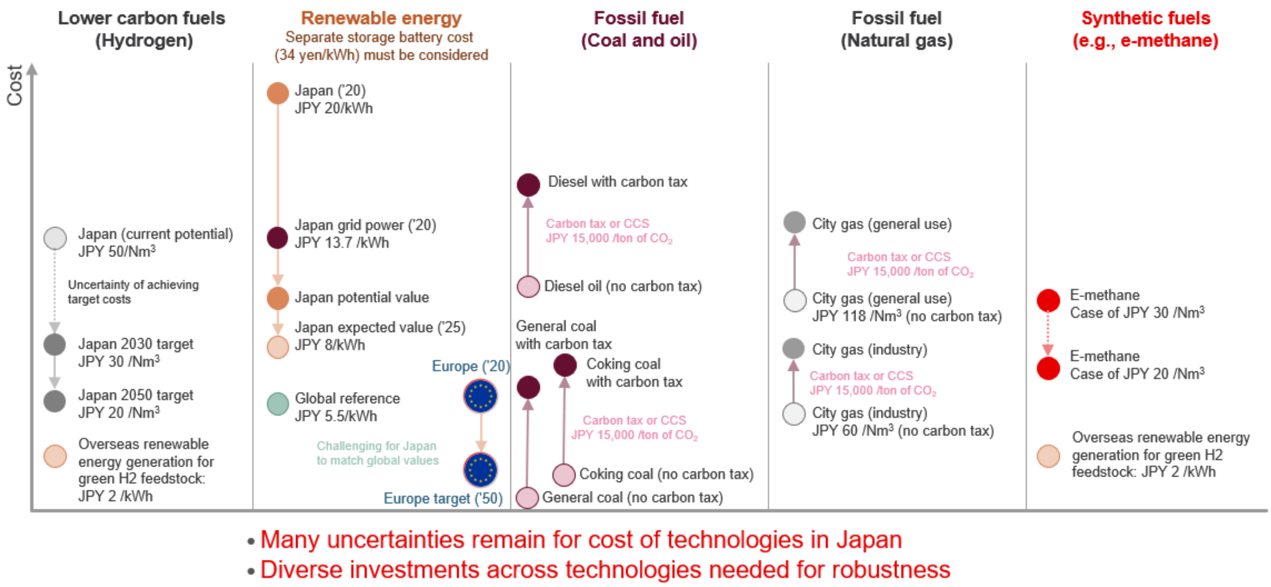
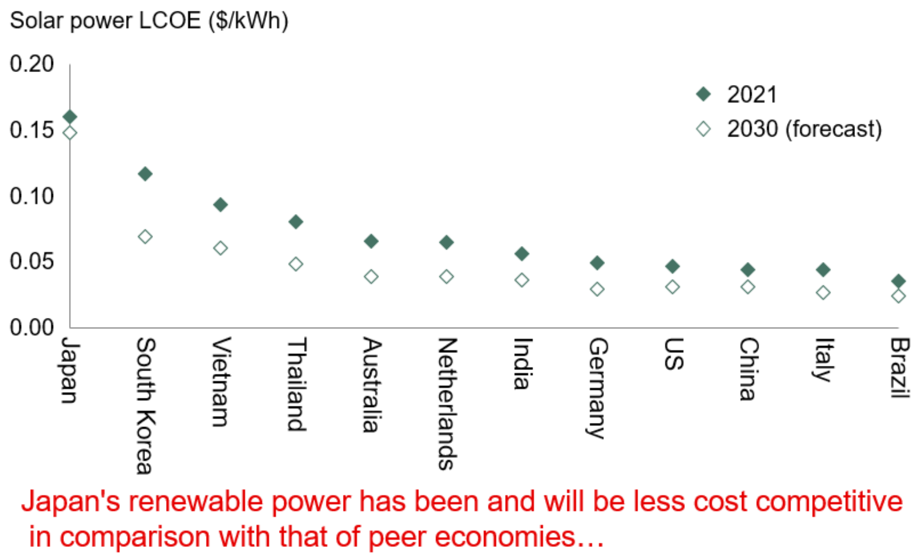


Figure 6.2 Renewables and hydrogen prices[181]



Japan's recent history is characterized by uncertainties over energy supply. In the 1980s, when Japan's GDP per capita exceeded that of the US,[182] Japan's energy costs were relatively high compared to countries outside Japan (Figure 6.3). This was due to low levels of energy self-sufficiency and a lack of connectivity with other countries. This was one catalyst for Japan's expansion of investment in the LNG market.

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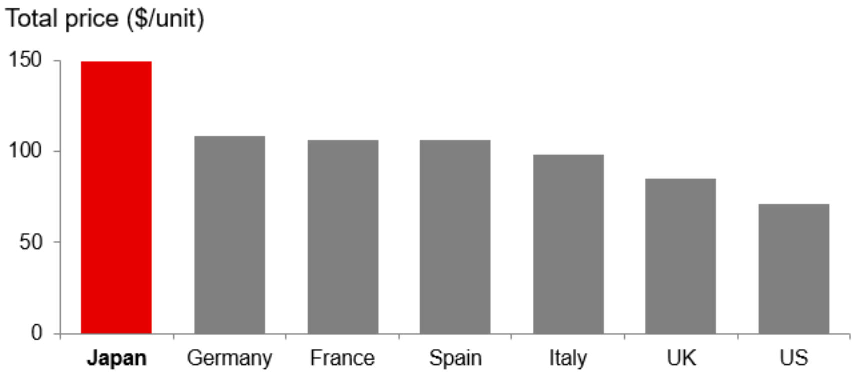
180 Hydrogen cost target: https://www.meti.go.jp/press/2022/02/20230210002/20230210002_3.pdf
Other values are most likely values or average of actual values based on BCG analysis based on multiple sources.

181 IRENA (2022), Renewable Energy Statistics 2022, International Renewable Energy Agency (IRENA), Abu Dhabi

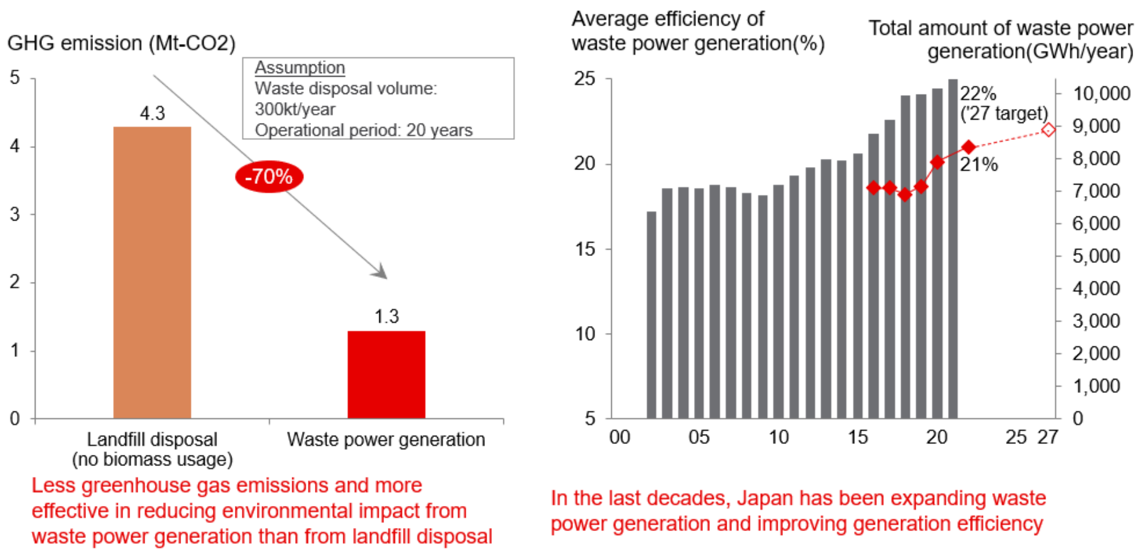
182 https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=JP-US

Figure 6.3 Comparison of residential energy in 1980s in which Japan advanced LNG import further[183]



In addition, Japan, which has always faced energy supply constraints, has focused on developing energy-saving technologies. Thermal recovery is a good example (Figure 6.4). In Japan, more than 60% of waste plastics are efficiently incinerated at power plants to generate heat and electricity.[184] This process allows for effective waste energy recovery and reutilization, and eliminates the need for landfill sites, which are scarce in any event. In many cases outside of Japan, waste tends to be disposed of in landfills. However, long-term landfill disposal produces methane, which has a global warming potential of 28 times greater than CO_2.[185] For an energy-constrained country, waste power generation has been an effective option in reducing both energy imports and environmental impact, because it produces less greenhouse gas emissions than long-term landfill disposal without biomass gas utilization or other measures. In addition, Japan has worked to expand and improve the efficiency of waste power generation, for example through automation and steam temperatures up to 400 degrees Celsius (Figure 6.5).

Figure 6.4 Effect of environmental load reduction of waste power generation and trends in waste power generation[186]



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[183] IEA (2023), End-Use Prices Data Explorer, IEA, Paris https://www.iea.org/data-and-statistics/data-tools/end-use-prices-data-explorer

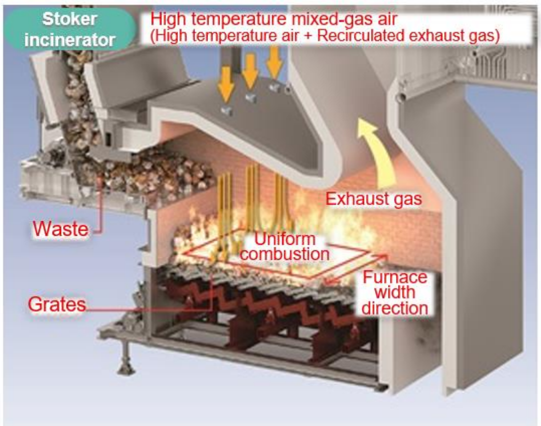
[184] https://www.pwmi.or.jp/pdf/panf1.pdf

[185] https://unfccc.int/process-and-meetings/transparency-and-reporting/methods-for-climate-change-transparency/common-metrics; https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf#page=73

[186] https://www.jsim.or.jp/pdf/products/env-equipment/a-1-53-04-00-00-20211011-02.pdf; https://www.env.go.jp/recycle/waste_tech/ippan/

Figure 6.5 Technological advancement for efficiency improvement [187]

Advanced waste incinerator

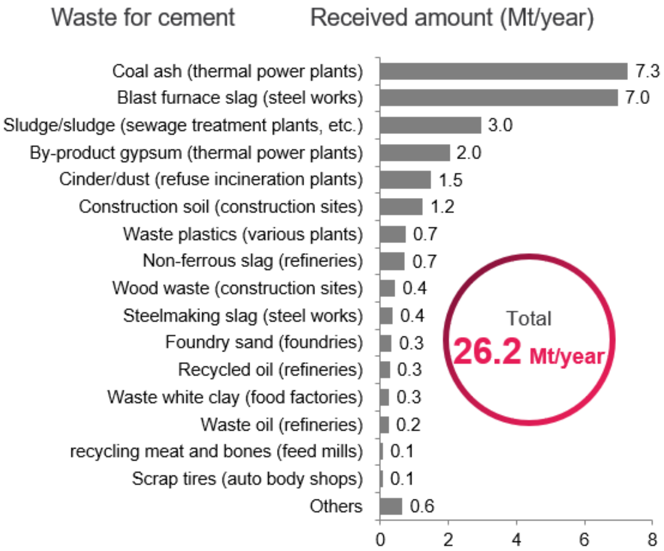


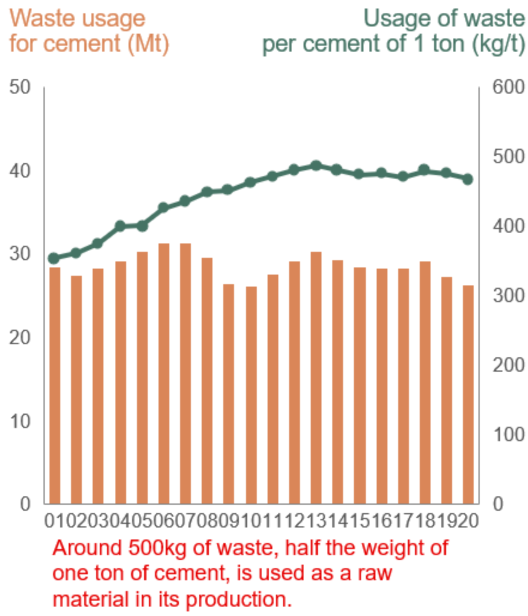
Global remote center to monitor waste to energy plants

To achieve carbon neutrality, Japanese government has been discussing to provide additional R&D support under the Green Innovation Fund to develop, among others, effective carbon capture technologies suitable for exhausts from existing waste incineration plants, and commercial-scale, high-efficient pyrolysis technologies, and biomethane technologies[188].

Another example of domestic innovation is waste recycling in the cement industry. The industry accepts a wide range of wastes and by-products and utilizes approximately 26.2 million tons annually (equivalent to approximately 5% of the total waste generated in Japan). Effective waste utilization in the Japanese cement industry has been an ongoing effort over the past several decades, and today nearly 500kg of waste is used per ton of cement, or about half of the total (Figure 6.6).

Figure 6.6 Trends in waste utilization in the Japanese cement industry[189]





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[187] https://www.jfe-eng.co.jp/news/2018/20180625.html; https://www.jfe-eng.co.jp/en/news/2018/20180316.html

[188] https://www.meti.go.jp/shingikai/sankoshin/green_innovation/green_power/007.html

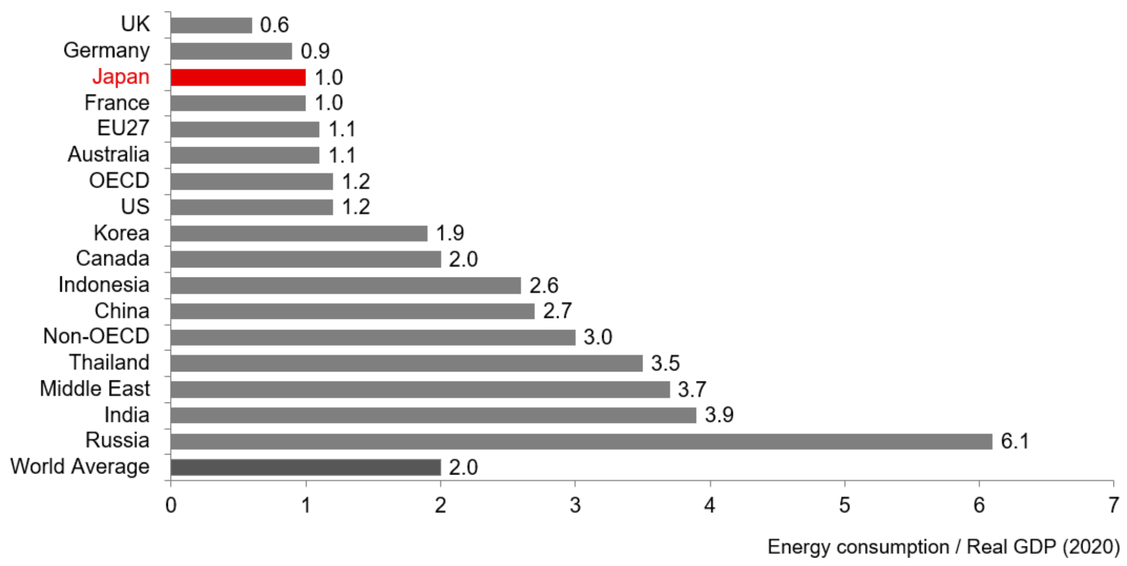
[189] https://www.meti.go.jp/policy/energy_environment/global_warming/transition/transition_finance_technology_roadmap_cement_jpn.pdf

Furthermore, Japanese companies have a history of not only working to reduce their own emissions, but also contributing to CO_2 emissions reductions (avoided emissions) by developing energy-efficient products thereby reducing energy consumption of users. For example, AGC, a leading manufacturer in the glass industry, was the first company in Japan to commercialize insulated glass units (IGUs) in 1954. In 1987, AGC introduced “low-E double-glazing glass” to its IGUs with higher heat shielding and insulation and helped raise awareness of the comfort provided by glass in hot summers or cold winters. In collaboration with a leading prefabricated house manufacturer in the 1990s, AGC strived to meet design needs and technical challenges to provide comfortable use of space. Now, about 99% of new homes in Japan use double glazing glass, of which 85% is low-E glass, from negligible use at the start of this endeavor. Japan has a climate with four distinctive seasons and a long history of unique architecture. AGC has pursued "comfort beside the window" with its technology and marketing efforts, which have yielded energy efficiency in newly-built houses.

The company has also contributed to a reduction in electricity consumption for heating and cooling through its high heat-shielding and insulation technology for applications such as automobiles. To promote global efforts to reduce emissions through energy-saving products, avoided emissions on a product level may require global recognition through a harmonized methodology.

Japan has achieved one of the highest energy consumption efficiencies in the world as a result of energy conservation efforts by a wide range of industries, despite the country's limited energy supply. (Figure 6.7).

Figure 6.7 Comparison of energy consumption per real GDP in major countries and regions (2020)[190]

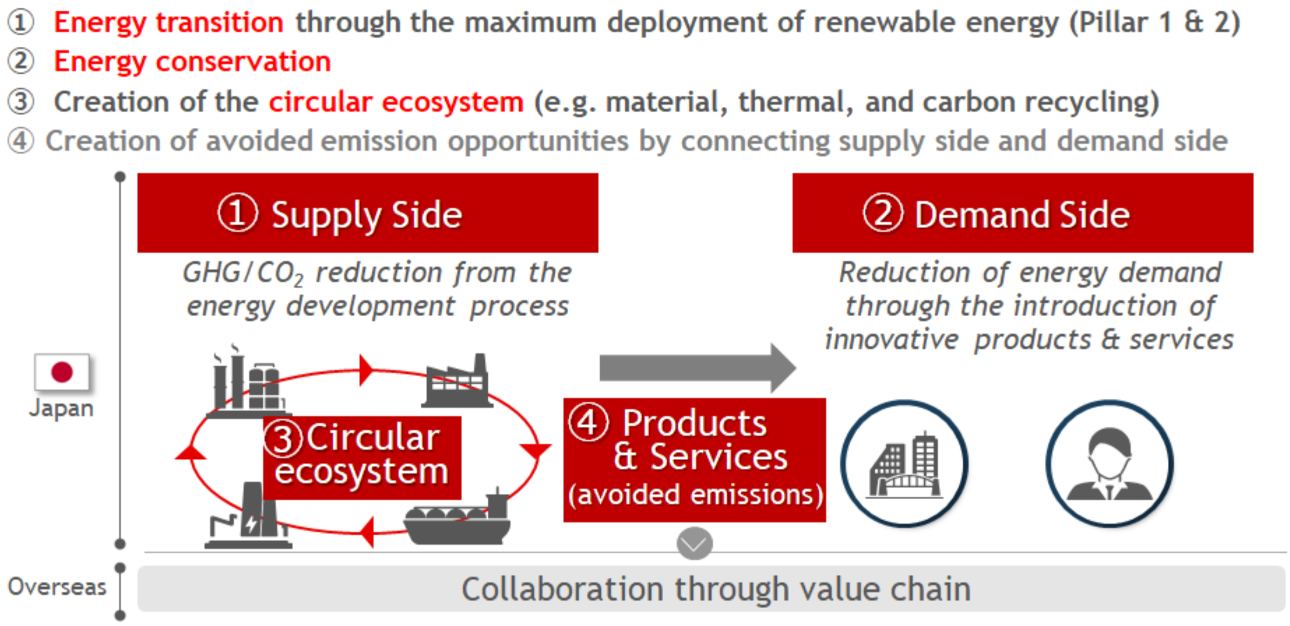


The development and introduction of new energy supply technologies, and refinement of energy-saving and demand technologies with waste heat and material recovery, will accelerate Japan’s journey toward carbon neutrality, as well as support the international community in its efforts to do the same where appropriate. These collaborative efforts through value chains may need to be deepened and expanded to shift toward a more circular and sustainable economy. Therefore, as we aim for sustainable growth over the middle to long term, we will deepen MUFG’s value chain collaboration across these topics, contributing to coordination between developed countries, and helping to forge

190 https://www.enecho.meti.go.jp/about/whitepaper/2023/pdf/2_1.pdf

partnerships among countries in the Indo-Pacific region, including ASEAN and its member states, in line with G7 Hiroshima Leaders' Communique (Figure 6.8).

Figure 6.8 Four levers of Japan's carbon neutrality



7. MUFG's role in fostering a sustainable society

In this whitepaper, we have outlined the key technologies necessary, as highlighted in Japan's GX Basic Policy, to achieve carbon neutrality in energy (i.e. electricity and heat supply), reflecting Japan's unique geographical characteristics, industrial base, and existing infrastructure.

The Japanese government's strategy outlined here would support economic growth and strategic positioning of key industrial sectors in a sustainable world market, while ensuring energy security and affordability. The GX Basic Policy laid out the next 10-year action plan with clear roadmaps. Together we will further polish the holistic strategy to minimize the social/financial cost associated with a "whole-of-economy transition," thereby achieving an "orderly transition".

MUFG's transition philosophy

While the technologies we highlighted are critical for Japan and the industry to achieve carbon neutrality, they are also vital for MUFG's Net Zero ambition. To recap our transition engagement philosophy, the unique challenges we face in pursuit of our Net Zero goal in our finance portfolio by 2050 provide opportunities to build partnership and unlock innovation. Our underlying philosophy can be summarized as follows:

- MUFG has a significant balance sheet size (approx. $3 trillion), including ample liquidity/deposits.
- As the largest bank in Japan with an extensive footprint/client base throughout Asia, we have exposures to clients in all sectors, including high-emitting sectors.
- Given the size of our loan book, our balance sheet reflects the underlying economy of Japan, Asia and the rest of the world.
- A carbon neutral real economy would translate to MUFG achieving its Net Zero ambition, but the reverse is not consistent with our corporate purpose of "Committed to empowering a brighter future."
- To achieve a carbon neutral economy in Japan and the rest of the world, MUFG, together with the public sector where appropriate, needs to provide new money to support emissions reduction (our conviction being "the money needs to flow where emissions are").
- Our holistic approach to enable a "whole-of-economy transition" means we do not subscribe to the idea of "cherry picking" certain sectors/assets or significantly divesting our existing exposures (i.e. "paper decarbonization") for the purpose of achieving carbon neutrality.
- As a financial group with commercial banking operations having many lending relationships, we engage throughout the origination lifecycle. That is, we aim to understand transition plans, identify financing opportunities, originate lending transactions, make financing decisions, and follow up. Our approach is not "transactional"; rather putting emphasis on engagement and dialogues with our clients to understand their climate ambition and strategies.

The distinctive challenges that Japan faces and our business model including our strong client base inform our underlying philosophy: "our clients' emissions reduction is our emissions reduction", and it is this core principle that is driving us to publish whitepapers and promote the global common good.

The role of banks in facilitating transition

As a commercial bank actively and directly lending in the "primary market" to clients across the industries, MUFG has a role to facilitate a whole of economy transition in Japan. Through frequent engagements with our clients, we would evaluate clients' transition plans and finance their transition to Net Zero/carbon neutrality. This is different from financial institutions who are mostly active in the secondary market (e.g. equities or bonds). The capital reallocation in the secondary market does not directly tie to funding issuers' financing needs for their transition. In this sense, commercial banks have an outsized role and responsibility to finance the Net Zero/carbon neutrality transition, especially in countries where the primary market plays a key role in corporate finance (such as Japan and Asia).

Business viability lens

MUFG's vision is broader than the technologies and pathways outlined in this whitepaper. Our objective is to actively support various stakeholders involved in the journey toward carbon neutrality, ensuring the successful innovation and implementation of transformative technologies. The pressing question from a MUFG's perspective is how we finance (i.e. providing new money to corporates or projects) to effectively deploy the technologies, many of which are still in the development stage and require substantial capital mobilization.

Having a commercial bank as one of its core entities, MUFG is committed to providing the necessary funding to deploy the key technologies (and the creation of associated supply/value chains) provided that financing opportunities are economically viable to ensure the safety and soundness of our operations. Debt, sometimes referred to as leverage, has the effect to magnify or scale the subject it is applied to. If the technology, business, or project that a debt is supporting is losing money, the loan would magnify the losses. It is therefore critical that technologies are proven to be commercially viable through, for instance, the efforts of the industry, de-risking by governments, among others, whereby making the businesses profitable and leveraging to increase the cashflow. Many of the key technologies discussed in this whitepaper are still in the development stages and making the early steps towards commercialization. There is a challenge for such technologies to obtain long-term debt financing without appropriate returns to the risks associated with nascent technologies.

We note that technologies contributing to achieve carbon neutrality may not generate stable cashflow until they become available for the broader rollout in the society, and until then, government support may be needed. We therefore will collaborate closely with the government and industry to foster an enabling ecosystem that encourages the development and seamless integration of these groundbreaking technologies in an effective manner.

To achieve sustainable growth in Japan while reducing emissions, and for banks to provide finance on a sustainable basis, we need to apply a lens to which we analyze "business viability". This lens has three components: legitimization, incentivization, and evidence with integrity (Figure 7.1).

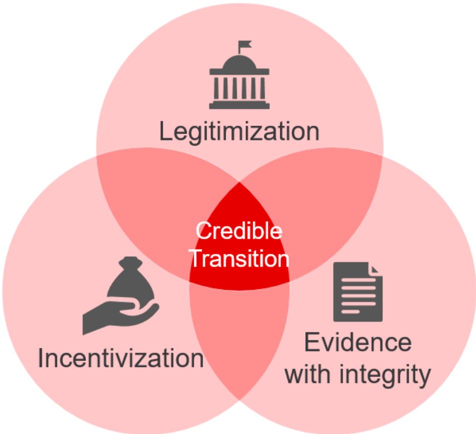
- **Legitimization**
  Framework to encourage the private sector to respond to climate change by establishing legally-binding regulations and rules (e.g., enhancing predictability in terms of introducing a carbon tax on fossil fuels, or introduction of an emissions trading scheme). Legitimization will foster awareness in terms of which technologies are required in the near term (e.g., increasing the mixing amount of hydrogen-based or biogenic fuel), for the purpose of longer-term emission reductions (i.e., zero-emission thermal power plants). In essence, legitimization will increase awareness and predictability among stakeholders. Many countries, including Japan, that have ratified the Paris Agreement have passed laws requiring various actors to introduce measures to achieve the ambition a country has pledged.

- **Incentivization**
  Mechanisms to attract external capital by providing financial incentives, including the use of public funds for the deployment and roll out of new technologies that contribute to carbon neutrality (e.g., support to promote capital mobilization for infrastructure through the JPY20

trillion Japan's GX Economic Transition Bonds, providing tax credit/financial assistance to address the cost disadvantage of cleaner technologies (compared with old technologies)). These features allow banks to assess the financial viability of the new technologies given the higher predictability in terms of future cashflow.

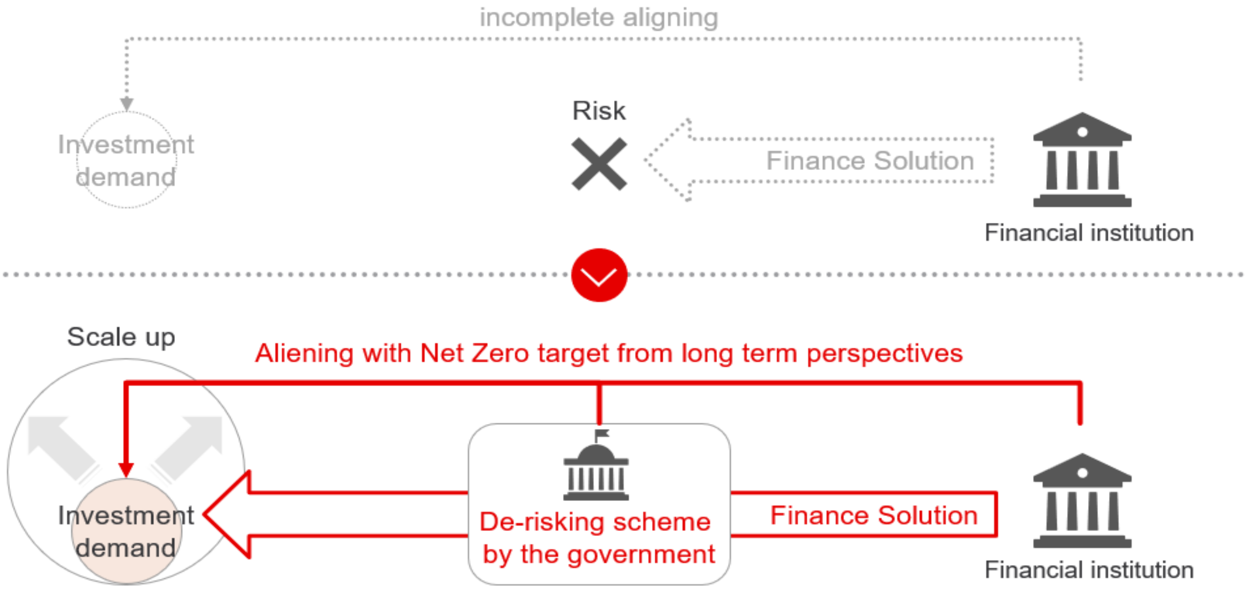
- **Evidence with integrity**
  Mechanisms to regularly monitor and report a company's commitments to carbon neutrality based on transparent evidence of its own emissions reductions (or avoided emissions where appropriate) and in the deployment and roll out of new technologies. This allows banks to monitor the progress of emissions reduction, which in turn will reduce banks' financed emissions.

Figure 7.1 The three components of a credible transition



To facilitate an orderly transition and mobilization of capital, it is vital to manage risks across the capital formation lifecycle. Government plays a critical role in identifying and mitigating early-stage risks in connection with innovation and commercialization. Stable capital flows can be generated from new technologies only where risks are effectively managed within the technology development lifecycle (Figure 7.2). Therefore, alignment between government and financial institutions is critical to ensure that sustainability goals are shared and a pathway toward implementation is clear. Long-term alignment of priorities across government, financial institutions, and companies in the real economy can be formed through dialogues and engagement, and MUFG may play an important role to convene stakeholders.

Figure 7.2 Aligning investment targets and the need for government de-risking scheme functionality



In this whitepaper, we highlight two main approaches to providing policy and financial support for carbon neutral financing projects (Figure 7.3).

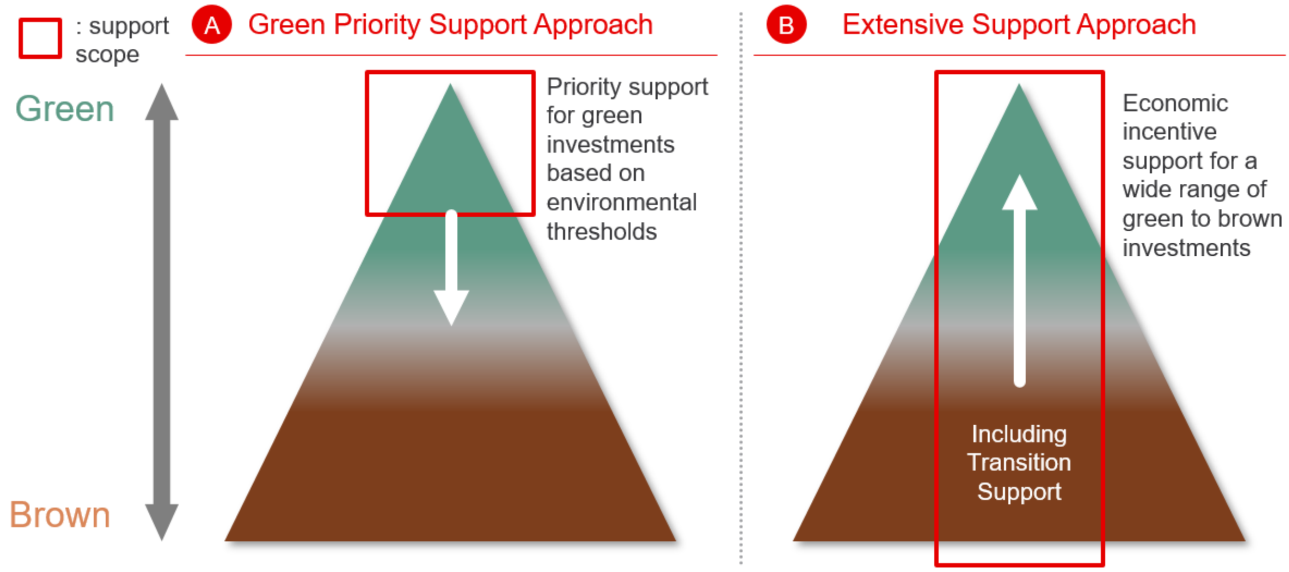
- **A) Green Priority Support Approach:**
  An approach that establishes criteria for green (or sustainability) eligibility and prioritizes policy and financial support for projects meeting "green" thresholds (and utilizing disclosure requirements to facilitate capital mobilization).

- **B) Extensive Support Approach:**
  Similar to Approach A above, but adding a broad range of economic incentives to various parties to encourage "brown" sector/activities to become "greener". This measure may require the selection of transition projects for brown assets that have the potential to convert to green in the future. The approach may also encompass just transition elements and reflect the need to support a range of technologies along a more nuanced carbon neutrality pathway.

As discussed throughout this whitepaper, each country will take its own pathway because there is no single winning climate strategy that can be applied globally. Japan's approach is a comprehensive one combining three key levers: emission reduction (supply side), reducing electricity demand (demand side), and developing circular ecosystem (circular economy).

In the context of emission reduction, Japan's energy transition strategy mobilizes most of state-of-the-art technologies, including renewable energy deployment, nuclear power usage, and the development of technology/infrastructure for hydrogen-based and biogenic fuels such as ammonia and hydrogen. To minimize the social cost associated with transition by using existing infrastructure and workforce, the plan includes repurposing of coal-fired power plants and the ramp-up of carbon capture, utilization, and storage (CCUS), both of which will contribute to affordability and stability of the electricity supply while reducing the emissions. The idea of mobilizing capital to both green and future green (currently brown) sector/activities is an optimized approach given Japan's challenges but also strong industrial base and technological capabilities.

Figure 7.3 Policy and financing support approaches to carbon neutral projects for financing



MUFG's approach towards transition finance

MUFG will continue client engagement and provide financing support in a wide range of projects, including the positive technologies presented in this whitepaper, without overly narrowing the options for carbon neutrality. As discussed earlier, MUFG's philosophy is to facilitate a whole-of-economy transition. To do this, we will support those companies with a genuine commitment and ability to deliver a transition that is in line with the country's nationally determined contribution (NDC) or carbon neutral strategy. This approach may require us to finance opportunities that may not be aligned with the Paris Agreement trajectory at this moment (i.e. "aligning" or "not aligned yet").

Our approach is to review low-carbon technologies in a holistic manner using the lens discussed above, and proactively support the development of an associated supply/value chain (both domestic and global), which will deliver the macro-level emissions reduction as well as the development of a resilient and robust energy system with the long-term perspectives. The business viability assessment will be conducted on a transaction by transaction to ensure safety and soundness of our operations.

Role of private finance and government

The projects will have different risks depending on the level of development. The role of government/industry/financial opportunities will also vary. MUFG will play the role of facilitator, connecting government and industry at each stage (Figure 7.4).

- **I: Market creation phase**

MUFG will seek to substantiate Japan's carbon neutrality pathway through dialogue with individual companies, including through the development of the whitepapers. Working with individual companies allows us to identify linkages and interdependencies between industries and confirm the alignement of individual and industry-wide approaches with national commitments. We will then work with other industries to identify the key deployment risks for each technology and with government to establish necessary de-risking measures. This de-risking approach will serve to incentivize implementation of the carbon neutrality measures needed to achieve national, sectoral, and individual commitments and targets.

MUFG may also engage in equity investment opportunities to the extent permitted under applicable laws and regulations.

- **II: Market scale-up phase**

The government can create a productive environment through subsidies and/or tax incentives, while industry will pursue continual cost reductions by refining mass production technologies through standardization and modularization. MUFG will contribute to market scale-up by providing financing solutions in the form of debt/lending as a main tool, including large-scale corporate/project financing, using our balance sheet or underwriting capabilities.

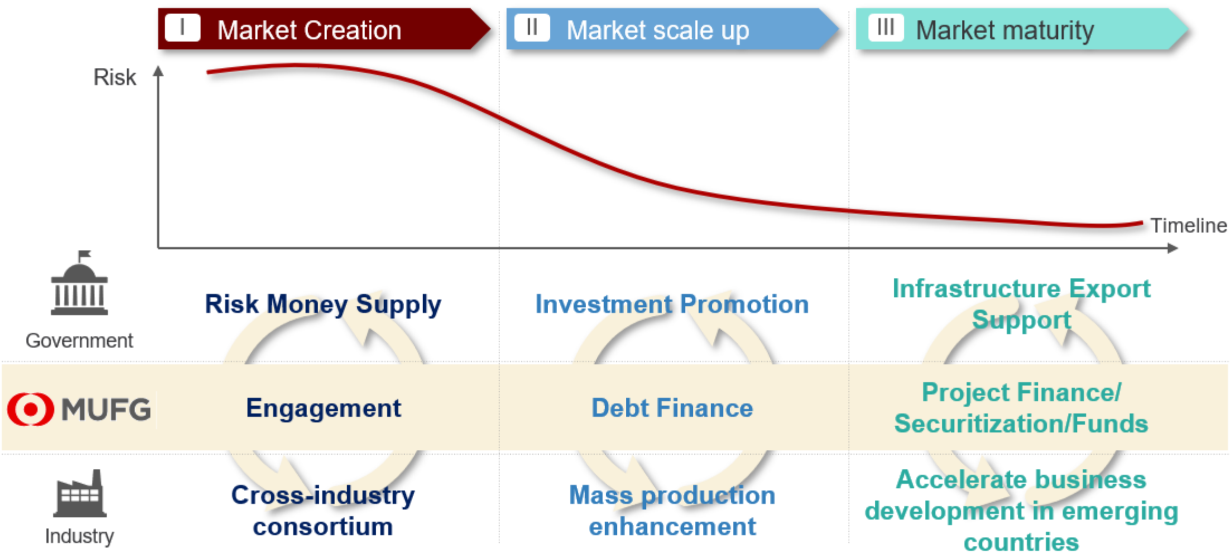
The loans at this stage onward play a role to magnify or scale what it is supporting. If the technology, business, or project that a loan is supporting is not viable, we cannot justify financing such business or project. It is therefore critical that technologies are proven to be commercially viable.

- **III: Market maturity phase**

The government has the role of providing support for infrastructure development to deploy technology roll-out in Japan and overseas. Industry can accelerate business development in the domestic market and in emerging economies. MUFG will finance emission reduction opportunities or provide our underwriting capabilities to facilitate mobilization of private capital from international markets, provided that the opportunities are economically viable, and the returns are appropriately provided against the risks at hand.

Through the three phases above, MUFG will support a whole of economy transition in line with national and sectoral pathways, as well as the pathways developed by individual companies, including by seeking evidence of progress and promoting reporting and transparency.

Figure 7.4 Expected roles of government/industry/financial institutions in each market stage



Conclusion

MUFG continues to play an important role in building mutual understanding between Japan and the rest of the world regarding Japan's carbon neutrality commitment and pathway. We seek to provide clarity with respect to Japan's carbon neutral pathway and put them in to wider context (i.e. how other economies are deploying new technologies). This will include the technologies to be deployed in the real economy and the associated timelines, and these initiatives will allow stakeholders to understand global transition pathways and will enhance predictability.

With policies in place in Japan and globally, the world's attention shifts toward tangible climate action—and the financing required to enable it. MUFG will play an active role in these activities in Japan, Asia, and globally though our capability to provide new finance to corporates and projects. In our whitepaper 2022, we outlined that we would engage proactively in the formation and implementation of Japan's strategy. Meanwhile, our engagement with clients has allowed us to develop our "transition plan assessment lens." MUFG's role naturally sits between the Japanese government and global industry, as a bridge to the finance industry in line with the government's priorities.

With these evolving landscapes, MUFG recognizes the importance of engaging with high-emitting sectors and supporting their transitions through the provision of financial solutions. Financial institutions, especially banks, have the critical role to play in supporting the global energy transition by providing new money in the rollout of the clean technologies. MUFG is committed to collaborating across sectors and industries to enable this global transition.

Appendix: Companies supporting this whitepaper

Acronym / Abbreviation	Company name	Industry	Website
AGC	AGC Inc.	Glass, chemicals, and high-tech materials	Link
ENEOS	ENEOS Holdings, Inc.	Oil and Gas Refining and Marketing	Link
IHI	IHI Corporation	Industrial Machinery and Supplies and Components	Link
JAL	Japan Airlines Co., Ltd.	Transport Services	Link
JERA	JERA Co., Inc	Electric Utilities	Link
JFE Engineering	JFE Engineering Corporation	Engineering and Construction	Link
Kansai Electric Power	The Kansai Electric Power Co., Inc.	Electric Utilities	Link
MHI / MHI Group	Mitsubishi Heavy Industries, Ltd.	Industrial Machinery and Supplies and Components	Link
Mitsubishi Chemical	Mitsubishi Chemical Group Corporation	Diversified Chemicals	Link
Mitsubishi Electric	Mitsubishi Electric Corporation	Electrical and Electronic Manufacturing	Link
MUCC	Mitsubishi UBE Cement Corporation	Building Materials and Cement	Link
Nippon Steel	Nippon Steel Corporation	Steel	Link
NYK	Nippon Yusen Kabushiki Kaisha	Marine Transportation	Link
Oji HD	Oji Holdings Corporation	Paper and Packaging	Link
Osaka Gas	Osaka Gas Co., Ltd.	Gas Utilities	Link

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