2022

Transition Whitepaper 2022

AN MUFG PERSPECTIVE ON HOW JAPANESE COMPANIES ARE MOVING TOWARDS CARBON NEUTRALITY

Transition Whitepaper 2022

AN MUFG PERSPECTIVE ON HOW JAPANESE COMPANIES ARE MOVING TOWARDS CARBON NEUTRALITY

Preface

Last year at MUFG, we defined our purpose as being "Committed to Empowering a Brighter Future." I believe that committing to help solve the environmental and social issues facing the world today is a great responsibility for financial institutions. Since pledging to achieve carbon neutrality by 2050 in May 2021, we have accelerated our efforts to tackle climate change. In the MUFG Progress Report published in April 2022, we announced interim targets for the power and oil & gas sectors in our financial portfolio to achieve net-zero greenhouse gas emissions. In addition, we have announced our cumulative target for a sustainable finance total of 35 trillion yen by FY2030 (from 14.5 trillion yen achieved by FY2021) to support renewable energy and other sustainable initiatives.

We believe that engagement, commitment, and persistence are the keys to achieving a carbon-neutral society. Advancing transition steadily through customer engagement is critical. It is clear that divestment is not a solution as there is no assurance that actual emissions will decrease, while divestment may reduce our financed emissions. It is conceivable that the buyer may have less ambition with respect to “net zero” and the emissions may even increase as a result. For this reason, we believe we have the responsibility to engage with our clients in all sectors and regions, and finance their transition journey. This is the only credible way to deliver “just and orderly” transition. Accompanying with our customers on their journeys to carbon neutrality through engagement is our core principle throughout MUFG. Also, technological innovation is essential for emissions reduction. Together, with various collaborators from both the public and private sectors, we intend to consider how the society can mobilize financing for such innovations.

In preparing this Transition Whitepaper, we held deep discussion with our customers. We also shared our views with policymakers outside Japan, who embraced the need for this type of research and for related initiatives by Japanese and foreign companies. We will continue to contribute to global decarbonization, paving a concrete path by maintaining engagement with our customers and by supporting the technological development needed to achieve carbon neutrality.

Mitsubishi UFJ Financial Group, Inc.

President & Group CEO

Hironori Kamezawa

Acknowledgement

MUFG is grateful to the industry companies that helped inform, and/or offered feedback on, this whitepaper, including JERA, Nippon Steel, Mitsubishi Ube Cement, Mitsubishi Chemicals, Oji Holdings and AGC. MUFG also acknowledges the contributions of Boston Consulting Group (BCG) for the research, writing and production of this whitepaper.

Contents

Executive summary 9

Introduction 14

Objectives 15

Our shared climate neutral ambition 16

Tailoring climate strategy to local conditions 22

Interdependency 26

Power 28

Power sector overview 29

Renewable energy 30

Nuclear power 31

Low-emission thermal energy 32

Spotlight on JERA 34

Steel 38

Steel sector overview 39

Japan’s carbon-neutrality pathway 42

Spotlight on Nippon Steel 45

Cement 48

Cement sector overview 49

Japan’s carbon-neutrality pathway 51

Spotlight on MUCC 55

Chemicals 58

Chemical sector overview 59

Japan's carbon neutrality pathway 61

Spotlight on Mitsubishi Chemical Group Corporation (MCG) 66

Paper 69

Paper sector overview 70

Japan's carbon neutrality pathway 71

Spotlight on Oji Holdings Corporation 74

Glass 77

Glass sector overview 78

Japan’s carbon-neutrality pathway 79

Spotlight on AGC 82

Conclusion 85

Japan’s clean energy future 86

Japan demonstrates strong commitment to a carbon neutral future 86
Japan's experience could accelerate efforts throughout Southeast Asia 87
Regional interdependencies warrant collaborative climate action 90
Appendix A. Glossary 92
Appendix B. Summary of Climate Drivers 93
Appendix C. History of Emissions Reduction in Japan 95
Appendix D. Carbon Capture, Utilization, and Storage (CCUS) 97
The need for CCUS 97
Development status of CCUS 97
CCUS in Japan 99
Appendix E. Hydrogen 102
Hydrogen as a CO_2-free alternative fuel 102
The development status of hydrogen fuel 102
Japan's plan for hydrogen procurement 103
Appendix F. Ammonia 105
Ammonia as a CO_2 free alternative fuel 105
Establishment of ammonia as an alternative fuel 105
Challenges in implementing ammonia combustion technologies 106
Disclaimer 107

Table of Figure

Figure 1. CO_2 Emissions by sector, 2019 16

Figure 2. A. Average age of existing coal power plants in selected regions in 2020. B. Average efficiency of coal-fired power plants, 2016. 17

Figure 3. A. Existing and proposed UK Interconnectors. B. Japan's electrical grid operates on two separate frequencies. 20

Figure 4. Long-term strategy under the Paris Agreement. 24

Figure 5. A. Global primary energy consumption per GDP. B. GDP growth and CO_2 emissions of Japan. 25

Figure 6. Marginal abatement cost by technology in Japan. 26

Figure 7. Global direct CO_2 emission per sector (2020). 26

Figure 8. Interdependencies between the energy sector and key industries. 27

Figure 9. Japan's electricity mix from 2020-2030. 29

Figure 10. A. Investment in renewable energy as a percentage of GDP, 2015. B. Share of primary energy from renewable sources. 30

Figure 11.A. Nuclear power capacity by country, 2020. B. Electricity generation from nuclear in Japan, 1965-2021. 32

Figure 12. Renewable energy projects. 35

Figure 13. JERA Zero CO_2 Emissions 2050 Roadmap. 36

Figure 14. Comparison of Crude Steel Production and Scrap Availability. 40

Figure 15. A. Ratio of scrap steel used in steel products in US. B. Ratio of high grade steel scrap used in US EAFs. 40

Figure 16. Industry end-user electricity prices, 2019. 41

Figure 17. Comparison of ironmaking methods in each country (2019). 43

Figure 18. Energy efficiency in steelmaking by country (2019). 43

Figure 19. Schematic diagram of COURSE50 and Super-COURSE50. 46

Figure 20. Roadmap of CO_2 reduction. 47

Figure 21. Cement manufacturing process 50

Figure 22. A. Specific thermal energy consumption for cement production in Japan. B. Energy consumption for clinker production in the world (2018). 51

Figure 23. Alternative fuel utilization transition (firing process) in Japan. 52

Figure 24. Use of wastes and by-products in Japanese cement industry, kg per ton of cement. 53

Figure 25. Overview of the Green Innovation Fund project. 54

Figure 26. Image of Methane Synthesis. 56

Figure 27. The Carbon Neutral Vision of MUCC 57
Figure 28. Chemical value chain and corresponding CO_2 emission reduction initiatives 61
Figure 29. Comparison of naphtha-based production, by country (kt). 62
Figure 30. Position of Japanese chemical companies in each product category (2019) 63
Figure 31. MCG's Roadmap for Carbon Neutrality 68
Figure 32. Paper and paperboard production CAGR (2010-2020). 70
Figure 33. Paper and pulp manufacturing process, and its emission. 71
Figure 34 A. Pulpwood Self-sufficiency rates. B. Recycled paper utilization rate, 2015-2020. 72
Figure 35. The energy mix of the global pulp and paper industry, 2020. 72
Figure 36. Oji HD's "Environmental Vision 2050" for the year 2050. 75
Figure 37. Glass manufacturing process. 79
Figure 38. AGC's initiatives to date. 83
Figure 39. AGC's technologies that contribute to reducing external emissions. 84
Figure 40. A. GDP per capita and B. energy demand per capita in Southeast Asia in 2000 and 2019. 87
Figure 41. A. Change in coal consumption since 2000, by region.
B. Electricity consumption by source and region, 2020. 88
Figure 42. Projected power generation and shares of variable renewables in Southeast Asia, SDS, 2020-2050. 89
Figure 43. Southeast Asian power grid. 90
Figure 44. Energy per GDP/ CO_2 emission per kWh in Japan; Energy efficiency milestones. 95
Figure 45. CCS potential around the world. 98
Figure 46. Proposed CCUS facilities 99
Figure 47. Distribution of CO_2 reservoirs in Japan. 100
Figure 48. Japan's plan for domestic hydrogen supply. 104

Executive summary

Objectives

Financial institutions will play a critical role in the global transition to a carbon-neutral future. This is especially true for capital intensive industries, where large financial resources are required to support the production of essential goods and where it is inordinately expensive to transition to low-carbon alternatives. In order to meet the dual objectives of reducing emissions while achieving economic growth, financial institutions need to accurately understand the characteristics of each industry and the available mitigation options.

As a Japanese company with a strong commitment to climate action, Mitsubishi UFJ Financial Group (MUFG) has pledged to reduce financed emission to Net Zero[1] by 2050[2]. To this end, MUFG is working closely with relevant stakeholders to deliver on Japan's commitment to achieve carbon neutrality. However, given several constraints unique to Japan, the emissions reduction strategies across MUFG's portfolio may differ from approaches used in Europe and the United States. We aim to provide insights on the factors that will shape Japan's transition to a low-carbon economy and to contribute to the broader dialogue on this critical topic with stakeholders who share our goal.

This paper aims to:

- Describe the underlying drivers of Japan's climate strategy and summarize key differences with those of the United States and Europe
- Deepen global understanding of the efforts made by leading Japanese companies to achieve carbon neutrality across six key sectors: power, steel, cement, chemicals, paper, and glass.

Furthermore, the paper stresses the need to identify and address interdependencies between sector-based and country-level carbon-neutrality strategies when assessing the transition plan of each organization. This understanding will result in mutual recognition of the factors that need to be resolved in order to unlock carbon-neutrality opportunities across all sectors.

This assessment presents a starting point from which to evaluate the current status of Japan's transition plan and the credibility of such a pathway given the available and anticipated technologies and interdependencies. It also acknowledges the need to develop new green approaches‑ to utilize carbon capture, utilization and storage (CCUS) technology, and to regularly review the changing energy landscape. Moreover, the paper highlights where financial resources are needed today in order to catalyze Japan's ambition, as capital expenditures to spark innovation will be critical to reducing emissions. Comprehension of Japan's strategy by a broad set of stakeholders will further accelerate the virtuous circle of financial resources and innovation.

Our shared ambition is to achieve climate neutrality by 2050

Nearly 200 countries have pledged to limit global warming to well below 2°C via the 2015 Paris Agreement. In realizing this commitment, roughly half of these countries have committed to, or are considering, Net Zero or climate neutral targets. Yet despite this shared goal, country-level strategies vary considerably. There is no single pathway to achieving Net Zero or climate neutrality, as most

---

[1] Net Zero implies a global "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (IPCC). The term originally was used to describe country level action at the United Nations Framework Convention on Climate Change, and was later extended to describe corporate action on climate change indicating that the value chain results in no net accumulation of CO2 in the atmosphere. The focus of Net Zero is climate mitigation, and while adaptation and resilience are equally important, our emphasis here will be on climate mitigation strategies.

[2] MUFG determined the power and oil & gas sectors as priority sectors: https://www.mufg.jp/dam/csr/report/progress/202204_en.pdf

countries leverage a suite of technologies. That said, the resulting optionality may help accelerate decarbonization[3] or carbon neutrality.

Overall, four factors will play an outsized role in shaping climate strategy:

- Sources of energy and emissions
- Connectivity with other regions via pipelines or electricity grids
- Energy security
- Sociopolitical factors

When combined, these drivers help to explain why certain countries ultimately adopt specific strategies that consider local constraints when shaping a realistic path forward.

- For example, European countries, while diverse, share common elements in their approach to carbon neutrality. For many, emissions reduction strategies focus on renewable energy driven by strong public support and the availability of wind and solar. Wind energy, in particular, has seen strong adoption in countries such as the UK, where wind potential is high, and Germany, where the political environment and available wind potential support development. For applications requiring high heat, Europeans are investing heavily in electric alternatives (e.g., in steel production). When that is not possible, biofuels, hydrogen, or CCUS technologies are considered viable alternatives. Across the continent, collaborative efforts, such as electricity grid expansion and favorable economic policies further unify regional approaches.
- Notably, the war in Ukraine has placed energy security atop most countries' agendas. Disruption to the natural gas supply from Russia has caused some countries, such as Germany, to delay the closure of nuclear and coal power plants and revise their energy strategies. Sociopolitical factors are also exerting an influence, as climate action is often codified into law—exemplified by French and German reduction targets, as well as by the European Climate Law. Frequently, such strategies look for a step-change in technology, moving from fossil fuels to renewable energy.
- The United States (US) takes a different approach. As a vast country with widely varied political views, sources of emissions, and energy options, the US relies more heavily on incentivizing behavior using economic levers. The largest shifts in the US power sector, namely the displacement of coal and expansion of natural gas and renewables, have been driven by cost and availability. Additionally, the US transportation sector generates a significant share of emissions, with the resulting climate strategy emphasizing the adoption of low-emission vehicles. Within the US industrial sector, which contributes 23% of the country's greenhouse gas (GHG) emissions, biofuel and hydrogen technologies are expected to compliment electrification. However, such technologies will require further development to reach adequate scale.[4] The US has also invested heavily in CCUS. It has operated CCUS facilities since the 1970s, and in 2021 the US had the highest number of operational sites in the world, counting up to 43.[5] The IRA (Inflation Reduction Act), which became law in August 2022, is expected to accelerate investment for climate measures. Department of Energy (DOE) also released "Industrial Decarbonization Roadmap in September 2022 to accleerate the US net-zero GHG goal by 2050.

[3] "Decarbonization" in this paper refers to the definition cited in the IPCC Special Report on Global Warming of 1.5℃ , where said "the process by which countries, individuals or other entities aim to achieve zero fossil carbon existence. Typically refers to a reduction of the carbon emissions associated with electricity, industry and transport". https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_AnnexI.pdf

[4] The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050 (whitehouse.gov)

[5] Global Status of CCS 2021 (Global CCS Institute)

- Japan, similarly shaped by local conditions, plans to achieve carbon neutrality by 2050, with an interim goal of reducing emissions 46% by 2030. The power and heat and industrial sectors will play a critical role, as they currently account for nearly 70% of the country's emissions. Japan's strategy calls for a diversified approach that emphasizes energy efficiency, renewable energy, and low-emission thermal power and heat (using alternative fuels such as ammonia and hydrogen). Where renewable resources are available, Japan has invested heavily, already having the third highest installed solar capacity and the highest flat-land density of solar panels globally. Ardent investment in offshore wind energy could further expand Japan's renewable energy potential.
- Nonetheless, Japan has no international grid or pipeline connections, and the isolation from other countries limits the nation's ability to buffer energy supply. Moreover, nuclear power remains a politicized issue as a result of the Fukushima nuclear incident in 2011. To maintain energy security, maintain affordability for households and businesses, and ensure reliability while reducing emissions, Japan will continue to rely on low-emission thermal power. This includes a "managed phase-out" of coal-fired power plants to be achieved by: (1) shutting down inefficient plants; (2) gradually reducing carbon intensity by co-firing with alternative fuels (e.g. ammonia); and (3) deploying CCUS once available. Increasing optionality will yield a more resilient energy infrastructure and accelerate carbon-neutrality efforts. Furthermore, cost considerations strongly influence the technological landscape, as the marginal abatement cost varies from one technology to the next, even among renewables. Japan aims to develop a broad spectrum of technologies in order to keep the cost of abatement manageable and achieve an orderly transition.

The industrial sector in Japan plays an outsized role in transition to carbon neutrality

Japan has a large manufacturing and industrial footprint that supports the development of energy and materials essential for modern life. Electrification has delivered economic growth, improved quality of life, and unlocked human potential. Meanwhile, raw materials, such as steel, cement, chemicals, paper, and glass build the foundation of the economy, and the power and industrial sectors account for roughly 70% of Japan's emissions and play an outsized role in achieving Japan's carbon neutral strategy. These five basic material sectors are critical as they are at the beginning of the value chain of various essential goods and have supporting industries. A "just and orderly transition"' in such sectors will continue to impact quality of life. Behind them all is the all-important power sector.

Power. Japan optimizes its carbon-neutrality pathway for the power sector by mixing realistic options with next-generation technologies to achieve the goal. Continued investment in solar power, as well as development of offshore wind, will drive expansion of renewable energy over the coming decades. Japanese companies are heavily investing in the development of floating off-shore wind and grid-scale batteries to support the expansion of renewables in the 2030s. Also, by 2030, nuclear power is expected to provide 20% to 22% of projected electricity demand. Fossil fuels will remain a part of the mix in the near term, and the managed phase-out of these plants is expected to play an important role. Japan's power companies will retire inefficient coal plants, and they further plan to "retrofit" high-efficiency coal plants through ammonia co-firing (in the short- to mid-term), as well as realize "carbon-free" thermal as technological innovation advances. Liquid natural gas (LNG) fired plants will follow a similar trajectory and be converted to hydrogen co-firing and dedicated combustion. Co-firing will be an important breakthrough technology to meet near-term emission reduction targets as renewable technologies mature in the coming decade and infrastructure expands to support full-operation.

Steel. The steel industry, Japan's highest-emitting industrial sector, supplies high-quality steel for industrial use worldwide. The majority of steel in Japan is produced using primary production (creating steel from iron ore), which requires high energy and heat. While some countries turn to secondary production (producing steel from scrap metal) to reduce emissions, a global shortage of steel scrap and higher rates of impurities mean that primary production will still be required in the future. To decarbonize primary production, Japanese companies are developing hydrogen reduction technology for blast furnaces that can be combined with CCUS. In the long term, they plan to achieve net-zero by combining 100% hydrogen-based Direct Reduced Iron (DRI) technology with electric arc or blast furnaces designed to use alternative fuels and equipped with CCUS, or simply high-energy efficient electric-arc furnaces. The production of high-quality steel can also play a critical role in reducing the CO_2 of other sectors, including automobiles.

Cement. Accounting for ~7% of global CO_2 emissions, the cement sector produces emissions through energy-intensive processes and chemical reactions. With no single technical solution available, cement companies turn to a range of carbon-neutrality levers. In the short term, Japanese companies aim to further improve energy efficiency and leverage waste such as plastic as alternative fuels. In order to achieve carbon neutrality by 2050, companies also plan to switch to biofuels, ammonia, and hydrogen, as well as develop CCU technology to improve the circularity of carbon. Any residual emissions will be neutralized by CCU, once it is commercialized.

Chemicals. Japan's chemical sector plays roles in stable supply of end-to-end chemical production for the automotive, semiconductor, and electronics industries. Since 2020, large Japanese chemical companies have announced 30% to 50% reductions in CO_2 emissions by 2030. In the near term, these companies plan to utilize clean energy sources, improve energy efficiency, and replace feedstock with materials that have low environmental impact. In the mid- to long-term, Japan aims to implement CCU technologies as well as explore ammonia and hydrogen as alternative fuels. The chemical industry also abates the CO_2 generated both by itself and by other industrial sectors, while advancing collaborative activities with the oil-refining sector.

Paper. For many years, Japan has led the world in paper recovery and recycling. These initiatives eliminate energy consumption during the pulping stage of paper making, but increases reliance on fossil fuels as there is less available waste biomass (i.e. 'black liquor'). Japanese companies are focusing on reducing their environmental impact by investing in energy efficiency, increasing the use of renewable energy, and investing in forest conservation. In addition, they are aiming to reduce CO_2 emissions from paper recycling in the long term by utilizing low-emission thermal energy.

Glass. Glass manufacturing generates greenhouse gas emissions through high-heat processes (50%-85%) and raw-material conversion (15%-50%). To date, energy efficiency improvements and high glass recycling rates have reduced Japan's emission footprint. Looking ahead, Japanese companies plan to reduce the energy intensity of glass-melting furnaces through partial electrification in the near-term, and by replacing fossil fuels with hydrogen, ammonia, or green electricity in the long-term. Recognizing the importance of glass in downstream applications, Japanese companies are also developing high-tech glass that can reduce emissions along the value chain.

While the sectors discussed above have ambitious plans to reduce emissions, their reduction strategies are interdependent. In particular, the power sector plays a central role in determining the speed of decarbonization in the industrial sector. This paper calls for "real-economy" carbon neutrality starting from the power sector and followed by industries that provide products essential for decarbonizing downstream industries.

Japan’s carbon neutrality pathway could serve as a blueprint for Southeast Asian countries

In 2018, Southeast Asia was responsible for roughly 6.5% of global GHG emissions.[6] Strong growth (4% to 7% per year) has led to an uptick. However, most countries within the region have not yet set emissions targets aligned with the Paris Agreement.

Indeed, like Japan, countries in Southeast Asia face barriers. The economy is largely characterized by manufacturing in high-emitting sectors. Furthermore, Southeast Asia's energy mix is dominated by thermal power plants that have been built recently, with the average age of existing coal power plants being 11 years, compared to 41 years in the US. Renewable energy potential varies considerably across the region, preventing some countries from easily transitioning to renewables, and the switch will be more challenging in places where the grid infrastructure is fragmented (i.e., not connected within the region).

Japan’s energy-efficiency and resource-conservation methods can be applied throughout the region—allowing for some country-specific adjustments—and Japan has already forged several partnerships to develop and deploy green technology. Paired with these measures, Southeast Asian nations will also need a path to reduce dependence on coal and natural gas. Japan’s innovations regarding offshore wind, grid-scale batteries, and ammonia and hydrogen co-firing—paired with fuel switching—could offer options to abate fossil-fuel power in the coming decades. Japan’s investment in CCUS (particularly its research in CO_2 utilization) will provide another tool for other countries to leverage.

Ultimately, ensuring reliable and feasible pathways by preserving optionality to reduce emissions in hard-to-abate sectors that support the nation is critical in Southeast Asia and elsewhere in the world. Japan's experience and efforts in adopting such an approach can serve as a reference in Asia, where the development of hard-to-abate industries is being promoted. Both within Japan and abroad, mobilizing transition finance will be critical for delivering the deep cuts in emissions necessary to meet the global carbon-neutrality ambition.

[6] Based on emissions form six countries: Indonesia, Thailand, Malaysia, Singapore, Philippines, and Vietnam.

Introduction

Introduction

Highlights

- Financial institutions will play a critical role in the transition to a green economy. In order to provide appropriate financing, they must understand local conditions and available mitigation options. It's important to leverage existing technology while pursuing new innovations. The best combination of options should be reviewed every few years based on shifting conditions.
- There is no single winning climate strategy. A combination of initiatives should be selected depending on a country's specific circumstances. Maintaining technical options will likely yield faster carbon neutrality.
- Four factors will play an outsized role in defining climate strategy: source of energy, grid and pipeline connectivity, energy security, and sociopolitical factors
- Given local constraints, Japan's carbon-neutrality strategy differs from those in the US and Europe. Japan will take a diversified approach, emphasizing a circular economy, renewable energy, expansion of nuclear power, and development of technology and infrastructure for next-generation fuels such as ammonia and hydrogen. Such initiatives will complement the "managed phase-out" of inefficient coal-fired power plants, while preparing for CCUS deployment.
- Roughly 70% of Japan's emissions come from power and heat generation and industry. Looking ahead, Japan's opportunities for carbon neutrality lie in its highest emitting sectors: power, steel, cement, chemicals, paper, and glass.

Objectives

Around the globe, financial institutions are calling for stronger action to address climate change. The sector's sphere of influence extends from climate risk reporting (e.g. TCFD)[7] to powerful consortiums that aim to mobilize climate finance—such as the recently established Glasgow Financial Alliance for Net Zero (GFANZ). Financial institutions can use financing decisions to catalyze the development of green technologies and hold companies accountable for emissions reductions.

For capital intensive industries, the role of finance is even more pronounced. For example, energy and industrial sectors require large financial resources to produce goods that are essential for social well-being. However, industrial goods tend to generate high emissions, and transitioning to low-emission alternatives will require significant financial resources over the next decade.

As more financial institutions set their own emissions targets, heightened due diligence will be required, particularly for traditionally high-emitting sectors. To simultaneously reduce emissions and meet growth targets, financial institutions must understand the mitigation pathways available in each industry, as well as the interdependencies between governments and business sectors.

As a Japanese company with a strong commitment to climate action, Mitsubishi UFJ Financial Group (MUFG) has a vested interest in reducing emissions across its portfolio. In fact, MUFG has pledged to reduce financed emission to Net Zero by 2050, and has announced an interim target for select sectors.[8] MUFG believes that engaging with clients and facilitating their emissions reduction is the preferred strategy to reduce its financed emission, as opposed to "greening" its balance sheet through divestment. To this end, MUFG is working closely with the Japanese government and industries to deliver on Japan's climate commitment to reduce greenhouse gas emissions by 46% (from 2013 levels) by 2030, and to achieve carbon neutrality by 2050. However, given several constraints unique to Japan, the emissions reduction strategies across MUFG's portfolio may differ from approaches used in Europe and the United States.

This paper aims to:

- Describe the underlying drivers of Japan's climate strategy and summarize key differences with those of Europe and the United States.
- Deepen global understanding of efforts taken by leading Japanese companies to achieve carbon neutrality across six key sectors: power, steel, cement, chemicals, paper, and glass.

This report provides an assessment of current initiatives within Japan and offers insight into the credibility of Japan's transition pathway. Ultimately, Japan aims to achieve carbon neutrality by using a combination of energy efficiency, renewable energy, alternative fuels (such as ammonia and hydrogen) to replace fossil fuels—along with the deployment of CCUS. Maintaining optionality will be critical when deciding the course of financing, as technological breakthroughs and interdependencies among sectors present a shifting landscape. Supporting a credible transition pathway requires incorporating current technology while pursuing the next technological innovation through capital expenditures. The optimal combination of energy sources will be reviewed every few years to reflect evolving circumstances—including availability and cost.

---

[7] Task Force on Climate-Related Financial Disclosures | TCFD) (fsb-tcfd.org)

[8] MUFG determined the power and oil&gas sectors as priority sectors: https://www.mufg.jp/dam/csr/report/progress/202204_en.pdf

Our shared climate neutral ambition

Climate change is the defining challenge of our generation. The potential devastation brought on by a warming planet will be felt in every corner of the globe. Collectively, through the 2015 Paris Agreement, more than 196 countries have agreed to reduce GHG emissions in line with a 2°C target. To achieve this, carbon emissions need to reach climate neutral by the middle of the century.

Of these countries, roughly half have set or are considering carbon-neutral targets. Often, their emissions reduction strategies leverage common elements such as transitioning to new low-emission technologies and introducing CO_2 removal measures. Nonetheless, the exact mix of technologies and policies deployed are governed by circumstances unique to each country. Furthermore, most nations will likely require a combination of initiatives to achieve their low-carbon ambition. A broad range of technologies, combined with capital to innovate, will yield faster carbon neutrality.

What will ultimately determine each country's climate strategy? Four factors will play an outsized role: sources of emissions, grid and pipeline connectivity, energy security, and sociopolitical factors.

1. Source of Energy and Emissions

To maximize impact, country-level strategies focus on sectors with high emissions. The energy transformation sector, including electricity and heat, contributes more than 30% of all CO_2 emissions in Germany and the US, and nearly 50% in Japan. (Figure 1). Accordingly, these countries are targeting electricity generation from low-emissions sources. In the United Kingdom and France, the majority of emissions come from transportation, so electrifying vehicle fleets, implementing stronger fuel-efficiency standards, and promoting biofuels carry greater weight.

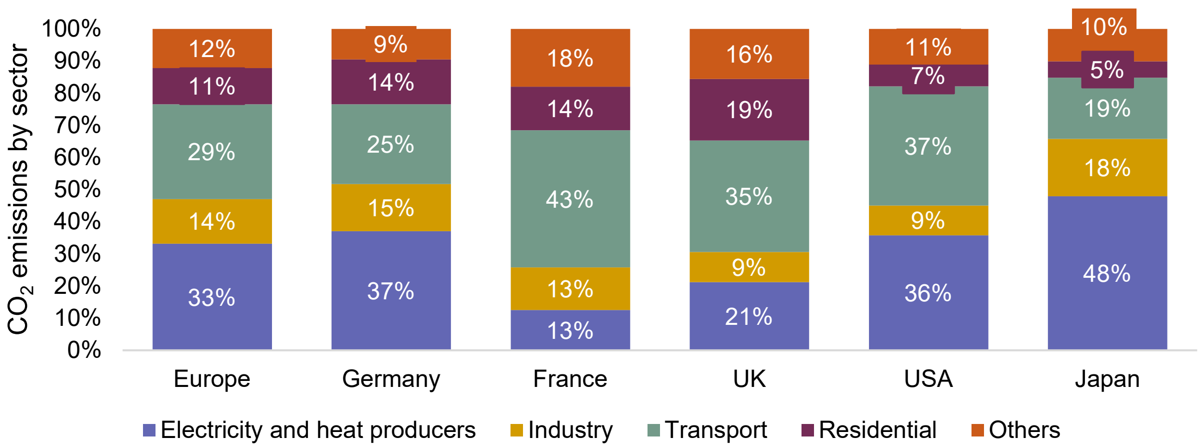
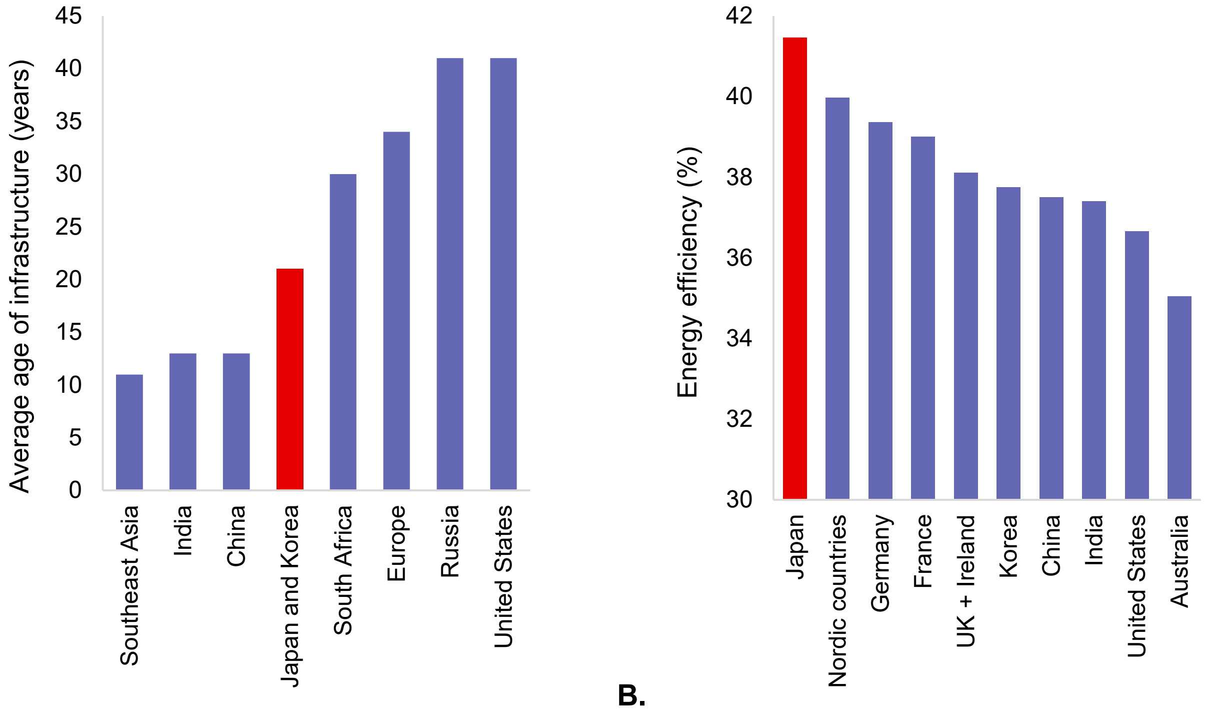


Figure 1. CO_2 Emissions by sector, 2019

Source: CO_2 emissions by sector, IEA[9]

[9] https://www.iea.org/data-and-statistics/data-product/co2-emissions-from-fuel-combustion

Carbon-neutrality strategies must also consider existing infrastructure. Take, for instance, the German strategy to phase out coal by 2030. Germany is well positioned to take this stance as many of its existing coal assets are nearing end of life (Figure 2A). The situation is similar in the US, where, without setting a coal phase-out target, more than 50% of the coal fleet has been decommissioned since 2000 because of aging infrastructure.[10] Moreover, decommissioning coal is more expensive in regions where coal infrastructure is relatively new. For example, Japan has invested heavily in high-efficiency technologies such as the ultra-supercritical (USC) and integrated gasification combined cycle, which can achieve 22% to 25% of CO_2 reduction.[11] In Japan, 62% of coal plants use these technologies. As a result, Japanese coal facilities are the most efficient in the world (Figure 2B).[12] Many countries across Asia are exploring alternative options such as "retrofitting" existing plants, increasing energy efficiency, and replacing fuel sources. For example, CO_2 emissions can be nearly eliminated by using hydrogen and ammonia as fuel in lieu of coal.



A. **B.**

Figure 2. A. Average age of existing coal power plants in selected regions in 2020. B. Average efficiency of coal-fired power plants, 2016.

Source: (A) IEA,[13] (B) Ecofys[14]

A credible transition pathway also requires viable alternatives such as renewable energy or CCUS. However, renewable energy sources are not evenly distributed across the globe. For example, the same size solar plant in the US might respectively produce 26% and 47% more electricity than facilities in Japan and Germany, owing to differences in average solar potential. [15] Likewise, the location and quality of wind potential influences the ease of wind development. The cost of wind

[10] Mapped: The world's coal power plants in 2020 (carbonbrief.org)

[11] https://iea.blob.core.windows.net/assets/da9d007d-66fa-490c-8ec7-70c01e8fd1cb/Clean_Coal_CIAB_2008.pdf , p.24-28

[12] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/sekitan_karyoku_wg/pdf/20210423_1.pdf , p.6

[13] Average age of existing coal power plants in selected regions in 2020 – Charts – Data & Statistics - IEA

[14] intl-comparison-of-fossil-power-efficiency--co2-in.pdf (guidehouse.com), p.13

[15] Global Solar Atlas

energy in Japan (0.113 $/kWh) is roughly double that in the US, France, and Germany (0.046 $/kWh - 0.065$/kWh), reflecting the lack of suitable sites. For example, because Japan's offshore wind potential is predominantly located in deep water, 94% of offshore wind sites would need floating platforms—which would require the market to grow and become more economically viable. Table 1 provides a snapshot of solar and wind resources in Germany, France, UK, US, and Japan.

Table 1. Solar and wind resources in Germany, France, UK, US, and Japan

	Germany	France	UK	US	Japan
Solar PV					
Specific yield[16] (kWh/kWp)[17]	2.96	3.39	2.61	4.36	3.45
Installed solar capacity (2020, GW)[18]	54	12	13	76	70
LCOE average (2019 $/kWh)[19]	0.0897	0.0804	0.111	0.0677	0.1439
Wind					
Mean power density for 10% windiest areas (W/m^2)[20]	595	728	1254	991	699
Offshore wind potential (GW)[21]	203	623	1,800	5,259	1,897
(% fixed vs. floating)	(100%)	(27%)	(24%)	(47%)	(6%)
Installed wind capacity (2020)[22]	62 GW	17 GW	24 GW	118 GW	4 GW
(% on installed wind capacity)	(31%)	(3%)	(1%)	(2%)	(0.2%)
LCOE average (2019 $/kWh)[23]	0.068	0.065	0.071	0.046	0.113

Notes: LCOE = levelized cost of energy

Low power densities for wind and solar energy[24] can also pose significant challenges for countries with physical space limitations. In Japan, where nearly 70% of the land mass is covered in forested and mountainous terrain, expanding onshore wind energy is arguably more difficult than in the US or UK, where wind power can be co-developed with cropland (Table 2). In addition, Japan's population density is highest among the major economies (Appendix B), which translates to greater electricity demand density (2.69MWh/km2). Per area of electricity supply, Japan's renewable energy is already among the highest.

16 Global Solar Atlas

17 kWp is the maxium output in kilowatts that the PV system can produce

18 https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Country-Rankings

19 Levelized cost of energy by technology, World (ourworldindata.org)

20 https://globalwindatlas.info/area/

21 Offshore Wind Technical Potential | Analysis and Maps | ESMAP

22 https://www.irena.org/Statistics/View-Data-by-Topic/Capacity-and-Generation/Country-Rankings

23 https://www.irena.org/Statistics/View-Data-by-Topic/Costs/Wind-Costs

24 **Energy Policy:** solar farm may need ten times more land space than a natural gas plant or nuclear facility for the same amount of power generation

Table 2. Land area and usage by country. Source: METI[25]

		Germany	France	UK	US	Japan
A	Land area (km_2)[26]	380,000	540,000	240,000	9,630,000	380,000
B	Flat land area (km^2) In 2020[27]	250,000	370,000	210,000	6,530,000	130,000
B/A		(69%)	(69%)	(88%)	(68%)	(34%)
C	Overall renewable energy generation (billion kWh)[28]	227.2	112.8	111.2	750.2	185.3
D	Power generated by solar and onshore wind (billion kWh)	138.4	38.7	43.3	365.0	76.7
D/C		(61%)	(34%)	(39%)	(49%)	(41%)

Geothermal power and carbon sequestration capacity are also governed by local geology. For example, the US is estimated to hold more than 812 gigatons (Gt) of CO_2 storage capacity.[29] Japan, on the other hand, has limited potential for CCS due to its volcanic substrates and the risk of earthquakes. Japan currently has capacity to bury roughly 8 Gt of emissions, approximately 1/100 of the US potential (See Appendix D).[30]

Further, the production of ammonia and hydrogen fuels depend on the availability of natural gas and CCS capacity for "blue" production and on renewable energy for "green." Many countries are looking for ways to cost-effectively produce these alternative fuels. In Japan, further development of CCS and renewable energy remains a pre-requisite for domestic production of ammonia and hydrogen.

2. Grid and pipeline connectivity with other regions

Regional grid and pipeline connectivity can amplify or limit a country's climate strategy. The electricity grid, in particular, plays a fundamental role in the expansion of wind and solar energy for three reasons:

1) Solar and wind energy production are weather dependent,
   - Sites with high energy potential may not be co-located with population centers; and
   - Electricity generated from wind and solar is difficult to store.

A strong electrical grid can stabilize volatile renewable energy supplies by creating more market opportunities to sell excess electricity, tap into renewable energy sources far from population centers, and offset the need for grid-scale storage. Stable renewable energy also enables the production of alternative fuels such as green hydrogen and green ammonia.

Both Germany and the UK have invested heavily in grid infrastructure to complement their expansion of offshore wind. Offshore wind accounted for 6% of Germany's electrical supply in 2020[31] but the

---

[25] 025_01_00.pdf (meti.go.jp), p.22

[26] https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/025_01_00.pdf, p.22

[27] Plains area is calculated by subtracting the forested area of the Global Forest Resources Assessment 2020 from the national land area. Source: https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/025_01_00.pdf, p.22

[28] Ibid.

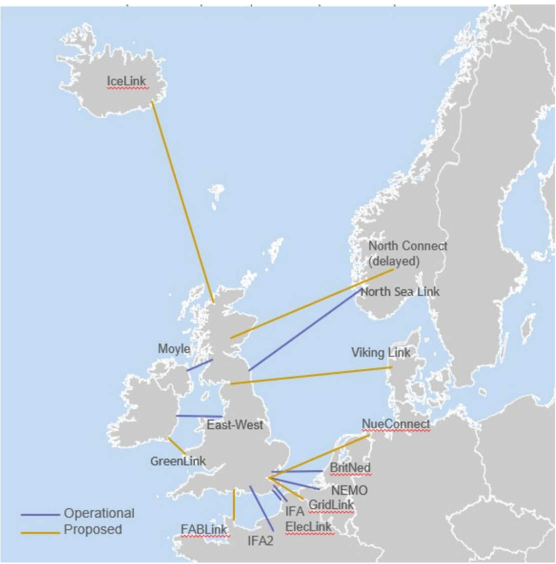
[29] The world has vast capacity to store CO2: Net zero means we'll need it – Analysis - IEA

[30] Ibid.

[31] Offshore Wind Energy in Germany: market overview and upcoming projects - Surfeo

country faces distribution challenges given the long distance between the North Sea, where offshore wind is produced, and industrial centers to the south. Several transmission line projects (e.g., SuedLink, SuedOstLink, NordLink) aim to support expansion of offshore wind and other renewables."[32] Similarly, the UK is investing in grid upgrades, and by 2023, the UK will be joined with France, the Netherlands, Belgium, Norway, and Denmark across six existing and two newly-created links.[33] (Figure 3A).

Japan, for its part, operates a relatively small electrical grid that runs on different frequencies in the east and the west of the country (Figure 3B). The limited grid infrastructure and lack of connectivity to neighboring regions makes it difficult to deploy renewable energy at scale. This is owing to the fact that, under the regulated system of nine electric power companies, power grids were formed in each region and transmission lines connecting the regions were not laid except for emergency flexibility. In addition, the concept of an international power transmission line has not progressed because of the scarcity of land for power transmission, the huge cost of laying deep-sea power transmission lines, and the lack of countries in the vicinity that could serve as stable power suppliers. Stable power supplies (e.g., nuclear or fossil-fuel energy) are needed in Japan to offset the intermittency of renewable power.

A.


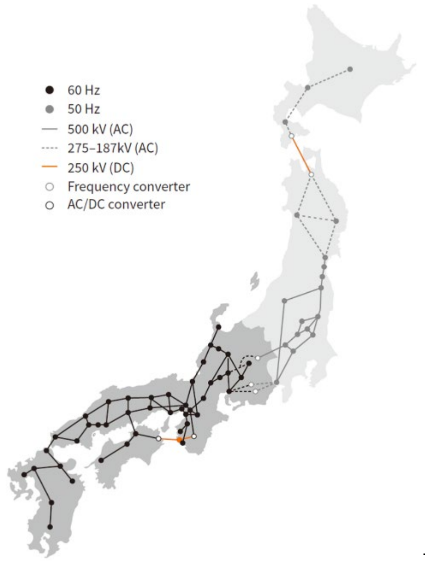
B.


Figure 3. A. Existing and proposed UK Interconnectors. B. Japan's electrical grid operates on two separate frequencies.

Source: (A) Ofgem, National Grid,[34] (B) Hitachi[35]

Like the electricity grid, natural gas pipelines across Europe and the United States have helped support the transition to a low-carbon economy by providing low-cost, low-emission alternatives to oil and coal. Moreover, it is technically possible to supply hydrogen using existing natural gas pipelines, provided the pipeline is made of suitable material to avoid fracture and corrosion.[36] Japan, by contrast, has no international pipeline connections, which hinders its ability to rely on natural gas.

32 https://www.nkt.com/references/corridor-projects-germany
33 Interconnectors | Ofgem
34 Ibid., Interconnectors | National Grid Group
35 https://www.hitachi.com/rev/archive/2021/r2021_03/04/index.html
36 HyWay 27: realisation of a national hydrogen network › HyWay 27

3. Energy security

Climate strategies also need to be compatible with energy security objectives. Globally, power systems are interconnected through physical connections (e.g., pipelines, the electricity grid) or through trade. Physical connection makes it easy to absorb the variability of transmission system supply and demand, but too much reliance on foreign governments for energy supplies can pose a national security risk.

Within Europe, the ongoing war in Ukraine underscores energy security risks in the region because of dependence on Russian natural gas and oil. Disruption to the European energy supply could lead to delays in carbon-neutrality programs. Germany, for example, plans to extend the use of nuclear and coal plants that were slated for retirement in order to offset the loss of natural gas from Russia.[37] Nonetheless, REPowerEU, an initiative aimed at reducing reliance on Russian fossil fuels, demonstrates the EU's ability to strengthen energy security while safeguarding the environment in a rapidly-changing world, thanks to coalitions throughout the European continent and to power-grid connectivity.

Energy security is particularly relevant for Japan, which can provide less than 10% of its energy demand using domestic sources.[38] For such countries, with few energy resources of their own, it is critical to diversify sources and suppliers. Like many countries in the Asia-Pacific region, Japan currently depends on fossil-fuel imports from abroad. But rising demand from neighboring economies (e.g., China, South Korea, and India) heightens the risk of geopolitical conflict and contributes to strain on supply chains. Japan hopes to maintain a diversified supply of energy from a wide range of countries in order to mitigate risk. Historically, energy-security pressures in Japan have contributed to the development of a global LNG supply chain that benefits countries around the world.

Achieving the dual objectives of climate neutrality and energy security will require a frequent re-evaluation of energy policy. Countries may need to consider a holistic approach to emission reductions rather than a strategy focused on individual sectors or subsectors.

4. Sociopolitical factors

Public opinion and local politics further shape the energy landscape. Within the US, state-level politics and political leanings heavily influence the energy mix. For example, strong state-level incentives such as California's Renewable Portfolio Standard, net metering program, and property tax exemptions have led to the strong adoption of solar energy where penetration rates are between 20% and 25%.[39] [40] Meanwhile, coal-mining states such as West Virginia have a larger share of coal-fired plants supported by constituents who rely on the coal industry for their livelihood.[41] Given the strong division in public opinion, the carbon-neutrality efforts within the US are not homogeneous. In fact, some states have introduced "Fair Access Laws," by which financial institutions are required to declare that they will not "boycott" energy companies.[42] Meanwhile, the Inflation Reduction Act represents a major step forward in creating nationwide initiatives for climate actions.

In Japan, a strong culture of environmental stewardship drives individual participation in energy efficiency and recycling measures, addressing carbon neutrality through reduced energy demand. This concept and the sense of "*Mottainai*" — an expression of regret at the full value of something not

---

[37] https://www.power-technology.com/news/germany-nuclear-facilities/

[38] 2019 – Understanding the current energy situation in Japan (Part 1) / Special Contents -Energy Japan- / Agency for Natural Resources and Energy (meti.go.jp)

[39] California Solar Incentives and Rebates 2022 | Solar Metric

[40] Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California (nrel.gov)

[41] https://www.eia.gov/state/print.php?sid=WV

[42] Texas Government Code Sec. 2274.002. https://statutes.capitol.texas.gov/Docs/GV/htm/GV.2274.v3.htm

being put to good use[43]— shape Japan's environmental policies. For resource-poor countries, these ideas have been promoted for the purposes of securing energy. In some nations, nuclear power is still widely accepted, while in others, such as Germany and Japan, negative public perception and tight regulatory environments have limited the growth of the nuclear sector, influenced by the Fukushima disaster in 2011.

- France: Nuclear power accounts for a high percentage of the power supply (70%), and public opinion is relatively positive. However, some stakeholders consider the high level of dependence on nuclear power to be dangerous, and hope to reduce the share to 50% by 2035[44].
- Germany: Public opinion toward nuclear power is negative, and all 17 nuclear power plants in the country are scheduled to be phased out by the end of 2022.[45] The conflict in Ukraine, however, has led to increased discussion of pushing back the decommissioning year.[46]
- US: Nuclear power provides an emission-free power source along with renewable energy, but public opinion is near-equally divided between those in favor (51%) and those opposed (47%).[47]
- Japan: Public opinion toward nuclear power has been mixed since the Fukushima accident, and there are hurdles to raising the ratio of nuclear power use to pre-accident levels.[48] To ensure a stable supply of electricity over the long term, the government announced a policy in August 2022 to consider the development and construction of next-generation nuclear power plants. In response, seven reactors are scheduled to be restarted by next summer, in addition to the ten currently in operation.

Tailoring climate strategy to local conditions

When combined, the drivers below help explain why countries ultimately adopt a specific, localized carbon-neutrality pathway.

- Within Europe, there are several common themes across countries. Overwhelmingly, renewable energy forms a centerpiece of the carbon-neutrality strategy. Strong public support paired with moderate to high availability of wind and solar energy have led to rapid deployment of renewables. In general, European countries have also collaborated to a large degree to achieve shared carbon-neutrality goals. Two strong examples include: (1) the investment in grid infrastructure, and (2) the proposed carbon tariff (CBAM).[49]
- To be sure, European countries often utilize legal and regulatory measures to incentivize change. Both Germany and France have implemented sector-specific emissions reduction targets that have been codified in law. More broadly, the European Climate Law, combined with the EU Sustainable Finance Action Plan and EU Taxonomy, aim to create an ambitious framework for achieving carbon neutrality. Of course, Europe is not a monolith, and it's also possible to find differences among domestic emissions reduction strategies. In France, for example, nuclear energy will form a core component of the National Low-Carbon Strategy (SNBC),[50] while Germany is actively working to phase out nuclear power and coal power plants. This difference

---

[43] Kojien dictionary

[44] https://world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

[45] https://world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx

[46] https://www.nytimes.com/2022/08/04/world/europe/germany-nuclear-power-russia.html

[47] Americans Divided on Nuclear Energy (gallup.com)

[48] https://world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx

[49] Carbon Border Adjustment Mechanism (europa.eu)

[50] https://www.ecologie.gouv.fr/sites/default/files/en_SNBC-2_complete.pdf

in approach stems from variations in local perception and the maturity of legacy infrastructure.

- By contrast, climate policy within the United States tends to focus on economic drivers, with a patchwork of reduction targets and energy policy set by individual states. The power sector, as the highest source of emissions, receives a lot of attention. Low costs and wide availability for solar, wind, and natural gas have led to large-scale deployment of these technologies. Moreover, the phase-out of coal is largely a by-product of price competition and aging infrastructure. On a national level, the Inflation Reduction Act is expected to accelerate investment in such areas as clean power generation, power grids, new energies, carbon capture, and electrified and sustainable transportation. Furthermore, In September 2022, the US Department of Energy (DOE) released “Industrial Decarbonization Roadmap,” with a view to accelerating emissions reductions in the “difficult-to-decarbonize” industrial sector, including iron and steel, chemicals, food and beverage, petroleum refining, and cement subsectors. It identifies four key “pillars” of industrial decarbonization: energy efficiency; industrial electrification; low-carbon fuels, feedstocks, and energy sources (LCFFES); and carbon capture, utilization, and storage (CCUS).
- Public perception also plays a significant role in US climate policy, with the energy choices of each state often reflecting local politics as much as available resources. Compared to other countries, the US transportation sector accounts for an outsized portion of emissions at 37%. Accordingly, electrifying passenger vehicles forms a more critical part of the US strategy.

As for Japan, as the world’s third-largest economy[51] and fifth-largest emitter of greenhouse gases,[52] the country plays a critical role in the global path toward carbon neutrality.[53] The majority of Japan’s emissions stem from its power and industrial sectors (approximately 70%). What is more, the inherent challenge of reducing emissions from hard-to-abate industries such as steel and cement is paired with the fact that Japan has few viable energy alternatives. Onshore wind and solar potential are relatively low, and the development of offshore wind remains prohibitively expensive. As an island, Japan also lacks the robust grid infrastructure required to support the large-scale deployment of renewable energy. Nonetheless, Japan has invested in maximizing the installation of onshore wind and solar at a notable scale. For solar, it has achieved the largest ratio of installed photovoltaic (PV) energy over flat land area in the world.

In order to achieve carbon neutrality, Japan will need to leverage a diverse array of emissions-reduction technologies, sequenced over the next few decades. The Japanese government has already developed a long-term road map toward 2050 under the Paris Agreement (Figure 4).

---

[51] GDP.pdf (worldbank.org)

[52] https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE?locations=JP

[53] What is Net Zero? - Net Zero Climate

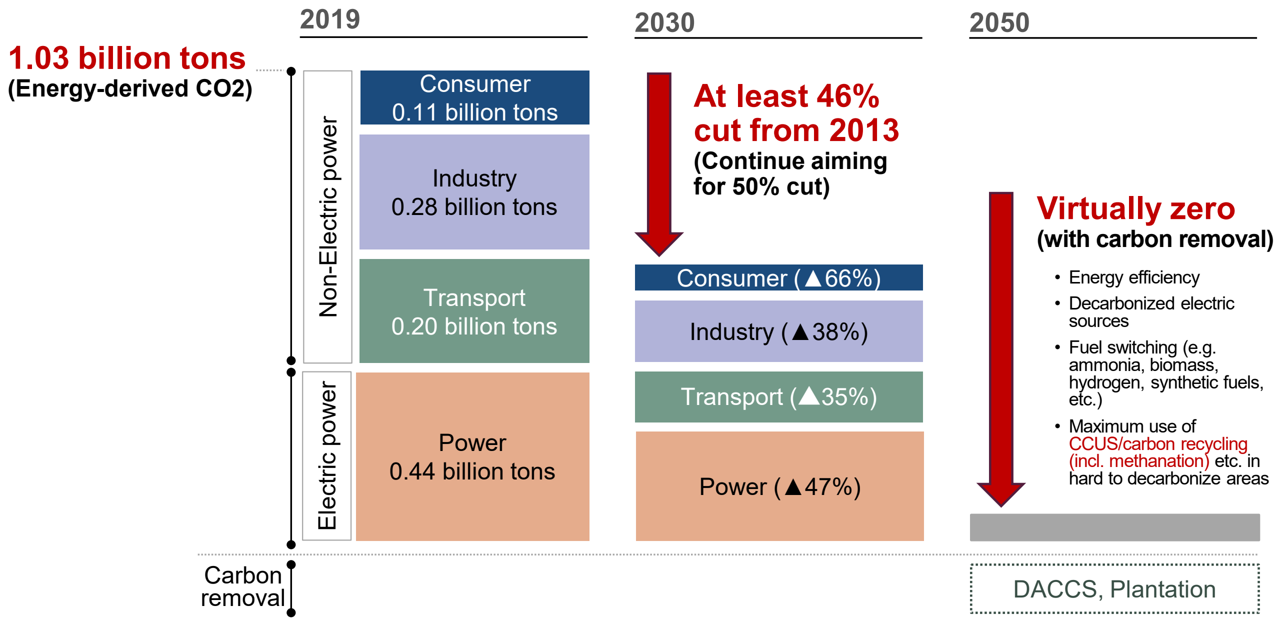


Figure 4. Long-term strategy under the Paris Agreement.

Source: The Government of Japan https://unfccc.int/sites/default/files/resource/Japan_LTS2021.pdf

Further, Japan plans to continue developing energy-efficiency measures and a circular economy□□ areas in which it has been a global leader for more than a half century (Appendix C). Currently, the country accounts for roughly 2% to 3% of global GHG emissions (1166.51 $MtCO_2e$ in 2019).[54] After peaking in 2013, emissions dropped by ~13% and are now at roughly the same levels as in 1989.[55] Per-GDP emissions have shown a similarly downward trajectory (Figure 5A). Japanese manufacturing industries, considering their large industrial footprints, maintain top performance in production within developed countries, excepting the UK which has smaller industrial footprints.[56] Notably, Japan's economic growth is no longer tied to its carbon-emissions profile. (Figure 5B).[57]

[54] https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE?locations=JP
[55] https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE?locations=JP
[56] http://www.globalcarbonatlas.org/en/CO2-emissions
[57] http://www.globalcarbonatlas.org/en/CO2-emissions

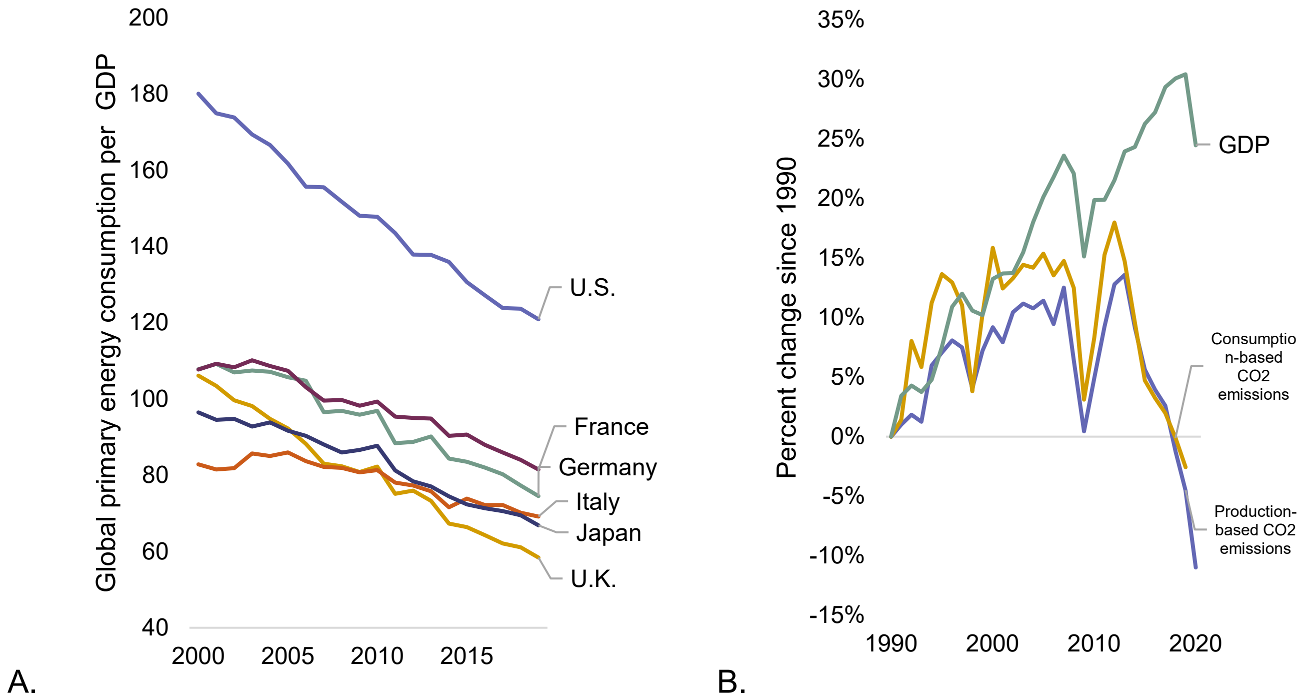


Figure 5. A. Global primary energy consumption per GDP. B. GDP growth and CO_2 emissions of Japan.

Source: (A) The Institute of Energy Economics, Japan; World Bank; and the IEA.[58] (B) Our World in Data based on Global Carbon Project, World Bank. Gross Domestic Product (GDP) figures are adjusted for inflation. [59] Note: In Japan, GDP has decoupled from CO_2 emissions. Consumption-based emissions consider the influence of trade on domestic emissions, calculated as: production-based emissions minus emissions embedded in exports, plus emissions embedded in imports.

Looking ahead, Japan's climate strategy will utilize a multi-pronged, phased approach. Where possible, and with technological advancement, the country will leverage renewable energy and nuclear power for its power supply. For the remaining power generation, Japan will manage the phase-out by retiring inefficient thermal energy while steadily reducing emission "intensity" by co-firing with ammonia or hydrogen, along with investing in CCUS. A similar approach will be adopted by Japan's industrial sector for applications requiring high heat. Fossil fuels will be phased out or reduced using CCUS or low-carbon fuels, pending the available supply. Cost considerations will certainly influence the final energy mix (Figure 6). For example, expansion of renewable energy will become increasingly expensive—the marginal cost will rise—as sites are occupied and further development extends into increasingly harsh territory.

[58] 日本エネルギー経済研究所(2022)「エネルギー・経済統計要覧」; World Bank (2022)「World Development Indicators」; IEA (2021)「World Energy Balances」

[59] https://ourworldindata.org/grapher/co2-emissions-and-gdp?country=~JPN

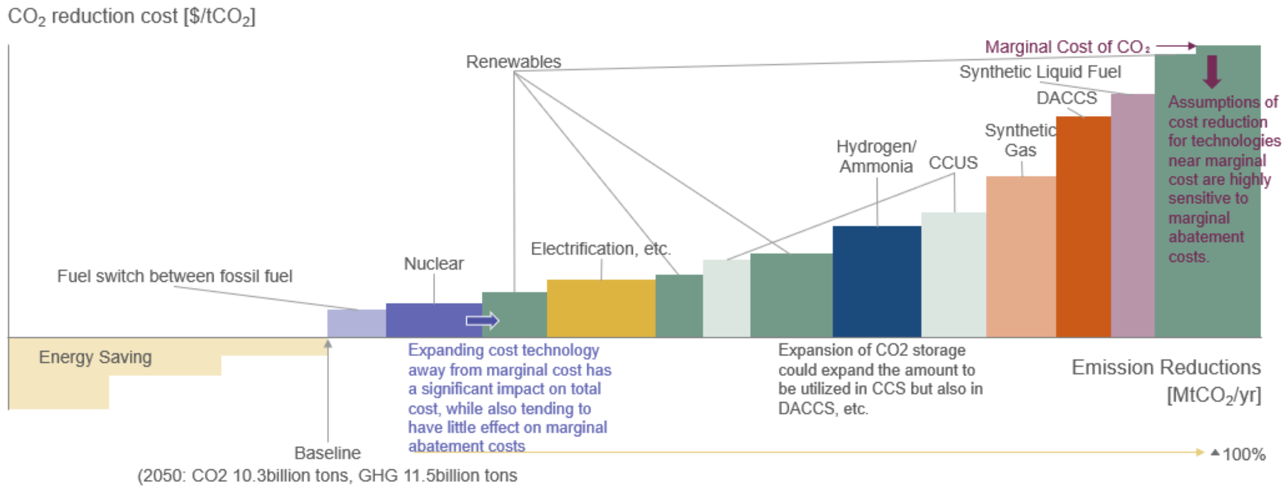


Figure 6. Marginal abatement cost by technology in Japan.[60]

Source: METI, https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/043/043_005.pdf

Interdependency

To further reduce carbon emissions, Japan will need to focus its attention on classically "hard-to-abate" industrial sectors—that is, industries with significant emissions where (1) the abatement cost is high; (2) technologies are in their infancy, and (3) significant innovation is required. Globally, power generation and industry account for two thirds of emissions (Figure 7), with a similar breakdown in Japan.

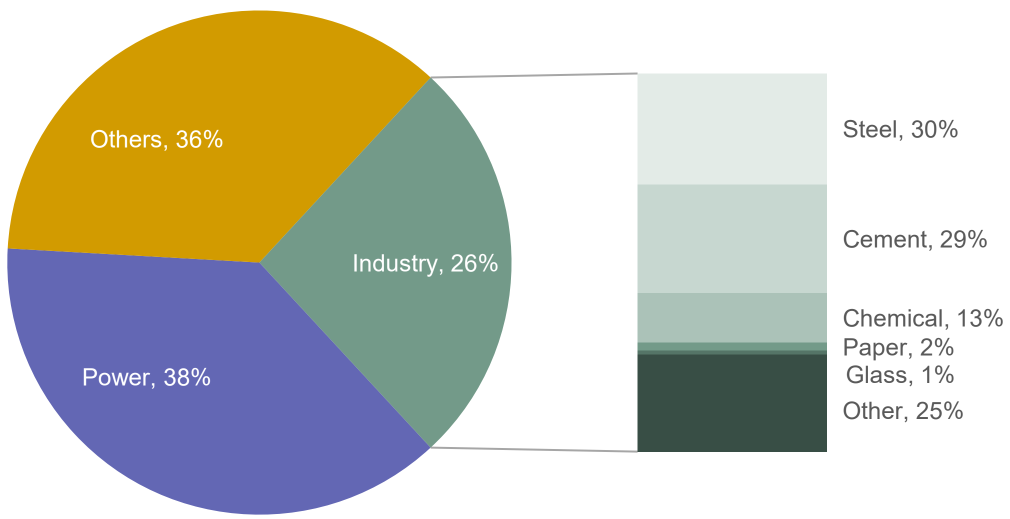


Figure 7. Global direct CO_2 emission per sector (2020).

Source: IEA[61]; Willy.[62] Note: The Glass section is based on the 2020 emission rate from a different source.

[60] Cost curves are for illustrative purposes only (In reality, it is complicated by correlations between technologies, etc.)

[61] https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf

[62] Global material flow analysis of glass: From raw materials to end of life - Westbroek - 2021 - Journal of Industrial Ecology - Wiley Online Library

Moreover, these sectors are heavily interdependent (Figure 8). For example, the power sector plays a central role in providing electricity for industrial applications. Clean electricity and low-emission alternative fuels are a pre-requisite for most industrial sectors in order to achieve carbon neutrality. Likewise, the chemical sector will be critical for domestic production of alternative fuels (e.g., biofuel, hydrogen, ammonia, etc.), as well as for CCU technologies that are needed across businesses. Steel, cement, paper, and glass also support a range of downstream industries. All told, emissions reductions and technological innovation in separate sectors can amplify emissions reductions throughout the entire, multi-industry value chain.

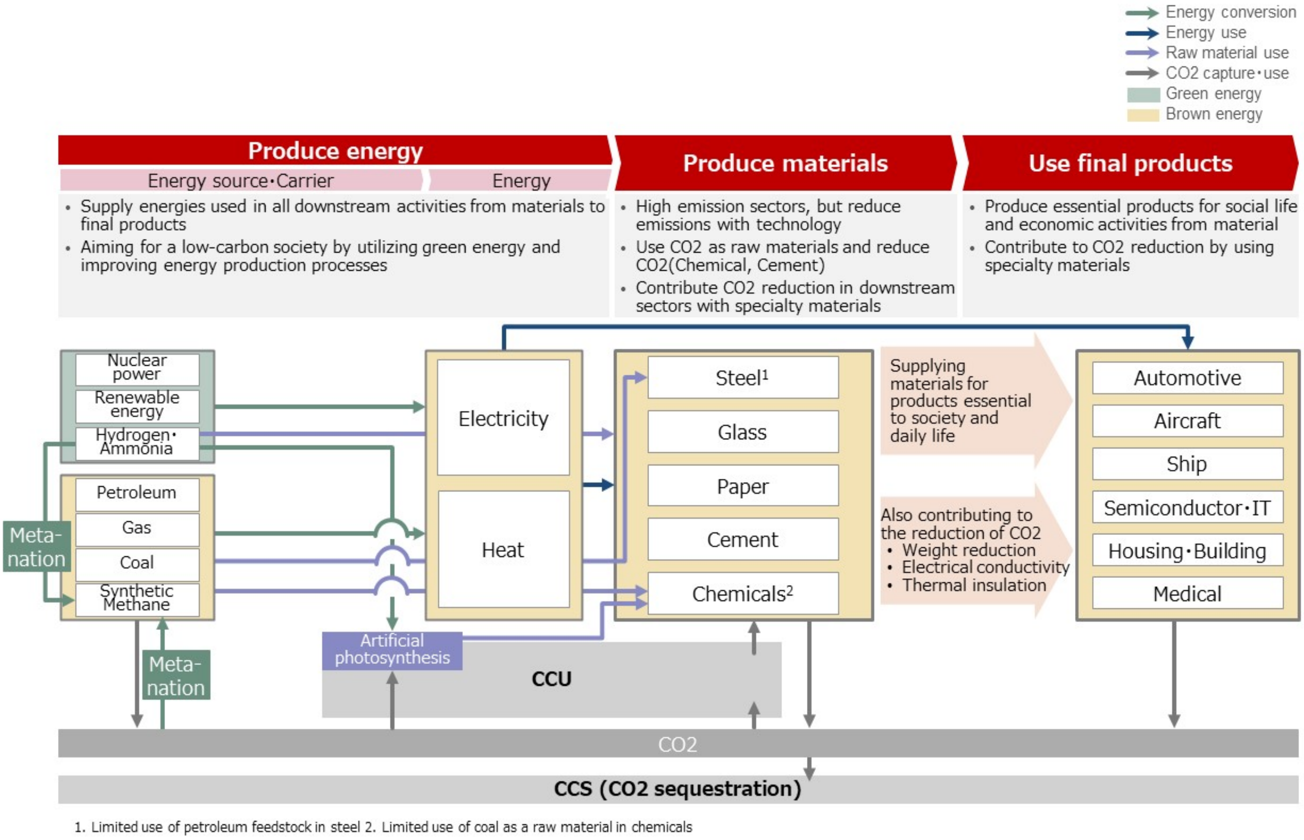


Figure 8. Interdependencies between the energy sector and key industries.

Source: Compiled from various sources.

In the following sections, we will review Japan's opportunities to reduce emissions from its highest emitting sectors: power, steel, cement, chemicals, paper, and glass.

Power

Power Fast Facts

Sector profile

Revenue:
2,462 billion USD in 2021[64]

Energy consumption:
412.8 EJ in 2020[65]

Production volume:
14,555 Mtoe in 2021[66]

Main emission sources

Energy-derived

Current CO_2 emissions

13,530 Mt CO_2 in 2020[67]

40% of the global CO_2 emissions

Interdependencies

Upstream: Chemical (hydrogen, ammonia)

Downstream: Steel, cement, chemicals, paper, glass

Highlights

One of Japan's largest opportunities for reducing carbon emissions is transforming its power sector, which accounted for 48% of CO_2 emissions in 2019.[63]

In order to achieve the sector's emission-reduction targets, the Japanese government is targeting 36% to 38% renewable energy, 20% to 22% nuclear power, and 41% thermal power by 2030.

Among renewables, solar power is expected to be the main driver of expansion until 2030, which will be further amplified with offshore wind afterward.

In addition, the pathway to increasing nuclear power generation is technically feasible given Japan's large number of inactive reactors, although there are mixed public opinions on nuclear power.

For Japan, decarbonation of thermal power plants is considered essential, as Japan's grid is not connected with other countries and needs to fulfill demand when the renewables supply fluctuates. Japan is committed to a managed phase-out of coal, and will retire 100 inefficient power plants in the coming years. Additionally, Japan plans to use 20% ammonia co-firing (with coal-fired power) and 30% hydrogen co-firing (with gas-fired power) by 2030. Hydrogen and ammonia together will account for 1% of the total electricity mix. Japan is also helping to establish ammonia and hydrogen supply chains.

Rapid transition of Japan's power sector is imperative as it underpins the emissions trajectory for many downstream sectors. Japan's balanced approach aims to maintain optionality in order to accelerate emissions reductions and mitigate risk.

---

[63] This 48% includes CO2 emissions from generation of heat.

[64] Global Power Generation Market Report And Strategies 2022 (thebusinessresearchcompany.com)

[65] World Energy Outlook 2021 (windows.net)

[66] World Energy Primary Production | Energy Production | Enerdata

[67] https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf

Power sector overview

Japan's power sector accounted for 48% of the country's total emissions in 2019.[68] Consequently, the sector provides the largest opportunity for rapidly reducing emissions. Not only are its emissions relatively concentrated, but cleaner electricity generation will provide leverage to other sectors such as manufacturing and transportation.

In Japan's Sixth Basic Energy Plan, released in 2021, the government announced its proposed 2030 energy mix: 36% to 38% renewable energy, 20% to 22% nuclear power, and 41% thermal power (Figure 9). This partition represents a sizable shift from the country's Fifth Basic Energy Plan (released in 2018), which targeted 22% to 24% renewable energy, 20% to 22% nuclear power, and 56% thermal power by 2030. The strengthened renewable-energy target, paired with a reduction in projected power demand (from 1065 TWh to 934 TWh), presents a step-change in ambition.

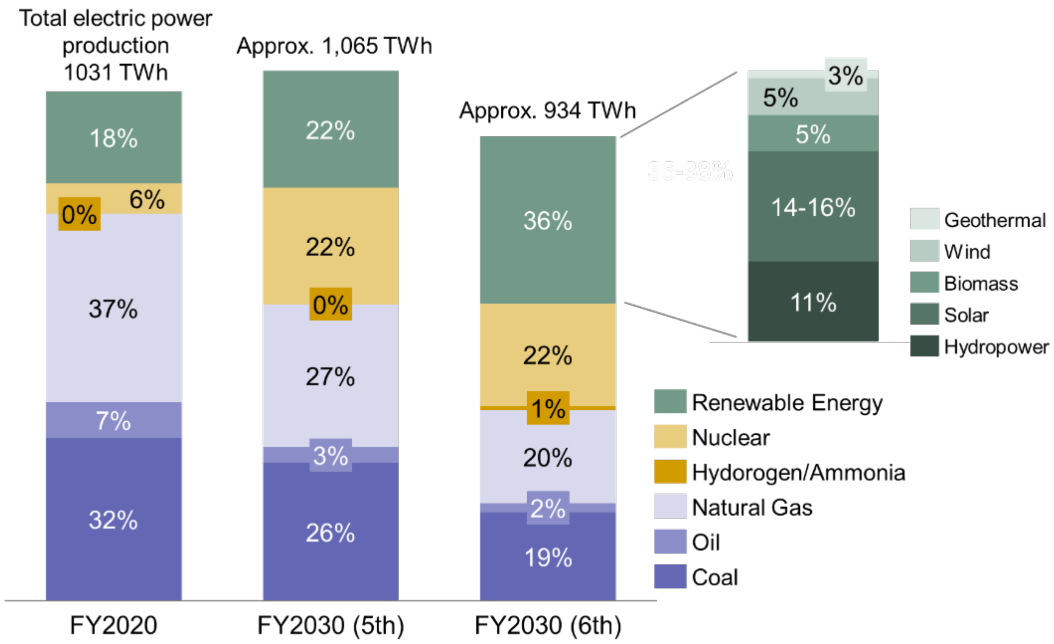


Figure 9. Japan's electricity mix from 2020-2030.

Source: IEA, (2022). Projected energy mix from Outline of Strategic Energy Plan, October 2021.

[68] This 48% represents emissions from electricity and heat producer and includes heat generation and private power generation (https://www.iea.org/countries/japan#data-browser). According to the Comprehensive Energy Statistics published by the Japanese government, carbon emissions from "commercial power generation" in FY2020 were about 36% of the total. （Source: https://www.enecho.meti.go.jp/statistics/total_energy/results.html）

Renewable energy

Japan's investment in renewable energy has grown steadily. In 2015, the country spent 0.8% of GDP on renewable energy investment (Figure 10A), and the share of primary energy coming from renewable sources has grown by 61% overall since then. In 2020, Japan eclipsed the US in the share of primary energy derived from renewable sources (Figure 10B).

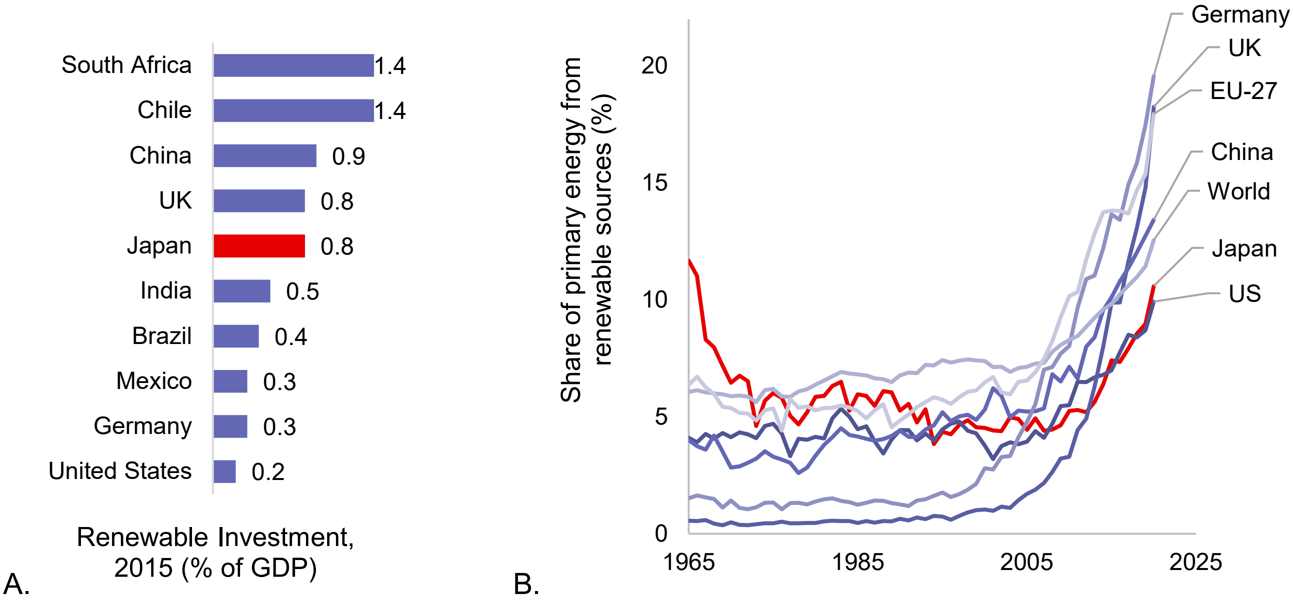


Figure 10. A. Investment in renewable energy as a percentage of GDP, 2015. B. Share of primary energy from renewable sources.

Source: (A) Bloomberg New Energy Finance; World Bank. Renewables include: hydropower, solar, wind, geothermal, bioenergy, wave, and tidal. They do not include traditional biofuels. (B) Our World in Data based on BP Statistical Review of World Energy (2021).

Note: Primary energy is calculated using the 'substitution method' which accounts for inefficiencies due to fossil fuel.

By 2030, more than a third of Japan's planned electricity supply is expected to come from renewable energy.

Moreover, Japan has the third-largest installed solar capacity in the world, and it plans to expand by an additional 26.2 GW (14% to 16% of the country's energy mix). However, since large-scale solar (so-called mega solar) has already been developed, and since suitable sites are limited, small-scale solar, deregulation, and new technologies are expected.

Wind power is projected to add ~9.9 GW[69] or roughly 5% of the electricity mix by 2030. Onshore wind energy potential in Japan is reasonably low, somewhere between 296 GW and 938 GW.[70] Apart from some coastal areas, wind speeds in Asia-Pacific are 16% weaker than in Europe and the US,[71] and

---

[69] These figures are the result of the maximum and reliable implementation of the policies that are being materialized at 2021. Assuming that only the current measures are continued in the future, the figure is 5.4 GW.
Source: https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/20211022_03.pdf, p.32

[70] 100% renewable energy in Japan | Elsevier Enhanced Reader; Ministry of Environemnt: REPOS (renewable Energy Potential System)

[71] Assuming that average wind speed of Japan is 8m/s compared to 9m/s in US and 10m/s in EU; adapting average of comparisons with EU and US figures.
Source:https://www.globalwindatlas.info/, "Comparison of the Economic Efficiency of Offshore Wind Power Generation in Japan and Europe under Different Wind Conditions", Kazuhiko Honbu and Yoshiharu Tachibana, Graduate school of public policy, The university of Tokyo (January 2021)

the region is also affected by typhoons that cause unstable wind conditions. As a result, efficiency is low, resulting in a higher cost per unit of power generated.

The above noted, offshore wind potential is high, and Japan is laying the groundwork to expand its development in the 2030s.[72] Most promising offshore wind sites in Japan are located in deep water far from shore, so development will require advancement in turbine and floating-platform technologies, a decrease in development cost, and government support. Although floating offshore wind technology has undergone significant advances over the past ten years, it remains complex and expensive compared to onshore and near-shore wind technologies. To this end, Japan has deployed a series of experimental floating windfarms. If successful, even in typhoon-prone areas, these installations could pave the way for further expansion of offshore wind. [73]

Japanese companies are also working to manufacture larger floating facilities, join wind turbines to floating facilities, and reduce the weight of turbines through material substitution.[74] To complement offshore wind facilities, technical advances are needed in offshore substations and high-capacity riser cables to integrate offshore wind with Japan's grid. To help ease the financing of new offshore wind projects, Japan's GI Fund will subsidize floating offshore wind demonstration projects up to 85 billion yen. The government has also begun to auction sites for offshore wind development. Currently, three sites have been auctioned, another two are available, and 17 areas are awaiting approval. Local opposition, particularly among fisherman, has slowed development.

Other sources of renewable energy add marginal contributions to the energy supply:

- Hydropower now accounts for 8% of Japan's electricity supply, and most of the country's hydropower potential is fully leveraged.[75] Nonetheless, projections show that the share of electricity generated by hydropower will increase to 11% by 2030.[76]
- Bioenergy now accounts for 2% of electricity production (22 TWh) and 4% of fuel and heat (3663 PJ).[77] By 2030, it is expected to grow to ~5% of Japan's electricity and heat supply.[78]
- Japan's geothermal power capacity has remained flat for the past three decades, hovering around 500 MW[79] and accounting for 0.3% of electricity production.[80] Still, Japan has taken measures to deregulate the market, and plans to double the number of geothermal plants in operation by 2030. [81,82]

Nuclear power

Nuclear power generation will also contribute to the clean energy supply in Japan, including both electricity and heat, although public opinion on this resource remains mixed. As a result of the Fukushima incident in 2011, nuclear power generation was suspended for several years, and the

---

72 In 2018, it established the Act for the Promotion of Use of Marine Areas for Development of Marine Renewable Energy Generation Facilities. Offshore Wind Outlook 2019: World Energy Outlook Special Report (windows.net)

73 Offshore Wind Outlook 2019: World Energy Outlook Special Report (windows.net)

74 http://windeng.t.u-tokyo.ac.jp/ishihara/article/2013-24.pdf

75 https://www.iea.org/countries/japan

76 6th_outline.pdf (meti.go.jp)

77 IEA World Energy Balance (2021)

78 Japan 2021 - Energy Policy Review (windows.net)

79 https://www.irena.org/geothermal

80 Japan - Countries & Regions - IEA

81 https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf

82 Japan 2021 - Energy Policy Review (windows.net)

industry is still recovering. As of 2020, nuclear accounted for 4% of Japan's electricity production (61TWh),[83] and plans are in place to increase that to 188-206 TWh[84] (20% to 22%) by 2030. Increasing nuclear power generation is technically feasible given the large capacity of existing nuclear reactors available but not currently in operation (Figure 11A). The 2030 target would return production to the level of March 2011, prior to the incident (Figure 11B). At that time, there were 54 nuclear reactors in operation supplying 25% of Japan's electricity.[85]

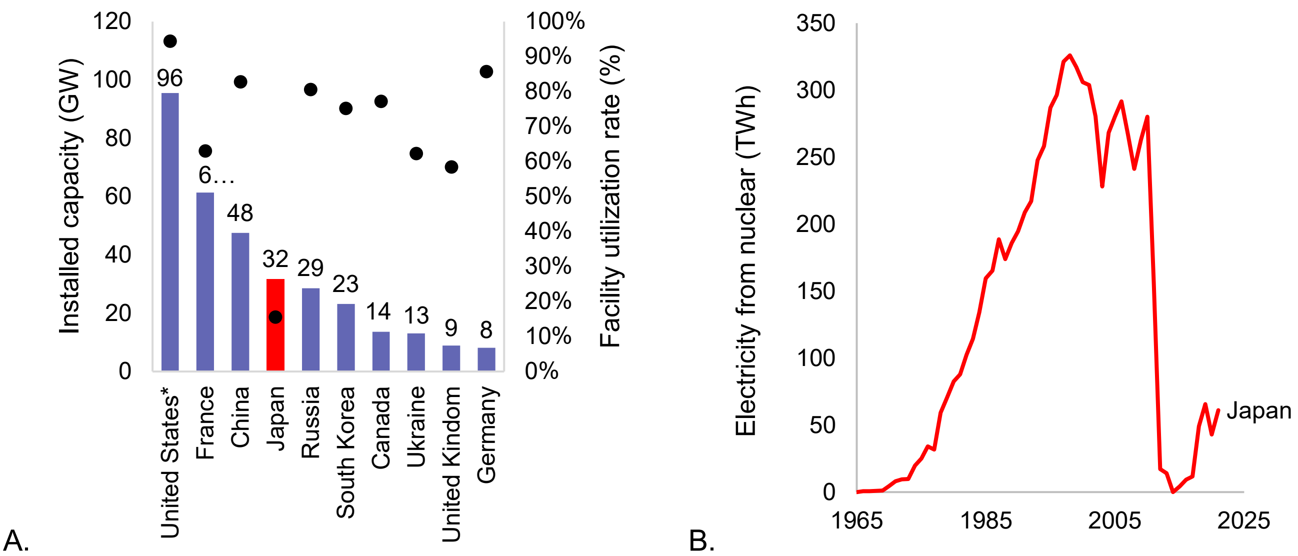


Figure 11.A. Nuclear power capacity by country, 2020. B. Electricity generation from nuclear in Japan, 1965-2021.

Note: For 11.A., Installed capacity depicted with bars, facility utilization rate with circles.

Source: (A) PRIS - Miscellaneous reports - Nuclear Share (iaea.org). (B) Our World in Data based on BP Statistical Review of World Energy & Ember [86]

Despite the slowdown in Japan's nuclear sector since 2011, the country remains a world leader in nuclear technologies. Japan captured critical insights from the 2011 incident that have contributed to the design of safer next-generation nuclear reactors not only in Japan, but worldwide.[87] Indeed, Japanese technologies developed in its nuclear sector could be used outside of the domestic market, including in newcomer countries.[88]

Low-emission thermal energy

Japan is resolute in its commitment to achieving carbon neutrality by 2050, and is actively exploring ways to reduce dependence on fossil fuels. The country's current policy calls for the "managed phase-out" of coal power plants and a reduction in natural gas.

Nonetheless, thermal energy is expected to continue to play an important role in the energy mix. Japan uses it to balance supply and demand in the grid and to manage the costs of renewable energy—including transmission-line expansion, supply-demand adjustment cost, and so on. The

83 https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/energy-charting-tool-desktop.html.html#/results/et/nucl-gene/unit/TWh/regions/JPN/view/area

84 20211022_03.pdf (meti.go.jp), p.72

85 Japan 2021 - Energy Policy Review (windows.net)

86 https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/energy-charting-tool-desktop.html.html#/results/et/nucl-gene/unit/TWh/regions/JPN/view/area

87 Japan 2021 - Energy Policy Review (windows.net)

88 Ibid.

advantage of using the existing thermal power generation facilities and transmission lines compared to developing new power generation facilities is the fast implementation with visibility. Japan has been aggressively investing in solar and wind power and will continue to do so in the future given the high demand. However, the more renewable energy that is introduced, the more land that will be lost. Furthermore, the marginal cost of installing transmission lines and building new renewable energy facilities will increase as development expands into more extreme environments. At some point, the cost of introducing renewable energy above a certain level is expected to exceed the cost of low-emission thermal power. The effective pathway to carbon neutrality is to make those thermal power facilities carbon free.

To achieve carbon neutrality by 2050, Japanese power companies will focus on four key initiatives:

1) **Retiring inefficient coal plants**. Japanese power companies plan to shutter inefficient coal plants by 2030.[89] This would include nearly 90% of coal-fired plants that were built before the mid-1990s, all with an efficiency rate below 42%.[90] Already, Japan operates one of the most energy efficient coal-powered fleets in the world at >43% average efficiency.[91]
2) **Reducing the carbon intensity of thermal power**. Some natural-gas and coal-fired plants will remain in operation. But the Japanese government has set a target to use hydrogen and ammonia for 1% of the total country's electricity mix by 2030—using 20% ammonia co-firing (with coal-fired power plants) and 30% hydrogen co-firing (with gas-fired power plants). In the case of ammonia, the technology is readily available and requires few modifications to existing facilities.[92] Alternative fuels will serve to expedite climate action while Japan expands grid infrastructure and develops CCUS capabilities over the next 10 to 20 years. Notably, Japanese power companies view hydrogen and ammonia as "hydrogen carriers". Both technologies will be pursued in parallel in order to maintain optionality as the technologies mature. The end objective is to economically reduce emissions from the existing infrastructure.
3) **Establishing a value chain.** To achieve the above, it is a prerequisite to establish a green ammonia/hydrogen value chain in Japan. This chain will not only decarbonize the power industry, but will also utilize the hydrogen/ammonia procured to decarbonize the heat sources of other industries. Under the current technological outlook, it appears that establishing shipping for large amounts of hydrogen within the next few years will be challenging. Until that transportation method is up and running, ammonia will be favored.
4) **Developing and deploying high-efficiency, new-generation technologies**. Looking toward 2050, more significant innovation will be required. Achieving carbon neutrality by 2050 will require Japan to expand its portfolio of viable solutions—such as 100% dedicated ammonia firing, Integrated Coal Gasification Combined Cycle (IGCC) technology, and Integrated Gasification Fuel Cell (IGFC) technology in addition to scaling its current portfolio of proven solutions.

Ultimately, the Japanese government has adopted a diversified approach to reducing emissions from Japan's power sector. No single technology will be sufficient to address the speed and magnitude of the energy transition. Thus, the country is investing in a broad suite of technologies.

[89] Japan to shut or mothball 100 ageing coal-fired power plants -Yomiuri | Nasdaq

[90] Ibid.; 20210423_1.pdf (meti.go.jp)

[91] 20210423_1.pdf (meti.go.jp)

[92] Japan has successfully conducted an experiment in which 20% ammonia was co-fired in an current coal-fired power plant facilities (1 million kW). (See: https://www.meti.go.jp/shingikai/sankoshin/green_innovation/energy_structure/pdf/003_04_00.pdf)

Spotlight on JERA

Beyond Japan, JERA contributes to economic development and decarbonization throughout Asia through its "clean energy supply platform." In this model, JERA shares best practices with other ASEAN countries operating under similar conditions on how to deploy clean-energy infrastructure that will achieve both stable supply and decarbonization.

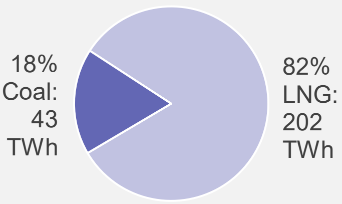
Company profile

Sales: 4,435.2 billion yen (FY2021)

Power generation: 245 TWh (FY2021)

Market share: 30% of Japan's electricity generation

Power Supply Configuration



Current emissions (2021)

Scope 1: 114.95 million t-CO_2,

Scope 2: 0.4 million t-CO_2

Emissions intensity: 0.491 kg-CO_2/kWh (domestic power)

Goals and Commitment Levels

2025: Expand power generation capacity of renewable energy to 5 million kW (now it is approx. 1.1 million kW).

2030: Reduce emissions 20% compared to emissions intensity from thermal power generation for the country (Scope 1)

2035: Reduce CO_2 emissions from domestic thermal power generation by 60% or more compared to fiscal 2013 levels (Scope 1)

2050: Achieve carbon neutrality

Decarbonization Key Levers

1) Development of renewable energy
2) Establishment of grid-scale battery storage
3) Zero-emission thermal power

As Japan's largest power generation company, JERA's approach to carbon neutrality is critical for Japan, and the company's strategy is aligned with the Japanese government. JERA is actively leading the way in realizing a low-carbon society, not only for itself but for the global carbon-neutral ambition by 2050.

JERA's approach focuses on three levers: 1) the development of renewable energy; 2) establishment of grid-scale battery storage; and 3) zero-emission thermal power.

Along with the expansion of renewable energy, thermal power plants will play a key role in providing stable and certain power supply. Since there are no international grid connections, consistent baseload power is necessary for absorbing the fluctuation of supply from renewable energy. JERA is expanding its business development to respond to both short-term and long-term fluctuations.

1. Development of renewable energy

Deployment of renewable energy will be an ongoing effort, with a near-term focus on large-scale offshore wind power generation.

JERA plans to increase its renewable energy capacity from 1.2 GW (2021) to 5.0 GW (2025). In its JERA Zero CO_2 Emissions 2050 plan, the company has announced its strategy to focus on offshore wind power in the expansion of renewable energy. Specifically, JERA is considering, or has announced, its participation in the development of offshore wind power in Hokkaido, the Aomori and Akita districts, and has decided to participate both in the Gunfleet Sands offshore wind farm in the UK, and in Formosa 1-3 in Taiwan, among other initiatives (Figure 12). JERA is also investing in overseas renewable companies, such as ReNew Power Ltd. in India and Aboitiz Power Corporation in the Philippines.

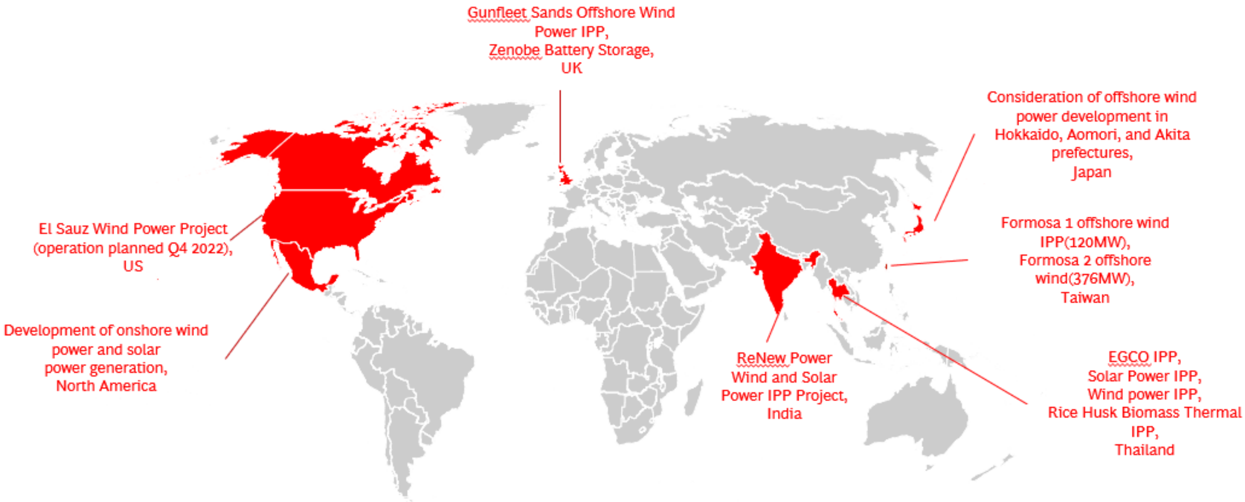


Figure 12. Renewable energy projects.

Source: Investment Projects | Our Business | JERA and Integrated Report 2021

JERA, together with MODEC, Toyo Construction, and Furukawa Electric Industry started a project to develop cost-reducing technology for tension-leg-platform (TLP) floating offshore wind turbines. This initiative aims to establish component technologies both for TLP floating and mooring systems and for subsea power transmission systems, leading to commercializing floating wind farms by the early 2030s. These TLP systems are expected to reduce the cost of power generation because the high stability of tension mooring to a seafloor foundation enables the installation of large, 15 MW-class wind turbines on compact floating platforms. In addition, TLP mooring lines are expected to be more socially acceptable than other mooring systems because they can reduce the space occupied under the sea by approximately 1/1000 and have less impact on existing businesses such as the fishing industry and ship operations.

2. Establishment of grid-scale battery storage

JERA is also investing up to £25 million for up to two years in the UK battery storage business Zenobe Ltd. and plans to accumulate knowledge on how to respond to fluctuations in supply and demand using storage batteries. With this savoir faire, the company is planning to install storage batteries on the premises of its thermal power plants in Japan to bolster efficiency. In addition, in collaboration with Waseda University, Kumamoto University, and other partners, JERA will develop a process to recycle electric vehicle lithium-ion batteries into energy storage systems, using a method with low environmental impact.

3. Zero-emission thermal power

JERA will also work to phase-out unabated coal. By 2030, the company plans to decommission all inefficient (sub-supercritical) coal-fired power plants. At the same time, JERA has started ammonia co-firing demonstrations with high-efficiency (ultra-supercritical) coal-fired power plants, beginning at a rate of 20% and scaling to 50%-cofiring by 2035. The studies are conducted in active, full-scale power plants and are expected to reduce emissions while also reducing cost by 20% to 50%, including burner care, tanks, etc. By 2050, JERA aims to operate dedicated ammonia-firing facilities. In parallel, the company will run demonstrations of hydrogen co-firing for LNG power generation with an aspiration to have full-scale hydrogen co-firing by 2040 (Figure 13).

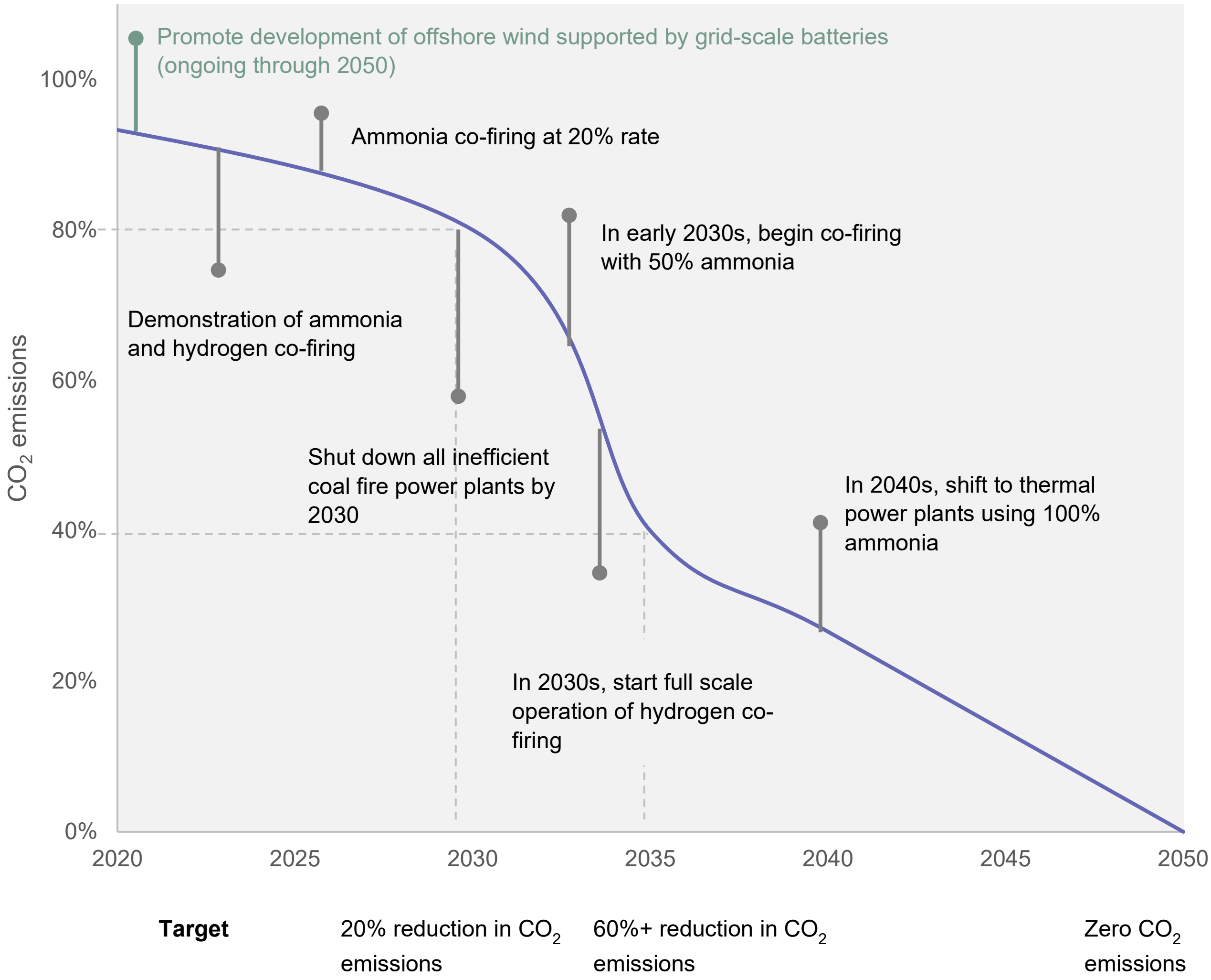


Figure 13. JERA Zero CO_2 Emissions 2050 Roadmap.

Note: Installed capacity depicted with bars, facility utilization rate with circles. Emissions reductions are based on 2013 baseline. By 2050, any remaining CO_2 emissions will be offset.

Source: Adapted from JERA

Low-emission thermal power systems have the advantage of lowering environmental impact in the process of implementing low-carbon and decarbonization methods, since existing infrastructure can be utilized as-is. Abolishing newly-built, coal-fired power plants and building new renewable-energy facilities on the same sites may be a backward step in terms of environmental impact.

JERA has already announced plans to develop ammonia and hydrogen co-combustion/mono-combustion technologies. In 2024, the Hekinan Coal-Fired Power Plant will use 20% fuel ammonia supported by a subsidy from the New Energy and Industrial Technology Development Organization (NEDO). By 2025, with investment from the Green Innovation Fund, JERA plans to use 30% hydrogen by volume at LNG-fired power plants owned in Japan, including the Linden Thermal Power Plant.

As another part of the transition to zero-emission thermal energy, JERA is establishing a value chain for ammonia and hydrogen as one of the world's leading off-takers. Ammonia co-firing is technically feasible with only minor adjustments to the facilities. The challenges lie in the supply of hydrogen and ammonia, and the co-firing ratio will be increased to 50% in proportion to the establishment of the hydrogen and ammonia value chain.

In 2021, JERA signed a memorandum of understanding (MOU) for collaboration with Yara International, a Norway-based global leader in the production and trade of ammonia for fertilizer use. That same year, JERA also invested €15 million in Hydrogenius, a proprietary technology for hydrogen energy carriers based in Germany. Through these collaborations/investments, JERA is trying to secure sources of ammonia/hydrogen outside of Japan. The company also began a joint study with ENEOS and JFE HD, discussing in detail the possibility of establishing a hydrogen and ammonia receiving and supply base, and developing a supply project at the Keihin Waterfront Area in Japan's Kanagawa District.

JERA is also working regionally to support Indonesia in developing a roadmap for the state-owned utility PLN. Indonesia plans to introduce LNG first, followed by co-firing of domestic biofuels, then ammonia and hydrogen. JERA aims to provide knowledge and expertise, adapted for local conditions.

Collectively, these initiatives will drive innovation within the power sector across the region and could contribute to decarbonization across other industries as well, by paving the way for ammonia and hydrogen co-combustion and mono-combustion.

Steel

Steel Fast Facts

Sector profile

Revenues: 2. 5 trillion USD in 2019[93]

Power consumption: 36 EJ in 2021[94]

Production volume: 1,951 M tons in 2021[95]

Main Usage

Buildings, infrastructure, transport, machinery, consumer goods, etc.

Current CO_2 emissions

2,591 Mt CO_2 in 2020 [96]

8% of the global CO_2 emission[97]

30% of the global industry sector CO_2 emission[98]

Interdependencies

Upstream: Power sector

Downstream: Industrial sectors (including automobile)

Highlights

Steel is an essential material for modern life, and demand for steel products is expected to grow. However, the production of steel contributes 8% of global CO_2 emissions and 30% of industrial sector emissions. Since there are only a few ways to manufacture steel, the technical paths for reducing carbon emissions are commensurately limited.

Japan's steel industry is committed to 30% emissions reduction by 2030, with a vison to achieve carbon neutrality by 2050. This pathway is designed to secure a steady supply of steel, including high-performance steel, while pursuing innovative ways to reduce emissions. In the short term, Japan's steel industry will continue to promote the low-carbonization of the blast furnace (BF) process by further improving its energy efficiency, which is currently at the world's highest level. In the mid-to-long term, the industry will further explore technologies aimed at reaching the global carbon-neutrality goal. These will include further improvement of the BF process, implementing 100% hydrogen direct-reduced-iron (DRI) technology, as well as developing large-size electric furnaces.

Furthermore, the steel sector's emissions trajectory is interlinked with initiatives in other sectors. Emissions reductions depend on the development of country-level supply chains for green and blue hydrogen and ammonia, as well as for green electricity. The steel sector also contributes to emission reductions in the automotive industry, among others.

---

93 https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

94 https://www.iea.org/reports/iron-and-steel

95 https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2022-1.pdf

96 https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf

97 Ibid.

98 Ibid

Steel sector overview

Steel is ingrained in our everyday lives. It is made from iron, the most abundant metal resource on the planet, and enriches our lives through multiple essential products. It underpins our human-built environment and plays a strategic role in supporting industry. Its high strength, recyclability, durability, versatility, and relatively low cost make its substitution or obsolescence unlikely in the foreseeable future.

At the same time, the iron and steel sector is one of the highest CO_2 emitting sectors, accounting for roughly 8% of global CO_2 emissions and 30% of emissions from the industrial sector.[99] With global steel demand projected to rise by more than 30% through 2050,[100] the sector will require substantial cuts in CO_2 emissions if it is to achieve global climate targets.

Steel production can be divided into two categories: primary production (producing steel from iron ore), and secondary production (producing steel from recycled steel scrap).

- Primary production requires a complex reaction to remove oxygen from iron ore (iron oxide).[101] Blast furnace (BF) or basic oxygen furnace (BOF) methods, using coking coal for reduction, is the most common route for primary steel production, amounting to 70% of global steel.[102] Primary production is the method of choice for producing high-performance steel products for industrial use.
- Secondary production melts steel scraps in an electric arc furnace (EAF) to produce steel products. To reach near carbon neutrality, EAFs can be powered by carbon-free electricity.

The secondary production route has become more common in some developed countries that have accumulated stocks of steel scrap, but primary production is still required for two reasons. First, global steel scrap supplies (including internal and home scraps) are insufficient to meet global demand (Figure 14). Second, high-performance steel products such as flat steels and some rods and wires—used for products such as automobiles, home appliances, and transformers—cannot be made solely by the secondary route.[103] Secondary steel tends to contain impurities (known as tramp elements, including copper, tin, etc.) that deteriorate performance.[104] Removing or avoiding impurities remains technically challenging, so the primary route is still needed.

---

99 https://www.globalefficiencyintel.com/new-blog/2021/global-steel-industrys-ghg-emissions; Tracking Industry 2021 – Analysis - IEA ; Global energy sector CO_2 emissions by sector in the Sustainable Development Scenario, 2019-2070 – Charts – Data & Statistics - IEA

100 https://www.sei.org/publications/net-zero-decarbonising-steel-by-2050/

101 Includes Blast furnace (BF) - basic oxygen furnace (BOF) route and DRI (direct reduced iron)-EAF route using national gas and carbon-free electricity.

102 https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf, p.29

103 For example, Advanced High-Strength Steel (AHSS) sheets are utilized heavily in exterior frame of automobiles, and electromagnetic steel sheets help improve the efficiency of motor products. Highly functional steel sheets with a rust-preventive finish are also used in offshore wind turbines, which are expected to increase in number in the future.

104 https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf, p.29

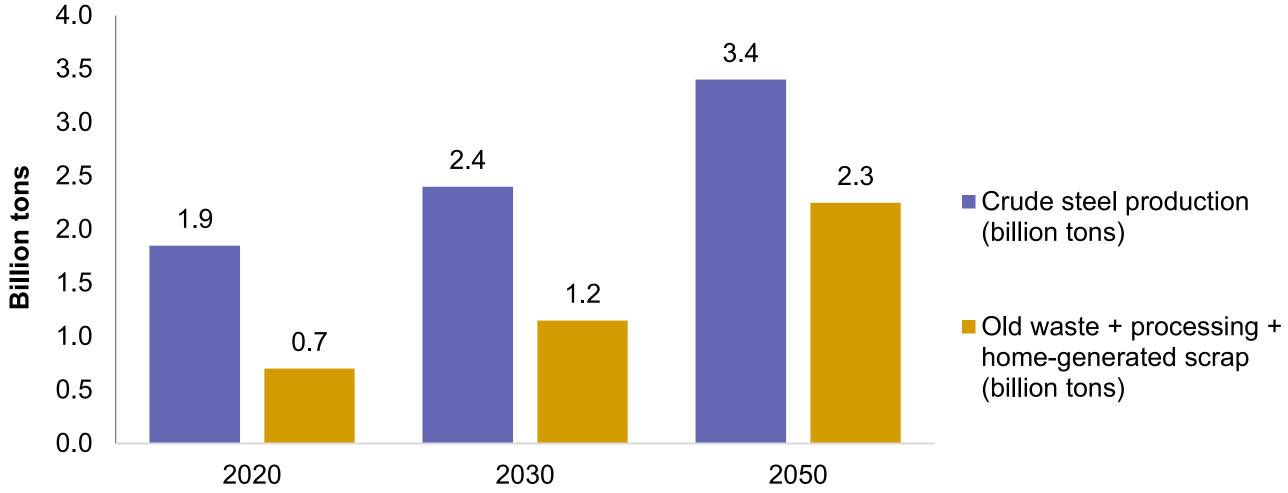


Figure 14. Comparison of Crude Steel Production and Scrap Availability.

Source: Vision for Long-Term Global Warming Countermeasures, Japan Iron and Steel Federation.[105]

In the United States, where 64% of steel is produced using EAFs, the scrap ratio in high- performance products can be less than 60% (Figure 15A). Moreover, the US imports a large volume of semi-finished or finished steel products made via primary production, as well as high-grade steel scraps needed for the secondary route. (Figure 15B).

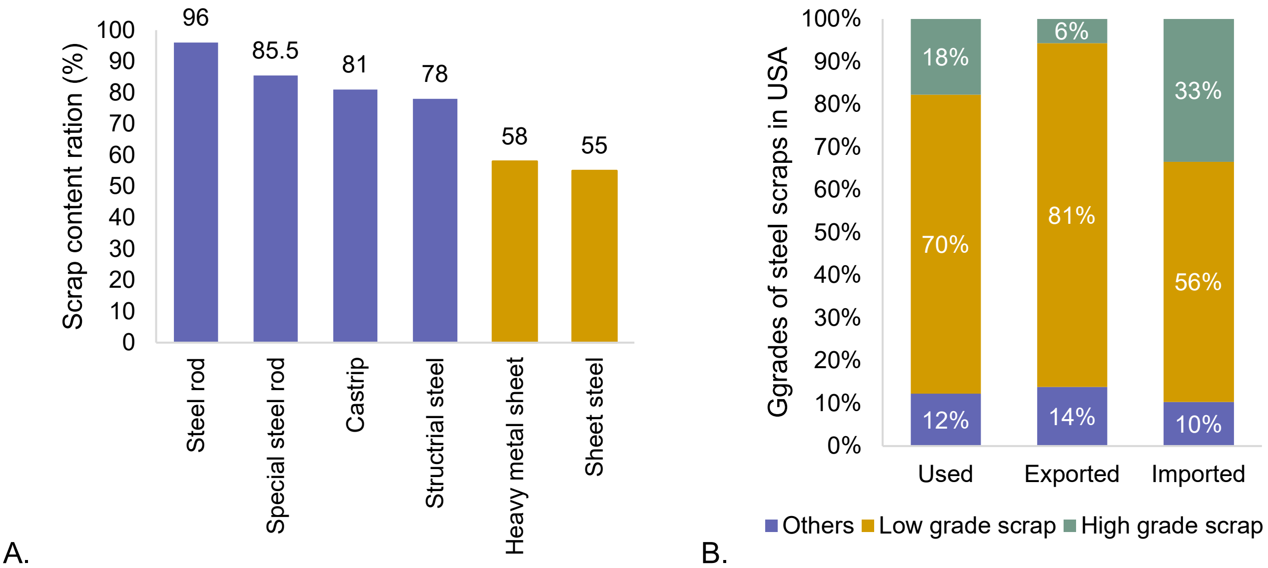


Figure 15. A. Ratio of scrap steel used in steel products in US. B. Ratio of high grade steel scrap used in US EAFs.

Source: (A) Nucor.[106] (B) USGS Minerals Year Book 2014 (Iron and Steel Scrap Statistics and Information) [107]

---

105 https://www.jisf.or.jp/business/ondanka/zerocarbonsteel/documents/zerocarbon_steel_honbun_JISF.pdf

106 https://www.jisf.or.jp/en/activity/climate/documents/JISFLong-termvisionforclimatechangemitigation_text.pdf

107 Iron and Steel Scrap Statistics and Information | U.S. Geological Survey (usgs.gov)

There are several approaches for reducing emissions in primary production. For example, European companies plan to gradually introduce the DRI-EAF method using natural gas and carbon-free hydrogen. However, only 5% to 10% of the world's iron ore qualified as raw material for this method, an insufficient amount considering demand for steel products. Moreover, the high costs of natural gas[108] and electricity in some regions, including Japan, make the feasibility of the DRI-EAF route more challenging (Figure 16).

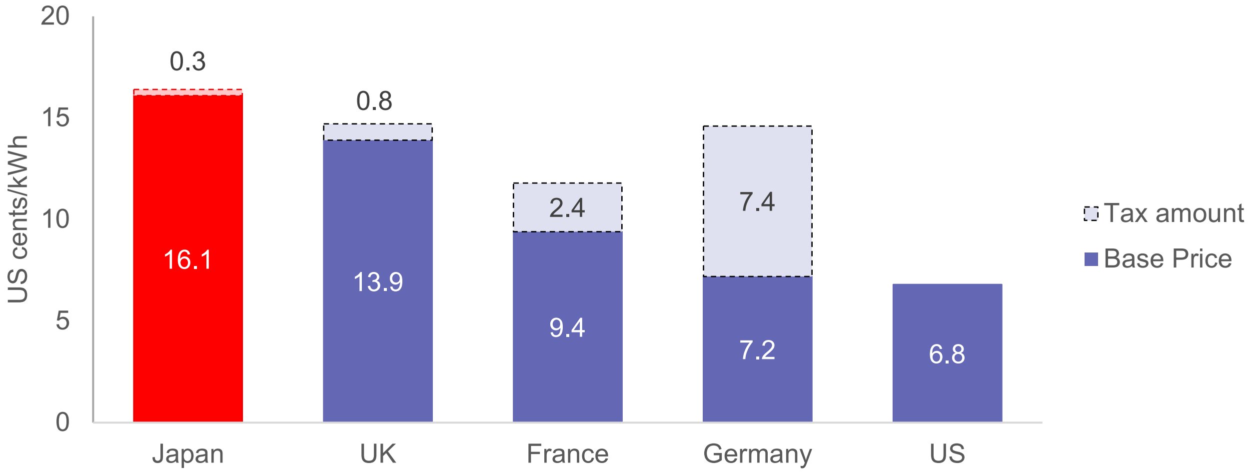


Figure 16. Industry end-user electricity prices, 2019.

Source: IEA.[109] Most of the taxes in the figure are exempted in Germany for large volume-power-using industries.[110]

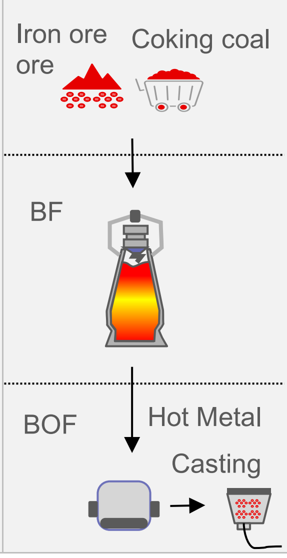
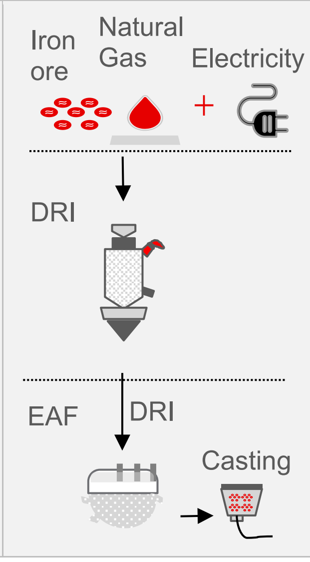
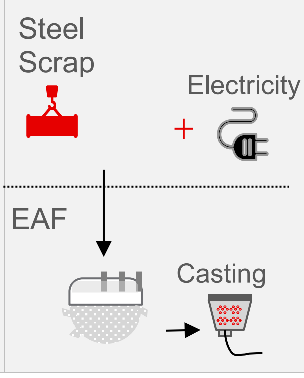
Given such circumstances, both BF-BOF using hydrogen and low-grade iron ore, as well as DRI-EAF, are the options for primary steel. Table 3 (below) provides an overview of steel-making processes.

---

[109] https://www.iea.org/data-and-statistics/charts/industry-end-user-electricity-prices-in-selected-oecd-countries-2019

[110] Each countries may include different types of taxes

Table 3. Steelmaking Processes: Carbon Emissions and Energy Consumption. Source: Fact Sheet: The facts about steelmaking. Steelmakers seeking Green steel, IEEFA[111]

	Primary Route		Secondary Route
Production Routes	BF-BOF	DRI-EAF	Scrap-EAF
CO_2(t) emissions/ t-crude steel	2.2	1.4	0.3
Energy consumption (GJ/t)	22.7 (World Steel) 21.4 (IEA)	21.8 (World Steel) 17.1 (IEA)	5.2 (World Steel) 2.1 (IEA)
Share of global production (%)	73.2	4.8	21.5
Image			

Japan's carbon-neutrality pathway

As the highest emitting industrial sector in Japan, the steel business has publicly committed to a 30% emissions reduction by 2030 (compared to 2013). The industry is aiming to revamp the manufacturing process to eliminate CO_2 emissions and advance toward its 2050 carbon-neutrality goal.[112]

Moreover, since the steel sector plays a pivotal role in many areas of Japanese manufacturing, it is committed to producing high-performance products. The BF-BOF route will be critical. Indeed, Japan's reduction strategy relies less on EAF than is common in Europe and the US, where scrap-EAF or DRI-EAF are already more prevalent (Figure 17). Japan intends to combine several technologies, all suited to its specific conditions, to reach the global carbon-neutral goal. Such initiatives are aligned with the transition-finance roadmap announced by Japan's Ministry of Economy, Trade and Industry (METI), and both the public and private sectors will work together to promote decarbonization.

111 https://ieefa.org/sites/default/files/2022-06/steel-fact-sheet.pdf
112 https://www.jisf.or.jp/en/activity/climate/documents/2021_tekkouwg_en.pdf

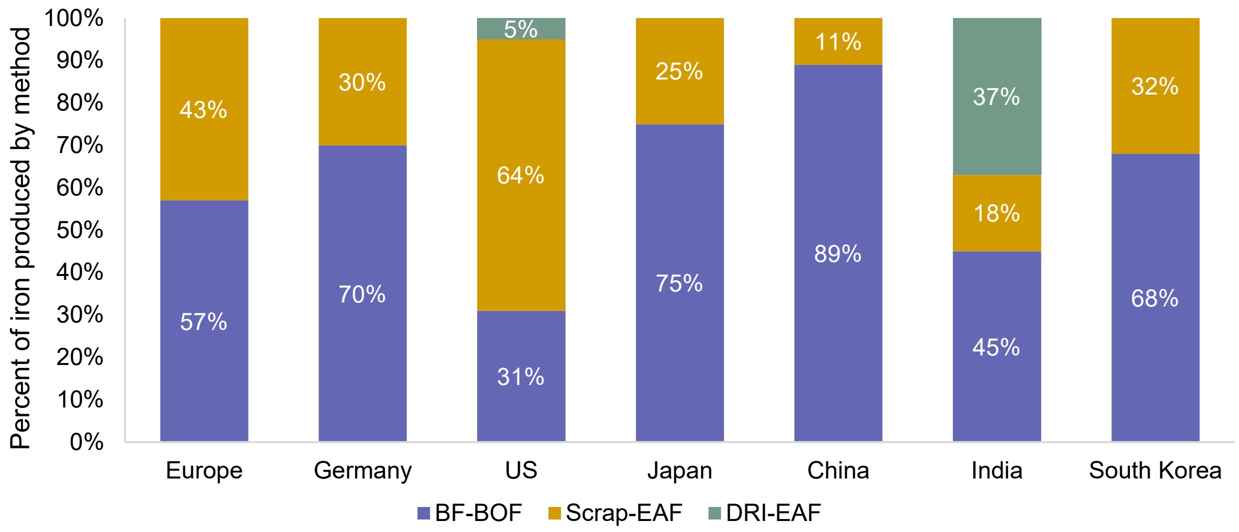


Figure 17. Comparison of ironmaking methods in each country (2019).

Source: World Steel Association.

Note: While more than 80% of global DRI plants use natural gas, DRI production in India is primarily coal-based.

Continued improvements in BF-BOF energy efficiency are crucial not only to Japan's strategy, but also regionally as countries across Asia manage their carbon footprints. Japan's steel plants have been achieving the world's highest energy efficiency for years, largely stemming from ongoing investments since the 1990s.[113] (Figure 18).

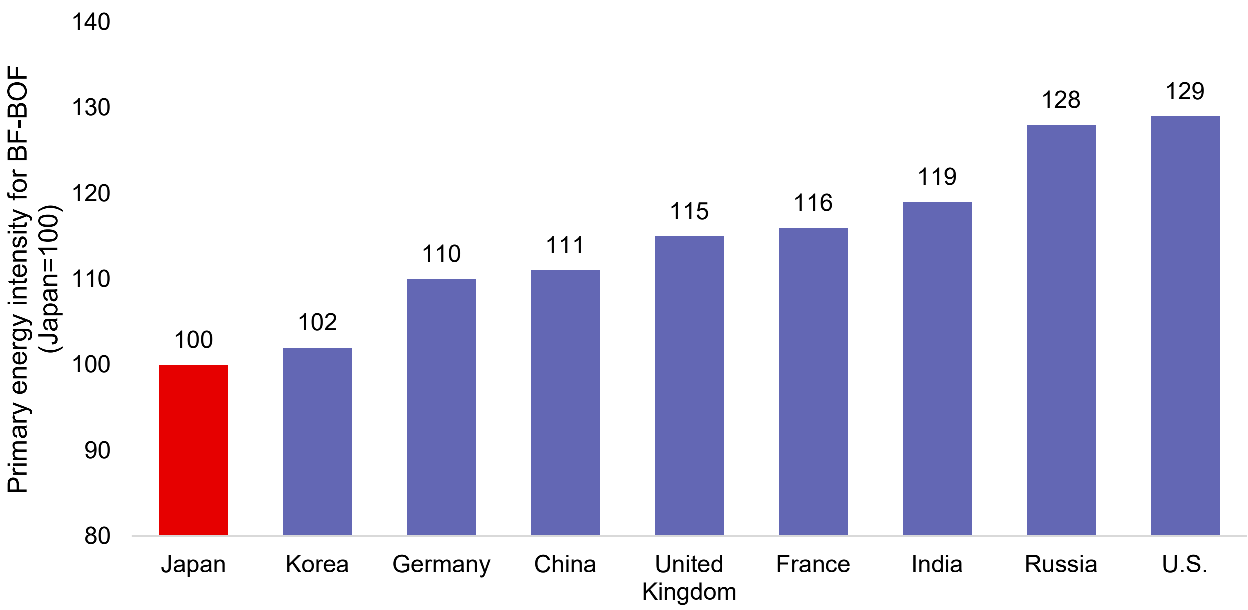


Figure 18. Energy efficiency in steelmaking by country (2019).

Source: RITE[114]

[113] https://www.iea.org/articles/driving-energy-efficiency-in-heavy-industries

[114] https://www.rite.or.jp/system/global-warming-ouyou/download-data/Comparison_EnergyEfficiency2019steel.pdf, p.4

Over the coming decade, Japanese steel producers plan to further reduce CO_2 emissions by introducing hydrogen technology in BF-BOFs. Since 2008, ongoing research has led to a high degree of maturity in experimental BF through the "COURSE50" project. Such technology can reduce CO_2 emissions by 10%, and when combined with CCUS by 30%.[115] In the future, researchers hope to reduce emissions up to 50% by maximizing the amount of hydrogen input—utilizing biomass and leveraging DRI as raw materials.[116]

Further, Japan's steel industry plans eventually to use 100% hydrogen DRI technology, with an aspiration to use DRI-EAF. In order to commercialize 100% hydrogen-based DRI, producers intend to establish supply chains of blue/green hydrogen. Japanese companies are also conducting R&D to scale up both EAF for steel scrap and DRI. The purpose is to produce steel at the same quality and quantity levels as BF-BOF. What is more, Asia has a number of relatively new BF-BOFs which, if they continue to operate under current conditions, will account for as much as 65 Gt of CO_2 emissions by the end of their lifetimes.[117]

Overall, Japan's leadership in energy efficiency and innovation toward a carbon-neutral future could serve as a valuable blueprint, not only for countries in Asia-Pacific but for the global community.

---

[115] https://www.course50.com/en/technology/; https://www.nedo.go.jp/content/100940993.pdf, p.1

[116] https://www.nedo.go.jp/content/100940993.pdf, p.

[117] https://www.iea.org/reports/iron-and-steel-technology-roadmap

Spotlight on Nippon Steel

Using a multi-pronged approach, Nippon Steel aims to establish a near carbon-neutral steel production process suited to the Asian region. The company will contribute to economic development and decarbonization throughout Asia by sharing its processes and technologies, and at the same time help reduce global emissions.

NIPPON STEEL

Company profile

- Sales: 6,808.8 billion yen in FY2021
- Power consumption: 1,025 petajoules (PJ) of energy in FY2021
- Production volume: 44 M tons in FY2021

Current emissions (2021)

- CO_2 emissions: 87 M tons CO_2
- Emissions intensity: 1.88 t-CO_2/ton

Goals and Commitment Levels

- 2030: 30% reduction in Scope 1 +2 CO_2 emissions compared to 2013 levels
- 2050: Carbon neutral

Decarbonization Key Levers

- Adopting hydrogen reduction ironmaking in blast furnaces and in converter processes
- Commercializing a fleet of large electric furnaces capable of producing high- grade steel and minimizing CO_2 emissions by DRI and carbon-free electricity
- Producing a direct iron reduction technology that uses 100% hydrogen reductant, reducing CO_2 emissions to nearly zero

Japan's largest steelmaker, Nippon Steel Corporation, has committed to reducing Scope 1 and Scope 2 CO_2 emissions 30% by 2030 (vs. 2013). The reduction would amount to 30 M tons of the 170 M tons of CO_2 emissions that Japan's steel sector aims to eliminate.

Nippon Steel plans to lower CO_2 emissions through both decarbonization of its manufacturing processes and the development of energy-saving products. The company will also contribute to the reduction of CO_2 emissions globally by transferring energy-saving technologies across borders.

Nippon Steel's decarbonization strategy emphasizes BF-based production, while developing both CCUS technology in the short-term and hydrogen-based DRI and improved scrap EAF technology in the long term.

Nippon Steel's roadmap to reduce CO_2 emission focuses on three levers:

1) Develop hydrogen reduction technology for BFs (Figure 19).
   - Commercialize the "COURSE50" technology by 2030
   - Implement "Super-COURSE50" by 2050 through the development of new technology and the establishment of a hydrogen supply chain.

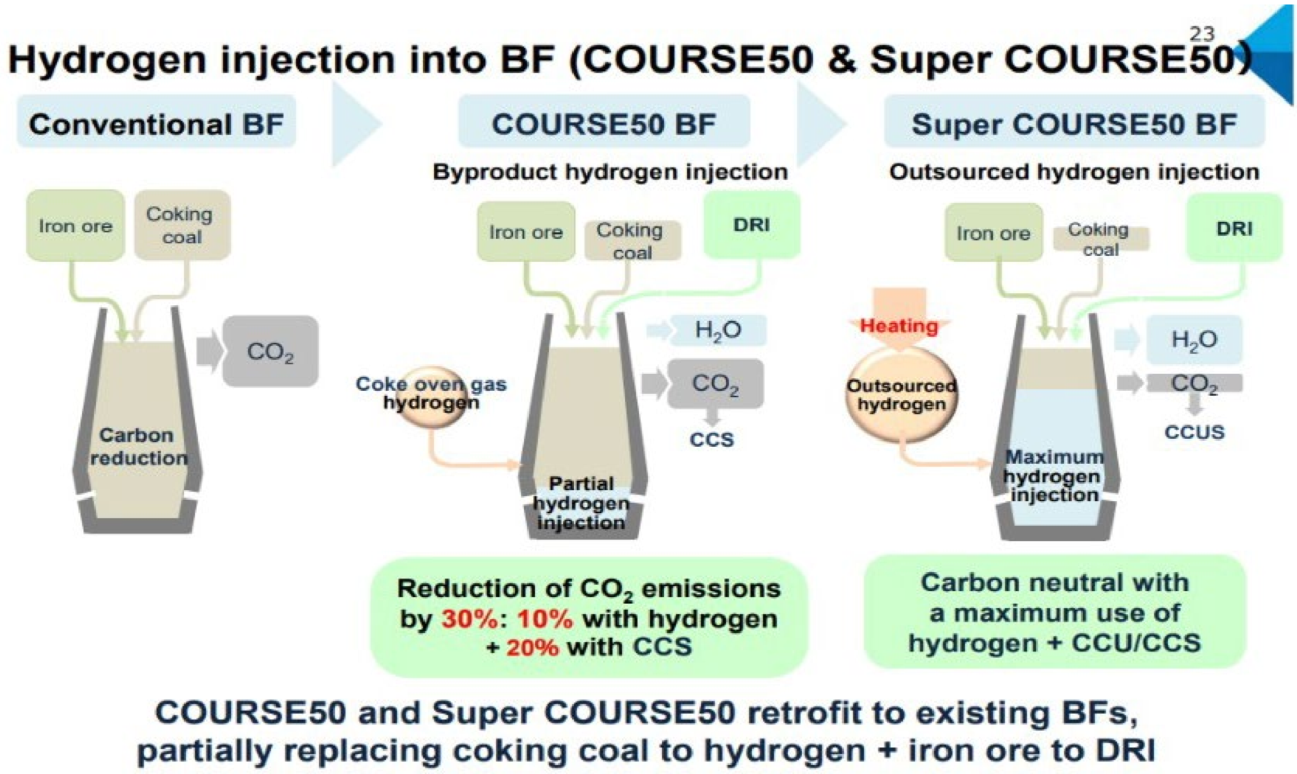


Figure 19. Schematic diagram of COURSE50 and Super-COURSE50.

Source: Nippon Steel[118]

2) Commercialize large electric-arc furnaces (Figure 20).
   - Develop a process to produce high-performance steel products in EAF by lowering the effects of impurities (e.g., tramp elements from scrap steel, as well as nitrogen contamination)
   - Scale EAFs to improve productivity and to match the requirements and costs currently met by BF-BOF
3) Produce DRI using 100% hydrogen.
   - Conduct R&D to achieve 100% hydrogen-based DRI using low-grade iron ore
   - Use 100% hydrogen-based DRI as raw material for EAF and BF- BOF

---

[118] https://www.nipponsteel.com/en/ir/library/pdf/20210330_ZC.pdf,p23

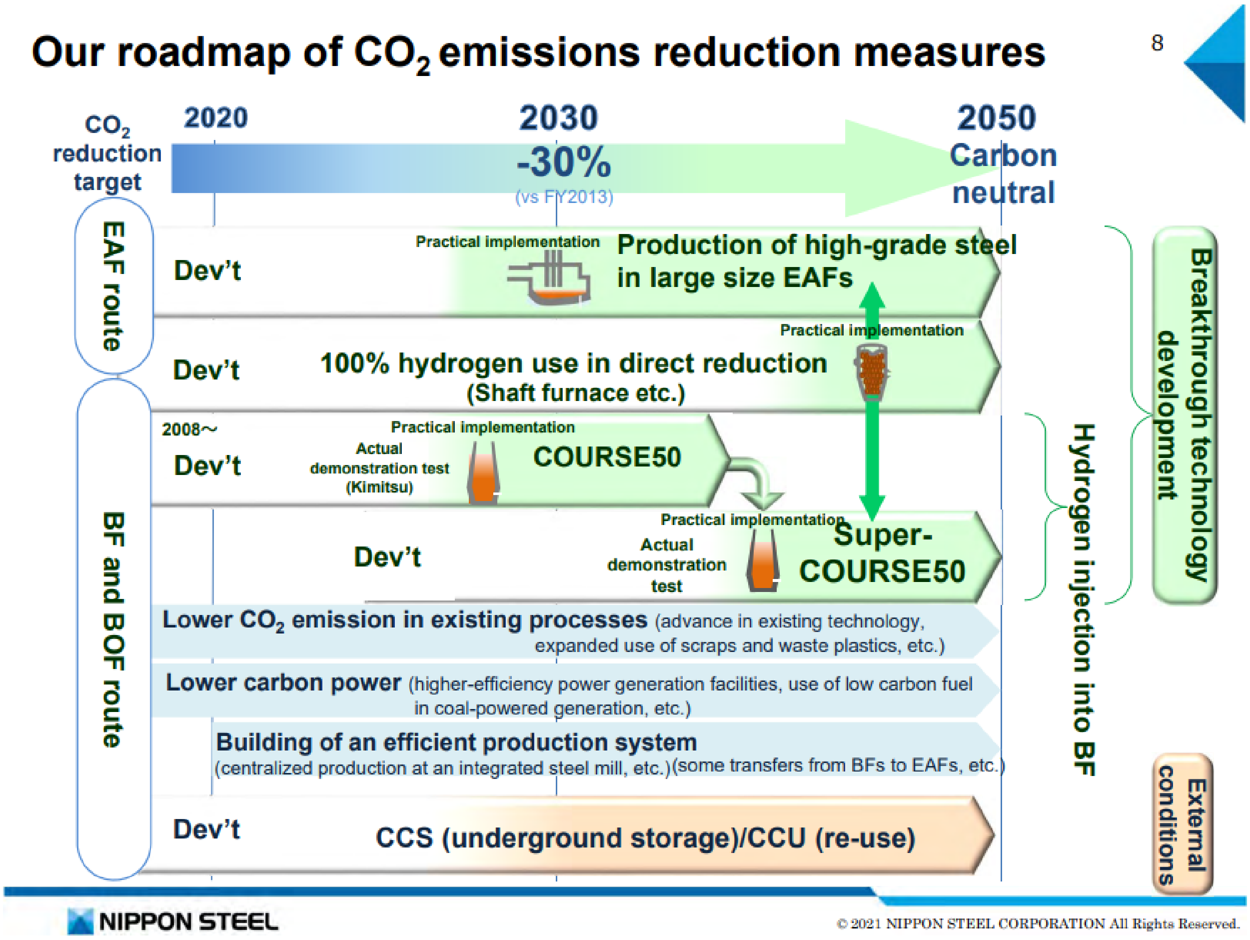


Figure 20. Roadmap of CO_2 reduction.

Source: Nippon Steel[119]

Nippon Steel estimates that it will need to invest 4 trillion to 5 trillion yen ($29B to $37B) to achieve carbon neutrality by 2050.

While reducing CO_2 from its steel-making processes, the company also intends to provide a wide variety of high-performance steel products, contributing to downstream emissions reductions. For example, advanced high-strength steel (AHSS) sheets used in automobiles improve fuel efficiency by reducing weight. Also, electrical-steel sheets contribute to the reduction of energy loss in motors and transformers, both of which are essential products in the quest for electrification.

Nippon Steel further intends to contribute to the reduction of GHG emissions globally by taking several steps: sharing best practices and technologies for energy saving with developing countries; promoting international partnerships; transferring energy-saving technologies via licensing; and promoting the evaluation of energy-saving efforts in the global steel industry. Finally, the company's innovation in low-carbon BF technology can reduce emissions from BF-based steel production, which remains essential to meet global demand.

[119] https://www.nipponsteel.com/en/ir/library/pdf/20210330_ZC.pdf,p8

Cement

Cement Fast Facts

Sector profile

Revenues:
327 billion USD in 2021[120]

Energy consumption:
11.48 EJ in 2021[121]

Production volume:
4.3 G tons in 2021[122]

Main emission sources[123]

Energy-derived (~40%)

Process-derived (~60%)

Current CO_2 emissions

2,445 Mt CO_2 in 2020 [124]

7% of the global energy sector CO_2 emissions

Interdependencies

Upstream: Power, chemical, transportation

Downstream: Construction

Highlights

Cement is a binder, manufactured using limestone and various other raw materials. It is a key ingredient in concrete, the most widely used man-made material. However, production of cement accounts for roughly 4.5% of global GHG emissions.

Reducing emissions from cement manufacturing is challenging, given the high energy demand as well as the CO_2 released as a bi-product of chemical reactions. Yet there are multiple levers that can be used to reduce CO_2 emissions, including efficiency improvement of the facilities, fuel- and power-source transitions, raw-material substitution, and CCUS. Although these levers are universal globally, local factors such as CCS potential and the frequency of earthquakes determine which levers will be emphasized.

Japan's cement industry has been aggressively investing in energy efficiency over the past decade, resulting in the lowest thermal energy consumption in the world. In addition to maintaining this position, the focus of Japan's cement industry centers around switching to alternative fuels and circularity. The country's strategy includes increasing the utilization of industrial waste/biomass for heat sources and raw materials, and effectively converting recovered CO_2 emissions from the cement production process into raw materials.

---

[120] Cemen Market Size, Share | Global Industry Trends, 2022-2029 (fortunebusinessinsights.com)

[121] Multiple average energy consumption and cement production volume (4.3Gt); average energy consumption(2.67GJ/t) is calculated by diverting figures of GNR member firms; Source: https://www.iea.org/reports/cement, GNR Project (gccassociation.org) "Total thermal energy consumption | excluding drying of fuels - Grey and white cement (GJ)"

[122] Cement – Analysis - IEA

[123] GCCA Concrete Future Roadmap

[124] https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf

Cement sector overview

Cement, a mineral binder, is a key ingredient in concrete, the most widely used man-made material.[125] Concrete is essential for construction and infrastructure, and no other material rivals its resilience, strength, and wide availability.[126] Other than concrete, cement is used for manufacturing products such as grout and whitewash. Moreover, global demand for cement is expected to increase as a result of population growth, urbanization, and infrastructure development—particularly in Africa, India, and Latin America.[127] As a whole, global cement production is projected to increase by between 12% and 23% by 2050 (cumulative).[128]

Unfortunately, manufacturing cement is a CO_2 intensive process. The business is the third largest industrial-energy consumer,[129] and the production of cement accounts for around 4.5% of global GHG emissions (and 7% of all CO_2).[130] Most CO_2 emissions are generated developing the clinker—a solid, intermediary product—through calcinating limestones by heating raw materials. The emissions stem from two sources (Figure 21):[131]

1) ~40% of CO_2 emissions are energy-derived. They come from the combustion of fossil fuels, primarily coal, used to create high thermal energy during the calcination process in making the clinker and to generate power.[132] Improvements in energy efficiency can lower emission intensity, but using alternative energy sources or CCUS will be necessary to reach carbon neutrality.
2) The remaining ~60% of CO_2 emissions are process-derived and generated during the conversion of calcium carbonate ($CaCO_3$) into calcium oxide (CaO), the main ingredient in clinker. The principal ways to reduce process-related emissions include raw-material substitution (e.g., reducing the clinker ratio) and CCUS.

[125] Concrete - the world’s most widely used material - targets carbon neutral future : GCCA (gccassociation.org)

[126] https://gccassociation.org/our-story-cement-and-concrete/

[127] GCCA Concrete Future Roadmap

[128] Cement technology roadmap plots path to cutting CO2 emissions 24% by 2050 - News - IEA; Technology Roadmap - Low-Carbon Transition in the Cement Industry (windows.net)

[129] Technology Roadmap - Low-Carbon Transition in the Cement Industry

[130] https://www.globalefficiencyintel.com/new-blog/2021/global-cement-industry-ghg-emissions

[131] GCCA Concrete Future Roadmap

[132] The power generated is for the captive use.

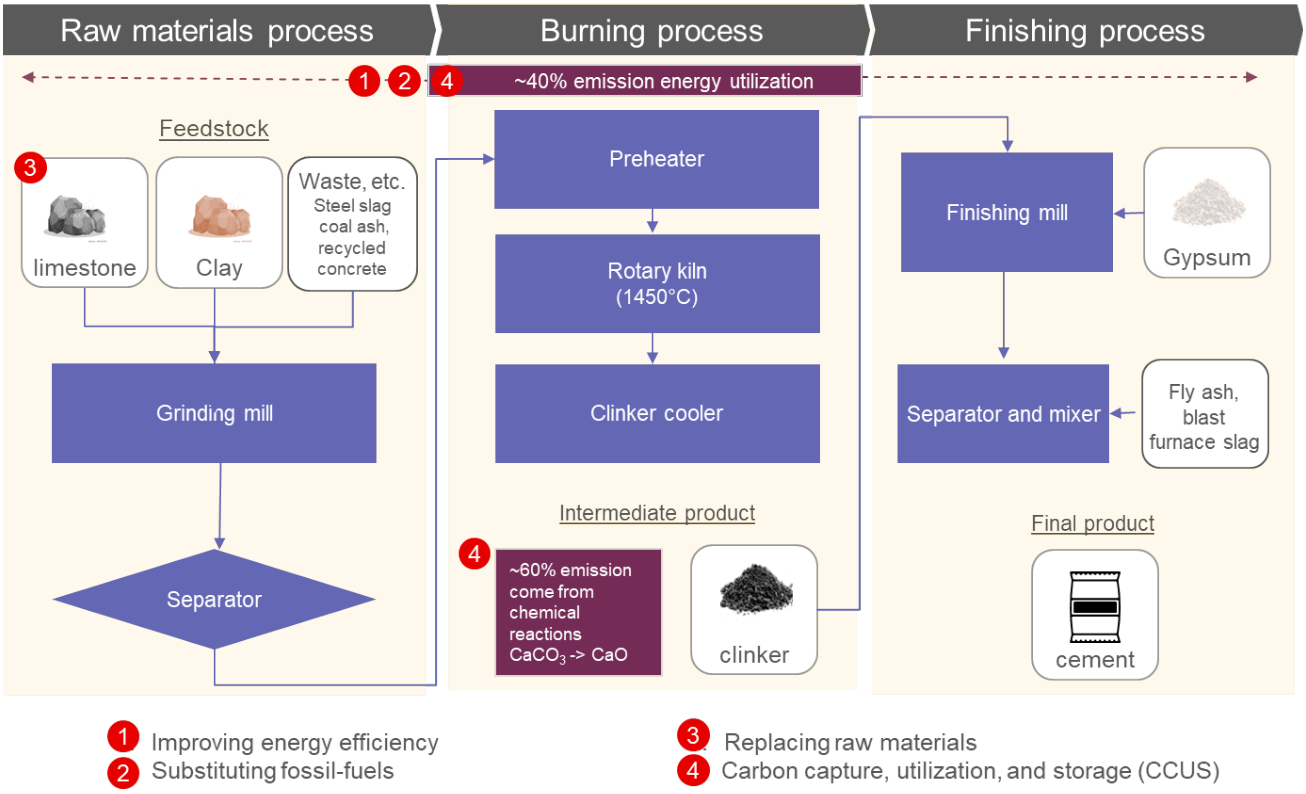


Figure 21. Cement manufacturing process

Note: The process emits ~40% of emissions due to energy intensive processes, and ~60% due to chemical transformation. Limestone and other raw materials are crushed in a grinding mill. The fine powder is heated to produce an intermediate material, clinker. The cement is finished by adding a few other compounds (gypsum, fly ash, etc.) to produce blended cement. Adapted from METI.[133]

Recognizing the importance of the cement industry to achieving global ambitions, the Global Cement and Concrete Association (GCCA)[134] has announced an industry-wide commitment to achieve both carbon neutrality by 2050 and a 20% reduction in CO_2 per ton of cement by 2030 (compared to 2020 levels).[135] To achieve this, most companies will need to leverage a mix of decarbonization strategies instead of betting on one breakthrough technology. According to the International Energy Agency (IEA), material efficiency, including raw-material substitution, as well as CCUS will likely contribute most to direct emissions reductions.[136]

[133] transition_finance_technology_roadmap_cement_eng.pdf (meti.go.jp)

[134] GCGA is comprised of 40 of the world's leading cement and concrete manufacturers

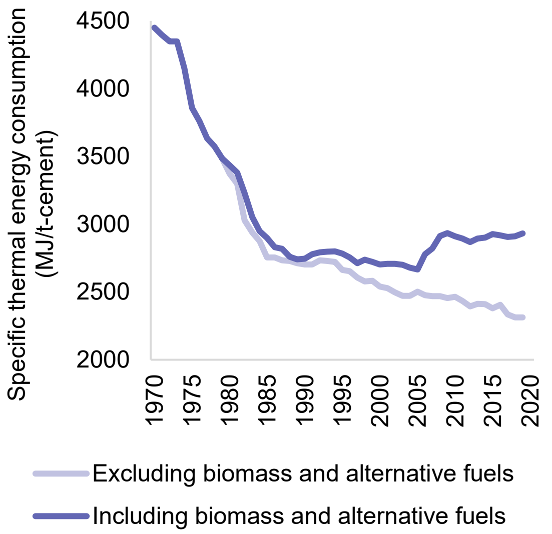
[135] GCCA Concrete Future Roadmap

[136] "Actions to reduce cement demand include optimising the use of cement in concrete mixes, using concrete more efficiently, minimising waste in construction, and maximising the design life of buildings and infrastructure. Material efficiency efforts have gained increasing support in recent years." IEA Cement

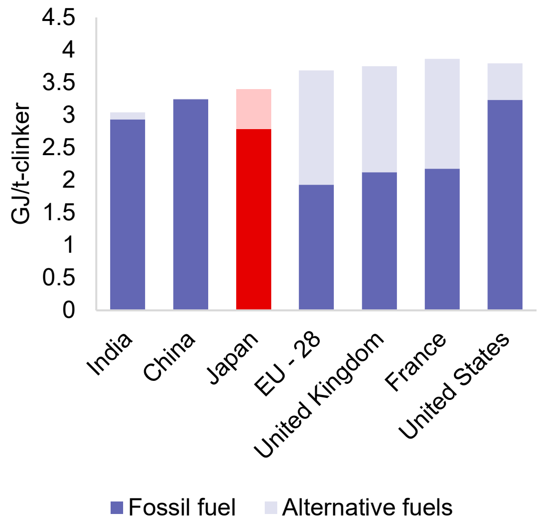
Japan's carbon-neutrality pathway

Japan produces 1.4% of world's cement and emits 42 Mt-CO_2e.[137] By 2050, the Japan Cement Association plans to achieve carbon neutrality.[138] Within the sector, Japan's environmental performance rivals that of European countries and the US. For example, CO_2 emission per t-clinker amounts to 828 kg-CO_2/t-clinker (2020) in Japan, a carbon intensity on a par with France (822 kg-CO_2/t-clinker, 2019), Germany (810 kg-CO_2/t-clinker, 2019), and the US (868 kg-CO_2/t-clinker, 2019). However, Japan's approach to emission reductions differs from those in Europe and the US, owing to geographical and resource constraints. The country's success in reducing its CO_2 emissions can be attributed to the following three initiatives:

1) Achieving higher energy efficiency in kilns.[139] Since the oil crisis of the 1970s, Japan has emphasized energy efficiency as a means to cope with limited energy resources. By 1997, ahead of the rest of the world, the country adopted high-efficiency kilns, namely NSP (Suspension preheater kiln with a pre-calciner), or SP (Suspension preheater kiln). These kilns contributed to a steep reduction in Japan's thermal energy consumption (Figure 22A), and as a result, Japanese cement production is among the most efficient in the world. Currently, Japan's thermal energy consumption per ton of clinker is 3.4 GJ/t, compared to 3.7 GJ/t in the EU and 3.8 GJ/t in the US (Figure 22B).[140]



A.



B.

Figure 22. A. Specific thermal energy consumption for cement production in Japan. B. Energy consumption for clinker production in the world (2018).

Source: (A) Japan Cement Association.[141] IEA.[142]

---

[137] https://www.meti.go.jp/shingikai/energy_environment/transition_finance_suishin/pdf/007_04_00.pdf

[138] https://www.jcassoc.or.jp/cement/1jpn/220324.html

[139] Rotary furnace/ ovens used to calcine cement clinker in a plant

[140] Thermal specific energy consumption per tonne of clinker in selected countries and regions, 2018(IEA); the figures are the sum of alternative fuels and fossil fuels; source: Thermal specific energy consumption per tonne of clinker in selected countries and regions, 2018 – Charts – Data & Statistics - IEA

[142] Thermal specific energy consumption per tonne of clinker in selected countries and regions, 2018 – Charts – Data & Statistics - IEA

2) Utilization of alternative fuels. Waste fuels composed of biomass, waste plastics, and other materials have lower CO_2 emissions than coal.[143] Thanks to its highly established infrastructure and national emphasis on recycling, Japan has built a strong foundation for utilizing municipal and industrial waste as fuel. Although the Japanese government provides less policy support, such as a landfill tax, to the cement industry compared to Europe, Japanese cement players managed to successfully increase the utilization of alternative fuels four-fold between 2000 and 2020 (Figure 23). In particular, the use of waste plastic has increased 30% since 2000, becoming a main driver for accelerating utilization of alternative fuels. With its efficient and interconnective plastic-recycling system, Japan successfully recycled 86% of its plastics in 2020,[144] with 746,000 tons utilized in the cement sector.

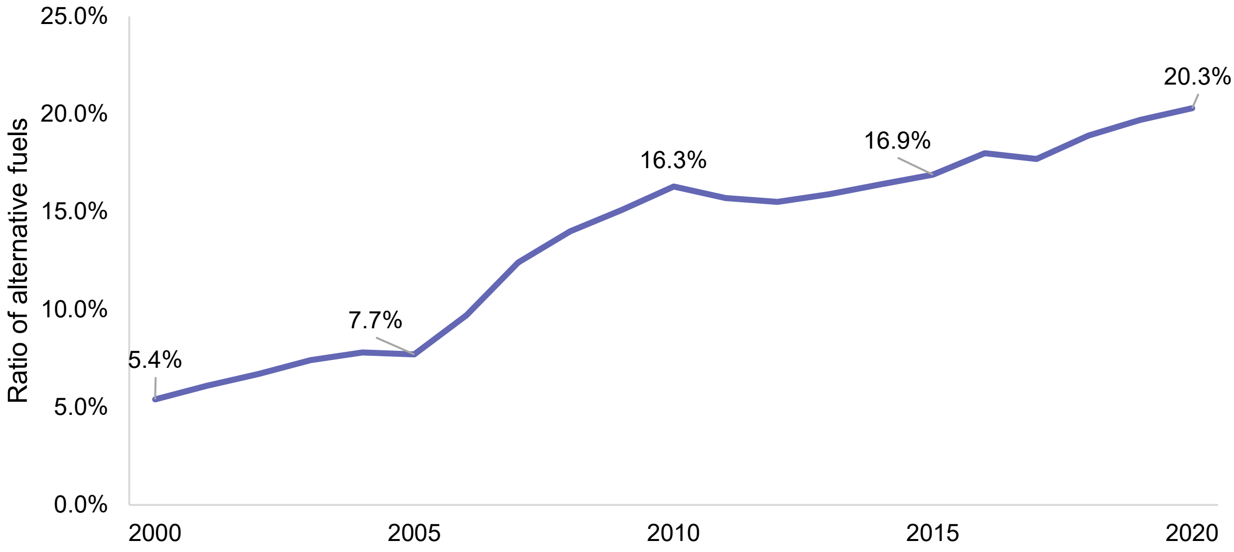


Figure 23. Alternative fuel utilization transition (firing process) in Japan.

Source: Japan Cement Association[145].

3) Incorporation of waste/by-products as raw materials. Utilizing slag, fly ash, etc. generated as byproducts in the industrial and power sectors as substitutes for raw materials can reduce CO_2 emissions during the process of producing clinker. Japan, owing to its large industrial sector and reliance on coal-fired power plants, has been rich in waste and by-products, namely slug/fly-ash, which can be used as raw materials to produce clinker (Figure 24).

In addition, it should be noted that the Japanese cement industry has been accepting waste originating from buildings that have been destroyed in earthquakes, and in so doing making a significant contribution to Japanese society by aiding crisis recovery.

[143] Waste materials such as plastics have a lower carbon content than coal, leading to lower emissions of CO_2 during combustion.
[144] This number includes thermal recycling in the power/ cement sector. Source: https://www.pwmi.or.jp/pdf/panf1.pdf
[145] JAPAN CEMENT ASSOCIATION (jcassoc.or.jp)

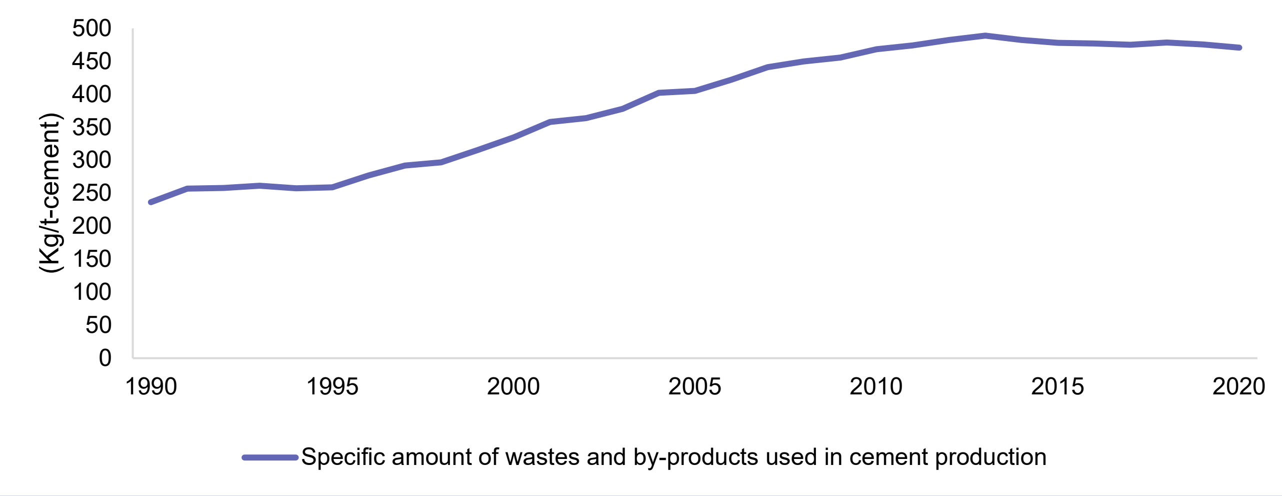


Figure 24. Use of wastes and by-products in Japanese cement industry, kg per ton of cement.

Source: Japan Cement Association [146] Note: These wastes and by-products used in cement production include both those used as alternative fuels and those used as raw material (clinker) substitutes.

Although Japan is implementing other emissions-reduction techniques, such as by reducing the clinker ratio, frequent earthquakes and the density of high-rise buildings in the country make it more difficult to reach the scale achieved in Europe and the US. Therefore, near-term initiatives (through 2030) will largely be a continuation of existing efforts such as improving efficiency and using alternative fuels.

- Improve the operational efficiency of cement production by increasing the number of facilities with high-efficiency equipment, such as (1) vertical roller mills, to crush raw materials, and (2) clinker coolers.[147] The penetration rate of high-efficiency equipment is still expected to be relatively low. For example, the penetration rate of high-efficiency vertical roller mills falls in the bottom 50th percentile for the cement industry, and clinker coolers are used in only 57% of facilities.[148] Currently, to realize consistent improvement in the penetration rate, the industry continues to invest approximately 1% of total annual sales for energy-saving efforts.[149]
- Use alternative fuel. The Japan Cement Association aims to reduce carbon emission by 19.2 million t-CO_2 by 2030, using waste-originated fuels, such as plastic.[150] Although plastic waste originates from fossil fuels, it emits less CO_2 than coal when combusted.[151] In addition, Japan is equipping cement production facilities with chlorine-bypass systems that can incinerate chloride-containing plastics such as PVCs, expanding both the types and the amount of alternative fuels to be used. Plastic-based alternative fuels still emit CO_2, so Japanese companies aim to utilize bio-based alternatives with higher thermal efficiency, such as solidified sewage sludge generated with the aid of the microorganism activities of fermentation.

---

146 JAPAN CEMENT ASSOCIATION (jcassoc.or.jp)

147 https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/007_01_05.pdf

148 JAPAN CEMENT ASSOCIATION (jcassoc.or.jp)

149 https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/031_04_00.pdf

150 https://www.env.go.jp/content/900440195.pdf

151 According to a paper, waste plastic emits 20% less CO2 than coal. “Carbon dioxide reduction by increased utilization of waste derived fuels in the cement industry”, Lars-André Tokheim, University of South-Eastern Norway(2007); source: (PDF) Carbon dioxide reduction by increased utilization of waste derived fuels in the cement industry (researchgate.net)

By 2050, Japan plans to leverage low-emission fuel sources and to use CCU to capture direct emission. Although CCS is gaining traction worldwide, Japan has limited potential for it.

- Low-emission fuels. Since waste fuels derived from fossil fuels will continue to emit CO_2, Japan's cement sector plans to switch to low-emission fuels (e.g., hydrogen/ammonia and biomass fuels).[152] The Japan Cement Association has stated that it will increase the usage of zero-emission fuels to at least 50% by expanding the use of alternative wastes, including biomass, and by co-firing with hydrogen, ammonia, and synthetic methane in the future.
- CCU. Furthermore, to reduce process-derived CO_2 emissions, Japanese companies have started to develop carbon recycling processes to produce cement from waste concrete. Experiments are underway to capture CO_2 and convert it to calcium carbonate under the "Green Innovation (GI) Fund" programs at the New Energy and Industrial Technology Development Organization (NEDO).[153] These technologies aim to extract CaO from waste (e.g., steel slag, coal ash, incinerated ash, sewage sludge, and recycled concrete), and fix CO_2 to it in order to create new calcium carbonates ($CaCO_3$). $CaCO_3$ made through this technology can be used as regenerated limestone and aggregates, making it possible to fully recycle concrete. These substances can also be used as material inputs in other sectors (Figure 25).

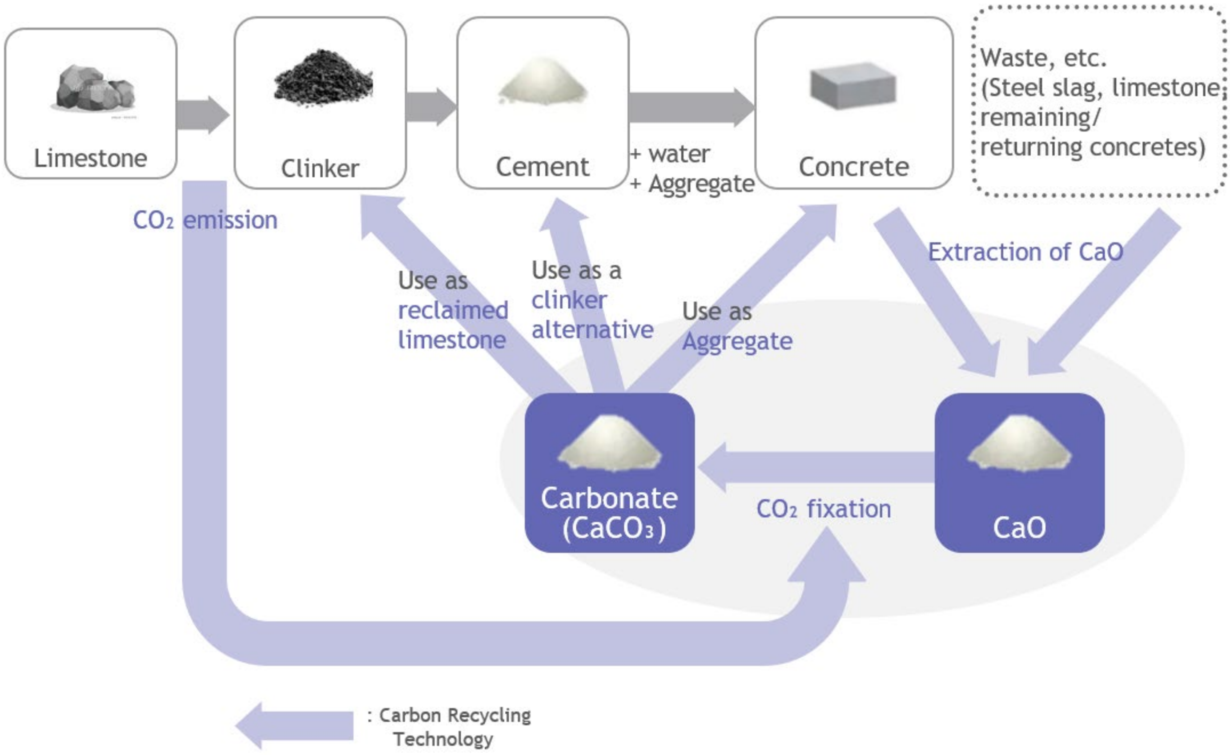


Figure 25. Overview of the Green Innovation Fund project.

Note: this figure is adapted from Technology Roadmap for "Transition Finance" in Cement Sector (METI)[154]

[152] https://www.meti.go.jp/shingikai/sankoshin/seizo_sangyo/pdf/012_05_00.pdf

[153] Green Innovation Fund is 2 trillion yen fund and was established as part of the government's "Green Growth Strategy" to achieve the set goals outlined in the "Technology Roadmap in the Cement Sector for Transition Financing Toward Decarbonization" of METI

[154] transition_finance_technology_roadmap_cement_eng.pdf (meti.go.jp)

Spotlight on MUCC

As a leader in Japan's cement industry, MUCC is targeting carbon neutrality by 2050 and will deploy multiple technologies, including that for recycling difficult-to-process wastes, in its overall effort to help establish a circular economy.

MUCC Mitsubishi UBE Cement Corporation

Company profile

Sales: 541 Bn yen in FY 2021

(Note: Simple sales total of Mitsubishi Materials / Cement Business Company, UBE / Construction Materials Company and UMCC before the merger)

Current emissions (2021)

CO_2 emissions: 14.6 Mn tons CO_2

Goals and Commitment Levels

2030: TBD

2050: Carbon neutral

Decarbonization Key Levers

1. Developing recycling technologies for difficult-to-process wastes
2. Replacing fossil-fuel with alternatives
3. Developing technology to recycle CO_2 (CCU technology)
4. Improving energy efficiency where possible

After partnering in a joint venture of sales and logistics called Ube-Mitsubishi Cement since 1998, Mitsubishi Materials and Ube Industries recently merged their cement businesses to form the Mitsubishi UBE Cement Corporation (MUCC).

MUCC is targeting carbon neutrality by 2050. To achieve this goal, the company is: (1) developing recycling processes for difficult-to-process wastes; (2) replacing fossil-fuel with alternatives; (3) developing technology to recycle CO_2 (CCU technology); and (4) continuing to improve energy efficiency where possible.

MUCC has developed a proprietary technology to recycle difficult-to-process wastes—including disaster waste, municipal waste, incineration ash, sewage sludge, and plasterboard. Such substances can be used as raw materials for making cement, and in the process help establish a circular economy, reduce limestone in the clinker production process, and reduce coal consumption. Further, MUCC's Kanda plant has introduced a waste-plastic de-chlorination and carbonization system that is capable of converting waste plastic with high chlorine concentration into fuel. The company is now operating a kiln based on waste plastic as fuel with the same efficiency as using pulverized coal. The replacement rate of pulverized coal in Scope 1 at the Kanda plant is approximately 33%, and MUCC plans to expand the use of this energy-replacement system to other plants in the future.

MUCC also intends to replace fossil fuel with alternative sources of energy, while maintaining the efficiency of kilns. The company has commercialized a technology to produce torrefied wood pellets, which can be used as a substitute for coal. In addition, MUSS has developed technologies to produce methane gas from coal by injecting chemicals and microbes into lignite (brown coal) mines. In addition to the current use of sewage sludge as fuel for kilns, such technologies would be important elements for the future use of biomass in kilns. MUCC is also developing technologies to displace fossil-fuel use with ammonia. Current experiments have established the operating conditions needed to fire cement using a mixture of heavy oil and ammonia.

In addition, the company will be contributing to the development of CCU technologies, in particular to create raw materials for cement, and of methanation technologies to synthesize methane. For example:

- Through 2025, MUCC is conducting a pilot to study the recovery efficiency of fine aggregates from waste concrete. The carbonation of cement raw materials, achieved by extracting CaO and fixing CO_2 to produce $CaCO_3$, could be used to sequester CO_2. The company is participating in a GI Fund project of approximately 6.9 billion yen aimed at developing this technology.
- In the Kurosaki area of its Kyusyu plant, MUCC is testing CCU technology to synthesize methane by capturing and separating CO_2 emitted from manufacturing processes. The CO_2 is chemically reacted with hydrogen, using waste heat, to produce synthetic methane (Figure 26).

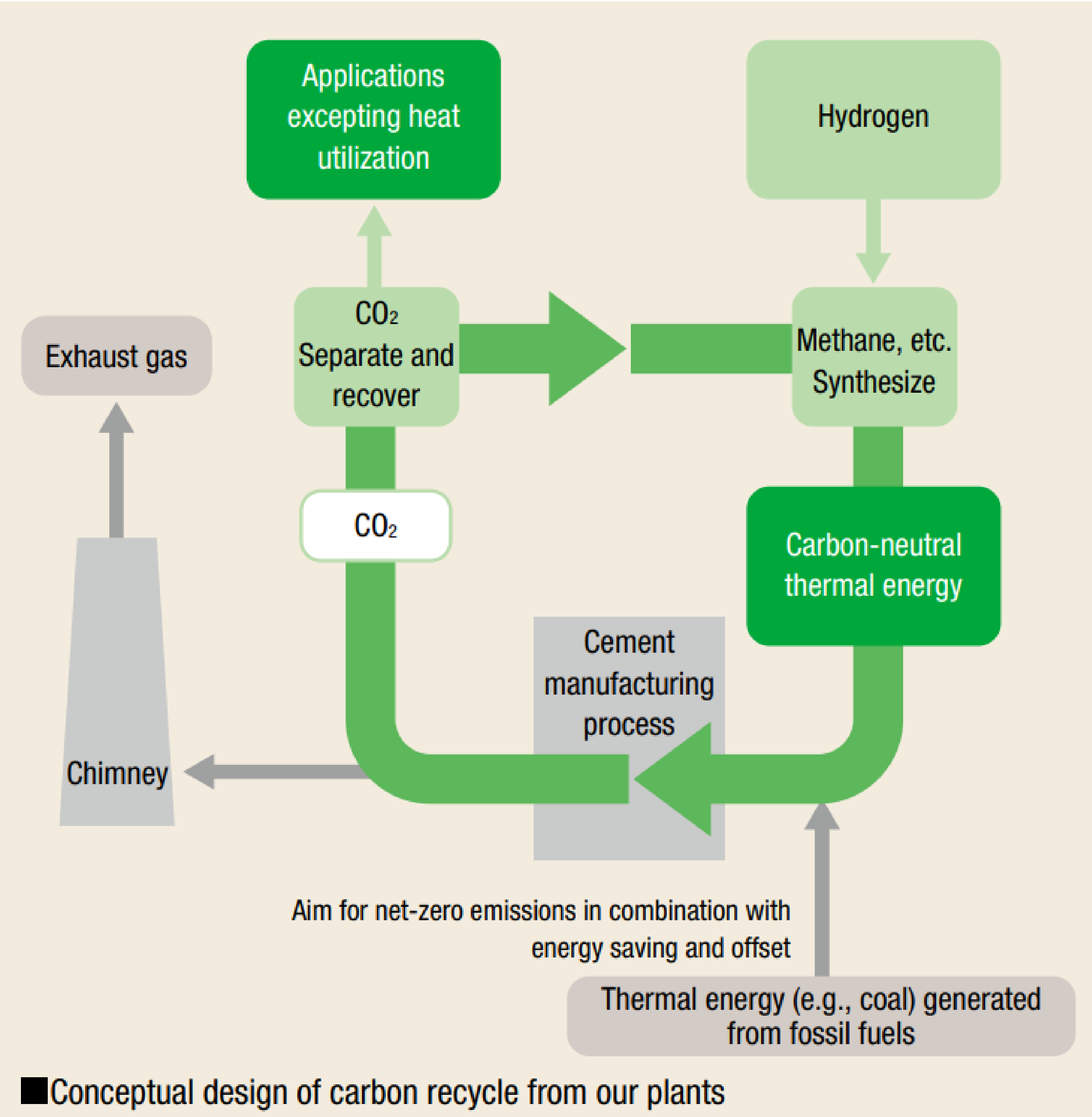


Figure 26. Image of Methane Synthesis.

Source: MUCC

In the future, the market for carbon capture is estimated to be worth over 15 trillion JPY.[155]

To compliment processes and technology developments, MUCC has continuously improved efficiency in its facilities by reviewing equipment, ensuring proper maintenance, converting to LED lighting, and adopting other general measures and best practices. The company has also introduced high-efficiency clinker coolers in 70% of plants.

Through such orchestrated efforts, MUCC is taking ambitious steps toward reaching carbon neutrality by 2050 (Figure 27).

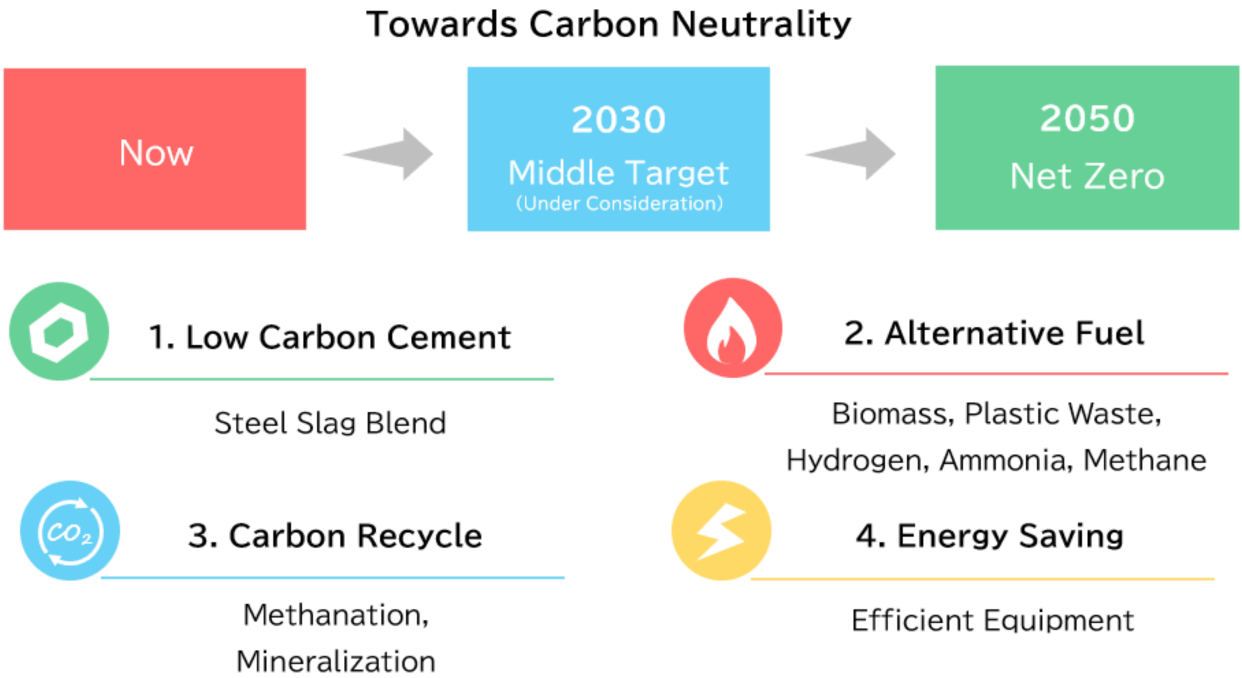


Figure 27. The Carbon Neutral Vision of MUCC

Source: MUCC

[155] R&D and Social Implementation Plan Formulated for "Development of Technology for Producing Concrete and Cement Using CO2" Projects, METI (2021); source: gif_09_randd.pdf (meti.go.jp), R&D and Social Implementation Plan Formulated for "Development of Technology for Producing Concrete and Cement Using CO2" Projects (meti.go.jp)

Chemicals

Chemical Fast Facts

Sector profile

Revenue:
3.5 trillion USD in 2020[156]

Energy consumption:
13.95 EJ in 2020[157]

Production volume:
2.3B tones in 2017[158]

Main emission sources

Energy-derived (majority)

Fossil-fuel feedstocks

Process-derived (minority)

Current CO_2 emissions

1,160 Mt CO_2 in 2020[159]

Accounts for 3% of the global CO_2 emission[160]

13% of the global industry sector
CO_2 emission[161]

Interdependencies

Upstream:
Power for green electricity

Downstream: Steel, cement, glass, paper by providing industrial materials and technologies to reduce GHG emission; ammonia and hydrogen supply

Highlights

The chemical industry plays a vital role in daily life globally, but it also accounts for around 3% of global CO_2 emissions.

Within Japan, the heavily integrated chemical sector serves as an engine for innovation and growth, ensuring a stable supply of end-to-end chemical production for the automotive, semiconductor, and electronics industries. Yet the sector is influenced by technology development and policies, making it challenging for companies to find simple solutions to achieve carbon neutrality. A mix of decarbonization options will be necessary.

Japan's chemical industry has improved its energy efficiency in recent decades. This has been achieved despite resource scarcity and fewer available options for fuels and raw materials compared with the EU and the US. Since 2020, large Japanese chemical companies have announced initiatives for 30% to 50% reductions in CO_2 emissions by 2030 in their path toward carbon neutrality. In the near term, these companies plan to utilize clean energy sources, improve energy efficiency, and replace feedstock with materials that have low environmental impact. In the mid- to long-term, Japan aims to implement CCU technologies to replace fossil-fuel feedstocks, reduce solid waste, and sequester CO_2. They are also exploring ammonia and hydrogen as alternative fuels.

Furthermore, the chemical industry plays a pivotal role in abating the CO_2 generated both by itself and by other industrial sectors, while advancing collaborative activities with the oil-refining sector. The chemical sector also contributes to downstream emissions reductions globally by developing functional materials and by monitoring product lifecycles.

---

156 Profile - cefic.org (Calculated based on the rate of 1 EUR = 1.02 USD)

157 Process energy for primary chemical production is 9.3 EJ. Considering that primary chemical production accounts for two-thirds of energy consumption in the chemical and petrochemical sector, the power consumption of chemical is 9.3*3/2=13.95EJ; source: Process energy for primary chemical production in the Net Zero Scenario, 2015-2030 – Charts – Data & Statistics - IEA; Chemicals – Analysis - IEA

158 Following global production capacity; source: Chemical Industry Production | IndustryARC

159 https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf

160 Energy Technology Perspectives 2020 (windows.net)

161 Ibid.

Chemical sector overview

The chemical industry produces materials essential for human life. Over the past two years, global demand for chemicals has been volatile owing to the COVID-19 pandemic. Nonetheless, demand is expected to grow by 2.7% in 2022, nearing the pre-pandemic average of 3.5% per year.[162]

Compared to other industrial sectors, chemicals produce the third-highest level of CO_2 emissions. In 2019, production generated 1,160 million tons of emissions, or 3% of the worldwide total.[163] Chemical production can be energy intensive, requiring high temperatures and pressures, typically produced through the combustion of fossil fuels. Moreover, CO_2 and other greenhouse gases can be generated as by-products of chemical reactions.

At the same time, the chemical sector plays a fundamental role in achieving carbon neutrality. First, the chemical industry has the potential to develop processes and technologies to abate the CO_2 generated not only by itself but by other industrial sectors. Second, the chemical sector plays a central role in building a circular economy by returning waste plastics back into raw material to produce new chemical products, or by utilizing CO_2 as a resource. Lastly, chemicals are foundational for many green technologies, such as energy storage, renewable energy generation, and the development of materials that improve energy efficiency in downstream products.

In its most simplistic form, the chemical sector can be divided into two broad categories, distinct in their positions and in their efforts toward achieving carbon neutrality: commodity chemicals and specialty chemicals.

- Commodity chemicals form the basic skeleton of most industrial materials. Many are produced from fossil-fuel feedstocks such as naphtha, and their production accounts for the majority of emissions from the chemical sector. They are the main target for Scope 1 and Scope 2 emissions reductions, owing to the significant GHG emissions that occur from fuel combustion during production. They are also expected to reduce GHG emissions as carbon-recycling technologies and related infrastructure develop.
- Specialty chemicals, including functional materials, are produced for specialized applications, typically at lower volume than commodity chemicals. The processes used to produce these chemicals require less energy than the high heat/pressure processes used to produce commodity chemicals. Their total contribution to GHG emissions therefore remain relatively low, although emissions intensity varies for individual products (as production processes for some specialty chemicals do not require fuel combustion). Moreover, specialty chemicals are essential for reducing emissions in downstream sectors. Next generation green technologies—such as batteries, solar photovoltaics, and lightweight wind turbines—all rely on functional materials generated by the chemical sector. Other chemicals, such as lubricants and coatings, can extend service life and improve efficiency in downstream products.

[162] 2022 Chemicals Outlook: Stability and sustainability over growth – ADI CMR (adi-cmr.com), Chemical Industry Outlook 2022 - Fineotex; Chemicals – Analysis - IEA

[163] Energy Technology Perspectives 2020 (windows.net)

Within the chemical sector, various strategies are deployed to reduce Scope 1 and Scope 2 emissions (Figure 28).

1) Improving energy efficiency. Energy efficiency gains can be realized through increasing the efficiency of facilities and equipment, redesigning chemical synthesis, recovering waste heat, and improving plant design and operations. Most companies around the world are investing in improving energy efficiency not only as a means to reduce emissions, but also to lower cost.
2) Switching fuels / using clean energy. Fossil-fuel-based energy sources can be substituted with low-emission combustible fuels such as waste, biofuel, green ammonia, and green hydrogen. Alternatively, clean electricity can replace fossil fuels in two ways: (1) it can be used to provide heat in traditional processes such as steam reforming and cracking; or (2) to drive chemical reactions directly (e.g., replacing steam reformation with electrolysis).
3) Replacing feedstock with materials that have low environmental impact. Similarly, fossil-fuel-based feedstocks can be replaced with biomass and synthetic feedstocks.[164] Substituting fossil-derived feedstock with waste materials, such as plastic waste, can also promote circularity in the economy.
4) Carbon capture, utilization, and storage (CCUS). CCUS aims to capture CO_2 before it enters the atmosphere and to either *utilize* the CO_2 for industrial applications or *store* the CO_2 deep underground. CCS technology is slightly more mature than CCU, the main advantage being that existing industrial production processes can remain intact. "However, the storage sites must be suitable in terms of their geology, offering for example deep sedimentary layers that contain salt water. Such sites are not found all over the world." [165] Due to ready availability, countries such as the United States and Norway are leading the development of CCS technologies. CCU in the chemical sector includes manufacturing products with raw materials that have been derived using CO_2. Such processes can potentially contribute to the circulation of carbon, but the technology is still in the experimental stage. The challenge will be when and on what scale they can be fully leveraged. CCU initiatives can also help the chemical sector aid other industries in achieving the carbon neutrality of their Scope 1 and Scope 2 emissions.

Furthermore, the chemical sector also contributes to emissions reduction of downstream industries by reducing the weight of materials, providing recyclable products and building recycling mechanisms.

[164] Saygin, Deger, and Dolf Gielen. "Zero-emission pathway for the global chemical and petrochemical sector." *Energies* 14.13 (2021): 3772. https://www.mdpi.com/1996-1073/14/13/3772/pdf

[165] How the chemical industry can meet the climate goals (phys.org)

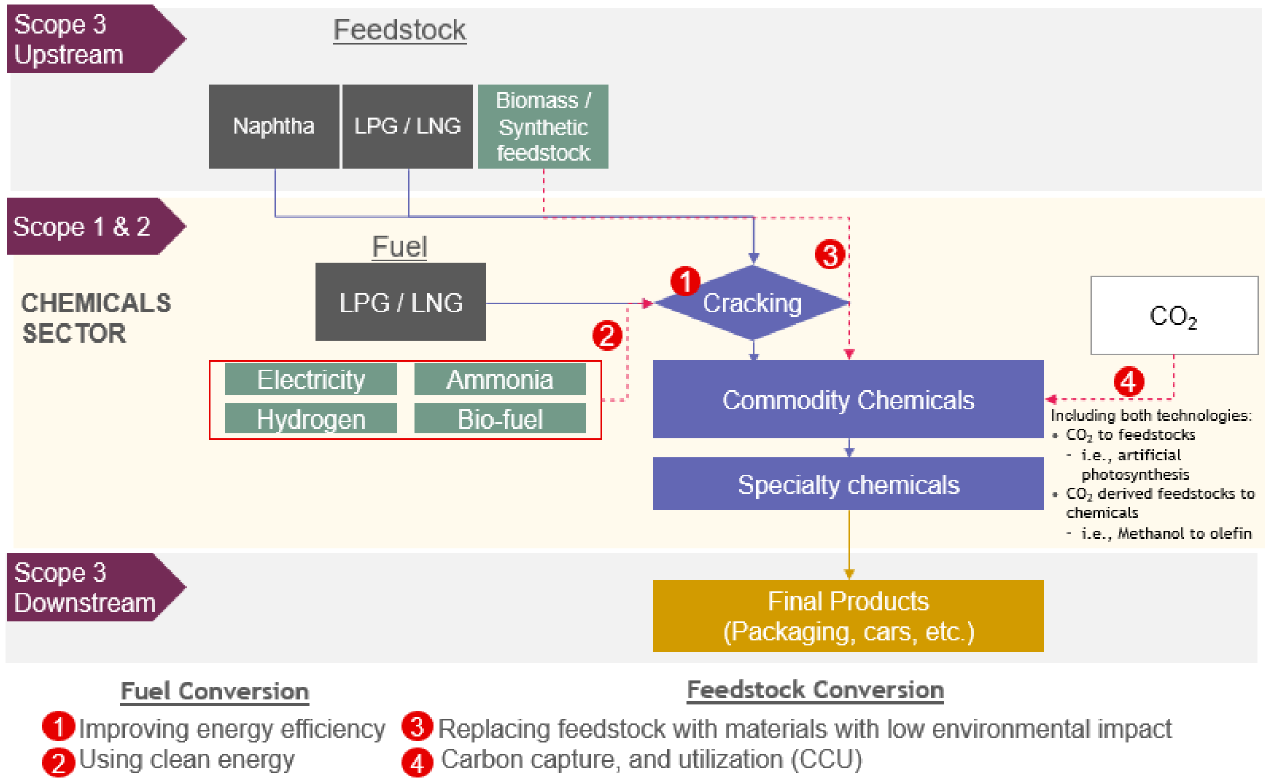


Figure 28. Chemical value chain and corresponding CO_2 emission reduction initiatives

Source: *https://sciencebasedtargets.org/resources/files/SBTi-Chemicals-Scoping-Document-12.2020.pdf.*

Notes: LPG = Liquified Petroleum Gas; LNG = Liquefied natural gas.

Japan's carbon neutrality pathway

In order to understand Japan's emissions reduction plans, it is important to first understand the underlying nature of the country's chemical sector.

As previously discussed, Japan has almost no domestic oil and gas production and no international gas pipelines. Ever since it began operating petrochemical complexes in the 1950s, the national petroleum policy has been to import crude oil and refine it domestically. The country's petrochemical industry has thus grown by utilizing the naphtha produced in the refining process, resulting in a high dependence on naphtha feedstock. In order to make the best use of a limited resource, Japanese chemical companies developed a unique process to produce niche chemical products, such as butene and pentane, from minor olefin residue. However, naphtha produces 1.5 to 2.0 times the emissions of ethane, an alternative feedstock widely available in the United States (Figure 29).[166]

[166] https://publications.jrc.ec.europa.eu/repository/handle/JRC105767, p.60

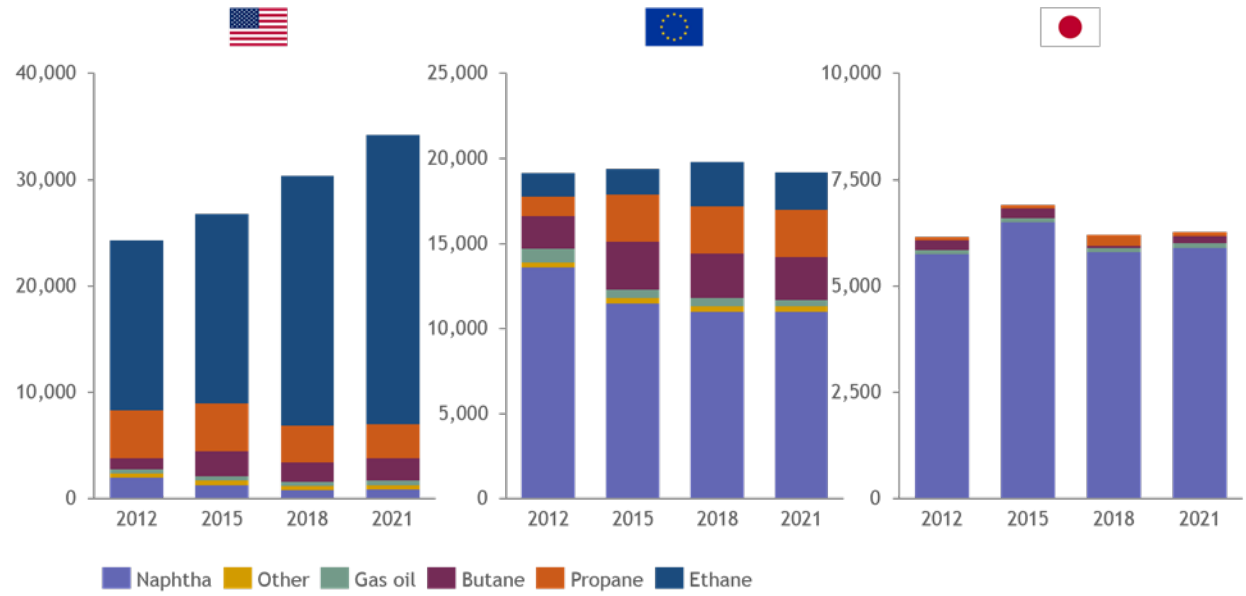


Figure 29. Comparison of naphtha-based production, by country (kt).

Source: IHS Markit, Western European countries only

Despite resource constraints, Japan's chemical sector has developed competitive downstream industries while reducing emissions intensity and conserving resources at levels comparable to the US and Europe.

Based on the concept of balanced development, different chemical companies with varying capital structures, including those active in both oil refining and petrochemicals, have grouped together to form a single industrial complex with a network that crosses regions. Moreover, Japan's heavily integrated industrial sector serves as an engine for innovation and growth. Strong materials development, paired with the proximity of automotive, semiconductor, and electronics industries, has enabled the country to rapidly and reliably provide reasonably-priced materials to countries around the globe.

Following this tradition, Japan's chemical sector is characterized by end-to-end production. Roughly half of the country's chemical manufacturing is in commodity chemicals—36.7% industrial organic products, 7.8% industrial inorganic products, and 0.9% fertilizer—typically derived from naphtha.[167] The remaining 54.6% includes specialty chemicals and functional materials.[168] Japan holds a large share of the global market for many of these functional materials (Figure 30), and although the size of individual markets can be small, each product occupies an extremely important position in the value chain.

[167] 2020 Chemical Industry of Japan - nikkakyo.org

[168] Ibid.

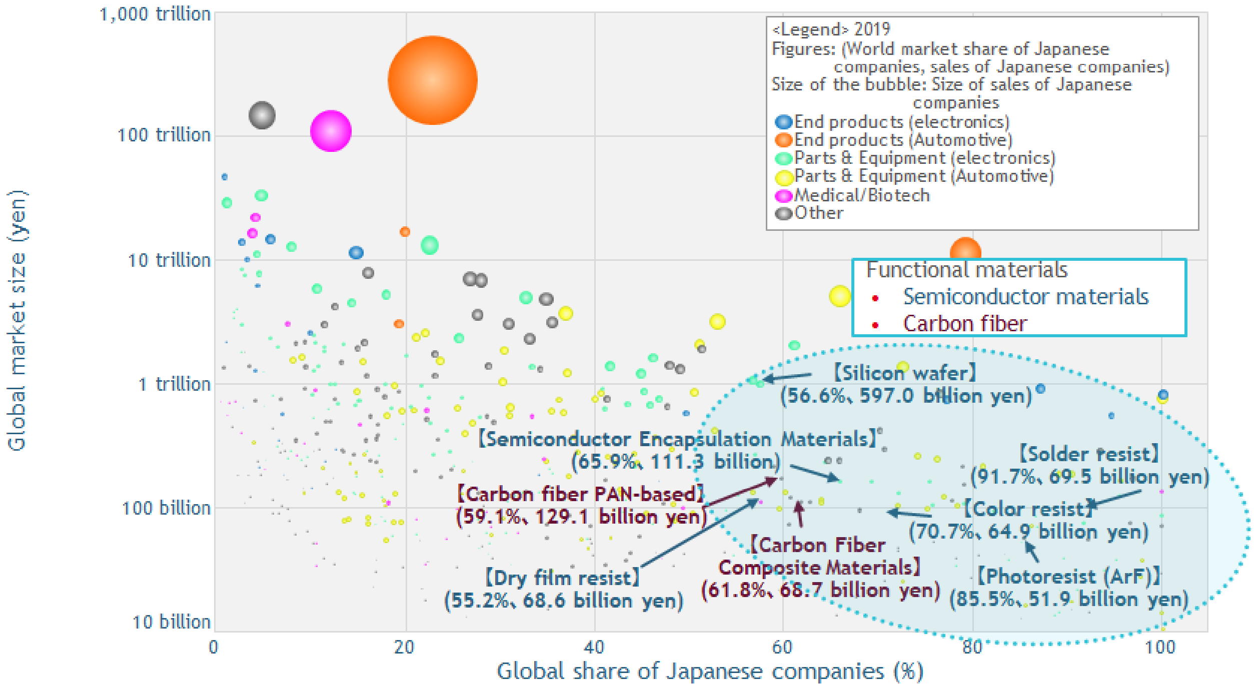


Figure 30. Position of Japanese chemical companies in each product category (2019)

Source: METI[169]

To further emphasize the importance of Japan's integrated supply chain, Table 4 summarizes a few examples:

Table 4. Examples of Japanese chemical companies in function materials. Source: Compiled based on METI

	Applications	Example of Japanese company
Carbon fiber & reinforced resin	▪ electric vehicles ▪ airplanes ▪ wind turbine blades	▪ Japanese players account for more than 60% of the global market share for carbon fiber ▪ Japanese chemical technology can further advance this space by developing carbon fiber that is easily recycled at the time of disposal
Semiconductor Materials	▪ data centers ▪ computers ▪ 5G communications ▪ sensors in smartphone cameras ▪ current control inside EVs	▪ Japanese players hold more than 60% of the global market share for encapsulants ▪ Epoxy resins, the raw materials for semiconductor materials, and phenol, which is further upstream, are produced in an integrated manner in Japan.
Medical Products	▪ catheters ▪ dialysis machines membranes	▪ Integrated quality and production control enables Japanese players to meet high standards for product quality ▪ Japan produces everything from upstream raw materials to downstream functional materials

[169] https://www.meti.go.jp/shingikai/sankoshin/seizo_sangyo/pdf/010_04_00.pdf, Pg. 16

Looking ahead, Japanese companies expect to reduce emissions through improvements in fuel and feedstock conversion, and to lower downstream GHG emissions through product development.

In 2018, the Japan Chemical Industry Association (JCIA) announced a goal to reduce CO_2 emissions by 19% (13.5 million t-gCO_2) by 2030 (compared to business-as-usual, Scope 1 and Scope 2, based on 2013).[170] In addition, large Japanese chemical companies have set more ambitious global targets, such as to reduce CO_2 emissions by 30% to 50% by 2030 as a path toward carbon neutrality—exceeding the target set by the JCIA.[171] Some companies are also launching joint projects with academia to demonstrate their pathways, using a quantitative modeling approach.

In the near term, by 2030, Japanese chemical companies[172] plan to eliminate 7 million t-CO_2 through purchasing green electricity, and another 6.5 million t-CO_2 through efficiency improvements and feedstock substitution.[173] In conjunction with switching from fossil fuels to green electricity and other low-emissions sources, energy efficiency improvements remain a critical short-term goal. From 2005 to 2019, chemical companies reduced CO_2 emission intensity by about 7% (cumulatively).[174] Moreover, continued investment in energy efficiency is expected to drive further emissions reductions. The Japanese chemical industry invested 63Bn yen in 2020 alone.[175]

Companies are also developing their ability to support a circular economy and replace naphtha feedstocks with recyclable waste—with the ability to convert plastic and rubber waste into chemicals expected to be economically viable within the coming decade. By 2030, Japanese companies also expect to commercialize carbon-recycling technologies for high-value products, and/or products that do not require hydrogen, such as polycarbonate and jet fuel.[176]

In the long term, through R&D, Japan's chemical sector plans to: (1) diversify its fuel supply to include ammonia and hydrogen; and (2) implement CCU. Various stakeholders are involved in restructuring the country's petrochemical industry, such as companies within the industrial complexes, companies within and outside the chemical sector, and the government. Since Japanese petrochemical complexes are composed of companies with different capital structures, there have been ongoing efforts to promote inter-company collaboration. For example, the use of hydrogen and ammonia is being jointly considered, and companies are working in concert to develop hydrogen and ammonia supply chains. Similarly, the chemical industry plays a central role in CCU, developing the means to repurpose CO_2 produced across industries (Table 5).

[170] https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/kagaku_wg/pdf/2021_01_05_01.pdf; P7

[171] JCIA https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/kagaku_wg/pdf/2021_01_05_01.pdf; p9; CDP report of each company (Home - CDP)

[172] Based on reported values from Japan's Chemical Industry Association

[173] https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/kagaku_wg/pdf/2021_01_05_01.pdf; P7

[174] As of 2019. https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/kagaku_wg/pdf/2021_01_05_01.pdf; P6

[175] https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/kagaku_wg/pdf/2021_01_05_01.pdf; P11

[176] 0726_003a.pdf (meti.go.jp)

Table 5. Decarbonization pathway for Japan's chemical sector.

Preparatory stage

Full-scale development

		Fuel conversion		Feedstock conversion	
		Process greening	Hydrogen & ammonia	CCUS	Replace feedstock w/ materials w/ low environmental impact
Chemical Sector	Short term (~2030)	Switching to natural gas and electricity for in-house power generation	Promote R&D using NEDO and other public funds • Practical application of ammonia fuel in naphtha cracking reactors, etc. • Recovery of CO_2 from exhaust gases, etc., to produce feedstock for plastics		Recycle waste plastic as feedstock • Conversion of waste plastic into feedstocks (~30's) • Conversion of waste rubber into feedstocks (~40's)
	Mid-term (~2050)	Streamlining manufacturing processes	Transition to hydrogen & ammonia fuels • In-house power generation (2030~) • Naphtha cracker (2035~)	Developing artificial photosynthesis Production of chemicals and feedstock from hydrogen and CO_2 feedstock	
		Collaborative Initiatives with other sectors			
Across Sectors	Mid-term (~2050)	Strengthening cooperation between petroleum refining and petrochemicals along with the plan of CN industrial complex concept (~2050) • Advanced utilization of byproducts and efficient use of energy by sharing among companies within the same industrial complex, etc.			

The chemical sector will also be integral in reducing downstream emissions. In addition to developing novel materials, Japanese companies are implementing effective carbon-management tools throughout the value chain, such as the introduction of Life Cycle Assessment (LCA) and measuring the financial cost of environmental impacts. Leading chemical companies, including Sumitomo and Mitsubishi, are spearheading initiatives related to LCA.

Spotlight on Mitsubishi Chemical Group Corporation (MCG)

MCG is actively working on achieving the carbon neutrality goal through short-term and long-term measures that include technological innovation in replacing current fuels, and converting feedstock (including carbon). It is also playing an active role in quantifying the lifecycle impacts, and contributing emission reductions in downstream industries.

MITSUBISHI CHEMICAL GROUP MITSUBISHI CHEMICAL CORPORATION

Company profile

- Sales: 3,976.9 Bn yen in FY2021
- Functional Products: 1,136.3 Bn yen,
- Chemicals (MMA, Petrochemicals, Carbon): 1,287.9 Bn yen,
- Industrial Gases: 950.1 Bn yen,
- Healthcare: 403.6 Bn yen,
- Others: 199.0 Bn yen

Current CO_2 emissions (Scope 1+2)

- MCG: 16.1 M t-CO_2 (FY2021)
- MCC: 8.0 M t-CO_2 (FY2020)

Goals and Commitment Levels

- MCG
  2030: 29% reduction in global CO_2 emissions compared to FY2019 levels
  2050: Carbon neutral
- MCC
  2030
  Global: Reduction 32% (v FY 2019)
  Japan: Reduction 43% (v FY2013)
  2050: Carbon neutral

Decarbonization Key Levers:

- Short-term: Continuous improvement in energy efficiency
- Mid/Long-term: Technological innovation in replacing current fuels, converting feedstock (expanding the use of feedstock with low environmental impact and accelerating R&D for carbon recycling)

Mitsubishi Chemical Group Corporation (MCG), together with its core company Mitsubishi Chemical Corporation (MCC), places climate change among its highest priorities. Both MCG and MCC have announced that they will achieve carbon neutrality by 2050.

To achieve this goal, MCG and MCC plan to further improve energy efficiency, convert fuels, and switch feedstocks. Feedstock conversion includes utilizing recycled materials, biomass, and carbon-recycling technology. To facilitate these activities, the company is promoting internal carbon pricing and the development of a measurement system for LCA. In addition, MCC is developing solutions that provide environmental value to downstream customers, such as by realizing the circular economy through recycling-oriented businesses and high-performance products that can contribute to reducing emissions.

As key initiatives, the company is advancing both fuel and feedstock conversion.

Energy transition: reducing emissions from production activities.

MCC aims to replace coal-fired power generation with renewable energy and LNG at domestic business sites and plants by 2030, including fuel conversion for in-house power generation and boiler facilities. The company will also achieve efficiency improvement and energy savings through process streamlining and digital transformation.

Feedstock conversion: expanding the use of feedstock with low environmental impact, and accelerating R&D for carbon recycling.

MCC, along with its associated supply chains, is developing technologies both to expand the use of low-emission feedstock and recycled carbon. Specifically, MCC aims to commercialize: (1) the conversion of waste plastics into materials such as regenerated oils and monomers; (2) the expansion of bio-based raw materials at the upstream level (e.g. bio naphtha); and (3) the use of CO_2 as a material with hydrogen derived from artificial photosynthesis. Further:

- In 2021, MCC and its partner, ENEOS Corporation, jointly presented a plan to construct a commercial chemical recycling facility at the MCC Ibaraki plant. The facility will have an annual processing capacity of 20,000 tons, which will be the largest commercial facility in Japan. Operation is expected to begin in FY2023.[177]
- In 2022, MCC announced its intention to manufacture and sell ethylene, propylene, and their derivatives, using bioethanol as a raw material beginning in 2025.[178]
- Since 2012, MCC has participated as a member of ARPChem,[179] a NEDO project aimed at realizing artificial photosynthesis. The company is also researching the production of hydrogen using a photosynthesis-like photocatalyst, and the production of chemicals using CO_2. In 2022, this project was selected for the Green Innovation Fund.

In order to promote both GHG emissions reduction and business growth, MCC introduced an internal carbon price in April 2022. The price is currently used as an indicator for making decisions on capital investments and R&D. In the future, it will also inform business portfolio strategy.

MCC is also addressing the climate change issue with a broader perspective of safeguarding global environmental ecosystems. The company is currently conducting a joint research project with the University of Tokyo to identify a role for the chemical industry in transforming ecosystems— including production and consumption for a circular economy, energy, food, and cities—toward a sustainable society and economy. The project examines pathway scenarios using a quantitative modeling approach[180]

What is more, MCC has established a capability to conduct LCA for its products. In the first half of 2022, the CFP (carbon footprint) for all MCC products manufactured in Japan could be calculated based on guidelines and toolkits established by the company. This CFP calculation capability will be expanded to cover products that are produced in domestic and overseas group companies. Additionally, MCC is playing a leading role in various industrial discussions on LCA, such as those with the JCIA. MCC aims to utilize LCA as a fundamental driver for GHG reduction, not only for its own emissions but externally through promoting R&D and focused corporate strategies. (Figure 31).

---

[177] 20210817_01.pdf (eneos.co.jp)

[178] Start of Assessment for the Commercialization of Ethylene, Propylene, Etc. Using Plant-derived Raw Materials | News Archive | Mitsubishi Chemical Corporation (m-chemical.co.jp)

[179] ARPChem: Japan Technological Research Association of Artificial Photosynthetic Chemical Process, comprising INPEX CORPORATION, TOTO LTD., Japan Fine Ceramics Center, Fujifilm Corporation, Mitsui Chemicals, Inc., and MCC.

[180] https://ifi.u-tokyo.ac.jp/en/news/9217/

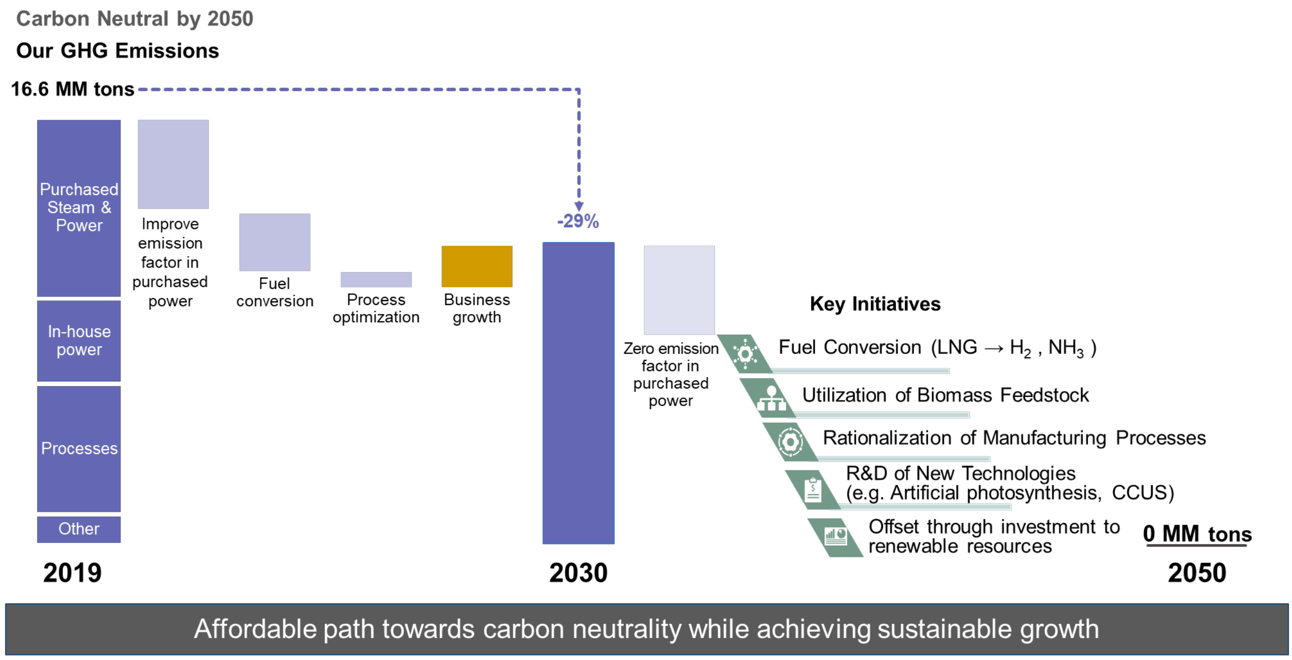


Figure 31. MCG's Roadmap for Carbon Neutrality

Source: https://www.mitsubishichem-hd.co.jp/english/ir/pdf/01169/01338.pdf; p15.

Contribution to GHG reduction through the value chain

MCC has also developed and launched environmentally friendly products that reduce emissions at the application site. Through these functional materials, MCC will contribute to emission reductions in downstream industries, such as:.

- Carbon fiber, composite materials, and engineering plastics used for lightweight aircraft, automobiles, and other mobility applications
- Mass production of gallium nitride (GaN), which reduces CO_2 emissions in semiconductors by reducing power consumption
- Biodegradable plastics and others derived from bio-based raw materials
- Electrolyte and anode materials for Li-ion batteries used in EVs

MCC is also developing materials that can be easily recycled at the time of disposal, and further progress is expected in this area. In the future, the company intends to scale these initiatives through collaboration among industry, government, and academia stakeholders. At the same time, it plans to promote climate-friendly investment by encouraging collaboration among companies.

Paper

Paper Fast Facts

Sector profile

Revenues: 352 billion dollars (FY2021)[182]

Energy consumption:
8.6 EJ in 2021[183]

Production volume:
400.9 million tons in 2020[184]

Main emission sources (FY2021)[185]

Bioenergy: 3.7 EJ
Electricity: 1.7 EJ
Gas: 1.3 EJ
Coal: 1.0 EJ

Current CO_2 emissions

187Mt CO_2 in 2020[186]
1% of the global CO_2 emission[187]

2% of the global industry sector CO_2 emission[188]

Interdependencies

Upstream: Power, chemical, transportation

Downstream: Construction

Highlights

The pulp and paper sector accounts for 1% of global CO_2emissions and 2% of all emissions from the industrial sector.[181] But emissions intensity for paper production appears to be decreasing. Within the pulp and paper industry, demand for packaging materials is growing while demand for manufactured paper is declining, especially in developed countries.

Japan, the world's third-largest producer of paper, has made continuous efforts to operate its businesses in a way that uses scarce forest resources effectively. As a result, Japan's recovered paper utilization rate is high. However, this dynamic limits the availability of black liquor, a biofuel derived from virgin pulp, putting Japan at a disadvantage in terms of CO_2 emissions during pulp and paper processing.

Japanese paper companies are striving to achieve both a circular economy and carbon neutrality, aiming to achieve these goals by further increasing their recovered paper utilization rate—while also switching to low-emission energy sources, improving energy efficiency, and expanding CO_2-absorbing afforestation.

181 https://www.iea.org/reports/tracking-industry-2021
182 Pulp and Paper Market Size, Growth & Trends | Overview, 2029 (fortunebusinessinsights.com)
183 https://www.iea.org/reports/pulp-and-paper
184 FAOSTAT
185 Pulp and Paper – Analysis - IEA
186 https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf
187 Ibid.
188 Ibid.

Paper sector overview

In 2020, the pulp and paper sector accounted for 1% of global CO_2 emissions and 2% of industrial emission.[189] Notably, emissions are decoupling from paper production. Between 2010 and 2019, the production of paper and paperboard increased by 3% with energy use rising ~0.5% over that period.[190] Part of this shift was driven by a change in the type of products produced. Overall, demand for newsprint, writing, and printing paper has declined since 2010 because of increasing digitization, while demand for wrapping, packaging, household, and sanitary paper products has increased.[191]

The IEA (International Energy Agency) expects global demand for paper to continue to grow moderately (~2% per year), but production trends vary by country. Paper and paperboard production in newly developed countries such as India, Indonesia, and China is expanding, while production in developed countries such as Japan, the US, and many European countries is gradually shrinking. (Figure 32). Paper manufacturers in developed countries are therefore in the difficult position of having to invest in emissions-reduction technologies amid an unfavorable business climate.

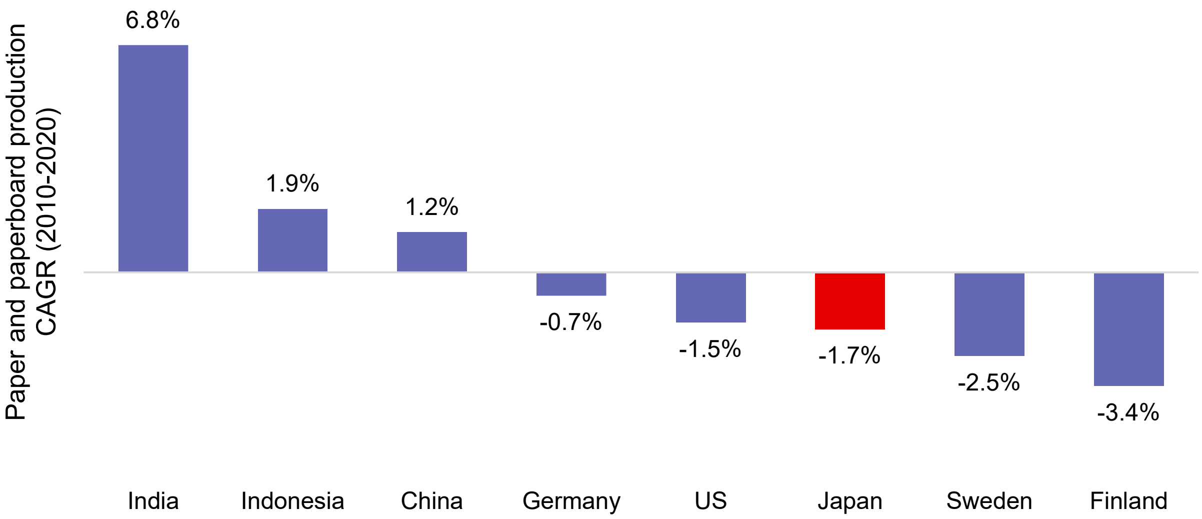


Figure 32. Paper and paperboard production CAGR (2010-2020).

Source: Food and Agriculture Organization of the United Nations

Furthermore, emissions reduction strategies can vary considerably from one country to the next. In general, emissions in paper manufacturing are generated in a variety of ways: combustion of fossil fuels during tree planting, logging, and chipping; shipping and transport of materials; treating wastewater; using purchased power in pulping and paper manufacturing; and disposing/ recycling.[192] The amount and source of wood pulp vs. recycled paper content, along with the source of power, shape the emissions profile and thus the decarbonization strategy (Figure 33).

[189] Emissions by sector - Our World in Data; https://www.iea.org/reports/tracking-industry-2021

[190] Pulp and Paper – Analysis - IEA

[191] Ibid.

[192] GHGRP 2019: Pulp and Paper | US EPA

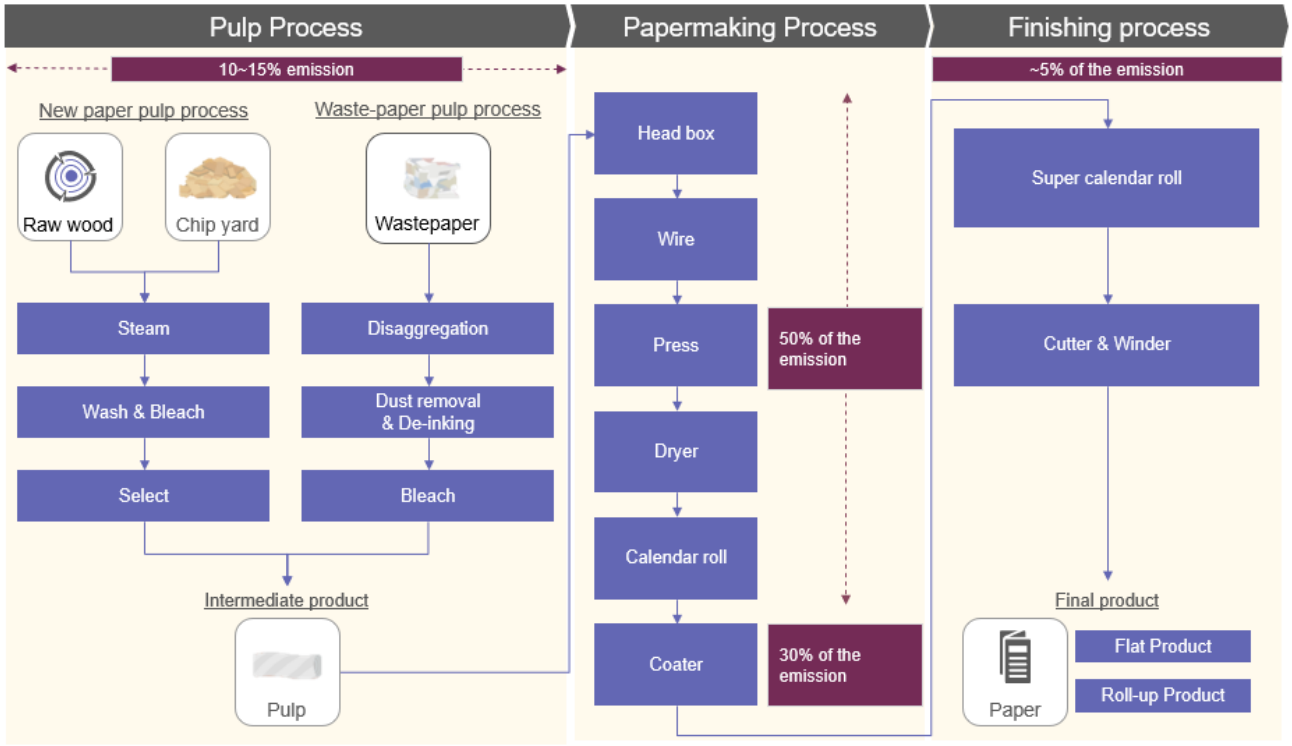


Figure 33. Paper and pulp manufacturing process, and its emission.

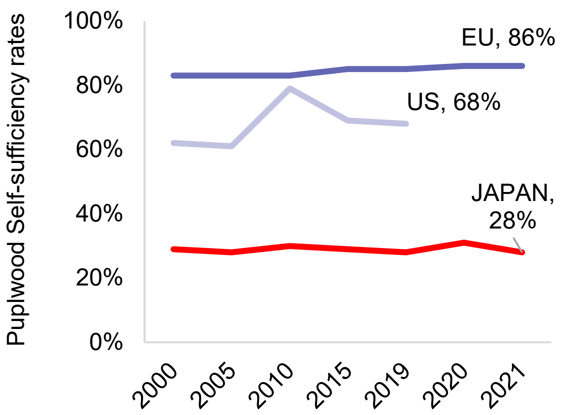
Source: Japan Paper Association[193] . Note: Only CO_2 emissions from fossil fuels are converted in this graph.

Japan's carbon neutrality pathway

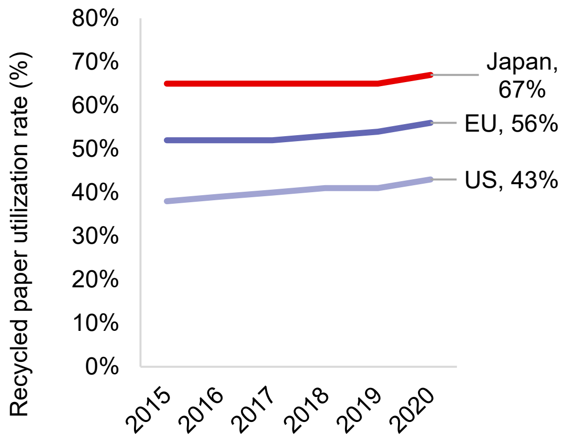
Japan is the world's third largest manufacturer of paper products,[194] and emissions from this sector therefore play an outsized role. In 2019, Japan's paper industry accounted for 5.5% of domestic GHG emissions.[195]

The cost of cutting wood for pulp material from steep, mountainous terrain is extremely high, making it difficult to use domestic wood at a level that balances cost and profitability. In fact, Japan's domestic wood utilization rate was only 28% in 2021 (Figure 34A), significantly lower than that in Europe (85.7%) and the United States (68%, 2019). In order to make effective use of scarce forest resources, the Japanese paper sector has therefore focused investment on resource recycling. As a result, the country's paper-recovery and recycling rates are among the highest in the world (Figure 34B). In 2020, 67% of new paper produced was made from recycled materials, compared to 56% in the EU and 43% in the US.

[193] 日本製紙連合会 | 紙のあれこれ | 紙をつくる工場 | 出荷 (jpa.gr.jp)
[194] PAPER-RECYCLING-IN-JAPAN-English.pdf (prpc.or.jp)
[195] transition_finance_technology_roadmap_paper_jpn.pdf (meti.go.jp)



A.



B.

Figure 34 A. Pulpwood Self-sufficiency rates. B. Recycled paper utilization rate, 2015-2020.

Source: (A) Japan Paper Association, Cepi, United States Department of Agriculture. Note: EU, for years for which data cannot be obtained (2005, 2019), the average of the before and after values is inserted. US, estimates are based on consumption and imports of oriented strand board (OSB). Data for 2020 and beyond are unknown. (B) Ministry of Economy, Trade and Industry, Technology Roadmap for Transition Finance in the Pulp and Paper Sector

Meanwhile, given its high rates of paper recycling, Japan has limited access to black liquor[196] and other paper bi-products that can provide renewable power. What is more, Japan's paper sector currently relies more heavily on fossil fuels, particularly coal, than its European and US counterparts (Figure 35).

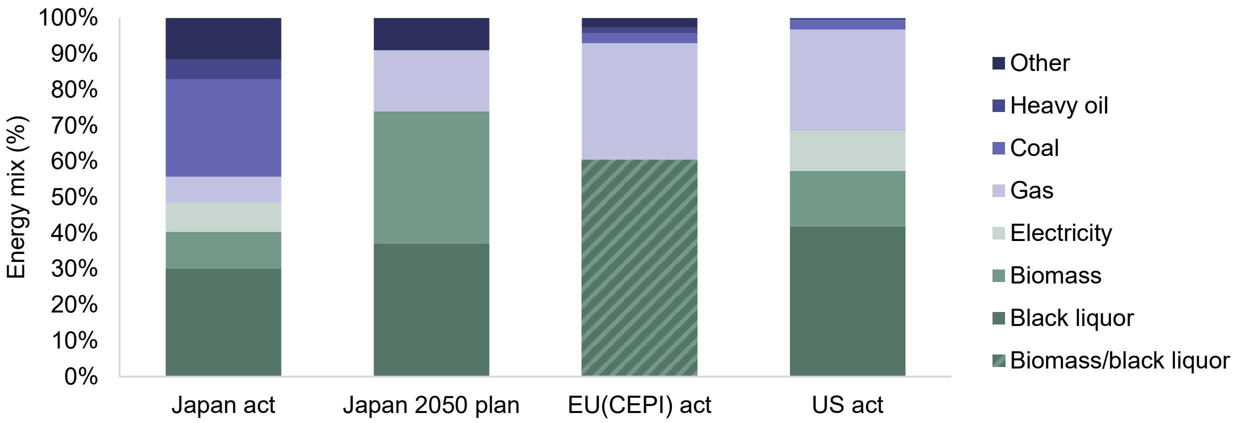


Figure 35. The energy mix of the global pulp and paper industry, 2020.

Source: Ministry of Economy, Trade and Industry, Technology Roadmap for Transition Finance in the Pulp and Paper Sector. Note: In Japan, biomass includes waste material and paper sludge; "Other" includes waste tires, RPF, etc. In the EU, purchased electricity (about 15% or less) is not included. "Others" is the total of other and other fossil fuels. In the US, black liquor includes pulp liquor and black liquor. Biomass includes agricultural and wood residues. Electricity includes others.

[196] Note: Black liquor is a black waste liquid generated during the production of pulp for papermaking. Pulp is produced by adding chemicals to wood chips and boiling and dissolving them in order to remove the wood fibers. Black liquor is what remains after the wood fibers are removed. The black liquor is a liquid mixture of the ingredients that held the wood fibers together and chemicals, and can be burned because it has about 1/2 to 1/3 the calories of heavy oil. Since this energy is derived from plants that store solar energy, it is treated as biomass energy.

Given such circumstances, Japan is planning to reduce GHG emissions while expanding its resource-recycling business. Although the country could produce paper from virgin pulp and reduce GHG through black liquor, paper companies believe that resource recycling (contributing to a circular economy) is just as important as GHG reduction. They thus intend to use alternative options.

In the near term, Japanese paper companies plan to reduce CO_2 emissions by shifting energy sources from coal to gas, wood fuel, and solar power—while at the same time expanding afforestation activities and increasing the utilization rate of recycled paper. More specifically:

- Many Japanese paper companies are already shifting to low-emission power supplies. For example, they are converting coal-fired power generation facilities to gas, and establishing domestic and international woody biomass collection networks to procure woody biomass fuel. They have also installed high-efficiency boilers capable of burning waste materials such as construction waste, scrap tires, and refuse paper and plastic fuel (RPF). In addition, solar power generation has been introduced.
- Many Japanese paper companies plan to expand their current afforestation activities. They already plant trees to provide the raw material for papermaking, and through cultivar improvement and production of high-growth varieties, the amount of wood harvested can meet demand. Furthermore, these companies are exploring ways to conserve biodiversity and reforest areas that have been damaged in natural disasters.
- Meanwhile, Japanese paper companies plan to strengthen their resource recycling business despite an already high recovered-paper utilization rate (81% in 2021). Technological development is underway to utilize difficult-to-process recovered materials (such as tissue paper, plasticized paper, and other paper waste that has been challenging to collect and use).

In the long term, companies are looking at the possibility of switching to hydrogen or ammonia co-firing for power generation facilities that have switched from coal boilers to gas as part of their current efforts.

By realizing these initiatives, Japanese paper companies aim to achieve both carbon neutrality and higher resource recycling.

Spotlight on Oji Holdings Corporation

Oji HD aims to achieve carbon neutrality by improving energy efficiency, utilizing low-emission fuel, and increasing GHG absorption by expanding afforestation activities. The company also helps achieve a circular economy by expanding its already-high paper recycling activities.

Company profile

- Sales: 1,470 Bn yen in FY2021
- Power consumption: 58,531 GWh of energy (electricity conversion) in FY2021

Current emissions (2021)

Total: 13.18 million tCO_2e

- Scope 1: 6.40 million tCO_2e
- Scope 2: 1.21 million tCO_2e
- Scope 3: 5.57 million tCO_2e

Goals and Commitment Levels

- 2030: 70% reduction in GHG emissions using the 2018 baseline (20% GHG emissions reduction, 50% net absorption by forests)
- 2050: Carbon neutrality, virtually zero GHG emissions

Decarbonization Key Levers

- Improving the energy efficiency of manufacturing processes
- Lower emissions of energy sources utilizing low-emission fuel
- Increase GHG absorption by expanding afforestation activities

Oji HD has declared that it will achieve zero greenhouse gas emissions by FY2050, and has set a target of 70% reduction in Scope 1 and Scope 2 emissions by the end of the decade. By 2030, the company expects 20% of its emissions reduction to come from efficiency improvements and renewable energy, and the remaining 50% through investment in forest conservation and afforestation aimed at increasing net absorption by forests (Table 6).

To achieve these targets, Oji HD plans to:

1) Improve energy efficiency in the manufacturing process. The company also plans to invest 100 billion yen to replace coal boilers with gasification facilities that are more energy efficient.

2) Achieve a renewable energy utilization rate of more than 60% by replacing coal with biomass and hydroelectric power generation. In addition, Oji HD will install private solar-power generation in new plant buildings and plant premises.

3) Practice sustainable forest management in Oji HD forests in Japan and abroad. This initiative includes increasing plantation productivity through tree cultivation and improving operations to maintain a sustainable supply of raw materials for paper production. Furthermore, the company is working to maintain biodiversity and restore ecosystems through afforestation activities. A certain percentage of company-owned forests are maintained as protected areas, both to guard them and to secure vegetation around rivers, lakes, and marshes. When natural forests in protected areas are lost because of fire or other events, the company works to restore the environment by planting native tree species. Oji HD is also involved in efforts to protect and nurture endangered animals. A total of 100 billion yen will be invested by 2030 to expand overseas production forests area by 140,000 hectares and to increase net CO_2 absorption by forests.

Table 6. Oji HD's emissions reduction timeline. Source: See Oji HD's Integrated Report and website.

Category	Sub-category	GHG reduction (kt-CO_2e)	GHG reduction	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
GHG emissions reduction													
Improve energy efficiency	Maintaining energy conservation	200	2.6%	Continue to reduce energy consumption by 1.0% or more on average over 5 years									
Increase the percentage of renewable energy use	Reducing coal consumption	1,007	12.9%	Technological research → Development → Investment decisions → Installations; Consider fuel conversion for 12 coal boilers in Japan									
	Installation of private solar panels, etc.	360	4.5%	Installation planning → Investment decisions → Installations; Consider installing private solar panels									
Subtotal		**1,567**	**20%**										
The net increment in carbon stocks by forests													
Invest in forestry conservation and tree planting	Expanding forest plantations	3,918	50%	Overseas production forests 256,000 ha → 400,000 ha; Survey for sites, land investigation → Assessment of business feasibility → Consideration of acquisition, decision									
	Afforestation of fast-growing trees			Continue forest tree breeding (variety improvement) and afforestation of superior varieties									
Total		**5,485**	**70%**										

Looking toward 2050, GHG emissions from wastepaper recycling will be further reduced by switching the heat source to low-emission thermal power (methane/hydrogen, etc.) and electricity. However, the greening of power sources (electricity) is not a measure that can be implemented by Oji HD alone. Figure 36 summarizes Oji HD's planned emissions reduction trajectory.

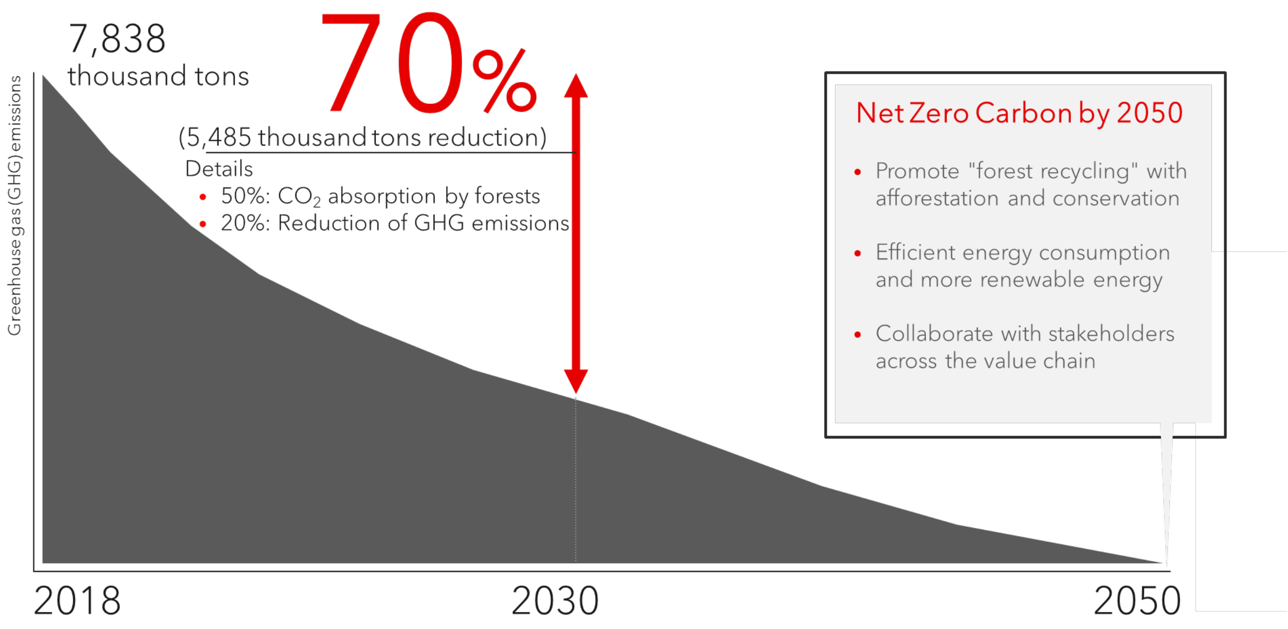


Figure 36. Oji HD's "Environmental Vision 2050" for the year 2050.

As a milestone toward the 2050 goal, the "Environmental Action Goals 2030" target a 70% (or more) emissions reduction by 2030 (v. FY2018) by: 1) improving energy efficiency of manufacturing processes through increased recycling of wastepaper; 2) Low emissions of energy sources used to recover paper; and 3) increase GHG absorption by expanding afforestation.

In addition to reducing its GHG emissions through the above levers, Oji HD aims to contribute to the reduction of external emissions by leveraging its technological advantages in: (4) resource recycling technology; and (5) the development of environment-friendly materials.

4) Oji HD will continue to promote the use of recycled paper and expand recycling efforts. The company hopes to expand the domestic recovered paper utilization rate to more than 70% by 2030, and to use waste as a substitute for fossil fuels. In addition, the company will contribute to CO_2 reduction in other industries by replacing plastic containers with paper and improving transportation efficiency through the production of size-adjustable corrugated boards (Rakudan).
5) In the long term, Oji HD intends to contribute to the decarbonization of all industries using cellulose nanofiber (CNF), an alternative to plastics made from pulp. CNF has already been put to practical use in construction, sporting goods, and cosmetics. Furthermore, the company is researching applications for CNF as a lightweight material for automobiles.

Glass

Glass Fast Facts[197]

Sector profile

Revenue:
125.7 billion USD in 2021[199]

Energy consumption: N/A

Production volume:
195.9 M tons in 2021[200]

Main emission sources

Raw material and process related (15-50%)

An energy intensive process for melting glass (50–85%)

Current CO_2 emissions

86 Mt CO_2 in 2020

1% of the global industrial GHG emissions

Interdependencies

Upstream: Power for green electricity, chemical for green hydrogen and ammonia

Downstream: Buildings, automotive, electronics (flat glass), utensils (other glass products)

Highlights

Glass is essential for modern life. We use it to build windows, containers, high-tech products, and much more. Flat glass, in particular, possesses unique material qualities that are difficult to replace with synthetic substitutes such as resin. However, the business accounts for 1% of global GHG emissions in the industrial sector.[198] Finding the zero-emission way of manufacturing glass is a necessary imperative.

The glass-melting process accounts for 50% to 85% of emissions, making it the main target for process improvements. In particular, reducing CO_2 emissions during the manufacturing process of flat glass, which accounts for 60% of emissions in the sector, is of great importance. Japanese flat-glass companies have improved energy efficiency, shifted from heavy oil to natural gas, adopted electric boosters, and contributed to avoiding downstream emissions by providing energy-saving glass products that can shield and insulate heat and reduce the energy used in air conditioning.

Looking ahead, Japan's flat-glass manufacturers will continue to build off their existing momentum. Most Japanese companies plan to electrify processes and introduce alternative fuels such as green hydrogen or ammonia that can further reduce CO_2 emissions. They are also experimenting with CCU technologies. Sizable financial resources are needed to support this transition.

High-tech glass products, such as windows with high-thermal insulation or IR-cut glass for automotive applications, can also reduce downstream emissions. Japanese companies will continue to develop products that support emissions reductions along the value chain.

[197] These figures is about overall glass sector including each product category

[198] Global material flow analysis of glass: From raw materials to end of life - Westbroek - 2021 - Journal of Industrial Ecology - Wiley Online Library; https://www.iea.org/reports/tracking-industry-2020;

[199] Glass Manufacturing Market Size & Share Report, 2028 (grandviewresearch.com)

[200] Ibid.

Glass sector overview

Glass provides significant value to society. It is used in a broad range of applications, but roughly 90% is used to manufacture windows and containers.[201] Increasingly, glass is used for packaging, construction, and electronics as well. Demand for glass is projected to grow, partly because there are few material substitutes for the flat glass used in automobiles, buildings, and displays. Resin can replace glass in some applications, but for automotive and architectural applications glass provides qualities such as scratch resistance, low thermal expansion, thermal insulation, and structural strength.

Nonetheless, manufacturing glass emits at least 86 million tons of CO_2 annually, accounting for 1% of worldwide GHG emission from industries.[202] Reducing emissions from the glass sector in the medium to long term is an imperative in the quest for carbon neutrality. In addition, while the emissions from glass manufacturing are the lowest of the sectors discussed in this White Paper, the glass industry has influence on CO_2 reductions in the other sectors. For example, glass companies have developed products with high heat shielding/ insulating double-glazing effects, which help reduce the amount of energy used for air conditioning in automobiles and buildings, thereby reducing CO_2 emissions over the entire product's lifecycle.

Most common types of glass are made by melting silica alongside soda ash, limestone, or other additives. Recycled glass, called cullet, can also be used in the production of new glass. There are two main sources of CO_2 emissions in the glass manufacturing process (Figure 37).

- Depending on the product and cullet ratio, 50% to 85% of CO_2 emissions are energy- derived and result from melting glass, an energy-intensive process that requires high heat (1200°C to 1600°C).[203] The majority of glass melting furnaces run on natural gas or other fossil fuels, and transitioning to an emission-free heat source is paramount to achieving carbon neutrality. Biofuels, hydrogen, and ammonia combustion are potential fuel substitutes, but there currently is no clear path to commercialization. Electrification of the heat source can also reduce the emissions intensity of glass- melting furnaces, but electrification still has limitations (e.g. cost, availability of renewable electricity) and cannot be used to manufacture all types of glass. With technological and scale advancement, complete electrification based on clean energy or the use of green hydrogen and ammonia could offer a mid- to long-term path toward carbon neutrality.
- Raw-material and process-related emissions account for the remaining 15% to 50% of CO_2 emissions.[204] The raw materials used in the production of glass, namely soda ash (Na_2CO_3) and limestone ($CaCO_3$), release CO_2 during the vitrification process. Using 100% recycled glass reduces raw-material derived CO_2 emissions by as much as 25% to 30%,[205] but from the standpoint of quality control, the mixing ratio is limited.[206]

[201] 48% hollow or container glass, 42% flat glass (for windows in construction and vehicles), 5% tableware, and 6% other products Global material flow analysis of glass: From raw materials to end of life - Westbroek - 2021 - Journal of Industrial Ecology - Wiley Online Library

[202] Ibid.

[203] A review of decarbonization options for the glass industry - ScienceDirect

[204] Raw material emissions assume a hypothetical case where no recycled material is used. In these instances, the share of emissions can be much higher than process-related emissions which consider glass made from a mixture of cullet and raw material. A review of decarbonization options for the glass industry - ScienceDirect

[205] Global material flow analysis of glass: From raw materials to end of life - Westbroek - 2021 - Journal of Industrial Ecology - Wiley Online Library

[206] Ibid.

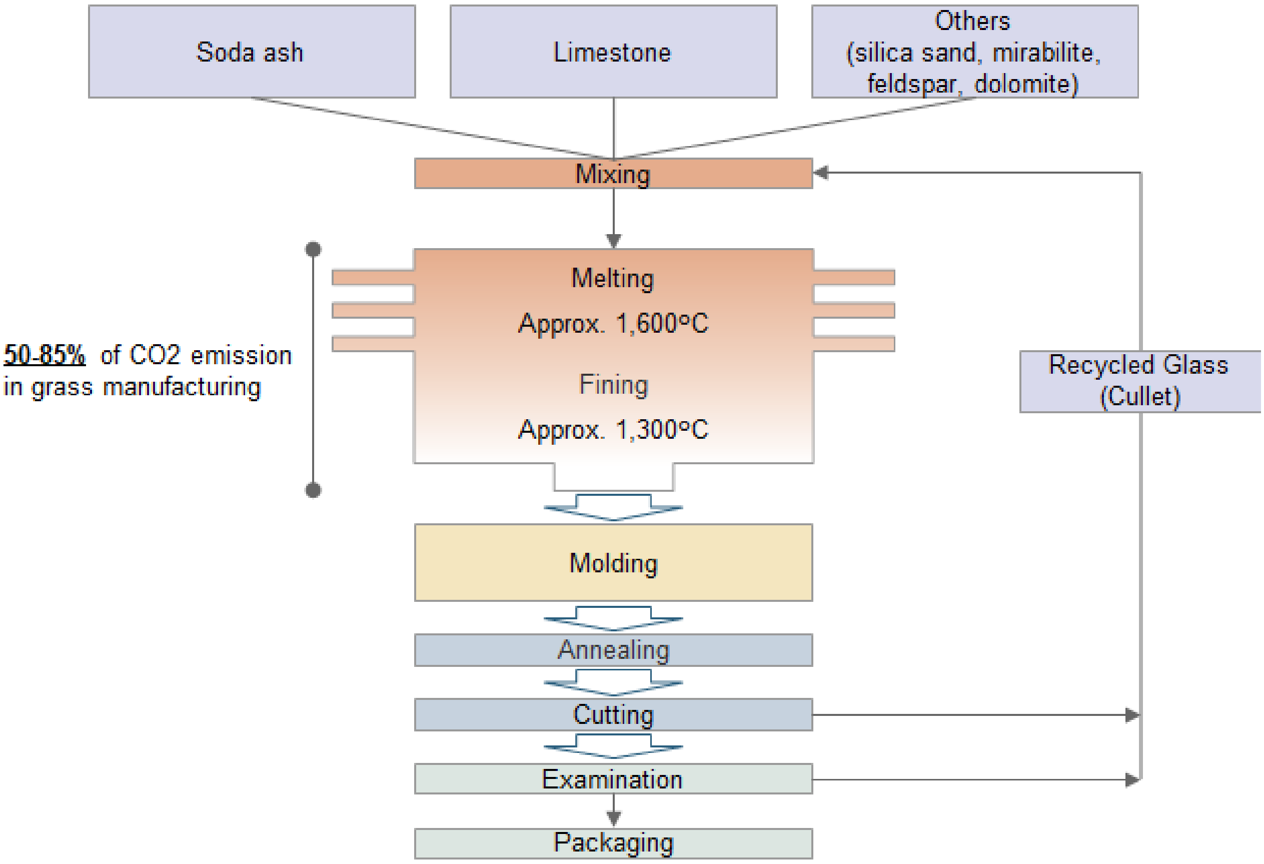


Figure 37. Glass manufacturing process.

Source: "Flat Glass in Japan" Flat Glass Manufacturers Association of Japan

Given the challenges inherent in reducing emissions via fuel swapping, electrification, and using alternative raw materials, many companies look to energy efficiency (e.g. waste-heat recovery, decreasing equipment size-to-output ratio), along with waste reduction, to reduce emissions. Like other hard-to-abate sectors, CO_2 emissions that cannot be avoided could be captured and stored via CCUS.

Japan's carbon-neutrality pathway

Unlike for industrial sectors such as steel, the Japanese government has not yet provided a clear roadmap for reducing emissions in the glass sector. In 2020, roughly 60% of emissions (94.1 M-t CO_2e[207]) came from the production of flat glass, with the remaining 40% attributed to containers (68.5 M-t CO_2[208]). Indeed, by some estimates, flat glass has a higher emissions intensity owing to its high heat requirement. [209] Given the lack of viable alternatives for flat glass and the large energy requirements, this section will focus mainly on the production of flat glass in Japan.

[207] 2021_001_09_01.pdf (meti.go.jp) P4

[208] http://glassbottle.org/quality/plan/

[209] A review of decarbonization options for the glass industry | Elsevier Enhanced Reader

In the short term, Japanese flat-glass manufacturers plan to reduce production emissions predominantly through improvements in energy efficiency and switching fuel supplies. There are several key dynamics:

- As a result of ongoing national efforts, domestic glass manufacturers have improved energy efficiency and reduced CO_2 emissions per unit of production. According to the Japan Flat Glass Manufacturers Association (JFGA), in FY2019, although production volume decreased by 7% compared to FY2005, energy intensity improved by 8% and CO_2 intensity by 10%.[210]
- Furthermore, the JFGA has set a goal of reducing the consumption of heavy oil equivalent by 60,159 kL through decreasing fuel and electricity consumption—utilizing the consolidation and suspension of production facilities as well as changes in manufacturing conditions.[211]
- At the same time, major Japanese glass manufacturers are switching from heavy oil to LNG, which emits less CO_2 per heat. They have leveraged combustion technology with high energy efficiency that is suitable for glass-melting furnaces. They also plan to expand such technology outside of Japan.

In the long term, Japan's glass sector is exploring all possible means to reduce emissions, with an emphasis on electrification, using alternative fuels, and developing CCU technologies, as explained below.

- Electrification. Japanese glass manufacturers such as AGC and NSG have already installed electric boosters at some facilities and plan to continue to adopt electric furnaces over the coming decades.[212]
- Alternative fuels. Additionally, AGC has begun tests to demonstrate glass melting using ammonia in Japan,[213] while NSG is testing the use of hydrogen fuel in the production of architectural glass in its European factories.[214] Transitioning to a new fuel requires sizable funds for technological development, and since glass supplies irreplaceable products, the industry needs partnerships with both the government and financial institutions. NEDO is supporting a project to establish a new ammonia synthesis technology through the Green Innovation Fund, targeting the "Development of ammonia production technology under normal temperature and pressure."[215] This initiative aims to build electrolytic synthesis technology for green ammonia production by 2030.[216] Expanding the supply of blue ammonia and green ammonia is essential to realizing emissions reductions by ammonia combustion.
- CCU. Given the difficulty of directly reducing emissions in the glass sector, there will be a need for technologies that directly abate CO_2. As discussed previously, Japan has limited storage potential for CCS and the associated development costs are high (Appendix D). However, Japanese companies across sectors are collaborating to develop CCU.

In addition to their own efforts to reduce emissions, Japanese glass companies are focusing on reducing CO_2 emissions downstream by supplying high-performance products such as eco-glass and double-glazing glass to the market. The JFGA believes that realization of a low-carbon society will

210 https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/seishi_wg/pdf/2020_001_08_02.pdf, P9

211 http://www.keidanren.or.jp/policy/2021/102_kobetsu16.pdf; P17

212 https://www.agc.com/en/news/pdf/20220113e.pdf

213 Ammonia Combustion Technology Development Project including AGC Selected as NEDO-Commissioned Project ｜ News ｜ AGC

214 https://www.nsg.com/en/media/ir-updates/announcements-2021/ag-production-powered-by-hydrogen#%3E

215 https://www.idemitsu.com/jp/news/2021/220107.html

216 001_03_00.pdf (meti.go.jp)

require widespread use of highly heat-shielding/ insulating double-glazing glass, such as Ecoglass and Ecoglass S. For example:

- In April 2006, the Association coined the promotional term "Ecoglass," calling on consumers to reduce CO_2 emissions and fight global warming by using it. The JFGA also established the trademark “Ecoglass S” for a high-performance, Low-E double-glazing glass in June 2019.
- The results of LCA studies show that society as a whole can expect CO_2 reductions far exceeding the increases associated with manufacturing new types of glass. The studies estimate that high-performance glass, throughout its lifecycle, can reduce up to 2.6 mt-CO_2 in new homes built in 2020. [217]

217 http://www.keidanren.or.jp/policy/2021/102_kobetsu16.pdf

Spotlight on AGC

AGC contributes to Net Zero carbon by achieving carbon neutrality in the glass manufacturing process, as well as by supplying products that enable downstream CO_2 emissions reduction. Through its global portfolio, AGC is horizontally deploying technologies developed in each business and region.

Company profile

Sales: 1,697.4 billion yen (FY2021)

- Flat glass: 648,400 million yen (FY2020)
- Display glass: 177,200 million yen (FY2020)

Current emissions:

Overall company:

- Scope 1+2: 11,60 million t-CO_2 (2021)

Building and automotive glass:

- Scope 1: 3.54 million t-CO_2 (2020)
- Scope 2: 1.16 million t-CO_2 (2020)

Goals and Commitment Levels:

- 2030: Reduce Scope 1+2 emissions by 30% compared to FY 2019; reduce scope 1+2 emissions intensity (emissions per revenue) by 50%
- 2050: Achieve Net Zero carbon (scope 1+2)

Decarbonization Key Levers:

- Improving energy efficiency in the glass manufacturing process, such as by: recycling resources ranging from waste heat to glass cullet; introducing a highly-efficient oxygen combustion system; and reducing waste through precise manufacturing planning
- Developing a carbon-neutral glass melting process by using electric boosters, electrifying the melting heat source, and deploying ammonia combustion technology in glass melting furnaces

AGC, a premier Japanese glass manufacturer, offers a unique global portfolio of flat glass covering three main applications: buildings, automobiles, and displays.

AGC has set a target to reach Net Zero carbon by 2050. By 2030, the company plans to reduce Scope 1 and Scope 2 emissions by 30% and emissions intensity (emissions per revenue) by 50% (compared with 2019).

To date, AGC's efforts to reduce emissions have focused on improving efficiency in the glass manufacturing process. Resource recycling, including waste-heat recycling, help curb energy demand. In 2020, the use of recycled glass(cullet) reduced CO_2 emissions by 99,000 t-CO_2.[218] Other energy-saving efforts include the introduction of an oxygen combustion system with high melting efficiency and precise manufacturing planning to reduce waste when switching glass types in the same furnace.

In addition, AGC successfully raised the percentage of LNG used in glass furnaces from 46% to 93% between FY2010 and FY2020.[219]

In developing technology and process improvements, AGC fosters a culture of knowledge-sharing across business units. For example, efficient technologies

[218] AGC Sustainability Data Book 2021; p47 (https://www.agc.com/en/csr/pdf/agc_sus_en_2021.pdf)
[219] https://www.agc.com/en/ir/library/bizbriefing/pdf/2021_0910eesg.pdf

developed for small furnaces in the display business are being used in large furnaces for construction and automobiles, and vice versa.

Furthermore, as a global company, AGC scales regional solutions to maximize the impact of GHG reduction on a worldwide scale. In 2009, AGC began to install solar panels and heat- recovery systems in its European facilities. Through 2021, electricity production steadily increased to 32,221 MWh of recovered and self-generated energy at AGC Europe.[220]

In order to achieve the Net Zero carbon target by 2050, further emissions reductions will require a carbon-neutral glass-melting process. AGC has already introduced electric boosters for melting that will reduce fuel use and accelerate the electrification of the melting heat source. AGC first plans to expand the use of electric boosters throughout Europe, where renewable energy is readily available, and later deploy them on a global scale pending renewable-energy availability.

AGC is also participating as an active member of the NEDO-commissioned project called "Development of Fuel Ammonia Combustion Technology in Industrial Furnaces," aimed at reducing future energy-derived emissions. Through this initiative, AGC plans to install an ammonia-oxygen combustion burner in its architectural glass production facility at the AGC Yokohama Technical Center. In addition to evaluating the effects of ammonia combustion on glass and on the materials that comprise the melting furnace, AGC and its partners will develop a burner that can meet environmental standards (Figure 38).[221] Eventually, the company intends to deploy ammonia in glass-melting furnaces on a wide scale.[222]

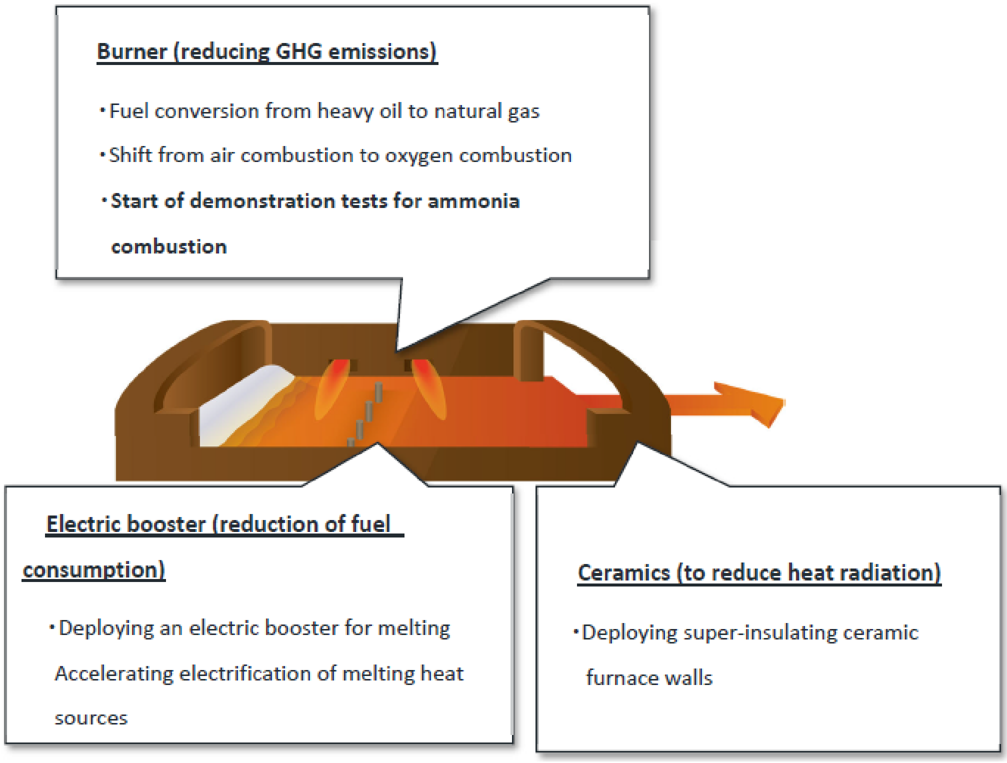


Figure 38. AGC's initiatives to date.

Source: AGC HP

[220] https://www.agc-glass.eu/en/sustainability/production-process-and-technologies/energy-efficient-technologies

[221] https://www.agc.com/en/news/detail/1202704_2814.html

[222] Ibid.

AGC's product innovation will also help catalyze downstream emissions reductions. In 2019, the company's energy-saving products eliminated downstream CO_2 emissions equivalent to 5.6 times AGC's annual emissions for the same year.[223] AGC currently sells energy-saving and energy-creating products such as low-emissive double glazing glass that reduces CO_2 emissions, Low-E glass that reduces annual energy consumption by 32.4% when attached to existing glass (Figure 39), and IR-cut glass for automotive applications.[224] By the end of 2022, AGC plans to launch a new product line of "low-carbon" glass with a smaller carbon footprint than traditional glass.[225]

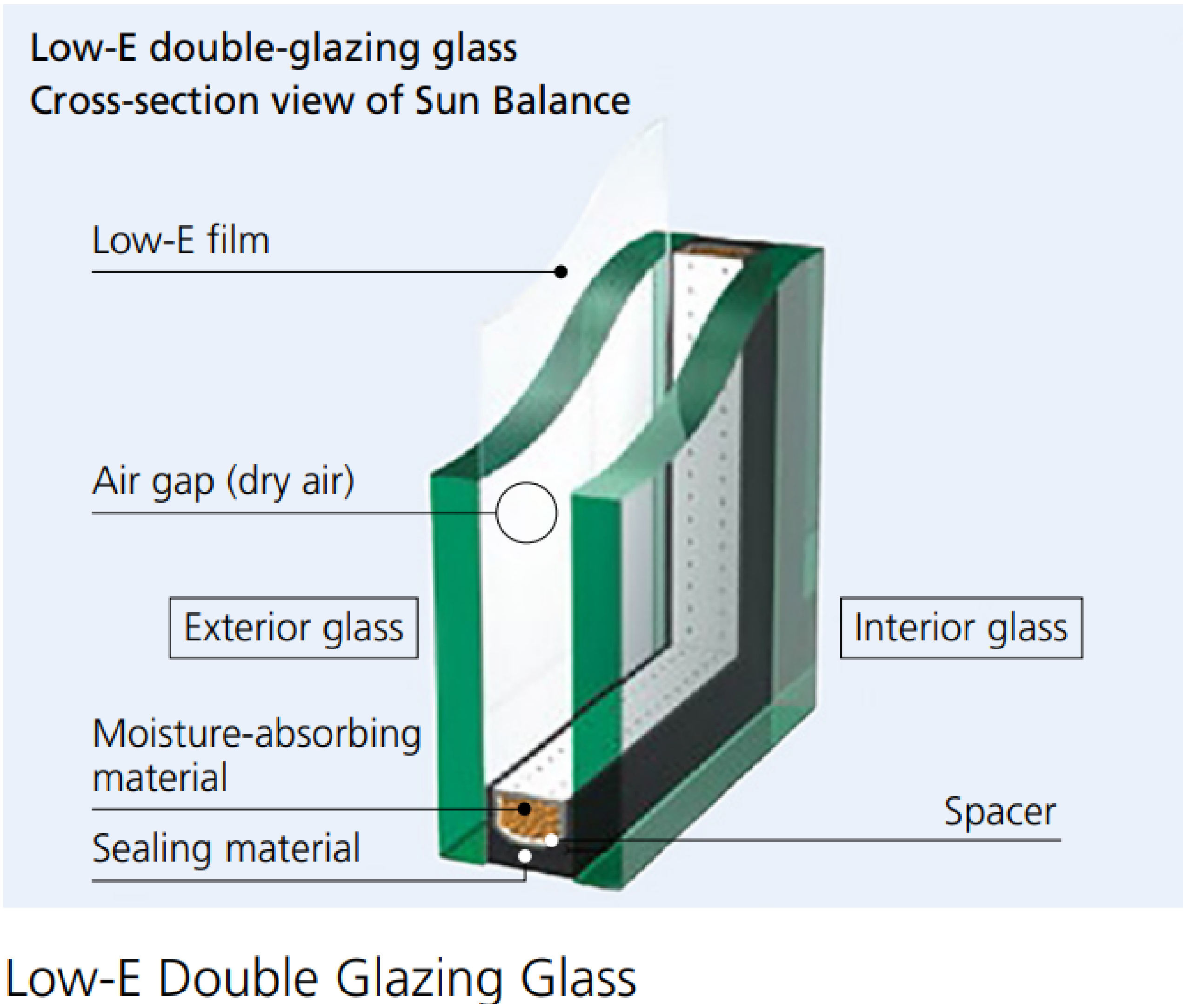


Figure 39. AGC's technologies that contribute to reducing external emissions.

Source: AGC HP[226]

223 https://www.glassonweb.com/news/agc-reduce-six-times-annual-co2-emissions-2020-through-energy-saving-energy-creating-products
224 https://www.eic.or.jp/news/?act=view&serial=32665
225 AGC Glass Europe announces new low-carbon glass range | AGC Glass Europe (agc-glass.eu)
226 agc_sus_en_2021.pdf

Conclusion

Conclusion

Highlights

Financial institutions play a key role in supporting the transition to a carbon neutral future, especially for capital intensive industries. This report has sought to achieve two objectives:

1) Present an overview of Japan's climate strategy as compared to those of Europe and the United States
2) Examine the role of Japan's industrial sector with a focus on six key industries

Japan plans to reduce emissions 46% by 2030 on its path toward carbon neutrality by 2050, and will invest heavily in energy efficiency and renewable energy. However, its limited grid infrastructure and lack of grid connectivity to neighboring regions will necessitate time to deploy renewable energy at scale.

In parallel to these efforts, Japan is developing low-emission thermal power, which will play an ongoing key role in its energy mix, through hydrogen and ammonia technologies. It is also developing CCU technologies that enable carbon recycling. Japan aims to maintain optionality in an effort to accelerate carbon neutrality and best leverage existing infrastructure, while also nurturing the green technology of the future.

Japan's path to carbon neutrality could serve as a blueprint for other Southeast Asian countries, many of which face similar challenges. Fossil fuels currently dominate the electricity mix, and the use of coal has grown sixfold since 2000. A relatively new infrastructure measure mandates that low-emission thermal technologies must achieve emissions reduction targets, and that coal emissions must peak, by 2030.

Furthermore, the expansion of renewable energy remains a tall hurdle. Southeast Asia is vast, with varied renewable-energy potential and access to finance. Like Japan, land and density constraints, as well as fragmented grid infrastructure, limit growth in renewables. The manufacturing sector, an essential driver of the region's economy, faces the task of reducing emissions while sustaining high growth.

Japan's leadership in energy efficiency, green technology, and low-emission thermal energy could enable faster carbon neutrality throughout the Southeast Asian region. Yet mobilizing financial resources will be necessary to achieve carbon-neutral ambitions.

Japan's clean energy future

The shift to clean energy requires collective, deliberate action, and financial institutions will play an essential role in funding capital intensive industries in their transition to a carbon-neutral future. Furthermore, making sound decisions requires a clear understanding of the opportunities and challenges in each industry.

This report has provided an overview of:

- Japan's climate strategy in comparison to those of the US and Europe, along with a brief explanation of Japan's motivation
- Efforts led by Japanese companies in hard-to-abate sectors: power, steel, cement, chemicals, paper, and glass.

Furthermore, the report highlights interdependencies between sector-level and country-level climate strategies, and the importance of addressing emissions in downstream sectors that can have an amplifying effect along the value chain. Although this accumulation of knowledge is just a beginning, we aim to foster dialog and build international collaboration with the goal of achieving our shared ambitions on climate change and sustaining a virtuous cycle of financial resources and innovation.

Japan demonstrates strong commitment to a carbon neutral future

Addressing climate change remains the quintessential challenge of our generation, and across the globe, countries share a vision to achieve climate neutrality by 2050. Japan remains committed to supporting this necessary outcome.

However, Japan's approach differs from those in the United States and Europe owing to several underlying drivers. First, some carbon-neutrality levers available in the US and Europe have largely been exhausted in Japan. For example, Japan leads the world in energy efficiency, and although that remains a priority there are few opportunities for further sizable emissions reductions. Similarly, Japan has both the third largest installed solar capacity and the highest density of installed solar capacity globally. Although investment in solar is expected to continue, many of the prime locations have already been developed and are providing diminishing returns. Japan also faces some parallel headwinds in that its current energy mix is skewed toward coal. Fossil-fuels currently provide an important source of baseload power through a relatively young fleet, making it entrenched in the present-day economy.

Overall, however, despite such challenging starting points, Japan continues to find optimal solutions both by combining different methods and technologies that are currently available, and by exploring innovation to bolster energy resilience in the future—taking into account its unique conditions as an island country.

In the power sector, Japan aims to diversify its energy mix by leveraging a significant expansion of both renewable energy and nuclear power through 2030. Advancements in offshore wind and grid-scale battery storage are expected to accelerate the deployment of renewables into the 2030s. The country has also committed to a managed phase-out of coal, including dismantling 100 inefficient coal-fired plants, and to gradually replace both coal and natural gas with hydrogen and ammonia, respectively, through co-firing technologies. Japan currently leads the world in ammonia co-firing, and has developed ambitious plans to construct ammonia and hydrogen supply chains throughout the Southeast Asian region. For remaining emissions, Japan is developing CCUS capabilities.

Japan's industrial sector—specifically steel, cement, chemicals, paper, and glass—will also play a critical role in the country's energy transition. Collectively, these industries account for ~20% of

Japan's emissions. In the near term, Japanese industrial companies are improving energy efficiency and exploring alternatives such as renewable energy, ammonia, hydrogen, biofuel, and waste. In the long term, Japanese researchers aims to rethink the way carbon is used in industry. Advancements in CCU—specifically the utilization of CO_2 as a raw material—is expected to help drive a circular economy.

In all sectors, Japan aims to maintain optionality in an effort to make the best use of existing technologies while exploring for breakthrough innovations that will secure the global climate's future.

Japan's experience could accelerate efforts throughout Southeast Asia

Japan's vision for carbon neutrality could provide a blueprint for emissions reductions across Southeast Asia, particularly in Indonesia, Thailand, Malaysia, Singapore, Philippines, and Vietnam.

As a region, Southeast Asia is growing rapidly. Most economies have doubled their GDP since 2000 (Figure 40A),[227] and growth is expected to continue at 4% to 7% per year through 2023.[228] However, this economic expansion has also accelerated demand for energy, with emissions following a similar trajectory (Figure 40B). The above six countries contributed 6.5% of global emissions in 2018.[229]

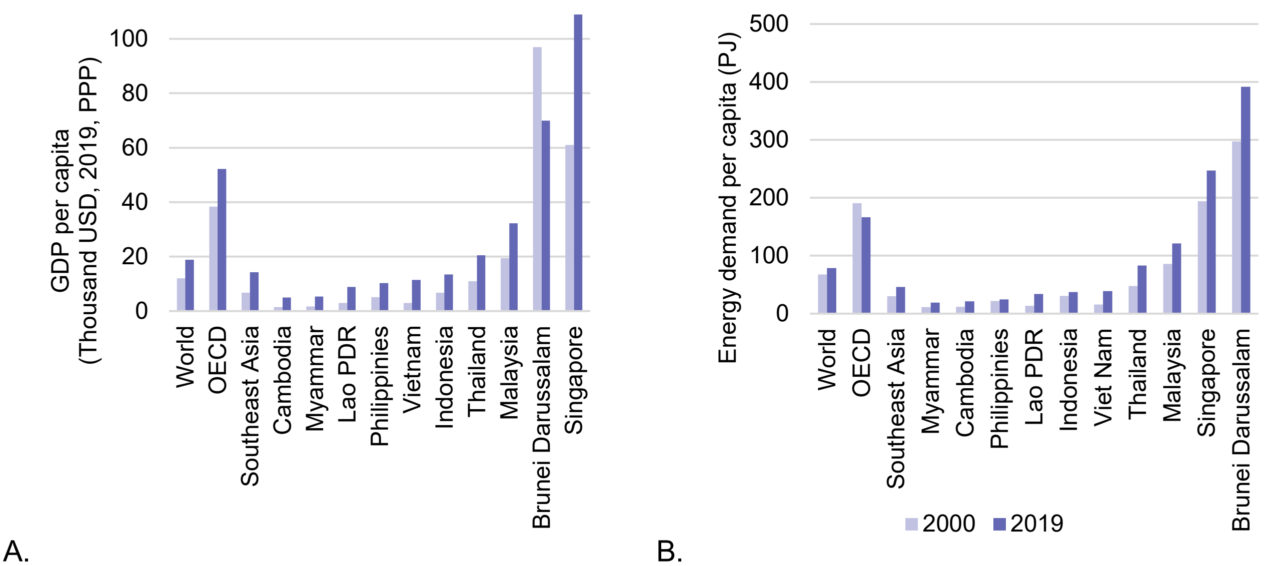


Figure 40. A. GDP per capita and B. energy demand per capita in Southeast Asia in 2000 and 2019.

Source: Southeast Asia Energy Outlook 2022 (IEA)[230]

[227] Southeast Asia Energy Outlook 2022 (windows.net)

[228] Chapter 1. Macroeconomic assessment and economic outlook in Emerging Asia | Economic Outlook for Southeast Asia, China and India 2022 : Financing Sustainable Recovery from COVID-19 | OECD iLibrary (oecd-ilibrary.org)

[229] ASEAN countries: Indonesia, Thailand, Malaysia, Singapore, Philippines, Vietnam, Myanmar, Brunei, Cambodia, and Laos, 2018, Greenhouse gas emissions - Our World in Data

[230] Southeast Asia Energy Outlook 2022 (windows.net)

Every country in Southeast Asia has signed the Paris Agreement, but only six have set carbon-neutral or Net-Zero targets. Those targets fall between 2050 and 2070.[231]

Reducing emissions throughout the region will not be easy. Southeast Asia is a richly varied area with a range of geographic, political, and economic circumstances. However, many of the barriers facing Japan are common throughout the region, namely sources of emissions and grid connectivity.

Sources of energy and emissions

Like Japan, Southeast Asia's energy mix is skewed toward fossil fuels. Total energy supply in the region grew by ~80% between 2000 and 2020.[232] Coal's contribution increased from 8% to 26%, with a sixfold increase in coal-power generation (Figure 41A).[233] In 2020, fossil fuel accounted for more than 70% of the electricity mix in Malaysia, Indonesia, Thailand, the Philippines, and Vietnam (Figure 41B).

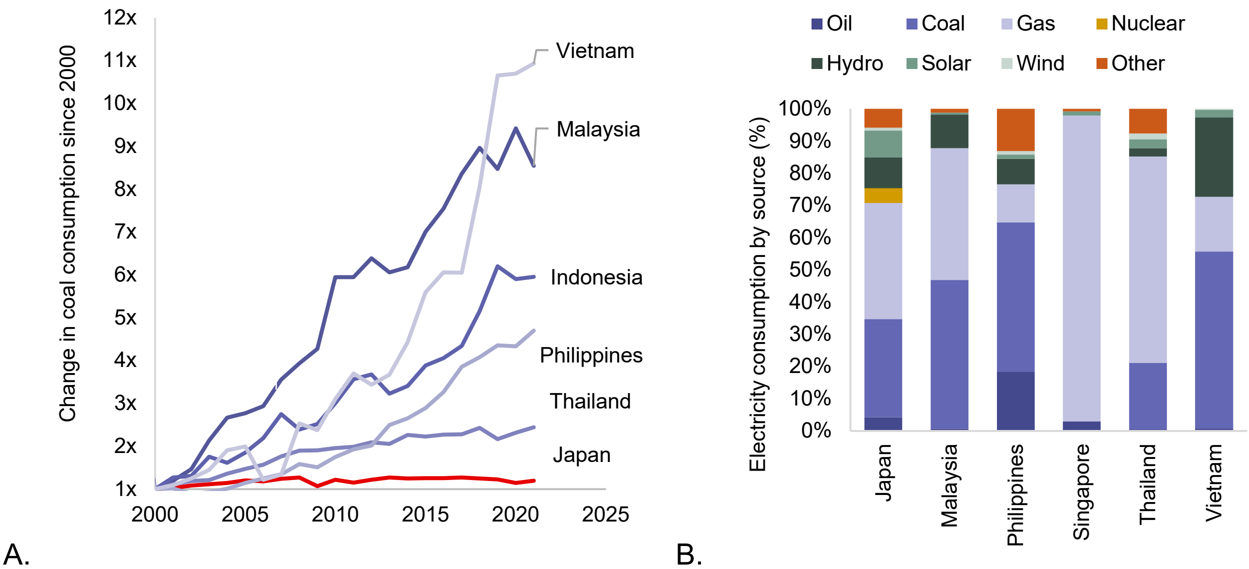


Figure 41. A. Change in coal consumption since 2000, by region. B. Electricity consumption by source and region, 2020.

Note: Singapore increased coal consumption from 0 TWh in 2000 to 9.0 TWh in 2021. Data was excluded from figure due to negligible contribution to total power supply. Source: (A) Our World in Data, Statistical Review of World Energy – BP (2022) (B) Our World in Data based on BP Statistical Review of World Energy, Ember Global Electricity review (2022), Ember European Electricity Review (2022). Note: Other renewables includes biomass and waste, geothermal, wave and tidal. OurWorldInData.org/energy.

Following the global trend to phase-out inefficient coal, Indonesia and the Philippines no longer plan to build unabated coal-fired power plants. Vietnam intends to phase out unabated coal by 2050.[234] However, even if few new plants are added to the mix, there are still nearly 90 GW of existing coal-fired plants in Southeast Asia, many of which are still relatively new. Currently, there is about 18 GW of coal-fired power under construction, and the existing fleet has an average age of about ten years.[235]

[231] Thailand to reach net-zero emissions by 2050 if supported: PM Prayut | Bangkok Tribune (bkktribune.com)

[232] Southeast Asia Energy Outlook 2022 (windows.net)

[233] Ibid.

[234] Ibid.

[235] Ibid.

As we have seen with Japan, the expansion of renewable energy is a top priority in Southeast Asia. Indeed, the ASEAN region is aiming for 23% of its energy mix to come from renewable energy by 2025 (Figure 42).[236] However, renewable energy potential varies considerably from one country to the next. Land and population density constraints, along with local policies, can hinder the spread of renewable energy.[237]

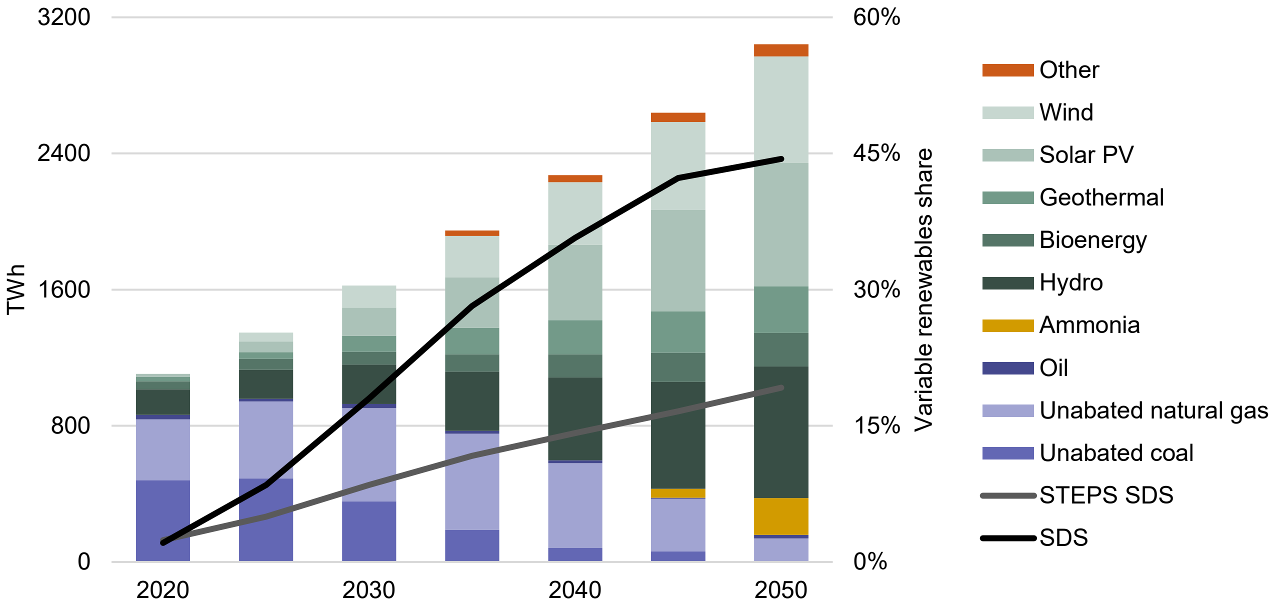


Figure 42. Projected power generation and shares of variable renewables in Southeast Asia, SDS, 2020-2050.

Source: IEA[238]. Note: The Sustainable Development Scenario (SDS) delivers on the Paris Agreement goal to limit the temperature to "well below 2°C", alongside the goals on energy access and air pollution. This scenario is consistent with Southeast Asia's current announced climate aspirations.The Stated Policies Scenario (STEPS) reflects the countries' current policy settings based on a sector-by-sector assessment of the specific policies that are in place or have been announced.

Grid connectivity with other regions

Distributed systems have allowed remote regions in ASEAN countries to gain access to electricity, and certainly play a role in promoting energy availability. Nevertheless, fragmented grid infrastructure, in part owing to geography, makes it more difficult to load balanced resources and create robust electricity markets. Indeed, expanding grid infrastructure is a goal of the ASEAN Power Grid (APG) program, which includes initiatives to build "physical infrastructure and create markets for multilateral power trade"[239] (Figure 43). Financing also remains a barrier to the perception of high risk and uncertainty in financial return.

[236] 2020 Regional focus: Southeast Asia – Electricity Market Report - December 2020 – Analysis - IEA

[237] Southeast Asia Energy Outlook 2022 (windows.net)

[238] Ibid.

[239] Ibid.

.

Figure 43. Southeast Asian power grid.

Notes: Lao PDR = Lao People's Democratic Republic. Source: IEA (2019), 2020 Regional focus: Southeast Asia. (2020 Regional focus: Southeast Asia – Electricity Market Report - December 2020 – Analysis - IEA). All rights reserved.

Regional interdependencies warrant collaborative climate action

Southeast Asia needs a balanced approach to facilitate an orderly transition to carbon neutrality. Japan's climate-change strategy could serve as a model, given its similarities to other countries throughout the region. For instance, a balanced approach—managing the phase-out of fossil-fuel use and improving energy efficiency—will provide flexibility to the power grid. Maintaining optionality will also provide greater flexibility in adapting to a changing energy landscape.

Japan is actively collaborating on initiatives throughout the region. For example:

- Japan is committed to assisting transition efforts in ASEAN through the Asia Energy Transition Initiative (AETI). It has pledged $10 billion in financial support for areas such as renewable energy deployment and the conversion of coal-fired power plants to gas-fired plants, or modifying existing plants to co-fire with ammonia/hydrogen.[240] Some of these efforts include partnerships with Japanese companies, such as the IHI-PLN collaboration in Indonesia.
- Japan is working with countries throughout the region such as Indonesia, Malaysia, and Brunei Darussalam to develop hydrogen supply chains.[241] In addition, there are seven large-scale CCUS projects planned throughout Southeast Asia.[242] As an active participant of the Asia CCUS Network, Japan is in a prime position to help other countries transition to a carbon-neutral future.
- International partnerships, such as the Japan-U.S. Clean Energy Partnership (JUCEP) and the Japan-U.S. Mekong Power Partnership (JUMPP), provide additional support for deployment of renewable energy technologies, regional power trade, and market development throughout the South Pacific. Japan is also working to accelerate the adoption and deployment of offshore wind and next-generation nuclear power, both domestically and abroad.
- Most recently, Japan announced the "Asia Zero Emissions Community Initiative" to provide a framework for joint decarbonization including: "(1) promoting the joint demonstration of biomass, hydrogen, ammonia, CCUS, and other technologies for zero emissions in thermal power generation; (2) establishing rules for an Asian version of transition finance; (3) establishing standards for zero-emission technologies; and (4) utilizing emission rights trading in Asia at large."[243]

Addressing climate change is a global challenge, and international collaboration is critical for encouraging the innovation and financial support required to mitigate emissions. This is especially true for nascent technologies where affordability remains a concern. Japan's leadership will help elevate the entire Southeast Asian region. Nonetheless, mobilizing substantial financial resources will be essential to realizing the carbon neutral ambition.

Overall, it is estimated that approximately US$32 trillion of financing will be needed over the next decade. Moreover, strategies and efforts to achieve carbon neutrality need to be viewed holistically in order to understand interdependencies between the components of sector-based and country-level strategies, as in the case of Japan.

Ultimately, although the road ahead will be a difficult one, achieving global carbon neutrality by 2050 is within reach if governments and industries grasp the urgency and work together to achieve the goal—one that is a must for the future of our planet and for all mankind.

---

[240] Japan also recognizes that low-emission thermal power will be a necessary part of the energy transition through ammonia and hydrogen technologies. Several countries – Malaysia, Indonesia, Singapore, Thailand, and Vietnam -- are actively conducting or planning studies around ammonia co-firing. Climate Action by Japan and Implications for Southeast Asia - ISEAS-Yusof Ishak Institute, Southeast Asia Energy Outlook 2022 (windows.net)

[241] Southeast Asia Energy Outlook 2022 (windows.net)

[242] Ibid.

[243] Speech by Prime Minister KISHIDA Fumio at the 27th International Conference on The Future of Asia (Speeches and Statements by the Prime Minister) | Prime Minister of Japan and His Cabinet (kantei.go.jp)

Appendix A. Glossary

Abbreviation	Definition
BAU	Business as usual
BF	Blast furnace (steel)
Bn	Billion
CCU (see CCUS)	Carbon capture and utilization
CCS (see CCUS)	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CO_2	Carbon dioxide
Decarbonization	Process by which countries, individuals or other entities aim to achieve zero fossil carbon existence. Typically refers to a reduction of the carbon emissions associated with electricity, industry, and transport
DRI	Direct reduced iron
EAF	Electric-arc furnace
GDP	Gross domestic product
GFANZ	Glasgow Financial Alliance for Net Zero
GHG	Greenhouse gas
GW	Gigawatt
H_2	Hydrogen
kW	Kilowatt
kWh	Kilowatt-hour
NEDO	New Energy and Industrial Technology Development Organization in Japan
Net Zero	A global "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (IPCC). The term originally was used to describe country level action at the United Nations Framework Convention on Climate Change, and was later extended to describe corporate action on climate change indicating that the value chain results in no net accumulation of CO_2 in the atmosphere. The focus of Net Zero is climate mitigation, and while adaptation and resilience are equally important, our emphasis here will be on climate mitigation strategies
NH_3	Ammonia
METI	Ministry of Economy, Trade, and Industry in Japan
Scope 1	Emissions directly controlled by an organization (e.g. fuel combustion)
Scope 2	Indirect emissions associated with purchased power (e.g. electricity, heat)
Scope 3	Indirect emissions from upstream or downstream activities in the supply chain
TCFD	Task force on climate related financial disclosures
TWh	Terawatt-hour
ZEV	Zero-emission vehicle

Appendix B. Summary of Climate Drivers

	EU	Germany	France	UK	US	Japan
1. Sources of emissions						
1-1. Source of emissions (2019)						
	Electricity & heat: 33% Transport: 29% Buildings: 11% Industry, Manufacturing and Construction: 14% Other: 12%	Electricity & heat: 37% Transport: 25% Buildings: 14% Industry, Manufacturing and Construction: 15% Other: 9%	Electricity & heat: 13% Transport: 43% Buildings: 14% Industry, Manufacturing and Construction: 13% Other: 18%	Electricity & heat: 21% Transport: 35% Buildings: 19% Industry, Manufacturing and Construction: 9% Other: 16%	Electricity & heat: 36% Transport: 37% Buildings: 7% Industry, Manufacturing and Construction: 9% Other:11%	Electricity & heat: 48% Transport: 19% Buildings: 5% Industry, Manufacturing and Construction: 18% Other: 10%
1-2. Sources of alternative energy						
	*Varies by country	Solar: Low potential, but low cost and sufficient space is available	Solar: Low solar potential, but low cost and sufficient space is available	Solar: Low potential, but moderate cost and sufficient space is available	Solar: High potential, esp. in southwest of country, low cost	Solar: Low potential, but low relative cost
		Onshore wind: Moderate potential, low cost, sufficient space	Onshore wind: Moderate potential, low cost, sufficient space	Onshore wind: High potential, low relative cost	Onshore wind: Extremely high potential, extremely low relative cost	Onshore wind: Moderate potential but difficult to construct, low relative cost
		Offshore wind: Moderate potential, moderate cost	Offshore wind: Moderate potential, moderate cost	Offshore wind: Extremely high potential, moderate relative cost	Offshore wind: Extremely high potential, moderate cost	Offshore wind: High potential, but mostly in deep sea. High cost and technical challenges
		Geothermal: moderate potential, favorable economic conditions	Geothermal: moderate potential, favorable economic conditions	Geothermal: low potential, unfavorable economics	Geothermal: High potential; higher cost than other alternatives	Geothermal: Moderate potential, but 56% located in national or semi national parks
		CCUS: potential to store carbon in North Sea, financing and government support are limited	CCUS: access to North Sea storage, strong commercial actors in CCUS value chain	CCUS: advanced regulatory frameworks and government support	CCUS: High storage potential; skilled workforce	CCUS: Few suitable sites for CCUS; prone to earthquakes making it highly hazardous
	Population density: 108[244]	Population density: 233	Population density: 118	Population density: 277	Population density: 34	Population density: 338
1-3. Legacy infrastructure						
	*Varies by country	Plans to phase out all coal-fired power plants by 2038 under the Coal-Fired Power Abolition Act. Many of the existing power plants are nearing the end of their life span and the above measures can be taken	Nuclear power accounts for 60% of power sources owing to positive perception	High ratio of natural gas/renewable energy/nuclear power. Coal-fired power plants, which originally had a low ratio, will be phased out by 2025	Over 50% of coal-fired power plants decommissioned owing to aging infrastructure	Relatively new infrastructure, making it less efficient to replace. The goal is to improve the energy efficiency of existing facilities by retrofitting existing plans, replacing fuels, etc. Current large fleet of nuclear power plants is aging but could be reinstated

[244] Population density data is from Ministry of Internal Affairs and Communications of Japan (people per sq. km).

	EU	Germany	France	UK	US	Japan
2. Grid/pipeline connectivity with other regions						
	International transmission lines between the countries with massive investments, setting an interconnection target of ~15% by 2030; natural gas pipelines connecting countries	Connected to neighboring countries via electric grid, investing in electric grid expansion. Natural gas imported from Russian pipeline	Connected to neighboring countries via electric grid, investing in electric grid expansion. Gas imported from Russia/North Africa through pipelines	International transmission lines with neighboring countries, investing in electric grid expansion across North Sea. Supply North Sea gas/oil from pipelines	International transmission lines between North American nations. One of the world's leading importers of electricity	International interconnecting lines have not yet been established. Dependent on LNG by sea, not pipeline, making natural gas prices expensive and unstable
3. Energy security						
	Robust, high-tech infrastructure and diversified energy supplies limit risk The war in Ukraine has delayed plans to decommission coal and nuclear power REPowerEU demonstrates EU ability to strengthen energy security while safeguarding the environment in a rapidly changing world	Diversified domestic energy supply helps build energy resilience, but reliance on natural gas imports highlights key vulnerabilities owing to Russian/Ukrainian war	Strong domestic nuclear-energy supply and large stockpile of uranium help to build resilience, but heavy reliance on fuel imports (natural gas, oil) create vulnerabilities, especially in light of Russian/Ukrainian conflict	UK has low energy risk due to liberalized energy markets, robust regulation and extensive North Sea resources provide energy stability	The US has a large, diversified supply of energy resources. Vast distances in US make critical infrastructure (roads, electrical grid, etc.) key for energy security	Limited domestic energy supply has led Japan to diversify the sources of energy imports from around the world to secure supply. Thermal power and nuclear energy are important sources of domestic electricity production
4. Socio-political factors						
	Ahead of the rest of the world, with strong support for climate action. Many policy directives are being promulgated to support the measures	Policies related to wind and solar power are being promoted as public opinion supports renewable energy. Low public support for nuclear; energy mix will shift away from nuclear power in wake of Fukushima accident.	Positive perception of nuclear power in France enables the country to generate more than 60% of its energy from nuclear power	Coal-fired power was originally the main power source, but deregulation of the electric power industry and policy measures to reduce the price of CO_2 have reduced the ratio of coal-fired power.	Attitudes toward climate change and associated policies vary by state. Economics, guided by government incentives, serve as predominant driver of energy mix.	Promotion of recycling / energy conservation at the national level in order to reduce demand. Mixed public support for nuclear, making it difficult to increase the percentage of nuclear power generation

Appendix C. History of Emissions Reduction in Japan

Emissions reduction in Japan stems from more than 50 years of technological innovation, policy implementation, and environmental stewardship. Ahead of the rest of the world, Japan has set and achieved ambitious goals through its Energy Efficient Act and Sunshine Projects. (Figure 44).

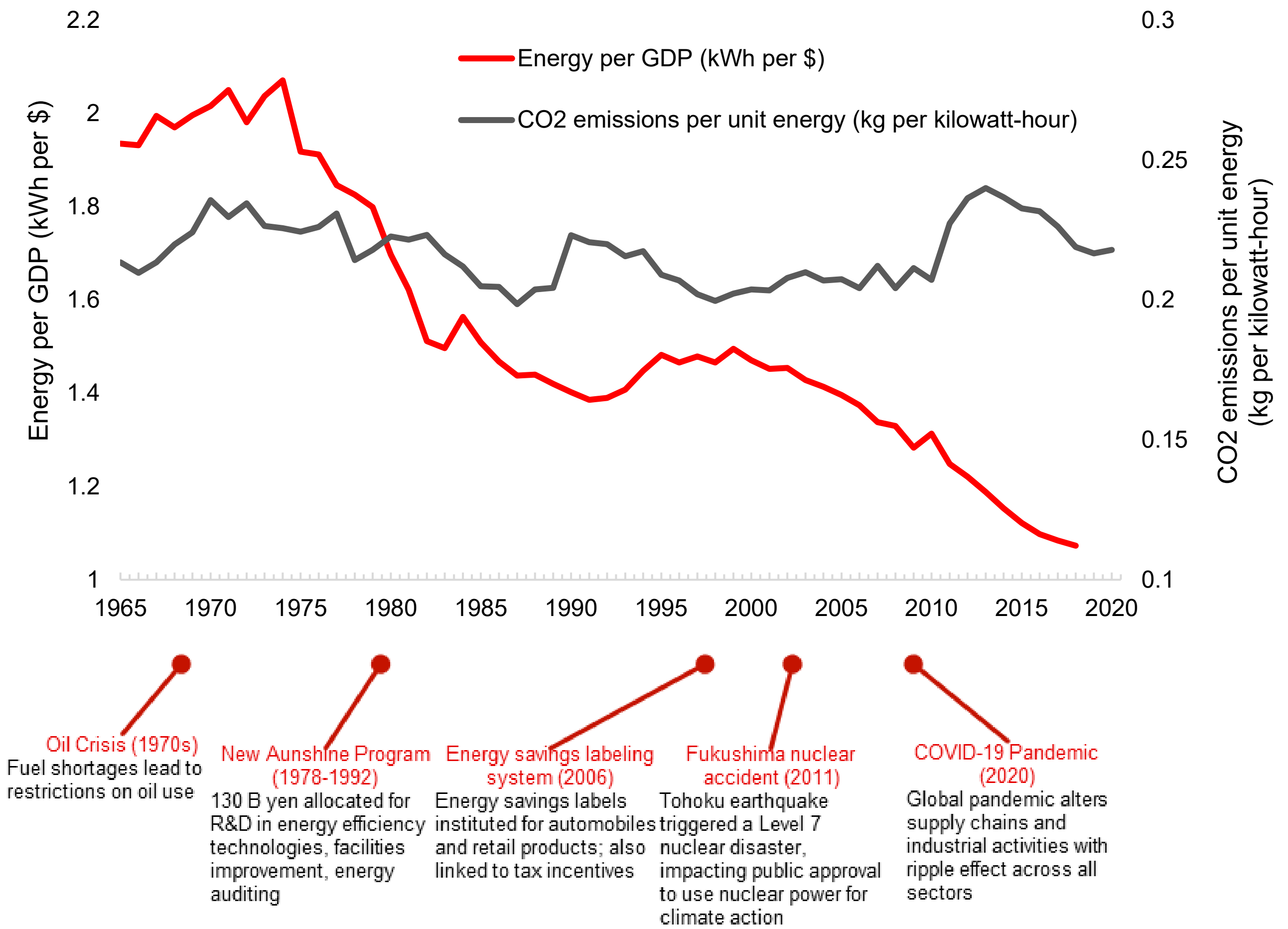


Figure 44. Energy per GDP/ CO_2 emission per kWh in Japan; Energy efficiency milestones.

Source: Energy intensity (ourworldindata.org); CO_2 Data Explorer - Our World in Data.

Note: In Japan, energy intensity has continued to improve, while CO_2 emissions per unit of energy have increased owing to the closure of nuclear plants following the 2011 earthquake.

The Energy Efficiency Act of 1979 introduced regulations targeting factories with high energy consumption. Periodic amendments through 2018 expanded the topics covered and established updated targets. In particular, the legislation introduced a mandatory periodic report system ahead of other countries, and initiated a regulatory standard program to improve the energy efficiency of electrical appliances.[245] To compliment regulatory measures, Japan implemented a range of promotional activities as well: tax incentives for buildings and automobiles, subsidies to promote investment in green facilities, R&D investment in breakthrough technologies, and public-awareness

[245] https://www.iea.org/policies/573-act-on-the-rational-use-of-energy-energy-efficiency-act

campaigns.[246] Overall, energy efficiency has increased 40% since the 1970s.[247] Since 2000, the largest efficiency gains have come from the services and industrial sector.[248]

The so-called “Sunshine Projects”[249] included a series of investment initiatives to develop new energy technology. The effort led Japan to become the world's largest producer and adopter of solar energy from 1995 to 2004, and helped its expansion in large-scale hydroelectric power. Diversification of the electricity sector, driven by heavy investment in renewable energy and the reintroduction of nuclear power, contributed to the decline in emissions. Currently, renewable energy accounts for ~24% of total electric power consumption.

Recycling and waste management have further contributed to energy savings. In 1991, Japan was the first country to implement legislation related to the circular economy, the goal being to “reduce oil dependence and high-energy-consumption industries, adjust energy structure, improve efficiency of energy utilization, and develop knowledge-intensive industries.”[250] By 2007, more than 98% of Japan’s metals were recycled, and only 5% of waste was landfilled.[251]

---

[246] スマートグリッドと電気自動車 (unfccc.int)

[247] スマートグリッドと電気自動車 (unfccc.int)

[248] Japan 2021 - Energy Policy Review (windows.net)

[249] The “Sunshine Project” (1974), “Moonlight Project”(1978).RD & D (1989) were combined into the “New Sunshine Program” 1993

[250] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.955.2170&rep=rep1&type=pdf

[251] https://www.env.go.jp/content/900453391.pdf

Appendix D. Carbon Capture, Utilization, and Storage (CCUS)

The need for CCUS

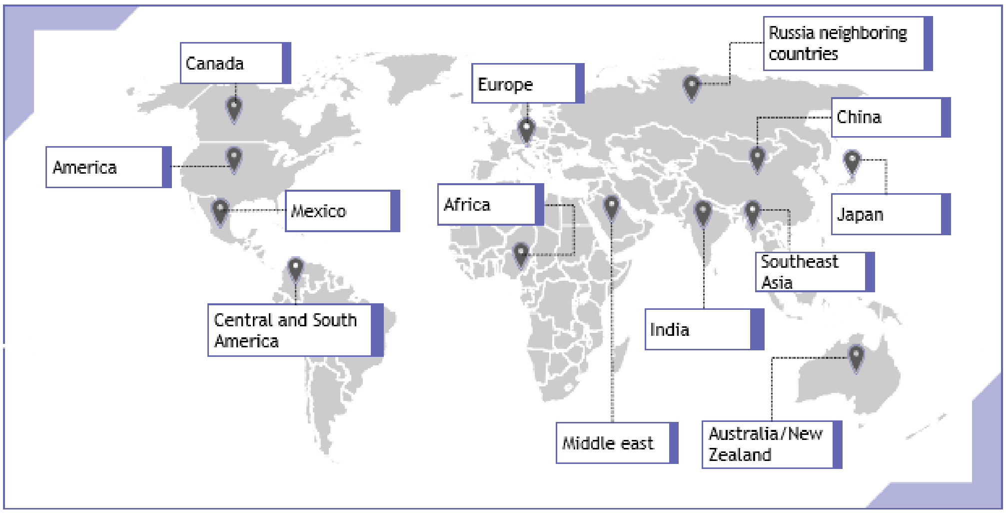
According to the IEA, "Reaching net zero will be virtually impossible without CCUS."[252] In particular, its versatility offers four clear advantages:

1) CCUS can reduce or eliminate emissions from existing infrastructure. For some high CAPEX sectors, like power, steel, and chemicals, it may be the least expensive abatement option. According to the IPCC Fifth Assessment report, excluding CCUS from emissions scenarios doubled the cost of abatement.[253] The option to reduce emissions from existing infrastructure could also accelerate the timelines needed to meet emissions reduction targets.
2) In some hard-to-abate sectors, CCUS may be the only viable abatement path. For example, cement produces CO_2 as a byproduct of the chemical reactions, with limited substitutes. CCUS provides a necessary path toward emissions reductions.
3) CCUS enables the development of some low-emission fuels. For example, the development of synfuel, produced from CO_2 and H_2, needs CCUS technologies to reach zero emissions. Similarly, it enables the production of blue hydrogen (zero-emission hydrogen produced from fossil-fuel feedstock in combination with CCUS), which will be needed to meet growing energy demands.
4) CCUS can be used in conjunction with direct air-capture. As the urgency of the climate crisis grows, society will likely turn to technologies that can clean CO_2 from the atmosphere. CCUS technologies will enable carbon disposal.

Development status of CCUS

Carbon capture, utilization, and storage (CCUS) technologies (1) capture CO_2 from large sources—typically power plants and industrial facilities—and then (2) uses the CO_2 in industrial processes, or (3) stores the CO_2 into geological storage basins to prevent its release into the atmosphere. Storing CO_2 requires specific geological conditions, and storage capacity varies around the world (Figure 45).

[252] CCUS in clean energy transitions (windows.net)
[253] Understanding Carbon Capture Use Storage (CCUS) (ogci.com)



	Canada	America	Mexico	Central and South America	Europe	Africa	Middle East	Russia neighboring countries	India	Southeast Asia	China	Australia/ New Zealand	Japan
Estimated Storage Capacity (Gt)	318	812	138	903	302	1,563	492	1,720	99	281	403	595	8
Land (%)	65%	68%	58%	74%	53%	86%	75%	93%	75%	53%	81%	56%	43%
Undersea (%)	35%	32%	42%	26%	47%	14%	25%	7%	25%	47%	19%	44%	57%

Figure 45. CCS potential around the world.

Source: IEA[254], Kearns, J.et al., (2017), Developing a Consistent Database for Regional Geologic CO_2 Storage Capacity Worldwide.

Worldwide, there are 65 commercial CCS facilities in various stages of development, with 26 operational facilities capable of storing 40 Mt of CO_2 each year.[255] The majority of CCUS facilities are located in North America, but multiple new CCUS projects are planned in Australia, China, Korea, the Middle East, and New Zealand.[256]

After a dip in investment in the early 2010s, investment in new CCUS projects has grown over the past five years, driven by strong corporate climate targets and a favorable investment environment. Between 2017 and 2020, more than 30 new commercial CCUS programs were announced, representing ~$27 billion in potential investment.[257] The proposed pipeline of projects will more than double CO_2 storage capacity over the next decade. Further, applications for CCUS are becoming more diverse. Although the main application for CCUS remains natural gas processing, an increasing number of facilities are targeting power generation, industrial applications, and fuel production (Figure 47).[258]

254 The world has vast capacity to store CO2: Net zero means we'll need it – Analysis - IEA

255 Of the remaining 39, 3 are under construction, 13 are in advanced development, 21 are in early development, and 2 have been suspended Global-Status-of-CCS-Report-2020_FINAL.pdf (globalccsinstitute.com)

256 CCUS in clean energy transitions (windows.net)

257 Ibid.

258 Ibif.

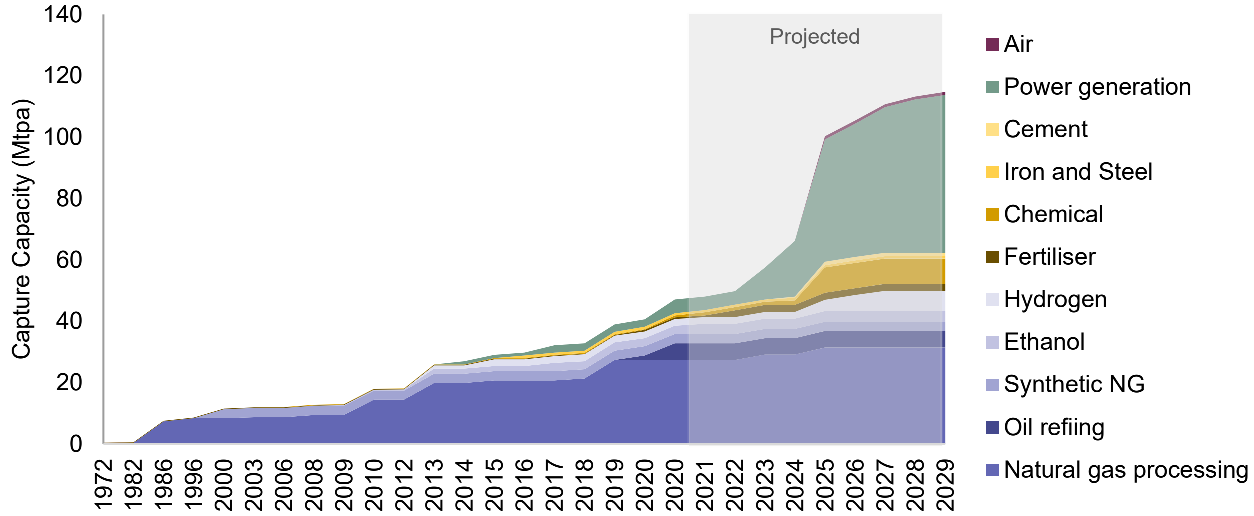


Figure 46. Proposed CCUS facilities

Note: Facilities will double CO_2 storage capacity in the next decade. Notably, applications of CCS are becoming more diverse with power generation and industrial use-cases driving future growth. Source: Global-Status-of-CCS-Report-2020_FINAL.pdf (globalccsinstitute.com)

CCUS in Japan

Japan's Environmental Innovation Strategy features CCUS as a central pillar. The strategy includes:[259]

1) The development of low-cost CO_2 separation and recovery
2) Conversion of CO_2 to fuel and other carbon-recycling technologies
3) Reclaiming CO_2 from the atmosphere.

Japan's industry ministry, METI, plans to create a legal framework for carbon capture and storage (CCS) to enable companies to start storing CO_2 underground or under the seabed by 2030, and to help the nation achieve its 2050 storage goal (~120-240 million tons of CO_2 per year). Companies would need to begin feasibility studies in 2023 and make final investment decisions by 2026 in order to start CCS businesses in 2030.

Recent seismic estimates suggest that Japan has 146 billion tons of storage potential within shallow water, with an additional capacity of 90 billion tons in depth areas of 200 meters to 1,000 meters. Such capacity could provide enough storage space for the next 100 years.[260] However, the results of existing geological exploration, seismic surveys, and the like, indicate there are only a few geological areas in the seas around Japan where billions of tons of CO_2 could be stored, and that continuing exploration will be needed to locate appropriate reservoir sites. The IEA estimates Japan's storage capacity to be around 8 billion tons—a far lower CCS potential than in Europe or the US. In addition, most large-scale CO_2storage sites in Japan are located in the coastal areas on the Pacific side, and the emission sources and suitable storage sites are not necessarily close together. Such circumstances will require consideration of long-distance transportation methods.[261] (Figure 48).

[259] PowerPoint プレゼンテーション (env.go.jp)

[260] Japan's annual CO2 emissions are 1.138 billion tons, of which Of this, about 270 million tons comes from coal-fired power generation (Note: this number is from the actual figures for 2018). Source: https://www.env.go.jp/earth/ccs/3-3_Storage_200805_1.pdf

[261] https://www.meti.go.jp/committee/kenkyukai/sangi/ccs_jissho/pdf/001_05_00.pdf, p.17 ; https://www.env.go.jp/earth/ccs/3-3_Storage_200805_1.pdf, p.4.

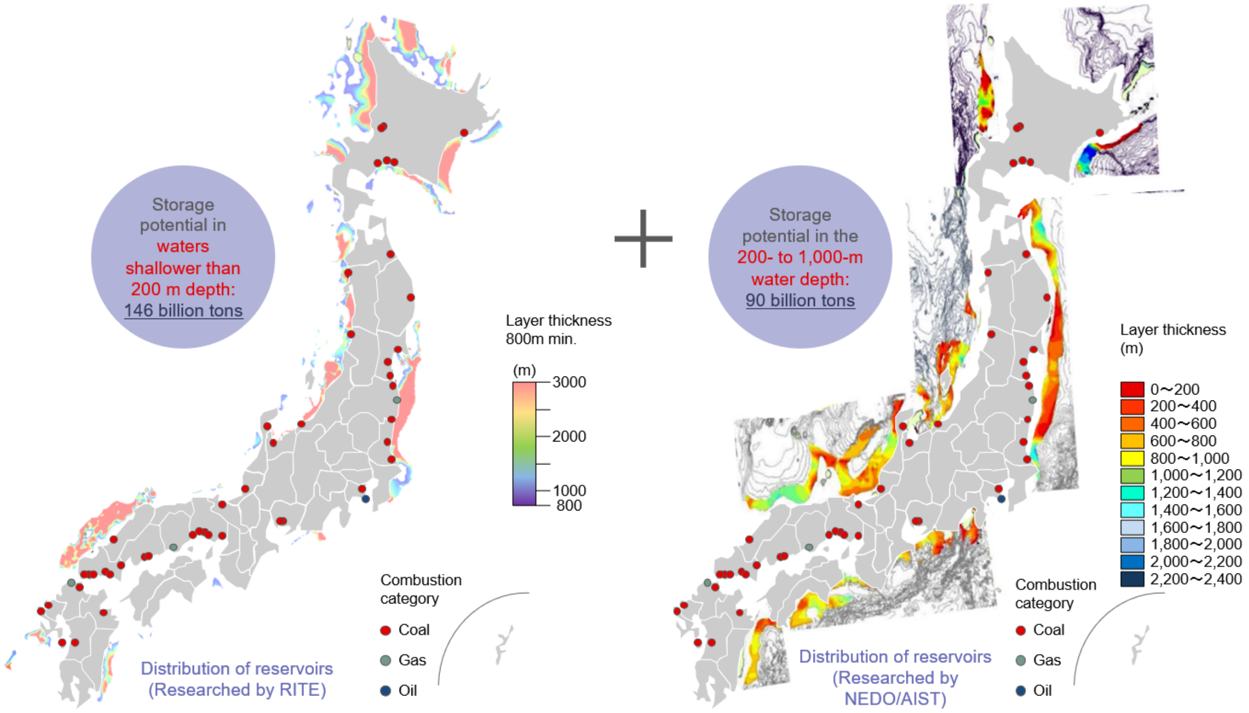


Figure 47. Distribution of CO_2 reservoirs in Japan.

Source: Ministry of the Environment, Japan[262]

Both domestically (Table 7) and abroad (Table 8), Japan is leading global innovation on CCUS technologies. The country continues to be a driver of international collaboration in terms of clean energy, project finance, capacity development, and technology transfer. In October, the new Prime Minister, Yoshihide Suga, announced his policy for Japan to become carbon neutral by 2050 by scaling up its use of renewables and hydrogen, as well as by accelerating the research and development of key technologies, including CCUS.

Expanding CCUS capabilities can reinforce the competitiveness of Japan's industrial sector in a world of rising carbon prices, border carbon adjustments, and premiums for low-carbon products. Moreover, it can spur growth in fields that have significant long-term potential—such as the development of "blue" hydrogen or direct air capture. However, given that confirmed CCS potential is still unstable and highly costly to develop, Japan's approach to carbon capture relies on the development of CCU technologies and related economic viability.

[262] https://www.env.go.jp/earth/ccs/3-3_Storage_200805_1.pdf; p.4

Table 7. Domestic CCUS initiatives in Japan

Project name	Description	Storage potential	Application	Partners
Osaki CoolGen Project	Targets CO_2 separation and capture technology for an integrated coal gasification combined cycle (IGCC) facility. Demonstration testing of oxygen-blown IGCC occurred from 2017-2019. CO_2 capture and separation (100k-150k tons / year) are slated for the late 2020s	0.1-0.15 Mtpa per year	Power generation	Chugoku Electric Power Co Inc., J-POWER
Mikawa Biomass Power Plant	The Mikawa project aims to convert a coal-fired power plant into a bioenergy with carbon capture and storage (BECCS) facility	500 tons per day	Power generation	Toshiba Corporation
Saga City Waste Incineration Plant	Aims to capture 10 tons of CO_2 per day from the flue gas of the Saga Waste Incineration plant to feed a nearby algae cultivation center	10 tons CO_2 per day	Waste - to - energy	Toshiba Corporation

Table 8. International collaboration on CCUS

Project name	Description	Storage potential	Application	Partners
Tomakomai Citty, Hokkaido refinery	With support from NEDO, researchers plan to pilot the production of methanol from captured CO_2 at the Tomakomai Citty, Hokkaido refinary. The CCU facility will be co-located with an existing Tomakomai CCS facility.	20 tons per day	Methanol production	Japan CCS Co. Ltd (JCCS); University of Texas
Gundih Project/ Joint Crediting Mechanism (JCM)	This joint Japanese-Indonesian initiative aims to study the application of Joint Crediting Mechanism (JCM) for a large CCS demonstration project by quantifying GHG emissions reductions.	30 tons per day; 20,000 tons over two years	Natural gas production	Indonesia
Joint Study on the Development of High CO_2 Gas Fields	An international consortium plans to evaluate the potential to produce natural gas fields with high CO_2 using CCS.	N/A	Natural gas production	Japan Oil, Gas and Metals National Corporation (JOGMEC), Petronas (Malaysia), and JX Nippon Oil & Gas Exploration Corporation
Asia CCUS Network	Consortium of public and private institutions organized to share knowledge and best practices for CCUS throughout the Asian region.	N/A	Varied	13 countries (ASEAN countries, Australia, US and Japan) and more than 100 companies, research institutions, and international organizations

Appendix E. Hydrogen

Hydrogen as a CO_2-free alternative fuel

Hydrogen is an energy carrier that can replace fossil fuels in a range of sectors that include long-haul transport, chemicals, steel, and cement. Owing to its wide availability, low emissions, and versatility, it is frequently seen as critical tool to reduce emissions in hard-to-abate sectors.

Most hydrogen, however, is itself produced from fossil fuels, and accounts for 6% of natural gas and 2% of coal consumption globally[263]. Globally, hydrogen production generates 830 Mt of CO_2 annually. To unlock it's potential as a clean energy resource, hydrogen must be produced using either renewable energy (green hydrogen) or fossil fuels with CCUS/nuclear power (blue hydrogen).

The development status of hydrogen fuel

Many regions and countries, including the EU and its member states such as Germany and the Netherlands, as well as Australia, have formulated national strategies for hydrogen, and efforts are in full swing to develop hydrogen capabilities. Countries are using hydrogen both in commercial vehicles and in industrial sectors where decarbonization is difficult, introducing hydrogen power generation and building out hydrogen supply chains.[264] (Table 9).

Table 9. Select hydrogen initiatives around the globe

EU	The EU announced its hydrogen strategy in July 2020, aiming for 40 GW of electrolytic hydrogen production capacity by 2030. In the interim, the EU will utilize low-carbon hydrogen (fossil + CCUS), and work toward hydrogen production, transportation/storage, and utilization. The EU has also launched the Clean Hydrogen Alliance, a public-private partnership, and plan to build a hydrogen supply chain using existing gas pipelines[265].
Germany	Germany developed a national hydrogen strategy in June 2020 and set domestic renewable-energy, hydrogen-production capacity targets (5GW by 2030, 10GW by 2040). Hydrogen production facilities using water electrolysis are exempt from the renewable-energy levy. Germany is also planning to start a supply chain demonstration project for medium-to-long term/ large scale hydrogen importation. An estimated €7 billion has been provided for the creation of a domestic market for hydrogen technology, and an additional €2 billion earmarked for the establishment of international partnerships. [266]
France	France revised its hydrogen strategy in September 2020 and set targets to install 6.5 GW of electrolyzers and produce of 600,000 tons of green hydrogen per year by 2030. Electricity used for green-hydrogen production is assumed to come from renewable energy and nuclear power, and the hydrogen is planned to be used not only to decarbonize the industry, but to develop large trucks.[267]
US	In the US, there is no unified national hydrogen strategy. However, zero-emission vehicles (ZEV) regulations have led to the introduction of over 8,000 fuel-cell vehicles, mainly in California. ZEV regulations will extend to commercial vehicles by 2024. As part of the Port of Los Angeles's initiative to achieve zero emissions, the use of hydrogen in the heavy-duty transportation sector is being evaluated.[268] As for power generation, Utah is planning a large-scale hydrogen project, aiming for 30% hydrogen co-firing by 2025 and 100% dedicated operation by 2045.

[263] https://www.iea.org/fuels-and-technologies/hydrogen

[264] https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/025_01_00.pdf

[265] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/025_01_00.pdf

[266] https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6; https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/025_01_00.pdf

[267] https://www.bdi.fr/wp-content/uploads/2020/03/PressKitProvisionalDraft-National-strategy-for-the-development-of-decarbonised-and-renewable-hydrogen-in-France.pdf; https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/025_01_00.pdf.

[268] Ibid

Challenges in implementing hydrogen as an alternative fuel

To realize a future hydrogen economy, further innovation and development are needed to address challenges across the value chain, including production, storage, and transportation.

- Production. In most scenarios, fuel costs are the single greatest expense in hydrogen production, and using fossil fuels currently holds a price advantage. For example, hydrogen produced with unabated natural gas is on the order of \$1.5–\$3/kgH_2, natural gas + CCS \$1–\$2/kgH_2, and hydrogen produced using renewable energy \$2.5–\$6/kgH_2.[269] The cost breakdown varies widely from one country to the next, and is heavily influenced by the local cost of electricity, natural gas, and coal.[270] In general, making green hydrogen one of the most expensive options.[271]
- Storage. Owing to its low energy density, hydrogen is difficult to transport and store. It is therefore often converted to liquid fuels such as synthetic methane, synthetic methanol, or ammonia. The selection of hydrogen carriers is an important issue because each carrier comes with its own set of constraints (e.g. toxicity, flammability, energy conversion cost, etc.). Hydrogen storage is an active area of research, and hydrogen carriers will likely be curated for specific applications in the future—depending on chemical characteristics and on the availability of existing infrastructure. Further support will be needed to overcome technological issues while maintaining optionality.[272]
- Transportation. Establishing sufficient infrastructure for the distribution of hydrogen as a fuel takes significant time and investment. In addition to hydrogenation and dehydrogenation costs, both international and domestic transportation costs must be taken into account.[273] Overall, infrastructure and cost will differ among carriers.

Japan's plan for hydrogen procurement

Japan is currently pioneering the renewable hydrogen economy in Southeast Asia. It is the first country in the region to adopt a basic hydrogen strategy to ensure that production will reach cost parity with gasoline fuel and power generation in the long term. The government as well as businesses are making efforts to kick-start hydrogen adoption and usage. Scaling up will be critical, however, in order to bring down the costs of technologies both for producing and using clean hydrogen—such as electrolysers, fuel cells, and hydrogen production with CCUS. Japan is targeting an emissions-free supply of hydrogen by 2040.[274]

---

[269] The Future of Hydrogen (windows.net)

[270] https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

[271] Ibid.

[272] https://www.meti.go.jp/shingikai/energy_environment/cid/pdf/002_03_00.pdf

[273] Ibid.

[274] https://www.cas.go.jp/jp/seisaku/saisei_energy/pdf/hydrogen_basic_strategy.pdf

Two major collaborations aim to build out the global supply chain:

International Collaborations	
	**Australia** Hydrogen Energy Supply Chain (HESC) The HESC project is on schedule to complete construction of a coal gasification and gas refining facility in Victoria, Australia. In Japan, the Kobe liquid hydrogen storage and unloading terminal is completed.[275]
	**Saudia Arabia** Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD) In April 2020, AHEAD launched the operation of the world's first international hydrogen supply chain. This endeavor involves producing hydrogen from natural gas and converting it into methylcyclohexane (MCH). The MCH is then shipped to Japan where it undergoes dehydrogenation to release the hydrogen. In May 2020, regenerated hydrogen from MCH was supplied to a gas turbine in the Mizue Thermal Power Plant for power generation. In September 2020, the world's first shipment of 40 tons of carbon-free ammonia—blue ammonia made using hydrogen produced from fossil fuels with CCS—left Saudi Arabia for Japan.[276]

Meanwhile, Japan is planning to develop 300,000 tons of hydrogen domestically in order to help meet projected demand after 2040 (~10 million tons). Scaling up production and transportation will lead to reducing the cost of hydrogen use from ~100 yen/NM³ to 30 yen/NM³ by 2030, and to 20 yen/NM³ by 2050.[277] (Figure 49).

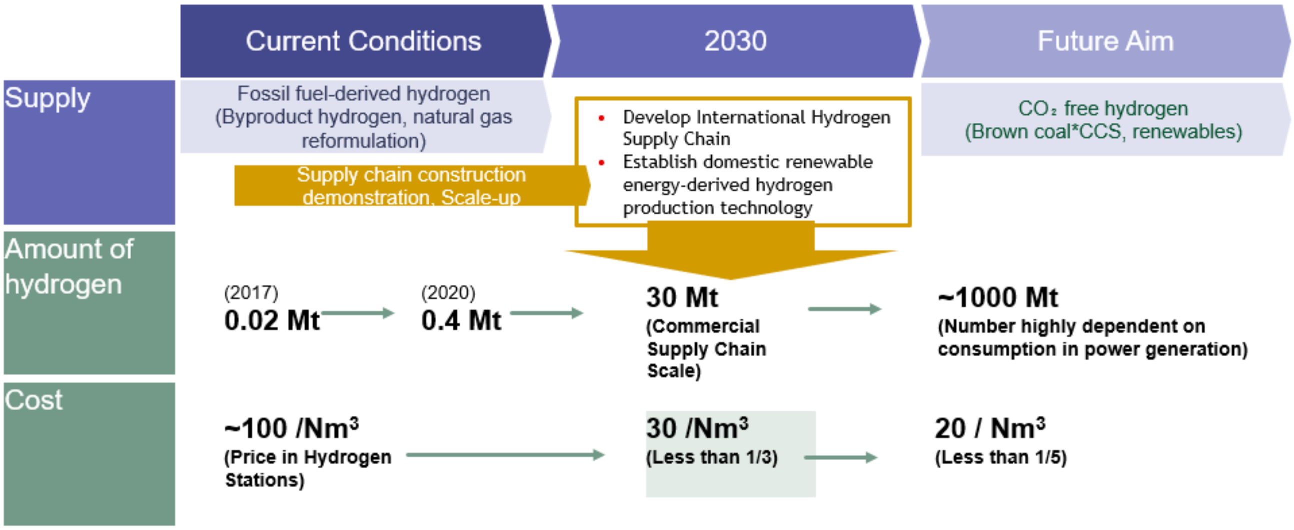


Figure 48. Japan's plan for domestic hydrogen supply.

Source: METI.[278]

---

[275] Home - HESC (hydrogenenergysupplychain.com)

[276] Global-Status-of-CCS-Report-2020_FINAL.pdf (globalccsinstitute.com)

[277] https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/events/PDF/shiryou06.pdf

[278] Ibid.

Appendix F. Ammonia

Ammonia as a CO_2 free alternative fuel

Ammonia (NH_3) is a carbon-free energy carrier that can be used for energy storage, transportation, and power generation. [279] It has high energy density, and does not emit CO_2 when burned. Moreover, ammonia is widely available and can be distributed using existing infrastructure, providing an attractive alternative to hydrogen.

Since current ammonia production accounts for about 2% of total energy consumption globally[280], virtually all of it from fossil fuels (resulting in high CO_2 emission), Japan is moving to produce ammonia both from renewable energy (green ammonia) and from fossil fuels with CCUS technologies (blue ammonia).

Establishment of ammonia as an alternative fuel

The Japanese government is pursuing ammonia for three basic reasons: (1) The country needs to maintain its electricity supply, which is currently reliant on coal-fired power plants; (2) Japan is committed to quickly reducing CO_2 emissions from coal, which is one of the highest sources of emission; and (3) Ammonia provides a viable option for Japan in terms of technological maturity, cost, and establishment of a supply chain.

Japanese companies aim to recover CAPEX expenses on relatively recent coal plants and maintain electricity prices at reasonable rates for consumers—all while reducing emissions.

Hydrogen, often viewed as an alternative fuel for thermal power generation, cannot be co-fired with coal in existing coal power plants, and would require new facilities. Furthermore, current cost estimates put hydrogen imports at 162 yen/Nm^3 compared to ammonia production at 4.3 yen/Nm^3—resulting in 97.3 yen/kWh to fire hydrogen compared to 23.5 yen/kWh of ammonia. Given ammonia's mature value chain, it also requires less time and investment to develop a stable supply compared to hydrogen, even if it must be sourced from overseas. [281]

Japan aims to build a supply chain for blue and green ammonia predominantly through imports from Saudi Arabia, the United Arab Emirates, Australia, and other countries.[282] The extent to which blue and green ammonia can be secured is currently unclear, but the Japanese government and utilities are working to ensure a sufficient and stable supply of the more cost-competitive fuel, as technologies mature.

Presently, the plan is to eventually produce green ammonia domestically, using electrolytic synthesis from water and nitrogen. In order to reduce cost, Japan has set two near-term targets:

1) Develop and demonstrate a new catalyst for ammonia production that can lower operating costs (excluding labor) by 15% or more.
2) Develop and demonstrate green ammonia electrolytic synthesis technology capable of producing 90% or more of the maximum production volume after one year of continuous operation.[283]

---

[279] https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/001_03_00.pdf

[280] https://www.iea.org/news/new-iea-study-examines-the-future-of-the-ammonia-industry-amid-efforts-to-reach-net-zero-emissions

[281] Ibid.; https://www.meti.go.jp/shingikai/sankoshin/green_innovation/energy_structure/pdf/003_04_00.pdf

[282] https://www.meti.go.jp/shingikai/sankoshin/green_innovation/energy_structure/pdf/003_04_00.pdf

[283] Ibid.

Given ammonia's versatility, the development of clean ammonia supply chains can serve multiple industries and applications outside of power generation.

Challenges in implementing ammonia combustion technologies

Combustion technologies and innovation

There are two main routes for combusting ammonia: co-firing in ultrasupercritical (USC[284]) facilities, or using IGCC/IGCF[285] technologies. Notably, the technical requirements to co-fire coal with 20% ammonia are distinct from co-firing with higher concentrations of ammonia or even burning ammonia exclusively. As a result, the technologies and equipment are being development separately.

To co-fire ammonia in an USC facility, a short breeze boiler is added to the existing coal-powered facility. In this process, liquid ammonia is mixed with pulverized coal prior to combustion. Scientists have successfully achieved 20% co-firing with low NO_x emissions. Further, experiments are underway at higher concentrations (60% co-firing), with an aim of clarifying the burner nozzle shape that can achieve NO_x emissions on a par with current coal-power generation. The cost is relatively low and the timeframe for development is relatively short.

An alternative method is to use gas turbines such as IGCC/IGFC. Currently, gas turbine technologies are mature, but further research is needed to modify these facilities for ammonia combustion.[286] Scientists have successfully demonstrated co-firing capabilities up to 70% liquid ammonia spray in a typical 2 MW-class gas turbine. Unburned NH_3 and N_2O at the turbine outlet can also be reduced to low concentrations, with NOx emissions suppressed to less than 15 ppm by the de-nitration system.[287]

Technologies to reduce NO_x emissions

Incomplete combustion of ammonia can generate NO_x, a class of air pollutant containing nitrogen and oxygen such as NO, NO_2, etc. Technology to control NO_x emissions during ammonia combustion is currently under development.

For a 20% ammonia co-firing rate, JERA has developed a burner that produces NO_x emissions in line with existing coal power plans. However, there is a need to improve this technology for higher concentrations of ammonia. In addition, Japan plans to establish an international standard that defines appropriate NO_x emissions for ammonia combustion. [288]

---

284 A method of generating electricity using only steam turbines. Current mainstay of coal power generation.

285 A method of generating electricity by gasifying coal and then burning it. IGFC combines a gas turbine and a steam turbine that uses waste heat from the gas turbine to generate electricity, resulting in high efficiency. https://www.enecho.meti.go.jp/about/special/johoteikyo/hikouritu_sekitankaryoku.html

286 https://www.meti.go.jp/shingikai/sankoshin/green_innovation/energy_structure/pdf/003_04_00.pdf

287 https://www.nedo.go.jp/content/100932835.pdf

288 https://www.meti.go.jp/shingikai/sankoshin/green_innovation/energy_structure/pdf/003_04_00.pdf

Disclaimer

The Boston Consulting Group ("BCG") provided MUFG with market research, data and analysis that MUFG used in preparation of this report. The report's recommendations do not necessarily represent BCG's views. BCG used data from various sources and assumptions provided to BCG from other sources. BCG has not independently verified the data and assumptions from these sources. Changes in the underlying data or operating assumptions will clearly impact the analyses and conclusions. BCG will not be liable for any loss, damage, cost, or expense incurred or arising by reason of any person using or relying on information in this report.