Carbon Neutrality in China, Japan and Korea

Current status and implications towards future trilateral cooperation

STEPI SCIENCE AND TECHNOLOGY POLICY INSTITUTE

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Publication Date October 31st, 2022
Publisher Mi Ock Mun
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Abbreviations

ALCA	Advanced Low Carbon Technology Research and Development Program
BASIC	Brazil, South Africa, India, China
BRAIN	Bio-oriented technology Research Advancement INstitution
CAO	Cabinet Office
CCER	China Certified Emission Reduction
CCS	Carbon Capture and Storage
CCUS	Carbon dioxide Capture, Utilization and Storage
CDR	Carbon Dioxide Removal
CN	Carbon Neutrality
CPC	Communist Party of China
CPCN	Carbon Peak and Carbon Neutrality
CSTI	Council for Science, Technology and Innovation
ERCA	Environmental Restoration and Conservation Agency
GDP	Gross Domestic Product
JSPS	Japan Society for the Promotion of Science
JST	Japan Science and Technology Agency
MAFF	Ministry of Agriculture, Forestry and Fisheries of Japan
METI	Ministry of Economy, Trade and Industry
MEXT	Ministry of Education, Culture, Sports, Science and Education
MHLW	Ministry of Health, Labour and Welfare
MIC	Ministry of Internal Affairs and Communications
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MOE	Ministry of the Environment
MOD	Ministry of Defence

Abbreviations

NARO	National Agriculture and Food Research Organization
NDCs	Nationally Determined Contributions
NEDO	New Energy and Industrial Technology Development Organization
NEV	New Energy Vehicle
STI	Science Technology and Innovation
PARMs	Provinces, Autonomous Regions, and Municipalities
R&D	Research and Development
UNFCCC	United Nations Framework Convention on Climate Change

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I Introduction

In the midst of the global COVID-19 pandemic, all three North-East Asian countries, People's Republic of China (hereafter China), Japan, and the Republic of Korea (hereafter Korea), pledged a commitment to net-zero carbon emissions by the mid-century. Among three countries, China, the world's largest greenhouse gas (GHG) emission country, was surprisingly the first promising to be carbon neutral until 2060 at the world leaders' meeting of the United Nations General Assembly in September 2020. Then, Japan and Korea followed China by making their pledges to carbon neutrality by 2050 in October 2022. Their pledge to carbon neutrality has significant influence on the global efforts to tackle climate change. China, Japan, and Korea combined consist of 20.5% of the world's population as of 2020, 25.2% of the world's GDP as of 2020, and 31.5% of the world's GHG emissions as of 2019 (World Bank, 2022)[1].

East Asian countries share several commonalities (or constraints) in achieving carbon neutrality. As shown in Table 1-1, they are ranked 1th, 5th, and 7th in the world in terms of the amount of GHG emissions. As of 2020, all three countries have more than 20% in terms of manufacturing value added as % of GDP with the strong presence of domestic heavy industry (c.f. EU 15%, US 10%). They are required to not only transform their current carbon intensive energy system to new low-carbon system but also decarbonize their industries. Moreover, Japan and Korea reached their GHG emission peaking only recently in 2013 and 2018, being late compared to other advanced countries due to their late industrialization. And China has not even reached its peaking, being expected to reach by 2030 according to their net-zero scenario. In this regard, all three countries may be able to attain their pledge to carbon neutrality only through drastic measures within a relatively short period, which emphasizes the importance of the role of science and technology in the carbon neutrality of three East Asian countries.

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[1] World Bank Databank homepage (https://data.worldbank.org), accessed 12/10/2022
*Author of Chapter I and V: Dong Un Park

[Table 1-1] Selected indicators of climate change in China, Japan, and Korea

Indicators	People's Republic of Chia	Japan	Republic of Korea
GHG emissions (million ton-CO_2 eq., 2019)	10,661.7	1,071.0	593.7
GHG emissions per capita (ton-CO_2 eq., 2019)	7.6	8.5	11.8
Ranking of GHG emissions	1th	5th	7th
Manufacturing value added (% of GDP, 2021)	27%	20%	25%
GHG emissions peaking year	2030 (expected)	2013	2018
Date of proclamation of carbon neutrality	22nd September 2020	26th October 2020	28th October 2020
Target year of carbon neutrality	2060	2050	2050

Source: https://kosis.kr/, https://data.worldbank.org/, accessed 14/07/2022, 12/10/2022

Therefore, this working paper attempts to present an overview of the policy and strategies on carbon neutrality of three East Asian countries, China, Japan, and Korea, and identify key issues and barriers in the respective country. Then, it aims to provide policy implications to facilitate mitigation actions through international collaboration among these countries.

The structure of this report is following. After the introduction, Chapter II, III, and IV provide an overview of national policies and corresponding R&D strategies on carbon neutrality in China, Japan, and Korea respectively. Each country chapter delves into major barriers and critical issues to achieve the strategy and scenarios of carbon neutrality in each country and then, deep-dives into key technologies, key strategic programs, and early success examples from the recent R&D programs. Drawing on the overview of national policies and R&D strategies in each country, this working paper constructs a matrix with type of mechanism (multilateral or bilateral/trilateral) and type of cooperation (policy or project) and discusses the potential mechanism of international collaboration among three East Asian countries based on the current international institutions and programs. It concludes by briefly discussing further research topics.

II People's Republic of China

II People's Republic of China

1. Policy Reviews and Issues of Carbon Neutrality[2]

As a responsible country, China is committed to building a global climate governance system that is fair, rational, cooperative and beneficial to all, and makes its due contribution to tackling climate change using its greatest strengths and most effective solutions. Confronted by the challenges of climate change, China is willing to work together with the international community to ensure the Paris Agreement delivers steady and lasting results, and make greater contribution to the global response.

At the general debate of the 75th Session of the United Nations General Assembly on September 22, 2020, President Xi Jinping announced that China would scale up its NDCs by adopting more vigorous policies and measures, strive to peak CO_2 emissions before 2030, and achieve carbon neutrality before 2060. China is taking pragmatic actions towards these goals.

After Xi Jinping put forward the goal of carbon peaking and carbon neutrality, he quickly made major strategic deployments, and various departments and fields have issued important documents to actively build a "1 + N" policy system of carbon peak and carbon neutrality (CPCN), which has initially formed a good situation in which the whole society mobilizes together.

1.1 Review on Carbon Neutrality policy and scenarios (energy mix)

1.1.1 Policy history

Why China is pledging for carbon neutrality by 2060? Some experts argue that: 1). To present the image of a responsible major country, adhering to the principle of common but differentiated responsibilities, and fulfill the principle of respective capabilities to tackle global climate change; and 2). And take the goal of carbon neutrality as a strategic starting

[2] Author: Xunmin Ou (Tsinghua University)

point to promote a greener and lower carbon transformation of the domestic economic system in China.

Climate change is a serious challenge for all of humanity. As a developing country with a population of 1.4 billion, China is facing multiple challenges such as developing its economy, improving people's livelihood and protecting the environment. China is also one of the countries most affected by climate change. China attaches great importance to addressing climate change. President Xi Jinping has stressed many times that responding to climate change is not what others want us to do, but what we ourselves want to do, which is an inherent need for China's sustainable development and a responsibility to promote the construction of a community with a shared future for mankind.

To achieve the goals of peaking carbon emissions and subsequent carbon neutrality is one of China's major strategies, defined after careful consideration. This is a must-do in order to relieve the serious constraints imposed by resources and the environment on China's economic growth, and to achieve sustainable development. It is also a solemn commitment towards building a global community of shared future. China has incorporated this decision into its overall economic and social development, adopting a holistic approach and balancing the relationships between economic growth and emissions reduction, between overall and regional interests, and between short, medium, and long-term growth. Led by the green economic and social transition, China is focusing on green and low-carbon development of the energy sector, and accelerating the formation of industrial structures, production modes, ways of work and life and spatial configurations that help to conserve resources and protect the environment. It is fully committed to high-quality development that prioritize eco-environmental protection and green and low-carbon way of life.

In a speech at the UN General Assembly on September 22, 2020, President Xi Jinping announced that China would peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. China has issued a series of documents on the carbon peaking and neutrality goals, which have become hot issues in society.

China is continuing to update NDC targets. In 2015, China set its nationally determined action objectives by 2030: to peak carbon dioxide emissions around 2030 at the latest and make every effort to peak early. By the end of 2019, China had delivered on its 2020 climate action target ahead of schedule. In 2020, China announced new NDC targets and measures. China aims to:

- Peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060.

- Lower its carbon intensity by over 65 percent by 2030 from the 2005 level.
- Increase the share of non-fossil fuels in primary energy consumption to around 25 percent by 2030.
- Increase the forest stock volume by 6 billion cubic meters by 2030 from the 2005 level.
- Bring its total installed capacity of wind and solar power to over 1.2 billion kW by 2030.

Compared with the objectives set in 2015, the new targets are more ambitious in timeframe. They involve a steeper cut in carbon intensity, an increase of another five percentage points in the share of non-fossil fuels in primary energy consumption, a new target for installed capacity of non-fossil fuels, an additional forest stock of 1.5 billion cubic meters, and a clear announcement to aim for carbon neutrality before 2060. China has announced in 2021 a decision to stop building new coal-fired power projects overseas, demonstrating its concrete actions in response to climate change.

The carbon neutrality (CN) goal is feasible. From the expert's view, China has a good tradition of fulfilling its promises, and is willing to make painstaking efforts to fulfill its promises. China has strong and centralized leadership institutions, long-term stable strategies and policies and a rapidly rising public awareness of low carbon.

1.1.2 Impact outlook

The carbon neutrality target will have a profound impact, affecting economic development models, energy systems, social consumption concepts and even public lifestyle habits.

CN goal will have a profound impact, affecting economic development mode, energy systems, social consumption concepts and even public living habits. There are some potential impacts on the world for to fulfil this pledge.

1) Driving global climate action in practice, not just commitment;

2) Accelerating the rapid development of carbon-neutral related technologies such as energy efficient, renewable energy, energy storage, hydrogen energy and CDR around the world; and

3) Promote the low-carbon development of the global energy system, industrial chain and economic pattern.

China is improving and adjusting the energy mix. The energy sector is a major source of GHG emissions. China has continuously intensified its efforts in energy conservation and emissions

reduction and accelerated energy mix readjustment to build a clean, low-carbon, safe, and efficient energy system. To achieve this, it has:

- Defined a new strategy for energy security that promotes a green revolution in energy consumption, supply, technology, and systems, strengthens international cooperation in an all-round way, prioritizes the development of non-fossil fuels, promotes the green development of hydropower, makes comprehensive and coordinated progress in wind and solar power development, pursues the orderly development of nuclear power under the precondition of guaranteed safety, develops biomass energy, geothermal energy, and marine energy based on local conditions, comprehensively increasing the rate of renewable energy use.
- Driven the supply-side structural reform of coal by cutting overcapacity in coal, strengthening safe, intelligent, green, and efficient exploitation and clean and efficient use of coal, promoting clean, efficient, and high-quality development of coal-fired power industries, reducing the consumption of coal and replacing it with other fuels, taking comprehensive measures to manage the use of coal in non-industrial sectors, and promoting the substitution of coal and petroleum by electricity as end-use energy.
- Expanded reform of the energy system, promoting efficient allocation of energy and resources.

The carbon neutrality target will have a significant impact on China's energy mix. China is strengthening the dual control of energy consumption intensity and total amount, and promoting a significant improvement in energy efficiency. China will strictly control fossil energy consumption, vigorously develop non-fossil energy, non-fossil energy accounted for about 25% of energy consumption, wind power, solar power total installed capacity of more than 1.2 billion kilowatts by 2030. A clean, low-carbon, safe and efficient energy system will be fully established, the energy utilization efficiency will reach the international advanced level, and the proportion of non-fossil energy consumption will reach more than 80% by 2060.

Relevant studies have shown that China's energy structure needs to accelerate its transformation under the CPCN target. Taking the research results of Wei Yiming's team as an example (see Table 2-1), the proportion of non-fossil energy in China's primary energy structure should be significantly increased, reaching 21% in 2025, and more than 25% in 2030, and the proportion of non-fossil energy in primary energy consumption by 2060 will exceed 80%. The proportion of coal in primary energy has steadily declined, but in a long period of time, China will still be a coal-based energy pattern, with coal accounting for about 44% in 2030, and coal will still play an important role in ensuring energy security in 2060. The share of oil in primary energy by 2025 was stable and rising, and then began to decline gradually, with an average annual decline rate of about 3% between 2025 and 2060. The proportion of natural gas shows a trend of first growing and then declining, and the proportion of natural gas consumption will reach about 12% in 2035 and remain until 2050, after which with the

maturity of renewable energy technology and energy storage technology and the high proportion of application, the proportion of natural gas consumption will fall back to about 7%.

[Table 2-1] Primary Energy Mix Outlook（in the scenario of medium GDP growth and high speed transition）

	2020	2025	2030	2035	2040	2045	2050	2055	2060
Coal	57%	50%	45%	41%	36%	30%	25%	15%	8%
Oil	19%	19%	18%	17%	15%	14%	12%	10%	5%
NG	9%	10%	11%	12%	12%	12%	12%	11%	7%
Non-fossil	16%	21%	26%	30%	37%	43%	50%	64%	80%

Source: Ref. Wei et al. (2022)

1.2 Policy governance and institutional arrangement for implementation

In order to do a good job in CPCN, China has formulated and issued relevant policy documents to build a "1 + N" policy system for carbon peaking and carbon neutrality, providing strong support for achieving carbon peaking and carbon neutrality goals on schedule; China has established corresponding governance mechanisms at the national and PARMs levels to promote the overall deployment and coordinated promotion of carbon neutrality work.

1.2.1 Policy governance

China is accelerating work on 1+N policies for peaking carbon emissions and achieving carbon neutrality. The country has formulated and released a top-level design document for peaking carbon emissions and achieving carbon neutrality, and is working on an action plan for peaking carbon emissions before 2030, with implementation plans for fields and sectors such as energy, industry, urban and rural construction, transport, and agriculture and rural areas. Support plans are being created in areas such as science and technology, fiscal funding, finance, pricing, carbon sinks, energy transition and coordination of pollution reduction and carbon emission reduction, with clearer timetables, roadmaps, and working plans. The country is shaping policies and actions with clear objectives, reasonable assignment of labor, effective measures, and sound coordination, ensuring that all efforts deliver positive results.

1.2.2 Institutional arrangement

In recent years, the State Council of China has twice adjusted and improved the members of the National Leading Group for Combating Climate Change and Energy Conservation and Emission Reduction, with Premier Li Keqiang of the State Council as the leader. Each PARM has set up a provincial-level leading group for climate change and energy conservation and emission reduction, as a cross-departmental comprehensive deliberative coordination body for local efforts to deal with climate change and energy conservation and emission reduction. In May 2021, the Leading Group for Carbon Neutrality work was established, with Vice Premier Han Zheng of the State Council as the team leader, and the office was located in the National Development and Reform Commission to further strengthen the overall deployment and coordination of carbon peaking and carbon neutrality work. All PARMs have successively set up carbon peaking and carbon neutrality work leading groups to strengthen the overall planning of local carbon peaking and carbon neutrality work. At the same time, supporting institutions such as the National Climate Change Expert Committee continue to play an advisory role.

China is actively exploring new, low-carbon models of development. China has actively explored low-carbon models of development. It has encouraged local governments, industries, and enterprises to explore low-carbon paths to development based on their individual conditions, and launched pilots and demonstrations on green and low-carbon development in fields such as energy, industry, construction, and transport, thus shaping a basic comprehensive and multi-tiered system for low-carbon piloting. It has launched low-carbon pilots in 10 provincial-level units and 77 cities, and explored low-carbon models of development and institutional innovations in respects including organizational leadership, support policies, market mechanisms, statistical systems, evaluation and assessment, coordination and demonstration, and cooperation and exchanges. The carbon intensity of these pilot areas has fallen faster than the national average, and a number of low-carbon models of development with distinctive features have emerged.

1.3 Major barriers and important issues

There are some main challenges to fulfil this pledge, including the following aspects:

1) An economic system focused on achieving long-term low-carbon development could lead to a slowdown in economic growth rates in the near and medium term;
2) Coal phase-down and oil use control in the energy system will impact the economic and social system, and whether the problems of asset stranded and employment transfer can be handled in place;
3) Whether the import pressure of low-carbon energy sources such as natural gas and the development rate of renewable energy can meet high expectations; and
4) Whether the rapid R&D of hydrogen, energy storage and CDR technologies required for low-carbon development can meet high expectations, whether the huge cumulative capital investment demand of over 100 trillion $ can be met, and whether the cost of carbon reduction can be rapidly reduced in several decades.

However, the revolutionary changes in the energy system will also face a number of challenges, in the short term: the traditional fossil energy industry has suffered a huge impact, the non-technical cost of renewable energy has risen rapidly, the economy of zero-carbon technology is insufficient, the resistance to the reform of the whole social system is large, and the energy security problem is more complex.

1.3.1 The time period from peak to neutralization is extremely short

It will not be easy for China to achieve its new NDC targets including the goal of CN; it will take approximately 30 years of painstaking effort to transit from peak carbon emissions to achieving carbon neutrality and the largest reduction in carbon dioxide emissions per unit of GDP (“carbon intensity”) in the world.

China is still a developing country, facing multiple challenges such as developing the economy, improving people's livelihood, and controlling pollution, and it is facing greater difficulties and challenges than some developed countries in achieving a comprehensive green and low-carbon transformation in a relatively short period of time. Walking the talk, China has already begun to implement positive and effective moves in its strategy to peak carbon emissions and achieve carbon neutrality.

1.3.2 The task of transforming the energy system is arduous

Forcing the energy system to accelerate the low-carbon transition is the core support for ensuring carbon neutrality by 2060. About 90% of China's emissions come from the energy system, and the core to achieve carbon neutrality is to force energy acceleration from the whole chain of supply, conversion and demand, build a clean, low-carbon, safe and efficient modern energy system, and decouple economic growth from fossil energy consumption. Some experts argue that China's fossil energy consumption should reach the peak as soon as possible, in addition to coal to reach the peak immediately, strive to reach the peak of oil before 2030, natural gas before 2040, and the proportion of non-fossil energy in primary energy consumption will increase to 70% in 2050.

China is a country rich in coal, poor in oil and gas, and is in a critical period of changing the mode of development, optimizing the economic structure, and transforming the driving force of growth; the process of industrialization and urbanization continues to advance, energy demand will still grow, the coal-based energy structure will be difficult to fundamentally change in the short term, and the adjustment of the energy structure requires a process.

1.3.3 Traditional energy systems will be severely impacted

The rapid transformation of China's energy system will have a serious impact on the traditional energy system. To achieve the 2060 carbon neutrality target, the proportion of fossil energy needs to drop by an average annual of 1.6 percentage points in the next 40 years, which is about 2 times the average annual decline in the proportion of fossil energy during the "13th Five-Year (2016-2020) Plan" period, which is very difficult. The fossil energy system has been highly integrated into all aspects of the production and life of the national economy, from upstream exploration and development, midstream storage and transportation to downstream consumption, as well as the layout of import and export trade networks and overseas assets, involving tens of trillions of assets, millions of employees employment, military diplomacy, and international energy cooperation. Changing the trajectory of fossil energy development in a short period of time, in a centralized manner, and on a large scale has a huge impact on China's economy and society, and it is necessary to make overall arrangements and systematic planning at the national level.

1.3.4 The large-scale development of renewable energy is facing the problem of increasing non-technical costs

The large-scale development of renewable energy is facing the problem of increasing non-technical costs. At present, the installed capacity of intermittent renewable energy sources such as wind and solar power is relatively large (accounting for 20.3%), but the proportion of grid-connected power generation is relatively small (less than 10%)。Under the carbon neutrality target, the proportion of renewable energy generation such as wind and solar power will rise rapidly, and it is expected to reach about 80% by 2060. The increase in the proportion of intermittent power supply makes the difficulty of stable operation and adjustability of the power system significantly increase, and the contradiction between the stability and the satisfaction of user needs will be highlighted, and it is necessary to be equipped with flexible adjustment of the power supply, but this will significantly increase the operating cost or non-technical cost of the power system. In addition, the rapid expansion of the installed capacity of renewable energy will increase the occupied area of land, oceans and other areas, and the negative impact on the ecosystem will also be highlighted.

1.3.5 Carbon-neutral related core technologies require long-term development

Key low-carbon zero-carbon technologies do not have large-scale layout conditions in the near and medium terms in China.

It is much more difficult to achieve China's carbon neutrality goal than that of developed countries judging from the existing technology reserves and the trend of deep decarbonization technology. While keeping up with the trend of world technological development, China needs to overcome many challenges such as intellectual property rights and capital needs, improve its independent innovation capabilities, tackle core technologies, and strive to grasp the future international climate discourse.

The following three areas of work need to be carried out by China:

1) Identify the needs of difficult emission reduction sectors and deep decarbonization technologies under the carbon neutrality target.
   Organize research to identify the main difficulties and obstacles to China's carbon neutrality goals, and the difficult sectors and areas of emission reduction, and then give an important basis for the reserve and deployment of deep decarbonization technologies.
2) Carry out the exploration, research and promotion of key technologies for deep decarbonization in different fields.

Combined with the characteristics of China's energy endowment and social and economic development, the research and development and promotion of deep decarbonization technology are carried out in different fields.

3) Form a guarantee mechanism for the development of deep decarbonization technology.
Deploy special scientific and technological plans in the field of medium- and long-term response to climate change, increase capital investment dedicated to the research and development of deep decarbonization technologies, and organize forces to actively promote the development and application of new technologies.

1.3.6 Production and lifestyles are facing systemic changes

Production lifestyles require systemic change. Achieving carbon neutrality not only depends on profound changes in the energy system, but also needs to change from the "energy end-user", such as economic structure, production mode, consumption habits, etc., so as to reduce the intensity of energy demand and create conditions for the large-scale application of renewable energy power generation as the main body of electricity. However, at present, the continuous and rapid decline in energy intensity faces two challenges: Firstly, the marginal effect of energy conservation brought about by industrial restructuring is getting narrower and narrower, and the future needs to rely more on technological progress and innovation to lead, which is more difficult; Secondly, with the increase in the proportion of energy consumption on the consumption side, energy conservation needs to cover a wider range of fields, which involves hundreds of millions of consumers, which is related to the transfer of consumer behavior preferences, which is very difficult. It is so necessary to build a low-carbon circular green economic system as soon as possible, shape a lifestyle that saves energy and energy, and cultivate a new trend of green and low-carbon consumption.

1.3.7 The management system requires revolutionary change

The management system and mechanism need to be revolutionized. For a long time, China's energy has mainly been based on guaranteed supply, and the management model has shown the characteristics of fragmentation and fragmentation. In the new journey of achieving the goal of carbon neutrality, the boundaries between energy production and consumption will be increasingly blurred, and the centralized supply of energy will gradually shift to centralized + decentralized complementarity, which requires strengthening management innovation on the demand side, guiding and promoting energy conservation throughout society, and fundamentally realizing the integration of energy production and consumption. In particular, the reform of the power system has become the key, mainly the issue of how to divide the

responsibility for power safety and supply, that is, how to divide the responsibility between the power supply and the power grid, between different power sources, and between the power grid and the consumer. In addition, consumers are also required to respond to scheduling arrangements, which are in conflict with long-term user energy habits.

1.4 Approach to policy measures

1.4.1 Strengthen detailed management

China is improving overall planning and coordination in response to climate change. The response to climate change covers a wide range of areas; therefore, to improve coordination and pool strengths, China has set up a national leading group headed by Premier of the State Council and with officials from 30 ministries and commissions as members. Its remit is responding to climate change, conserving energy, and reducing emissions, and all provinces, autonomous regions, and municipalities (PARMs) directly under the central government have set up corresponding groups. In April 2018, China adjusted the functions of relevant government departments, and put the newly established Ministry of Ecology and Environment in charge of responding to climate change, thus reinforcing the coordination between responding to climate change and protecting the eco-environment. In 2021, China set up a special leading group to guide and coordinate the work related to peaking carbon emissions and achieving carbon neutrality. All PARMs have established leading groups for peaking carbon emissions and achieving carbon neutrality, so as to strengthen the coordination of their efforts.

China is incorporating the response to climate change into national economic and social development plans. Starting from the 12th Five-year Plan period (2011-2015), China has incorporated reducing carbon intensity into the outline of the plans for national economic and social development as binding targets, and defined key tasks, priority areas, and major projects. China's Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 sets a binding target of slashing carbon intensity by 18 percent from 2020 to 2025. All PARMs have taken on the response to climate change as an important part of the 14th Five-year Plan, and set themselves specific targets and tasks.

China is establishing a mechanism of breaking down and meeting the targets for responding to climate change. To meet its targets, China has set tiered provincial-level carbon emission caps for its PARMs based on factors such as their development stage, resource endowment,

strategic positioning, and eco-environmental protection. It has assessed the performance of the relevant governments in meeting the targets and fulfilling the responsibilities for controlling GHG emissions, and uses the results as an important reference for the comprehensive performance assessment and appraisal of officials holding principal posts and leadership teams in the PARMs, as well as for the appointment, reward, sanction, and removal of officials. PARM governments have also assessed the performance of administrative divisions at lower levels in meeting their targets and fulfilling their responsibilities for controlling GHG emissions, thus ensuring that the effort is coordinated and effective.

1.4.2 Implement the ETS system

The carbon market provides an effective approach to managing the relationship between economic development and carbon emissions reduction. China is pushing ETS as a tool for carbon emissions reduction. he national carbon emissions trading market (national carbon market) is a major institutional innovation that uses market mechanisms to control and reduce GHG emissions and promote green and low-carbon development. It is also an important policy tool for China to reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060.

China is carrying out pilot programs on carbon emissions trading. The carbon market institutions motivate companies to commit to curbing their emissions and use market-based instruments to price carbon reasonably, thus better allocating carbon emission resources. Starting from October 2011, seven provinces and municipalities – Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin – were selected to pilot projects for carbon emissions trading. Since 2013, seven local-level pilot carbon markets have been launched, covering nearly 3,000 key emissions companies in more than 20 industries, including power, steel, and cement. As of September 30, 2021, the total trading volume of the seven pilot carbon markets had reached 495 million tons of carbon dioxide equivalent, representing a value of approximately RMB12 billion. Major emitters in the pilot carbon markets have maintained a relatively high level of compliance rate, with both volume and intensity of carbon emissions within the market coverage maintaining a downward trend. This has given a significant boost to enterprises' contribution to emissions reduction, and raised the awareness of low-carbon development in all sectors of society. The local-level pilot projects have accumulated valuable experience for the launch of the national carbon market in terms of providing institutional references and training personnel.

China is building a national carbon market system. Systems are key in advancing carbon market development. To better regulate the carbon market, the Chinese government promulgated the National Carbon Emissions Trading Market Construction Plan (Power Generation Industry), Measures for the Administration of Carbon Emissions Trading (for Trial Implementation), and a quota allocation plan for the national carbon market in the first compliance period. In 2021, with the release of guidelines for accounting and reporting corporate GHG emissions and three sets of management rules for carbon emission rights regarding registration, trading, and settlement, a basic national carbon market system was established. The legislative process has moved forward on the Interim Rules on the Administration of Carbon Emissions Trading, which consolidated the legal basis for carbon emissions trading, and ensured standardized operation and management in the key links of the national carbon market.

China has launched the national carbon market. On July 16, 2021, the national carbon market started online trading. A total of 2,162 power generation companies were involved, representing 4.5 billion tonnes of carbon dioxide emissions, making this the world's largest emissions trading system. The launch attracted great attention and positive comments in China and elsewhere. As of September 30, 2021, the total trading volume in the market had reached 17.65 million tonnes, with turnover of RMB801 million. In general, the operation of the market has been stable and orderly.

China has established a GHG voluntary emission reduction program. The China Greenhouse Gas Voluntary Emission Reduction Program was established in 2012. Its goals are to encourage the whole of society to participate in emissions reduction activities, ensure that the transaction entities fulfill their social responsibilities, pursue a low-carbon development path, and promote a low-carbon industrial structure and low-carbon energy consumption. As of September 30, 2021, the total trading volume of GHG voluntary emission reduction had exceeded 334 million tonnes of carbon dioxide equivalent, with turnover approaching RMB3 billion. China Certified Emission Reduction (CCER) has been introduced to pilot markets in offsetting carbon emissions, or writing off emissions occurred for public welfare purposes, effectively optimizing China's national energy mix and its compensation mechanism for eco-environmental conservation.

1.5 International co-operations

China will honor its promises and continue to support multilateralism, however the global situation changes. It will work with other parties to achieve the full, balanced, effective and sustained implementation of the United Nations Framework Convention on Climate Change and the Paris Agreement, to fulfill its NDC goals, to control GHG emissions, and to increase its ability to adapt to climate change. It will redouble its efforts to promote a global community of shared future, and make a greater contribution to a better home planet for all humanity.

1.5.1 Participate in the construction of a fair and reasonable global climate governance system with win-win cooperation

China calls on the international community to take immediate action, strengthen solidarity and cooperation, and remain committed to multilateralism, and build a fair and rational global climate governance system for win-win results.

China has been an active and constructive participant in international climate talks. It is committed to the principles of equity, common but differentiated responsibilities, and respective capabilities, and maintains that negotiations should be open, transparent, inclusive, party-driven and consensus-based. It played a leading role in and pressed ahead with the conclusion of key documents including the Paris Agreement. China initiated the establishment of multilateral negotiation mechanisms such as the BASIC Ministerial Meeting on Climate Change and the Ministerial on Climate Action. It actively coordinates the positions of countries within climate negotiation blocs such as the BASIC countries, the Like-Minded Developing Countries, and the Group of 77 and China, playing an important role in maintaining the unity of developing countries and defending their common interests. China actively participates in climate negotiations through the Group of 20, the International Civil Aviation Organization, the International Maritime Organization, the BRICS meetings and so forth, promoting the synergy of multiple channels and multilateral processes.

China will continue to actively participate in global climate governance. Multilateralism and the principle of common but differentiated responsibilities will be upheld in the fundamental position of global climate governance. As the world's largest developing country, China firmly supports addressing climate change based on multilateralism, adheres to the core and main channels of the UNFCCC, its Kyoto Protocol and the Paris Agreement, and is committed to promoting the construction of a fair, reasonable, and win-win global climate governance system on the basis of common but differentiated principles of responsibility, fairness and

respective capabilities. China will Adhere to the full and effective implementation of the UNFCCC and its Paris Agreement. On the basis of the principles of common but differentiated responsibilities, fairness and respective capabilities, China will solidly implement China's Nationally Determined Contribution and work with all parties to promote mitigation and adaptation actions.

1.5.2 Deepen South-South cooperation on climate change

China has actively carried out South-South cooperation with the vast number of developing countries in addressing climate change.

China provides assistance and support within its means to other developing countries to tackle climate change. China engages in South-South cooperation on climate change with other developing countries. It has done its best to help those countries – in particular small island states, the least developed countries, and African countries – to build capacity to fight climate change and reduce the adverse impact of climate change. This cooperation has yielded real, tangible and solid results. Since 2011, China has allocated about RMB1.2 billion for South-South climate cooperation and signed 40 cooperation documents with 35 countries. It has helped countries to build low-carbon demonstration zones and provided them with climate-related supplies such as meteorological satellites, PV power generation and lighting equipment, NEVs, environmental monitoring devices, and clean cookstoves. It has trained about 2,000 officials and professionals in the field of climate change for nearly 120 developing countries.

On September 21, 2021, President Xi Jinping announced at the general debate of the 76th Session of the United Nations General Assembly that China will vigorously support the green and low-carbon development of energy in developing countries and will no longer build new offshore coal power projects.

1.5.3 Strengthen international cooperation in science, technology and industry in addressing climate change

China is strengthening international cooperation in science, technology and industry in addressing climate change. China will promote technological breakthroughs in renewable energy, hydrogen energy, smart grid and energy storage, carbon capture utilization and storage (CCUS), circular economy, low-carbon transportation and smart cities, climate change impacts and risk assessment to support the green and low-carbon transition. China advocates that all countries adhere to multilateralism, strengthen technological and industrial

cooperation, establish international cooperation platforms, cooperation centers and cooperation networks for advanced technology research and development and technology transfer, jointly carry out breakthrough technology research, promote the mature application of advanced technologies, and carry out the international promotion of applicable technologies.

1.6 Summary

China's CPCN goals are major strategies, and also highlight China's image as a responsible major country. China's CPCN target strategy will have a significant impact on China's domestic and foreign affairs. China is accelerating the construction of a CPCN "1+N" policy system and establishing a mechanism for implementing targets that are broken down to local levels.

In the process of implementing the dual carbon target, a series of challenges will be encountered, such as macroeconomic impacts, energy supply security risks, and weak technical support.

China has actively intensified its efforts to control emissions and played the role of the ETS market mechanism to promote the process of low-carbon development.

China, Japan, the ROK and other countries need to cooperate in the full implementation of the Paris Agreement and adhere to win-win cooperation; It is also possible to cooperate in the construction of regional ETS system, low-carbon technology development and industrialization application.

2. Net-Zero R&D strategies[3]

2.1 R&D Management

Climate change is a common challenge for all mankind. Coping with climate change is related to the sustainable development of the Chinese nation and the future and destiny of mankind. China attaches great importance to addressing climate change. As the largest developing country in the world, China has overcome its own economic and social difficulties, implemented a series of strategies, measures and actions to address climate change, participated in global climate governance, and achieved positive results.

As a responsible country, China actively promotes the joint construction of a fair, reasonable, cooperative and win-win global climate governance system, and contributes China′s wisdom and strength to tackling climate change. Facing the severe challenge of climate change, China is willing to work together with the international community to promote steady and long-term progress of the Paris Agreement and make greater contributions to the global effort on addressing climate change.

Carbon peaking and carbon neutrality will bring about a technological revolution which will cause a major change in the economic and social environment. Technology will be the key to realizing carbon peaking and carbon neutrality, and achieving economic and social development. In this process, it is necessary to give full play to the supporting and leading role of scientific and technological innovation, improve the system and mechanism of scientific and technological innovation, strengthen innovation capabilities, and accelerate the green and low-carbon scientific and technological revolution.

2.1.1 Improve the innovation system and mechanism

China formulated The Action Plan for S&T-based Carbon Neutrality (2022-2030) to support carbon peaking and carbon neutrality with science and technology, launched S&T projects under the National Key R&D Program, such as the study and demonstration of key technologies for carbon peaking and carbon neutrality, and adopted mechanisms, such as the open competition mechanism, to select the best candidates to develop key and core technologies for low-carbon, zero-carbon, and negative-carbon development. Colleges and universities, research institutions and state-owned enterprises incorporated innovation

[3] Author: Chao Wang (Chinese Academy of Science and Technology for Development, CASTED)

achievements of green and low-carbon technologies into their performance assessments. China strengthened the dominant position of enterprises in green technology innovation, improved the guiding mechanism for green technology innovation, supported enterprises to undertake major national green and low-carbon S&T projects. A national green technology trading center was built to accelerate the transformation of innovation achievements. In addition, China strengthened the protection of intellectual property rights of green and low-carbon technologies and products, and improved testing, evaluation and certification systems of such technologies and products.

2.1.2 Increase R&D investment

The Special Plan on Science and Technology Innovation of Climate Change during the 13th Five-Year Plan Period was released in 2017 to comprehensively deploy science and technology works on climate change. The National Key R&D Program has become the main channel for S&T investment on climate change. From 2016 to 2018, 11 projects in priority areas, including "Global Changes and Responses" "Clean and Efficient Coal Utilization and New Energy-saving Technology", as well as 2 National Major S&T Projects, namely "Development of Large Oil and Gas Field and Coalbed Methane" and "Large Advanced Pressurized Water Reactor Nuclear Power Plant" have been carried out to support the realization of carbon peaking and carbon neutrality. The R&D results provided important support to deal with climate change. Since 2018, the Chinese Academy of Sciences (CAS) has deployed strategic S&T pilot projects such as "Key Technologies and Demonstrations of Transformative Clean Energy" "Earth Big Data S&T Project" "Pan-Third Pole Environmental Change and Green Silk Road Construction" and "S&T Project for Beautiful China Ecological Civilization Construction".

2.1.3 Strengthening innovation capacity building and talent training

China established national key laboratories and national technology innovation centers on carbon peaking and carbon neutrality, and moderately deploy in advance some major national S&T infrastructure, and guide enterprises, colleges and universities and research institutions to jointly build a number of national green and low-carbon industry innovation centers. China innovated the talent training model, encouraged colleges and universities to speed up the construction of disciplines and personnel trainings in new energy, energy storage, hydrogen energy, carbon emission reduction, carbon sink, carbon emission trading, and built a number of future technical colleges, modern industrial colleges and exemplary energy academies in green and low-carbon technology. China deepened the integration of industry and education,

encouraged schools and enterprises to jointly carry out industry-academia cooperation and collaborative education projects, formed an industry-education development alliance, and built a number of industry-education-integrated national innovation platforms for energy storage technology.

2.1.4 Strengthen applied research and basic research

China implemented a number of forward-looking and strategic National Major Cuttingedge S&T Programs, and promoted breakthroughs in the R&D of low-carbon, zero-carbon and negative-carbon equipment. It focused on green and intelligent development and clean and low-carbon utilization of fossil energy, large-scale utilization of renewable energy, new power systems, energy conservation, hydrogen energy, energy storage, power batteries, as well as capture, utilization and storage of carbon dioxide, and deepened applied and basic research. China actively developed advanced nuclear power technologies, and strengthened research on cutting-edge disruptive technologies such as controllable nuclear fusion. It also strengthened basic theoretical and methodological research on the causes and impacts of climate change and carbon sinks of ecosystem.

2.1.5 Accelerate the R&D, promotion and application of advanced and applicable technologies

China concentrated on technological innovations such as safe and stable operation and control of complex and large power grids, large-capacity wind power, high-efficiency photovoltaics, high-power LNG engines, large-capacity energy storage, low-cost renewable energy hydrogen production, and low-cost carbon dioxide capture, utilization and storage, etc. While at the same time, it accelerated the R&D of basic materials such as carbon fiber, aerogel, and special steel, and made up for shortcomings in key components, components and software. It also promoted advanced and mature green and low-carbon technologies and carried out demonstrative applications. In 2016, China released the second batch of Transformation and Promotion List of Energy Conservation, Emission Reduction and Low-Carbon Technology Achievements, and in 2017 released the Promotion Catalog of National Key Energy-Saving and Low-Carbon Technology" to speed up the transformation, application and promotion of achievements with good demonstration performance and great potential on emission reduction. It guided enterprises to adopt advanced and applicable energy-saving and low-carbon technologies. These have provided an important reference for upgrading low-carbon transformation of related industries.

2.2 Key Strategic Programs

In order to realize S&T-supported carbon neutrality, the Ministry of Science and Technology, the National Natural Science Foundation of China, the Chinese Academy of Sciences have successively issued special research projects in the field of carbon neutrality to comprehensively promote basic theoretical research and key technology R&D.

2.2.1 Ministry of Science and Technology (MoST)

In 2022, the Ministry of Science and Technology (MoST) helped promote the National Key R&D Program: Research and Demonstration of Key Technologies for Carbon Peaking and Carbon Neutrality. According to the program, it is expected that by the end of the14th Five-Year Plan, China will make key breakthroughs in R&D in key technologies, and will complement key special projects in other fields to provide important technical support for carbon peaking by 2030 and to provide technical reserves for carbon neutrality by 2060, giving technical contributions and system solutions for global climate governance.

″Research and Demonstration of Key Technologies for Carbon Peaking and Carbon Neutrality″ is based on the complexity and urgency of carbon peaking and carbon neutrality and highlights the comprehensive cross-field major S&T innovations. It focuses on the R&D of four key areas, including the research and demonstration of common supporting technologies for carbon neutrality; technology and demonstration of low-carbon/zero-carbon reengineering of industrial process; frontier and disruptive technology innovation and R&D for carbon neutrality; and innovation system for carbon neutrality and technology for global climate governance.

In addition, MoST has deployed special R&D projects such on new energy vehicles, energy storage and smart grid, and hydrogen energy technology during the 14th Five-Year Plan period, focusing on the key areas of carbon peaking and carbon neutrality, to promote R&D and commercial application of key technologies in key areas.

2.2.2 National Natural Science Foundation of China (NSFC)

In order to meet the needs for basic scientific research in implementing the carbon neutrality strategy, and give full play to the basic, scientific and forward-looking advantages of the National Natural Science Foundation of China, NFSF launched in 2021 a special program named ″Major Basic Scientific Issues and Countermeasures for National Carbon Neutrality″.

Focusing on “reduction” and “accumulation increase” – the two fundamental paths to achieve the national carbon neutrality strategy, the program aims to systematically reveal the ocean and terrestrial carbon sink patterns, process mechanisms, evolution trends and their interaction with the climate system. It aims to clarify the mechanism of geological carbon sequestration process, carbon sequestration efficiency, sink increase potential, technical risks and management models, and to analyze management and policy problems in carbon neutrality process, such as economic transformation, path optimization, climate governance, and international cooperation. Through interdisciplinary research, they aim to condense key basic scientific problems, propose solutions, and serve the national carbon neutrality strategy.

2.2.3 Chinese Academy of Sciences (CAS)

Based on the strategic goals of carbon peaking and carbon neutrality, the Chinese Academy of Sciences (CAS) innovated the system and mechanism, coordinated resources and advantages, clarified the division of tasks, organized a multidisciplinary strategic research team, and systematically carried out research on key issues in the field. In March 2022, CAS officially released the “Action Plan for Supporting Carbon Peaking and Carbon Neutrality Strategy by S&T”. The Plan focuses on solving key and core S&T problems, promotes the construction of a green, low-carbon and cyclical economic system and a clean, low-carbon, safe and efficient energy system. At the same time, it promotes the energy revolution and industrial optimization and upgrading, and accelerates the green and low-carbon technological revolution. It supports China to participate in and lead global climate governance, and provides strong S&T support for the country to achieve the strategic goal of carbon peaking and carbon neutrality. The Plan systematically lays out eight major actions: S&T strategic research, basic frontier cross-field innovation, key and core technology breakthrough, comprehensive demonstration of new technologies, talent support and cultivation, international cooperation support, innovation system capability improvement, and science popularization. Facing the major S&T needs of the carbon peaking and carbon neutrality strategy, the Plan regards S&T innovation as the core task, and deploys a whole chain layout in the fields of energy and carbon sinks, from basic research, key and core technology breakthroughs to comprehensive demonstration. It also focuses on the tasks of S&T innovation, and guarantees an all-round support in the construction of talent teams, international cooperation, platform condition building, and science popularization and dissemination.

2.3 Applications of Key Technologies

Energy is an important material basis for economic and social development and the most important source of carbon emissions. The R&D of key technologies in the energy field and the development of the clean energy industry are important guarantees for China to achieve the strategic goal of carbon peaking and carbon neutrality. The world today is undergoing profound changes unseen in a century. A new round of S&T revolution and industrial transformation has formed a historic intersection with the requirements for high-quality economic development. The hydrogen energy development and utilization technology represented by fuel cells has made major breakthroughs, providing important solutions for the realization of zero-emission energy utilization. We should firmly grasp the trends and opportunities of global energy revolution and development, accelerate the cultivation and development of the hydrogen energy industry, and speed up the clean and low-carbon transition of the energy industry in China.

Hydrogen energy is a kind of secondary energy which is abundant, green and low carbon, and is widely applied. It is gradually becoming one of the important carriers of global energy transformation and development. Major developed countries in the world highly valued the development of the hydrogen energy industry, and hydrogen energy has become an important strategic choice for accelerating energy transformation and upgrading, and cultivating new economic growth points. The key and core technologies of the global hydrogen energy industry chain are maturing. Fuel cell shipments are growing rapidly with continuous declining costs. The construction of hydrogen energy infrastructure has accelerated significantly, and a regional hydrogen energy supply network is being formed. China is the largest hydrogen producer in the world, with an annual hydrogen production output of about 33 million tons. The installed capacity of renewable energy ranks first in the world, and it has a great potential for clean and low carbon hydrogen energy supply.

2.3.1 Development goals of hydrogen energy industry

By 2025, the demonstration application of hydrogen energy will achieve obvious results. Great progress will be made in clean energy hydrogen production and hydrogen energy storage and transportation technology, and the market competitiveness will be greatly improved. A hydrogen energy supply system based on industrial by-product hydrogen and focuses on utilization of hydrogen produced from renewable energy will be preliminary established.

By 2030, a relatively complete technology innovation system of hydrogen energy, and a production and supply system of clean energy hydrogen will be formed. The industrial layout will be reasonable and orderly, and the renewable energy hydrogen production will be widely used, which will strongly support the realization of the carbon peaking goal.

By 2035, a hydrogen energy industry system will be formed, and a diversified hydrogen energy application ecology covering transportation, energy storage, industry and other fields will be built. The proportion of renewable energy hydrogen production in terminal energy consumption will increase significantly, which plays an important supporting role in the development of green energy transformation.

2.3.2 Diversified demonstration application of hydrogen energy

Transportation

Based on the local hydrogen energy supply capacity, industrial environment and market space, and combined with the development characteristics of the transportation industry, China will focus on promoting the application of hydrogen fuel cells in medium and heavy vehicles, and orderly expand the application space of hydrogen fuel cells and other new energy vehicle markets. A complementary development model of fuel cell electric vehicles and lithium battery pure electric vehicles will be gradually established.

China will actively explore the application of fuel cells in ships, aircraft and other fields, and continuously increase the market size of hydrogen energy applications in the transportation field.

Energy conservation

China will give full play to the advantages of hydrogen energy which is known for its long adjustment period and large energy storage capacity, and carry out demonstrations of hydrogen energy storage in renewable energy consumption, power grid peak regulation and other application scenarios. It will explore and cultivate a new integrated application model of ″wind-solar power generation + hydrogen energy storage″, and gradually form an energy storage system that integrates various energy storage technologies such as pumped storage, electrochemical energy storage, and hydrogen energy storage. China will explore the potential for synergistic optimization of hydrogen energy across energy networks, and promote the interconnection of heterogeneous energy sources such as electricity, heat and fuel.

Electricity Generation

According to the existing energy infrastructure conditions and economic affordability in different places, distributed cogeneration facilities with hydrogen fuel cells will be deployed according to local conditions, and the demonstration of comprehensive utilization of hydrogen energy in communities, parks, mining areas, ports and other areas will be promoted. By building infrastructure projects such as communication base stations, data centers, railway communication stations, power grid substations, etc., China will promote the market application of hydrogen fuel cells in the field of backup power. In the renewable energy base, China will explore the R&D and demonstration of technology for regulating power generation with fuel cells during peak times.

Combined with the electricity demand in remote areas and islands, the demonstration application of fuel cell distributed power generation will be carried out.

Industry

China will continuously improve the economy of hydrogen energy utilization, and expand the space of application of clean and low-carbon hydrogen energy in the chemical industry. It will carry out the R&D and application of hydrogen metallurgy technology using hydrogen as a reducing agent, and explore the application of hydrogen energy as a high-quality heat source in industrial production. China will expand the application scale of hydrogen energy to replace fossil energy in the industrial field, actively guide the transformation of ammonia, methanol, refining, coal-to-gas and other industries from high-carbon processes to low-carbon processes, and promote the green and low-carbon development of high-energy-consuming industries.

2.4 Recent R&D Achievements

After two Five-year Plan periods, China has initially established a "four-in-one" energy S&T innovation system, incorporating R&D of major technologies, R&D of major equipment, major demonstration projects, and technological innovation platforms. It supports the construction of major energy projects and plays an important role in ensuring energy security and promoting industrial transformation and upgrading.

2.4.1 High proportion renewable energy system technology

The rapid development of wind power and photovoltaic technology has strongly supported the output and installed capacity of China's wind turbines and photovoltaic cells, which ranks first in the world. The 10-megawatt offshore wind turbine has been hoisted. The average conversion efficiencies of mass-produced single-polycrystalline cells reached 22.8% and 20.8% respectively. The solar thermal power generation technology has entered the commercial demonstration stage. China masters the electricity transmission technology of 1000 kV AC, ±1100 kV DC and below. A breakthrough has been made in flexible DC transmission technology. The Zhangbei ±500 kV flexible DC power grid demonstration project and the Wudongde demonstration project of ±800 kV UHV multi-terminal hydropower transmission have been put into operation.

[Figure 2-1] Case: A new model of green poverty alleviation in "Photovoltaic Village"

Liangshan, Ganzi and Aba in the western part of Sichuan Province are relatively backward regions in China, but are rich in renewable energy resources such as solar energy. In February 2018, when General Secretary Xi Jinping inspected the hinterland of Daliangshan, he said we should push forward poverty alleviation and let the common people live a good life. Through implementing photovoltaic poverty alleviation projects, Sichuan Province organically combines poverty alleviation with green transformation, and explores new paths for targeted poverty alleviation, improvement of human settlements, increase of farmers' income and construction of new village. By June 2020, 18 centralized photovoltaic poverty alleviation projects with an installed capacity of 450,000 kilowatts have been built, covering more than 20,000 poor households in 17 counties; 70 grid-connected village-level photovoltaic poverty alleviation power stations with an installed capacity of 31,000 kilowatts have been built, covering 20 counties 3553 poor households. The accumulative power generation income was 44.69 million yuan, and 6,187 public welfare jobs were created. Photovoltaic poverty alleviation has driven the poor households to increase their income, transformed employment,

and achieved a win-win situation for poverty alleviation and ecology through preferential on-grid tariffs for power generation, reasonable distribution of income, and innovative operation and maintenance business models. (Image source: China News Service)

2.4.2 Technology for safe supply of oil and gas

Great progress has been made in unconventional oil and gas exploration and development technology. The annual output of shale gas exceeds 20 billion cubic meters, and the "Shenhai No. 1", a 100,000-ton deepwater semi-submersible production and storage platform, has been put into operation. In terms of long-distance oil and gas pipeline technology, major breakthroughs have been made in core equipment and materials such as electric-driven compressor units, fuel-driven compressor units, large ball valves and high-grade pipeline steel.

2.4.3 Nuclear power technology

The main technical and safety performance indicators of "Hualong No. 1" and "Guohe No. 1" million kilowatt-class third-generation nuclear power have reached the expected goals. The commercial demonstration reactor of high temperature gas-cooled reactor with the characteristics of the fourth generation has been put into operation to generate electricity, and the construction of the fast neutron reactor demonstration project has started. Advanced nuclear reactor technologies such as modular small reactors and marine nuclear power platforms are stepping up efforts to tackle key problems and demonstrate them.

2.4.4 Clean and efficient development and utilization technology of fossil energy

Coal development and utilization technology and equipment, including coal caving mining equipment with an annual output of more than 10 million tons of ultra-thick coal seams and dense medium coal preparation technology have achieved large-scale application. The technical level of gas control and disaster prevention and control in coal mines has been significantly improved, and the death rate per million tons has continued to decline. A number of major demonstration projects for deep processing of coal, including Shenhuaningmei′s 4 million tons/year indirect coal liquefaction, were completed and put into operation. 1.35 million kilowatts of ultra-supercritical secondary reheat units arranged in high and low positions have been put into operation, and the 50MW gas turbine has achieved stable operation at full load.

2.4.5 New energy technologies, new models, new formats

Electrochemical energy storage and compressed air energy storage technologies have entered the commercial demonstration stage. The iterative upgrade of hydrogen energy and fuel cell technology has promoted the hydrogen energy industry to move forward from model exploration to multiple demonstrations. Continuous innovation in areas such as intelligent energy infrastructure, energy big data, multi-energy complementarity, energy storage and electric vehicle applications, utilization of smart energy and value-added services are continuously upgrading.

2.5 Summary

Since its pledge to carbon neutrality by 2060, Chinese government has actively implemented its efforts to promote scientific and technological innovations to realize carbon peaking and carbon neutrality by improving the system and mechanism of scientific and technological innovation, strengthening innovation capabilities, and accelerating the green and low-carbon scientific and technological revolution. In this regard, China formulated The Action Plan for S&T-based Carbon Neutrality (2022-2030) in order to improve the innovation system and mechanism. It also increased R&D investment on climate change, supported by the Special Plan on Science and Technology Innovation of Climate Change. This led to the strengthened basic and applied research and talent training to accelerate the application of technologies to tackle climate change.

The key players to deliver national level research activities are the Ministry of Science and Technology (MoST), the National Natural Science Foundation of China (NSFC), the Chinese Academy of Sciences (CAS). They have successively initiated special research projects in the field of carbon neutrality to comprehensively promote basic theoretical research and key technology R&D. One of important key technologies identified includes hydrogen energy, which will be used for transportation, energy conservation, electricity generation, and industry. Some of recent R&D achievements were presented.

As a responsible country, Chinese government will continue its efforts to give full play to the supporting and leading role of scientific and technological innovation so that China can deliver its pledge to carbon neutrality by 2060.

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III | Japan

III Japan

1. Policy Reviews and Issues of Carbon Neutrality[4]

1.1 Background

After the Paris Agreement was adopted at the 21st United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties in December 2015, countries around the world have set voluntary GHG reduction goals (National Determined Contribution, hereafter referred to as NDC) and presented Long-term Low Greenhouse Gas Emission Development Strategies (LEDS) by December 2020.

After Sweden and Norway declared carbon neutrality for the first time in the world in 2017, as of December 2020, a total of 128 countries declared carbon neutrality. In the case of Japan, in October 2020, Prime Minister Yoshihide Suga announced that it would achieve carbon neutrality by 2050, and Prime Minister Fumio Kisida, newly elected in October 2021, will reduce GHG emissions to 46% of the 2013 level by 2030 and achive carbon neutral by 2050 in his speech and pledged a total of $100 billion to support carbon neutrality of developing countries. The Japanese government established a global warming countermeasure plan and a government action plan to reduce GHG emissions in accordance with the Act on the Promotion of Global Warming Countermeasures. The law was amended to explicitly stipulate the transition to a decarbonized society. As part of this, Japan is actively promoting related plans, such as digitizing corporate emission information and making it open data to revitalize carbon-neutral management.[5]

In addition, the Japanese government recently recognized the situation of the climate crisis and strengthened the redesign and response of the economy and society in Japan to overcome it and Recognizing the challenge of achieving carbon neutrality in 2050 as a momentum for a

[4] Author: Chulho Park(Green Technology Center, GTC)

[5] Asia VOA News, Japan “Achieving carbon neutrality by 2050”, 2021.11.3

new growth strategy, we are accelerating investment in the environment sector, introduction of new technologies in the energy industry, and R&D.[6]

Therefore, this study examines Japan's carbon neutral-related policies and governance system in stages, and comprehensively analyzes Japan's mid-to-long-term strategies and scenarios related to carbon neutrality, and identifies major obstacles and major issues for Japan's implementation of carbon neutrality. On the other hand, policy implications and major implications for achieving 2050 carbon neutrality in Korea will be drawn.

1.2 Carbon Neutrality Policy and Governance System

1.2.1 Carbon Neutrality Policy

Japan's carbon-neutral policies include “Green Growth Strategy for 2050 Carbon Neutrality”, “6th Basic Energy Plan”, and “Global Warming Countermeasure Plan”.

Green Growth Strategy for 2050 Carbon Neutrality[7]

Japan's Ministry of Economy, the relevant ministries of Japan jointly announced on December 25, 2020, to achieve 2050 carbon neutrality, "Green Growth Strategy for 2050 Carbon Neutrality” was announced and on June 18, 2021, this strategy was embodied with detailed promotion strategies and an emphasis on benefits for the people's lives.

The goal of this strategy is to pursue sustainable growth and innovation, and to increase the potential for realizing a carbon-neutral society in 2050. This strategy includes in five main contents such as “Green growth strategy based on carbon neutrality in 2050”, “Realization of carbon neutrality in 2050”, “Framework of green growth strategy”, “Main policy means by sector”, “Sectoral action plan (tasks and responses, roadmap)”.

As shown in Table 3-1, this strategy describe, to achieve carbon neutrality in 2050, policies by eight main policy means such as “Budget (Green Innovation Fund)”, “Tax”, “Finance”, “Regulatory reform standardization” , “International cooperation”.

[6] World Legislation Information Center, Greenhouse Gas Reduction Goals and Related Laws of Countries around the World, 2022.04.21

[7] 2050 年カーボンニュートラルに伴うグリーン成長戦略, 経済産業省, 2021.6.18

[Table 3-1] Main policy means and contents of the green growth strategy for 2050 carbon neutrality

Main policy means	Major contents
Budget (Green Innovation Fund)	• Continuous support is provided from technology development to demonstration and commercialization for companies that have agreed to achieve the goal of an important project for realizing carbon neutrality → (NEDO) 2 trillion yen fund raising over 10 years • Essential for realizing a carbon-neutral society and is linked with the implementation plan of the green growth strategy targeting key areas such as capacitors, offshore wind power, next-generation solar cells, hydrogen, and carbon recycling, which are the foundation of industrial competitiveness. • By setting up evaluation standard of "Level of contribution about "CO2 reduction and economic ripple effect etc.", "Necessity of policy support based on technological difficulty and practical application potential", "Potential market growth potential, international competitiveness," etc., and focused support on high-priority projects. • Promoting the participation of "small and medium-sized enterprises (SMEs) and venture companies" in charge of new business creation, etc. • Promoting ambitious innovation by inducing R&D and facility investment for private companies worth 15 trillion yen based on the government's 2 trillion won budget by establishing a system to induce company manager participation
Tax	• Active tax support suitable for achieving the challenging goal of achieving carbon neutrality in 2050 (expected to create about 1.7 trillion yen of private investment over 10 years) • In the case of companies that have continuously increased their test and research expenses despite a decrease in sales of 2% or more compared to pre-COVID-19 to expand innovation creation, which is the basis for the continuous development of the Japanese economy, including the realization of carbon neutrality in 2050, the upper limit of the deduction for the R&D tax increase from 25% to 30% of corporate tax.
Regulatory reform standardization	• Attracting private investment based on government funds • Supporting policies that pursue green, change and innovation • Creating an environment for the smooth issuance of social bonds (bonds issued to finance projects that contribute to solving social problems) • Establishment of Green International Financial Center and active participation in International Accounting Standards (IFRS) Foundation • In the demonstration phase, ① strengthening regulations that create demand for new technologies, ② reorganizing domestic regulations and systems such as alleviating unreasonable regulations that do not assume new technologies, and ③ actively participating in international standardization to facilitate the use of new technologies in the world • Promote mass production and cost reduction by expanding demand and green investment by improving domestic and international institutional environment • The purpose of standardization is to promote standardization for market formation, such as ① market expansion, ② new market formation or differentiation, ③ safety, convenience, and regulations or standards about environmental impact
International cooperation	• Reinforcing the competitiveness of the domestic industry by reducing costs by pioneering overseas markets • Innovative policy alliances with the US and Europe, promoting individual projects including support for third countries, strengthening alliances such as standardization of element technologies, and promoting bilateral and multilateral cooperation in terms of market development • Leading international discussions and collaborations on hydrogen, carbon recycling, and fossil fuel decarbonization

Source: written by the author referring to 2050 年カーボンニュートラルに伴うグリーン成長戦略

In addition, this strategy selects 14 key areas in three industrial sectors: “energy-related industries”, “transportation/manufacturing-related industries”, and “home/office-related industries” for the realization of carbon neutrality. And the goals, detailed strategies, and roadmaps were presented by dividing them into “R&D”, “demonstration stage”, “introduction expansion stage” and “independent commercialization stage” for each key field.

6th Basic Energy Plan[8]

As the need to present a new policy direction has been greatly emphasized in accordance with the strengthening of global decarbonization response and changes in the energy-related domestic and foreign environment, the Japanese government has implemented The draft of the 6th Energy Basic Plan was announced, and the finalized plan was announced on October 22, 2021.

In this plan, In order to achieve carbon neutrality and NDC by 2050, the plan includes the goal of reducing GHG by 46% compared to 2013 in 2030 and 50% by 2050, as well as energy supply and demand forecast in 2030 and "policy direction for achieving carbon neutrality in 2050" was presented.

And, this plan, as shown in Table 3-2, “Basic Policy”, “Response to Demand”, “Renewable Energy”, “Nuclear Power”, “Thermal Power”, “The Reform of Power System”, "Hydrogen/Ammonia”, " Resources/Fuel”, "Focus of the Outlook for Energy Supply and Demand in 2030” etc. Policy directions for 2030 considering carbon neutrality in 2050 were presented.

[8] 第6次エネルギー基本計画が閣議決定されました，経済産業省，2021.10.22

[Table 3-2] The policy direction towards 2030 for 2050

Classification	Policy Direction
Basic Policy	• The basic policy of energy policy is to put safety as a major premise, then put a top priority on stable energy supply, and respond to the realization of S+3E, which promotes environmental compatibility while supplying low-cost energy through improvement of economic efficiency
"Response to Demand	• Pursuing thorough energy conservation in the industrial, commercial, home, and transportation sectors • Review of amendments to the Energy Conservation Act to support the energy transition • Advancement of secondary energy fields such as the use of distributed energy resources
Renewable Energy	• S+3E as the main premise, make renewable energy the main power supply, and introduce renewable energy as the top priority, suppressing the burden on the people and promoting symbiosis with the local community
Nuclear Power	• Under the premise that stability and resolving public concerns are the top priority, the nuclear power plant is restarted when it is recognized that it meets the world's most stringent regulatory standards through the Nuclear Regulatory Commission. And efforts will be to gain the understanding and cooperation of stakeholders, such as local governments, led by the government • ① Safety-first restart, ② Spent fuel measures, ③ Nuclear fuel cycle, ④ Final disposal, ⑤ Coping about various tasks for securing safety and long-term operation, ⑥ Public sympathy, ⑦ Building trust with local governments, ⑧ Promotion of R&D
Thermal Power	• Under the safety as a major premise, Reducing the proportion of thermal power generation in the power supply configuration while securing facility capacity that can respond to a decrease in the temporary and continuous power generation strategy of renewable energy • In the case of coal-fired power plants that do not have measures to reduce emissions through government development assistance, export finance, investment, financial/trade promotion support, etc., the government will stop supporting new exports.
The Reform of Power System	• Establishing a power system for stable supply in terms of decarbonization
Hydrogen/Ammonia	• Accelerate hydrogen supply by utilizing hydrogen as a new resource • Securing the basis for hydrogen production using domestic resources and utilizing cheap overseas hydrogen to provide stable and large quantities of cheap hydrogen and ammonia in the long term • Expanding hydrogen utilization on the demand side (power generation, transportation, industry, household sector)
Resources/ Fuel	• Securing resources and fuels that are constantly needed in the future while proceeding with the smooth implementation of carbon neutrality • We plan to strengthen the fuel supply system so that we can respond to emergencies as well as usual, and to respond to decarbonization
Outlook for Energy Supply and Demand in 2030	• Based on the new reduction target for 2030, we present the composition of the power supply in 2030 to overcome various challenges in promoting thorough energy conservation and expansion of non-fossil energy ([Table I1-3])

Source: written by the author referring to 第6次エネルギー基本計画が閣議決定されました, 経済産業省

[Table 3-3] Japan's 2030 Energy Power Composition

			2019	→	Previous 2030 Power Mix	→	2030 Power Mix (Ambitious Outlook)	
Energy Saving			16.55 million kl	→	50.3 million kl	→	62 million kl	
Final energy consumption (before energy saving)			35 million kl	→	377 million kl	→	35 million kl	
Power configuration (Power generation: 1065 billion kWh → about 934 billion kWh)	**Renewable Energy**		18%	→	22~24%	→	36~38% (Set a target of 38% or higher if the current R&D results in the renewable energy field are utilized and demonstrated)	
		Solar Power	6.7%	→	7.0%	→		14~16%
		Wind Power	0.7%	→	1.7%	→		5%
		Geothermal Power	0.3%	→	1.0~1.1%	→		1%
		Hydro Power	7.8%	→	8.8~9.2%	→		11%
		Biomass	2.6%	→	3.7~4.6%	→		5%
	Hydrogen/ Ammonia		0%	→	0%	→	1%	
	Nuclear Power		6%	→	20~22%	→	20~22%	
	LNG		37%	→	27%	→	20%	
	Coal		32%	→	26%	→	19%	
	Petroleum etc.		7%	→	3%	→	2%	
(+ non-energy based gas and absorption source)								
Greenhouse gas reduction rate			14%	→	26%	→	46% (50% reduction target challenge)	

Source: written by the author referring to 第6次エネルギー基本計画が閣議決定されました, 経済産業省

Global Warming Countermeasure Plan[9]

The Global Warming Countermeasure Plan was approved by the Cabinet on October 22, 2021. This plan is the government's comprehensive plan based on the Global Warming Measure Promotion Act, and the previous plan approved by the Cabinet on May 13, 2016 was revised for the first time in five years. Japan declared "carbon neutrality by 2050" and set a goal of reducing GHG emissions by 46% by fiscal 2030 compared to fiscal 2013, in addition, it announced that it would continue the challenge to achieve above 50%. The global warming

9 地球温暖化対策計画, 閣議決定, 2021.10.22, https://www.env.go.jp/earth/ondanka/keikaku/211022.html, 環境省

countermeasure plan formulated based on these new reduction targets deals with reduction targets and reduction measures and measures for all GHGs, including non-CO_2. And Actions to support the new fiscal year 2030 goals was described and pathways to achieve the new goals was suggested.

Looking at the reduction targets for each sector in Japan, as shown in Table 3-4, compared to 2013, the target was set to reduce carbon dioxide from energy sources by 45% in 2030 and reduce carbon dioxide from non-energy sources by 15%. In the case of methane and nitrous oxide, reduction targets of 11% and 17% compared to 2013 were presented, respectively, and reduction targets of 4 gases including freon were set as reduction targets of 44%.

In the case of GHG sinks, forest sinks will secure an absorption of about 38 million t-CO_2 in 2030, and plan to secure an absorption of about 9.7 million t-CO_2 by promoting measures for carbon sinks in farmland and soil and urban greening. And. by establishing and implementing JCM to secure overseas reductions, such as distributing excellent carbon technology, product services, and infrastructure to developing countries, we aim to reduce and secure absorption of 100 million t-CO_2 by 2030.

[Table 3-4] Japan's Targets and Standards for Each Sector by Greenhouse Gas

(Unit: million t-CO_2)

	2013 Performance	2013 Performance (Compared to 2013)	2030 Goals and Standards* (Compared to 2013)
Greenhouse gas emissions and absorption rate	1,408	1,166** (▲17%)	760 (▲46%***)
Energy source carbon dioxide	1,235	1,029 (▲17%)	677 (▲45%)
Industrial sector	463	384 (▲17%)	289 (▲38%)
Business Others sector	238	193 (▲19%)	116 (▲51%)
Household sector	208	159 (▲23%)	70 (▲66%)
Transport sector	224	206 (▲8%)	146 (▲35%)
Energy conversion sector ****	106	89.3 (▲16%)	56 (▲47%)
Carbon dioxide from non-energy sources	82.3	79.2 (▲4%)	70.0 (▲15%)
Methane (CH_4)	30.0	28.4 (▲5%)	26.7 (▲11%)
Nitrous oxide (N_2O)	21.4	19.8 (▲8%)	17.8 (▲17%)

		2013 Performance	2013 Performance (Compared to 2013)	2030 Goals and Standards* (Compared to 2013)
	4 gases including alternative Freon	39.1	55.4 (+42%)	21.8 (▲44%)
	Hydrofluorocarbons (HFCs)	32.1	49.7 (+55%)	14.5 (▲55%)
	Perfluorocarbons (PFCs)	3.3	3.4 (+4%)	4.2 (+26%)
	Sulfur Hexafluoride (SF_6)	2.1	2.0 (▲4%)	2.7 (+27%)
	Nitrogen trifluoride (NF_3)	1.6	0.26 (▲84%)	0.5 (▲70%)
	Greenhouse gas absorption source	-	▲45.9	▲47.7
	Bilateral Credit System (JCM)	Aiming to reduce and absorb cumulative global emissions of about 100 million tCO_2 by 2030 through public-private partnership, and properly calculate domestic credits to achieve national NDC		

* Total GHG emissions minus the amount absorbed by GHG sinks

** Each sector of energy source carbon dioxide is the value of the standard

*** Continue to challenge for further 50% reduction target

**** Since the statistical error of electricity heat distribution is excluded, the sum of the performance of each sector and the emission of carbon dioxide from energy do not match

Source: 地球温暖化対策計画, 閣議決定, 2021.10.22

In addition, the plan proposed three major global warming countermeasures and policies such as “Measures and measures for GHG emission reduction and absorption”, “Cross-sector countermeasures”, and “Basic measures”.

To summarize the major measures and policies that are positioned in the global warming countermeasure plan, as shown in Table 3-5, there are divided in three major categories such as “renewable energy/energy saving”, “industry/transportation, etc.”, and “cross-sector countermeasures”.

[Table 3-5] Main measures of Japan's global warming plan

Classification	Main Measures
Renewable energy and energy saving	• Set local governments as promotion areas and expand renewable energy suitable for the area (solar power, etc.) • Expansion of mandatory compliance with energy saving standards for houses and buildings
Industry/ transportation, etc.	• Supporting innovation for 2050 • Support for R&D and demonstration to save more than 30% of energy in data centers
cross-sector countermeasures	• Build more than 100 “decarbonization leading areas” by 2030 • Reduction of emissions in developing countries using excellent decarbonization technology, etc.

Source: written by the author referring to 地球温暖化対策計画, 閣議決定, 2021.10.22

In the case of carbon dioxide origined energy, reduction measures and measures for each of the five sectors were presented such as “industry,” “work, etc.,” “home,” “transport,” and “energy conversion.”

1.2.2 Governance System Related to Carbon Neutrality

Japan established the “Global Warming Countermeasures Promotion Headquarters (地球温暖化対策推進本部)” in the Cabinet on December 19, 1997 to comprehensively promote concrete and effective measures for the implementation of the Kyoto Protocol adopted at the 3rd Conference of the Parties to the Convention on Climate Change (COP3).

In 1998, the「Global Warming Measures Promotion Act」was enacted to prepare the basic framework for policies to respond to climate change. The「Global Warming Measure Promotion Act」was amended based on the Kyoto Protocol that came into effect in 2005, and the tasks, organization, and management of the “Global Warming Countermeasures Promotion Headquarters” were specifically stipulated according to the revised contents.

Afterwards, Japan's transition plan to a low-carbon society began to be accelerated by the government through the「Fukuda Vision」announced by Prime Minister Fukuda in June of the same year as「Cool Earth 50」announced by former Prime Minister Abe at the Davos Forum in January 2008. Japan's transition to a low-carbon society led to the transition to a de-carbon society in line with each country's declaration of carbon neutrality. To this end, in September 2020, the Japanese government held “the 1st Central Environment Council Global Environment Subcommittee Medium- to Long-term Climate Change Countermeasures Subcommittee Industrial Structure Council Industrial Technology and Environment Subcommittee Global Environment Subcommittee Global Warming Countermeasures Working Group Joint Meeting”10. Here, future "climate change measures", "energy policies", "initiatives for other climate change measures by the Ministry of Environment" and "initiatives according to changes in the industrial structure" were discussed.

Meanwhile, Prime Minister Yoshihide Suga, at the G20 Summit in November 2020, clarified Japan's goal to achieve zero real GHG emissions by 2050, and reviewed the implementation of carbon neutrality by the central government and local governments, and the “National and Regional Decarbonization Realization Meeting (国・地方脱 炭素実現会議)” was held on December 25th of the same year, chaired by the Cabinet Secretariat for the establishment of phased implementation goals and cooperation between the central and local governments, and

[10] https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/chikyu_kankyo/ondanka_wg/001.html

On June 9, 2021, the “Local Decarbonization Roadmap(地域脱炭素ロードマップ)” closely related to regional initiatives was announced. As a result, decarbonization plans according to local governments are taking shape.

1.3 Mid-to-long-term Strategies and Scenarios Related to Carbon Neutrality

1.3.1 Mid-to-Long-Term Strategies for Carbon Neutrality

In this section, we would like to introduce detailed strategies for each industry in detail based on the aforementioned “Green Growth Strategy for 2050 Carbon Neutrality”. As shown in Table 3-6, Japan’s carbon neutrality-related strategy is divided into three major categories such as “energy-related industries,” “transportation/manufacturing-related industries,” and “home/workplace-related industries", and composed a total of 14 industries.

Table 3-6 summarizes detailed strategies for each technology sector in the industrial sector.

[Table 3-6] Main measures of Japan's global warming plan

Classification	Industry Field	Technology Field	Detailed strategy
Energy-related industries	**Offshore wind power, solar power, geothermal industry (next-generation renewable energy)**	**Offshore wind**	• By creating an attractive domestic market, it invites domestic and foreign investment and builds a competitive and strong supply chain • Creating next-generation industries that lead international competition through international partnerships and development of next-generation technologies that are expected to advance into Asia
		Solar power	• Through the technological development of next-generation solar cells, achieving the transition to the supply stage by 2030, and realize the expansion and marketization of installations in houses and buildings, which are difficult to install with existing solar cells • Re-establishment of related industries and expansion by "introduction of FIP system" or "promoting of aggregation business by using distributed energy sources" etc. • To promote the use of renewable energy in the region and to expand the farming type, etc.
		Geothermal industry	• Aiming for widespread adoption by supplying risk money, promoting local understanding, and reviewing the operation of related laws and regulations • In 2050, entire geothermal power generation system as a package enters overseas markets throught the world's only innovative geothermal power generation technology realization

Classification	Industry Field	Technology Field	Detailed strategy
	Hydrogen and fuel ammonia industry	**Hydrogen**	• Reduce the cost of hydrogen power generation (hydrogen cost: about 20 yen/Nm3 or less) to less than gas-fired power by increasing the amount introduced, and enhance competitiveness compared to fossil fuels by 2050 • The amount introduced is aims to reach a maximum of 3 million tons by 2030 and about 20 million tons by 2050
		Fuel ammonia	• Established co-firing technology early and exported to Southeast Asia • Secure an initiative in the global ammonia supply and use industry by quickly establishing an international supply chain
	Next-generation thermal energy industry		• Facilitate the transition to a comprehensive energy services company • Realize decarbonization by converting fuels through improved methanation efficiency, large-scale demonstration, and innovative technology development
	Nuclear industry		• Progress in the steady, safety-first restart in the country while reducing possible dependence • In cooperation with Japanese companies with high manufacturing capacity, in the development of next-generation nuclear reactors such as SMR (Small Modular Reactor) conducted overseas (USA, UK, Canada, etc.), various nuclear technology innovations will be accelerated
Transportation and manufacturing related industries	**Automotive and battery industry**		• Aiming to be carbon neutral throughout the lifecycle of automobiles by 2050, while at the same time strengthening the competitiveness of the battery industry as a new energy base
	Semiconductor and information communication industry		• Efficiency energy demand through digitalization and promote energy saving and greening of digital devices and information communication
	Ship industry		• Establish a production base by securing technology related to the development of gas fuel vessels such as LNG, hydrogen, and ammonia, which are essential for achieving zero emission • Leading the modification of international standards, strengthening the international competitiveness of Japan's shipbuilding and shipping industries, and promoting carbon neutrality in maritime transport
	Logistics, human resource movement, civil engineering infrastructure industry		• Comprehensively promoting of "Formation of carbon-neutral ports", "Introduction of smart transportation", "Promotion of adoption of bicycle movement", "Promotion of efficiency and low carbonization of transportation networks, bases, and transportation", "Zero emission in infrastructure and urban space, etc.", "Realizing Carbon Neutrality in Construction"
	Food, agriculture and forestry, and fishing industry		• Actively promote measures such as zero emission through accelerated demonstration, reduction of GHG emissions in agriculture and livestock, carbon dioxide absorption and long-term and mass storage

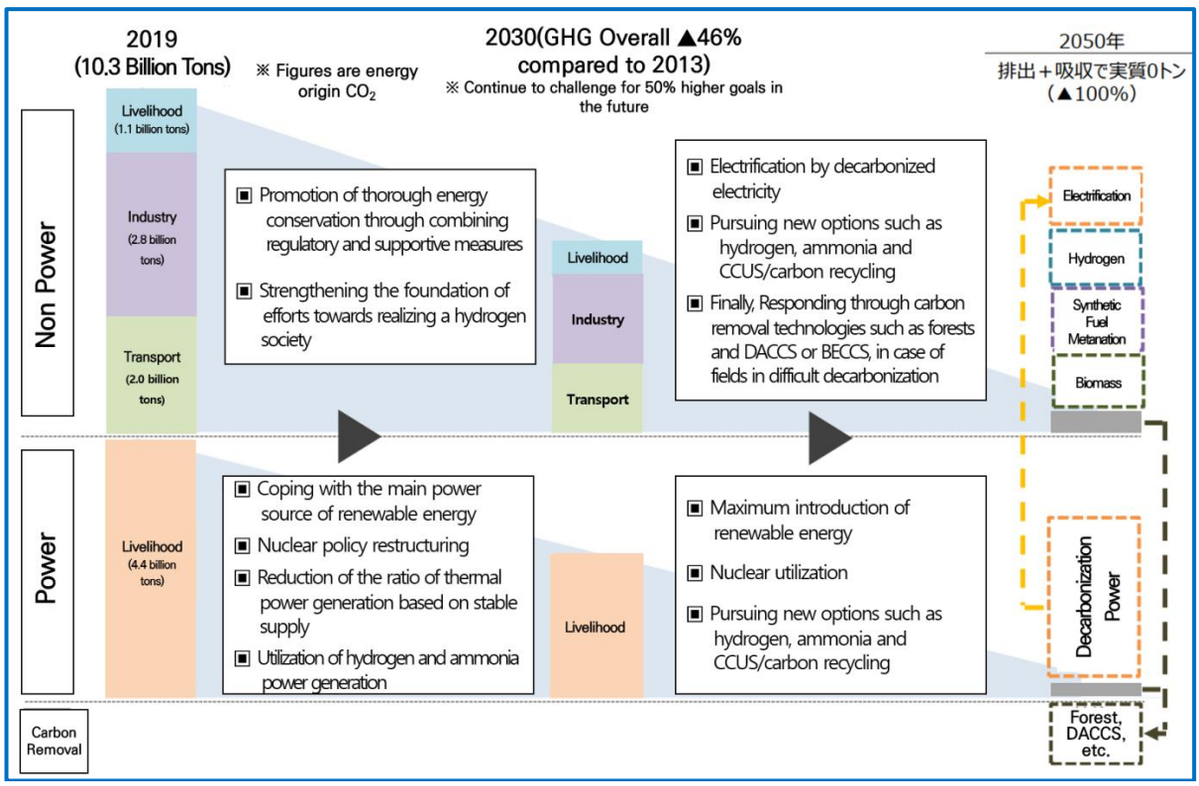
Classification	Industry Field	Technology Field	Detailed strategy
			in farmland, forest, timber, and ocean, and improvement of productivity. Realizing the innovatively balance of productivity improvement and sustainability in the food, agriculture, forestry and fishery industry
	Aircraft industry		• In the midst of rapidly increasing low-carbon demand in international aviation, the International Civil Aviation Organization (ICAO) is institutionalizing not to increase CO_2 emissions compared to 2019. Using these changes in environment and technology as an opportunity to dramatically strengthen the competitiveness of the Japanese aircraft industry, secure technological superiority in various factors such as composites, electrification, hydrogen and alternative fuels.
	Carbon recycling/Material industry	**Carbon recycling**	• Contribution of carbon neutrality through "cost reduction and expansion of supply through large-scale demonstration", "support for large-scale and technological development of synthetic fuel", "cost reduction and supply expansion through establishment of an overseas supply chain", and "development of technology to convert waste plastic, waste rubber or CO_2 into plastic raw materials", etc.
		Material	• By promoting decarbonization and low CO_2 emissions at the manufacturing stage, such as decarbonization of heat sources or changes in the entire manufacturing process, and resource saving and energy saving at the distribution and retail stages, the supply of materials with high environmental performance is expanded and new markets are created
Home/work related industry	**Housing/building industry/next-generation power management industry**	**Housing/building industry**	• As a sector that has a major impact on energy saving in the private sector, it is carbon neutral and creates an environment in which cutting-edge technologies that contribute to economic growth are disseminated in Korea to promote overseas expansion by improving living conditions and carbon neutralization of cities
		next-generation power management	• By consolidating the value of variable and renewable energy and distributed energy resources through the advancement of data utilization technology, we promote aggregation business that is used in digital control and market transactions, and build a next-generation grid
	Resource circulation related Industry		• Support for technology development and demonstration by reorganizing regulations and plans for Reduce, Reuse, Recycle, and Renewable • In the future, based on discussions at the “National and Local Decarbonization Realization Meetings”, etc., technology advancement and efficiency enhancement, facility maintenance, cost reduction, digitalization, etc. will be strengthened in the future.

Classification	Industry Field	Technology Field	Detailed strategy
	Lifestyle related industries		• Based on the “National and Local Decarbonization Realization Meeting”, promotion of “technology development and demonstration”, "support for introduction", and "system construction", etc. related to Crediting of CO_2 reduction by total management and digital technology

Source: written by the author referring to 2050 年カーボンニュートラルに伴うグリーン成長戦略

1.3.2 Scenarios for Carbon Neutrality

Japan will reduce carbon emissions by about 560 million tons in 2030 in non-power and power sectors such as “livelihood”, “industry”, “transport” and “power” compared to 1.03 billion tons in 2019 as shown in Figure 3-1. And Japan is making various efforts under the ambitious goal of reducing to 520 million tons, and further plans to realize carbon neutrality in which the sum of emissions and absorption will be zero by 2050.



Source: 2050 年カーボンニュートラルに伴うグリーン成長戦略

[Figure 3-1] Japan's Carbon Neutral Scenario

In the case of the non-power sector, significantly reduce carbon dioxide emissions by 2030 by reinforcing efforts towards the realization of a hydrogen society and thorough energy conservation efforts in the “livelihood”, “industry” and “transportation” sectors. And In 2050,

we plan to achieve the carbon neutral goal by applying new technologies such as decarbonization electrification, hydrogen, ammonia, and CCUS/carbon recycling, and introducing carbon removal technologies such as forestry, DACCS and BECCS. In the case of existing fossil fuels, carbon-neutral support is planned by utilizing carbon removal technologies such as forest absorption and DACCS.

In the electricity sector, in the “livelihood” section, by 2030, deal with the main power source of renewable energy, reorganize the nuclear power policy, reduce the rate of thermal power generation, and significantly reduce carbon dioxide emissions by using hydrogen and ammonia power generation, and by 2050, it plans to achieve non-carbon power supply by applying new technologies such as expansion of new and renewable energy, use of nuclear power, hydrogen, ammonia, and CCUS/carbon recycling.

1.4 Major Barriers and Important Issues

Although Japan is one of the countries that has a huge impact on climate change, ranking 5th in carbon dioxide emissions as of 2019, it is evaluated that the specificity of its move toward carbon neutrality is somewhat lacking. For example, the “Green Growth Strategy for 2050 Carbon Neutrality” announced by the Ministry of Economy, Trade and Industry in December 2020 is offshore wind power, ammonia, hydrogen, nuclear power, automobiles, semiconductors, ships, logistics, food, aircraft, carbon recycling, and next-generation solar power. A total of 14 key areas such as mining and lifestyle-related industries are selected, and these are materialized as carbon-neutral implementation measures. However, unlike the goal of carbon neutrality, there is lack of plan for major carbon dioxide emission sources such as steel and cement. Because it excludes the consideration of major industries that have led the carbon society and the perspective of restructuring, it is inevitable to question whether Japan's carbon-neutral implementation strategy and goal have been achieved.

In addition, it is understood that there are many voices expressing negative opinions from the international community in connection with the carbon tax for carbon neutrality and the emission trading system, etc. For example, in July 2018, the Japanese Ministry of Environment installed a review meeting to introduce carbon pricing, but the review meeting was canceled after 2019 due to concerns and conflicts of opinion with members who were concerned about slowing economic growth[11]. In addition, there are conflicting opinions regarding carbon neutrality. The economic and industry has taken positive steps toward carbon neutrality. For instance, the president of the Federation of Economic Organizations

[11] World Energy Market Insight No. 21-4, 2021.2.22.

announced that it is inevitable to discuss the introduction of a carbon pricing system. Furthermore, the Japan Steel Federation confirmed achieving carbon neutrality by 2050 in the steel industry. On the other hand, there are conspiracy theories about carbon-neutral implementation measures that are being formed in European Union, such as the Carbon Border Adjustment Mechanism (CBAM) recently announced by the European Union. They insist that the implementation of carbon neutrality in terms of enhancing the competitiveness of the European Union and promoting protectionism[12].

As mentioned above, the absence of measures to reduce GHG emissions, difficulties in securing financial resources for the implementation of carbon neutrality, and internal conflicts are likely to become obstacles in achieving carbon neutrality in 2050.

1.5 Summary

Recognizing the seriousness of the climate crisis, Japan set a carbon-neutral goal for 2050, and announced three policies related to carbon neutrality such as "Green Growth Strategy for 2050 Carbon Neutrality", "6th Basic Energy Plan", and "Global Warming Countermeasure Plan".

In the case of “Green Growth Strategy for 2050 Carbon Neutrality”, it was jointly announced on December 25, 2020 by the relevant ministries, and on June 18, 2021, this strategy was materialized with an emphasis on detailed implementation strategies and benefits to people’s lives. In order to achieve carbon neutrality in 2050, this strategy proposes policies for each of the eight major policy means, including “budget (Green Innovation Fund),” “tax,” “finance,” “regulatory reform standardization,” and “international cooperation.” 14 key areas of three industrial sectors, including “energy-related industries”, “transportation/manufacturing-related industries”, and “home/office-related industries” were selected and goals for each key field were presented.

The “6th Basic Energy Plan” announced the finalized plan on October 22, 2021 based on the 「Framework Act on Energy Policy」. The plan suggested the policy direction in the energy sector to reduce GHGs by 46% in 2030 compared to 2013 and achieve carbon neutrality in 2050. In this plan, various scenarios and response strategies were presented for realize carbon neutrality in 2050, such as making renewable energy the main power source, introducing

[12] World Energy Market Insight No. 21-4, 2021.2.22.; Gyu-Pan Kim, Japan's 2050 Carbon Neutrality and Green Growth Strategy, 2021.3.30, Korea Institute for International Economic Policy, p. 15.

renewable energy as the top priority, and reducing the burden on the people and promoting symbiosis with the local community.

The “Global Warming Countermeasure Plan” is a comprehensive plan of the government based on the Global Warming Countermeasure Promotion Act, and was decided by the Cabinet on October 22, 2021. This plan was prepared major countermeasures and policies divided into three major categories such as “renewable energy/energy saving”, “industry/transportation, etc.”, and “cross-sector countermeasures”. In the case of energy-originating carbon dioxide, it presented reduction countermeasures and policies for each of the five sectors, such as “industry,” “work, etc.,” “household,” “transport,” and “energy conversion”.

Looking at Japan's carbon-neutral governance system, basic framework for policies to respond to climate change was prepared through enacting「Global Warming Measure Promotion Act」in 1998. Based on the Kyoto Protocol that took effect, the「Act on the Promotion of Global Warming Measures」was amended. The tasks, organization, and management of the “Global Warming Countermeasures Promotion Headquarters”, which is the core organization for the comprehensive and systematic implementation of the above-mentioned global warming countermeasures, are specifically stipulated in Article 10 and below of the same law. Meanwhile, the「National and Regional Decarbonization Realization Meeting」chaired by the Cabinet Secretariat was held in 22 December 2020 for "checking the implementation of carbon neutrality of the central government and each local government", "establishing step-by-step implementation goals", and "cooperating between the central and local governments".

In the aforementioned “Green Growth Strategy for 2050 Carbon Neutrality”, detailed strategies and roadmaps for each of the 14 key areas are presented, and Reduce carbon emissions to about 560 million tons in 2030 in non-electric power and power sectors such as “people’s livelihood”, “industry”, “transport” and “electricity” compared to 1.03 billion tons in 2019, a carbon-neutral scenario for 2050 is presented, including setting a challenging target and proposing a means to reduce up to 520 million tons.

In the aforementioned “Green Growth Strategy for 2050 Carbon Neutrality”, detailed strategies and roadmaps for each of the 14 key areas are presented, and Japan suggests carbon-neutral scenario for 2050, which aims to reduce carbon emission about 560 million ton by 2030 in the non-electric power sector such as “people’s livelihood”, “industry”, “transportation” and “electricity”, compared to 1.03 billion tons in 2019. In addition, it sets the challenging target to reduce carbon emission about 520 million tons by 2030 and suggests potential methods to achieve it.

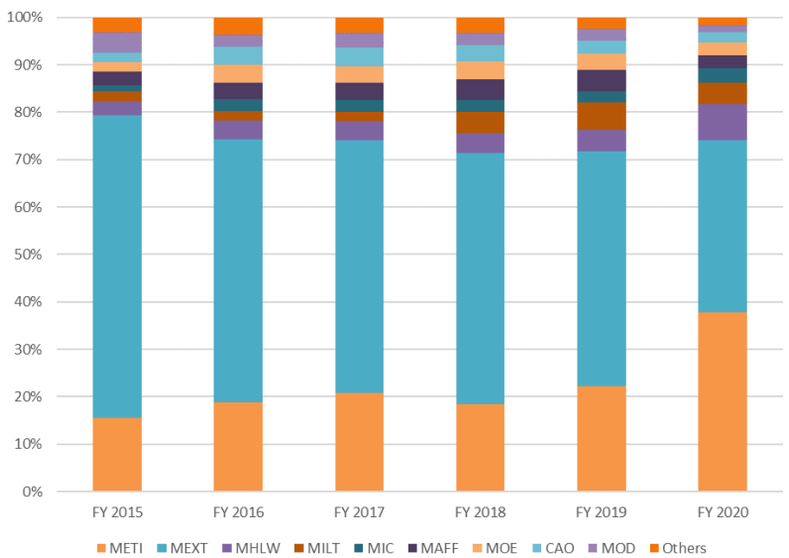
Finally, when analyzing the major barriers and important issues for Japan's carbon neutrality, it shows that two potential obstacles should be considered as major issues. Japan selected 14 key areas in "Green Growth Strategy for 2050 Carbon Neutrality" and presented specific carbon neutral implementation plans. However, there is lack of plan for major carbon dioxide emission sources, such as steel and cement. Also, the consideration of the existing major industries that have led the carbon society and the viewpoint of restructuring are excluded. Hence, these are highly likely to become major obstacles in achieving carbon neutrality in 2050.

2. Net-Zero R&D Strategies[13]

2.1 R&D Governance

2.1.1 Government R&D Implementation Structure

The Government science, technology and innovation (STI) budget of Japan in FY2020 was 9.2 trillion yen[14] including supplemental budgets, comprising 2 trillion yen for the Green Innovation Fund[15]. This amount was significant as the STI budget before FY2019 had been in the range of 4.0 trillion yen to 5.7 trillion yen since 2001. Figure 3-2 shows each relevant ministry's spending as a ratio of the STI budget, where the Ministry of Economy, Trade and Industry (METI) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) are significant players contributing over 70% of the total budget.



Source: Modified by JST/APRC from NISTEP "Japanese Science and Technology Indicators 2021"

[Figure 3-2] The Ratio of STI Budget of Japanese Government by Ministry

In regard to governmental policy implementation, the Council for Science, Technology, and Innovation (CSTI) acts as the control tower of STI policy in Japan. CSTI is one of the Cabinet Office's essential policy councils and is comprised of the Prime Minister, relevant Ministers, and experts. CSTI formulates significant STI policies, including the "Science, Technology and Innovation Basic Plan" (hereafter referred to as "Basic Plan") and "Integrated Innovation

[13] Authors: Thi Nu Pham, Mikkiko Azuma and Junko Okayama (Japan Science and Technology Agency, JST)

[14] Sum of central and local governments.

[15] National Institute of Science and Technology Policy (NISTEP), STI Budget (Accessed 1 June 2022)

Strategy," which are described in the next section. Based on direction from CSTI, each ministry implements STI policy including R&D activities. Moreover, cross-ministry activities are undertaken occasionally. In terms of carbon neutrality policy implementation, cross-ministry meetings for Green Innovation Strategy[16] have been held under the leadership of METI since 2020, acting as a command tower for implementing the related policies in line with the "Integrated Innovation Strategy."

Most public R&D competitive funds are allocated to researchers via funding agencies. The major funding agencies in Japan supporting energy and environmental research are the Japan Society for the Promotion of Science (JSPS), the New Energy and Industrial Technology Development Organization (NEDO), and the Japan Science and Technology Agency (JST). Among them, JSPS, which is affiliated with MEXT, is providing bottom-up funding based on the curiosity of scientists, and the others are providing top-down funding based on government policy. Among the top-down funding agencies, NEDO, which is affiliated with METI, focuses on promoting industrial technology and commercialization, including the Green Innovation Fund. JST, which is affiliated with MEXT, promotes top-down, strategic basic research. This report will look in detail at the activities of NEDO and JST in a later section. There are also other institutions conducting funding programs related to carbon neutrality, such as the National Agriculture and Food Research Organization (NARO) and the Environmental Restoration and Conservation Agency (ERCA). NARO is a research institution focused on the agricultural field, which also has a top-down funding body named the Bio-oriented Technology Research Advancement Institution (BRAIN). ERCA is an institution with several functions, such as compensation and prevention of health hazards caused by pollution and providing grants for environmental conservation, including research for carbon neutrality.

2.1.2 STI Policies under the Science, Technology and Innovation Basic Plan

In Japan, the Science, Technology and Innovation Basic Plan (hereafter referred to as the "Basic Plan") is the primary policy for STI. The "Basic Plan" has been formulated every five years since FY1996 based on the Science, Technology and Innovation Basic Law (formerly Science and Technology Basic Law). The latest Basic Plan is the "6th Science, Technology and Innovation Basic Plan" (hereafter referred to as "Sixth Basic Plan") started in FY2021. The core concept of the Sixth Basic Plan is the realization of "Society 5.0", a human-centered society that balances economic advancement with the resolution of social problems through a

[16] METI, Japan's Roadmap to "Beyond -Zero" Carbon, July 07, 2020.

system that highly integrates cyberspace and physical space, which was first presented in the former Basic Plan. The plan includes steps towards promoting social change and discontinuous innovation to overcome global issues, including implementing the Paris Agreement.[17]

As an action plan of the Basic Plan, the "Integrated Innovation Strategy" (formerly "Comprehensive Strategy on Science, Technology and Innovation") has been formulated every fiscal year since 2015. Under the vision of Society 5.0, the latest strategy[18] formulated in June 2022 emphasizes addressing the climate change issue, including contributions to achieving carbon neutrality. From the standpoint of innovation, the promotion of energy conservation, through electrification, and the decarbonization of electric power (accelerated diffusion of technology for maximum levels of introduction of renewable energy and use of nuclear energy with top priority on safety) are mentioned. Along with this, the development of next-generation solar cells, CCUS/carbon recycling, and hydrogen-based technologies are also stated. At the same time, to promote the introduction of technologies and their practical application, the government will promote the decarbonization of people's lifestyles, realize and expand zero-carbon cities, foster public understanding, and consider the systems, standards, and other mechanisms critical to implementation.

There are many policies affiliated with the “Integrated Innovation Strategy,” and among them, the “Environment Innovation Strategy[19]”, formulated in January 2020, is the most important for promoting innovation. The Basic Plan also refers to the “Basic Energy Plan” concerning R&D and international cooperation.

Besides these policies, the “Growth Strategy” of the Cabinet Secretariat is closely related to STI. The latest action plan of the Growth Strategy was approved on June 18, 2021, emphasizing green growth associated with carbon neutrality. This policy was decided by the committee on the Growth Strategy, which was taken over by the Council of New Form of Capitalism Realization as of October 15, 2021. Concerning carbon neutrality, the “Sixth Basic Plan” and “Integrated Innovation Strategy” both refer to the “Green Growth Strategy Through Achieving Carbon Neutrality in 2050[20]” which was formulated as an industrial policy aiming to contribute to the “Growth Strategy.”

[17] Government of Japan, Science, Technology and Innovation Basic Plan, March 26, 2021.

[18] Prime Minister Cabinet Office, Integrated Innovation Strategy, June 3, 2022.

[19] Prime Minister Cabinet Office, Environment Innovation Strategy, January 21, 2020.

[20] METI, Green Growth Strategy (provisional translation), December 25, 2020.

2.2 Key Technologies

Key technologies required to realize carbon neutrality are described in the “Environment Innovation Strategy.” Five target sectors noted in this strategy are (1) energy, (2) transportation, (3) industry, (4) business, household and cross-sectoral, and (5) agriculture, forestry and fisheries/ carbon sinks. Table 3-7 shows the key technology described in the “Environment Innovation Strategy” by these sectors.

Among the five target sectors, the transformation of the energy sector is the most important issue in achieving carbon neutrality since more than 80 percent of Japan's GHG emissions are derived from this sector. Among these, technologies to maximize the introduction of renewable energy and promotion of innovation in the field of next-generation solar cells, CCUS/carbon recycling, and hydrogen are especially highlighted, referred to both in the "Sixth Basic Plan" and "Integrated Innovation Strategy." Furthermore, next-generation batteries, which are needed to realize a resilient energy network with renewable resources as a prime force, are referred to as a key technology in the "Growth Strategy."

[Table 3-7] Key Technologies by target sector

Target Sector	Key Technologies
(1) Energy	• Technologies to maximize the introduction of renewable energy (next-generation solar cells etc.). • Technologies to realize a resilient energy network with renewable resources as a prime force (next-generation batteries etc.). • Technologies to realize a low-cost hydrogen supply chain. • Nuclear and fusion technology. • Technologies for low-cost CO_2 separation and capture (CCUS/carbon recycling).
(2) Transportation	• Green mobility (high efficiency battery, fuel cell, utilization of fuel derived from carbon recycling etc.).
(3) Industry	• Technologies to break dependence on resources based on fossil fuels (hydrogen reduction ironmaking). • Carbon recycling technologies to utilize CO_2 as a raw material.
(4) Business, household, cross-sectoral	• Utilization of cutting-edge Greenhouse Gas (GHG) reduction technology. • Transformative technology utilizing bigdata, AI or distributed control systems for urban management. • Energy reduction by promoting sharing economy, telework, behavioral transformation etc. • Fulfill the scientific knowledge for verification of GHG reduction effect.
(5) Agriculture, forestry and fisheries / Carbon sinks	• CO_2 capture and storage by utilizing cutting-edge biotechnology etc. (blue carbon, smart agriculture, forestry and fisheries, etc.) • Reduction of CH4, N2O emission from agriculture sector. • DAC (direct air capture) technology.

Source: Extracted by APRC/JST from Environment Innovation Strategy (2020)

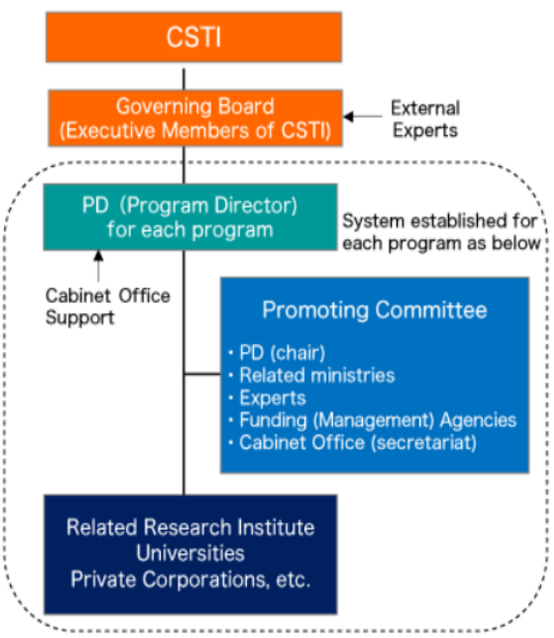
2.3 Key Strategic Programs

Key strategic programs of the Japanese government related to carbon neutrality are undertaken by CSTI, METI, MEXT, MOE and MAFF as mentioned above. In this section, several of the government's top-down funding projects and carbon-neutral related R&D programs are introduced.

2.3.1 CSTI: SIP, Moonshot

Cross-ministerial Strategic Innovation Promotion Program (SIP)[21]

SIP is a national project established by CSTI to realize science and technology innovation by functioning as a control tower and providing management across the boundaries of ministries, agencies, and traditional fields as shown in Figure 3-3.



Source: Cabinet Office

[Figure 3-3] The structure of SIP

SIP undertook eleven projects in its first phase in FY2014 and twelve projects in its second phase, which began in FY 2018 (August FY2018). Each subject has a Program Director (PD) who can reliably link industry, academia, and government. The Cabinet Office itself secures the budget and transfers it to each ministry and agency for implementation, creating an unprecedented and revolutionary mechanism.

Carbon-neutral related projects in the first phase included the "Energy Carriers" project which had the three research and development topics of: "develop energy carriers and identify promising candidates," "develop peripheral technologies supporting a low-cost, highly efficient hydrogen value chain," and "conduct research and development linked to safety standards deregulation for hydrogen transportation and use."[22].

[21] Prime Minister of Japan Cabinet Office, Brochure SIP " Pioneering the Future: Japanese Science, Technology and Innovation 2021", January 2022.

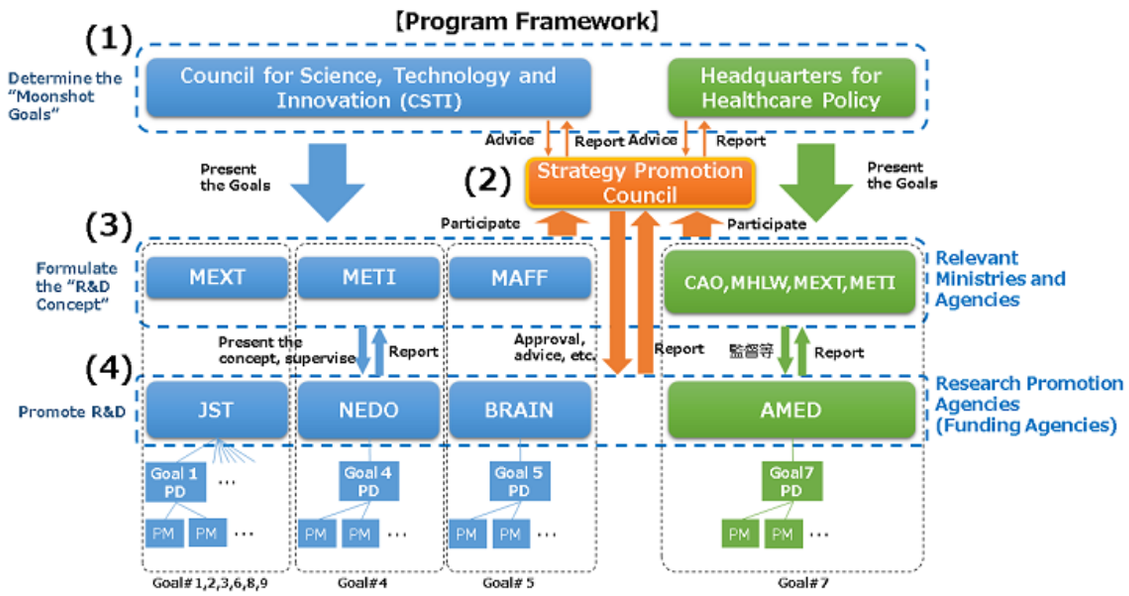
[22] Prime Minister of Japan Cabinet Office, Brochure SIP page 22-25, Energy Carriers, January 2022.

In the second phase (2018-2022), the carbon-neutral related project is the “energy system for and IoE society[23]” project directed by Prof. KASHIWAGI Takao at Tokyo Tech. The research and development topics include "Design and energy system for an IoE society," "IoE common platform technology," and "R&D for an application/practical implementation of IoE."

Moonshot Research & Development Program

The Moonshot Program was established in December 2018 by CSTI, with a maximum of 10 years’ support (budget: 115 billion JPY). The Moonshot Research and Development Program, launched by the Cabinet Office (CAO), promotes high-risk, high-impact R&D aiming to achieve ambitious ‘Moonshot’ goals and solve issues facing future society such as super-aging populations and global warming. As shown in Figure 3-4, CSTI, MEXT, METI, MAFF and MHLW formulated the R&D concept. By June 2022 (present), a total of 66 Project Managers (PMs) have been selected to carry out R&D projects related to the nine Moonshot Goals[24].

The Moonshot Goal most focused on carbon neutrality is Goal 4, being promoted by NEDO, "Realization of sustainable resource circulation to recover the global environment by 2050," which aims to contribute to solving the global warming problem (Cool Earth) and the environmental pollution problem (Clean Earth) while accounting for continued industrial and consumer activity. The R&D projects in Moonshot Goal 4 are presented in Table 3-8.



Source: Cabinet Office.

[Figure 3-4] The program Framework of Moonshot

[23] Prime Minister of Japan Cabinet Office, Brochure SIP page 8-9, Energy system for and IoE society, January 2022.

[24] Prime Minister of Japan Cabinet Office, Moonshot R&D Projects, (Accessed 1 June 2022).

[Table 3-8] R&D projects in Moonshot Goal 4[25]

(1) Development of technologies to recover greenhouse gases ("GHGs") and convert them into valuable materials
• Development of a Bioprocess That Uses Electrical Energy to Fix Atmospheric CO_2 • Development of Highly Efficient Direct Air Capture (DAC) and Carbon Recycling Technologies • Integrated Electrochemical Systems for Scalable CO_2 Conversion to Chemical Feedstocks • C^4S* Research and Development Project • * C^4S: Calcium Carbonate Circulation System for Construction • Research and development toward saving energy for direct air capture with available cold energy • Development of Combined Carbon Capture and Conversion (quad-C) Systems for the Utilization of Atmospheric CO_2 • Development of Global CO_2 Recycling Technology towards "Beyond-Zero" Emission • Mitigation of GHG emissions from agricultural lands by optimizing nitrogen and carbon cycles
(2) Development of technologies to recover nitrogen compounds and convert them into harmless or useful materials
• Innovative Circular Technologies for Harmful Nitrogen Compounds/ To Solve Planetary Boundary Issues • Development of recovery and removal techniques of dilute reactive nitrogen to realize nitrogen circulating society
(3) Development of marine biodegradable plastics which can control the timing and speed of their degradability
• Development of Multi-lock Biopolymers Degradable in Ocean from Non-food Biomasses • Research and development of marine biodegradable plastics with degradation initiation switch function • Development of photoswitching ocean-degradable plastics with edibility

2.3.2 METI/New Energy and Industrial Technology Development Organization (NEDO)

NEDO is one of Japan's largest public funding agencies. As one part of the government's economic and industrial administration, its two missions are to address energy and global environmental problems and enhance industrial technology. NEDO promotes four technology development fields, include "Energy Systems", "Energy Conservation and Environment", "Industrial Technology", and "New Industry Creation and Discovery of Technology Seeds". The "Energy Conservation and Environment" projects are shown in Table 3-9. Apart from its energy conservation/environment projects, NEDO also has some projects related to the energy system[26], where the areas of focus are "system provision technology", "energy storage technology such as batteries", "technology related to hydrogen production, storage, transport, and use", and "renewable energy technology".

[25] Prime Minister of Japan Cabinet Office, Moonshot Goal #4 R&D Projects, (Accessed 1 June 2022).

[26] NEDO, Energy System, (Accessed 1 June 2022).

[Table 3-9] NEDO's energy conservation/environment projects

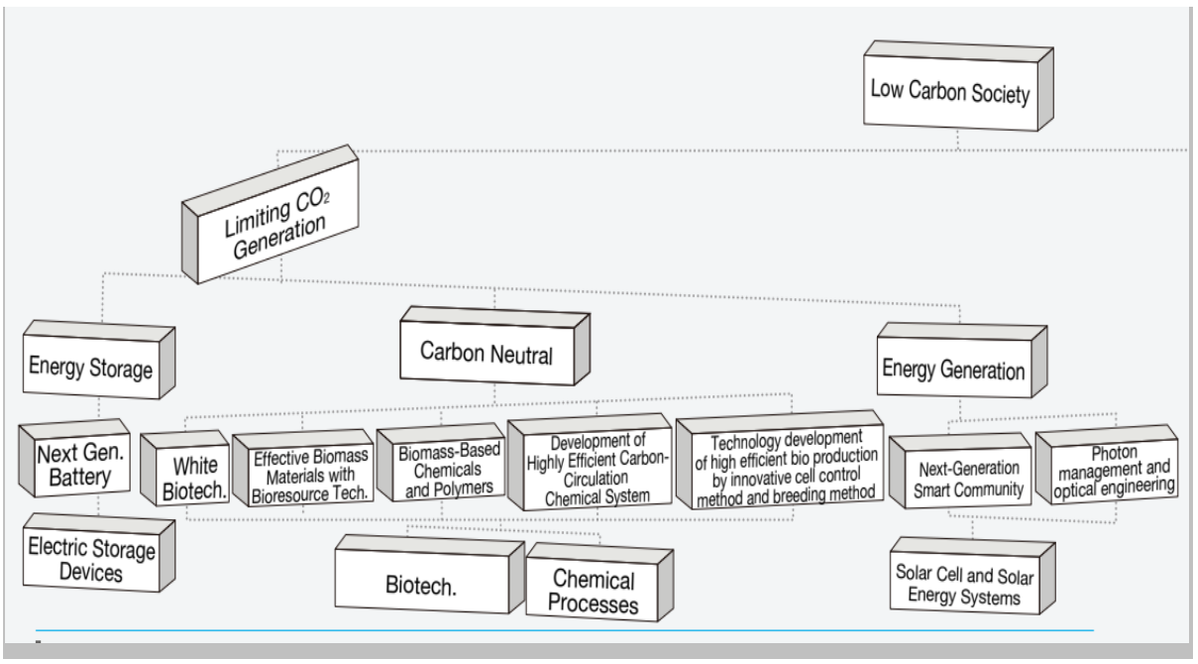
Type	Project's name
National Projects	• Research and Development Project on Innovative Thermal Management • Materials and Technologies • Development of Environmental Technology for Steelmaking Process • Development of Technologies for Carbon Recycling and Next Generation Thermal Power Generation • Research and Development of Recycling Technologies for Establishing • a High Efficiency Resource Circulation System • Development of Technology and Assessment Techniques for Next • Generation Refrigerants with a Low GWP Value • Development of Zero-Carbon Steel Technologies • Development of Carbon Circulation Technology for the Cement Industry • Innovative Plastic Resource Circulation Process Technology Development • Research, Development and Demonstration of CCUS Technology • Development of advanced circulation technology for aluminum • materials
Proposal – Based Activities	• Strategic Innovation Program for Energy Conservation Technologies • Program to Develop and Promote the Commercialization of Energy Conservation Technologies to Realize a Decarbonized Society • NEDO Feasibility Study Program
International Demonstration and Joint Projects	• Demonstration Project for Introducing an Energy-Saving Resource Circulation System in Asia • Project for International Promotion and Dissemination of Carbon Recycling and Advanced Thermal Power Generation Technologies • International Demonstration Project on Japan's Energy Efficiency Technologies • Program to Facilitate Private-Sector-Led Promotion of Low Carbon • International Research and Development Co-Funding Project • Research and Development Program for Promoting Innovative Clean Energy Technologies Through International Collaboration
Specified Proposal-Based Research and Development	• Moonshot Research and Development • Green Innovation Funding Program

METI, assigned a Green Innovation Fund of approximately 2 trillion yen to NEDO to accelerate their current initiatives, such as structural and demand transformation in the energy and industrial sectors, as well as innovation through bold investment, to achieve the goal of "Carbon Neutrality by 2050." For ten years, the fund will provide funding to firms and organizations that approach these goals as business problems, from research and development through to social implementation.

2.3.3 MEXT/Japan Science and Technology Agency (JST): Advanced Low Carbon Technology Research and Development Program (ALCA) - Specially Promoted Research for Innovative Next Generation Batteries (SPRING)

MEXT promotes research and development from fundamental research to advanced technologies to transform the nation into a “low-carbon society” through cutting GHG emissions while enabling sustainable development. This section introduces the ALCA and ALCA-SPRING programs, which are operated by JST under MEXT.

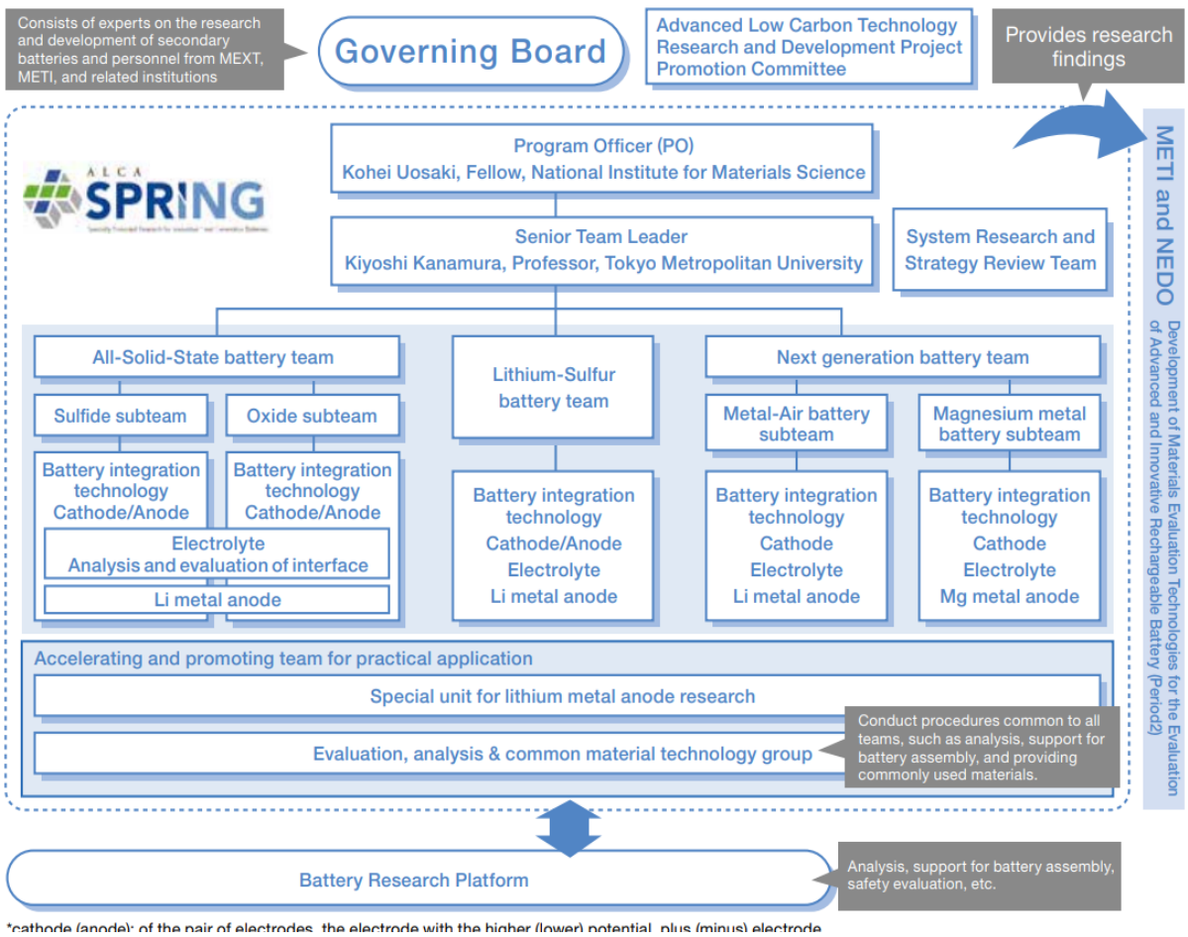
As shown in Figure 3-5, ALCA aims to promote research and development to create technologies with great potential for reducing GHG emissions based on new scientific and technological knowledge under the research and development strategy formulated by MEXT. The objective is to achieve R&D results that will lead to the creation of green innovation. The FY2022 budget allocation for ALCA is approximately 2,173 million yen.



Source: ALCA

[Figure 3-5] Layered Structure of ALCA Technology Areas

As a Special Priority Research Area of ALCA with the aim of accelerating research and development of high-capacity secondary batteries, the next generation of the existing lithium ion batteries, ALCA-SPRING was launched in 2013. As shown in Figure 3-6, the project aims to accelerate research and development of high-capacity secondary batteries, the next generation of the existing lithium ion batteries, and develop revolutionary secondary battery technology that is far superior in performance compared to existing secondary batteries, accelerating basic/ fundamental research toward practical applications.



Source: ALCA

[Figure 3-6] Layered Structure of ALCA-SPRING

Besides ALCA, there are also other programs that focus on carbon neutrality such as JST-Mirai "Low Carbon Society" mission area (FY2017-) and some research areas in the Strategic Basic Research Programs[27].

[27] JST, Mirai "Low Carbon Society" mission area and the Strategic Basic Research Programs., (Accessed 1 June 2022)

2.3.4 MAFF/The Bio-oriented Technology Research Advancement Institution (BRAIN)

BRAIN supports basic research and development based on research strategies concerning the development of bio-oriented technologies stipulated by MAFF, including the "Basic Plan for Agricultural and Fishery Researches," and commissions this to universities, national colleges of technology, and private sector companies. BRAIN was assigned the Moonshot Goal 5 “Creation of the industry that enables sustainable global food supply by exploiting unused biological resources by 2050”.

Besides BRAIN, MAFF also has some projects related to agricultural and forestry climate change research initiatives. MAFF’s main research projects focus on the topics of “Observed and Predicted Effects of Climate Change on Japanese Agriculture”, “Sustainable Food System Research (MeaDRI)”, and “Government of Japan Environment Innovation Strategy”. The “Zero-Emission Agriculture, Forestry and Fisheries” component aims to avoid and/or sequester more than the equivalent of 15 billion MT of CO_2 through four areas of research, consisting of 10 specific programs, see Table 3-10.

[Table 3-10] Areas of Research for Zero-Emission Agriculture, Forestry and Fisheries (source: Prime Minister of Japan Cabinet Office)

CO_2 absorption and fixation in the ocean, farmland, forest with advanced biotechnology	• Genome editing technology and other applied biotechnology • Development of alternative raw material using biomass • Carbon sequestration in farmland using biochar • Wooden high-rise buildings and wood-based bioplastics • Smart forestry and fast-growing trees • Blue carbon (carbon sequestration in the marine ecosystems)
Reduction of CH_4 and N_2O from agriculture and livestock industry	• Breeding new varieties of crops and livestock as well as development of new farm and livestock management to acclimate to climate change
Smart agriculture, forestry, and fisheries	• Building a new energy system based on local production and consumption (best suited for rural areas) • Reduction of fossil fuel usage in agricultural sectors by introducing more energy efficient machinery and/or optimizing practices.
Capturing CO_2 in the Air	• Development of Direct Air Capture technology

2.3.5 MOE/ Environmental Restoration and Conservation Agency of Japan (ERCA)

To achieve a decarbonized society, the MOE supports many funds that are critical to foster innovation in order to further cut CO_2 emissions in all sectors and promote implementation in society at an early stage, such as the "Environment Research and Technology Development Fund (ERTDF)[28]"through ERCA, the "Low Carbon Technology Research and Development Energy Program[29]" among others. The main areas of the "Low Carbon Technology Research and Development Energy Program" are: Low Carbon Transportation, Low Carbon Buildings, Low Carbon Renewable Energy, Low Carbon Biomass and Recyclable Resources and Innovations for Decarbonization of Social Infrastructure.

2.4 Successes from Recent R&D Results

With the support of R&D funding programs from government organizations, research on carbon neutrality in Japan has achieved many excellent results. In this section, some of the successful results in fundamental research and their applications are introduced.

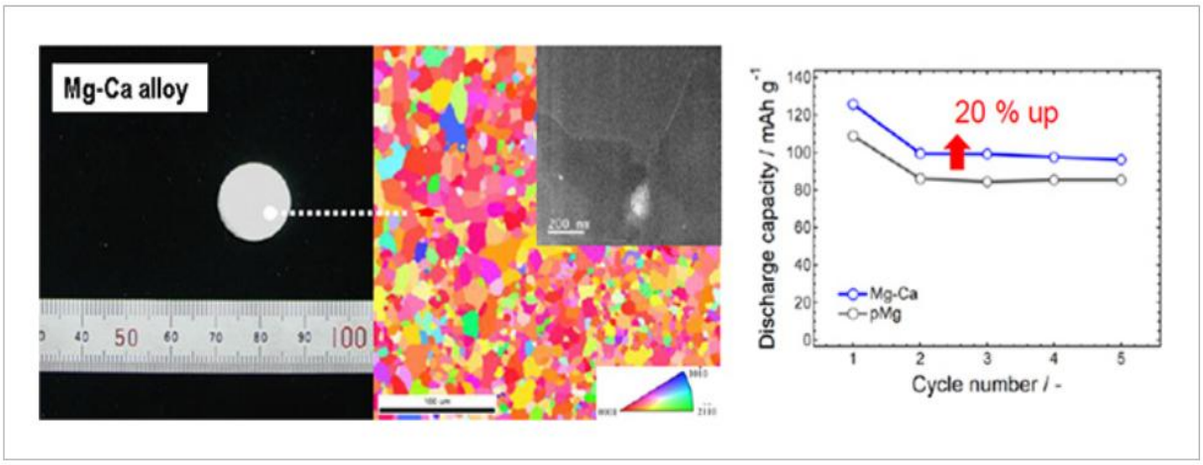
2.4.1 Higher performance of magnesium metal batteries[30]

The "Next Generation Battery Team" (2013-2022), ALCA, which is led by KANAMURA Kiyoshi, Professor at the Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University has significantly improved the cycle characteristics and capacity of magnesium metal batteries. As shown in Figure 3-7, a prototype battery was manufactured using an alloy material (Mg-Ca) with the positive electrodes made from $ZnMnO_3$, a Zn-Mn-based defect spinel-type oxide, and calcium (Ca) was added as the negative electrode. This research is the world's first achievement to improve battery characteristics by alloying magnesium metal and controlling the structure.

[28] MoE, Environment Research and Technology Development Fund, (Accessed 1 June 2022)

[29] MoE, Pamphlets for Low Carbon Technology Research and Development Program, (Accessed 1 June 2022)

[30] JST, Higher performance of magnesium metal batteries achieved, May 2022.



source: JST

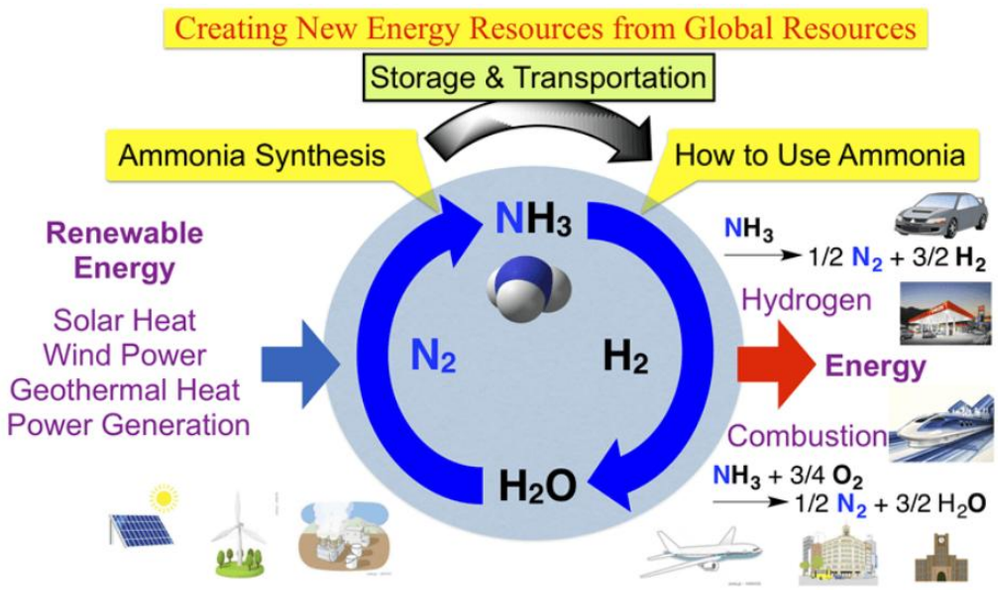
[Figure 3-7] (Left) Photograph of the new Mg -Ca alloy material, (Center) Observed microstructure of the new material, (Right) Battery charge/discharge test results using pMg and Mg-Ca material as the negative electrode

2.4.2 Development of a new method of ammonia synthesis[31]

Professor NISHIBAYASHI Yoshiaki, Research Director of CREST[32] and Professor, Graduate School of Engineering, the University of Tokyo, was the first in the world to develop an innovative method for synthesizing large amounts of ammonia from nitrogen gas and water at room temperature and atmospheric pressure. The study's findings were published in *Nature* (online) in April 2019. Professor Nishibayashi identified a phenomenon whereby ammonia synthesis proceeds at room temperature and atmospheric pressure at a rate comparable to nitrogenase by employing samarium diiodide, one of the significant achievements made possible by this synthesis process. For a long time, the combination of samarium diiodide and water has been utilized as a reducing reagent for the carbon-oxygen double bond (C=O) in organic synthesis. Professor Nishibayashi realized that this chemical could also be used to disrupt the nitrogen-nitrogen triple bond (N≡N). This approach is supposed to take the place of the traditional "Haber-Bosch process," lowering the energy required and the amount of CO_2 generated during ammonia synthesis.

[31] JST, Innovative "Method of Ammonia Synthesis", April 2019.

[32] Core Research for Evolutional Science and Technology (CREST) is a program under the Strategic Basic Research Programs. of JST.



Source: JST

[Figure 3-8] Paradigm Shift in energy Resources of Society

2.4.3 Mitsubishi Heavy Industries (MIH) Engineering – Development of Low-Cost CO_2 Separation and Recovery Technology[33]

As a program supported by NEDO, more than 90% of the CO_2 from factories and power plants may be recovered using the exhaust gas CO_2 recovery technology created by MIH Engineering.

Sixteen units have already been delivered by the company to destinations all around the world. This equipment provides operators with significant cost savings due to its strong energy saving performance and durability. In Tomakai City, Hokkaido, Japan, a refinery has started a joint research program with MHI Engineering and Mitsubishi Gas Chemical to test technologies for the efficient recycling of CO_2 emissions as well as the production of methanol from captured CO_2 emissions.

2.4.4 Application of autonomous battery-powered vehicles[34]

Toyota Motor Corporation unveiled plans to build a prototype city of the future at the base of Mt. Fuji in early 2020. The autonomous battery-powered Toyota e-Palette cars will be the

[33] NEDO, Report ofTomakomai CCS Demonstration Project at 300 thousand tonnes cumulative injection, May 2020.

[34] METI, Tapping Hydrogen's Energy Potential, (Accessed 1 June 2022).

main mode of transportation as the corporation tested mobility-as-a-service and other cutting-edge technology. Toyota has helped fuel the growth of the fuel cell vehicle market by making the Mirai passenger car widely available. They intend to increase the variety of long-distance buses, trucks, and other heavy vehicles available. The firm is also putting an emphasis on electric vehicles and plans to develop batteries and use materials informatics in the next years.

2.5 Summary

A public-private sector effort is currently underway in Japan following the Prime Minister's carbon neutrality declaration in October 2020. The Science, Technology, and Innovation (STI) Basic Plan is addressing climate change and carbon neutrality, promoting energy conservation and the decarbonization of electric power through the development of next-generation solar cells, CCUS/carbon recycling, and hydrogen-based technologies. The government will also promote the decarbonization of people's lifestyles, realize and expand zero-carbon cities, foster public understanding, and consider the systems, standards, and other mechanisms critical to implementation.

The establishment of the Green Innovation Fund in 2020 has become a major topic of discussion, providing 2 trillion yen in R&D funding for carbon neutrality over 10 years and positioned as a catalyst for R&D investment in the private sector. Considering that the government's annual STI budget has ranged from an approximate annual 4.0 to 5.7 trillion over the past two decades, the new 2 trillion fund represents a significant investment.

A variety of large-scale basic research programs such as Moonshot Research & Development and ALCA-SPRING are also promoting projects that contribute to carbon neutrality, with results including: higher performance magnesium metal batteries; a method for synthesizing large amounts of ammonia from nitrogen gas and water at room temperature and atmospheric pressure; technology that can recover up to 90% of the CO_2 emitted by factories and power plants.

In response to the global movement to curb global warming, a public-private sector effort is underway following the carbon neutrality declaration by the Prime Minister in October 2020. However, the goal is extremely lofty: to reduce GHG emissions to 54% of the fiscal 2013 level by 2030, and to reduce overall GHG emissions to zero by 2050. So, what is Japan's science and technology doing to meet this challenging goal, and how can we achieve a carbon-neutral society?

The majority of the R&D activities undertaken in Japan are carried out in the private sector, with a greater than 80% share of expenditure. Despite this, most basic and applied research conducted in universities and public research institutions is performed using public funds. This chapter focuses on the activities of the Japanese government and the structure of R&D governance, key technologies, key strategic programs, and some recent R&D results.

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IV | Republic of Korea

IV Republic of Korea

1. Policy Reviews and Issues of Carbon Neutrality[35]

1.1 Background

Korea is the eleventh-largest emitter of GHGs in the world, having constantly increasing GHG emissions. As of 2018, the total GHG emissions of Korea were 727.6 million tons of CO_{2eq}, or around 1.51% of the global total. By sector, energy, industrial processes, Agriculture, LULUCF and waste sector emit 632.4, 57.0, 21.2, -41.3, 17.1 million tons of CO_{2eq}, respectively (The Government of the ROK, 2022). In the past three decades, overall emissions have climbed by 149%, from 292,2 million tons in 1990 to 736,6 million tons in 2018. The high level of GHG emissions is attributable to the heavy reliance of the national economic structure on manufacturing and exports (The Government of the ROK, 2022). Despite being a large emitter of GHGs, Korea actively participates in the international community's efforts to combat climate change by ratifying the Paris Convention in 2016 and announcing the 2050 carbon neutrality target in October 2020. This article introduces Korea’s carbon neutrality policy, objectives, governance, and major challenges in achieving carbon neutrality.

1.2 Carbon Neutrality National Policy and Institutional Framework

1.2.1 Overview

The ROK established green growth as the main pillar of its policy in the late 2000s and has played a leading role in establishing national climate change policies. The ROK voluntarily set a national GHG reduction target for 2020, which is a 30% reduction compared to BAU (Business-as-Usual), in November 2009. In response, the country established the Framework

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Act on Low Carbon, Green Growth (Green Growth Act) in January 2010, the nation's first law with a GHG emission reduction goal. The Act established the fundamental principles for encouraging green growth, as well as national policies, implementation plans, and the operations of the Green Growth Committee. Furthermore, in order to achieve the goal of reducing GHG emissions in a cost-effective manner, a national emission trading system has been in place since 2015.

The ROK's efforts to reduce GHG emissions were accelerated in June 2015 when its Intended Nationally Determined Contribution (INDC) was submitted in accordance with the Paris Convention. The INDC proposed reducing the country’s emissions by 37% below the BAU level by 2030 as shown in Table 4-1. The 2030 National Greenhouse Gas Reduction Roadmap was introduced in the following year as a sectorial implementation plan to lay out detailed implementation plans to achieve a total reduction of 37%, with Korea reducing 25.7% and other countries reducing 11.3%. In 2019, the county updated the Enforcement Decree of the Framework Act on Low Carbon, Green Growth in 2019 to strengthen its reduction goal of a 24.4% reduction from the 2017 level, utilizing an absolute-quantity-based target (The Government of the ROK, 2022). Additionally, the government has revised and supplemented the existing road map to achieve the 2030 national GHG reduction target. Accordingly, the 2nd National Emissions Allocation Plan (2018-2020) for the national emission trading scheme reflected the revised roadmap and established the total emission allowance of 591 companies subject to the emission trading scheme, expanding the permitted facilities and increasing the emission coefficient relative to the 1st. As the gravity of the climate change agenda has grown, the country has shifted its position from low carbon to carbon neutrality, declared its commitment for carbon neutrality by 2050. Accordingly, in the most recent NDC submitted December 2021, the country set an updated and enhanced target to reduce GHG emissions by 40% from the 2018 level, which is 727.6 $MtCO_{2eq}$, by 2030. The country has implemented new legal and institutional frameworks to further the agenda. In fact, it is the fourteenth country to legislate the 2050 carbon neutrality vision. The subsequent section will provide a concise summary of the country's legal and institutional framework initiatives.

[Table 4-1] Changes in Reduction Targets in Korea

	2020 Roadmap (Jan. 2014)	2030 Roadmap (Dec. 2016)	2030 Roadmap revised (Jul. 2018)
Sector	7 sectors (25 sub-sectors)	8 sectors (31 sub-sectors)	8 sectors
Goal	30%↓from 2020 BAU	37%↓from 2030 BAU (domestic: 25.7% International: 11.3%)	37%↓from 2030 BAU (domestic: 32.5% others: 4.5%)
Mitigation Pathway	Mitigation pathway between 2014 and 2020	Amount of emissions to be reduced in 2030	Every three year emission reduction target until 2030
	Updated National GHG Reduction Target for 2030 (NDC) (Dec. 2020)	Revised GHG Reduction Target for 2030 (Oct. 2021)	
Sector	8 sector	8 sector	
Goal	24.4%↓from 2017 level (709.1 $MtCO_{2\text{-eq}}$) by 2030	40%↓from 2018 level (727.6 $MtCO_{2\text{-eq}}$) by 2030	
Mitigation Pathway	Every three year emission reduction target until 2030	Amount of emissions to be reduced in 2030	

Source: Ministry of Environment(2020); The Government of the Republic of Korea(2022b)

1.2.2 Framework Act on Carbon Neutrality, Green Growth[36]

The ROK abolished the Green Growth Act and enacted the Framework Act on Carbon Neutrality, Green Growth (Carbon Neutrality Act) in August 2021 as a "legal foundation to respond to the climate crisis and to achieve carbon neutrality" (The Government of the ROK, 2022). The Carbon Neutrality Act outlines national vision and strategy, mid- to long-term NDC reduction goals, and programs for domestic carbon neutrality by 2050. The Act also provides major concepts and procedures for the transition to a carbon-neutral society and green growth. It established a strong foundation for carbon neutrality by significantly increasing the GHG reduction target to 40% by 2030. While this is a difficult target to attain given the country's high concentration of manufacturing, it indicates the government's strong desire to achieve carbon neutrality and reduce GHG emissions (Office of Government Policy Coordination, 2022). In addition, it presented an opportunity to create a new governance structure, Carbon Neutrality Commission, involving all social classes, including central-local, industrial, future generations, and workers. The Act emphasizes a comprehensive and balanced approach to future and current generations, climate crisis adaptation and GHG

[36] This section is a summary of the Office for Government Policy Coordination's press release on 22 March, 2022 (Office of Government Policy Coordination, 2022), https://www.opm.go.kr/opm/news/press1.do?mode=view&articleNo=144090

reduction, and all sectors and sectors of society (Article 3 of the Carbon Neutrality Act). The Carbon Neutrality Act recognizes the following four sectors as the primary pillars of carbon neutrality and green growth: GHG mitigation, climate crisis adaptation, just transition, and green growth.

GHG mitigation

The Act introduces a variety number of measures for GHG mitigation. First, it establishes the 'Greenhouse Gas Reduction Awareness Budget', which examines the national budget's influence on GHG reduction, incorporates it into the budget composition, and assesses if it is properly performed at the time of settlement. Second, the Climate Change Impact Assessment has been introduced to assess the impact of climate change on large-scale development plans and projects that produce high volumes of GHGs or are vulnerable to climate crisis, will be implemented in stages after pilot projects in September 2022. Third, the Ministries of Environment and Land, Infrastructure, and Transport will work together to disseminate a "carbon neutral city" model and develop strategy for building a carbon-neutral city by diagnosing the region's carbon-neutral level. In the transportation sector, relevant ministries such as the Ministry of Trade, Industry, and Energy, the Ministry of Land, Infrastructure, and Transport, and the Ministry of Oceans and Fisheries will collaborate to set GHG reduction targets, revitalize public transportation, convert electric and hydrogen vehicles, and build eco-friendly railways. In addition, carbon sinks will be expanded through sustainable forest management. Lastly, in accordance with Article 6 of the Paris Agreement, the Act has also laid the groundwork for encouraging worldwide GHG reduction projects that each country or business operator can undertake and employ to meet national objectives.

Vision	Carbon Neutrality by 2050 + Environmental and Economic Harmony			
Goal	National Strategy + Mid- to Long-Term Goals for Greenhouse Gas Reduction			
Implementation	Fundamental Plan for Carbon-Neutral Green Growth (National, Municipal, Municipal, and Municipal)			
Sectoral Policy	GHG mitigation	Climate Crisis Adaptation	Just Transition	Green Growth
	· Carbon neutral city · Regional energy conversion · Green building and transportation · Carbon Sinks/CCUS · International reduction initiatives · Comprehensive handling of information	· Measures to adapt to the climate crisis (State, local, public institutions) · Responding to the regional climate crisis · Water management · Green national territory · Conversion of agricultural, forestry, and fisheries · Adaptation center	· Social safety net · Special district · Business conversion · Minimize asset loss · National participation · Enhancing cooperatives · Support Center	· Green economy · Green industry · Green management · Green technology · Tax system · Green finance · Information and communication · Circular system
Implementation Base	Implementation of carbon neutrality and green growth (local governments, production and consumption, green living, carbon neutral support centers, etc.)			
	Climate Change Response Fund			

[Figure 4-1] Overview of Framework Act on Carbon Neutrality, Green Growth

Climate Crisis Adaptation

The Carbon Neutrality Act has enhanced policies to proactively prepare for intensifying climatic disasters and adapt to the climate crisis. To measure, analyze, and report changes in the concentration of GHGs in the atmosphere, and to improve the precision of climate crisis monitoring and forecasting, a meteorological information management system has been established. In addition, a climate crisis adaptation information management system will be operated to explore and assess the effects of the climate crisis on the environment. And,

Climate Crisis Adaptation Measures will be established and monitored every five years at the national level, including vulnerable groups and catastrophe prevention, and then expanded to provinces, cities, counties, and districts.

Just Transition

Measures on just transition have been introduced in the Act to protect and assist regions and groups harmed by the transition to carbon neutrality. The Ministry of Trade, Industry, and Energy and the Ministry of Employment and Labor will collaborate to reinforce the climate crisis social safety net and develop comprehensive support measures, such as employment stability, unemployment assistance, and business conversion assistance. The government will identify and support vulnerable places significantly impacted by the rapid implementation of carbon neutrality, operating a "just transition support center" as a support organization.

Green Growth

As one of the primary carbon neutrality implementation strategy, green growth measures are also developed to implement a green economy and promote and support green industries. Technical assistance and financial support to reform the system, as well as policies such as the creation of financial products to combat the climate issue have been included in the Act to stimulate the development and commercialization of green management and green technology. In addition, green transformation of the entire society and economy will be strongly supported with standardization of green technologies and industries, creating green jobs.

Climate Change Response Fund

In January 2022, the Climate Response Fund was established to support the long-term development of carbon-neutral policy and industrial restructuring. The fund this year has a total budget of 2.4 trillion won, focusing on four main areas: (1) GHG reduction, (2) the development of a new promising and low-carbon industry ecosystem, (3) fair transformation, and (4) institutional and infrastructural construction. It intends to give top priority assistance for reduction initiatives that maximize GHG reduction impacts in the future, as well as to constantly increase the size of investment in green finance and technology development projects.

1.2.3 Emission Trading Scheme

Greenhouse gas emission trading scheme was first introduced in Korea in 2015. After completing the first (2015-2017) and the second planning period (2018-2020), it is now in the third planning period (2021-2125). Despite the fact that its emission trading system is still in its early phases of implementation, it has two significant advantages (Song, 2021). First, the scope of GHGs susceptible to the emission trading scheme is broader in comparison to large countries. Korea has six of the seven GHGs defined by the international community, while EU ETS covers three GHGs and RGGI and China covers only one. Second, the share of emissions that are subject to the emission trading scheme is very high, at 73%, which is far

higher than other countries. However, most allocation systems are free of charge, and allowances are relatively generous. The greater the share of free allocation, the less motivation there is for enterprises to sell emissions rights. For the second planning period, the proportion of paid allocation was 3%, and it is expected to be 10% during the third planning period. The carbon-neutral scenario emphasizes the establishment of a virtuous cycle in which carbon costs are reflected in power generation costs by strictly managing the total emission allowance of the emission trading system and raising the paid allocation ratio as Korea's carbon reduction target is strengthened (Cooperation of related ministries, 2021).

1.2.4 GHG Target Management System

The Target Management System (TMS) is a regulation program that manages the emissions of small and medium-sized businesses whose emissions are relatively low and not covered by the emission trading scheme. A corporation subject to the TMS is obligated to make voluntary efforts not to exceed a quota on GHG emissions or energy consumption determined by the government in cooperation with the company. If a corporation falls short of the goal, it will receive an improvement order or be penalized. Since the TMS was initially implemented in 2010, the emissions and energy consumption thresholds above which enterprises must comply have been reduced three times. Based on the latest three-year average GHG emissions, the current criteria for an entity and a business site are 50,000 tons CO2eq (energy consumption of 200TJ) and 15,000 tons CO2eq (energy consumption of 80TJ) respectively.

1.2.5 Institutional Framework

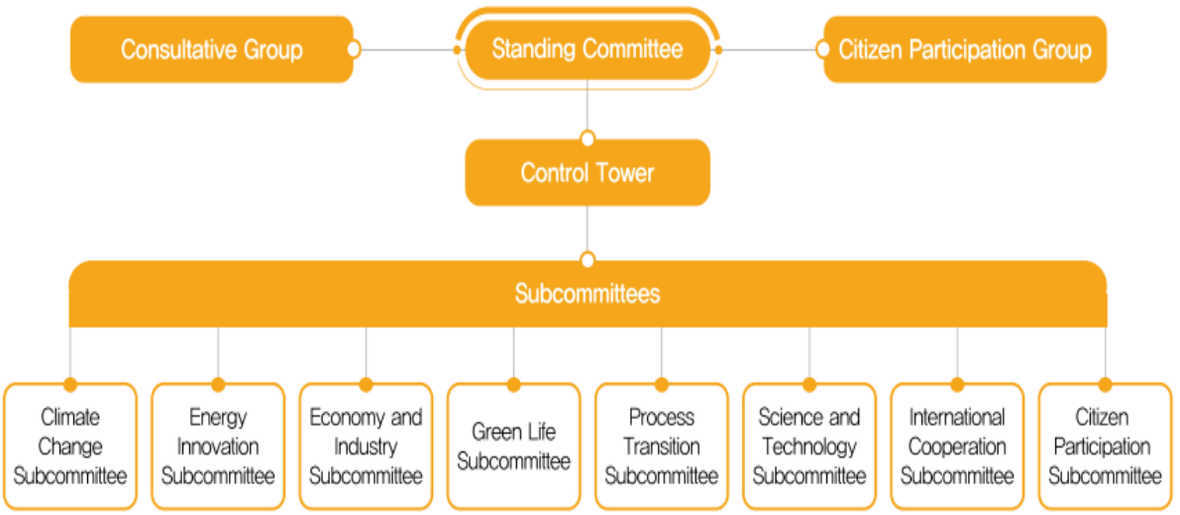
Carbon Neutrality can be achieved only though collaboration across sectors. To ensure transparent and effective implementation of GHG emission reduction in Korea, the Office for Government Policy Coordination and the Ministry of Environment takes a lead in coordinating and managing the tracking and assessment process, while each sector is managed by relevant government ministry and office. Ministry taking in charge of each sector shall develop appropriate performance index, set goals and collect relevant data for tracking and evaluation.

Categoty	All	Transition	Industry	Building	Transport	Waste	Public	Agriculture & livestock	Forestry
Led by	MOE OPC	MOTIE	MOTIE	MOLIT MOTIE	MOLIT MOTIE	MOE	MOE	MAFRA	KFS
Supported by	Relevant ministries & offices	–	MAFRA, MOLIT, MOF	–	MOE MOF	–	MOLIT MOTIE	RDA KFS	–

Source: The Government of the ROK(2022b)

[Figure 4-2] Institutional arrange for GHG reduction progress tracking and assessment

In the meantime, Korea has launched the 2050 Carbon Neutrality Commission, the key governance to support its carbon-neutrality transition in May 2021. The Commission is co-chaired by the Prime Minister and a representative from the private sector, and its membership is broad from cabinet members to businesses, experts, the youth and civil society from the private sector. The main responsibility of the Commission includes reviewing carbon-neutrality policies and taking stock of the NDC implementation. Furthermore, in order to directly hear the views of the general public, region, and field, industry, labor, civil society, youth, and local governments develop and communicate a "Consultative Group," and a "Citizen Participation Group" is formed and run (Yoon, 2021).

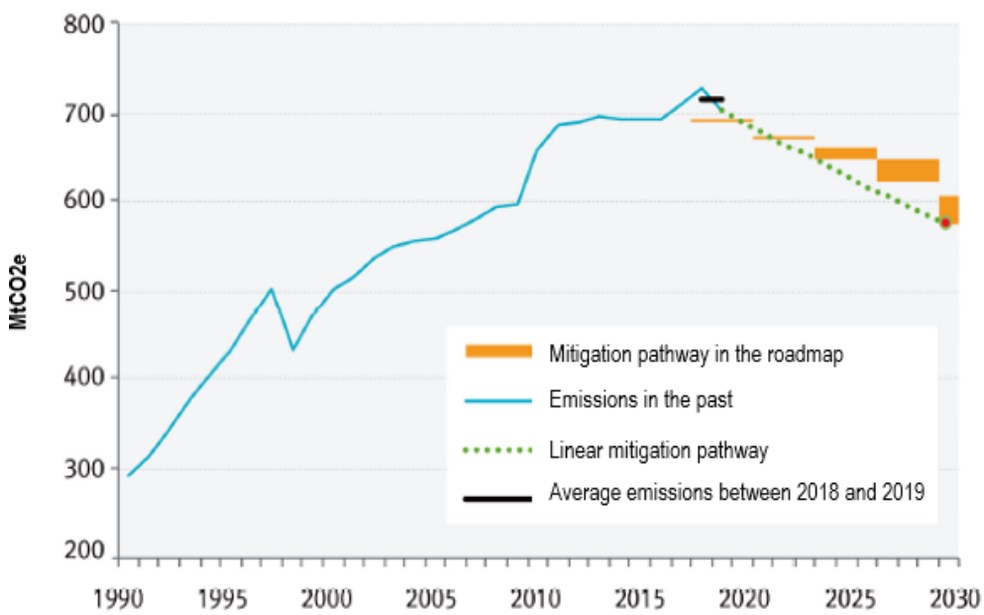


Source: The Government of the ROK (2022a)

[Figure 4-3] The structure of Carbon Neutrality Commission

1.3 GHGs Reduction Target vs. Progress[37]

Although Korea made an early commitment to reduce its GHG emissions in 2014, the country has not been very effective at monitoring and analyzing the GHG reduction progress. By concentrating mainly on qualitative indicators, the first official evaluation of 2020 roadmap implementation failed to adequately represent the implementation performance. Accordingly, the total GHG emissions exceeded the initial emission target by 5.0% and 8.6% for the years 2014 and 2015, respectively, even though the evaluation report estimated that the implementation goals had been met by 92% and 98%, respectively (Ministry of Environment, 2020). In order to address the issues with the existing evaluation method and to analyze the sector-specific reduction initiatives, the target emissions or unit emissions established by sector were compared with actual emissions performance in the 2030 updated roadmap review.



Source: The Ministry of Environment (2020).

[Figure 4-4] Mitigation pathway in the roadmap vs. actual emission between 2018 and 2019

The most current official assessment report, which examined GHG reduction efforts in 2018 and 2019, was published in 2021. According to the report's key findings, Korea still needs to exert effort in a variety of sectors to meet its GHG reduction target. The target of 690.9 million tons of CO_{2e} was exceeded by an average of 24.4 million tons of CO_{2e}, or 3.5%, between 2018 and 2019. The energy intensity effect and the carbon intensity effect are the key contributing factors, hence it is necessary to increase energy efficiency and switch to low-

[37] This section is a summary of "Evaluation of Greenhouse Gas Reduction Implementation Performance (2018-2019)" by the Ministry of Environment (2020).

carbon energy sources. To reduce energy intensity, the government must maintain and increase consistent long-term policies and expenditures in energy efficiency, the supply of renewable energy, and the replacement of high-carbon energy sources (Ministry of Environment, 2020).

The performance results for each key sector are specifically as follows. First off, the energy sector's average CO_2 emissions from 2018 to 2019 were 260.4 million tons, or around 6.7% above than the target level. Continuous energy reduction and demand management activities in the electricity and heating are necessary to meet the reduction target. As of 2019, the industrial sector accounted for 55.6% of the national emissions, making it the greatest contributor of GHG emissions. The average industrial sector emissions between 2018 and 2019 were 398.0 million tons CO_{2e}, or roughly 1.7% less than the target. However, it was due to a decrease in industrial activity that the emission target was successfully met. Therefore, efforts should be made to reduce energy and carbon intensity continuously. 153.0 million tons of CO_{2e} were released in the building sector, which was 5.0% more than the target level. Energy intensity is the primary culprit, hence it is essential to increase renewable energy production while also enhancing building energy efficiency. The average emission in the transportation sector was 100.4 million tons CO_{2e}, or around 7.3% more than the target emission. In the medium to long term, it is urgent to increase the average fuel efficiency of cars and supply eco-friendly cars to reduce GHGs in the road sector, which accounts for 97% of GHG emissions in the transportation sector.

1.4 Carbon Neutrality Strategy and Scenarios

1.4.1 Long-term Low Greenhouse Gas Emission Development Strategy[38]

The ROK submitted 2050 Carbon Neutral Strategy, so called Long-term Low GHG emission development strategy (LT-LEDS) in December 2020. In the LEDS, the country envisions to achieve carbon neutrality by 2050, using the Korean New Deal, specifically the Green New Deal and the Digital New Deal, to harness green innovations and advanced digital technologies. The strategy has been developed through active consultations with various groups. The initial draft proposal was prepared by 2050 Low-Carbon Vision Forum in which academia, industry, and civil society participated, followed by online survey, expert consultation and public discussion. There are five key elements for the national carbon neutrality: 1) Increasing the use of renewable energy and hydrogen in all industries; 2)

[38] Joint Relevant ministries of the Republic of Korea (2020)

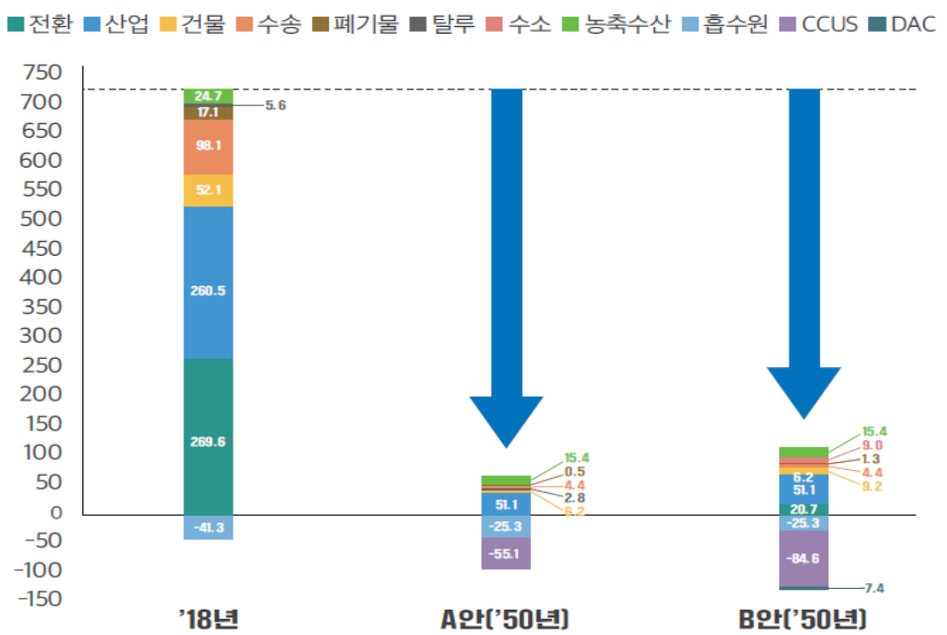
significantly enhancing the energy efficiency of buildings; 3) implementation of carbon removal and other future technologies on a commercial scale; 4) expanding the circular economy to strengthen industrial sustainability; and 5) increasing carbon sinks. The strategy also presents key strategies for each sector as shown in Table 4-2.

[Table 4-2] Carbon Neutrality Strategies by Sector (The Government of the Republic of Korea, 2021)

Sector	Major Strategies
Energy	The government will develop an accurate power demand and supply forecasting system and provide enhanced support for future innovative technologies, e.g., Energy Storage System (ESS) for reliable power supply, and hydrogen fuel cells for auxiliary power sources. Korea plans to phase out coal power plants or convert them into LNG power plants. In addition, Carbon Capture, Utilization and Storage (CCUS) technology will be applied to coal-fired power plants to minimize GHG emissions.
Industry	The government plans to: i) facilitate the industry sector's transition to a high-value-added structure by combining ICT to the existing industries; ii) use regulatory measures in combination with incentives to improve energy efficiency; and iii) strengthen policies and technology developments for reusing wastes as resources that could dramatically reduce the use of raw materials and fuels for the purpose of efficient use of resources.
Transportation	The government plans to: i) promote the use of public transportation; ii) expand shared mobility; iii) build systems for traffic demand management and intelligent transportation; iv) reduce energy consumption by promoting commercial use of autonomous vehicles; and v) promote the modal shift from road to rail or shipping, the low-carbon modes of transportation.
Building	The government plans to use a combination of regulatory measures and incentives in two-track approaches for: i) newly-built buildings and ii) old buildings. Starting from 2020, all new public buildings to be built will be subject to the zero-energy building standards, and from 2030, all new public and private buildings (with gross floor area of 5 million ㎡ or larger) will be subject to the standards. Old buildings, if they adopt green remodeling solutions, will be eligible for government incentives such as tax cuts and grants for interest expenses. Along with improving energy efficiency, using low-carbon energy sources is another important mitigation strategy.
Waste	The waste sector's strategy seeks to identify ways to convert wastes into useful materials and reuse them as energy sources. Any unrecycled wastes left should be disposed of in an eco-friendly manner. Plastics are one of the most serious problems in this sector that should be dealt with urgently, and measures to phase out plastics need to be established for a plastic-free society.
Agriculture	ICT-enabled smart farming could minimize inputs (i.e., energy sources, fertilizers, water, etc.), and farm automation could further improve productivity. Therefore, the government plans to scale up the deployment of smart technologies on farms. To reduce GHG emissions originating from crop cultivation and livestock farming, it is essential to develop and deploy low-carbon farming practices and replace fossil fuels used on farms with clean energy sources.
Carbon Sinks	Innovative forest management is a key to improving the aging forest structure, promoting the use of wood products/timber and increasing carbon stocks. The government plans to increase carbon sinks by creating urban green spaces for recreational use, restoring degraded forestlands and tree-planting in underutilized lands. It will continue its forest management to maintain the forest carbon removals at the highest level possible by changing tree species and implementing programs to keep the forests healthy.

1.4.2 Carbon Neutrality Scenarios[39]

The carbon neutrality scenario is the subsequent response to the 2050 goal of carbon neutrality. As depicted in Figure 5, its creation involves active consultations with diverse groups of professionals, residents, and economic sectors. Based on the principles of Responsibility, Inclusiveness, Fairness, and Competition, the carbon-neutral scenario was formed from the vision "As a safe and sustainable carbon-neutral society protected from the impact of the claim." Ultimately, two scenarios were accepted, and both intended to attain net zero in Korea by 2050 without the use of foreign reduction credit.



[Figure 4-5] 2050 Carbon Neutrality Scenarios (Yoon, 2021) [40]

The only areas in which the two scenarios differ are energy conversion and transport, hydrogen, and evasion. Assuming that the remaining emissions (80,4 million tons in A and 108,3 million tons in B) are absorbed and eliminated by carbon reduction technologies such as forests and CCUS, the net emissions are estimated to be zero. In the first scenario (A plan), fossil fuel power generation is supposed to be completely eliminated in the energy sector to achieve zero emissions, while electric and hydrogen vehicles are to be expanded to 97% in the transportation sector, and only green hydrogen is to be used in order to minimize emissions.

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[39] Joint Relevant Ministries of the Republic of Korea(2021a) (https://www.2050cnc.go.kr/eng/board/read?boardManagementNo=28&boardNo=608&searchCategory=&page=1&searchType=&searchWord=&menuLevel=2&menuNo=65)

[40] 윤순진(2021)

In the second scenario (proposal B), coal power is projected to cease, as in proposal A, but a part of LNG power generation is supposed to remain for flexible power usage. In addition, some internal combustion locomotives are assumed to continue to operate due to the development of alternative fuels (e-fuels, etc.) in the transportation industry. Plan B releases more emissions than Plan A, but the final net emission in Plan B is also zero by using carbon absorption and removal technologies such as CCUS more aggressively.

Despite disparities between Plan A and B, the increase of renewable energy is crucial as shown in Table 4-3. The proportion of renewable energy in the energy sector is assumed to climb to 70.7% in Plan A and 60.9% in Plan B, respectively. A specific level of power generation is maintained due to the slow reduction of nuclear power during operation during the design life. The discrepancy between the proportion of nuclear power plants in Plans A and B is related to the difference in usage rate, which is 77% of the world's average utilization rate over the past decade and 87% of Plan B, which is based on enhancing safety measures. In addition, although not yet marketed, hydrogen-based fuel cells and carbon-free new power turbines are also responsible for the creation of electricity.

[Table 4-3] Energy Mix

Scenario	Nuclear Power	Coal	LNG	Renewable	Fuel Cell	NEA Grid	Carbon Free gas turbine	By-product Gas	Total
A	76.9	0.0	0.0	889.8	17.1	0.0	270.0	3.9	1257.7
B	86.9	0.0	61.0	736.0	121.4	33.1	166.5	3.9	1208.8

Energy conversion is critical to achieving carbon neutrality. However, simply altering the energy sector will not result in carbon neutrality. It is particularly critical to cut emissions in the industrial sector as well, which is responsible for 36% of GHG emissions (54% including indirect emissions). In all A and B plans, the 2050 carbon neutral scenario cuts industrial sector emissions by 80.4%, from 260.5 million tons CO_{2eq} in 2018 to 51.1 million tons CO_{2eq}. However, in Plan A and B, industrial sector emissions account for 63.6% and 47.2% of total emissions, respectively, up from 35.8% in 2018. In the building sector, consumption is expected to fall by nearly 23% in 2018, from 46.9 million TOE to 36.0 million TOE, while GHG emissions are expected to fall by 88.1%, from 52.1 million tons CO_{2eq} to 6.2 million tons CO_{2eq}. Furthermore, the agriculture and livestock sectors should lower their CO_2 emissions by 37.7%, from 24.7 million tons CO_{2eq} to 15.4 million tons CO_{2eq}, and the garbage sector should reduce their CO_2 emissions by 74.3%, from 17.1 million tons CO_{2eq} to 4.4 million tons CO_{2eq}.

1.5 Major barriers and important issues

1.5.1 Energy Intensive Economy

The ROK has a very high manufacturing-to-GDP ratio of 26.1% as of 2020, compared to Japan (19.5%), the EU (14.0%), and the United States (14.0%). In particular, six industries, including steel, petrochemical, cement, oil refining, displays, and semiconductors, account for 79% of the total industrial GHG emissions. The steel industry is the largest emission sources among the six. While the manufacturing sector has been a major contributor to Korea's economic growth, its expansion ultimately led to a rise in energy consumption and GHG emissions. Thus, carbon neutrality is a difficult goal to achieve in the country, as the industrial structure is heavily energy dependent. Despite the fact that GHG emissions per GDP have decreased due to industrial efforts, particularly greater energy efficiency, total emissions continue to climb. The elimination of GHGs implies an increase in costs for businesses, which is closely related to corporate competitiveness; hence, industrial opposition to strong carbon neutrality policies is still strong. Nonetheless, the reduction of GHGs is also crucial for business competitiveness, given the recent international demand for RE100 and the strengthening of ESG (Environment, Social and Governance) standards. To promote industry's engagement in carbon-neutral activities, it is necessary to combine regulation with incentives rather than relying solely on regulation alone. Under appropriate and effective regulations and incentives, the industrial sector should restructure its sector to be more environmentally friendly, create novel process technologies, and expand resource circulation.

1.5.2 A politically and ideologically motivated energy policy[41]

In the Republic of Korea, energy policy has become a political agenda that is heavily influenced by the political party in power. While the energy plan must be long-term and consistent for efficiency and stability, the major direction of the national energy basic plan varied from administration to administration. This is partially attributed to the regularity with which laws are altered, as the national energy plan is typically revised every five years, the same as the presidential system. When a new president is installed, a new energy plan is established as a result of the five-year presidential system. The 1st National Energy Basic Plan (2008–2030) prepared by the government of Lee Myung Bak in August 2008 recognized nuclear power as a major low-carbon energy source, planning to operating 41% of its

[41] 에너지신문(2022. 3. 4.), 『[사설] 이념·정치화 않는 에너지정책 바란다』, https://www.energy-news.co.kr/news/articleView.html?idxno=81129 (accessed on 15 June 2022)

electrical facilities as nuclear power. In January 2014, the government of Park Geun Hye announced the 2nd National Energy Basic Plan (2011-2035), which included a drastic reduction in the proportion of nuclear power plants in consideration of changes in power demand, transmission system conditions, and national water solubility since the first plan. In June 2019, the next administration of Moon Jae-In stated in the 3rd National Energy Basic Plan (2019-2040) that the life of outdated nuclear power plants will not be extended and previous plans to build further nuclear power plants are not to be proceeded. Consequently, the target share of new and renewable energy needed to be increased to 30 - 35% by 2040, while nuclear power and coal power would need to be reduced progressively. However, the administration of the newly elected president Yoon Seok Yeol supports the expansion of nuclear energy, which would need the modification of the current carbon neutrality scenarios. The course of the country's nuclear policy has been continuously altered. Energy policies, which play a crucial role in the state's foundation, have been formed not in a consistent way, depending on which political party becomes the dominant party. As energy plans have been politicized, an "opposite extremes" policy has been adopted and implemented. We need a long-term and consistent energy policy that fit for our condition.

1.5.3 Need for appropriate monitoring and evaluation framework

For GHG reduction to be effective, it is required to build a monitoring and evaluation framework capable of measuring the efficacy of relevant policies and programs. Numerous indicators and quantitative target indicators were added to the most recent implementation evaluation report for 2018-2019 in order to compensate for the flaws in the existing monitoring and evaluation system. However, there is a drawback in that it is not stated that monitoring and evaluation results can be incorporated in each sector's policy. To achieve carbon neutrality, it is required to construct a system to design and monitor indicators capable of evaluating the efficacy and level of implementation of policies, and to feed the evaluation results back into policymaking.

1.5.4 Difficulties in the Expansion of Renewable Energy

As of 2018, the energy sector accounts for 86.9% of the country's total GHG emissions. Therefore, energy conversion is the most crucial aspect of carbon neutrality in Korea. Nevertheless, the country's share of (new and) renewable energy generation in 2020 is only 7.43%, the lowest among OECD member states (OECD, 2022)[42]. This indicates that the

[42] OECD (2022), “Renewable energy (indicator),” https://doi.org/10.1787/aac7c3f1-en, (accessed on 15 June 2022)

expansion of renewable energy is not rapid enough to achieve carbon neutrality. Since the passage of the Alternative Energy Development Promotion Act in December 1987, the country has promoted the development of renewable energy at the national level. It has established a new and renewable energy facility certification system, a roadmap for mid- to long-term new and renewable energy supply and promotion strategies, and a system to promote related industries as major industries. Additionally, it has designated specialized institutions to strengthen support for the commercialization of renewable energy. Large-scale projects are subject to an environmental impact assessment, and environmental evaluation rules, which are the nature of renewable energy site guidelines, are designed to encourage environmentally responsible facility locations. Moreover, local inhabitants are urged to engage in the project through the promotion of benefit sharing and lending programs (Korea Energy Corporation New and Renewable Energy Center, 2021a). The Ministry of Trade, Industry, and Energy and Korea Electric Power Corporation are attempting to expand the system connection for renewable energy. It ensures unrestricted system access for small firms, assists with building expenses, temporarily raises the standard for linked capacity per transformer, and discloses system network information. However, this resulted in a time lag as it took time to expand the requisite distribution lines or transformers. As a result, due to a shortage of power substations or distribution line capacity, system connection is not completed properly when it is necessary, and there are a great number of renewable energy facilities waiting to be connected. Moreover, as renewable energy sources with variable characteristics proliferate, the complexity of system management increases. In the case of renewable energy, it is first purchased in the power market without participating in price bidding; therefore, there is no market mechanism to improve renewable energy prediction because there is no incentive or punishment system for prediction.

Finding an adequate location and increasing local support for the power system infrastructure are additional barriers for renewable energy. Regional conflicts in Korea are intensifying as a result of damage to mountainous regions and the influence of solar and wind power development on physical built environment. Since 2015, when its yearly installation capacity surpassed 1 GW for the first time, solar power in the country has been growing at an exponential rate. Solar power on the mountain has frequently been achieved by chopping down trees that act as carbon sinks, which is undesirable from a climate change standpoint. Consequently, local governments have developed their own regulations to restrict the site of solar and wind power installations. In addition, licensing procedures and regulations pertaining to renewable energy have been tightened, making it more challenging to secure permits for renewable energy projects. The proliferation of renewable energy installations is

causing an increase in the number of cases in which a project is terminated during the environmental impact assessment procedure.

1.5.5 Population Decline and Urban Decline

As a result of the country's relatively low fertility rate, its population is fast declining. Another cause for concern is the high population density in the Seoul Metropolitan Area (SMA). As of 2019, more than fifty% of the nation's population resides within the SMA. Future projections indicate that the demographic difference between SMA and Non-SMA will continue to widely expand. This change in population distribution is closely related to the demand for transportation and building energy, as the declining population in the Non-SMA will lead to inefficient land use, an increase in traffic demand, and an increase in GHG emissions. Moreover, the current population decline in nonmetropolitan cities is tied to the regional industrial structure. Specifically, manufacturing-based cities experience population and economic competitiveness declines. As the carbon neutrality policy is implemented, the attractiveness and competitiveness of the region are expected to deteriorate even further due to a lack of human capital and financial resources, resulting in an even faster decline. Therefore, a regional strategy for an inclusive and equitable energy transition is necessary. Diverse support measures are necessary not only for process conversion programs for industries and people as a result of energy conversion, but also for place-based energy process conversion that takes into consideration regional characteristics.

1.6 Summary

With its manufacturing-based, energy-intensive industrial structure, Korea ranks as the 11th highest emitter of GHGs globally, making carbon neutrality challenging. Future changes in the demographic structure, geographical decline, and industrial structure as a result of technological advancement will present both opportunities and obstacles for carbon neutrality. Nonetheless, with a strong desire to achieve carbon neutrality by 2050, the government set an ambitious GHG reduction target to reduce by 40% from the 2018 level by 2030 and has introduced various policy and institutional measures. The Framework of Carbon Neutrality, Green Growth is at the center of the legal framework for carbon neutrality policy, and the Carbon Neutrality Commission has been established to facilitate participatory governance. In addition, since 2015, the emission trading system has been in place to reduce GHG emissions in a cost-effective manner. However, the country is facing many challenges. First, energy transition, which is the most critical component for carbon neutrality, has been beset by

technical, economic and social reasons, such as technical difficulties and low social acceptability for expanding renewable energy. Second, due to the energy and economic nature of Korea's manufacturing sector, achieving carbon neutrality will be challenging without innovative and systematic approaches across all industry sectors. Furthermore, proper policies for a just transition should be in place during the carbon neutrality policy implementation process, so that disparities in negative consequences between regions or industrial sectors can be reduced. Carbon neutrality is no longer a question of choice but a necessary obligation that must be met despite these obstacles. Through a combination of appropriate legislation and incentives, education, and social consensus-building, the government should continue to advance its efforts to achieve carbon neutrality.

2. Net-Zero R&D Strategies[43]

2.1 R&D Policy

2.1.1 2050 Carbon neutral Promotion Strategy(2020)

After declaring 2050 carbon neutral in October 2020, Korea presented the 3+1 policy direction and 10 key tasks to promote carbon neutral through the establishment of the '2050 Carbon neutral Promotion Strategy' in December of the same year. The 3+1 policy directions of the carbon-neutral strategy for 2050 are presented as low-carbon economic structure, creation of a promising low-carbon industrial ecosystem, process transition to a carbon-neutral society, and strengthening of the carbon-neutral institutional foundation.

The 10 key tasks are energy conversion, high-carbon industry, future mobility, cities and land, promising industries, innovative ecosystem, circular economy, incorporation into new industrial system, regional focus, public awareness, emission trading system, green finance, R&D, international offer cooperation.

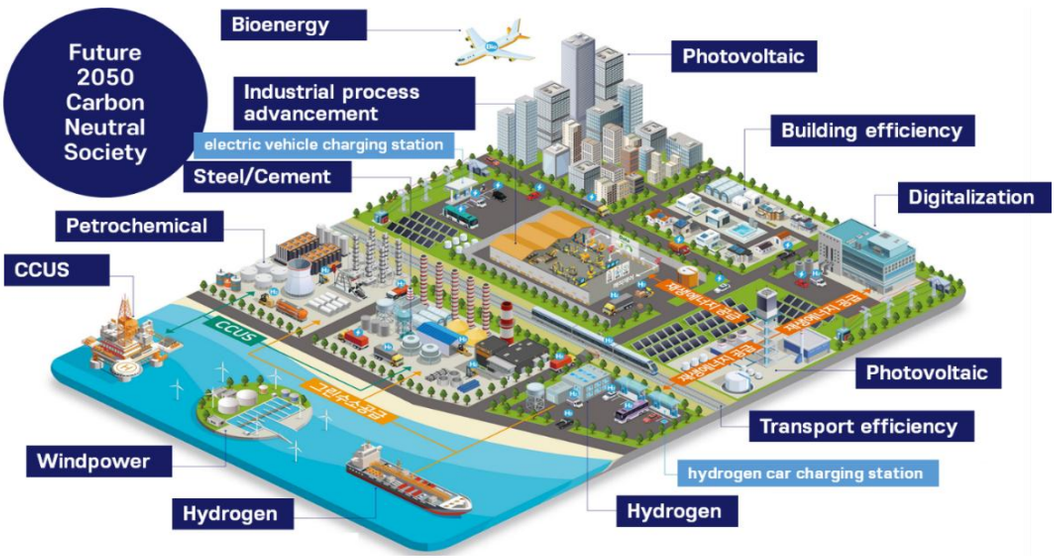
Research and development (R&D) is one of the key tasks for strengthening the carbon-neutral institutional foundation, and the Ministry of Science and ICT establishes a carbon-neutral R&D strategy as the lead ministry, and the National Science and Technology Advisory Committee appoints a special committee for carbon-neutral R&D.

2.1.2 Carbon-neutral Technology Innovation Promotion Strategy (2021)

Therefore, at the 16th Science and Technology Ministerial Meeting on March 31, 2021, the 'Carbon neutral Technology Innovation Promotion Strategy' and 'Carbon-neutral R&D Investment Strategy' were discussed and finalized for the realization of the 2050 carbon-neutral goal. 'Carbon neutral technological innovation promotion strategy' presents detailed implementation plans for each of the five strategies for technological innovation, along with goals and strategies to achieve by 2050 for each of the 10 core technologies.

The 10 core technologies considering the long-term low-carbon power generation strategy (LEDS) and the reduction contribution of technologies are solar power/wind power, hydrogen, bio energy, steel/cement, petrochemical, industrial process, transportation, Buildings, Digitization, and CCUS.

[43] Author: Mina Lee(Green Technology Center, GTC)



Source: Joint Relevant Ministries of the Republic of Korea (2021b)

[Figure 4-6] 10 key technologies in Carbon-neutral Technology Innovation Promotion Strategy

2.1.3 Carbon-neutral R&D Investment Strategy (2021)

「Carbon-neutral R&D investment strategy」 suggests investment directions for all carbon-neutral R&D fields, from resource circulation and adaptation to climate change, so that the effect of reducing carbon dioxide is large and the R&D needed immediately in the field can be urgently carried out. Therefore, the government plans to expand investment continuously, focusing on areas with high GHG reduction effects, such as investing 1.59 trillion won in 2021 in renewable energy, industrial processes, and energy efficiency. In addition, according to this strategy, each ministry agreed to plan and promote R&D projects aimed at application to industrial sites by sector as shown in Table 4-4.

[Table 4-4] Areas of focus on carbon-neutral R&D by ministries

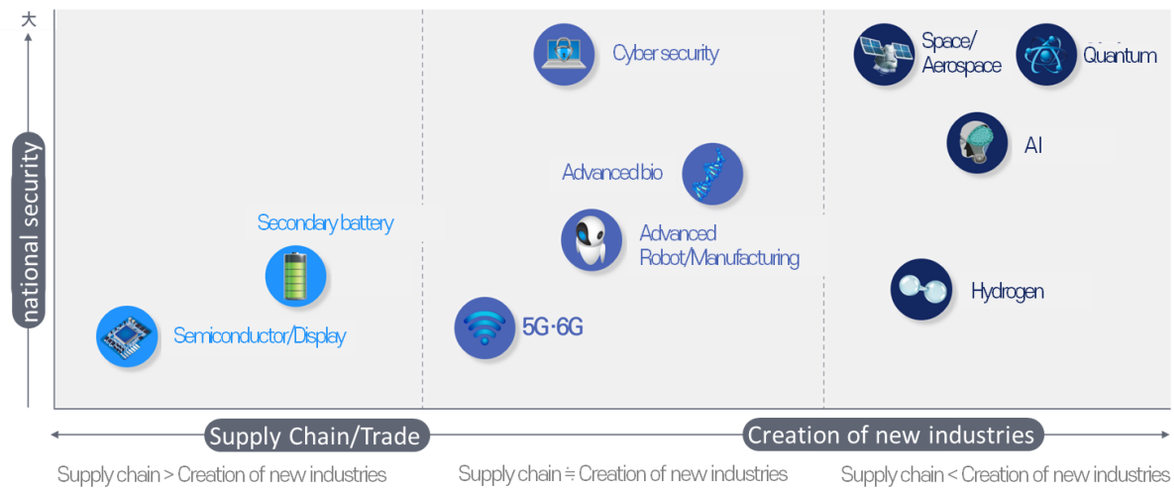
Ministries	Areas of focus on carbon-neutral R&D by ministries
Ministry of Science and ICT	• Securing source technology for carbon-neutral core fields and enhancing energy efficiency using ICT
Ministry of Trade, Industry and Energy	• Industrial process improvement to reduce GHG emissions for industries with high carbon emissions • Technology for revitalization of renewable energy and hydrogen economy, system stabilization, and consumption efficiency
Ministry of Land, Infrastructure and Transport	• Strengthening technology development for zero-energy buildings, eco-friendly transportation, and hydrogen infrastructure
Ministry of Environment	• Reinforcement of resource recycling technology such as plastic removal technology, carbon absorption, and climate adaptation technology
Ministry of Oceans and Fisheries	• Enhanced carbon absorption and storage based on marine energy and marine ecosystems

Source: : Joint Relevant Ministires of the Republic of Korea (2021c)

2.1.4 Strategy for the Selection and Development of National Essential Strategic Technologies (2021)

As for 「Strategy for the Selection and Development of National Essential Strategic Technologies」, the government selects technologies that Korea must take the lead in from an integrated perspective, such as supply chain and commerce (economic security), national security (diplomacy and defense), and new industries (future innovation). Accordingly, the final 10 technologies, including artificial intelligence, 5th generation (5G) and 6th generation (6G), advanced biotechnology, semiconductor/display, secondary battery, hydrogen, advanced robot/manufacturing, quantum, space/aerospace, and cybersecurity, are listed as world technologies. From the point of view of hegemony, it was selected as a 'necessary national strategic technology' that should be intensively fostered and protected.

For technologies directly related to carbon neutrality, secondary batteries and hydrogen were selected. In the case of secondary batteries, they are important as eco-friendly energy sources such as eco-friendly and electric vehicles. In the case of hydrogen, which is expected to account for about 30% of energy sources in 2050, it is necessary to secure technological competitiveness throughout the entire cycle, from clean hydrogen production to transport, storage and utilization.



Source: : Joint Relevant Ministires of the Republic of Korea (2021d)

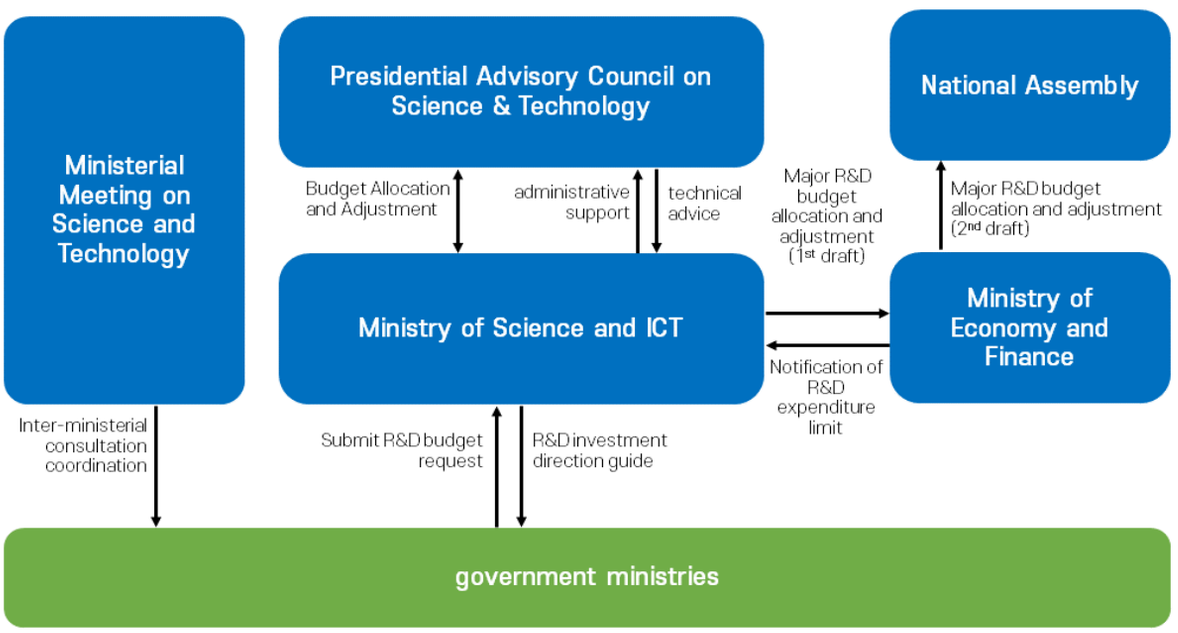
[Figure 4-7] 10 key technologies in Strategy for the Selection and Development of National Essential Strategic Technologies

2.2 R&D budget

2.2.1 Government R&D budget system

Government R&D projects in Korea can be broadly divided into major national R&D projects and general national R&D projects. Major national R&D projects refer to R&D in science and technology fields such as mid- to long-term large-scale R&D for more than 5 years and basic science R&D. The major national R&D projects accounts for about 75% of the total R&D budget. General national R&D projects are national R&D projects in the humanities and social fields and R&D projects that require high security. The authority to allocate and adjust the R&D budget is held by the Ministry of Science and ICT for major national R&D projects and the Ministry of Strategy and Finance for general national R&D projects.

Carbon-neutral R&D budgeting is carried out in the same process as other R&D projects. In the case of major national R&D, each ministry first submits a request for national R&D for the next year, and the Ministry of Science and ICT allocates and adjusts the budget for R&D investment together with the Presidential Advisory Council on Science & Technology (PACST). PACST is the presidential continuation agency and serves as the highest level advisory and deliberation body for Korea's science and technology policy. After that, the Ministry of Economy and Finance submits the government R&D budget (2nd draft) to the National Assembly, and the R&D budget is finally decided after deliberation by the National Assembly.

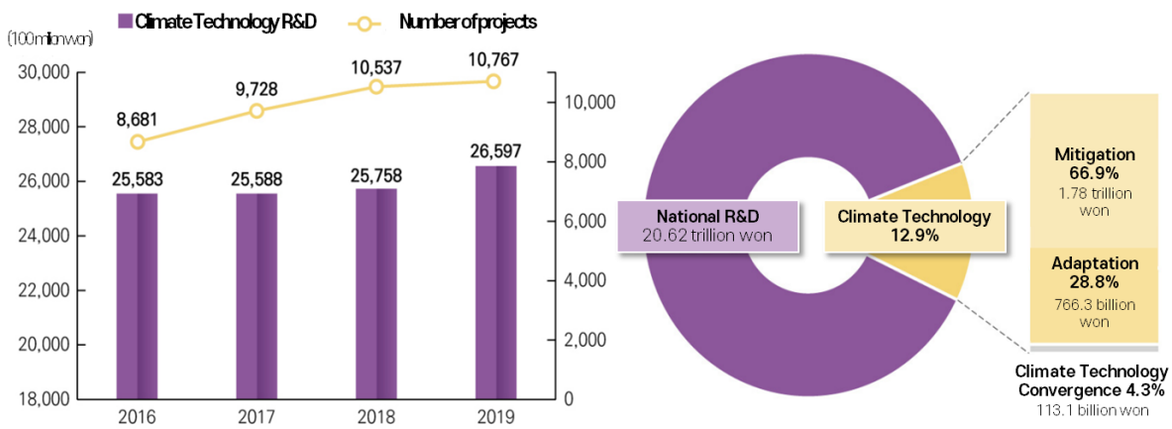


Source: KISTEP (2019)

[Figure 4-8] Korean major national R&D budget allocation system

2.2.2 Government and Private R&D Investment

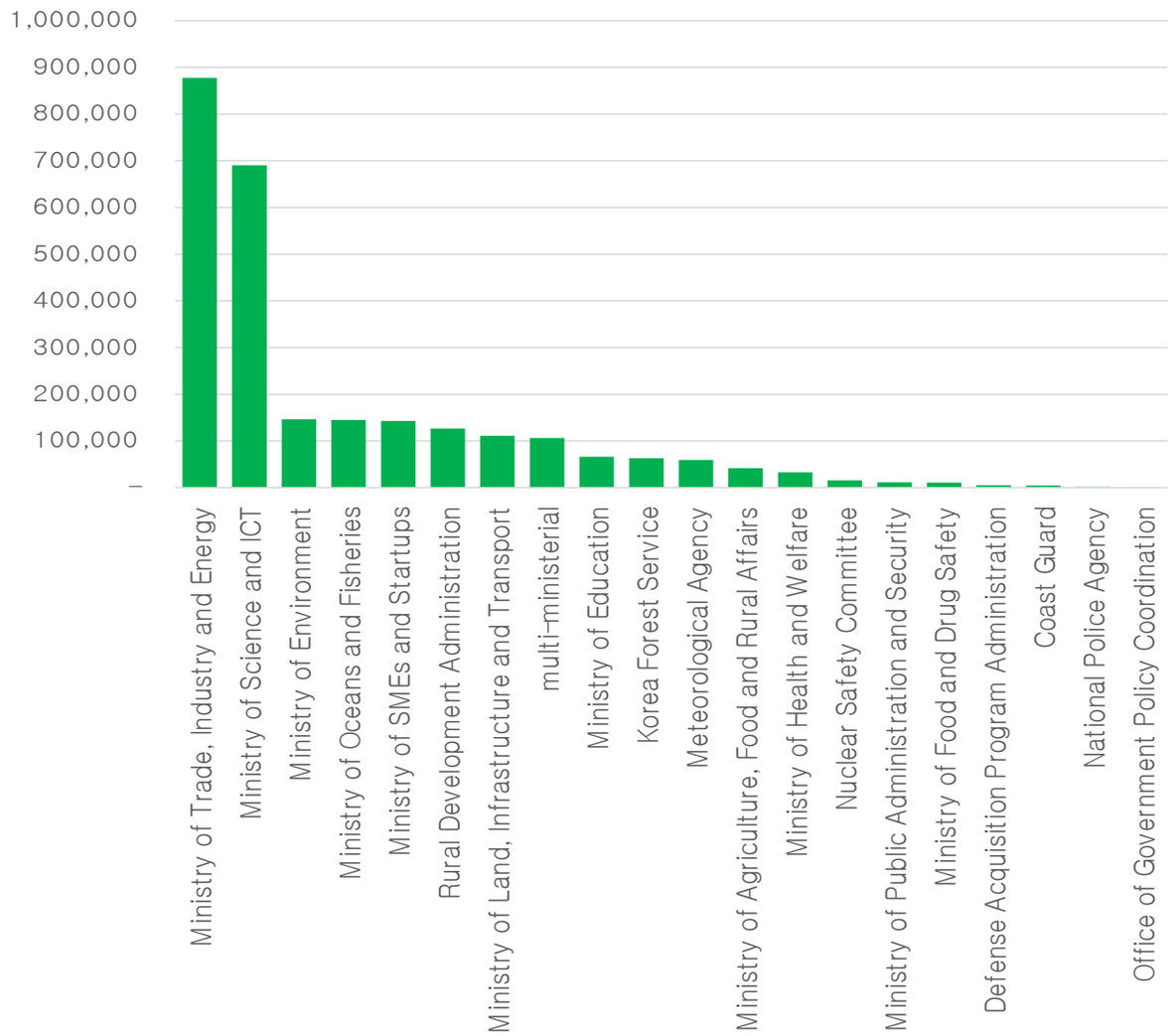
In Korea's climate technology R&D, 2659.7 billion won was invested in 10,767 projects in 2019, which accounts for 12.9% of the total national R&D projects. Climate technology can be largely summarized into mitigation technology that reduces GHG emissions, carbon utilization technology, and climate change adaptation technology. The climate technology R&D budget and the number of tasks have been steadily increasing at an average annual growth rate of 1.30% and 7.44%, respectively, since 2016. Of the climate technology R&D budget as of 2019, the GHG reduction sector was KRW 1.780.3 trillion (66.9%), the adaptation sector was KRW 766.3 billion (28.8%), and the convergence sector was KRW 113.1 billion (4.3%). Therefore, the proportion of R&D in the field of GHG reduction is high.



Source: 2019 Climate Technology R&D Investment & Performance Analysis (2021)

[Figure 4-9] Government R&D Investment in Climate Technology in Korea

According to the 2019 national R&D project standards, there are 396 projects that include climate technology, and 110 of them have climate projects accounting for more than 60% of the total project weight. The Ministry of Trade, Industry and Energy has 33 tasks, the Ministry of Science and ICT 14 tasks, the Ministry of Oceans and Fisheries and the Ministry of Environment 12 and 10 each.



Source: 2019 Climate Technology R&D Investment & Performance Analysis (2021)

[Figure 4-10] Investment in Climate Technology R&D by Ministries in Korea

For private R&D, there are 7,648 companies holding climate technology-related patents, and their sales volume is 168.68 trillion won as of December 2020. The size of private R&D investment in climate technology in 2020 is 7.29 trillion won. By sector, energy demand is the highest at 2.29 trillion won (27.8%), followed by energy storage with 1.89 trillion won (26.0%) and renewable energy with 1.423.1 trillion won (19.5%).

2.2.3 Government R&D Project

There are 24 projects worth 10 billion won or more, including the new and renewable energy core development project of the Ministry of Industry, the climate change response technology development project of the Ministry of Science and Technology, and the global top environmental technology development project of the Ministry of Environment.

New and renewable energy core development project of the ministry of Ministry of Trade, Industry and Energy

The purpose of this R&D program is to secure global competitiveness in renewable energy such as solar and wind power systems to achieve 20% of the proportion of renewable energy generation in 2030, and to develop core parts localization technology as shown in Table 4-5. In addition, green hydrogen production for building a hydrogen industry ecosystem, localization of hydrogen charging stations, securing the safety of hydrogen life cycle, and development of high-efficiency fuel cell technology are also included.

[Table 4-5] Project main contents by technology of New and renewable energy core development project of the ministry of Industry

Technology	Project Main Contents
photovoltaic	• Crystalline silicon solar cell unit cost reduction, high efficiency, and technology development for each supply chain • Development and demonstration of high-value-added market expansion technology to expand domestic distribution and enter overseas markets • Mid-to-long-term promotion of next-generation solar cell technology development to preoccupy new markets
wind power	• Promoting technology development for large offshore wind power generation systems to preoccupy the wind power export market • Technology development and demonstration to reduce wind farm LCOE such as installation, construction, and grid connection
fuel cell	• Focus on technology development to improve fuel cell performance, durability, and price reduction • Securing a business model for the commercialization of fuel cells and promoting technology development
hydrogen	• Technology development for hydrogen production, hydrogen storage and transportation, infrastructure construction and safety establishment for the creation and reinforcement of the hydrogen industry ecosystem
bio energy	• Focus on developing technologies to improve bioenergy productivity and securing urban-friendly production technologies using various raw materials
waste	• Development of retrofit technology and export-linked technology to improve the energy conversion efficiency of various wastes
solar thermal	• Large-scale solar system design and operation technology, development of solar thermal application industry technology
geothermal	• Development of technologies such as geothermal resource exploration and evaluation techniques to secure the economic feasibility of geothermal energy • Technology development such as high-efficiency heat pumps and cooling/heating systems using alternative refrigerants

Technology	Project Main Contents
hydrothermal	• Development of core element technology related to hydrothermal energy to maximize utilization of seawater thermal energy such as hot water from power plant and minimize operation/maintenance
waterpower	• Localization of major parts such as water wheel and development of technology to improve the efficiency of water turbine generator • Development of technology for localization of large-scale hydroelectric power generation systems targeting old hydroelectric power generation/replacement markets
ocean power	• Development of source technologies for using marine energy such as tidal power, tidal current, wave power, and ocean temperature difference, and promotion of real-sea empirical research projects
coal use	• Design technology independence and Korean standard model development through 300MW class IGCC demonstration plant
renewable fusion	• Development of fusion technology between new and renewable energy sources or with heterogeneous technologies to improve new and renewable energy efficiency, reduce power generation cost, and provide stable energy
Hydrogen fusion charging station pilot project using biogas	• Development of hydrogen production technology using biogas and demonstration by building a charging station

The project period of this program is from 2006 to 2025, and KRW 2.79 trillion was executed by 2020. The budget for each technology for the period 2016-2020 is detailed in Table 4-6.

[Table 4-6] 2016-2020 budgets by technologies of New and renewable energy core development project of the ministry of Industry

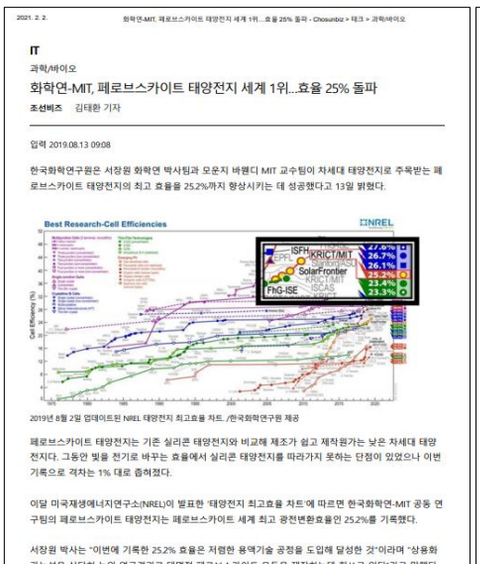
(million won)

Technology	2016	2017	2018	2019	2020	2016～2020 average growth rate(%)
Photovoltaic	56,997	58,760	61,808	72,533	69,404	5.3
wind power	33,984	27,966	34,235	60,279	84,946	30.4
fuel cell	30,760	27,681	28,146	21,456	31,285	3.4
bio energy	20,763	20,413	21,625	16,146	25,407	9.1
Hydrogen	8,892	12,370	12,750	8,271	16,003	25.1
waste energy	9,600	8,600	2,270	549	-	△65.0
renewable fusion	15,648	18,030	19,575	16,652	16,348	1.8
Geothermal	5,500	3,236	4,805	612	-	△45.0
water power	7,675	5,970	4,525	2,618	683	△40.6
coal use	4,572	4,328	3,928	2,090	330	△36.4
Ocean	7,187	4,062	3,082	2,457	1,642	△30.3
solar thermal	4,805	3,215	2,260	2,812	1,110	△24.7
Hydrothermal	2,500	2,065	1,500	-	-	△48.3
IGCC	-	-	-	-	-	-
Hydrogen fusion charging station pilot project using biogas	-	-	-	1,500	4,000	166.7
Planning and evaluation cost	7,405	7,081	7,432	7,457	8,321	3.1
Total	216,288	203,777	207,941	215,432	259,479	5.1

Representative performance of New and renewable energy core development project

<Achieved the world's highest perovskite solar cell efficiency of 25.2%>

- ✓ Developers are Korea Chemical Research Institute and MIT
- ✓ Successfully developed a new concept perovskite thin film technology (DHA: Double-layered Halide Architecture) for the commercialization of perovskite solar cells and achieved the world's highest efficiency of 25.2% (September 2019)
- ✓ Securing overseas competitiveness through publication in the world-class academic journal Nature (mrnIF 100)
- ✓ Nature 2019 567, 511. "Efficient, stable and scalable perovskite solar cells using poly(3-hexylthiophene)“



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화학연-MIT, 페로브스카이트 태양전지 세계 1위...효율 25% 돌파

조선비즈 김태환 기자

입력 2019.08.13 09:08

한국화학연구원은 서장원 화학연 박사팀과 모운지 바렌디 MIT 교수팀이 차세대 태양전지로 주목받는 페로브스카이트 태양전지의 최고 효율을 25.2%까지 향상시키는 데 성공했다고 13일 밝혔다.

2019년 8월 2일 업데이트된 NREL 태양전지 최고효율 차트. /한국화학연구원 제공

페로브스카이트 태양전지는 기존 실리콘 태양전지와 비교해 제조가 쉽고 제작원가는 낮은 차세대 태양전지다. 그동안 빛을 전기로 바꾸는 효율에서 실리콘 태양전지를 따라가지 못하는 단점이 있었으나 이번 기록으로 격차는 1% 대로 좁혀졌다.

이달 미국재생에너지연구소(NREL)이 발표한 '태양전지 최고효율 차트'에 따르면 한국화학연-MIT 공동 연구팀의 페로브스카이트 태양전지는 페로브스카이트 세계 최고 광전변환효율인 25.2%를 기록했다.

서장원 박사는 "이번에 기록한 25.2% 효율은 저렴한 용액기술 공정을 도입해 달성한 것"이라며 "상용화 가능성을 상당히 높인 연구결과로 대면적 페로브스카이트 모듈을 제작하는데 힘쓰고 있다"라고 말했다.

이번 결과는 올 4월 한국화학연구원이 중국과학원의 23.7%를 제치고 세계 최고 효율 24.2%를 기록한 지 4개월 만에 또 다시 1%이상 효율을 향상시킨 것이다. NREL은 해마다 분기별로 태양전지 최고 효율을 기

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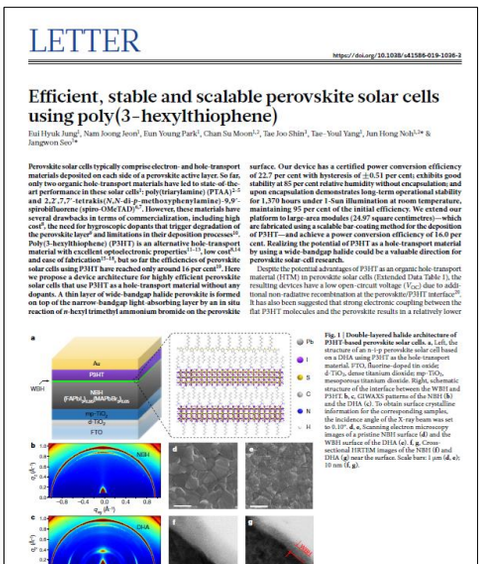

LETTER

https://doi.org/10.1038/s41586-019-1036-3

Efficient, stable and scalable perovskite solar cells using poly(3-hexylthiophene)

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Perovskite solar cells typically comprise electron- and hole-transport materials deposited on each side of a perovskite active layer. So far, only two organic hole-transport materials have led to state-of-the-art performance in these solar cells[1–5]: poly(triarylamine) (PTAA)[1–5] and 2,2′,7,7′-tetrakis(*N*,*N*-di-*p*-methoxyphenylamine)-9,9′-spirobifluorene (spiro-OMeTAD)[6,7]. However, these materials have several drawbacks in terms of commercialization, including high cost[8], the need for hygroscopic dopants that trigger degradation of the perovskite layer[9] and limitations in their deposition processes[10]. Poly(3-hexylthiophene) (P3HT) is an alternative hole-transport material with excellent optoelectronic properties[11–13], low cost[8,14] and ease of fabrication[11–14], but so far the efficiencies of perovskite solar cells using P3HT have reached only around 16 per cent[15]. Here we propose a device architecture for highly efficient perovskite solar cells that use P3HT as a hole-transport material without any dopants. A thin layer of wide-bandgap halide perovskite is formed on top of the narrow-bandgap light-absorbing layer by an in situ reaction of *n*-hexyl trimethyl ammonium bromide on the perovskite surface. Our device has a certified power conversion efficiency of 22.7 per cent with hysteresis of ±0.51 per cent; exhibits good stability at 85 per cent relative humidity without encapsulation; and upon encapsulation demonstrates long-term operational stability for 1,370 hours under 1-Sun illumination at room temperature, maintaining 95 per cent of the initial efficiency. We extend our platform to large-area modules (24.97 square centimetres)—which are fabricated using a scalable bar-coating method for the deposition of P3HT—and achieve a power conversion efficiency of 16.0 per cent. Realizing the potential of P3HT as a hole-transport material by using a wide-bandgap halide could be a valuable direction for perovskite solar-cell research.

Despite the potential advantages of P3HT as an organic hole-transport material (HTM) in perovskite solar cells (Extended Data Table 1), the resulting devices have a low open-circuit voltage (V_{OC}) due to additional non-radiative recombination at the perovskite/P3HT interface[16]. It has also been suggested that strong electronic coupling between the flat P3HT molecules and the perovskite results in a relatively lower

Fig. 1 | Double-layered halide architecture of P3HT-based perovskite solar cells. a, Left, the structure of an n-i-p perovskite solar cell based on a DHA using P3HT as the hole-transport material. FTO, fluorine-doped tin oxide; d-TiO_2, dense titanium dioxide; mp-TiO_2, mesoporous titanium dioxide. Right, schematic structure of the interface between the WBH and P3HT. **b**, **c**, GIWAXS patterns of the NBH (**b**) and the DHA (**c**). To obtain surface crystalline information for the corresponding samples, the incidence angle of the X-ray beam was set to 0.10°. **d**, **e**, Scanning electron microscopy images of a pristine NBH surface (**d**) and the WBH surface of the DHA (**e**). **f**, **g**, Cross-sectional HRTEM images of the NBH (**f**) and DHA (**g**) near the surface. Scale bars: 1 μm (**d**, **e**); 10 nm (**f**, **g**).

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Climate change response technology development project of the Ministry of Science and ICT

The purpose of this project is to support the creation of future growth engines and secure world-leading source technologies in the fields of GHG reduction and resource conversion and adaptation to climate change in response to the climate change crisis as shown in Table 4-7 and 4-8. In other words, in response to the climate change crisis, it is to secure world-class source technologies in the fields of GHG reduction and resource conversion and climate change adaptation, and to support research and build a foundation to create future growth engines.

[Table 4-7] Project main contents by technologies of Climate change response technology development project of the Ministry of Science and ICT

Technology	Project Main Contents
Solar cell	• Support for the development of non-silicon next-generation source technology to overcome the economic and technological limitations of silicon solar cells
Fuel cell	• Support for the development of next-generation fuel cell source technology to secure fuel cell price competitiveness and overcome the limitations of commercial technology
Bio energy	• Artificial photosynthesis, biorefinery, biomass-crude oil refinery support
Secondary battery	• Support for next-generation secondary battery development, such as large-capacity charging system development and rapid charging EV secondary battery development
Ccs	• Development of source technology for carbon dioxide capture, storage and conversion
Hybrid energy	• Development of future energy storage technology using renewable hybrid
Next-generation carbon resources	• Support for the development of next-generation innovative technologies for by-product gas and carbon waste resource conversion and CO2 conversion
C1 gas refinery	• Development of core catalysts for C1 biocatalyst and C1 chemical catalyst, development of core materials for C1 refinery

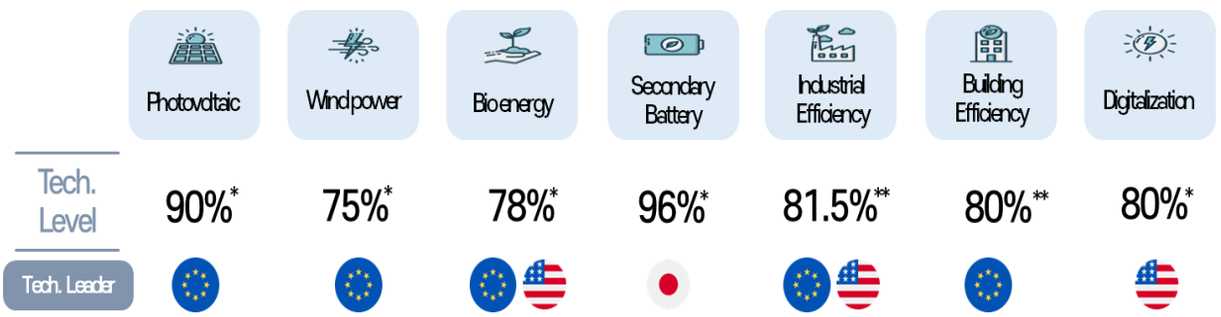
[Table 4-8] 2016-2020 budgets by technologies of Climate change response technology development project of the Ministry of Science and ICT

(million won)

Technology	2016	2017	2018	2019	2020	2016～2020 average growth rate(%)
Solar cell	4,940	7,696	9,534	11,243	14,829	31.6
Fuel cell	4,570	6,185	8,127	10,774	12,760	29.3
Bioenergy	6,300	8,259	9,844	7,883	10,085	12.5
Secondary battery	2,010	3,974	6,047	6,464	6,923	36.2
Korea CCS 2020	23,000	19,167	17,331	17,431	6,671	△26.6
Development of energy environment basic source technology to respond to global warming	6,716	5,685	5,596	5,596	-	△5.9
Next-generation carbon resources	-	6,246	6,423	6,506	7,805	7.7
Support for global local commercialization of climate technology	-	2,475	780	780	-	△43.9
Basic technology research	3,050	3,988	5,453	14,068	22,800	65.4
Planning evaluation and evaluation fee	200	170	170	175	300	10.7
Multi-ministerial joint research	2,000	2,000	2,000	2,400	2,400	4.7
C1 Gas Refinery	14,000	13,142	15,278	16,278	17,800	6.2
Total	66,786	78,987	86,583	99,598	102,373	11.3

2.3 Summary and Future Challenges

In the case of Korea, after declaring carbon neutrality in October 2020, many policy proposals such as '2050 Carbon Neutral Promotion Strategy', 'Carbon Neutral Technology Innovation Promotion Strategy', and 'Carbon Neutral Research and Development Investment Strategy' are being established. However, it is disappointing that the investment in carbon-neutral technology development was not made immediately. On the other hand, major countries have recently declared carbon neutrality and are actively presenting plans to expand investment in the development of innovative low-carbon technologies to achieve carbon neutrality. Major countries' R&D investment for carbon neutrality is about $35 billion in the US, 2 trillion yen in Japan, and 8 billion euros in Germany, and is currently in progress.



Source: * KISTEP (2021), ** GTC (2021)

[Figure 4-11] 2020 Carbon Neutral Technology Level

Korea's carbon-neutral technology development is at a level that is chasing leading countries, and it can be said that it is highly dependent on other countries for core parts due to the lack of source technology. In the case of solar power and secondary batteries, it is judged that they have a certain share in the global market by securing source technologies. It can be seen that there is a difficult competition in the global market as it is only at the level of assembling by introducing technology. Therefore, in order to properly implement the carbon-neutral scenario in 2050, it is necessary to secure the source technology for key technologies through continuous mid- to long-term investment support for carbon-neutral R&D by the government and then make efforts to commercialize them. Therefore, there is a need to secure national technological and industrial competitiveness to achieve national carbon neutrality by 2050 by rapidly expanding investment in carbon-neutral technology development.

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V | Towards International Collaborations

V Towards International Collaborations

As shown in the previous sections, China, Japan, and Korea are all endeavoring to derive technological, economic, and policy measures to facilitate GHG emissions reduction after their pledge to carbon neutrality. As much as it is important for each country to work hard, it is also important for neighboring countries as an international community to work together toward the common global challenge, climate change. And the measures to promote international cooperation should be carefully coordinated so that it is sustainable. However, efforts to collaborate among three countries so far seem to be negligible at best. This is astonishing considering the transboundary nature of climate and environment and the interdependence of their economies among the three neighboring countries. For instance, China and Japan are ranked 1st and 5th respectively in terms of the size of exports and also 1st and 3rd in terms of the size of imports in Korea. In this regard, this section begins by looking at the urgency of GHG emissions reduction in three countries and explores the opportunities of international collaboration among the three countries, focusing on the institutional arrangements, both previously established and newly emerging.

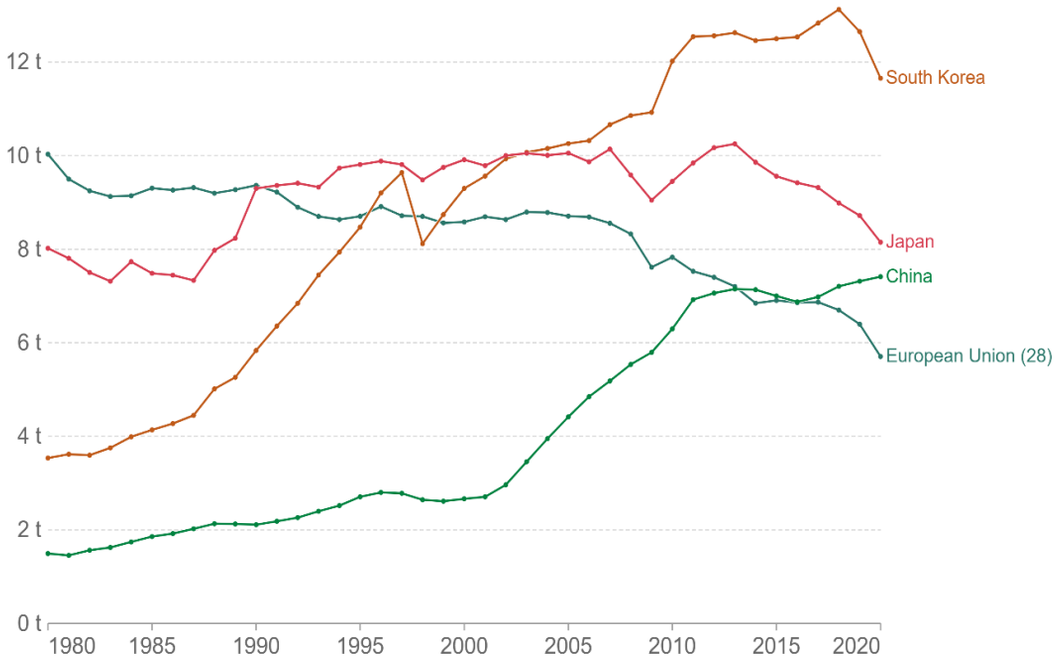
1. Background

China, Japan, and Korea influence and pressure each other on related decisions. It is evident when we look at the timing of their pledge to carbon neutrality, which took roughly one month, starting from China (22 September), Japan (26 October), and lastly Korea (28 October) in 2020. Their decisions were all considered as a surprise and bold considering their dependence on energy-intensive industries which are extremely difficult to decarbonize. Similar instance occurred when China announced its decision not to invest and build overseas coal-fired power plants in September 2021. This move prompted similar decisions in April and May 2021 by Korea and Japan respectively. Whether they are virtuous or vicious, it is clear that they affect each other on this global challenge.

As neighboring countries, China, Japan, and Korea also share commonalities regarding the urgency of climate response. According to each country's scenario of carbon neutrality, the time given to achieve carbon neutrality for North-East Asian countries is short compared to other advanced countries. As shown in Figure V-1, for example, Japan, Korea, and China need to reach carbon neutrality 37, 32 and 30 years after carbon peaking respectively, compared to EU which has 60 years. All three countries also have high share of coal-fired power generation compared to EU and US as shown Table V-1. In particular, the dependence on coal-fired power plant in China is significantly higher than in other countries with 63.2%. Korea has also high share of nuclear energy in its energy mix with 27.9%. In addition, the ratio of renewables and hydropower in Korea is significantly lower than other countries, lagging behind China and Japan. To this end, Korea[44] will be the country which will be influenced the most by the introduction of EU's Carbon Border Adjustment Mechanism (CBAM).

To make matters worse, both Japan and Korea lack the potential of renewables in their territory and require more cost than the EU or the US, even their neighbor China due to high density of population and mountain area. This is the reason why both Japan and Korea are eager to pursue a decarbonization pathway with the help of countries which have abundant resources to produce low (or zero) carbon energy such as ammonia or hydrogen. They make efforts to establish a global value chain of low-carbon energy such as blue ammonia or blue/green hydrogen, importing them from Australia or Middle East countries such as Saudi Arabia. To this end, it is imperative to promote international collaboration as a mechanism to compensate for the lack of potential of the production of low carbon energy and decarbonization of industry.

[44] Trade openness (measured as share of exports and imports per GDP) of the Korea is 80%, compared to 37% of PRC and 31% of Japan as of 2021 (World Bank, https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS?locations= CN-JP-KR, accessed 14/07/2022).



Source: Our world in data, https://ourworldindata.org/co2-emissions, accessed 14/07/2022

[Figure 5-1] Per capita CO_2 emissions between 1980 and 2020 in EU, China, Japan, and Korea

[Table 5- 1] Energy mix in China, Japan, and Korea in 2021

	Coal	Oil	Natural gas	Nuclear	Hydropower	Renewables	Biofuels and waste
China*	63.2%	0.1%	3.2%	4.7%	17.0%	11.1%	0.7%
Japan	29.7%	4.1%	35.2%	4.3%	7.7%	12.5%	6.4%
Korea	36.3%	1.2%	26.7%	27.9%	0.7%	6.5%	0.7%
US	19.7%	0.4%	40.6%	19.4%	6.7%	12.9%	0.3%
EU	12.9%	1.6%	22.3%	22.4%	12.5%	26.6%	1.8%

*2019 data

Source: compiled by author from *https://www.iea.org/countries*, accessed 14/07/2022

2. International collaboration towards carbon neutrality

In order to explore the opportunities of international collaboration among China, Japan, and Korea, we here focus on the previously established and newly emerging institutional arrangements. For systematic discussion, we adopt a matrix of international collaboration based on types of mechanism (multi-lateral vs bi-lateral or multi bi tri) and types of cooperation (policy vs project) as shown in Table V-2. Here, bi-lateral or tr-lateral means collaboration between two or among three countries within the group of the three North-East Asian countries. The main logic is that in each category, it is reviewed the potential of

previously established mechanisms (e.g. CTCN under the UNFCCC and Joint Crediting Mechanism) or newly emerging mechanisms (e.g. Climate Club). And the objective of this matrix is not exhaustive but provides ground for discussion.

[Table 5-2] Matrix of international collaboration towards carbon neutrality

		Type of mechanism	
		Multi bi tri	Bi-lateral or Tri-lateral
Type of cooperation	Policy		
	Project		

Source: Authors based on the forum discussion

We first look at policy level cooperation from the matrix. The United Nations Framework Convention on Climate Change (UNFCCC) is undoubtedly the most important official multi-lateral cooperation mechanism on climate change in a global scale of 198 parties, since it became effective March 1994. Apart from the UNFCCC where all parties gather and negotiate terms and conditions of how we mitigate and adapt to accelerating climate change, a new voluntary initiative among like-minded countries such as 'the Climate Club' is emerging.

The concept of the Climate Club was originally conceived and put forward by Olaf Scholz in 2021, then finance minister of Germany. The initiative can be explained as a group of like-minded countries which are 'Ambitious', 'Bold', and 'Cooperative' to respond to climate change, shortly 'ABC'. It mainly targets countries "with large amounts of emissions, important EU trade partners, countries with a price on CO_2 emissions, and those with a large industrial sector"[45]. Olaf Scholz, now the federal chancellor of Germany, put forward the initiative as a key discussion topic of the G7 summit in June 2022, taking advantage of his presidency. The G7 leaders from Canada, France, Germany, Italy, Japan, the UK, and the US have endorsed and agreed to establish the Climate Club by the end of 2022.

This kind of an open and collaborative initiative can be emerging in many ways. Although there is only Japan included in the G7, China and Korea also belong to the Climate Club's exact targeted countries "with large amounts of emissions, important EU trade partners, countries with a price on CO_2 emissions, and those with a large industrial sector"

Three main pillars of the initiative are 1) sophisticating climate mitigation policies through explicit carbon pricing, other carbon mitigation approaches and carbon intensities to facilitate

[45] https://www.euractiv.com/section/energy-environment/news/germanys-scholz-rallies-g7-countries-behind-climate-club-idea/, accessed 25/09/2022

the pathway towards climate neutrality in addition to sharing best practices, 2) transforming industries into decarbonization through new emerging industrial agenda such as hydrogen, 3) promoting international partnerships and cooperation to encourage climate action and just energy transition (G7 Statement on Climate Club, 2022).

So far, three North-East Asian countries are considered rather passive in response to the global climate change regime due to the concerns on their industrial competitiveness. However, now the global direction toward net-zero emission seems irreversible and all three countries have industrial competitiveness in technologies related with carbon neutrality. According to Harrison (2022), for example, China, Japan, and Korea have strong presence in the global green technology patent landscape as shown in Table V-3. Therefore, it is recommended that they participate in this kind of an open and cooperative initiative for climate change in the early stage and actively get involved in detailing terms and conditions within the initiative. Strategy to become a late entrant in this kind initiative can make them a good rule-abiding country at best.

[Table 5- 3] Revealed technological advantage by country in key climate technology fields

Relative Specialization Index Ranking	Offshore Wind	Low-carbon Hydrogen	Nuclear Power	Greener Vehicles	Greener Building	Carbon Capture, Usage and Storage	Flood and coastal defences
1	UK	Australia	France	Germany	UK	Australia	**Korea**
2	France	Canada	UK	France	France	Canada	Australia
3	**Korea**	USA	Canada	UK	Australia	India	Canada
4	India	France	**Korea**	USA	Canada	UK	**Japan**
5	Australia	Germany	**Japan**	Canada	Germany	**Korea**	**China**
6	**China**	**Japan**	USA	India	India	USA	France
7	Germany	UK	**China**	**Korea**	USA	France	UK
8	USA	**Korea**	Australia	**China**	**Korea**	**China**	India
9	Canada	India	India	Australia	**China**	**Japan**	USA
10	**Japan**	**China**	Germany	**Japan**	**Japan**	Germany	Germany

Note: Rankings calculated using the Relative Specialisation Index, and limited to comparing the top 10 patenting countries worldwide
Source: Harrison (2022, p.6)

Similar to the policy level, there are international mechanisms both at the UNFCCC and the initiative that the North-East Asian countries can engage more actively at the project level, for instance, the Climate Technology Centre and Network (CTCN) and the Partnering for Green Growth and the Global Goals 2030 (P4G). In 2010, the UNFCCC established the Technology Mechanism in order to facilitate climate technology development and transfer. It consists of the Technology Executive Committee (TEC) and the CTCN. While the TEC as a policy arm concerns policy issues and provides recommendations on accelerating and enhancing climate technology development and transfer, the CTCN, which is an implementation arm and our focus of discussion, comprises a network of more than 150 National Designated Entities (NDEs) and international and public/private sector entities specialized in climate technology and policy, which is the key asset of the institution. The main task of the CTCN is the implementation of technology assistance (TA) projects and capacity building programs on climate technologies between developed and developing countries. All the TA projects are carried out through a demand-driven approach at the requests of developing countries. While the CTCN TA projects are financially supported mainly from different sources, another category of 'pro bono' in TA was created in 2017 by CTCN in a way to secure additional financing. Between 2017 and 2020, total 18 pro bono TA projects were implemented by Japan, Belgium, Germany, the US, and Korea which dominated with 13 projects. This institutional addition of pro bono can provide a donor country with the opportunity to focus on where the country has competitiveness.

The P4G is a market-based public-private partnership aiming to deliver inclusive and tangible technical solutions to build sustainable and resilient economies and meet the global goals such as the United Nations Sustainable Development Goals and the Paris Agreement. It was mainly led by Denmark since its inception in 2017 and has 12 member countries as of October 2022. They include both developed and developing countries as member countries. They are Korea, Denmark, Netherland, Viet Nam, Mexico, Chile, Ethiopia, Kenya, Bangladesh, Indonesia, South Africa, and Colombia. It supports transformative solutions to tackle challenges in water (SDG 6), food and agriculture (SDG 2), energy (SDG 7), city (SDG 11), and circular economy (SDG 12) through two kinds of partnership: start-up and scale-up depending on the stage of commercialization. It is more focused on pioneering market-based solutions with their economic viability. Korea became a strong supporter of P4G by hosting the P4G summit in 2020.

The CTCN and P4G are notable examples of recently established and actively operating international mechanism related with carbon neutrality. Currently, Korea is actively engaging in both CTCN and P4G and Japan is intermittently engaging in the CTCN TA program. These

mechanisms can provide room for North-East Asian countries' collaboration based on the early participant's experience.

In regards to bi- or tri-lateral regional mechanism for policy sharing, three countries currently do not have a meaningful collaborative mechanism. However, considering the potential as an official platform to conceive and launch such mechanisms, they have regular ministerial meetings that can play role of a stepping stone. Currently, three North-East Asian countries have two official meetings at the ministerial level in regards to climate response[46]. They are 'Tripartite Environment Ministers Meeting (TEMM)'[47] and 'Trilateral Ministerial Meeting on Science and Technology (TMMST)'[48]. Since its first meeting in 1999, TEMM has been held annually until 2019 and the last TEMM (22nd) was held in December 2021 online after two years of TEMM21 due to the global COVID-19 pandemic. The main topic of TEMM22 was carbon neutrality as it was the first TEMM since three countries' pledge to carbon neutrality in 2020. On the other hand, TMMST has been held intermittently since its first meeting in January 2007. There were four additional meeting held so far: 2nd in 2009, 3rd in 2021, 4th in 2019. Since then, there was no meeting due to the COVID-19 pandemic. As we consider the characteristics of roles and responsibilities of a ministry for environment and a ministry for science and technology, both mechanisms derived from these meetings should be science- and evidence-based. While TEMM may focus on a mechanism collecting and analyzing data related with climate change and carbon emissions, TMMST can focus on applications of newly emerging technologies to tackle these issues.

Despite bumpy relationships among three countries on the way of how they collectively work together, TEMM has been highly important and one of few formal mechanisms that so far successfully launched a trilateral collaborative program tackling transboundary issues such as air pollution among the North-East Asian countries. The North-East Asia Clean Air Partnership (NEACAP) is a science-based and policy-oriented collaboration scheme run by UNESCAP that aims to collect and share information and experience of good policy examples on air pollution in the region. NEACAP originated from the UNESCAP's mechanism focusing on coal-fired power plant, NEASPEC (North-East Asian Subregional Programme for Environmental Cooperation) which was launched in 1993 by six North-East Asian countries, Mongolia, DPR Korea, and Russia as well as China, Japan, and Korea. And it was launched at SOM (Senior Official Meeting)-22 in 2018. There is also a mechanism on modeling of

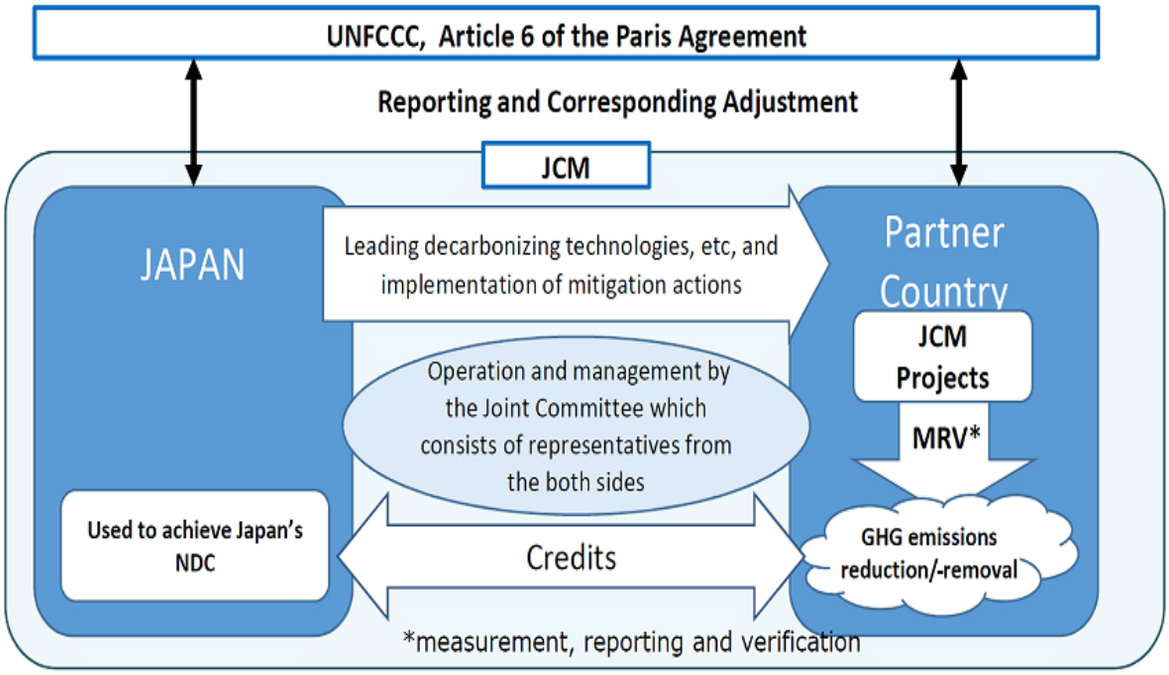
[46] There are 12 different meetings at the ministerial level in total.

[47] Ministry of Environment (Korea and Japan) and Ministry of Ecology and Environment (China)

[48] Ministry of Science and Technology (China), Ministry of Science and ICT (Korea), Ministry of Education, Culture, Sports, Science and Technology (Japan)

source-receptor relationship, Long-range Transboundary Pollutants in North-East Asia (LTP – China, Japan and Korea). What matters here is not whether these collaborative schemes are success or failure but what we can learn from these schemes in order to strengthen the regional collaboration on tackling climate change and achieving carbon neutrality. What was each country's initial stance on the program? What were the initial concerns that did not encourage them to participate if any? How could those concerns be accommodated and resolved under the program? What have been main issues and barriers during the program implementation? These are the questions that we have to have and draw implications and lessons learnt from the previous and ongoing mechanisms. In that regard, NEACAP is extremely valuable and important program in regards to enhanced future collaboration.

Regarding bi- or tri-lateral mechanisms on carbon neutrality at the project level, Japan is ahead of other two countries. Since 2013, Japan has been implementing a project-based bilateral offset crediting mechanism, namely Joint Crediting Mechanism (JCM), with partner developing countries. Through the bilateral agreement with a partner developing country, Japan can utilize the amounts of GHG emission reduction from mitigation projects to its own national reduction target under the UNFCCC. This can be applied by Article 6.2 of the Paris Agreement to achieve Japan's NDC as shown in Figure 1. And therefore, the JCM by Japan can contribute to the goal of the UNFCCC by facilitating bilateral mechanism on the global GHG emission reductions. As of February 2022, total 205 projects in 17 different countries have been implemented. In addition, five additional countries are added to the list of JCM host countries in 2022. They are Senegal, Tunisia, Azerbaijan, Moldova, and Georgia. Benchmarking Japan's JCM, Korea began to implement a similar bilateral scheme by designating 18 different countries as a key cooperation country for bilateral crediting mechanism. Viet Nam signed the agreement with Korea in May 2021 and remains as the only country for the Korean JCM.



Source: JCM homepage (*https://www.jcm.go.jp/*, accessed on 13/10/2022)

[Figure 5-2] The JCM scheme between Japan and host country

With its experience more than 10 years, Japan can be an anchor country to promote a JCM-kind cooperative approach in collaboration with China and Korea. In case of Korea, there are 11 countries in common as partner countries as shown in Table V-4 from the (potential) partner country list of two countries. Under the JCM scheme of both countries, we can conceive a diverse set of forms of GHG emissions reduction projects between two or even three countries if China is also willing to create a similar mechanism. They may share a project site and apply their own climate change mitigating technologies. Or they can create a consortium in providing a set of technologies across the value chain required where each country provides related technologies in its competitive area. For example, Japan has been strong in materials and key components compared to China and Korea. Japan can also share its best project practice and the Measurement, Reporting, and Verification (MRV) methodologies that have been developed with China and Korea.

[Table 5-4] (Potential) Partner country comparison between Japan and Korea

	Region	Japan	Korea*
Partner countries	**Africa**	Ethiopia, Kenya, Senegal, Maldives	-
	Asia and Pacific Islands	Mongolia, Bangladesh, Viet Nam, Lao PDR, Indonesia, Cambodia, Myanmar, Thailand, Philippines, Palau	Mongolia, Bangladesh, Viet Nam, Lao PDR, Indonesia, Myanmar, Thailand, Philippines, India, Sri Lanka, Uzbekistan
	Central Europe and Middle East	Saudi Arabia, Tunisia, Azerbaijan, Moldova, Georgia	Saudi Arabia, UAE, Morocco
	Latin America	Chile, Costa Rica, Mexico	Chile, Colombia, Peru, Brazil
Total		22 countries	18 country

*Only Vietnam signed with Korea for bilateral crediting mechanism so far.
Source: compiled by author from the JCM homepage and Korea

As summary of this section, we adopted a matrix of international collaboration based on types of mechanism (multi-lateral vs bi-lateral or multi bi tri) and types of cooperation (policy vs project) as presented in Table V-2. According the matrix, we then reviewed the potential of previously established mechanisms or newly emerging mechanisms where North-East Asian countries can make space to get involved or already got engaged. The CTCN, P4G, UNESCAP's NEACAP from TEMM, and JCM are briefly discussed in the perspective of enhancing international collaboration. The corollary of the discussion is that confronting the urgency of carbon neutrality on all three countries, it is time to actively engage in a diverse set of mechanisms and in particular, three countries should learn from each other as they share many commonalities in response to their pledge to carbon neutrality.

3. Conclusion

Since the pledges to carbon neutrality by mid-century, key policy measures and R&D strategies have been promoted in China, Japan, and Korea as presented in Chapter II, III and IV. Due to the COVID-19, however, economic activities and people's movements significantly decreased. As a result, the national GHG emissions have decreased in majority of economies. This somewhat helped China, Japan, and Korea with the burden of urgent actions towards their pledge of NDC by 2030 during the pandemic.

Although the economic recovery has begun from the global pandemic, we are still confronting uncertainties at both global and national levels. For example, the US-China conflicts in the global power competition that began since the Trump's administration do not seem to be reconciled in near future and political and economic blocks among like-minded countries are rapidly emerging. At the national level, the consistency of the policy on carbon neutrality can be an issue in Korea for instance. Korea has a presidential election every five years and depending on which side takes power, details in a decarbonization path can change significantly. For example, how Korea should use nuclear energy in its energy mix for carbon neutrality has always been a public controversy.

Nevertheless, the global actions and coalitions towards carbon neutrality will continue with the full support of the global community. Even the research collaboration in carbon neutrality between the US and China survived in the midst of the US-China conflicts. Sharing the commonalities in terms of the urgency to obtain carbon neutrality, all three countries must reconsider their strategies for international and regional collaboration on carbon neutrality.

In this regard, China, Japan, and Korea should make their best to come up with collective measures among three countries, considering not only regional urgency on climate response but also the importance of three countries in the global climate change landscape. While chapter V of this working paper discussed the opportunities to promote and expand trilateral collaboration based on established or emerging international mechanisms on climate change, it may be easier to take advantage of already established but less actively utilized programs, one of which is Joint Research Collaboration Program among young scientists from three countries. During the Trilateral Ministerial Meeting on Environment or Science and Technology, the young scientists' trilateral policy dialogue on carbon neutrality is proposed as a main pillar of the Joint Research Collaboration Program where early career scientists share best practices and their creative policy ideas to accelerate the speed of efforts to achieve carbon neutrality. As mentioned earlier, three countries face similar economic, technological, and social context in terms of carbon-intensive economic structure and therefore, can learn a lot from each other. With overcoming the global pandemic but confronting new challenges, it is high time for the North-East Asia to take collective actions.