Chapter 2

Energy Transition Outlook and Best-Available Technologies

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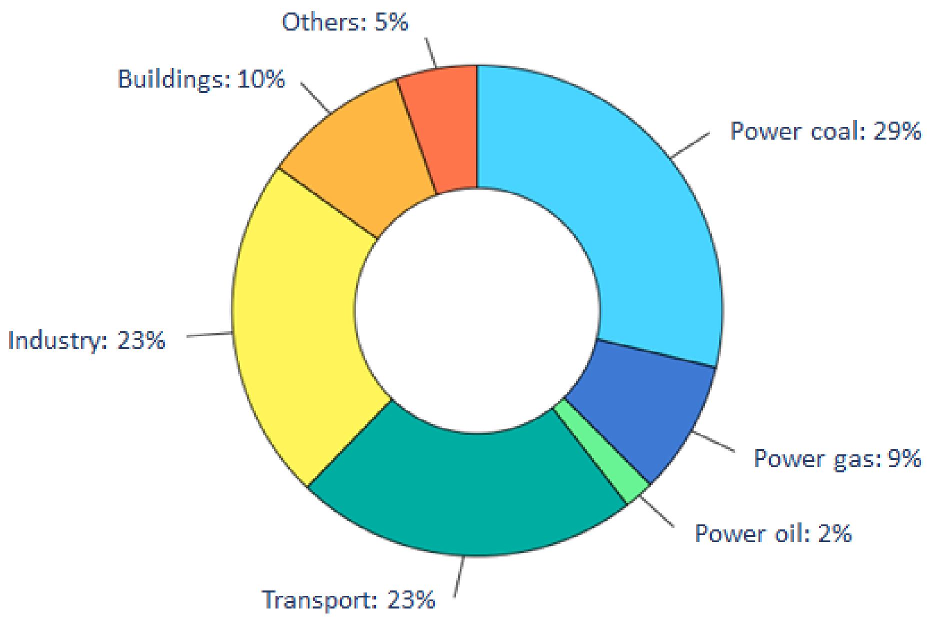
Chapter 2

Energy Transition Outlook and Best-Available Technologies

1. Background of Technologies Towards Carbon Neutrality

To address the global climate change issue, the CO_2 emission/absorption balance must be equivalent to zero by the effort of all sectors emitting CO_2 with everyday activities. As shown in Figure 2.1, the power and industry sectors are essential in mitigating their emission by introducing an innovative technology shift, often recognised as energy transition.

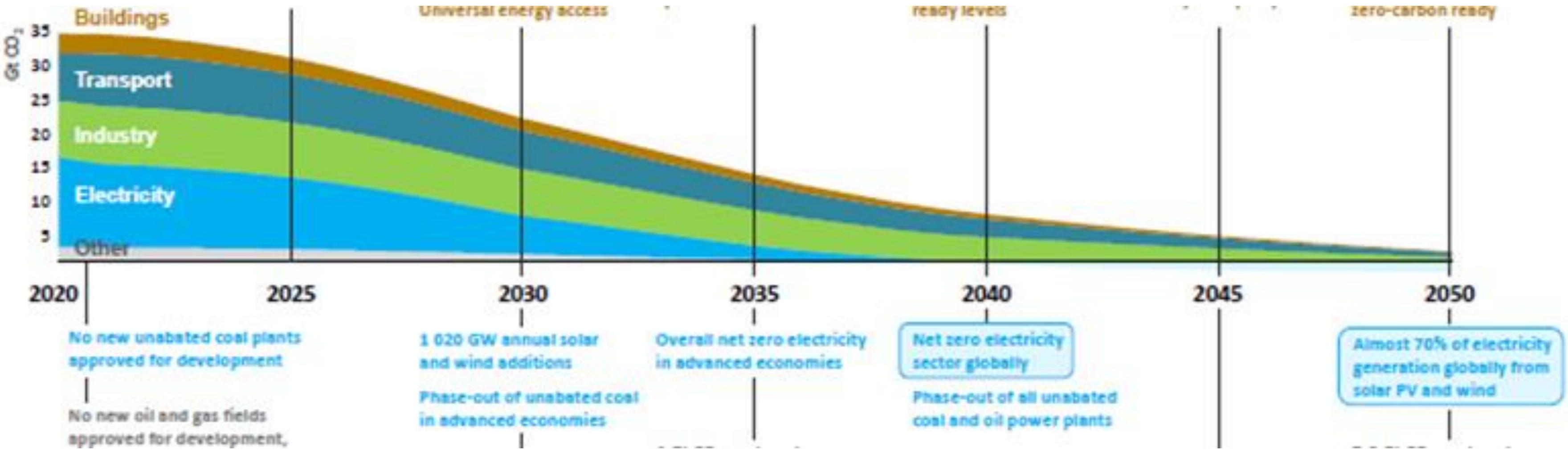
Figure 2.1. Global Energy–related CO_2 Emissions by Sector



Source: IEA (2021a).

Many countries are working towards carbon neutrality by 2050 and have set targets for each sector (Figure 2.2). The main focus in the transport sector is reducing CO_2 emissions through electric vehicles (EVs). The main countermeasures in the industry sector are the electrification of manufacturing processes and heat sources and the use of hydrogen.

Figure 2.2. CO_2 Reduction Milestones by 2050

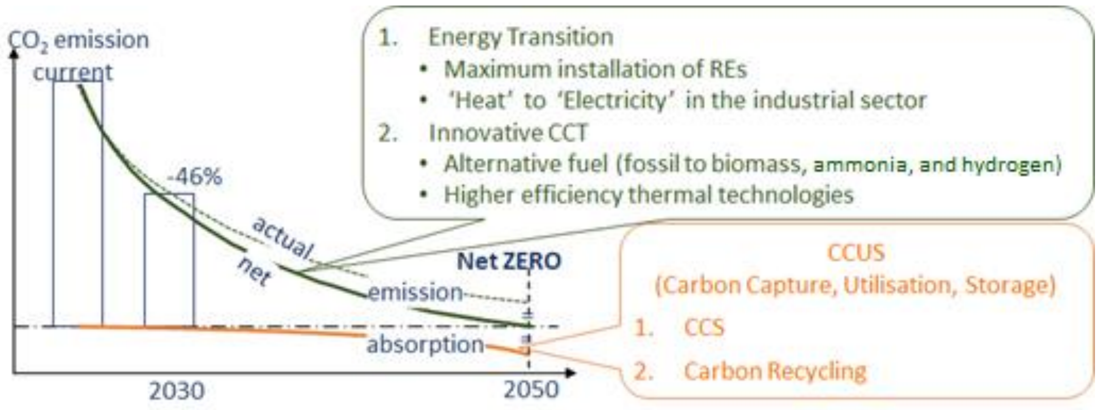


Source: IEA (2021b).

In this way, all industries are premised on using the so-called 'green power' that does not generate CO_2. Thus, how to achieve a transition to non-fossil energy in the power sector is most important.

CO_2 reduction measures towards net zero (as indicated by the dashed line in Figure 2.3) include the maximum introduction of renewable energy (RE), conversion from thermal energy to electrical energy, innovative CCT such as the introduction of carbon-neutral alternative fuels and power generation technology with higher efficiency,

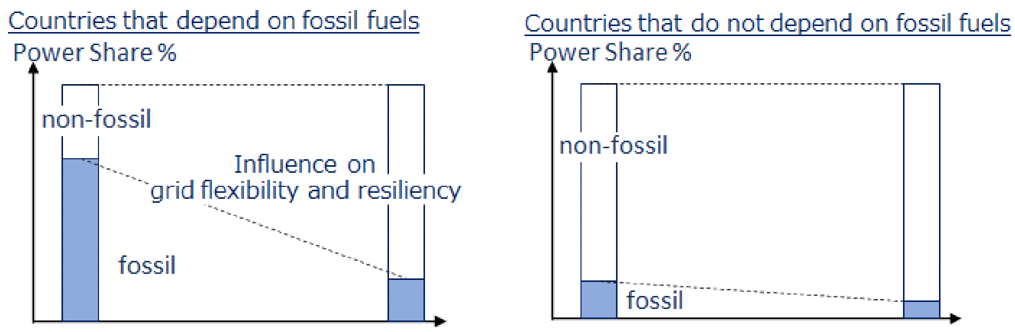
Figure 2.3. Conceptual Image towards Carbon Neutrality



Source: Edited by JCOAL Study Team based on data from METI (2021).

Since CO_2 reduction alone cannot achieve net zero, it is necessary to put the so-called 'negative emission" technology into practical use, which reuses or stores the emitted CO_2. The solid line of Figure 2.3 indicates that net zero will be achieved by integrating CO_2 reduction and CO_2 utilisation/storage.

Figure 2.4. Influence of Energy Transition on the Power Grid



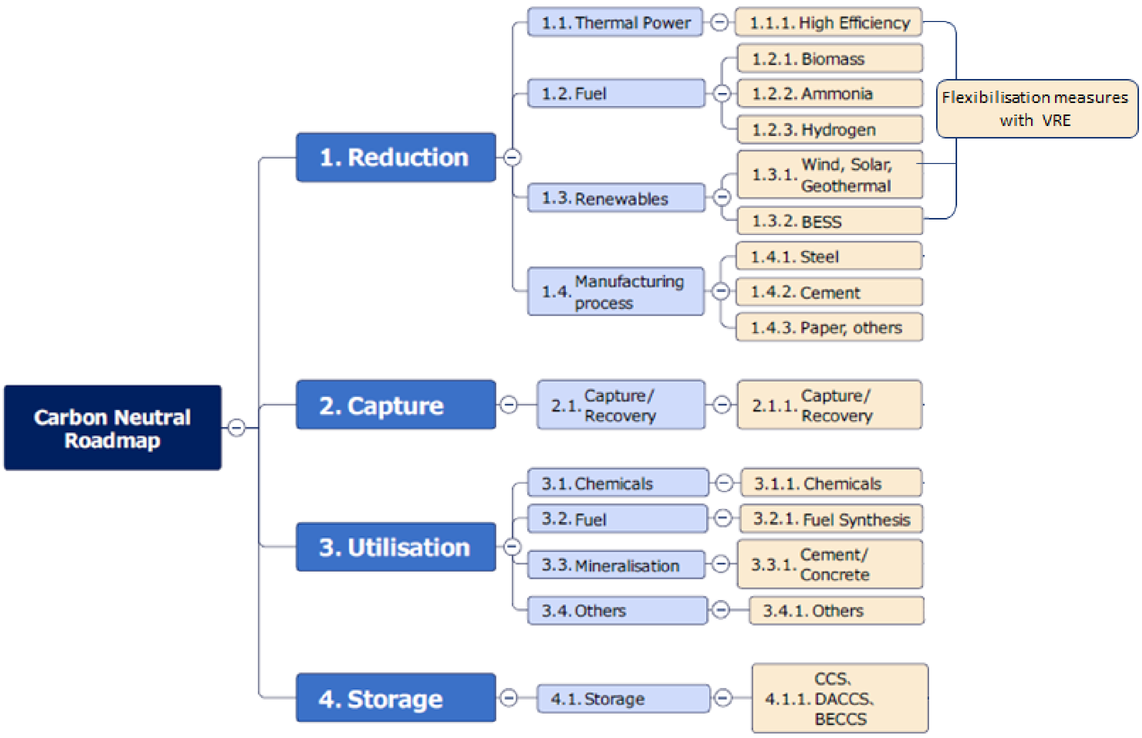
Source: JCOAL Study Team.

When introducing RE (Figure 2.4), we must consider that the fossil energy share directly affects the change in the RE share; then, the grid fluctuation and resilience will be affected.

1.1. Technology Roadmap Towards Carbon Neutrality and Its Categories

JCOAL is compiling a 'Technology Roadmap towards Carbon Neutrality'. Figure 2.5 indicates the four major technology categories – reduction, recovery, utilisation, and storage – and lists several specific technologies. Each technical example is described in the following sections.

Figure 2.5. Categories of Technology for Carbon Neutrality



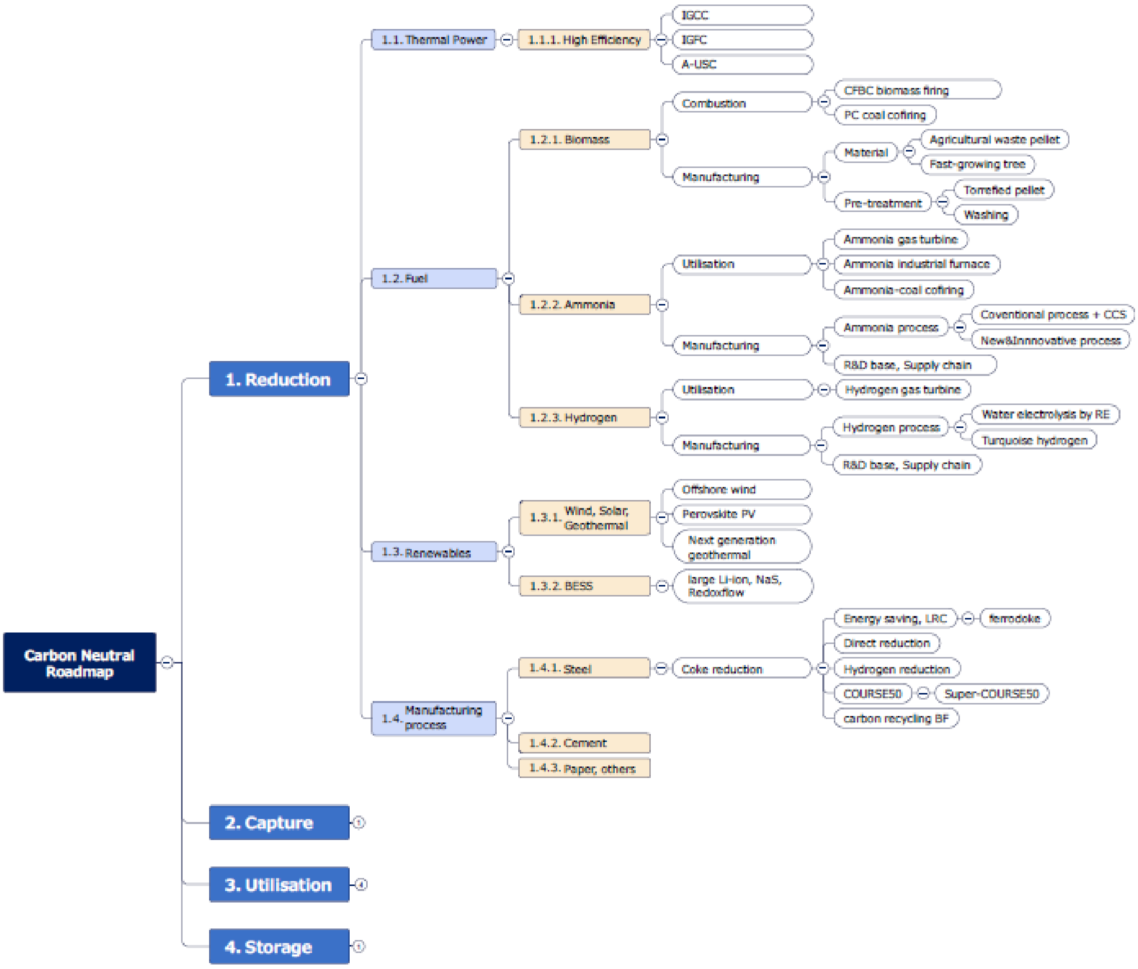
Source: JCOAL Study Team.

2. Key Technologies for CO_2 Reduction, Capture, Utilisation, and Storage

2.1. CO_2 Reduction

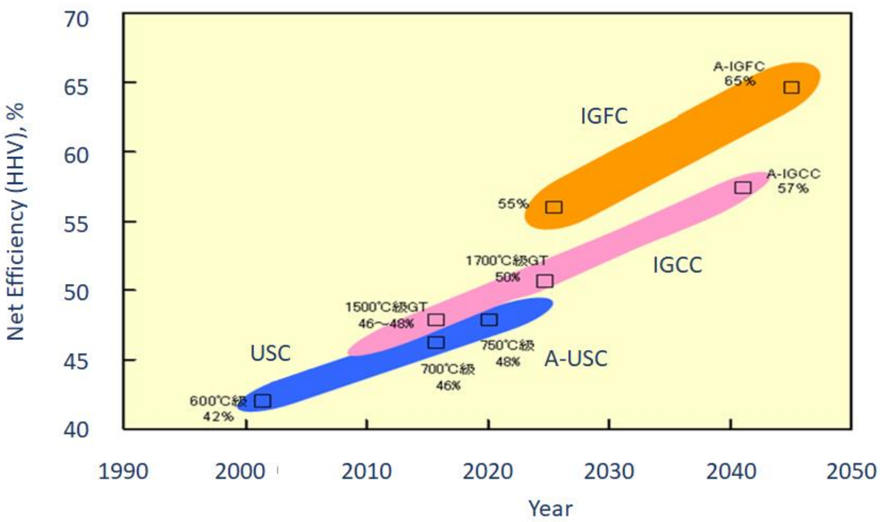
Figure 2.6 shows technologies in the 'reduction' category, including high-efficiency thermal power generation technologies, alternative fuels, RE, and industrial processes. For alternative fuels, utilisation of biomass, ammonia, and hydrogen are described. The example of a factory system integrating solar power, fuel cells, and power storage is shown later for RE. Finally, energy-intensive steel, cement, and paper industries are introduced for decarbonization in industrial processes.

Figure 2.6. CO_2 Reduction Technologies



Source: JCOAL Study Team.

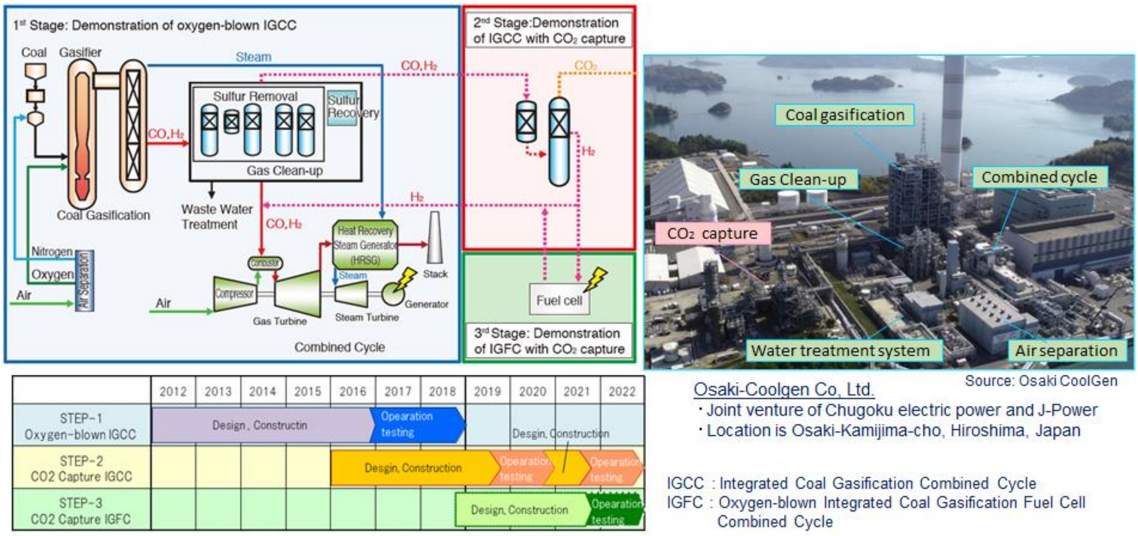
Figure 2.7. Efficiency Improvement of Low-emission Coal-fired Generation



Source: Edited by JCOAL Study Team based on data from METI (2010).

Since increasing power generation efficiency directly leads to reduced coal consumption per unit of power generated, it is one of the effective technologies for countries that have no choice but to use coal for energy security. Figure 2.7 shows the relationship between power generation efficiency and development year. Most coal-fired power plants (CFPPs) in Japan are USC, and several IGCC plants are in commercial operation. We believe that USC will be replaced with IGCC and IGFC as it reaches the end of its plant residual life.

Figure 2.8. IGFC Demonstration Project at Osaki



IGFC = integrated coal gasification combined cycle + fuel cell.
Source: Edited by JCOAL Study Team based on data from Third Regional HELE Seminar, 2021, presented by NEDO.

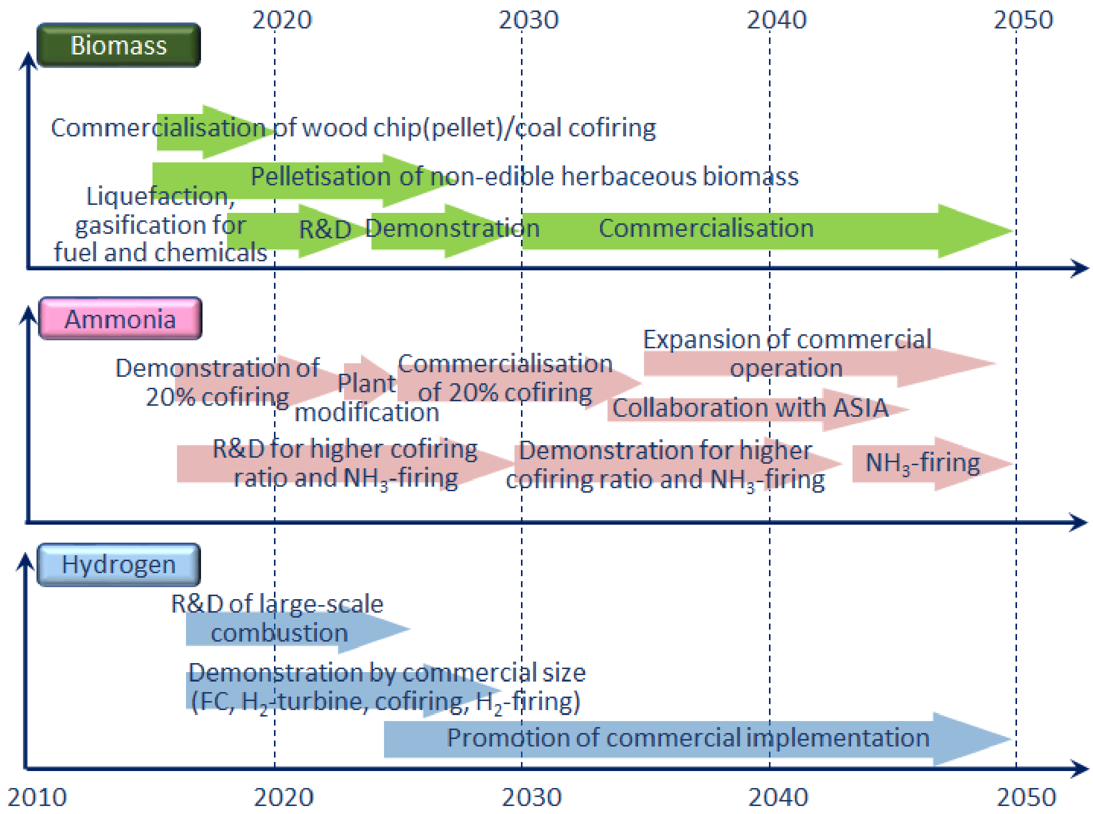
NEDO has been conducting the Osaki CoolGen Project with the technologies of oxygen-blown IGCC combined with solid oxide fuel cell (SOFC) at Osaki Kamijima, Hiroshima, to realise an innovative low-carbon emission CFPP. Its target is energy efficiency (HHV) of 47%, with 90% capturing CO_2, in the case of a 500 MW commercial plant.

Figure 2.9 shows the roadmap for the development of technologies for biomass fuel, which is carbon-neutral, and for ammonia and hydrogen, which are carbon-free. Biomass fuel is a proven and commercialised technology, although the combustion method differs depending on the type and scale. The focus of future R&D is shifting to the use of unused biomass resources, such as agricultural waste, and developing utilisation methods other than combustion, such as gasification.

Ammonia coal cofiring demonstration is undergoing a 20% cofiring ratio at the existing coal-fired USC plant, aiming for practical application by 2030. At the same time, the R&D of a high cofiring ratio and ammonia-dedicated firing technology is also underway. The Japanese government intends to spread 20% ammonia cofiring to the Asian region after 2030.

In addition to being used as a carbon-free fuel, hydrogen has many uses as an important reducing material for fuel cells and carbon recycling, which will be described later. Large-scale demonstrations of hydrogen combustion turbines are underway for fuel utilisation. But the highest development challenge for expanding use is cost reduction.

Figure 2.9. R&D Roadmap of Carbon-neutral Fuel for Power Generation



Source: Edited by JCOAL Study Team based on data from MAFF (2019) and METI (2020).

Examples of biomass-coal cofiring plants are shown in Figure 2.10 and 2.11. Both plants have been modified for operation with a higher cofiring ratio than the existing PC boiler.

Figure 2.10 is a biomass coal cofiring plant using the circulating fluidised-bed (CFB) combustion method. While the cofiring ratio of existing PC boilers is from 2% or 3% to less than 10%, this technology is widely applicable from a few percent cofiring to 100% biomass combustion. The range of combustible fuel types is also wide. But the maximum capacity size is not more than 500 MW class.

Figure 2.10. Biomass Cofiring Plant Designed for High Cofiring Ratio (1)

Panoramic view of the plant | Basic Configuration of CFB

CFB = circulating fluidised-bed.

Source: Chugoku Electric Power website, https://www.energia.co.jp/e/index.html.

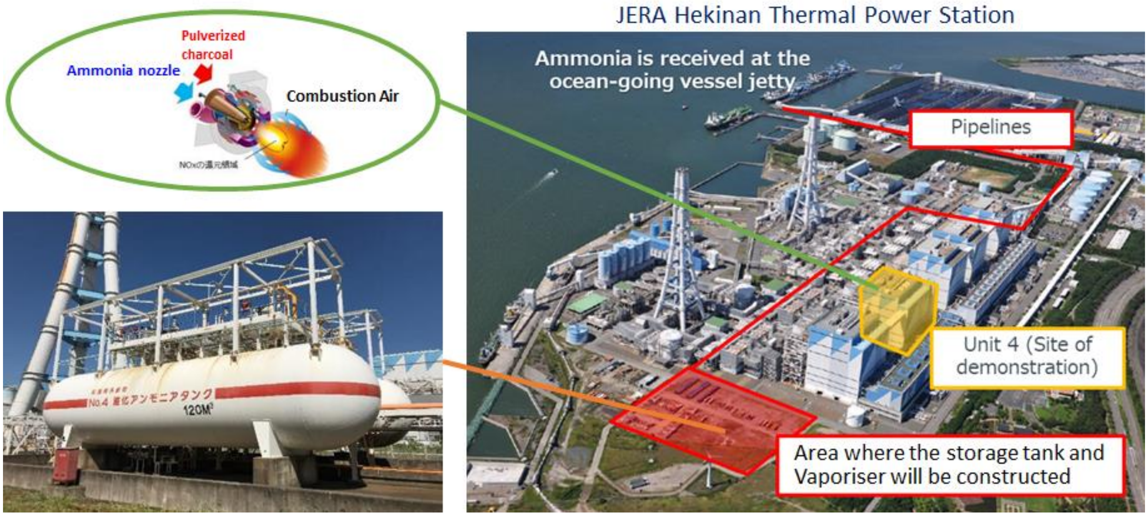
Figure 2.11 is a method in which cofiring is performed inside the furnace by using a pulverising mill exclusively for coal and biomass in the existing PC boiler. The advantage of this method is that it can be used by modifying the existing PC boiler, but it is often used for wood chips and palm kernel shells due to its 'grindability' in mills.

Figure 2.11. Biomass Cofiring Plant Designed for High Cofiring Ratio (2)

Panoramic view of the plant | Mixed combustion application using the dedicated mills

Source: MHI website, https://power.mhi.com/news/20180329.html.

Figure 2.12. Demonstration of Ammonia Cofiring in Existing USC Plant



Source: JERA (2022).

Figure 2.12 is an existing 1000 MW USC coal-fired plant that implements 20% ammonia cofiring. The test is performed in the unit in yellow. The ammonia is loaded in the area in red. The upper left is a burner modified for cofiring.

If 20% cofiring is done in this plant, 600,000 tons of ammonia will be required annually. Therefore, cofiring demonstration and establishment of a supply chain related to fuel ammonia are simultaneously being studied.

Figure Figure 2.13 shows an example of the energy transition to green electricity, called 'RE100' factory, Panasonic 'H_2 KIBOU FIELD Demonstration'. All electricity for the polymer electrolyte fuel cell (PEFC) assembly factory is supplied by hydrogen-PEFC and solar cells. Its energy supply share is PEFC 80%, solar photovoltaic (PV) 20%, peak electricity is 680 kW, and annual energy consumption is around 2.7 GWh.

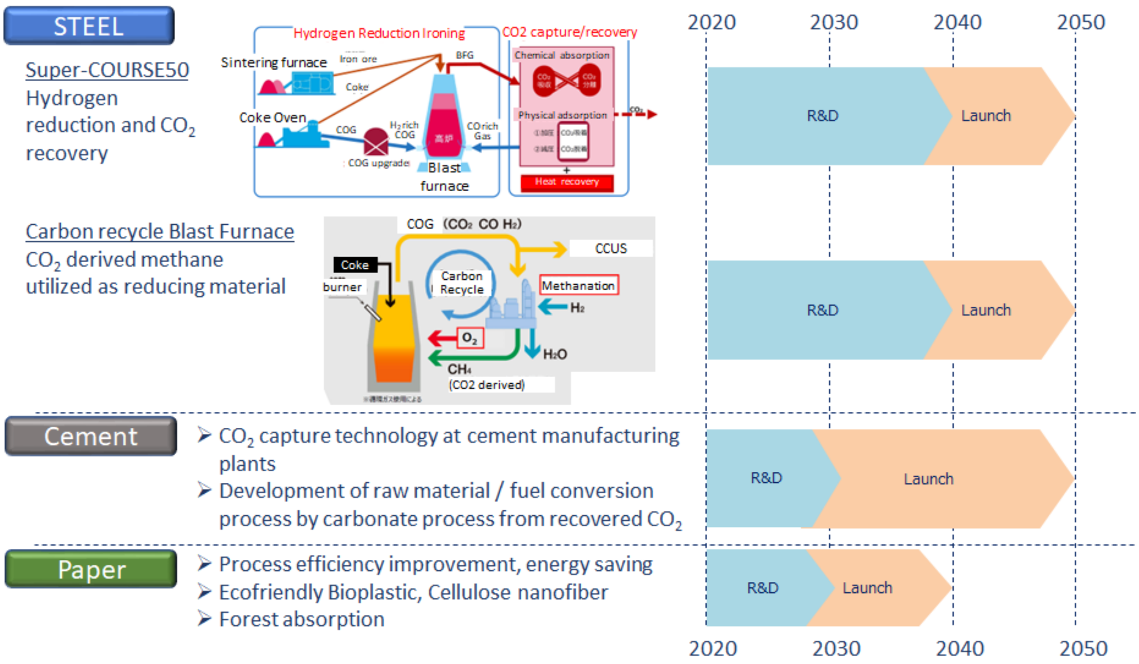
Figure 2.13. Demonstration of RE100 Factory, Panasonic 'H_2 Kibou Field Demonstration'

Source: Panasonic website, https://news.panasonic.com/jp/press/jn210524-1.

During sunny days, power from solar PV is consumed preferentially. During cloud days, power from a lithium-ion battery (LiB is consumed, and LiB is charged from the PEFC at night. Tentatively, conventional H_2 is supplied for PEFC generation, then will be shifted to green H_2 when its price becomes commercially competitive.

Figure 2.14 shows the carbon-neutral technology R&D roadmap in the industry sector – steel, cement, and paper. For example, coke used in pig iron production is the second-largest consumer of coal after power generation and emits a large amount of CO_2 in the process. Although it depends on the industrial structure, in the case of Japan, coke used in pig iron production accounts for about 40% of the CO_2 emissions of the entire industrial sector. Currently, two major development projects, Super-COURSE50 and carbon-neutral blast furnace, are underway for the carbon neutralisation of the steel industry. The former involves separating and recovering CO_2 from the coke oven gas, concentrating the hydrogen in the coke oven gas, returning it to the blast furnace, and using it for iron ore reduction. The latter uses hydrogen recovered from coke oven gas to synthesize methane, which is then used for iron ore reduction. The government supports both projects because of their large R&D investment.

Figure 2.14. Carbon-neutral Technology R&D Roadmap in the Industrial Sector



Source: Edited by JCOAL Study Team based on data from Nippon Steel website, JFE website (https://www.nipponsteel.com).

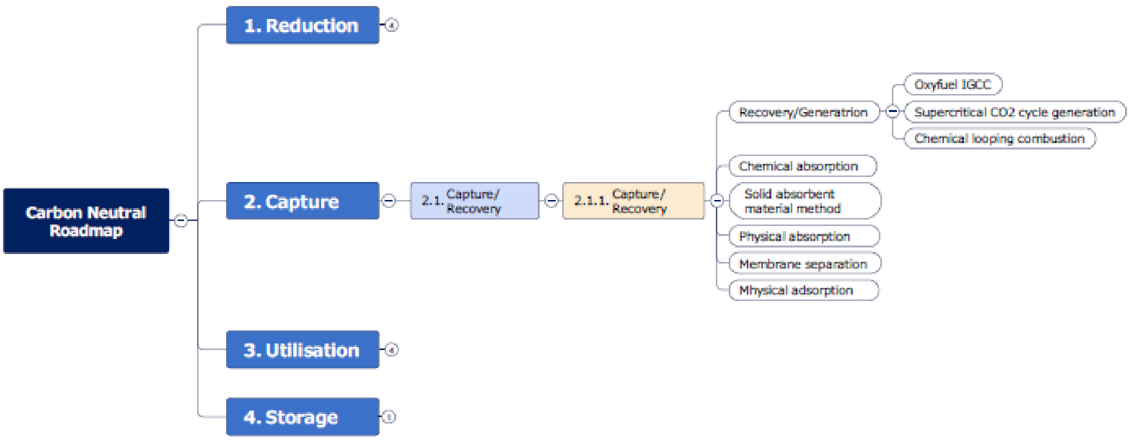
The main measures in the cement sector are to reduce CO_2 emissions by saving energy in processes, utilising hydrogen for heat sources, and recycling high-concentration CO_2 recovered from kilns.

The paper manufacturing sector, in addition to energy-saving processes and electrification of heat sources, is considering the development of bioplastic and cellulose nano-fibres, and the absorption of CO_2 by afforestation in their property.

2.2. CO_2 Capture

Figure 2.15 shows the classification of CO_2 capture technology. It can be broadly divided into two: a technology that separates CO_2 simultaneously as power generation (Table 2.1) and one that separates and recovers CO_2 from exhaust gas (Table 2.2).

Figure 2.15. CO_2 Capture Technologies



Source: JCOAL Study Team.

Table 2.1. Combined Power Generation and CO_2 Capture Technologies

Technology	Process	Status
Chemical looping cycle	Generation and CO_2 separation utilising the oxidation reaction by the fluidised bed combustion medium	R&D
Oxyfuel IGCC	CO_2 in the exhaust gas is circulated as an oxidant to gasifiers and turbines to generate combined power generation.	R&D

Source: Edited by JCOAL Study Team based on data from NEDO, Oki et al. (2011).

Chemical looping cycle and oxyfuel IGCC are innovative concepts that generate power and separate CO_2. However, they are still at the basic R&D stage; it will take time to put them to be proven.

On the other hand, the technologies for CO_2 recovery from flue gas shown in Table 2.2 and Figure 2.16 are getting closer to commercialisation. Several large-scale plants are being constructed around the world. However, efforts to reduce operating costs are still necessary, so several technologies are being developed in parallel.

Table 2.2. CO_2 Capture Technologies

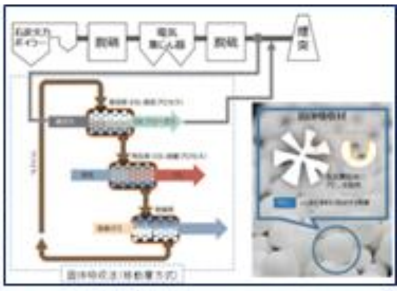
Technology	Process	Application	Status
1. Chemical absorption	CO_2 separation/recovery through chemical reaction	Coal, cement, steel, refinery, chemical industry, LNG	Commercial
2. Physical absorption	CO_2 separation using dissolution equilibrium with solvent	Coal (high pressure), cement, refinery, chemical industry, LNG	Commercial
3. Solid absorbent material method	CO_2 separation using absorption equilibrium with porous material	Coal, cement, refinery, chemical industry	Demonstration
4. Physical adsorption	CO_2 separation using pressure swing of adsorption/desorption with porous material (PSA)	Coal, cement, steel, refinery, chemical industry	Commercial
5. Membrane separation	CO_2 separation using gas selectivity of ultra-membrane	Coal (high pressure), refinery, chemical industry, LNG	R&D

Source: Edited by JCOAL Study Team based on data from NEDO. (https://www.nedo.go.jp/english/).

Figure 2.16. CO_2 Capture Plant and Process Listed in Table 2.2

1. USA, Petra Nova, 4776t/d, EOR

1. Fukuoka, Sigma Power, 500t/d



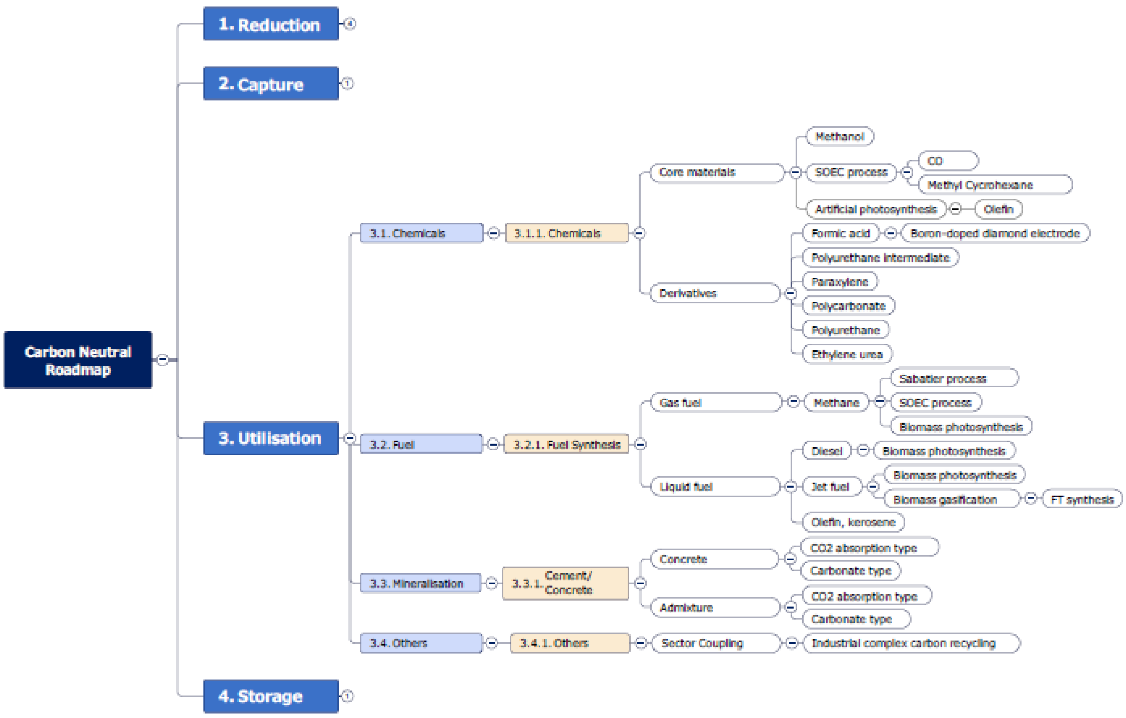
3. Kyoto, Maizuru, 40t/d

Source: Edited by JCOAL Study Team based on data from MHI, Toshiba, and KHI websites.

2.3. CO_2 Utilisation

Reusing CO_2 as a resource without releasing it into the atmosphere is an important negative emission and storage measure. Figure 2.17 shows the technology tree under 'Utilisation'. The main subcategories under 'Utilisation' are 'Chemicals', 'Fuels', 'Mineralisation', and 'Others'. CO and methanol, key substances obtained from CO_2 reduction reaction, are being studied in chemicals. Subsequent derivatives such as hydrocarbons, paraxylene, and polycarbonate are also being investigated. In terms of fuel, methane synthesis, sustainable aviation fuel (SAF), and other liquid fuels are also being studied. As for mineralisation, absorption into coal ash, cement, and concrete is being considered, and expected SAF commercialisation by the 2030s as a recycling method that does not use hydrogen.

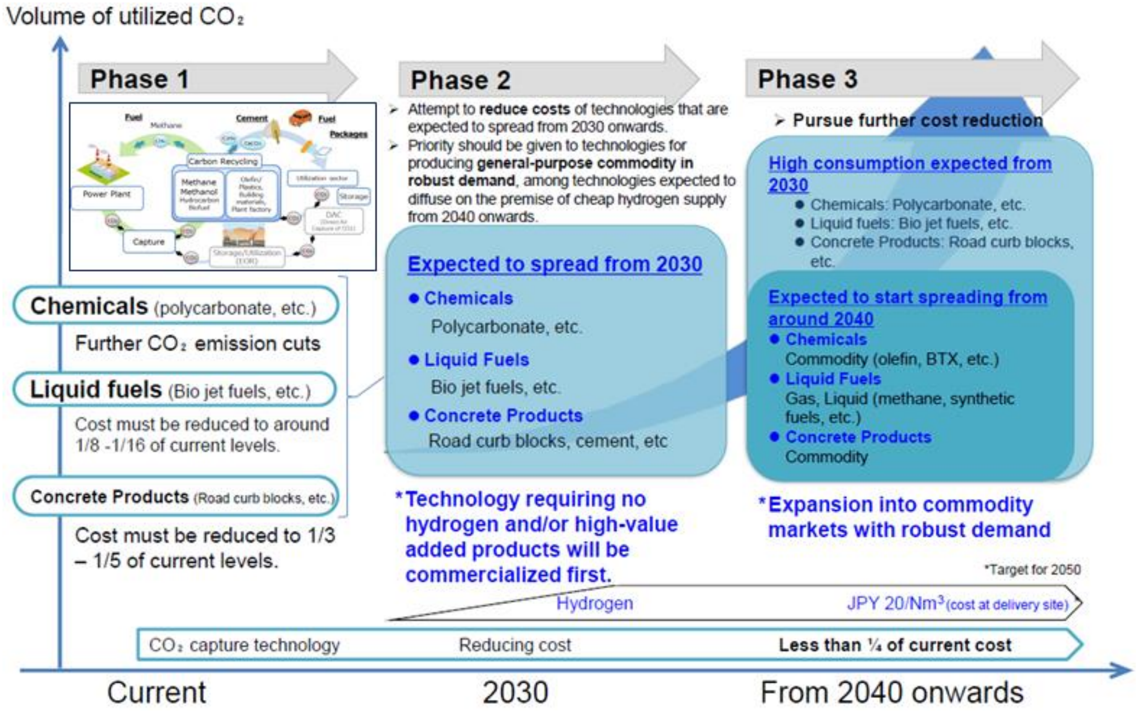
Figure 2.17. CO_2 Utilisation Technologies



Source: JCOAL Study Team.

Figure Figure 2.18 is the technology development roadmap for CO_2 recycling utilisation indicated by the Japanese government. Technologies that do not use hydrogen will be put into practical use in the 2030s, and technologies that use hydrogen will be developed along with reduced hydrogen costs.

Figure 2.18. Roadmap for Carbon-recycling Technologies



Source: METI (2019).

Figure 2.19 shows the SAF synthesis process and plant using photosynthetic reaction by algae, and biomass gasification with the Fischer-Tropsch process. SAF development is underway in the aviation sector to replace 10% of the total fuel capacity with SAF by 2030.

Figure 2.19. Biojet Fuel Process (Algae Photosynthesis, FT Synthesis)

FT = Fischer-Tropsch.
Source: Edited by JCOAL Study Team based on data from Nikkei (2021a).

In many cases, the conversion of CO_2 to chemicals is thermodynamically unfavourable, and hydrogen costs are directly affected. Therefore, price competitiveness must be considered severe compared to conventional products. However, it is possible to establish a policy considering the cost burden for carbon neutrality (CN), so we think technology development should be continued. Figure 2.20 shows the pilot plants for methane and methanol synthesis from CO_2, with multiple companies participating.

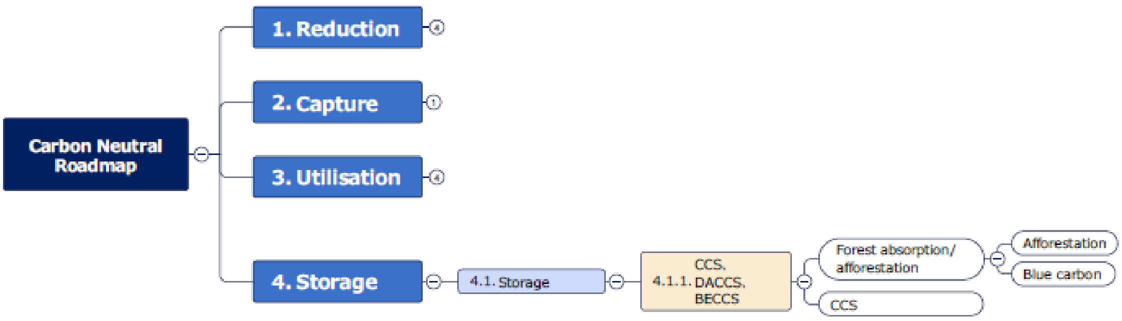
Figure 2.20. Pilot Plant of Methane and Methanol Syntheses from CO_2

Source: Edited by JCOAL Study Team based on data from the Hitachi Zosen website, Nikkei (2021b).

2.4. CO_2 Storage

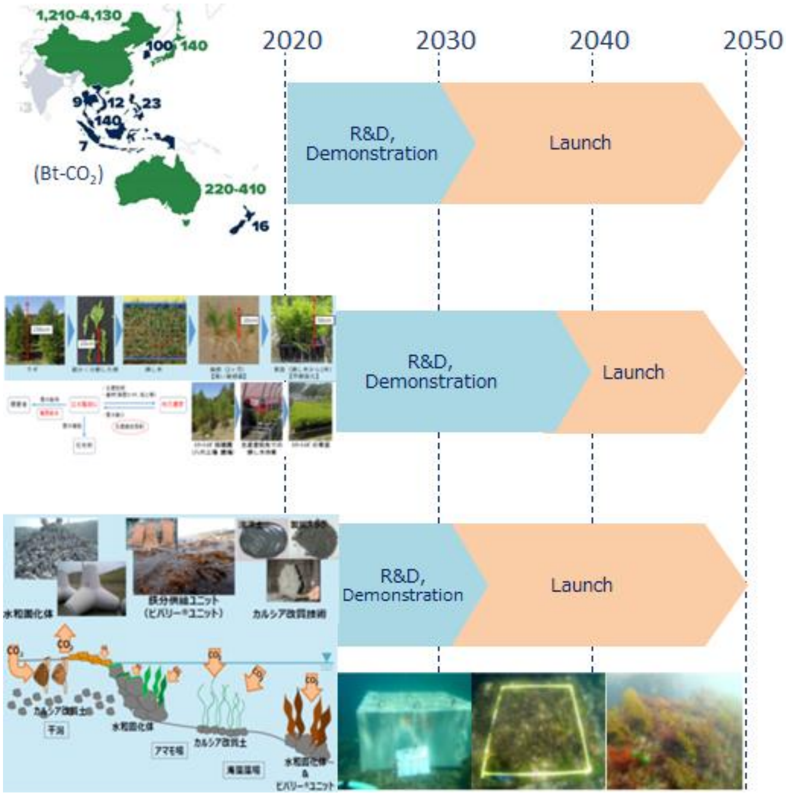
The final category is storage (Figure 2.21). The most common storage method is CCS. Many projects are underway worldwide as underground storage. There are also several absorption technologies by forests and absorption by seaweed. The development roadmap and examples of these technologies are shown in Figure 2.22. The ASEAN region is expected to have a large potential for this CO_2 storage.

Figure 2.21. CO_2 Storage Technologies



BECCS = bioenergy with CCS, CCS = carbon capture and storage, DACCS = direct air capture with CCS.
Source: JCOAL Study Team.

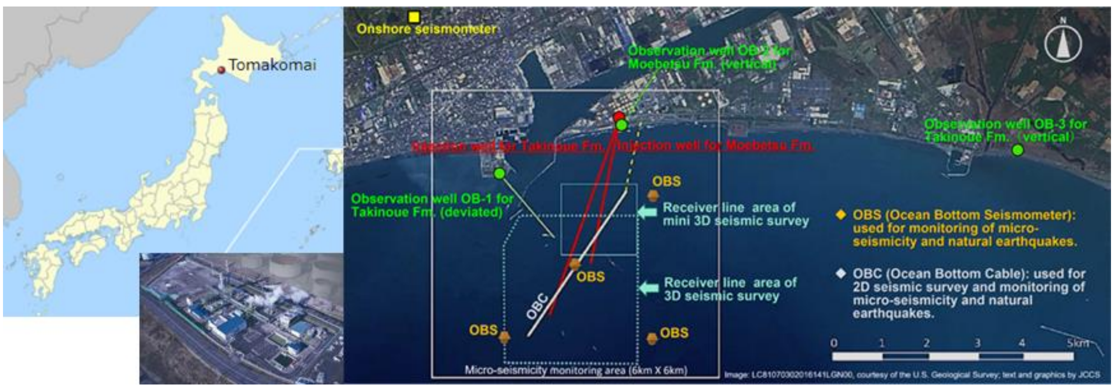
Figure 2.22. Roadmap of CCS, Afforestation, and Blue Carbon



Source: METI website, original data from Global CCS Institute, JCOAL Study Team, https://www.globalccsinstitute.com.

Figure 2.23 shows the Tomakomai CCS Project, conducted by the Ministry of Economy, Trade and Industry (METI), New Energy and Industrial Technology Development Organization (NEDO), and Japan CCS Co., Ltd (JCCS). It is the first large-scale CCS demonstration in Japan. The entire plant was constructed in FY2012–2015, followed by the injection starting from April 2016 at a scale of 100,000 tonnes per annum. The Tomakomai CCS Project achieved the initial target cumulative injection of 300,000 tonnes on 22 November 2019. Now the project is in the post-injection monitoring phase.

Figure 2.23. CCS Demonstration Project in Tomakomai



Source: Japan CCS website, https://www.japanccs.com/en/.

3. Recommendations

Below are the recommendations from the technological aspects.

1) The pathway to CN depends on the situation of the country. So, considering energy security and feasibility, selecting a tailored technology option for each country is necessary. For example, the use of the existing coal-fired plants is a practical solution for biomass and/or ammonia cofiring.

2) It is necessary to take comprehensive measures to achieve CN, including CCUS, which captures CO_2 and uses it for storage and carbon recycling, as well as technology to reduce CO_2 emissions.

3) In particular, CO_2 recovery has become a major issue in the power and industry sectors, so cross-sectoral cooperation is required. Policy initiatives for supporting such cooperative activities are effective. Also, financing schemes covering the entire carbon-neutral project would be essential to make this possible.

4) Proceeding with international cooperation when studying the adaptability of specific carbon-neutral technologies is also effective.