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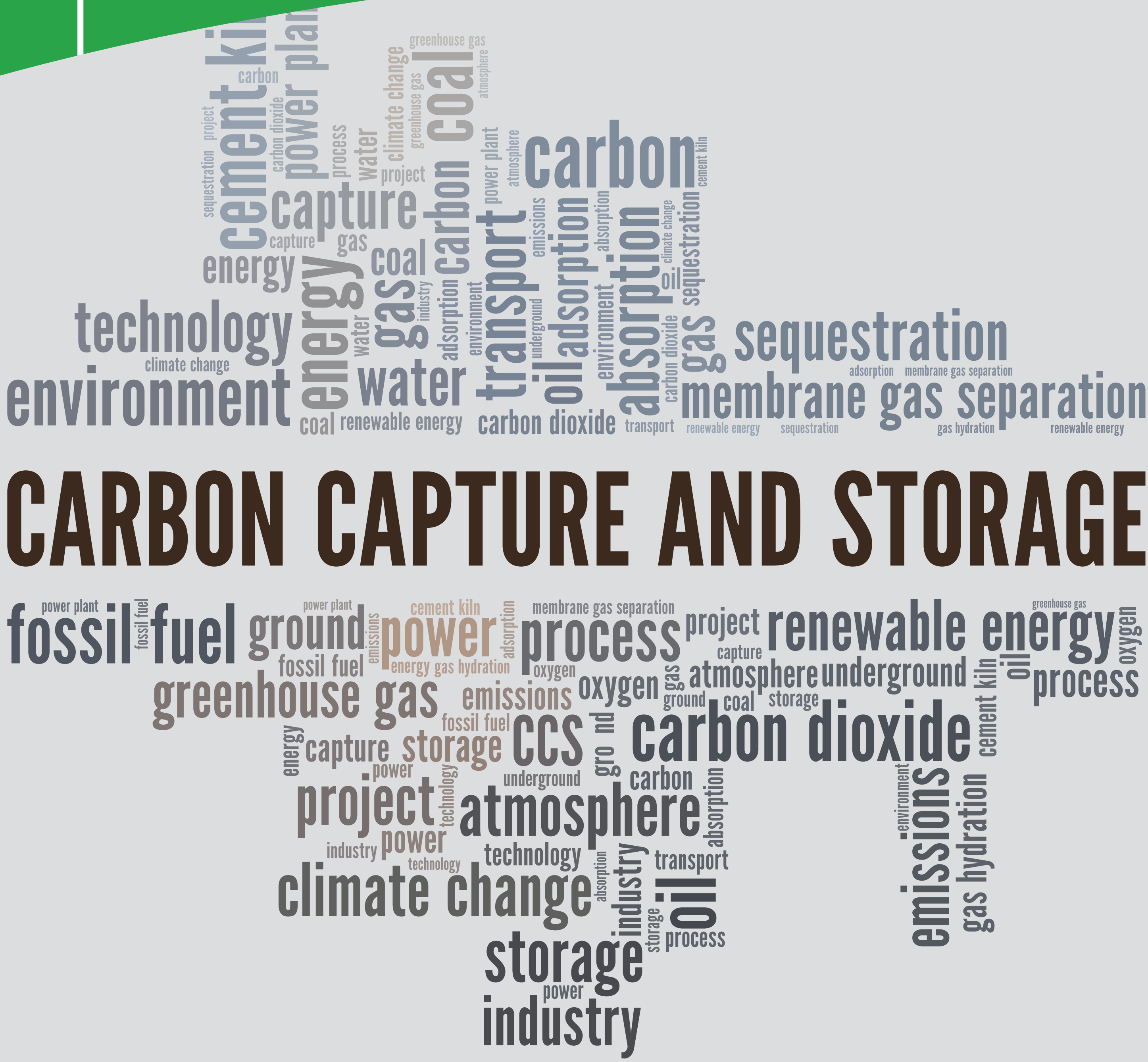
RENEWABLE ENERGY INSTITUTE

Bottlenecks and Risks of CCS Thermal Power Policy in Japan

English Edition

May 2022



Acknowledgments
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About Renewable Energy Institute
Renewable Energy Institute is a non-profit think tank which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Son Masayoshi, Chairman & CEO of SoftBank Corp., with his own resources.

This report is the English excerpt of "Bottlenecks and Risks of CCS Thermal Power Policy in Japan," originally published in Japanese on 14 April 2022. In the English version, only bottlenecks 3 and 5 are translated, which are particularly relevant to Japan. For other bottlenecks, please see the summary.

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Summary

Japan's Energy Strategy Overly Dependent on Carbon Capture and Storage

Many countries around the world are aiming to supply around 90% of their electricity from renewable energy sources by 2050 as the cost of renewable energy continues to decline rapidly. In Japan, however, the review process of the government's Strategic Energy Plan indicated that the share of renewable electricity in 2050 would be limited to between 50% to 60%. This scenario is also assumed in the government's current review of the wide-area power grid development plan.

On the other hand, the Japanese government has positioned the "Zero Emission Thermal Power Generation" strategy which includes thermal power with CCS (herein after referred to as "CCS thermal power") , ammonia co-firing with coal power, and hydrogen power generation, and has emphasized its development as "a trump card for decarbonization." In the process of reviewing the Strategic Energy Plan, the Japanese government proposed a future scenario for power mix consisting of about 30% from CCS thermal power and 10% from ammonia and hydrogen in 2050. CCS thermal power plants have been claimed as being able to capture and reduce 90% of CO_2 emissions, but the actual capture rate has been limited to 60% to 70%. Ammonia-based thermal power still emits about twice as much CO_2 as natural gas when comprising a 20% mix in coal power plants, as stipulated in the Strategic Energy Plan. The introduction of CCS and ammonia-based thermal power will likely enable operators to have reason to prolong the life of coal-fired power plants.

The Five Bottlenecks of CCS Thermal Power Policy

■ Bottleneck 1: Stagnancy in the introduction of CCS thermal power plants

Currently, there is only one CCS thermal power plant in operation in the world, a small facility of 115 MW in Canada, and only one other plant in the United States (equivalent to 240 MW) that operated for three years from 2017 but ceased operation for economic reasons in 2020. While the EU once promoted the idea of CCS, it is now excluded from measures to reduce emissions in the power generation sector. Thus, relying on CCS to reduce emissions in the power sector is a risky strategy based on recent evidence.

■ Bottleneck 2: Incomplete capture of CO_2

The European decarbonization strategy notes that CCS has not yet achieved complete decarbonization, and the IPCC's Sixth Assessment Report assesses CCS to be an immature technology in the power generation sector. Of the two plants with operation experience thus far (one active in Canada and the other currently non-operational facility in the US), the capture rate was recorded at 60% to 70%.

■ Bottleneck 3: There are no geographical conditions suitable for sequestration in Japan.

Of the 31 commercial-scale CCS projects realized around the world to date, land-based storage accounts for 28. Of these, 22 generate income by injecting captured CO_2 into exhausted oil and gas fields to increase the production of fossil fuels with Enhanced Oil Recovery (EOR). Since there is no land area in Japan suitable for this purpose, marine areas are assumed, but few examples have been identified anywhere in the world. Technologies for transportation and storage have yet to be established, and no specific storage sites have been found in Japan. There are also no conditions for implementing an EOR to ensure the economic viability of the project.

■ Bottleneck 4: Rising costs of CCS thermal power generation

The Ministry of Economy, Trade and Industry (METI) is aiming for a target cost for future CCS power generation of 13 to 15 yen/kWh[1], which compares unfavorably to METI's own solar PV cost target of 7 yen in 2025 and wind power cost target of 8 to 9 yen in 2030. In addition, the actual cost of generation by CCS thermal power is estimated to exceed METI's target.

■ Bottleneck 5: Risks posed by the overseas export of CO_2

The Japanese government energy strategy assumes a large amount of CCS for thermal power generation and it will also be used in the industrial sector. For this reason, it is very unlikely that sufficient storage sites will be found in Japan, and as such, there are plans for overseas export, especially to Southeast Asia. According to an estimate based on government request, as much as 230 million to 280 million tons of CO_2 is expected to be exported each year. Southeast Asia has abundant and diverse renewable energy resources. Japanese companies would be better suited to utilize their technologies for the development of renewable energy sources and the realization of power transmission networks.

Global Trends of CCS and Renewable Energy

According to the IEA's "Net Zero by 2050", released in May 2021, 88% of the world's electric power in 2050 will come from renewable energy sources, and only 3% from CCS thermal power. The European Union's 2050 strategy specifies that in 2050, CCS will play a very limited role in power generation because of the large-scale availability of competitive wind, solar, and other renewable sources. In Germany, a policy was proposed for almost 100% of the domestic electricity supply to be provided by renewable energy sources by 2035. The role of CCS is limited in the industrial sector as well. In the United Kingdom, there is still the possibility of using CCS in the power generation sector, but its share is expected to be insignificant.

The United States is aiming for zero emissions from the power generation sector by 2035 and carbon neutrality by 2050, but it has not yet disclosed the composition of its power sources. The US Department of Energy has a tax-deductible CCS assistance program, but none of the projects supported as coal-fired CCS demonstration programs have been successful. The long-term strategy submitted to the United Nations shows that solar and wind power will account for the majority of new power generation capacity by 2050, indicating that CCS thermal power generation is not regarded as important.

According to the scenario of the Energy Research Institute under the Chinese government's National Development and Reform Commission, renewable energy will account for about 90% of the Chinese electricity supply in 2050, and neither coal nor gas is expected to be used in 2060, when China aims to become carbon neutral.

According to the Sixth Assessment Report of the IPCC, wind and solar power are the least expensive and have an overwhelmingly large potential for decarbonizing the energy sector, while CCS power generation is the most expensive and has the least potential. Even in the industrial sector, CCS is assessed as having the highest cost and the smallest potential.

Japan's Decarbonization Strategy – the Way Forward

The likelihood of success for Japan to decarbonize seems low with an energy policy relying heavily on CCS. Going this route, Japan will be forced to spend large sums to implement the technologically incomplete CCS, and will be required to pay for credits for CO_2 emissions that are not able to be captured and stored. Furthermore, ongoing dependence on fossil fuels will continue to drain national wealth as the country spends on fuel imports. It is clear that urgent policy reconsideration is required for Japan to meet its own goal and global responsibilities towards decarbonization.

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[1] Annual average exchange rate in 2021 was USD 1 = JPY 110.8. 10 yen is about 9 US cents.

Chapter 1: Japan's Energy Strategy Overly Dependent on Carbon Capture and Storage

The Position of CCS in Climate Change Measures

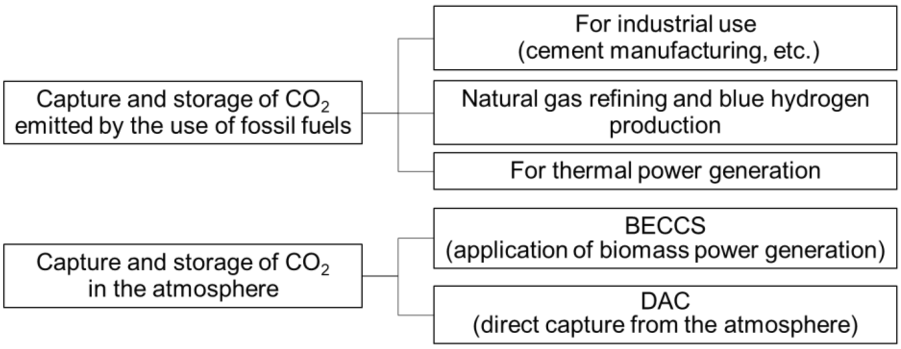
Since former Prime Minister Suga's declaration of 2050 carbon neutrality in October 2020, the government's energy policy and climate change measures have seen progress. Examples of such progresses include; the stipulation of "Principles of Renewable Energy First" in the Strategic Energy Plan, the promotion of offshore wind power development, and setting a new target to reduce greenhouse gas emissions by 46% to 50% by 2030.

On the other hand, there are still policies that aim to continue using fossil fuels under the banner of decarbonization, which is represented in the policy of large-scale utilization of Carbon Capture and Storage for thermal power generation (hereinafter referred to as “CCS thermal power”) .[2]

Since the 1970s, CCS has been considered around the world as a way to reduce CO_2 emissions,[3] but 50 years later, as we enter the 2020s, there are only 27 projects still in operation worldwide. The total amount of CO2 captured is only 35 to 39 million tonnes. The largest part of CCS currently in operation is projects to capture CO_2 from natural gas refining, and there is only one CCS for thermal power generation.

Recently, regarding the purpose of CCS, there have been increasing discussions on the capture of CO_2 that is already present in the atmosphere, rather than that emitted from newly used fossil fuels. Delays in reducing emissions to achieve the 1.5°C target will increase the amount of already released CO_2 that must be captured. There is BECCS (Bioenergy with Carbon Capture and Storage), which utilizes biomass power generation, and DAC (Direct Air Capture), which captures directly from the atmosphere. Neither is in full-scale use yet.

Figure 1 Types of Carbon Capture Storage (CCS)



Source: Renewable Energy Institute

In the past year or two, CCS introduction plans around the world have increased as the international community aims to realize the target of 1.5°C. However, even in steel production, where CCS was once thought to be the core of measures, the need for the industrial use of CCS is decreasing as methods using green hydrogen and renewable electricity are increasingly sought.[4]

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2 The term "CCUS" (Carbon dioxide Capture, Utilization and Storage) is used in government documents. It includes CCU that utilizes captured CO_2 to produce chemical products. However, CCU is in the initial stages of technological development and has not been put into practical use. The IEA's 2050 Net Zero strategy (Net Zero by 2050) has limited the use of CCUS even in 2050, with CCS accounting for 95% and CCU for 5%. Given this, this report focuses on CCS.

3 International Energy Agency (IEA): "About CCUS" (April 2021) https://www.iea.org/reports/about-ccus

4 All of the world's low-carbon steelmaking projects scheduled for construction by 2030 will be electric furnaces and direct reducing furnaces with hydrogen, and none will be blast furnaces with CCS. Renewable Energy Institute: "Toward the Decarbonization of the Steel Industry" (December 2021)

There are even fewer plans for power generation. The reason is that renewable energy is rapidly decreasing its cost and has become available in large quantities. For example, the “Net Zero by 2050” strategy of the International Energy Agency (hereinafter, the "IEA") assumes that 88% of electricity is provided by renewables and only 2% by fossil fuel-fired CCS thermal power generation.[5] This trend is common to the European, US, and Chinese strategies. Overall, CCS has become less attractive as a means of reducing CO_2 emissions from fossil fuel resources. (This is explained in detail in Chapter 3.)

Introduction of Zero-Emission Thermal Power Plants That Rely on CCS

What is unique about Japan's energy policy is that, despite the "Principle of Renewable Energy First," the government does not set forth a policy of introducing renewable energy to the maximum extent of 90% by 2050, as in IEAs’ and other countries’ scenario. In addition to CCS thermal power generation, ammonia co-firing power generation and hydrogen power generation are called "zero-emission thermal power generation," and their development and large-scale use are emphasized as "the trump card of decarbonization."[6]

Although advanced countries are required to phase out coal-fired power by 2030 and many countries have decided to stop using coal for power in the early 2020s. What Japan is pursuing is only a fade-out of inefficient ones, and the country has clearly set forth a policy of continuing to use coal-fired power beyond 2030, by focusing on what it calls "highly efficient" coal, with virtually no change in CO_2 emissions.

The government has justified such policies, saying it will "replace coal-fired power plants with decarbonized ones by increasing these costs while utilizing hydrogen, ammonia, CCUS, etc."[7] However, as explained in Chapter 2 of this report, although CCS thermal power plants have been claimed to capture and reduce 90% of CO_2 emissions, the actual capture rate has remained between 60% and 70%, as examples have shown. Moreover, ammonia co-fired coal power plants, as stipulated in the Strategic Energy Plan, still emit about twice as much CO_2 as natural gas.[8] The introduction of CCS and ammonia-based thermal power will likely enable operators to have reason to prolong the life of coal-fired power plants.

In addition, both ammonia and hydrogen power generation are part of renewable power generation if green hydrogen and green ammonia are used as fuels, but the government is actually focusing on the blue hydrogen and blue ammonia produced from fossil fuels. Again, the use of CCS is required to reduce CO_2 emissions from the manufacturing process. Therefore, the government's Zero-Emission Thermal Power strategy is directly and indirectly based on the large-scale use of CCS.

Plans to Introduce CCS Defined in the Strategic Energy Plan

In October 2021, the Japanese government decided on the 6th Strategic Energy Plan, but in discussions aimed at revising the plan, it was proposed that renewable energy power should be limited to 50% to 60% in 2050 and that large amounts of CCS thermal power should be introduced. The figures themselves were ultimately removed, but in subsequent reviews of the national energy policies, these ideas seem to be implicit assumptions.

In December 2020, at the Subcommittee on Basic Policy reviewing the Revision of the Strategic Energy Plan, the METI presented a reference value for the 2050 power generation mix, specifying 50% to 60% for renewable electricity, about 30% to 40% for nuclear and CCS thermal power, and about 10% for ammonia and hydrogen power generation.

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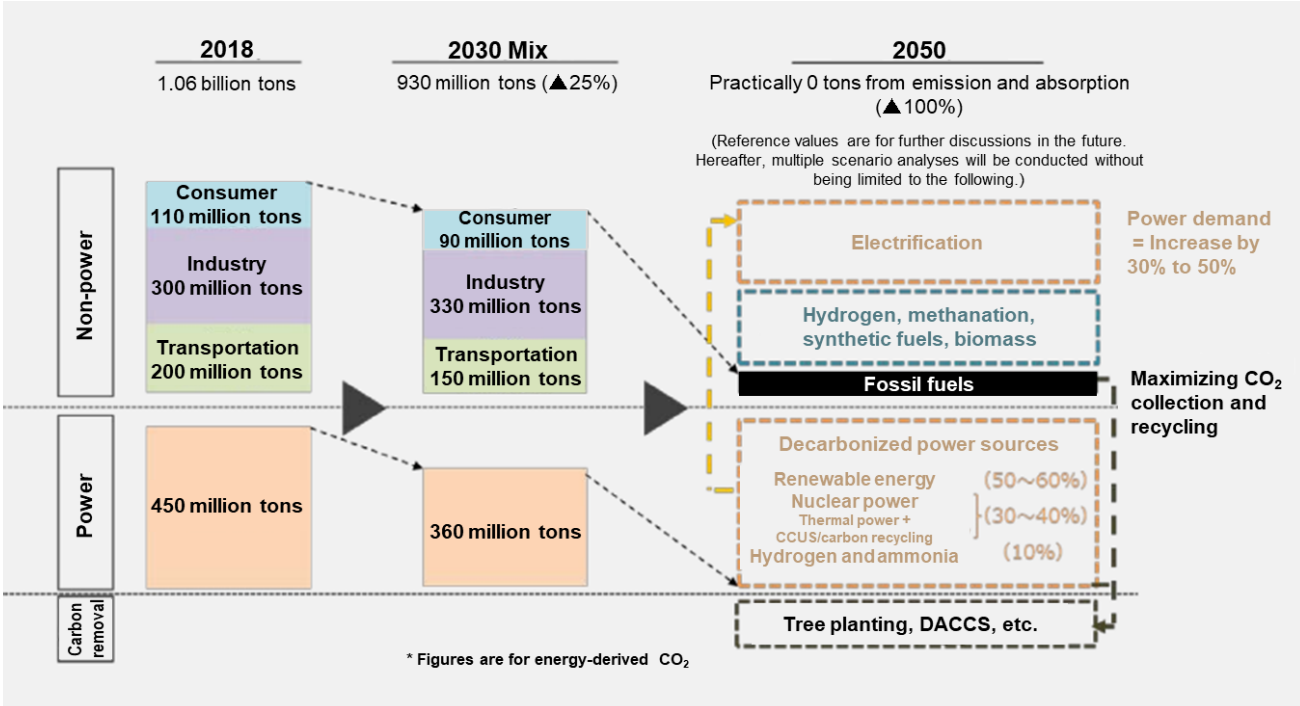
5 IEA "Net Zero by 2050 A Roadmap for the Global Energy Sector" (May 2021)

6 For example, Mr. Hagiuda, Minister of Economy, Trade and Industry, stated at the ASIA-Japan Investing for Future Initiative on January 10, 2022, that "CCS is a trump card for decarbonization in Asia, and Japan and ASEAN are eager to realize it".

7 Remarks by Prime Minister Fumio Kishida at the Budget Committee of the House of Representatives on February 2, 2022

8 JERA, which promotes ammonia-based power generation, plans to develop new burners capable of combusting with more than 50% of ammonia mixed by FY2024 and to start combusting with more than 50% of ammonia mixed in actual machines by FY2028. Since the use of coal-fired power is internationally allowed only when the target capture rate of about 90% with CCS is achieved, an ammonia co-firing rate of about 90% is also required. Also, if ammonia is produced from fossil fuels as it is now, it will emit almost as much CO_2 as can be reduced.

Figure 2
Scenario of Transforming to Carbon Neutrality Presented in the Green Growth Strategy



Source: METI: "Green Growth Strategy with Carbon Neutrality by 2050" (December 25, 2020)

The Green Growth Strategy with Carbon Neutrality by 2050, which was formulated in the same month, also stated that "thermal power generation based on the assumption of nuclear and thermal power with CO_2 capture is about 30% to 40%," following the reference value. As existing nuclear power plants continue to be decommissioned, it is extremely difficult to supply 10% of the electricity required in the 2050s because the development of new sites is impractical from the standpoint of cost and public consensus.[9] Consequently, about 30% will be supplied by CCS thermal power.

A study commissioned by the METI and conducted by the Research Institute of Innovative Technology for the Earth (hereinafter, the "RITE")[10] presents the analytical results on the Basic Scenario (based on the reference value) and six other scenarios. According to this, 555 million tons of CO_2 must be captured and stored every year in CCUS Scenario, and 326 million tons of CO_2 must be captured and stored every year in other scenarios including the Basic Scenario.

[9] In order for nuclear power to supply 10% of electricity in 2050, the following four assumptions need be made: (1) all existing nuclear power plants will be restarted (except for the nuclear reactors slated for decommissioning); (2) all nuclear power plants will operate for 60 years, a length of time that is considered an exceptional case; (3) three new nuclear power plants, whose construction has been suspended or has yet to be started, will be all completed; and (4) a high facility utilization rate of 80% will be realized, which is much higher than the past results (with an average of 67.8% from 2001 to 2010). Even under these assumptions, decommissioning will occur in succession in the 2050s, and by 2060 the capacity will decrease to 40% of that in 2050. If we stop making unreasonable assumptions, we can only supply a very small percentage by 2050 and 2% to 3% by 2060. To supply 10% of nuclear power plants after 2050, it will be necessary to build 10 new reactors with a capacity of 1000 MW. See P. 100 of Material 1 of the Subcommittee on Basic Policy of the Advisory Committee for Natural Resources and Energy (35th meeting).

[10] RITE: "Analysis on Scenario of Carbon Neutrality by 2050 (Interim Report)" (May 2021)

Figure 3 Examination on Scenarios When Formulating the Strategic Energy Plan

Scenarios Assumed by RITE

May 13, 2021
Advisory Committee for Natural Resources and Energy Subcommittee on Basic Policy (RIEI handout is partially processed)

Scenario Name	Renewable energy cost	Nuclear power ratio	Hydrogen cost	CCUS (Potential for storage)	Fully automated driving (Car/Ride sharing)	Percentage of renewable energy in the power supply mix
Cases with reference values *1	Standard cost	Up to 10%	Standard cost	Storage in Japan: up to 91 Mt CO_2/yr; transport overseas: up to 235 Mt CO_2/yr	Standard assumption (Not assuming realization and popularization of fully automated vehicles)	54% (Optimization results)
(1) Renewable energy 100%		0%				Almost 100% (Assumption of the scenario)
(2) Innovation by renewable energy	Lower cost	Up to 10%				63% (Optimization results)
(3) Use of nuclear energy *2	Standard cost	Up to 20%				53% (Optimization results)
(4) Innovation by hydrogen		Up to 10%	Costs of facilities for hydrogen production such as water electrolysis, and hydrogen liquefaction: Halved			47% (Optimization results)
(5) Use of CCUS			Standard cost	In Japan: Up to 273 Mt CO_2/yr; Overseas: Up to 282 Mt CO_2/yr		44% (Optimization results)
(6) Demand transformation				In Japan: Up to 91 Mt; Overseas: Up to 235 Mt	Realization and popularization of fully automated driving in and after 2030, increased car/ride sharing, and decreased production of materials due to a reduced number of vehicles	51% (Optimization results)

*1: No feasible solutions available without DAC, assuming the availability of DAC in all scenarios
*2: Separate analysis conducted for scenarios of nuclear utilization with a ratio of up to 50%

Source: Petroleum and Natural Gas Division, Agency for Natural Resources and Energy: "Future Issues for the Commercialization of CCS" (January 28, 2022) Brief by the Secretariat of the 1st CCS Long-Term Roadmap Review Meeting

In the revised version of the Green Growth Strategy released on June 18, 2021, the share of power sources was omitted from the power mix chart. Regarding the power mix in 2050, it states, "In order to achieve these reference values for 2050, each power source must overcome various hurdles such as natural conditions, social constraints, and technological challenges, and achieving this level will not be easy." Officially, it is unclear what kinds of energy will be used to realize decarbonization in Japan.

However, the process taken by the METI and others to examine energy policies since then suggests that the basic strategy of limiting the share of renewable electricity and promoting the large-scale use of other zero-emission thermal power has been maintained. For example, a Basic Scenario of 50% to 60% renewable energy sources in 2050 is being considered to examine the development of a future wide-area power grid, promoted by the Organization for Cross-regional Coordination of Transmission Operators.[11]

The Ministry of Economy, Trade and Industry Aims to Introduce CCS Thermal Power by 2030

In January 2022, the METI launched the CCS Long-Term Roadmap Advisory Committee, which aims to introduce CCS thermal power by 2030. At the first meeting of the Advisory Committee, the METI presented a figure of about 120 million to 240 million tons per year as of 2050 as the estimated annual storage volume by CCS in Japan.[12] According to METI, its rationale is to multiply the global CO_2 capture and storage volume under the IEA's three energy scenarios by Japan's current share of the global CO_2 emissions (3.3%).

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[11] The 14th Meeting of the Review Committee on the Master Plan for Wide-area Interconnection Systems and the Rules for Utilizing Systems: "On the Review Situation of Scenarios toward Formulating the Master Plan" (December 20, 2021)

[12] Explanatory material: "Future Issues for the Commercialization of CCS," prepared by the Secretariat for the first meeting of the CCS Long-term Roadmap Advisory Committee (January 28, 2022), the Petroleum and Natural Gas Division of the Agency for Natural Resources and Energy

However, the number of CCS required by each country should be calculated on the basis of its decarbonization strategy. As Chapter 3 explains, Germany, which makes full use of renewable electricity and green hydrogen, does not envisage the use of CCS. It is not at all reasonable to calculate Japan's requirements for CCS in 2050 by prorating the global requirements for CCS.

The volume of about 120 million to 240 million tons per year is about half the level of the 300 million to 500 million tons estimated by RITE in the process of reviewing the Strategic Energy Plan. If this figure is used exclusively to reduce emissions from CCS thermal power, it would be equivalent to about 30% of the electricity supply in 2050 at the upper limit[13], but the storage capacity for the industrial sector would be lost. If the assumed storage volume is changed, the entire decarbonization strategy should be reviewed accordingly, taking into account the changes in the share of power sources.

However, the METI is promoting CCS thermal power as the trump card for decarbonization without conducting such a review. According to the materials and discussions at the Roadmap Review Meeting, METI assumes CCS thermal power being realized in 2030, and it is obviously leaning forward to shorten the development schedule. It is uncertain whether the government will make other necessary reviews, such as considering technical possibilities, costs, and environmental conservation.

IPCC Calls for Phase-Out of Coal-fired Power Stations

The Intergovernmental Panel on Climate Change (hereinafter, the "IPCC") released its Working Group 3 Report on its 6th Assessment Report on April 4, 2022, which warned that the global temperature rise would reach 3.2°C under current policies, and stated that achieving the 1.5°C target agreed at COP26 would be essential to achieve a peak-out of greenhouse gas emissions by 2025 at the latest and a 43% reduction by 2030 (compared to 2019).

The key to reducing emissions by 2030 is to stop using coal-fired power generation. The IPCC report says that a net-zero energy system that satisfies the 1.5°C target will use far less fossil fuel than it does today, and that coal in particular must be cut by 75% by 2030 and by 95% by 2050 from the level of 2019.

As described in Chapter 3, the IPCC report assesses that CCS has high costs and low potential for reduction in both the energy and industrial sectors. For the analysis of energy scenarios described in the 6th Assessment Report, the UK energy policy think tank Ember noted that the decreasing costs of wind and solar power make the 1.5°C scenario more realistic, eliminating the need to rely on unproven and costly technologies such as CCS in the power generation sector.[14] According to Ember's analysis, coal-fired power generation with CCS accounted for only a median of 0.3% of electricity generation in 2040 under many 1.5°C scenarios assessed in the 6th Assessment Report.

On March 1, 2022, Japan's Cabinet approved the revision of the Act on Sophisticated Methods of Energy Supply Structures to "legally approve thermal power generation promotion if it is equipped with CCS". At the same time, it has decided to "position hydrogen and ammonia as non-fossil energy sources and promote the use of these decarbonized fuels".[15] At present, it is unclear what kind of institutional changes the bill is aiming for, but if it also aims to promote the use of CCS thermal power plants, whose effectiveness in reducing emissions has not been verified, and hydrogen and ammonia, which emit CO_2 in the manufacturing process, it would undermine the decarbonization of Japan's energy system.

In the following chapters, this report clarifies the bottlenecks of CCS thermal power generation from five standpoints, and introduces how various countries position renewable energy and CCS in their decarbonization strategies. In the final chapter, we propose the way forward for Japan's decarbonization strategy.

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13 If 35% of the 1350 TWh generated in 2050 is supplied by CCS thermal power plants (50% each by coal and natural gas), the required storage volume would be 245 million tonnes, assuming a CO_2 capture rate of 90%.

14 Ember "The science is clear, coal needs to go" (April 7, 2022) https://ember-climate.org/insights/commentary/the-science-is-clear-coal-needs-to-go/

15 News Release from the METI (March 1, 2022) https://www.meti.go.jp/english/press/2022/0301_004.html

Chapter 2: The Five Bottlenecks of CCS Thermal Power Policy

**In the English version, only bottlenecks 3 and 5 are translated, which are particularly relevant to Japan. For other bottlenecks, please see the summary.*

Bottleneck 3:
There Are No Geographical Conditions Suitable for CCS Usage in Japan

The third bottleneck in the CCS thermal power policy is the lack of geographical conditions suitable for CCS in Japan. Of the 31 commercial-scale CCS projects realized in the world to date, 28 have been land-based storage. Of these, 22 have been implemented using Enhanced Oil Recovery (EOR), in which captured CO_2 is injected to increase production in depleted oil fields (Table2). This is a system that can only be realized with the economic benefit of increasing oil production.

Table 2 Commercial-Scale CCS Projects Realized to Date

	In operation	Operation suspended	Completed	**Total**
Land area (EOR)	19	2	1	**22**
Land area (stratum storage)	4	0	1	**5**
Land area (other)	1	0	0	**1**
Sea area (EOR)	1	0	0	**1**
Sea area (stratum storage)	2	0	0	**2**
Total	**27**	**2**	**2**	**31**

Land area 28
Sea area 3

Source: Created by Renewable Energy Institute based on GCCSI "Global Status of CCS 2021" (November 5, 2021), GCCSI "CO_2 RE Facilities Database" (last accessed on March 29, 2022) https://co2re.co/FacilityData, and the Research Institute of Innovative Technology for the Earth "FY2020 Research Report on the International Cooperation Project for Global Warming Countermeasures (CCS International Cooperation Project (Cooperation Project with CCS-related International Organizations))" (March 2021).

Japan Aims to Store in the Most Expensive Marine Area, Without the EOR Method

Japan has no land areas suitable for CO_2 storage, nor oil fields that can be used for EOR in the first place. Consequently, the METI is only trying to find storage sites in marine areas. This method comes with high cost, and transportation and storage technologies are not well established. In other words, the CCS project in Japan is doubly handicapped in that it has to depend on marine areas for storage and EOR cannot be used. The METI openly admits this weakness, noting, "EOR is not realistic in Japan, and in the power generation field, separation and capture costs are relatively high. The business model to be considered will be a pattern of adding CO_2 capture and aquifer storage.[16]"

A report from the Global CCS Institute,[17] an organization dedicated to promoting the development of CCS, analyzes the differences in costs across storage sites. It indicates that in the case of existing depleted oil and gas fields, the characteristics of the storage site are well understood because exploration has already been performed sufficiently, and development costs can be saved. Consequently, it concludes, "The highest costs occur when there is no existing knowledge at the offshore site and no existing infrastructure that can be reused for CO_2 storage." What Japan is trying to do is exactly this, the most expensive possible case.

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16 Material 1 of the Subcommittee on Basic Policy of the Advisory Committee for Natural Resources and Energy (35th meeting): "Study for Realizing Carbon Neutrality in 2015" (December 21, 2020)

17 GCCSI "TECHNOLOGY READINESS AND COSTS OF CCS" (March 2021)

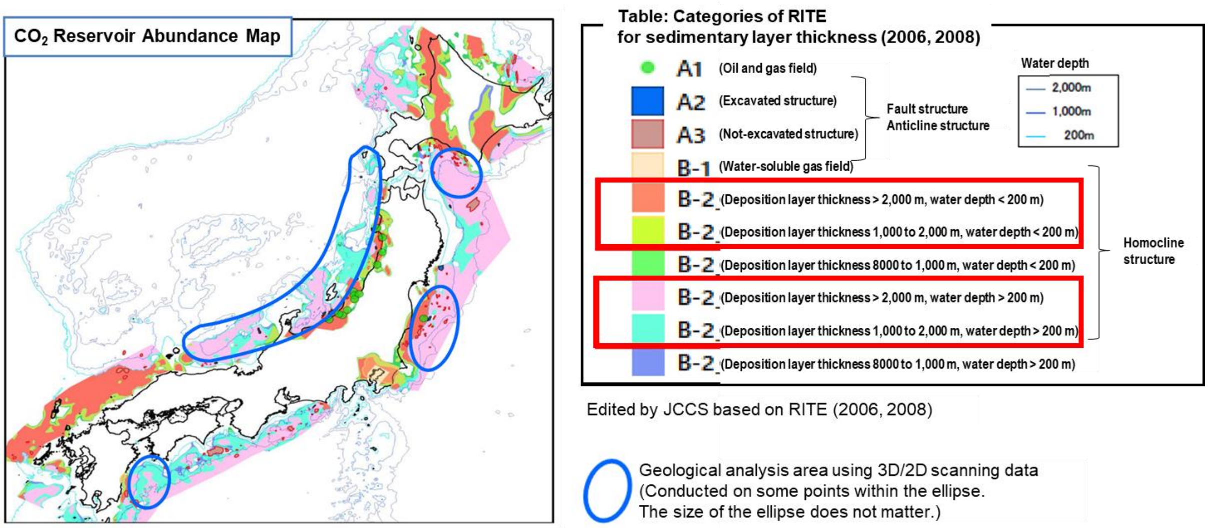
The METI reported that Japan's first large-scale CCS demonstration test, conducted in Tomakomai, had achieved a cumulative injection volume target of 300,000 tons, stating, "It will be realized soon."[18] However, this test was carried out as the case that the METI deems ideal for storage under the sea floor close to the emission source using a pipeline,[19] and it cannot be said that the technology necessary for full-scale development has been established in Japan. The storage volume also reached 300,000 tons in the three and a half years from April 2016 to November 2019, bringing the annual storage volume to nearly 100,000 tons. The amount of CO_2 emitted from a 1000 MW coal-fired power plant is about five million tons per year, even with the ultra-supercritical (USC), which is called "high-efficient,"[20] so the Tomakomai project is only about 1/50 of the actual scale required, even though it is said to be large-scale.

No Specific Storage Sites Have Been Found

Although the METI stated in the material for the Subcommittee on Basic Policy held in January 2021, "The results of 3D exploration analysis in the investigation project for suitable sites for storage indicate a total storage capacity of approximately eight billion tons in Japan,"[21] in the material submitted to the CCS Long-Term Roadmap Review Meeting in January 2022, it doubled its estimate in one year by estimating "a storage capacity of approximately 16 billion tons at 10 sites."

Figure 7 is the CO_2 Reservoir Abundance Map presented in the Roadmap Review Meeting, but as pointed out by the company that conducted the CCS demonstration test in Tomakomai, the current situation is that "the research well has not been drilled, and a suitable site for storage to implement CCUS on a social scale has not been identified."[22]

Figure 7 CO_2 Reservoir Abundance Map



Source: Excerpt from the explanatory material "Future Issues for Commercialization of CCS" prepared by the Secretariat for the 1st CCS Long-term Roadmap Review Meeting (January 28, 2022), the Petroleum and Natural Gas Division of the Agency for Natural Resources and Energy

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[18] Special Content of the Agency for Natural Resources and Energy: "The CCS technology, which capture and store CO_2, has been tested and is about to be realized"
(Part 1: November 27, 2020) https://www.enecho.meti.go.jp/about/special/johoteikyo/ccs_tomakomai.html (Japanese)
(Part 2: December 25, 2020) https://www.enecho.meti.go.jp/about/special/johoteikyo/ccs_tomakomai_2.html (Japanese)

[19] Explanation by the Secretariat in the Minutes of the 7th Working Group on Verification of Power Generation Costs

[20] In the case of a capacity factor of 70% and an emission factor of 0.82 kg/kWh.

[21] Material 2 of the Subcommittee on Basic Policy of the Advisory Committee for Natural Resources and Energy (36th meeting): "Study for Realizing Carbon Neutrality by 2050" (January 27, 2021)

[22] Japan CCS Research Co., Ltd.: "Toward the Social Implementation of CCUS" (February 24, 2022), Material 8 of the 2nd CCS Long-term Roadmap Review Meeting

Shipping Technology for CO_2 Has Not Been Established

Another problem is the transport of CO_2. As shown in the figure above, the areas with high potential for storage are mostly distributed along the Sea of Japan side, but the emission sources are concentrated on the Pacific Ocean side. For this reason, the Roadmap Study Group says, "CCS requires high-capacity, long-distance transport," but "the shipping technology that can transport large volumes of liquefied CO_2 has not been established, so the challenge is to establish this technology."

According to the aforementioned estimate by RITE as requested by METI, it is necessary to store 300 million to 500 million tonnes of CO_2 per year. Meanwhile, the estimate by METI based on the IEA estimate gives the annual storage volume in Japan as approximately 120 million to 240 million tonnes. As shown in the fifth bottleneck, these estimates do include the amounts intended for export overseas, which shipping to storage sites is required as well. According to the material (Figure 8) submitted by the Ministry to the Subcommittee on Basic Policy, even if low-temperature and low-pressure technologies are developed, "500 vessels would be required in 2050 to transport 50 million tons/year." A simple calculation made based on this shows that a minimum of 1200 and a maximum of 5000 transport ships are needed. Currently, for the international transport of liquefied natural gas, about 600 large LNG carriers are in operation around the world.[23] Since there are no CO_2 carriers yet, it is difficult to compare them with LNG carriers, however, in-depth examinations are required on the feasibility of shipping CO_2 on the scale targeted by METI.

Figure 8 Estimated Number of Vessels Required for CO_2 Transport

Building of Transportation Network

- The emission sources and storage sites are separated, and transportation by ship is necessary in Japan to ensure flexibility.
- The annual transportation volume of CO_2 is determined by the annual transportation volume per ship and the number of ships.
- The transportation volume per ship is estimated to be about 100,000 ton-CO_2/year/ship if the development of low-temperature and low-pressure technology advances.
- For example, 500 ships will be needed in 2050 to transport 50 million tons/year.
  * The domestic transportation of LPG carriers with similar characteristics is 2.5 million tons/year by operating 30 ships.

Source: Excerpt from Material 1 of the Subcommittee on Basic Policy of the Advisory Committee for Natural Resources and Energy (35th meeting): "Study for Realizing Carbon Neutrality by 2050" (December 21, 2020), the Agency for Natural Resources and Energy

[23] "Technological Innovation of LNG Marine Transportation" (Oil and Natural Gas Review 2021.1, Vol. 55, No. 1) by Yoshihiko Sugimoto, Deputy General Manager, Technology Department, Technology Innovation HQ, Mitsui O.S.K. Lines, Ltd.

Identifying Environmental Risks from CO_2 Storage

It should also be noted that there are concerns about the safety and environmental risks associated with CO_2 storage. In this regard, the EU decarbonization strategy cited above states that uncertainties about the long-term behavior of carbon storage and public acceptability issues (also shown in the results of public consultations) also hinder the proper introduction of this technology (CCS) in the EU, and some Member States have effectively banned carbon storage in their countries. [24] For example, according to a 2018 report from the German Bundestag, four CO_2 storage projects were initially planned in Germany, but only one was realized as a pilot project due to opposition from local citizens and various social organizations.[25] The German Federal Environmental Agency points out the environmental risks of CCS as follows.[26]

Risks of CO_2 storage:

- There are no adverse effects on human health under normal operation, but there is a possibility that health hazards may occur due to release from storage facilities caused by an accident or from gradual leakage.
- CO_2 leakage can release pollutants into the ground and salty groundwater from aquifers, possibly causing damage (salt damage) to groundwater, soil, and surface water.
- Ground facilities for CO_2 storage and transport can adversely affect animals and plants, landscapes, and biodiversity. Efficient impact monitoring is a prerequisite.
- Adequate storage capacity is required, but suitability depends, above all, on natural conditions. Also, for economic reasons, the storage facility should be located near the separator.
- The use of large portions deep underground for permanent storage of CO_2 over several thousand years would limit other uses, such as geothermal.

Need for Seismic Risk Assessment of CO_2 Storage

In Europe and the United States, research and investigations have been conducted on the risks associated with CO_2 storage, such as the risk that CCS may trigger earthquakes and the impact of earthquakes on the safety of storage. Stanford University and the National Research Council have previously published study results indicating that CCS can trigger earthquakes.[27] In 2021, the U.S. Department of Energy launched four pilot projects to identify and mitigate the risks associated with CCS-induced earthquakes.[28] "During natural ground motion, such as volcanic activity or earthquakes, cap-locked reservoirs may crack and leak CO_2 through the strata to nearby groundwater sources," the DOE explained in these projects.

The government's CCS Roadmap Review Meeting has not discussed the risks associated with CCS-induced earthquakes and natural earthquakes, as has been done in the United States. On the Sea of Japan side, which is considered to have a high potential for storage, there are no areas known to have a high probability of an earthquake within 30 years, like the Nankai Trough on the Pacific Ocean side. However, the stored CO_2 must be kept safe for much longer than a short 30-year period.

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[24] European Commission "IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM (2018) 773 A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" (December 12, 2018)

[25] German Bundestag Drucksache 19/6891: Unterrichtung durch die Bundesregierung, Evaluierungsbericht der Bundesregierung über die Anwendung des KohlendioxidSpeicherungsgesetzes sowie die Erfahrungen zur CCS-Technologie (December 21, 2018)
https://dserver.bundestag.de/btd/19/068/1906891.pdf (German)

[26] German Federal Environmental Agency website: "Carbon Capture and Storage" (Updated on January 15, 2021; Accessed on March 31, 2022)
https://www.umweltbundesamt.de/themen/wasser/gewaesser/grundwasser/nutzung-belastungen/carbon-capture-storage#grundlegende-informationen

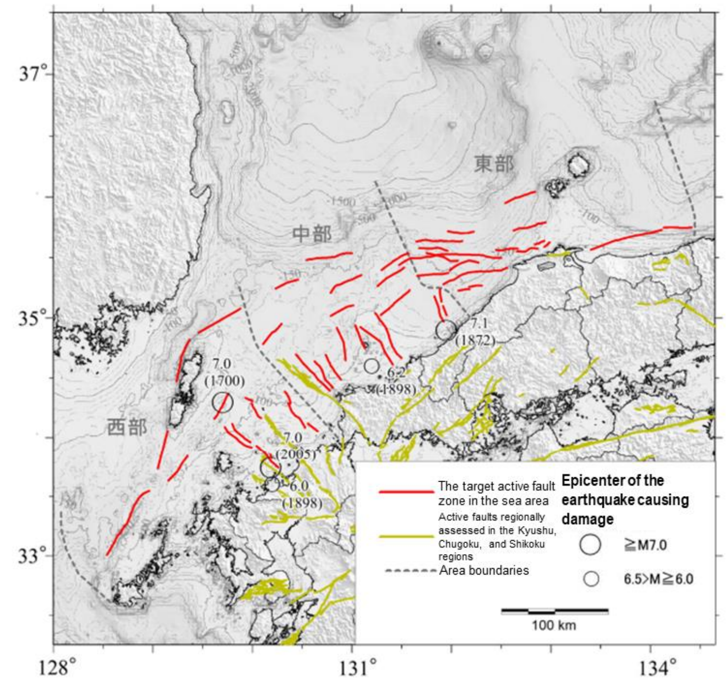
[27] Stanford Report "Carbon capture and storage likely to cause earthquakes, say Stanford researchers"(June 19, 2012)
https://news.stanford.edu/news/2012/june/carbon-capture-earthquakes-061912.html
Mark D. Zoback and Steven M. Gorelick "Earthquake triggering and large-scale geologic storage of carbon dioxide"(PNAS June 26, 2012, 109 (26) 10164-10168)

[28] DOE "DOE Announces Nearly $4 Million To Enhance the Safety and Security of CO_2 Storage" (May 28, 2021)
https://www.energy.gov/articles/doe-announces-nearly-4-million-enhance-safety-and-security-co2-storage

In March 2022, the Headquarters for Earthquake Research Promotion of the government released its Long-term Assessment of Offshore Active Faults in the Southwestern Japan Sea (First Edition), in which it identifies numerous offshore active fault zones off northern regions, including Tottori, Shimane, and Yamaguchi Prefectures.[29] According to the report, as the largest earthquakes that could occur in these areas, "there is the possibility of an earthquake of magnitude 7.7 to 8.1" in the eastern areas (offshore of Tottori Prefecture and eastern Shimane Prefecture) and "the possibility of an earthquake of magnitude 7.8 to 8.2 or higher" in the central area (offshore of western Shimane Prefecture and off northern Yamaguchi Prefecture).

The Eastern Hokkaido Iburi Earthquake occurred on September 6, 2018 in the vicinity of Tomakomai, where the CCS demonstration test was conducted. A report of the research on the impact of the earthquake concluded that there was "no evidence of CO_2 leakage from this earthquake." The magnitude of the Eastern Hokkaido Iburi Earthquake was 6.7, meaning that the scale of one of the largest earthquakes possibly occurring in the southwestern Japan Sea is 30 to 180 times larger. If CCS is to be developed in Japan, one of the most earthquake-prone countries in the world, it is definitely necessary to conduct a thorough investigation to eliminate earthquake-related concerns.

Figure 9 Active Faults To Be Assessed and Epicenters of Major Affected Seismic Centers in the Southwestern Japan Sea (the target marine area)



Source: Earthquake Research Committee, Headquarters for Earthquake Research Promotion, "Long-Term Assessment of Offshore Active Faults in the Southwestern Japan Sea (First Edition) − Offshore of the Northern Kyushu and Chugoku Regions" (March 25, 2022)

[29] Earthquake Research Committee, Headquarters for Earthquake Research Promotion, "Long-Term Assessment of Offshore Active Faults in the Southwestern Japan Sea (First Edition) −Offshore of the Northern Kyushu and Chugoku Regions" (March 25, 2021)

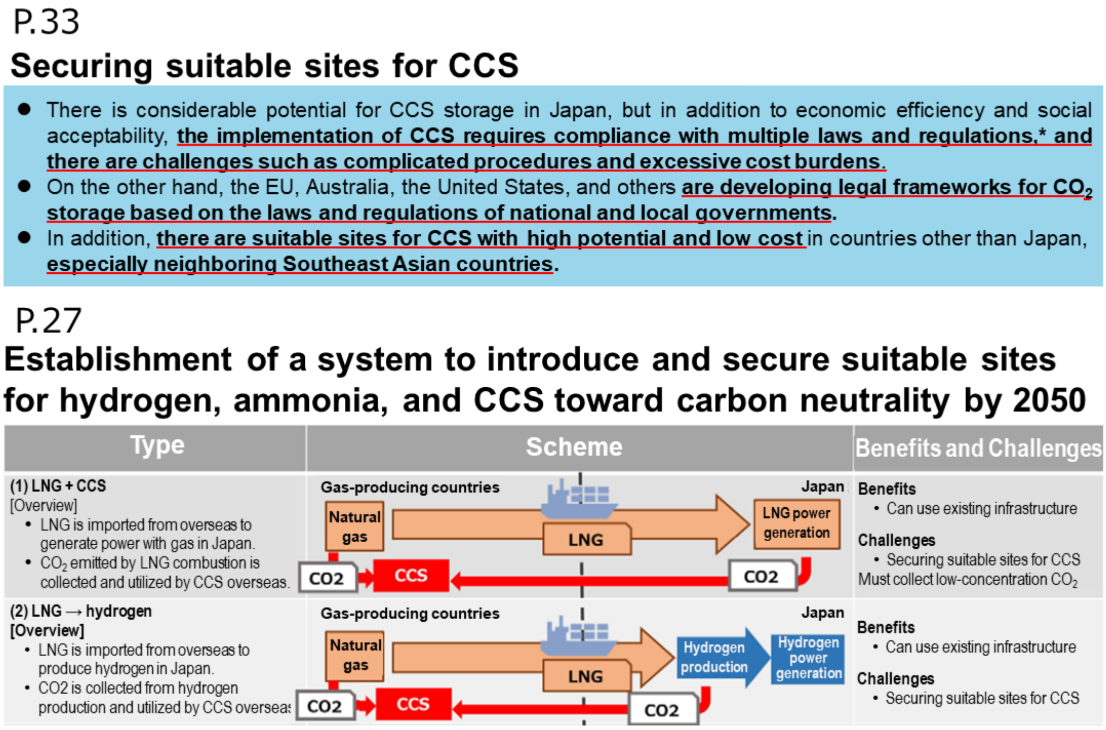
Bottleneck 5: Risks Posed by the Overseas Export of CO_2

Looking to Southeast Asia for inexpensive storage sites

Among the problems of CCS thermal power policy proposed by the METI, one of the most serious problems from the viewpoint of international evaluation of Japan's climate change measures is its plan to export a large amount of the CO_2 emitted in Japan overseas, especially to Southeast Asia. In June 2021, the METI launched the Asian CCUS Network with the aim of (1) sharing CCUS knowledge and experience and conducting potential surveys, (2) creating common rules and formulating projects, and (3) creating an Asia-wide storage network. The project also targets the export of CO_2 emissions in Japan to Southeast Asia, although the document released at the launch meeting does not specify as much.

The material submitted by the Secretariat to the Session of Resources and Fuel of the Subcommittee on Oil and Natural Gas (13th meeting) on February 15, 2021, as shown in Figure 14, clearly indicates a plan to export the CO_2 emitted from LNG power generation and hydrogen production in Japan to gas-producing countries, where it will be processed by CCS.

Figure 14 Material of the Session of Resources and Fuel, Subcommittee on Oil and Natural Gas (13th meeting)



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Securing suitable sites for CCS

- There is considerable potential for CCS storage in Japan, but in addition to economic efficiency and social acceptability, **the implementation of CCS requires compliance with multiple laws and regulations,* and there are challenges such as complicated procedures and excessive cost burdens.**
- On the other hand, the EU, Australia, the United States, and others **are developing legal frameworks for CO_2 storage based on the laws and regulations of national and local governments**.
- In addition, **there are suitable sites for CCS with high potential and low cost** in countries other than Japan, **especially neighboring Southeast Asian countries**.

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Establishment of a system to introduce and secure suitable sites for hydrogen, ammonia, and CCS toward carbon neutrality by 2050

Type	Scheme	Benefits and Challenges
(1) LNG + CCS [Overview] • LNG is imported from overseas to generate power with gas in Japan. • CO_2 emitted by LNG combustion is collected and utilized by CCS overseas.	Gas-producing countries / Japan Natural gas → LNG → LNG power generation CO2 ← CCS ← CO2	Benefits • Can use existing infrastructure Challenges • Securing suitable sites for CCS Must collect low-concentration CO_2
(2) LNG → hydrogen [Overview] • LNG is imported from overseas to produce hydrogen in Japan. • CO2 is collected from hydrogen production and utilized by CCS overseas	Gas-producing countries / Japan Natural gas → LNG → Hydrogen production → Hydrogen power generation CO2 ← CCS ← CO2	Benefits • Can use existing infrastructure Challenges • Securing suitable sites for CCS

Source: Excerpt from the Resources and Fuel Department, Agency for Natural Resources and Energy, "Direction of Oil and Natural Gas Policy Looking toward 2030/2050 (Draft)" (February 15, 2021), Session of Resources and Fuel, Subcommittee on Oil and Natural Gas (13th meeting), Material 3, Pages 27 and 33

The director in charge of the Agency for Natural Resources and Energy said, after recognizing the issues such as economic efficiency and social acceptability in securing suitable sites for CCS in Japan, "There are suitable locations overseas, especially in Southeast Asia, which have high potential and are economically reasonable for storage," and "This is a pattern of storing CO_2 emitted from thermal power plants in normal operation in Japan at sites in Japan or overseas." "In terms of using existing LNG carriers and existing thermal power plants, the cost will be very low. This can be a promising candidate for achieving 30% to 40% in 2050, which I mentioned earlier, including thermal power plus CCS, and of course nuclear power." In this way, he officially expressed his aim to export CO_2 from the cost perspective.[30]

Overseas Export of 230 Million to 280 Million Tons of CO_2 Annually

The scale of planned CO_2 exports overseas was first reported in the 2050 scenario analysis conducted by RITE at the request of the METI as mentioned in Chapter 1. For domestic storage capacity, RITE estimates the export volume to be between 230 million and 280 million tons, noting that "considering the difficulty of rapid expansion due to the limited number of drilling rigs, the expansion rate of CO_2 storage is assumed to be limited." Japan's CO_2 emissions amounted to 1.044 billion tons in FY2020[31], which is a huge amount accounting for 22% to 27% of the total.

The material submitted to the Long-Term Roadmap Review Meeting from the METI says that "as of 2050, the scale of Japan's annual CCS is estimated at 120 million to 240 million tons both in Japan and overseas." The assumption remains unchanged that CO_2 will be exported overseas, although the amount is unclear.

At a time when the entire world, including developing countries, must achieve net-zero CO_2 emissions, it is highly unlikely that the world will understand the proposal by Japan, an advanced country, to export CO_2 to developing countries for processing because it cannot handle processing by itself. That the METI is planning such a large-scale CO_2 export is not well known internationally. If this plan is pursued, it is inevitable that Japan, which is already under severe international criticism for its insistence on the continued use of coal-fired power, will meet with even further criticism.[32]

Another risk that needs to be addressed in the plan to export CO_2 overseas is that it will further increase Japan's dependence on other countries for energy use. The vulnerability and weakness of the Japanese economy has been that it has inevitably relied on imports for most of its energy supply in an era dominated by the use of fossil fuels. Relying on exports to dispose of large amounts of CO_2 would create a double vulnerability, depending on foreign countries not only at the entry point but also at the exit point.

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[30] Minutes of the Session of Resources and Fuel, Subcommittee on Oil and Natural Gas (13th meeting) (February 15, 2021) https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/sekiyu_gas/pdf/013_gijiroku.pdf (Japanese)

[31] The Ministry of the Environment/National Institute for Environmental Studies: "Greenhouse Gas Emissions in FY2020 (Preliminary Figures)" (December 9, 2021)

[32] One cross-border CO_2 storage project is the Norwegian government's Longship project. It is planned to start operation in 2024, but there are some important differences from the Japanese plan. First of all, the essential difference is that this project is not about Norway exporting its own CO_2 emissions to other countries, but about accepting it from other countries in order to achieve decarbonization for Europe as a whole. Secondly, the target source of CO_2 emissions is from cement and steel production, and emissions from the power generation sector are not considered. As we will see in Chapter 3, there are few plans to use CCS thermal power in Europe. Incidentally, Norway itself already generates 95% of its electricity from hydropower today. Thirdly, the scale is different. The Longship project plans to store five million tons per year. This accounts for only about 1.6% of the amount of Norway's CO_2 emissions of 317 million tons (2020).

Supporting Southeast Asia in the Future Use of Renewable Energy

Shortly after taking office in November 2021, Prime Minister Kishida attended COP26 and delivered a speech on Japan's climate change measures, in which he said, "Japan will promote the transition to clean energy and create a decarbonized society, while maximizing the use of renewable energy, particularly centering on Asia. The introduction of renewable energy in Asia is often dominated by solar power, and at the same time, zero emission should be pursued while using the existing thermal power generation in order to realize stable frequency management. Through the Asia Energy Transition Initiative, Japan will implement a leading $100 million project to convert fossil fuels to zero-emission fuels such as ammonia and hydrogen."[33]

This was an important speech in which Japan, which has announced its intent to achieve carbon neutrality by 2050 and set a target of 46% reduction by 2030, should have shown the world its proactive stance on climate change. Unfortunately, it was perceived by many participants as expressing the intention to continue using fossil fuels, including coal-fired power generation, even to the point of winning a fossil award from an international NGO.

There seems to have been a misunderstanding in some important points among the government ministries and agencies that prepared Prime Minister Kishida's speech. One is the recognition that to meet the rapidly growing demand for electricity in Asia (mainly in Southeast Asia), it is necessary to reduce emissions while continuing to use fossil fuel thermal power generation. However, there is the potential for abundant renewable energy sources in Southeast Asia, and the IEA scenario indicates that 43% could be supplied from renewable energy sources in 2030 and 86% in 2050.[34]

Another is the recognition that in Asia, solar power is the main source of renewable energy, so zero-emission thermal power is necessary for frequency stability. Also in this regard, according to the IEA scenario[35], hydropower is the largest source of renewable energy in Southeast Asia in 2040, accounting for 33% of the electricity supply, followed by solar for 26%, wind for 20%, geothermal for 13%, and bioenergy for 8%. This means that Southeast Asia has a rich variety of renewable energy sources. Some power sources are distributed unevenly across countries and regions, but plans are underway to develop an international power transmission network linking Southeast Asia as a whole.[36]

What benefit Japan are to cooperate in the development of power sources and the realization of power transmission networks by maximizing the use of abundant renewable energy sources with high potential in Southeast Asia, while utilizing the technologies of Japanese companies and not by tying the region's future to fossil fuels.

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33 Prime Minister's Official Residence: "Speech by Prime Minister Fumio Kishida at COP26 World Leaders Summit" 2021.11.2

34 IEA "World Energy Outlook 2021" (2021.10)

35 IEA "World Energy Outlook 2020" (2020.10)

36 See "Energy Transition in Southeast Asia" (December 2019), "The Trend of Independence from Coal-Fired Thermal Power Generation in Asia" (April 2020), and "Four Reasons Why Coal-Fired Thermal Power Exports Should be Stopped and the Shift to Renewable Energy Should be Supported" (June 2020) of the Renewable Energy Institute.

Final Chapter: Japan's Decarbonization Strategy -the Way Forward

This report has identified five bottlenecks associated with CCS thermal power. Several countries around the world have adopted a strategy of either not using CCS at all or limiting its use. The METI's plan to continue to use fossil fuels in power and industry sectors in 2050, and to process the large amount of CO_2 with CCS, as well as to export the excess amount that cannot be stored in Japan to Southeast Asia, is inconceivable from an international perspective.

It is essential to shift to a strategy where 90% to 100% of electricity is supplied from renewable energy sources, green hydrogen derived from renewable power sources, and green synthetic fuels to meet the demand for non-electrifiable portion, on the premise of thorough improvement of energy efficiency. As in the Renewable Energy Institute's March 2021 report "Renewable Pathways: The Strategies to 100% RE for a Carbon-neutral Japan," it is possible for Japan to realize an energy system that is independent of both fossil fuels and nuclear power generation.

It is clear that there are many challenges that must be overcome to achieve a 100% renewable energy system. However, these challenges are not unique to Japan. How can stable power supply and demand be realized using fluctuating renewable energy sources? How can we secure an energy supply throughout the year, even in cloudy or wind-less weather conditions? There are already various practices to overcome these challenges, mainly in Europe, which is leading the way in introducing renewable energy, and a solution is in sight.

The METI aims to introduce CCS in 2030 with the main goal to provide reasons of extending the lifetime of coal-fired power plants, which advanced countries are required to phased out by 2030. However, even if CCS is equipped, the actual capture rate is low, as seen in past examples, and it cannot serve as a decarbonized power source. The cost of power generation is also high, meaning that it is not economically feasible. If the implementation of CCS is rushed forward, various environmental risks may not be sufficiently taken into account and evaluated.

The likelihood of success for Japan to decarbonize seems low with an energy policy relying heavily on CCS. CCS cannot capture all emissions from thermal power plants and it will be extremely difficult to store the large amounts that the METI intends even storage site is searched domestically and abroad Going this route, Japan will be forced to spend large sums to implement the technologically incomplete CCS, and will be required to pay for credits for CO_2 emissions that are not able to be captured and stored. Furthermore, ongoing dependence on fossil fuels will continue to drain national wealth as the country spends on fuel imports

When keeping the energy policy relying heavily on CCS, Japan will fall further behind the rest of the world in decarbonization that may cause additional burdens in the future. Slow decarbonization would also put Japanese companies at a competitive disadvantage at a time when other countries are pursuing more cost competitive solutions.

It is clear that urgent policy reconsideration is required for Japan to meet its own goal and global responsibilities towards decarbonization.

Bottlenecks and Risks of CCS Thermal Power Policy in Japan
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