6

Trends in the Development of Measures Against Global Warming Centered on CO_2 Underground Storage

KAZUAKI MIYAMOTO
Environment and Energy Research Unit

6.1 Introduction

Greenhouse gases, which cause global warming, are comprised of six gases including carbon dioxide (CO_2) and methane (CH_4). Of these gases, CO_2 constitutes some 94% of the total greenhouse-gas emissions. Reductions in CO_2 emissions are therefore becoming a major challenge. The IPCC (The Intergovernmental Panel on Climate Change) 3rd Assessment Report points out that a number of adverse effects may arise from global warming ─ e.g., abnormal weather conditions, a decline in agricultural productivity, a deterioration in the global ecosystem, and a rise in sea levels that would decrease the area of our living environment. In addition to the technological aspects, there have been some political movements over the past several years. For instance, the Seventh Conference of the Parties to the United Nations Framework Convention on Climate Change (COP7 held in 2001) saw an agreement on the management of the Kyoto Protocol (1997). In response to this, each of the countries concerned is gearing up for the ratification of the protocol. Japan aims to reduce the total greenhouse-gas emissions by 6% from the 1990 level during the period between 2008 and 2012. However, the track record for 1999 stood at 1.314 billion tons (CO_2 equivalent), already up 6.9% from the 1990 level — a situation that necessitates some 13% reduction in real terms. All segments of industry as well as the public should thus make further efforts to cut down on greenhouse-gas emissions.

In accordance with this worldwide progress in measures against global warming, Japan set out the Law Concerning the Promotion of Measures to Cope with Global Warming (2002), bringing up the promotion of forest absorption of CO_2, energy-saving measures and innovative technologies, and the utilization of the Kyoto mechanism*1. The Council for Science and Technology Policy (CSTP), in its "Promotion Strategy for the Environment Sciences (2001)", specified R&D of zero-garbage/resource-recycling technologies and global warming as priority issues, announcing a national initiative designed to develop technologies for reducing and sequestering greenhouse gases. Among the variety of measures and technologies to cope with global warming, the significance of which is being recognized worldwide, this report highlights those for CO_2 separation, capture, storage, and sequestration technologies while addressing potential technological problems in order to recommend possible solutions for them.

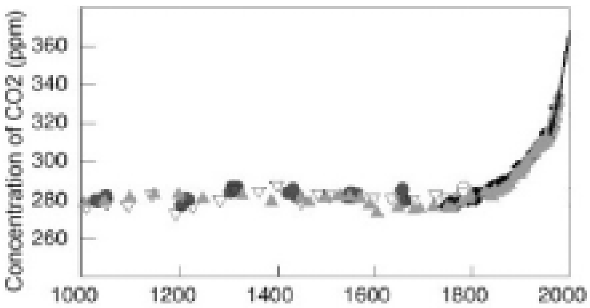
6.2 The present state of global warming issues

6.2.1 The present state of global warming

The atmosphere stabilizes temperatures that may otherwise fluctuate dramatically due to natural phenomena such as sunlight, radiational cooling, etc. Among others, CO_2 plays an essential role in maintaining the mean air temperature of our planet nearly 115 F. However, the concentration of CO_2 in the atmosphere, which stood at 280ppm (0.0280%) before the Industrial Revolution, has increased to 368ppm (0.0368%). It is on the rise hand-in-hand with increasing global temperatures (see Figure 1 and 2).

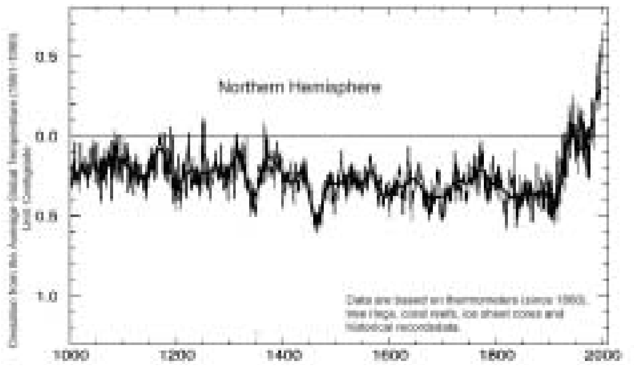
According to a forecast made by IPCC, future CO_2 emissions may vary substantially, depending on several scenarios of economic growth. For

Figure 1: Variation of the CO_2 concentration in the atmosphere



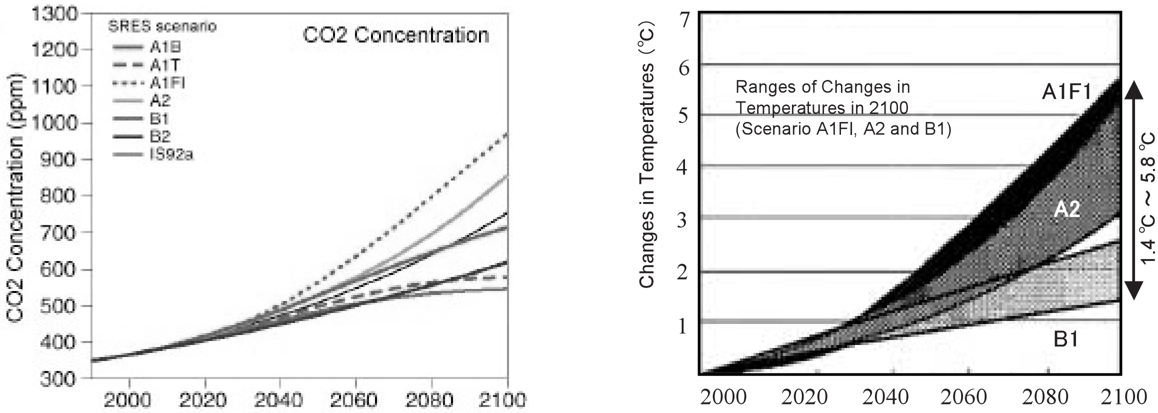
Source: The Third Assessment Report of the IPCC (2001, WGI-SPM Fig. 2)

Figure 2: Deviation of annual mean temperatures from the average global temperature (1961-1990)



Source: The Third Assessment Report of the IPCC (2001, WGI-SPM Fig. 1)

Figure 3: Forecasts of atmospheric CO_2 concentrations and increases in global mean temperatures



instance, a scenario that emphasizes fossil energy sources*2 forecasts that the world's mean temperature in 2100 will increase by 1.4~5.8 degrees centigrade from the 1990 levels (see Figure 3).

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize the concentration of greenhouse gases within the range where the climate system is not threatened by dangerous human intervention. This very range, however, has yet to be determined scientifically. The issue of global warming involves considerable risks; left unattended without any measures being adopted, the costs of alleviating its potential effects could be tremendous, reaching the point of no return if worst comes to worst. Therefore, despite a number of uncertainties, the issue must be addressed properly and promptly.

6.2.2 An overview of technologies for curbing global warming

Table 1 shows an outline of technologies for curbing global warming, R&D of which is being conducted at home and abroad.

As mentioned at the outset, measures for reducing CO_2 emissions (the promotion of energy-saving technologies, etc.) specified in the Law Concerning the Promotion of Measures to Cope with Global Warming are promising technologies for reducing greenhouse gases (see Figure 4).

However, making dramatic improvements in the field of energy saving is by no means easy for Japan, which has been leading the world in energy use efficiency. Shifting fuel sources to generate power from conventional fossil fuels to natural gas does not reduce our dependence on fossil fuel; it is hardly a fundamental solution to global warming. Moreover, given several constraints (the current technological level, the considerable amount of investment involved, geographical requirements, etc.), environmentally friendly energy is not likely to be the main source of energy in a decade or so unless innovative technologies come into being. Likewise, it is least likely that nuclear power plants, the mainstay of measures against CO_2 emissions, will be newly set up anywhere in the world over the next 10 years or so.

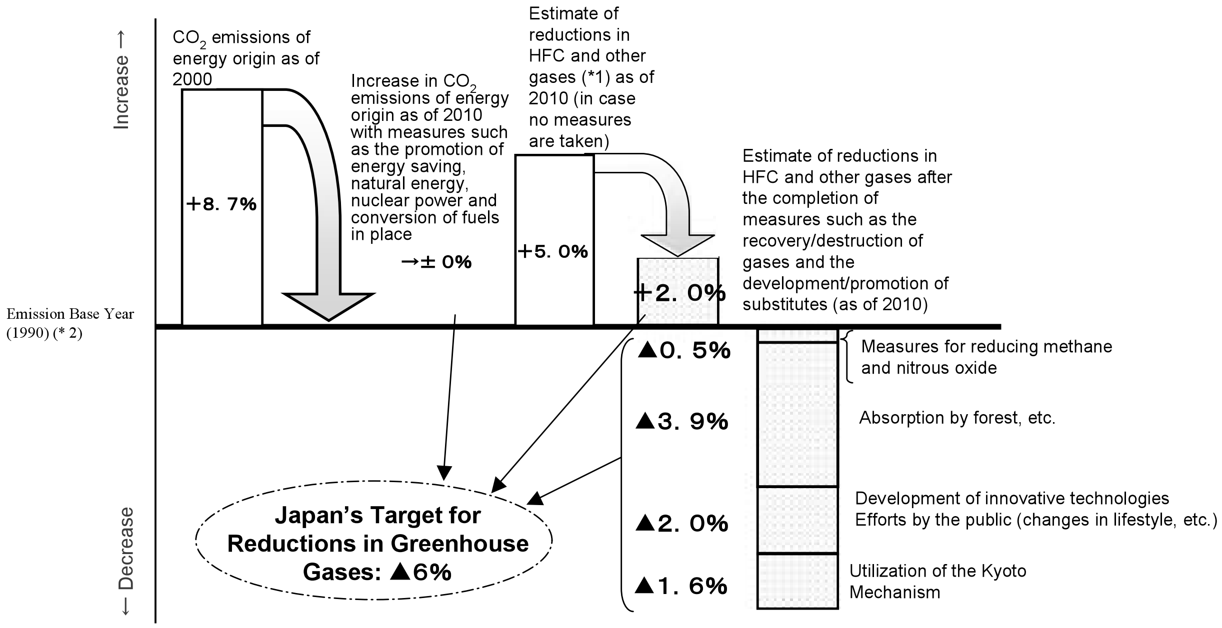
In the meantime, technologies for reducing emitted CO_2 (hereinafter referred to as "emitted-CO_2 reduction technologies"), particularly those for removing CO_2 contained in combustion gas, are being developed worldwide. These technologies cover a fairly broad spectrum, as shown in Figure 4, with their technological levels ranging from experimental stages to close-to-commercial stages. Measures against global warming are not mandatory at the moment. Industry and other sectors concerned are thus offered little incentive to promote practical measures. For this reason, relevant technologies that have been developed and commercialized so far are limited to secondary measures for curbing global warming — e.g., a plant producing urea from CO_2 recovered from effluent gas, using an absorption process (160 tons per day), and the Enhanced Oil Recovery (EOR), a process that

Table1: Overview of technologies to cope with global warming

Classification		Technologies		Description	
CO_2 Emission Control (Proactive Measures)		Energy Conservation		Improve efficiency in energy use.	
		Conversion to Other Fossil Fuels		Shift to natural gas.	
		Conversion to Non-fossil Fuels		Renewable energy such as solar power, wind power, waterpower, geothermal heat, biomass and ocean energy.	
				Nuclear power.	
				New energy-use technologies such as electric cars, fuel cells and hydrogen engines/turbines.	
Reductions of Emitted CO_2 (Passive Measures)	Reductions of CO_2 in Effluent Gas	Capture	Absorption Method	Amine Absorption Calcium Carbonate Absorption	— Absorb CO_2 in alkaline solutions.
			Adsorption Method	Physical Adsorption	— Adsorb CO_2 with solid adsorbents
			Gas Separation Method	Polymer Membrane Separation	— Utilize the differences in the permeability of gases to membranes.
				Cryogenic Separation	— Utilize the differences in the concentration of gas components.
		Storage	Underground Storage	Storage in Aquifers	— Inject CO_2 into aquifers lying some 1,000m underground.
				Storage in Oil and Gas Fields	— Inject CO_2 into oil/gas strata to recover oil and gas, and to dispose of CO_2.
				Storage in Coal Beds	— Dispose of CO_2 in unexploitable coal beds.
			Ocean Storage	Deep-sea Storage	— Store CO_2 in abyssal floors (3,000m or deeper). Utilize the density of CO_2, which is higher than that of deep-sea water.
		Sequestration	Chemical Sequestration	Electric / Optical Reactions	— Reduce CO_2 electrochemically (irradiation,electrode reaction, etc.).
				Catalytic Hydrogenation Reaction	— Synthesize organic compounds (methane, etc.) from CO_2 and hydrogen in the presence of catalysts.
	Reductions of CO_2 in the Atmosphere		Biological Sequestration	Afforestation / Reforestation	— Promote afforestation (mangroves, etc.) to fix CO_2 into plants through photosynthesis.
				Fungi	— Fix CO_2 into algae as $CaCO_3$.

Source: Author's own compilation

Figure 4: Scenario for Reducing Greenhouse Gases (The Law Concerning the Promotion of Measures to Cope with Global Warming)



*1: These gases include HFC (hydrofluorocarbon), PFC (perfluorocarbon) and SF6 (sulfur hexafluoride), all of which are greenhouse gases to be regulated by the Kyoto Protocol.

*2: The emission base year for HFC, PFC and SF6 is 1996. The total greenhouse gas emission of 1223.8 million tons (CO_2 equivalent) serves as a standard for calculating increases and decreases.

Source: Author's own compilation

improves recovery rates of crude oil by injecting CO_2 into oil strata.

6.3 The present state of CO_2 capture, storage and sequestration technologies

As mentioned at the outset, the Council for Science and Technology Policy specified R&D of zero-garbage/resource-recycling technologies and global warming as priority issues, announcing a national initiative designed to develop technologies for reducing and sequestering greenhouse gases. Since the beginning of fiscal 2002, in particular, a global warming initiative encompassing all the ministries concerned has been in place in order to promote efficient and effective researches in these areas.

In the US, meanwhile, the Department of Energy (DOE) presented in 1999 emitted- CO_2 reduction technologies (referred to as "carbon sequestration technology" in the US) as one of five technological categories indispensable for energy plants in the 21st century[1]. DOE subsequently announced a plan in 2000 for promoting these technologies[2], and has launched a number of research projects so far. Moreover, President Bush stressed in his speech in June 2001*3 that reducing emitted CO_2 holds the key to curbing greenhouse gases. CO_2 capture, storage, and sequestration technologies are thus receiving widespread attention as promising measures against global warming mentioned in Chapter 6.2. In view of these circumstances, this chapter addresses these particular technologies, highlighting their development trends and future prospects.

6.3.1 Domestic trends in emitted-CO_2 reduction technologies

Japan has been pursuing R&D to address global warming, with the government taking the initiative. Table 2 shows a variety of research projects that have been carried out under the auspices of the Ministry of Economy, Trade and Industry (METI).

Although these national projects have come up with some remarkable element technologies, their performance as a total system for commercializing specific technologies is said to be insufficient.

Table 3 shows the ongoing research projects of METI.

As is evident from Table 2 and 3, R&D is being conducted for almost all of the measures shown in Table 1. Japan maintains high levels of R&D in this particular area, yielding practical results as far as element technologies are concerned. On the other hand, some of the EU nations (U.K., Norway, etc.) are introducing systems designed to give incentives to emitted-CO_2 reduction technologies — e.g., taxes against global warming and emission trading. The EU and Japan have both ratified the Kyoto Protocol, and hence the need to develop these technologies is expected to grow further.

Table 2: Completed researches on emittted-CO_2 reduction technologies

Project Name	Description	Achievements and Appraisal	Period
Technologies for Utilizing Catalytic Hydrogenation Reaction, and for Sequestering CO_2	• Capture high concentration CO_2 (discharged from fixed sources) massively and continuously with the use of separation membranes. Add hydrogen to the captured CO_2 to synthesize useful chemical substances such as methanol.	• Developed element technologies in the fields of catalytic hydrogenation reaction, separation membranes and electrolytic layers. • Remains uncompleted in terms of system technologies.	1990-1999
Technologies for Utilizing Bacteria and Algae, and for Sequestering CO_2	• Culture bacteria and algae industrially. Sequester CO_2 by means of their photosynthesis activity in order to recycle resources.	• Accumulated the highest level of knowledge in the course of exploring and culturing useful bacteria and algae. • Poor prospects for commercialization.	1990-1999
Technologies for Capturing and Recycling CO_2 Under High Temperature Conditions	• Develop technologies for capturing and recycling CO_2 under high temperature conditions, using materials such as ceramic separation membranes. Research adaptability of developed systems to the market.	• Developed technology for producing separation membranes that function under high temperature conditions (the state-of-the-art technological field). • Poor prospects for commercialization; project targets are unlikely to be achieved in the foreseeable future.	1992-1999
Technologies for Estimating Impacts of Sequestering CO_2 in the Ocean	• Develop technologies for estimating impacts of CO_2 disposed of in the ocean on the marine environment - e.g., possible behavior of CO_2 stored in the ocean.	• Evaluated findings in the marine ecosystem as basic materials for the marine environment. • Poor prospects for commercialization due to the considerably long periods required for evaluating impacts on the marine environment.	1997-2001

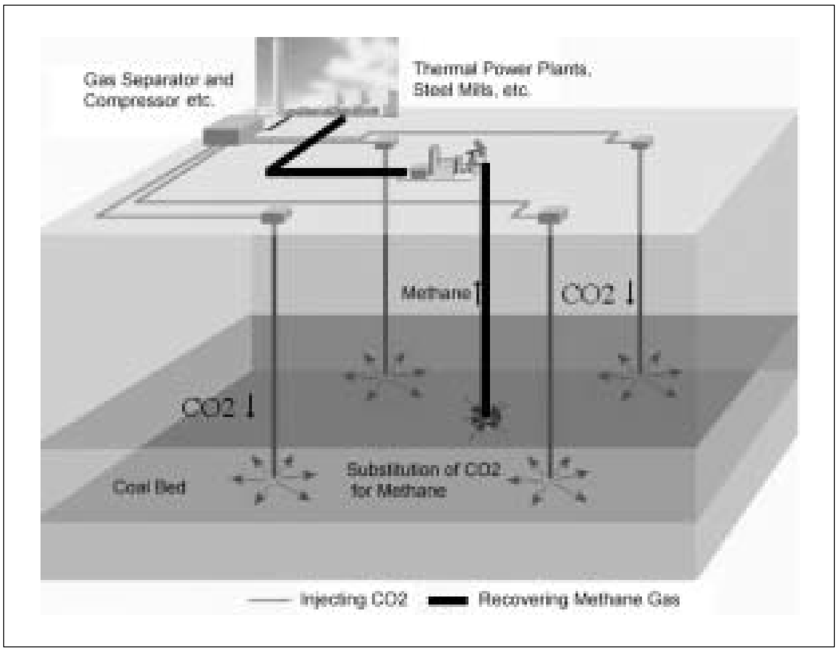
Source: Author's compilation based on the 2001 Sectoral Assessment Report of the Industrial Structure Council, METI.

Table 3: Ongoing development of emitted-CO_2 reduction technologies in Japan

Project Name	Description	Period
Technologies for CO_2 Underground Storage (Aquifer Storage Technology)	• Develop technologies for storing CO_2 recovered from major source origins (thermal power plants, etc.) in underground aquifers, tools for selecting optimal places for storage, and models for appraising the behavior of CO_2 injected into aquifers.	2000-2004
Technologies for Capturing and Utilizing CO_2 with the Use of Coal and Natural Gas	• Reform the quality of coal and natural gas with the heat recovered from sunlight, and add hydrogen produced by renewable energy (the electrolysis of water) to reformed CO and hydrogen gases, thereby establishing the process technology for synthesizing methanol without producing byproducts, namely CO_2.	2000-2004
Technologies for Biologically Sequestering and Utilizing CO_2	• Develop plants resistant to drought and intense sunlight based on genetic manipulation technology.	1993-2002
Technologies for Sequestering CO_2 through the Utilization of Used Paper	• Convert used paper (biomass) into sugar by means of microorganisms, and sequester CO_2 in the course of converting the sugar into organic acids.	2000-2004
Technologies for Estimating the Impacts of Storing CO_2 in the Ocean	• The second phase of the "Research on Circulation Mechanisms of Carbon in the Ocean." • Develop technologies for evaluating impacts of CO_2 disposed of in the ocean on the marine environment, and contribute to creating international and social agreements on technologies for sequestering CO_2 in the ocean.	2002-2006

Source: Author's compilation based on the original business record of NEDO.

Figure 5: Concept of CBM



Source: Author's own compilation

6.3.2 *Trends in overseas technological development*

The EU and other countries are pursuing international joint researches within the framework of the IEA Greenhouse Gas Research and Development (IEA GHG R&D). Aside from the EOR technology, which is not feasible in Japan due to geographical constraints, their researches are almost identical to those being conducted in Japan. However, the EOR technology, which is being developed in the EU and other countries, is primarily designed to increase oil production; reduction in CO_2 emissions remains a spillover effect.

The US, as is the case with Japan, is pursuing almost all of the technologies shown in Table 1. DOE has been increasing the budget for developing emitted-CO_2 reduction technologies[3]: 18.4 million dollars in 2000; 32.4 million dollars in 2001; and 54.0 million dollars in 2003 (budgetary request). This dramatic increase in the budget clearly indicates that the U.S. is placing great expectations on these technologies, which may reduce emitted CO_2 despite the continuous use of fossil fuel. Among all the research subjects, the CBM (Coal Bed Methane) technology is given the highest priority in terms of budget allotments. This particular technology takes advantage of the properties of coal, which absorbs CO_2 several times as much as methane. Specifically, CO_2 is injected into coal beds lying deep underground, and methane adsorbed in the coal beds is replaced by CO_2 — a process that serves the double purpose of CO_2 sequestration and the recovery of methane gas (see Figure 5). The U.S. and the EU nations are pushing ahead with this CBM technology along with the EOR technology (see Table 4).

Unlike conventional measures against CO_2 emissions, state-of-the-art technologies such as CBM and EOR make the most of CO_2 in securing new energy sources, while functioning as measures for curbing global warming.

6.4 Prospects of emitted-CO_2 reduction technologies

Figure 6 shows the feasibility of introducing emitted-CO_2 reduction technologies along with their potential capacity. Of these technologies, the aquifer storage technology (see Figure 7) seems promising due to the following reasons:

1. This technology has solid track records abroad in EOR and other processes, and is an application of established technologies in the field of oil and natural gas production.
2. There is little likelihood that CO_2 injected into aquifers will be released into the

atmosphere, and its safety risks are almost negligible.

3. Unlike the ocean storage technology, in which impacts on the ecosystem need to be monitored carefully, the aquifer storage technology is not likely to have secondary impacts on the ecosystem.
4. It is estimated that aquifers off the coast of Japan can store some 90 billion tons of CO_2, the equivalent of 70~80 years of CO_2 emissions in Japan.

Thus, the aquifer storage technology needs to be pursued and developed.

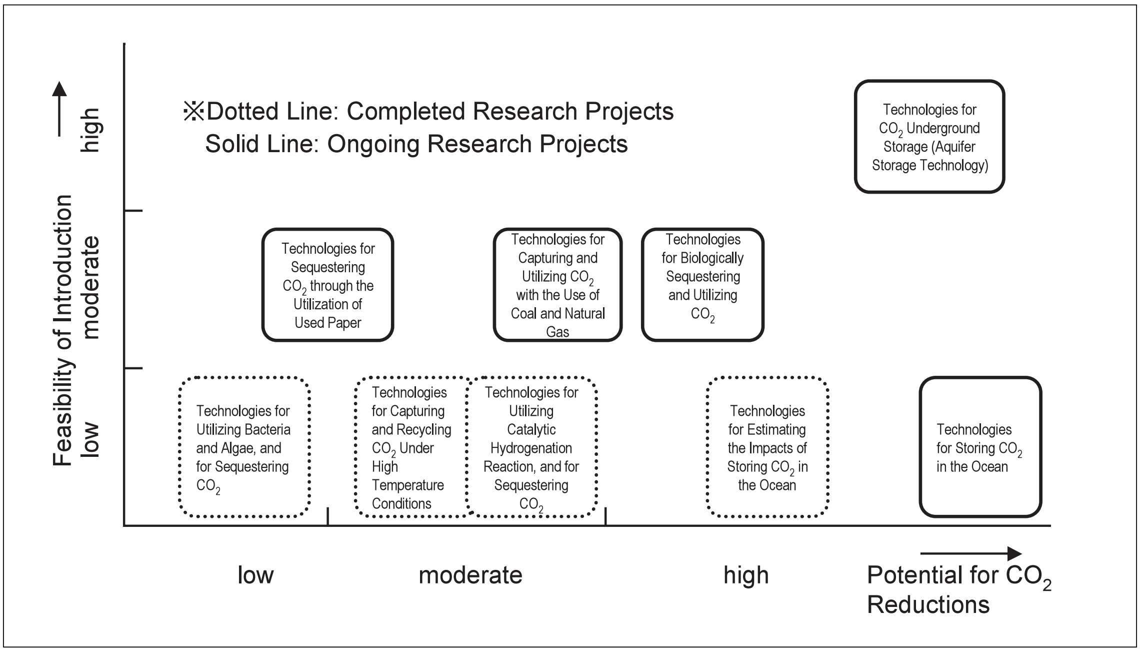
On the other hand, the CBM technology, on which Western countries are placing great

Table 4: Overseas projects for developing technologies for CO_2 underground storage

Country	Project Name	Operating Body	Description	Period
Norway	SACS (Saline Aquifer CO_2 Storage)	Stat Oil (State-owned Oil Company)	CO_2 contained in natural gas (concentration: 9%) produced by oil / gas fields in the sleipner west field, which is located 240km off the coast of Norway (the center of the Northern Sea), is captured through the amine absorption method. The captured CO_2 is then stored in sandstone aquifers about 1,000m below the surface of the sea. One million tons of CO_2 is injected into underwater aquifers annually — a volume equivalent to 3% of the total annual CO_2 emissions. The incentive for the project is derived from carbon tax imposed on offshore oil fields. The amount of tax at the planning stage of the project stood at 350 krone per one ton of CO_2 emissions (1 krone = 12 yen).	1996-
U.S.	Carbon Sequestration R&D Program	DOE (Department of Energy)	An R&D program for technologies for capturing, storing and sequestering CO_2: DOE will conduct a CBM pilot test in the San Juan Basin with an eye toward reducing carbon sequestration costs from the current 100-300 dollars / ton to 10 dollars/ton. The total budget for carbon sequestration projects to be carried out by 2015 is estimated at 922 million dollars.	1999-
Australia	GEODISC (Geological Disposal of Carbon Dioxide)	APCRC (Australian Petroleum Cooperation Research Center)	A research project for evaluating technological, economical and risk aspects of technologies for CO_2 underground storage in Australia: APCRC is looking at six options (aquifers, depleted oilfields, CBM, etc.) in order to dispose of CO_2 produced by northwest gas fields, investing 10 million dollars in four years. CBM is a promising option. In addition to the Australian government, seven companies including BP, Amoco, Chevron and Shell have a stake in the project.	1999-2003
Canada	Weyburn CO_2 Monitoring Project	PTRC (Petroleum Technology Research Center)	A CO_2 Monitoring Project being conducted at the Weyburn oilfield in Saskatchewan: the total cost of the project is estimated at 15.3 million Canadian dollars. With Environmental Canada and the Alberta Research Committee (ARC) as the center, the governments of Canada, the U.S., Australia and the Netherlands as well as fifteen other organizations take part in the project. CO_2 to be injected into oilfields for EOR (enhanced oil recovery) purposes is transported from a coal gasification plant in North Dakota through pipelines. The purpose is to gather information regarding the behavior of stored CO_2, mechanisms of storage, and its long-term safety.	July 2000-2004
The Netherlands	The RECOPOL Project	VROM (The Netherlands Ministry of Housing, Special Planning and the Environment)	The purpose is to create a CO_2 network among European countries, and to evaluate the feasibility of storing CO_2 in coal beds in Europe. The project is being carried out at the Silesian coalfield, which was identified as an optimal site for CBM in the IEA report (2000). The total cost of the project is estimated at 3.5 million euro, with the EU shouldering 50% (1 euro = 115 yen). Universities in the Netherlands, Poland, Germany, France and Australia as well as nine other organizations take part in the project.	November 2001-2004

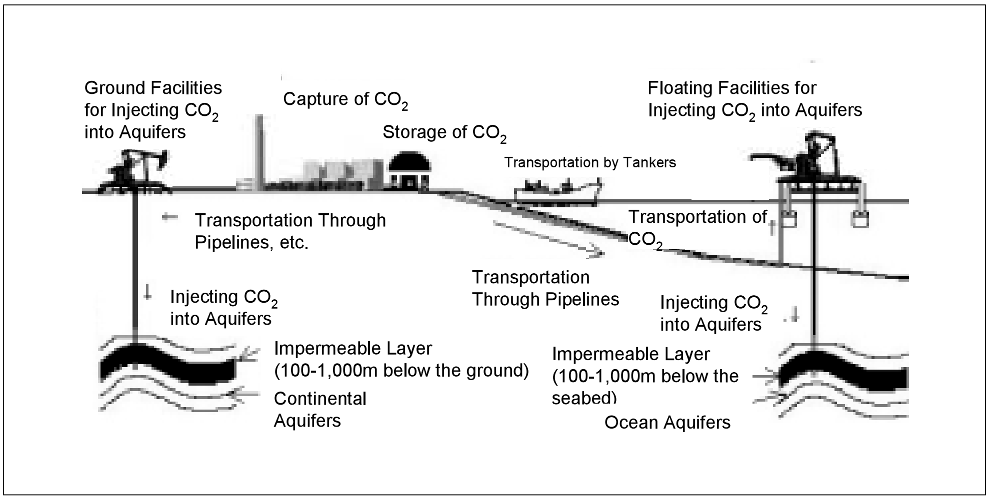
Source: Author's compilation based on relevant materials [2, 4, 5, 6, 7].

Figure 6: Evaluation of emitted-CO_2 reduction technologies



Source: Author's compilation based on the 2001 Sectoral Assessment Report of the Industrial Structure Council, METI.

Figure 7: Concept of aquifer storage technology



Source: Author's own compilation

expectations, is not being studied in Japan, though it is categorized within the underground storage technology, along with the aquifer storage technology. Coal beds in Japan generally contain large amounts of methane gas, and hence there is great possibility that methane gas trapped in depleted mines or in deep coal beds, exploitation of which is not yet feasible, can be recovered through this technology[9]. Moreover, some reports state that coal beds in Japan can sequester 10 billion tons of CO_2[9], since the technology accommodates even low-grade coal (The Agency of Natural Resource and Energy plans to launch new researches regarding coal-bed storage in 2002 [10]). This technology is expected to develop in China, which is blessed with coal resources; the country is most likely to emit increasing amounts of CO_2 in response to expanding domestic demand for energy. Supported by systems such as Clean Development Mechanism (CDM) and Joint Implementation (JI), the effectiveness of these emitted- CO_2 reduction technologies will probably be further improved.

6.5 Conclusion

Various measures against CO_2 emissions typified by energy-saving technologies are effective in curbing global warming since they are designed to control the emissions themselves. However, being technologically feasible is one thing, while implementation of these measures by all segments of industry as well as the public. Therefore, regardless of what measures or systems will be adopted in the future, the government must educate everyone concerned about the significance of their participation in economic and practical efforts toward the resolution of global warming, and request them to take specific measures against global warming. In addition to these activities, the introduction of a system that provides economic incentives for measures against global warming (e.g., a global warming tax) could increase the awareness among industry and the public about this problem — a situation that will inevitably promote various measures against global warming. Meanwhile, the concentration of CO_2 in the atmosphere cannot be reduced only through the combination of these measures, even if they function as originally intended. As mentioned in Section 6.2.2, renewable energy and nuclear energy are not likely to be reliable energy sources for the foreseeable future. Therefore, looking ahead into the next decade or two, there is a need to develop emitted-CO_2 reduction technologies.

Japan has been addressing a number of technologies in this particular area, and there have been some achievements, namely the development of element technologies. However, there is a general recognition that total systems have yet to be developed. While the whole world is basically still dependent on fossil fuel, developing countries typified by China and India are expected to emit increasing amounts of CO_2 in response to their growing demand for energy. For this reason, CO_2 underground storage, which could control increases in CO_2 despite the continuous use of fossil fuel, is expected to be of help not only to developed countries but also to developing countries. With a growing movement toward the ratification of the Kyoto Protocol as a backdrop, the advantage of these technologies will probably increase further due to external factors associated with obligatory reductions in greenhouse gases (a global warming tax, etc.).

Considering these circumstances, R&D of emitted- CO_2 reduction technologies should be pursued with particular emphasis on the following aspects:

1. Looking ahead into the next decade or two, the importance of emitted-CO_2 reduction technologies will increase as effective measures against global warming. Therefore, considering their feasibility for introduction as well as potential for reducing CO_2, R&D of CO_2 underground storage should be prioritized.
2. In pushing forward with R&D, the course of development should be determined explicitly (including evaluations on the practicability of projects as a system) at the planning stage of R&D projects, and energy policies should be taken into consideration.
3. With regard to technologies (the CBM technology, etc.) that can be applied to overseas projects, R&D should be promoted in a comprehensive manner, encouraging technological exchanges between countries with versatility of those technologies in mind (initiatives in international standardization, applications to overseas projects, etc.).

References

[1] DOE, Vision 21 Program Plan —Clean Energy Plants for the 21st Century, 1999.
[2] DOE, CARBON SEQUESTRATION —Overview and Summary of Program Plans—, 2000.
[3] DOE, FY2003 Budget in Brief, The President's Coal Research Initiative, Sequestration R&D, 2002.
[4] SACS Web site, http://www.ieagreen.org.uk/sacs2.htm#latest
[5] K. Alarcon, GEOLOGICAL DISPOSAL OF CARBON DIOXIDE, 1999.
[6] Government of Alberta, Request for Funding for the Weyburn CO_2 Monitoring Project Submitted to "Climate Change Central", 2000.
[7] Netherlands Agency for Energy and the Environment, Potential for CO_2 sequestration and Enhanced Coalbed Methane production in the Netherlands, 2001.
[8] The 1994 Report (The Engineering Advancement Association of Japan)
[9] The 12th Energy Symposium (1999) (Shinji Yamaguchi, Toyohiko Yamazaki)
[10] Application Guidelines (2002) for Subsidies

for the Development of Technologies for Sequestering and Utilizing CO_2 (Technologies for CO_2 Sequestration in Coal Beds) (The Agency of Natural Resources and Energy)

Glossary

*1 Kyoto Mechanism

The Kyoto Mechanism is a system through which its member countries are allowed to count emissions reduced by other countries as their own reductions, or their reduction targets can be achieved by purchasing emission credits from other countries. The mechanism is comprised of the following three systems.

- Joint Implementation (JT): Developed countries jointly implement projects for reducing greenhouse gases in order to transfer or acquire CO_2 credits.
- Clean Development Mechanism (CDM): Developed countries and developing countries jointly implement projects for reducing greenhouse gases in order to transfer or acquire CO_2 credits.
- Emission Trading (ET): Developed counties trade with one another in the balance between targets and the actual amount of emissions as emission credits.

Through this mechanism, each country concerned will be able to implement specific measures against global warming in countries where the cost of implementation is relatively lower, or to purchase emission credits at lower prices, thereby economically achieving its reduction target.

*2. A1FI Scenario

The Third Assessment Report of the IPCC presented a scenario dubbed "A1FI scenario," which emphasizes fossil energy sources. There are scenarios forecasting a future society where the world economy continues to grow, the world population starts to decline after peaking in the middle of the 21st century, and new technologies for improving efficiencies are adopted rapidly. These can be divided into the following three scenarios according to the energy sources they emphasize:

- A1FI : a scenario that emphasizes fossil energy sources.
- A1B : a scenario that emphasizes a well-proportioned balance among all the energy sources.
- A1T : a scenario that emphasizes non-fossil energy sources.

References

- A2 : a scenario based on regional economic development. Forecasted economic growth per capita and technological innovations are slower than those of other scenarios.
- B1 : a scenario that emphasizes global measures for achieving sustainability of the world economy, society and environment.
- B2 : a scenario that emphasizes regional measures for achieving sustainability of the world economy, society and environment. The world population increases more slowly than the forecast made by A2; economic growth remains at moderate levels; and extensive technological innovations take place, though its pace is slower than those forecasted by A1 and B1.

Incidentally, each scenario specified in SRES (Special Report on Emission Scenarios), namely A1FI, A1B, A1T, A2, B1 and B2, should be regarded as having common grounds. None of these scenarios assumes that reduction targets based on the Framework Convention on Climate Change and the Kyoto Protocol will be completed.

*3. Speech of President Bush in June 2001

"America's the leader in technology and innovation. We all believe technology offers great promise to significantly reduce emissions- especially carbon capture, storage and sequestration technologies." REMARKS BY THE PRESIDENT ON GLOBAL CLIMATE CHANGE, THE WHITE HOUSE, June 11, 2001.

(Original Japanese version: published in June 2002)