Current Situation of Technologies to Reduce Greenhouse Gases

By Yamaguchi Tsutomu

Introduction

Japan has done much to address the issue of global warming and pollution of the earth's environment. It is true that, during its heyday of tremendous economic growth, the air and water in some parts of the country became seriously polluted. But the government and corporations went to extraordinary lengths to address these problems over a period of more than 30 years, achieving the praise warranted by the Organization for Economic Cooperation and Development (OECD), which reported that Japan is the only developed country to have made economic growth compatible with environmental conservation. Making good use of its experience and technological advances, Japan has led the world in developing a wide range of technologies for environmental conservation, and now aims to achieve a technological breakthrough that would help solve one of the world's most intractable problems: global warming.

This article looks at some of the innovative measures Japan is adopting to tackle global warming, especially through the development of new technologies that can be used to reduce the amount of carbon dioxide (CO_2).

I. A Brief Look at Japan's Efforts to Solve Global Warming

(1) The government's Action Program to Arrest Global Warming

In a meeting of cabinet ministers concerned with the protection of the global environment in October 1990, the Cabinet established the Action Program to Arrest Global Warming. One of the goals of this action program was to stabilize Japan's per-capita CO_2 emissions at 1990 levels by the year 2000. The plan proposed the following seven measures needed for the country to reach this objective.

(a) Reduction in CO_2 emissions through: (i) the development of manufacturing methods and energy resources that emit only small amounts of CO_2 (e.g., through use of a wide range of energy-saving equipment, solar cells and fuel cells); and (ii) the promotion of consumer lifestyles that produce fewer CO_2 emissions (such as environmentally-conscious use of air conditioning and heating devices in homes and offices)

(b) Reduction in the emission of methane and other greenhouse gases

(c) Measures to promote carbon sinks by: (i) conserving and planting forests; and (ii) conserving and developing wooded areas in cities and other areas (e.g., increasing the area of green spaces around public facilities and factories)

(d) Scientific research, observations and monitoring activities that will lead to a reduction in greenhouse gas emissions

(e) The development and use of technical innovations, such as: (i) natural energy sources, including the sun and wind, and new alternative energy-related technologies; and (ii) the development of new technologies to capture CO_2 and boost the capacity of biological processes that can store (sequester) carbon

(f) Public education programs, including: (i) more emphasis on environment-related education; and (ii) the promotion of national movements to conserve resources and reduce energy consumption

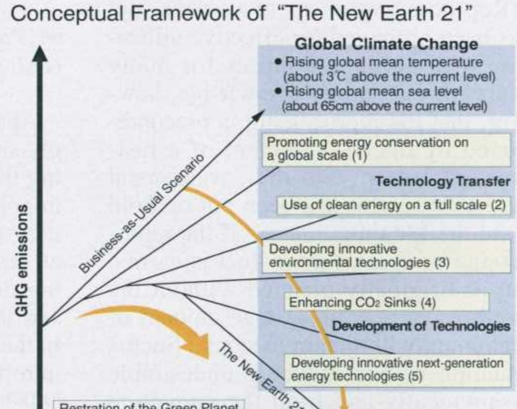
(g) Promotion of international cooperation aimed at preventing global warming

(2) Proposals for ways to improve the global environment, "The New Earth 21," and the establishment of the Research Institute of Innovative Technology for the Earth (RITE)

At the G-7 Summit in Houston in July 1990, the Japanese government called on all countries to cooperate in a plan entitled "The New Earth 21," a

Figure 1

Conceptual Framework of "The New Earth 21"



(1) Promotion of comprehensive energy saving and prohibition of CFCs
(2) Development of technology and introduction of new reusable energies, for example solar energy and fuel cells. Promotion of the introduction of safe nuclear energy
(3) Development of sequestration and utilization technologies for CO_2, biodegradable plastics, a new generation of CFC replacements, environmentally-friendly production technologies, and technologies for the isolation of CO_2 in oceans
(4) Reforestation and maintaining of forests, afforestation of desert areas, and strengthening of the ability of oceans to sequester CO_2
(5) Development of technology for solar power plants in space and of nuclear fusion technology

plan aimed at returning the global environment to a more pristine condition. Basic agreement was reached regarding this plan. The plan was based on the common understanding that it is vital: (i) to achieve technical breakthroughs that will permit sustainable development on a global scale that economic growth and environmental conservation proceed hand in hand; and (ii) to transfer the advanced technologies that can be used to protect the global environment to every part of the world. The plan recognized the fact that the global environment had changed because of 200 years of negative impacts since the Industrial Revolution, and envisioned the cooperation of all countries over the next 100 years to return our planet's environment to a more pristine condition.

The plan promotes the following five objectives. (Figure 1)

(a) All countries would adopt energy-conservation measures that had as much effect as those adopted by Japan.

(b) Clean energy resources would be adopted throughout the world (e.g., by developing and introducing renewable energy sources and nuclear power).

(c) The development of innovative technologies to protect the environment (e.g., the capture, disposal and use of CO_2)

(d) Increase in the area and potential of carbon sinks (e.g., large-scale planting of tropical rain forests, and the greening of deserts)

(e) The development of next-generation energy technologies (e.g., solar electric generators based in space, and nuclear fusion)

In order to promote the plan's third and fourth objectives, Japanese industries established the Research Institute of Innovative Technology for the Earth (RITE) in Kyoto, in July 1990, supported by the government and academic society. RITE was created to serve a pivotal role in international environmental science and technology. Since its establishment, RITE has followed the basic program devised by the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry), and has worked through the New Energy and Industrial Technology Development Organization (NEDO) to promote national research and development (R&D) projects, coordinating its efforts with government, industry and academic circles in Japan, and with the international community as well. RITE's projects focus on the development of innovative technologies that can be used to reduce CO_2, using biological, chemical and other means to sequester CO_2.

Table 1 Initial and Amended Objectives Set Out in the General Principles for the Introduction of New Energy

	1996 Levels (A)	Initial Objectives for 2010 (B)	Amended Objectives for 2010 *2 (C)	2010/1996 C/A
Electricity from solar energy	14,000 kl (55,000 kW)	4,600,000 kW	1,220,000 kl (5,000,000 kW)	approx. 90¥
Use of solar heat	1,040,000 kl	5,500,000 kl	4,500,000 kl	approx. 4¥
Electricity from wind turbines	6,000 kl (14,000 kW)	150,000 kW	120,000 kW (300,000 kW)	approx. 20¥
Electricity generated from waste products	820,000 kl (890,000 kW)	4,000,000 kW	6,620,000 kl (5,000,000 kW)	approx. 5.5¥
Number of motor vehicles powered by clean energy *1	12,000	3,240,000	3,650,000	approx. 300¥
Cogeneration *1	3,850,000 kW	19,120,000 kW	10,020,000 kW	approx. 2.6¥
Fuel cells *1	16,000 kW	2,200,000 kW	2,200,000 kW	approx. 140¥
Heat energy supplied by energy sources not presently used	77,000 kl	720,000 kl	720,000 kl	approx. 9¥
Total (percentage of energy supplied by primary energy sources) *3	6,850,000 kl (1.1%)		19,100,000 kl (3.1%)	approx. 3¥

*1: The Government's Projection of Energy Supply and Demand over the Long Term, amended in October 1998, defines these as "new ways to use conventional energy sources ('new energy sources' in the broad sense of the term)."

*2: New objectives set out in the above-mentioned Projection of Energy Supply and Demand Over the Long Term.

*3: Total does not include 'new energy' in the broad sense of the term.

(3) The government's general principles for the introduction of new energy

Because one of the major objectives of the government's Action Program to Arrest Global Warming was the development and use of new forms of energy, the Cabinet drew up guidelines called "general principles for the introduction of new energy" in November 1994. The principles were amended in October 1998 to include as one objective a 300% increase of new energy resources by 2010, compared to 1990 levels. These new energy resources include electricity generated by solar power, wind, and the use of waste materials. Their use would boost the ratio of primary energy sources from the 1996 level of 1.1% to 3.1%. (Table 1)

(4) General principles for measures to arrest global warming

Delegates to the Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3), which was held in Kyoto in December 1997, adopted the Kyoto Protocol, which called for the reduction of greenhouse gas emissions. This brought the international community to a new stage in the fight against global warming. Japan agreed to reduce its greenhouse gas emissions to 6% less than 1990 levels, during the period between 2008 and 2012. It is now apparent that this objective will be harder to achieve than was originally assumed before the Kyoto conference, and this means that even greater effort, at the government, corporate and citizen levels, is essential. Recognizing this, the Japanese government established the headquarters for global warming countermeasures. This body is headed by the prime minister, and was asked to devise concrete measures that would help Japan achieve its commitments under the Kyoto Protocol.

Table 2 Reduction in CO_2 Emissions through Energy Conservation (in the case where the overall decrease in emission levels over time is 0%)

	(Carbon conversion / 10,000 tons)
I. Energy conservation measures obligated by law	▲ 2,720
1. Industrial sector :	▲ 1,430
Ensured through legislation based on sectoral voluntary action plans	
2. Public welfare sector :	▲ 970
Stiffer energy consumption norms for electric appliances (using the "top runner" method)	
3. Transportation sector :	▲ 320
Stiffer fuel consumption norms for motor vehicles (requiring more than a 20% decrease in fuel consumption)	
II. Incentives	▲ 2,300
1. Industrial sector:	▲ 220
(a) Energy conservation incentives for major factories, etc.	(▲ 120)
(b) Future development of technology (e.g., development of high-performance boilers)	(▲ 100)
2. Public welfare sector:	▲ 1,270
(a) Incentives promoting greater energy conservation in the home	(▲ 280)
(b) Incentives for energy-efficient buildings	(▲ 750)
(c) Future development of technology	(▲ 240)
3. Transportation sector:	▲ 810
(a) Incentives promoting greater transportation efficiency	(▲ 250)
(b) Traffic measures	(▲ 310)
(c) Promotion of "tele-work" through greater use of telecommunications	(▲ 110)
(d) Future development of technology, etc.	(▲ 140)
III. Radical change in lifestyles	▲ 640
1. Public welfare sector	▲ 500
2. Transportation sector	▲ 140
Total	▲ 5,660

Notes: 1. Data obtained from the Ministry of Economy, Trade and Industry.
2. "0% decrease in emissions" indicates the case where emissions in 2010 are equal to 1990 levels.

These efforts led to the Cabinet adopting "general principles for measures to arrest global warming" in June 1998. The following six points formed the gist of these principles.

(a) Adoption of measures on energy demand and promotion of energy conservation: (i) revision of Japan's Energy Conservation Law in order to legislate application of the "top runner method" when establishing energy conservation norms (Under the "top runner method," when several companies manufacture the same type of product, the amount of energy used by the most energy-efficient product is to be used as the target when establishing energy conservation norms); (ii) the government will encourage voluntary energy conservation efforts under the voluntary action plans which the Japan Federation of Economic Organizations (Keidanren) has proposed for each major industrial sector; and (iii) greater emphasis is to be placed on public education programs that promote environmentally-friendly lifestyles. (Table 2)

(b) Adoption of measures on energy supply: (i) the supply of clean sources of energy, such as solar power and wind for the generation of electricity, is to be increased; and (ii) the construction of new nuclear power plants is to be facilitated by obtaining a general consensus among the population.

(c) Adoption of measures to curb the emission of greenhouse gases other than CO_2, such as CFC substitutes

(d) Promotion of R&D of innovative technologies: these include the development of high-performance boilers for industrial use before 2010, since these are expected to offer more immediate results in CO_2 sequestration. This research will complement the R&D of new technologies envisioned in the project for CO_2 fixation and utilization, which began in 1990.

(e) International efforts: feasibility studies will be conducted into projects related to international joint action and clean development mechanisms (CDM), for which the Kyoto Protocol called.

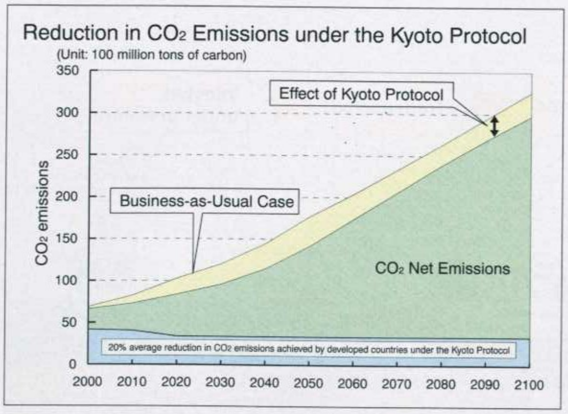
(f) Medium and long-term efforts: these efforts should include the development and promotion of innovative energy sources and environment technologies expected to be available after 2010, and the transfer of these technologies to developing countries.

II. The Need for Innovation over the Medium and Long Term

Figure 2 shows anticipated future global CO_2 emissions over the long term if levels are reduced as set out in the Kyoto Protocol. These calculations, made using a world energy and environment model named DNE 21 (Dynamic New Earth 21), indicate that if developed countries act first, reducing their emissions as called for in the Kyoto Protocol, subsequently an average reduction of 20% will be achieved; but if developing countries do not reduce their rising level of emissions during this same period, cuts by developed countries will unfortunately have almost no effect in reducing overall global CO_2 emissions. In other words, although it is true that the reductions called for in the Kyoto Protocol are an important first step in halting global warming, it is essential that medium and long-term efforts be taken to reduce emissions after 2010 as well, and that these efforts include the participation of developing countries.

When we take into account population increases and economic development in the second half of the 21st century, especially in today's developing countries, it is readily apparent that even if nations throughout the world promote energy conservation and clean energy and switch to low-carbon energy sources such as natural gas, the world will not be able to halt global warming unless it reduces global CO_2 emissions (even while depending to a considerable extent on fossil fuels over the next few decades), and unless it develops new technologies to sequester atmospheric CO_2. To be more concrete, new technologies must be developed for the separation, capture, storage and utilization of CO_2, the world must promote tree planting in large desert areas and tropical rain forest renewal, and new technologies are needed to facilitate higher levels of CO_2 absorption by marine creatures. In addition, the social infrastructure must be

Figure 2



improved to apply these new technologies.

Recognizing these obligations, in 1990 the Japanese government proposed to all nations the above-mentioned New Earth 21 Plan, and established the RITE, giving it the task of developing innovative environment technologies. The government has also promoted R&D efforts in such areas as CO_2 sequestration through biological and chemical means.

III. RITE's Development of Technologies to Prevent Global Warming

RITE has developed 14 state-sponsored R&D projects in three technical areas: (i) technology to mitigate global warming; (ii) low environmental burden technologies, including the development of CFC substitutes; and (iii) technical innovations for high-performance bio-reactors and other production technologies that will protect the environment. Here I will discuss only projects promoting the development of technology to mitigate global warming.

(1) Biological CO_2 fixation project (FY 1990 - 2000):

These projects focused on the development of technologies to capture CO_2 emitted from thermal electric generators and other large facilities, and effectively fix it in bio-reactors that use microorganisms and sunlight to create a product that can be used as a source of energy and fertilizer. The projects' main areas of research were: (i) the discovery and propagation of microorganisms that are capable of fixing CO_2 at rates 10 times or greater than those of land-based plants; and (ii) the collection, transmission and use of sunlight.

These efforts led to the discovery of microorganisms (such as chlorella) which can photosynthesize at rates five times or greater than rates seen among regular plant forms, and *Botryococcus*, a microorganism that is highly effective in absorbing oils. By developing a bio-reactor in which microorganisms are propagated in dense concentrations, Japanese scientists have succeeded in their aim of fixing CO_2 at rates that could only be achieved by a forest with 10 times the surface area. (In one day, each square meter of temperate forest can absorb about 5 grams of CO_2, but RITE has developed a bio-reactor in which each square meter of microorganisms can absorb 50 grams of CO_2 per day, in other words, 10 times the amount. Thus, the same amount of CO_2 can be fixed in one-tenth of the area.)

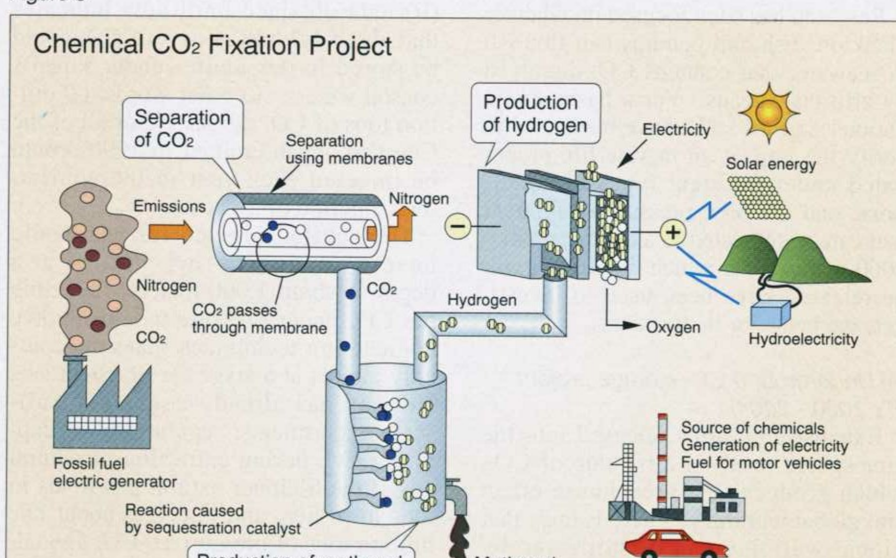
(2) Chemical CO_2 fixation project (FY 1990 - 2000):

These projects involved the development of technologies to collect CO_2 emitted from thermal electric generators and other large facilities, using energy-efficient separation membranes and capture the CO_2 in large quantities on a continual basis. Development also focused on technology that can be applied to add hydrogen to the captured CO_2, to yield useful chemical substances such as methanol. (Figure 3)

The research focused mainly on the development of: (i) membranes to efficiently separate CO_2 from emissions; (ii) efficient methods to produce large volumes of hydrogen; and (iii) technologies for catalysts to synthesize methanol highly efficiently.

Researchers succeeded in developing the world's most efficient CO_2 separation membrane. It is capable of concentrate into 90 vol. % of CO_2 from emission gases containing 10 vol. % of CO_2 in one stage. They have also succeeded in developing a highly effective catalyst that can synthesize 600 g/h of methanol per liter catalyst from highly concentrated CO_2 and hydrogen. RITE has installed benchscale experimental apparatus that can produce 50 kilogram of methanol per day. It also achieved success in continual test runs on public roads of a vehicle that uses as its fuel methanol derived from CO_2 and hydrogen. This research proves that it is technically possible to produce and use

Figure 3



methanol that is derived in part from captured CO_2. However, the high cost of extracting hydrogen is one hurdle that must be surmounted before this technology can find practical application.

(3) CO_2 ocean sequestration project (FY 1997 - 2001):

The first two kinds of projects involved the production of useful substances from captured CO_2. On the other hand, ocean CO_2 sequestration projects harness the ability of the ocean to absorb CO_2. The objective is to release captured CO_2 into the ocean depths and dissolve it there, in order to reduce the amount of atmospheric CO_2.

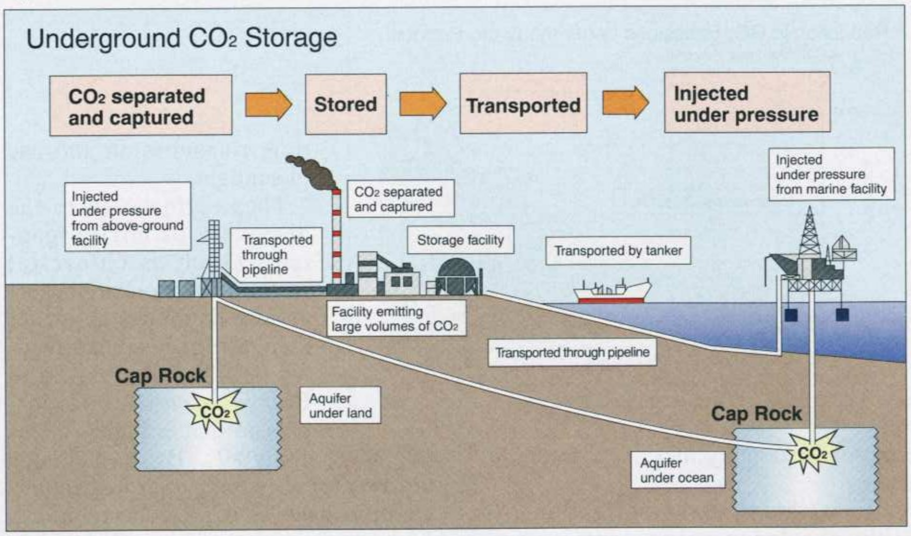
The research focuses mainly on: (i) the development of technologies that can be used to predict the environmental impact on marine areas around the point of CO_2 release; and (ii) experiments scheduled for 2001, in which CO_2 is released into ocean water, and research conducted jointly by Japan's RITE, the Massachusetts Institute of Technology (MIT) in the United States, the Norwegian Institute for Water Research (Norsk institutt for vannforskning: NIVA), and entities in other countries, to discover changes that may occur after CO_2 is dispersed in ocean water.

Research has been focused on whether plankton, fish and benthos can flourish in seawater that contains CO_2 dissolved by artificial means. For a basic study, various sizes of tanks have been used to verify the impact on marine life propagated under different types of conditions, and the high pressure equipment that can be subjected to a depth of 1000-2000 meter under which liquid CO_2 will be released have been used to investigate the behavior in the ocean.

(4) Underground CO_2 storage project (FY 2000 - 2004)

Exhaust emissions released into the atmosphere result in a buildup of CO_2, which produces the greenhouse effect and global warming. There is hope that global warming can be mitigated by separating and capturing CO_2 from fixed large emission sources, then

Figure 4



sequestering the CO_2 in oceans or storing it underground. This is why RITE launched the projects for ocean CO_2 sequestration mentioned in (3) immediately above, and why it began research in FY 2000 into the effectiveness of storing CO_2 underground. (Figure 4)

Underground CO_2 storage is seen as the most promising way to reduce CO_2 in the near future after 2010. If Japan is to use this technology, it is assumed that the CO_2 would be separated and captured from large emission sources, then transported by pipelines to areas where CO_2 could be injected into the aquifer under the seas surrounding Japan. The reasons for storing it there are: (i) conditions would be safer there when injecting CO_2 under pressure; and (ii) data obtained until now indicates that about 1.2 billion tons of CO_2 could be stored in the aquifer under Japan's coastal waters. In other words, 60 million tons of CO_2 (about 5% of all of the CO_2 that Japan emitted in 1990) could be injected each year in the aquifer, over a period of 20 years.

The aquifer targeted for use would have a strong cap rock located at a depth of about 1,000 meters. Injecting the CO_2 under pressure would involve engineering techniques that are reputedly almost at a stage for practical use. Norway has already conducted full-scale experiments, separating and capturing CO_2 during extraction of natural gas at the Sleipner natural gas fields in the North Sea, and injecting about one million tons of pressurized CO_2 annually in the ground.

Japan's research in this technology is focusing on safety factors, such as the behavior of the CO_2 and chemical reactions that can occur when CO_2 is stored underground for long periods of time. The purpose of this research is to make sure that the method is safe, and that the technology is therefore desirable.

(5) Desert plantation projects (FY 1993 - 2002)

The first four projects mentioned above showed that it is possible to capture CO_2 from fixed large emission sources. However, it is inefficient to capture CO_2 from fixed small emission sources and mobile emission sources, and this is why CO_2 from these sources will continue to be released into the atmosphere. This could lead to the assumption that CO_2 will continue to accumulate in the atmosphere. But to prevent global warming it is important to reduce this atmospheric CO_2 as well, or at least stop its increase. This can be done partly by planting vegetation on large expanses of desert, which are still areas of the planet that are greatly underused. Reforestation would increase the amount of vegetation available to absorb CO_2. Japan's desert plantation project uses genetic engineering in an attempt to develop new plant cultivars that can withstand dry conditions under strong sunlight.

The research focuses mainly on: (i) improving the ability of enzymes to sequester CO_2 through photosynthesis; (ii) the development of chloroplast transformation technology; and (iii) the enhancement of active oxygen elimination systems.

RITE has succeeded in developing a plant (which we have named the "RITE Desert Plant No.1") that can withstand dry desert conditions under strong sunlight. Development involved introducing catalase of *E.coli* to plants and making it function in the chloroplasts. The catalase eliminates active oxygen which can contribute to the death of plants that are subjected to strong sunlight in desert conditions. RITE is also attempting to improve the ability of Rubisco enzymes to accomplish photosynthesis through effective absorption of CO_2 in areas where water is scarce, and introducing the genes of microorganisms which are highly efficient in CO_2 absorption.

IV. One Scenario to Halt Global Warming – Promoting the Objectives of the New Earth 21 Plan

To promote the aims of the above-mentioned New Earth 21 Plan, RITE obtained data on such factors as world population and energy, then developed scenarios for the choice of suitable energy sources and technologies that would ensure achievement of the plan's objectives by 2100.

In 1994, RITE established a research committee of academic experts. The committee studied global energy demand, evaluated various energy and technology-related measures that are expected to mitigate global warming, and examined environmental conditions. The DNE 21 model is used to develop an ideal dynamic optimized scenario under an atmospheric CO_2 concentration of 550 ppm targeted in 2100 by minimizing the cost of total energy systems during the 21st century.

Thus, the objective of this scenario is to choose energy sources and technologies for use worldwide that will ensure a reduction of atmospheric CO_2 to 550 ppm by 2100, at minimum cost. The level, 550 ppm, was chosen as it is seen as being low enough to halt global warming. The scenario is unique because it does not posit a short period of action over a decade, as envisioned in the Kyoto Protocol, but action taken over a very long period of time – 100 years.

Figure 5

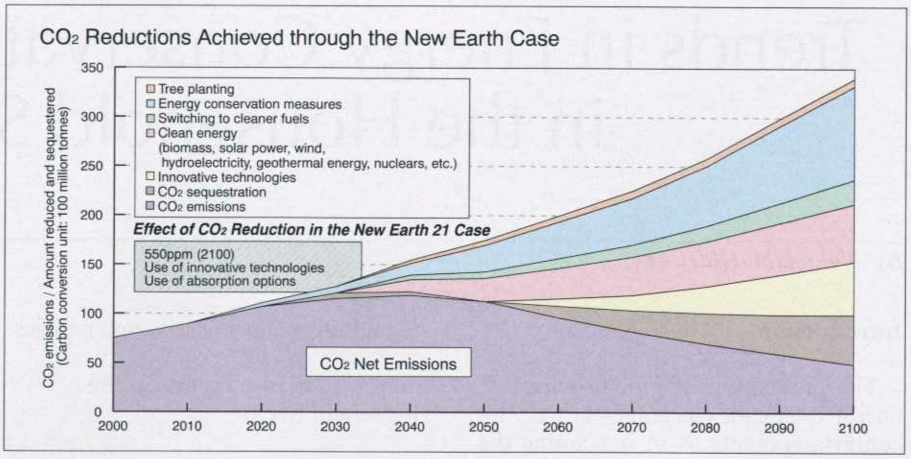


Figure 5 shows a projection of greenhouse gas emissions if atmospheric CO_2 is reduced to 550 ppm in 2100 (I call this the "New Earth case"), and the contribution made by various measures to reduce CO_2 emissions from those of the business-as-usual (BAU) case. In the New Earth case, CO_2 emissions will increase or decrease slightly until 2050, after which all CO_2 reduction measures will be applied. The notable feature here is that CO_2 emission reductions are concentrated in the second half of the century.

As the figure illustrates, CO_2 emission reduction measures from the BAU case level to the New Earth case level can be classified as follows: (i) energy conservation measures; (ii) conversion to clean energy sources; and (iii) CO_2 capture and disposal through such measures as ocean sequestration. These three measures each contribute about one-third toward the 2100 objective. CO_2 emissions drop dramatically in the second half of the century, with CO_2 capture and sequestration contributing the most in the effort to reduce atmospheric CO_2 concentrations. The objective here is to choose measures which can be achieved at the lowest total cost, so measures that are relatively inexpensive are chosen.

This analysis makes clear that the following three points should be taken into account when countries throughout the world cooperate in the fight against global warming.

(1) To achieve the objectives of the New Earth 21 Plan, CO_2 reduction measures should envision long-term actions taken over an entire century. In the first half of the century, energy conservation should be pursued while developing innovative environment-protection technologies. In the second half of the century a wider variety of measures should be implemented in unison, with a view to reducing CO_2 at a reasonable cost.

(2) CO_2 sequestration and innovative technologies should play a significant role in achieving the objectives of the New Earth 21 Plan at a reasonable cost.

(3) Developed and developing countries should cooperate in devising effective global warming countermeasures. For example, developing countries are generally rich in energy sources (such as solar and biomass energy) that can contribute greatly to the reduction of CO_2, while they need advanced technologies that will help them improve energy-use efficiency levels and conserve energy. In addition, under-populated areas of the world hold the potential for future hydroelectric projects, and electricity from these projects and solar energy can be converted into methanol, hydrogen and other fuels which can then be transported long distances as part of global projects promoted under international cooperation. The end result would be further reductions in CO_2 levels. JJTI

Yamaguchi Tsutomu is the Senior Managing Director at the Research Institute of Innovative Technology for the Earth (RITE). He is also a Visiting Professor at the Nara Institute of Science and Technology.