

GLOBAL WARMING

Mitigation Technology and its Assessment


National Institute of
Advanced Industrial Science
and Technology
AIST

GLOBAL WARMING

Mitigation Technology and its Assessment

In 2007, Intergovernmental Panel on Climate Change (IPCC) released the Fourth Assessment Report (AR4) composed of Working Group Ⅰ Report (Physical Science Basis), Working Group Ⅱ Report (Impacts, Adaptation and Vulnerability), Working Group Ⅲ Report (Mitigation of Climate Change), and the Synthesis Report providing an integrated view of climate change as the final part of the AR4. The AR4 states that warming is occurring in the climate system of the earth, very likely due to the increase in anthropogenic greenhouse gas concentrations. It also strongly states that many options for reducing global greenhouse gas emissions exist. We, at AIST, aim to give constructive proposals in supporting policy planning and execution concerning global warming measures, and have stated in the Second Period Research Strategy (Environment & Energy), formulated in April 2005, that our strategic goal is to contribute to global warming prevention and assessment. Over a wide variety of research fields, we have been engaged in developing mitigation technologies and assessment methods for their environmental impacts. In this brochure, we will first review the discussions on global warming mitigation plan in an international framework and on the present situation, by introducing the IPCC AR4 and the two IPCC Special Reports in which researchers at AIST played major roles in writing. As mitigation technologies in various fields are presented and put to practical use, there is a demand for an appropriate assessment of these technologies and their environmental effects. Here we would like to introduce the researches of AIST on carbon dioxide capture and storage technologies anticipated as promising mitigation options, the utilization technologies of the clean and renewable energy sources already put to use, and also environmental assessments for the mitigation technologies.

Edited by

Masayuki Kamimoto Research Coordinator for Environment & Energy

Masahiro Suzumura Research Institute for Environmental Management Technology

Taizo Sano Research and Innovation Promotion Office

Climate Change Mitigation in a Sustainable World

–Findings of the IPCC 4th Assessment Report–

Dr. Bert Metz (of Netherlands Environmental Assessment Agency), co-chairman of IPCC Working Group Ⅲ, gave a lecture on IPCC Fourth Assessment Report at “AIST Environment and Energy Symposium Series Special Lecture: The activities of IPCC Working Group Ⅲ and the summary of Fourth Assessment Report” held in October, 2007. Here is the summary of the lecture.

Dr. Bert Metz who gave the lecture

Does climate change threaten sustainable development?

The present global mean temperature is already about 0.7 ℃ higher than it was before the industrial revolution. Precipitation patterns have changed, glaciers are retreating, and the arctic ice cap and the Greenland ice sheet are melting. Ecosystems are reacting to these changes showing notable impact such as the coral reefs being at the edge of extinction. Extreme weather events as heat waves and droughts are more frequent, and the intensity of tropical storms is escalating. The cause of the temperature increase and the changes that follow has now been established with a very high likelihood (of 90 % or more) to be the sharply increased greenhouse gas (GHG) emissions as a result of human activities.

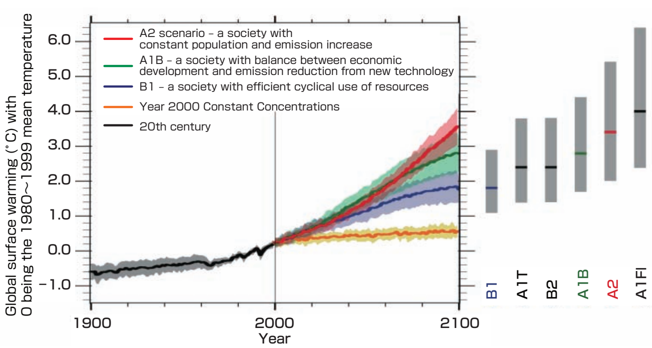


Fig.1 Projection of future temperature increases for different scenarios

As a range of scenarios of our future society, global mean temperatures are projected to increase 1.1 to 6.4 °C by 2100, compared to 1980~1999 (Fig.1). Impacts of climate changes could be serious and could overwhelm the coping capacity of human beings. With several degrees warming, food production of tropical areas will decline, many people will be faced with drought and flooding, ecosystems will be endangered and diseases will spread. These impacts pose a serious threat to sustainable development, and in monetary terms, could wipe out up to 5 % of GDP.

Can technologies for reduction of greenhouse gas emissions limit climate change sufficiently to allow for a sustainable future?

There are technologies available today to reduce GHG emissions and to increase the absorption of CO_2 by the biosphere. These are efficient lamps, cars, low-carbon electricity generation technologies, such as wind, biomass, nuclear, geothermal and solar, clean industrial processes that avoid methane and nitrogen oxide emissions, avoiding deforestation and forest deterioration, management technology of agricultural soils and forests. Other technologies are under development, such as fuel cells for cars, affordable photovoltaic cells, advanced energy saving and tidal and wave energy. Based on the scenario of these innovative technologies, the GHG concentration in the atmosphere is thought to be able to be stabilized at 450 ppmv (CO_2-equivalent, presently at 380 ppmv).

As bringing in new technology takes time socially and economically, a stabilization level at 450 ppmv CO_2 eq. is probably the highest (the lowest number) that can be achieved. In order to achieve this, global emissions need to be decreased to 50 % by 2050, and great efforts need to begin right away.

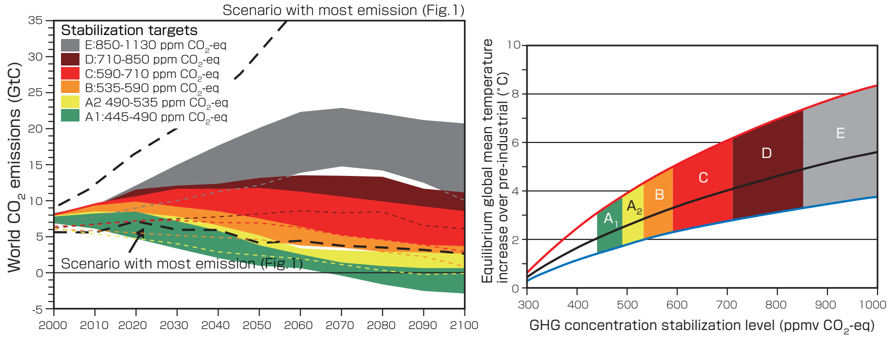


Fig.2 Global CO_2 emissions and corresponding relationship with stabilization level

However, even with stabilization at 450 ppmv, the global mean temperature will be about 2 °C higher (Fig.2), and a certain amount of impact is apprehended. Several countries and environmental NGOs are stating that global mean temperature increase must be kept below 2 degrees level to allow countries to develop in a sustainable manner. With implementation of effective strategies, this reduction scenario will only cause a few tenth of a percentage reduction in annual economic growth rate. However, on the other hand, some believe that emission reduction strategies will cause great setback of growth, and therefore, realization of such scenarios is a great challenge.

What is required for sustainable development to happen?

Thus, it is very doubtful if a pure climate oriented policy is sufficient. Fortunately, there are many ways to lower GHG emissions without sacrificing development of each country. The examples are listed here:

- **Macro-economic policies: design of taxes, subsidies, other fiscal policies, structural adjustment**
- **Trade policies: removing barriers for low-carbon products, promoting domestic energy sources**
- **Energy security policies: efficient energy use, domestic energy sources**
- **Policies to enhance replacement to modern energy: bioenergy, poverty tariffs**
- **Air quality policies: clean fuel, non fossil fuels**
- **Bank lending policies: lending for efficiency/renewables, avoid lock-in into old technologies in developing countries**
- **Insurance policy: differentiated premiums, liability insurance exclusion, improved conditions for green products**

Moreover, in reducing vulnerability to climate change, well designed infrastructure, agricultural and coastal development and other policies can be pursued.

Strategies using these various methods are required to realize a truly sustainable development of the world that avoids the risk of climate change. Climate change cannot be solved with climate policies alone.

Research Institute for Environmental Management Technology

Koh Harada

The 2005 IPCC/TEAP Special Report on the Ozone Layer and the Global Climate System

Preparation of the Special Report [1]

The Montreal Protocol adopted in 1987 mandates the stepwise phase-out of ozone depleting substances (ODSs [2]) to the Parties that ratified the Protocol. In the pre-Montreal period, the worldwide production of ODSs exceeded 1,800,000 metric tonnes per annum, but it was decreased down to approximately 90,000 metric tonnes in 2005 by the successful implementation of the Montreal Protocol mainly in the developed countries since 1996. What played important roles in the phase-out of ODSs have been the two fluorinated alternatives, that is, HCFCs (hydrochlorofluorocarbons) and HFCs (hydrofluorocarbons) as well as the introduction of not in kind (non-fluorine) alternative technologies. Above all, HFC-134a (CF_3CH_2F) has been rapidly introduced in replacement of CFC-12 (CCl_2F_2) as a refrigerant in the mobile air-conditioning application. Meanwhile, the HFC compounds along with PFC (perfluorocarbon) and SF_6 (sulfur hexafluoride) have been listed as greenhouse gasses and are targeted for reduction under the Kyoto Protocol in 1997. The relevant industries are looking seriously for the solution to meet the requirement of the two Protocols in treating HFCs.

In 2002, the Parties to the United Nations Framework Convention on Climate Change as well as the Montreal Protocol decided to request the Intergovernmental Panel on Climate Change (IPCC) and the Technology & Economic Assessment Panel (TEAP) under the United Nations Environment Programme (UNEP) to produce a special report on"*Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons*". With this request, both organizations (IPCC and TEAP) nominated 140 lead authors from academia and industries worldwide, and published the Special Report in the fall of 2005.

Summary of the Special Report

This report consists of Part A : Ozone depletion and the climate system, Part B : Options for reducing greenhouse gas (GHG) emissions from ODS replacements, Part C : Future estimation and availability of HFCs and PFCs. However, its content focuses on emission behaviors of CFCs, HFCs, and HCFCs which affect global warming as potential GHG, and the mitigation to reduce those GHG emissions.

(1) Part A : Ozone depletion and the climate system

Figure 1 shows the extent of the global ozone depletion against the years and the simulation of recovery of the ozone layer, optimistically predicting recovery by around 2050. However, at the 19th Meeting of the Parties to the Montreal Protocol in 2007, the recovery was feared to be delayed to around 2065 due to the rapid increase of HCFC emissions in developing countries and the uncertainty of the effect of climate change on the ozone layer. Figure 2 shows fluorocarbon (CFC, HCFC and HFC) emissions expressed by CO_2 equivalent tonnes against the years, and compared them to total CO_2 emissions from fossil fuel burning. The fluorocarbon emissions that were 7.5 giga tonnes (Gt) in 1990 (approximately 33 % of CO_2 emissions derived from fossil fuel) were reduced

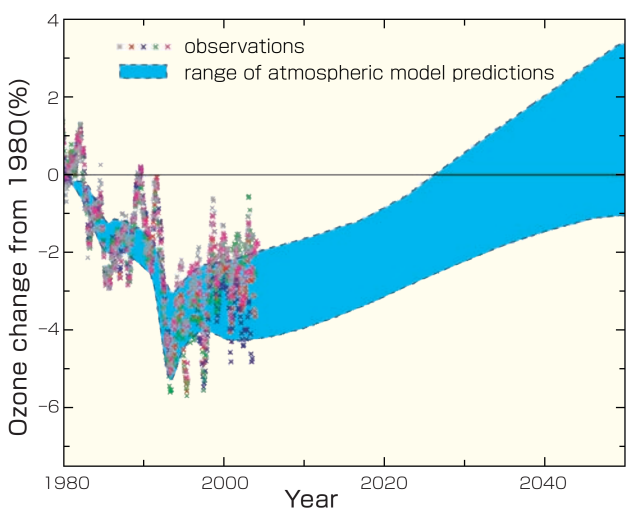


Fig.1 The ozone depletion and recovery

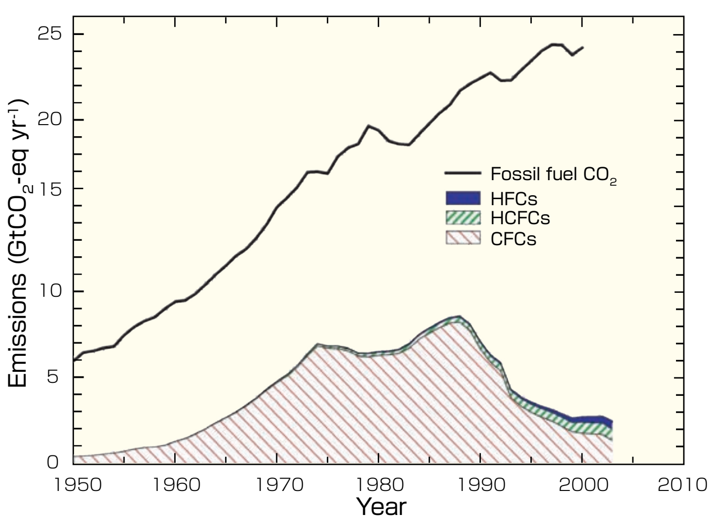


Fig.2 Halocarbon emissions

Table　Emission reduction effects of halocarbons

Emissions ($GtCO_2$-eq yr^{-1})	2002	2015 business-as-usual (BAU)	2015 with mitigation measures
CFC/HCFC/HFC	2.5	2.4	1.2
CFC/HCFC	2.1	1.2	0.7
CFC	1.6	0.3	0.2
HCFC	0.5	0.9	0.5
HFC	0.4	1.2	0.5

From G8 agenda for global growth and stability in G8 summit 2007 at Heiligendamm

59. We will also endeavour under the Montreal Protocol to ensure the recovery of the ozone layer by accelerating the phase-out of HCFCs in a way that supports energy efficiency and climate change objectives. In working together toward our shared goal of speeding ozone recovery, we recognize that the Clean Development Mechanism impacts emissions of ozone-depleting substances.

This declaration adopted in the G8 agenda clearly supports the decision by the "Montreal Adjustment" to accelerate phaseout of HCFCs.

greatly to 2.5 Gt in 2000 (approximately 10 % of CO_2 emissions from fossil fuel). This clearly indicates that CFC is not only an ODS but also a strong greenhouse gas, and its phase-out is contributing greatly to the prevention of global warming as well as to the recovery of the ozone layer.

(2) Part B, C: Fluorocarbon emissions and reduction measures

The CFC, HCFC and HFC emissions between 2002 and 2015 were estimated. In addition to these gasses being emitted at the production, transport and usage stages, the amount of HCFCs and HFCs preserved for long periods in devices or equipments as future banks[3] is especially increasing. Therefore, the importance of bank treatment at the end of their lives has been pointed out. The table shows in contrast the actual emissions in 2002 bearing in mind the bank load, the business-as-usual (BAU) estimation in 2015, and the expected estimation with the possible mitigation for reductions. In the BAU cases, the emissions of HFC in 2015 will be three times larger than those in 2002, the emission of HCFC and CFC will be twice and about one fifth respectively, and, in total, it will result in about the same as 2002; however, if any mitigation is taken, it is estimated to be possible to halve the emissions. This report concludes that the total phase-out of ODS and the significant emission reductions of HCFC and HFC can be achieved by: 1) improvement of containment technology, 2) recovery, recycling and destruction, 3) use of not-in-kind or alternative substances with low global warming potential (GWP), and 4) introduction of innovative technology.

The effect of the Special Report on the Montreal Protocol

In the Montreal Protocol, it has been decided that the developed countries must completely phase-out HCFC by 2020 and the developing countries by 2040. Here, the HCFCs include HCFC-22 ($CHClF_2$) as an important feedstock for fluorinated polymers or an effective refrigerant, and HCFC-14lb (CH_3CCl_2F) as a useful blowing agent and a cleaning solvent. Especially on the production of HCFC-22, a strong greenhouse gas, HFC-23 (CHF_3: GWP of 14,800) is produced as a by-product. If a destruction process of this HFC-23 is certified as a CDM (clean development mechanism) set in the Kyoto Protocol, a large amount of credit will arise making a high income possible. Actually a number of HCFC-22 manufacturing plants have been constructed in developing countries as China and more than ten of them have already received CDM certification. This Special Report expresses growing concern over such unnecessary production increase of HCFC-22. Triggered by this report, the necessity of the earlier phase-out of HCFC was aggressively discussed at the 19th Meeting of the Parties in its twentieth anniversary of the Montreal Protocol in September 2007. There, a revolutionary "Montreal Adjustment" was adopted which stated that the developing countries also must completely phase-out HCFC by 2030 via its stepwise reduction, a date brought forward by 10 years.

Research Coordinator for
Environment & Energy
Masaaki Yamabe

Related Information
[1] The author participated in the preparation of the Special Report as one of the coordinating lead authors.
[2] ODSs include CFCs, HCFCs, methyl chloroform, carbon tetrachloride, methyl bromide and halons.
[3] Bank is defined by the loaded ODSs in devices and equipment during their lifetime in use, for example the refrigerant in the mobile air-conditioning.

Summary of the Special Report on Carbon Dioxide Capture and Storage (SRCCS)

Introduction

Carbon dioxide (CO_2) capture and storage (CCS) is a process consisting of the separation of CO_2 emitted from thermal power plants and other industrial sources, transport to a geological or ocean storage location and long-term isolation from the atmosphere. Upon receiving advice from Conference of the Parties 7 (COP7) in 2001, the Special Report of Carbon Dioxide Capture and Storage (SRCCS) was issued in 2005, which is the first report from the Inter-governmental Panel on Climate Change (IPCC) to assess a specific "technology". The report helped putting CCS into a policy agenda, and has influenced negotiations at United Nations Framework Convention on Climate Change (UNFCCC).

Contents of IPCC Special Report

The contents of SRCCS is shown in the table. Its summary is shown in the Summary for Policymakers (SPM) which is written in answer to the important points of issue in the eyes of the policymakers. The major points are as follows.

(1) What is CO_2 capture and storage technology and how could it contribute to mitigating climate change?

There is a need for a portfolio of mitigation measures for stabilization of atmospheric greenhouse gas concentrations, and CCS may reduce overall mitigation costs and increase flexibility in the measures that can be taken.

(2) What are the characteristics of CCS?

A power plant with CCS would need approximately 10 – 40 % more energy of which most is for capture.

(3)What is the current status of CCS technology?

Components of CCS are in various stages of development and there are few examples of integrated systems.

(4) What are the geographical relationship between the sources and the storage opportunities for CO_2?

Large point sources of CO_2 are concentrated in major industrial and urban areas and many are within 300 km of areas that potentially hold formations suitable for geological storage.

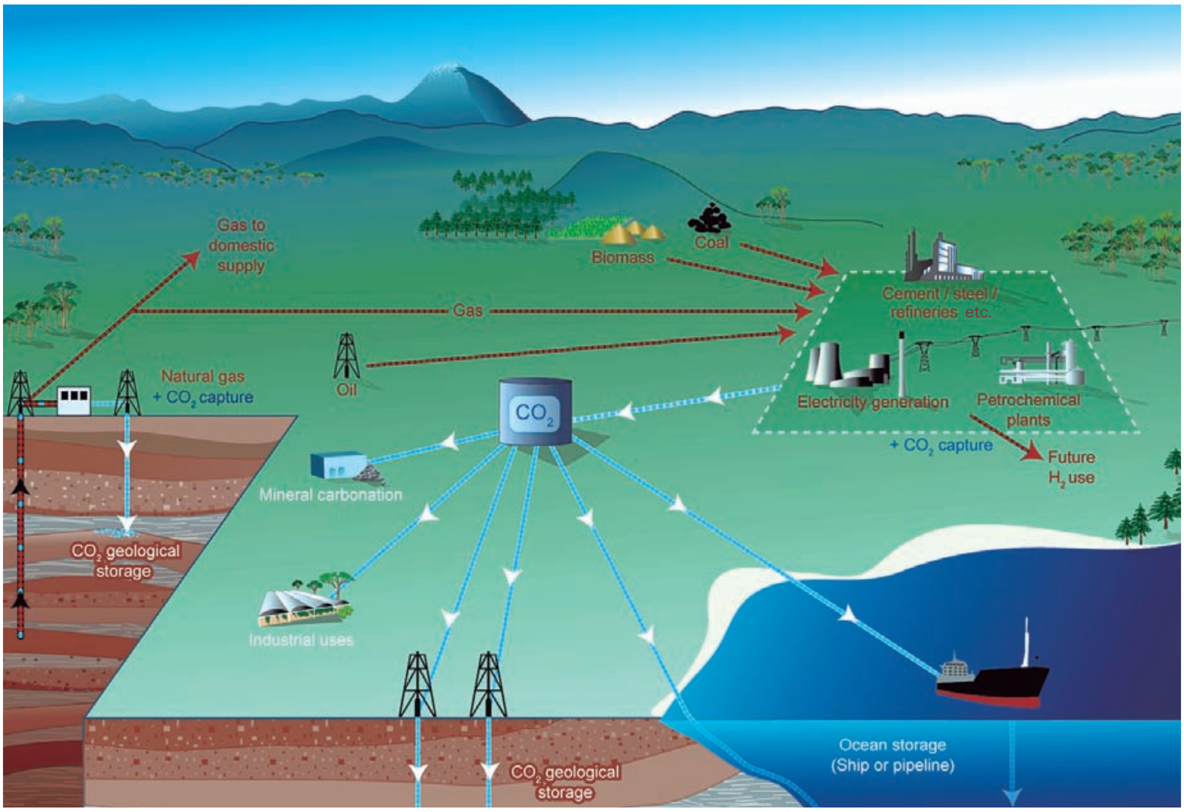


Fig. Schematic diagram of possible CCS systems (taken from IPCC SRCCS)

Contents of IPCC Special Report

Chapter 1	Introduction
Chapter 2	Sources of CO_2
Chapter 3	Capture of CO_2
Chapter 4	Transport of CO_2
Chapter 5	Underground geological storage
Chapter 6	Ocean storage
Chapter 7	Mineral carbonation and industrial uses of carbon dioxide
Chapter 8	Costs and economic potential
Chapter 9	Implications of carbon dioxide capture and storage for greenhouse gas inventories and accounting
Annexes	

(5) What are the costs for CCS and what is the technical and economic potential?

Application of CCS to electricity production system would increase generation costs by about 0.01 – 0.05 $/kWh which , in most cases, would be predominantly the cost of capture (and compression).

Worldwide, there is a technical potential of roughly 2,000 Gt CO_2 of storage capacity in geological formations at a probability of 66 – 90 %. In the ocean, the capacity could be thousands of Gt CO_2, depending on the stabilization level of CO_2 in the atmosphere.

In most scenarios for stabilization (of 450 to 750 ppm), the economic storage potential of CCS would be 220 – 2,200 Gt CO_2 (cumulatively from 2000 to 2100), which would mean a 15 – 55 % contribution to the mitigation efforts and a reduction of the costs of stabilization by 30 % or more.

(6) What are the local health, safety and environment risks of CCS?

With an appropriate site selection, a monitoring program, a regulatory system and an appropriate use of remediation methods to stop CO_2 releases if they arise, the risks of geological storage would be comparable to the risks of current activities such as natural gas storage, EOR (Enhanced Oil Recovery) and deep underground disposal of acid gas.

(7) Will physical leakage of stored CO_2 compromise CCS as a climate change mitigation option?

The fraction retained in appropriately selected and managed geological reservoirs is to exceed 99 % over 100 years at the probability of 90–99 %, and is likely to exceed 99 % over 1,000 years at the probability of 66–90 %. In the case of ocean storage, the fraction retained is 65–100 % after 100 years and 30 – 85 % after 500 years (a lower percentage for injection at a depth of 1,000 m [writer's note: 800 m to be correct], a higher percentage at 3,000 m).

(8) What are the legal and regulatory issues for implementing CO_2 storage?

Few countries have specifically developed legal or regulatory frameworks for long-term CO_2 storage. No interpretations so far have been agreed upon with respect to whether CO_2 injection into the geological sub-seabed or the ocean is compatible to specific international regulations.

(9) What are the implications of CCS for emission inventories and accounting?

The current [writer's note: when SRCCS was issued] 1996 IPCC Inventory Guidelines do not include methods associated with CCS. However, these are expected to be provided in the 2006 revised edition.

Conclusion

When I look back over the 20 years or so that I have been involved in CCS, the conditions surrounding CCS are poles apart, and CCS is now considered a policy issue in our country. However, for CCS to effectively function as a CO_2 mitigation process, there are many problems to be solved and technology is only one of them. Besides efficiency improvement through technological development and cost reduction, it is internationally common knowledge that there are mounting non-technological problems as the need to form regulatory and other systems, the application to Clean Developing Mechanism (CDM), or the consideration of a new international framework that could treat CCS properly and replace or complement CDM, the setup of incentives as economic support, and the gain of social acceptance. With this background in mind, if we are to choose CCS as a policy option in our country, we have come to a stage where not only technological research and development but the groundwork and the system structure for its realization should be considered and concrete policies should be made.

Energy Technology Research Institute
Makoto Akai

CCS Technology Development and Evaluation

Current situation of CO_2 geological storage and its perspectives

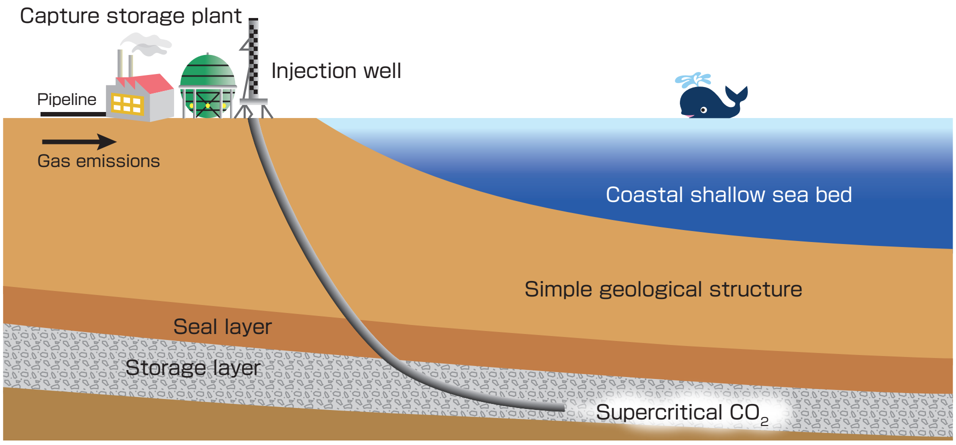
As no wait is allowed for global warming, there is a demand for speedy practical implementation of measures that cut the emissions of carbon dioxide (CO_2) which has quantitatively the most significant greenhouse effect. Carbon dioxide capture and storage (CCS) technology which captures and stores CO_2 emitted into the atmosphere from large scale emission sources is an important technology of atmospheric CO_2 reduction. For the final step of CCS, CO_2 storage in the water-filled geological strata (aquifer), or CO_2 geological storage, is drawing attention.

In our country, the large scale emission sources of CO_2 are located in the metropolitan areas along coastal plains, and the plains are mostly underlain by young geological strata of relatively simple structure. The underground strata are filled with groundwater (mostly saline water) which is stagnant for a long time and which can not be used as water resource. CO_2 geological storage technology attempts to store CO_2 by injecting it with physical characteristics between gas and liquid (supercritical CO_2 with low viscosity and small volume) into the underground strata. Such attempts are already underway in several countries, and in Norway, 1 million tons of CO_2 is stored a year. The 2005 total greenhouse gas emission of our country was 1.36 billion tons (certain value), and the possible CO_2 geological storage capacity (approximation) is estimated to be 146.1 billion tons; and it can be, therefore, said that there is ample storage capacity around our country.

The technology of injecting fluid into deep geological strata is an extension of the accumulated technology of geological storage of natural gas and enhanced oil recovery (EOR). Moreover, we have a peculiar natural gas deposit called "dissolved-in-water type" that is commonly found in geologically young strata. The occurrence of this type of natural gas indicates that gases dissolving in fluid can be stored underground for long periods as hundreds of thousands of years, supporting the idea of CO_2 geological storage. However, for it to become operational, many problems still exist and the following need to be elucidated: 1) what is happening underground where CO_2 is injected (scientific understanding of the behavior), 2) how to keep CO_2 underground (storage mechanism), 3) how to monitor the injected CO_2 movement within the geological strata (monitoring). These issues all involve elucidation of the interaction of CO_2 fluid, underground rock strata, and deep groundwater. There is a demand for research and development of technology using various geoscientific methods as the collection of basic data from geochemical and rock mechanics experiments, the analysis of general groundwater flow based on well observation, numerical computer simulation, and the case studies on natural analogous phenomena.

Climate change due to the increase of CO_2 concentration in the atmosphere is often considered as a problem of the atmosphere and the ocean. However, for CO_2 geological storage as a measure of climate change, the interaction of CO_2 in the earth interior becomes important. AIST Geological Survey of Japan, being the top geological research institute in our country, is contributing to solving the climate change problem by conducting researches on CO_2 geological storage based on the accumulated knowledge of geoscience.

Institute for Geo-Resources and Environment
Toshiyuki Tosha
Yasuko Okuyama



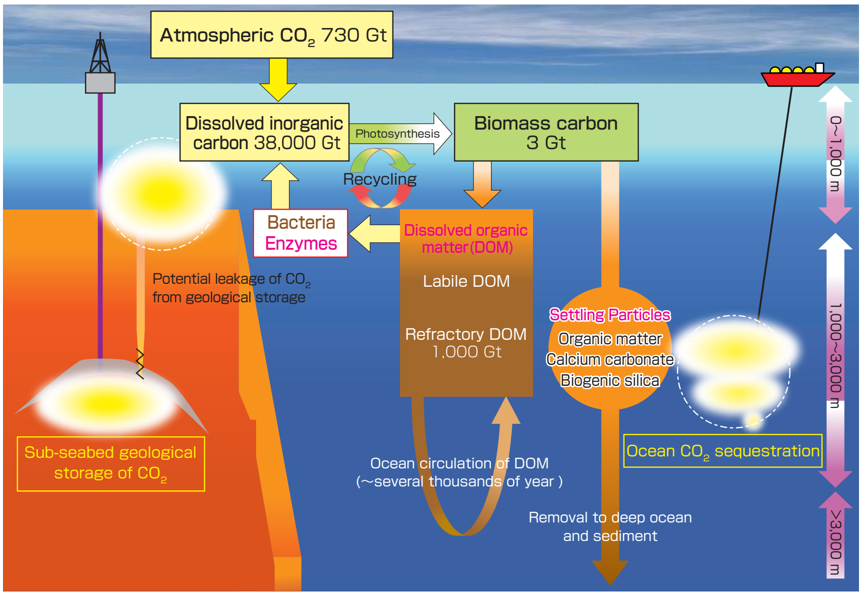
Geological storage

Environmental assessment for ocean CO_2 sequestration

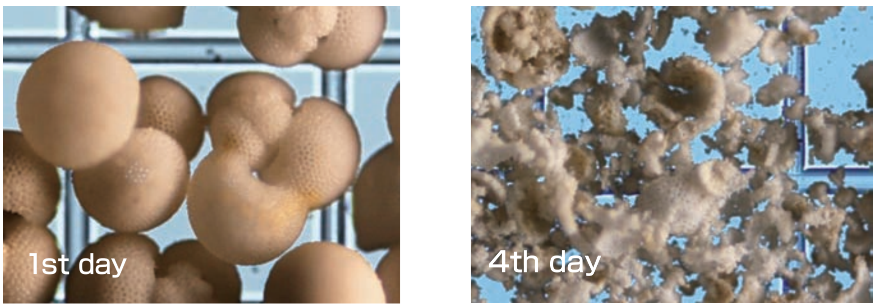
The ocean covers 70 % of the earth's surface and contains roughly 50 times more CO_2 than in the atmosphere. Moreover, the ocean has absorbed and stored about 30 % of human-generated CO_2 emissions into the atmosphere. Ocean CO_2 sequestration (injection to and storage in the bathypelagic layer of 1,000~3,000 m) is a technology that actively utilizes the potential of the ocean to dissolve extremely large amounts of CO_2. While geological storage is the option to entrap CO_2 in confined space, ocean sequestration is a technology utilizing the open space of the ocean to curb the rapid increase of atmospheric CO_2 concentration by the long-term retention potential. Because of the direct usage of the open environment, more rigorous and cautious assessments of the potential impacts on the marine environment are needed.

With ocean sequestration, CO_2 is widely and thinly dissolved as to keep the impact on the marine environment at the minimum. However, in considering a long-term, large-scale operation, an appropriate evaluation of the long-term effect on the marine ecosystem which supports the carbon storage potential of the ocean is essential. It was considered that bathypelagic is a zone with very little life. However, now it has become known that various microbial communities including bacteria exist and play important roles in marine carbon cycle through the degradation of labile organic matter and the formation of refractory organic matter. Bathypelagic layer is also important as the site where settling particles dissolve. In order to assess the effects of the increase of CO_2 concentration and the decrease in pH with CO_2 injection on the marine biogeochemical cycling, we are executing laboratory experiments under high CO_2 and low pH conditions by using bathypelagic seawater samples and special high pressure apparatus which simulates the ambient environment of the deep sea.

In November 2007, in the international convention for conservation of marine environment (the London Protocol 1996), assessment guideline was adopted for the implementation of CO_2 storage in sub-seabed geological formations. In the guideline, it is stated that environmental impact assessment will be done in regard to the potential leakage of CO_2 into the marine environments. The results obtained from our research will not only provide important knowledge for the ocean CO_2 sequestration but also will be pioneering research of environmental assessments for sub-seabed geological storage.



Schematic view of CCS technologies and carbon cycling in the ocean.



High pressure dissolution experiment of calcium carbonate settling particles (foraminiferal shell)
The spheric shells are rapidly dissolved in sea water of high concentration of CO_2.

Research Institute for Environmental Management Technology
Masahiro Suzumura

Life Cycle Assessment (LCA) of Photovoltaic Power Generation

Increasing installation of photovoltaic power generation system

There is a growing expectation for clean and inexhaustible solar energy as a renewable energy source indispensable for sustainable society and for preventing global warming. Photovoltaic power generation above all is a system which converts solar energy directly to electricity and, as it has no moving part like a turbine, its maintenance is easy and it can be applied in various scales and forms from pocket calculators to large-scale power plants.

Ever since the Sunshine Project which started in 1974 as a long-term national project after the first oil crisis, research and development efforts through industry-government-academia cooperation and governmental promotion policies effectively resulted in reducing the cost, and there has been rapid increase in production and installation in recent years. As can be seen in Fig. 1, our country is the largest producing country of solar cells in the world.

Life cycle assessment

Although photovoltaic power generation system is an effective energy source in preventing global warming, a certain amount of energy is needed in manufacturing system components like photovoltaic cells and inverters, and naturally carbon dioxide (CO_2) is emitted in the process. The time needed to recover input energy and to reduce CO_2 emission during production is called energy payback time (EPT), and CO_2 payback time (CO_2PT) respectively. If these payback times are not sufficiently short compared to the life time of the system, it does not make sense at all as an energy producing technology. Life cycle assessment (LCA) which analyzes and evaluates these payback times are indispensably important in assessing the energy technology.

In fig.2 is shown the production process of polycrystalline silicon solar cells. In order to make accurate assessment of the input energy and the CO_2 emission in production, it is necessary to thoroughly investigate the input materials and to sum up the energy needed for fabrication at each process.

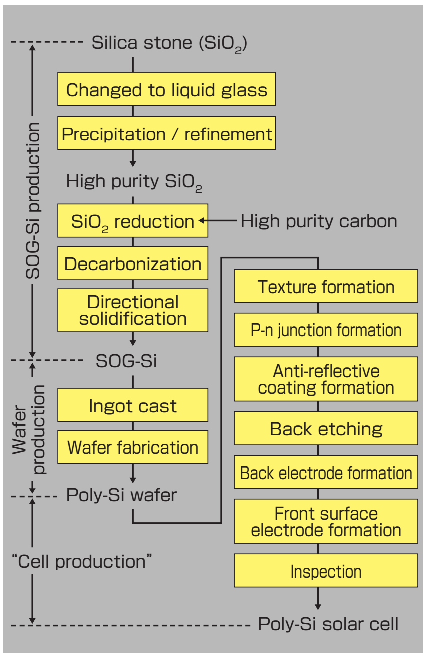


Fig. 2 Production processes of polycrystalline silicon solar cell

The payback time of photovoltaic power generation system is calculated from the ratio of the production energy and CO_2 emission at production of all system components like solar cells, and the annual electricity production and CO_2 reduction. As the former gradually decreases through development of new solar cells, improvement of production technology and expansion of production scale, and the latter increases along with improvement in conversion efficiency and efficient usage of the system, the payback time of photovoltaic power generation system, which is still in the middle of technological innovation, is rapidly shortening year by year. However, as the recent payback time value is not sufficiently known to the public, even now it is sometimes incorrectly stated that the payback time of photovoltaic

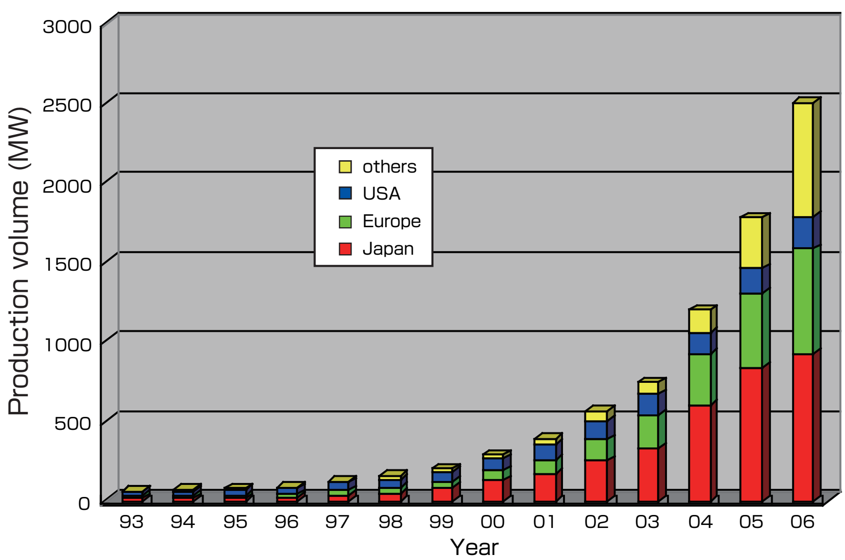


Fig. 1 Progress in world solar cell production

power generation system is more than 10 years based on old data of over ten years ago.

The most recent EPT data published in our country (in the case of residential roof-top installations) states that EPT of polycrystalline silicon is 1.5 year, for amorphous silicon is 1.1 year, for compound thin film (CIS) is 0.9 year and CO_2PTs are 2.4, 1.5 and 1.4 year respectively[2]. Please note, however, that with crystalline silicon, the above calculation was done with the new silicon manufacturing method presently being developed, and if calculated with the current method, the EPT is 2.0 years and CO_2PT is 2.7 years (Fig.2). Similar figures have been reported in Europe and the US. As the life time of solar cells is considered to be at least 20 to 30 years, both the EPT and CO_2PT based on the most recent data is sufficiently short, and a photovoltaic system is a good power generating system from the view point of LCA.

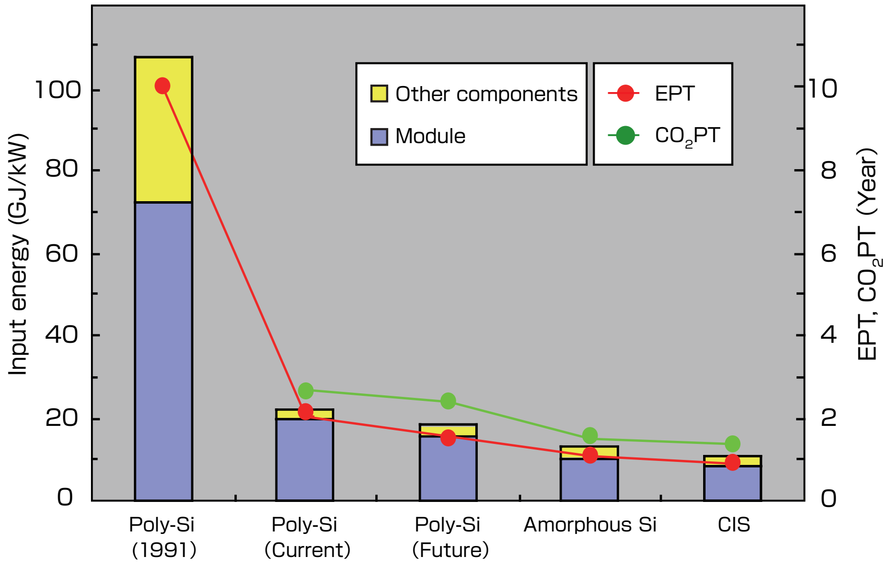


Fig. 3 Input energy for production and payback times of photovoltaic power generation systems
Assumptions:
PolySi (1991): ground installation 1 MW, production capacity = unknown, operational energy = 1 %
Others: residential 3 kW system, production capacity = 100 MW/year, operational energy = neglected
Current data of poly-Si is recalculated based on the document[2]

Toward a sustainable society

In the "New Energy Innovation Plan", which is one of the 4 pillars of the "New National Energy Strategy" made in May 2006 as the basic policy of the energy measures of our country, it is clearly stated that the cost of photovoltaic power generation will aim for a reduction to the level of conventional thermal power generation by 2030. In the long-term road map of research and development concerning photovoltaic power generation (PV2030) made in 2004, it is assumed that by 2030 the cumulative installation will be 100 GW (100 million kW) which will cover 10 % of the total electricity need.

In order to achieve these installation goals, it is indispensable to do research and development for further efficiency improvement of solar cells, cost reduction, and introduction of new system concepts that would allow expansion of application areas and installation sites. It is also important that, with the assessment of environmental effects with LCA introduced here, the latest information is constantly provided by continually investigating the results of new production technology introduction based on advancement in research and development and from expansion of production scale, in order to gain public understanding of photovoltaic power generation as a new energy technology.

Research Center for Photovoltaics
Koichi Sakuta

References
[1] Uchiyama, *et al.* Central Research Institute of Electric Power Industry Research Report Y90015 (1991.1.11)
[2] NEDO Report, "Research Study of Photovoltaic Generation Evaluation", Association of photovoltaic generation technology research, (2001.3)

Life Cycle Assessment (LCA) of Biomass Utilization

What is life cycle assessment (LCA)?

LCA is a method to quantitatively assess the influence of a product to the environment. It is one of the tools that is expected to contribute to establishing an environmentally-friendly society by, for example, inspecting the manufacturing and transport of necessary materials and energy for a product, and checking and assessing its impact on environment through the product's life cycle from production, distribution, consumption, disposal and recycling. Presently its use is spreading mainly in the manufacturing industry and we are at a stage where consumers may use LCA results as one of the factors in decision making.

Application of LCA to biomass utilization

With biomass, it is widely accepted that CO_2 is fixed during the growing period and that CO_2 emitted at combustion is balanced out. Therefore, the utilization of biomass is anticipated to be environment-friendly from the view point of greenhouse gas (GHG) emission control worldwide. There is a need to quantitatively assess it by using LCA and to clarify the necessary efforts for its utilization with even lower impact on the environment.

At Research Center for Life Cycle Assessment of AIST, we have promoted development of a method to locally assess the effective use of one kind of biomass, organic waste (livestock excretion, kitchen refuse, food industry leftovers, construction debris *etc*.), and have developed and made public a method for local optimization called "RCACAO".[1] In collaboration with researchers of Asian countries, LCA assessment of large-scale biomass utilization is being done, and are conducting studies of sustainable biomass utilization. From these results, here is presented an example of LCA assessment of a large-scale plantation.

A case study of bioethanol

Thailand is the fourth largest producer of sugarcane after Brazil, India, and China, and is expected to produce and utilize ethanol in a large scale. We have done trial calculations of GHG emission of sugarcane life cycle, supposing that sugarcane is made into ethanol in Thailand, transported to Japan, upgraded in purity and mixed directly with gasoline.

With this utilization system there are many uncertainties as fluctuation of yield depending on the location and weather, variation of fertilizers, difference of transportation path depending on producing district, difference of generating efficiency using bagasse, the dregs after squeezing the raw material of ethanol. In order to quantitatively grasp these effects, we have made assessment by analyzing or supposing the distribution. We calculated the GHG emission of a life cycle which makes and uses absolute ethanol of 1 MJ. Fig. 1 shows results from using the Monte Carlo method which simulates by repeatedly using random values for uncertain data. According to these results, there is about 44 g to 78 g emission within the 95 % confidence interval. Here is reflected the uncertainty arising from the difference in yield and fertilizer usage, and as a result, there is a wide distribution.

The emission breakdown of the median value is shown in Fig.2, and the emission at the cultivation stage is large. This is due to the large influence of fertilizer production and dinitrogen monoxide (said to have 300 times as much greenhouse effect as CO_2) emissions from fields, as well as fuel consumption of machines used for cultivation. Next, the emission of transportation and dehydration processes is large. The GHG emission reduction effect (shown as negative value in Fig.2) from electric generation using bagasse left from ethanol production is also large, and with the improvement of generating efficiency and ethanol production efficiency, there may be possibilities for further increase in the amount of reduction.

According to our calculations, the GHG emission of 1 MJ gasoline from oil production, transportation, refinement is approximately 70 g/MJ. When comparing the two, even with biomass

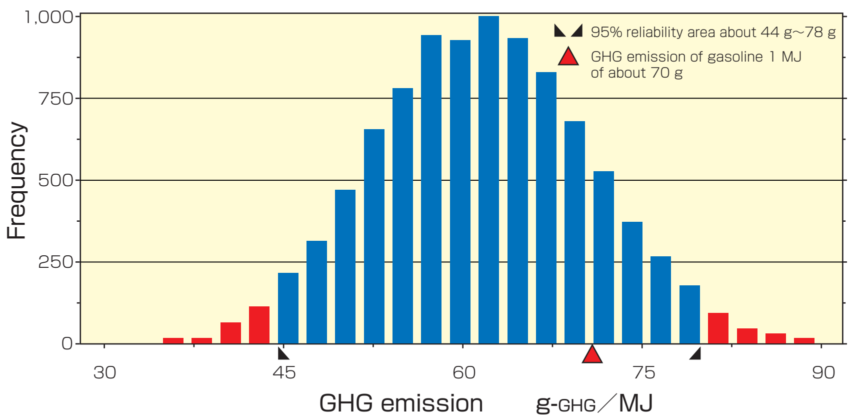


Fig.1 Life cycle GHG emission and emersion frequency of bioethanol

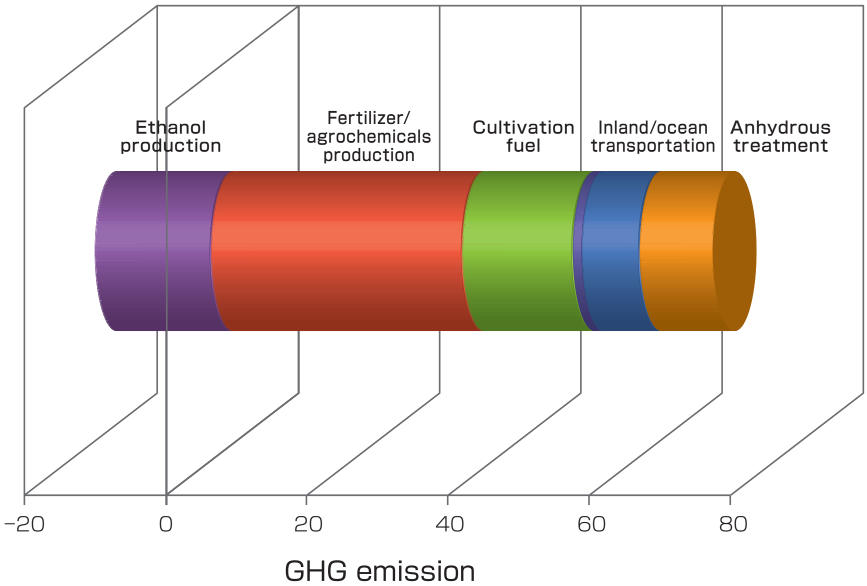


Fig.2 Breakdown of GHG emission

Sugarcane brought into the sugar factory in Thailand

Sugarcane just before harvest

origin ethanol, the GHG emission surpassing that of fossil fuel is suggested to be possible if the cultivating conditions are bad and the utilization efficiency is low.

The direction and future of biomass utilization from the LCA results

With biomass ethanol, GHG emission will be in the decline with the development of more efficient ethanol conversion technology and anhydrous technology, the development of technological and management methods such as appropriate fertilizer control, production management, and ways of consumption. It is, therefore, important that these developments are to be advanced.

Moreover, for the LCA results to be used in decision making, it is necessary to lead to certain conclusions. By collecting and analyzing data on the location where biomass is actually to be made and used, the application process, and the consumption pattern, the emission distribution indicated here can be reduced, and therefore can lead to definite conclusions.

Presently at Research Center for Life Cycle Assessment, we are proceeding with examinations of fertilizer origin GHG emission data, additional uncertainty data of ethanol production process, in order to improve the accuracy of the results. We are also promoting assessment studies to clarify the course for GHG emission reduction by evaluating biodiesel, and by examining combinations of utilization processes and systemization of usage within a district. Furthermore, along with other Asian countries, we are promoting assessment of environmental impact of land use other than GHG emission, and also research that includes social development of biomass producing areas as an assessment factor, and are acting as a leader of this area.

Research Center for Life Cycle Assessment
Masayuki Sagisaka

Reference
[1] Shimizu, Yang, Ihara, Genchi, “Design Method of Intraregional Livestock Excretion Treatment in View of Life Cycle”, Collection of Environmental System Papers., vol.33, pp241-248 (2005)

Assessment of Biomass Utilization System

Biomass (bio resources) utilization is drawing attention as global warming measure and rural vitalization method. We view the whole utilization system in terms of process planning and are doing research and development of economical and environmental assessment technology.

Simplified economy simulation

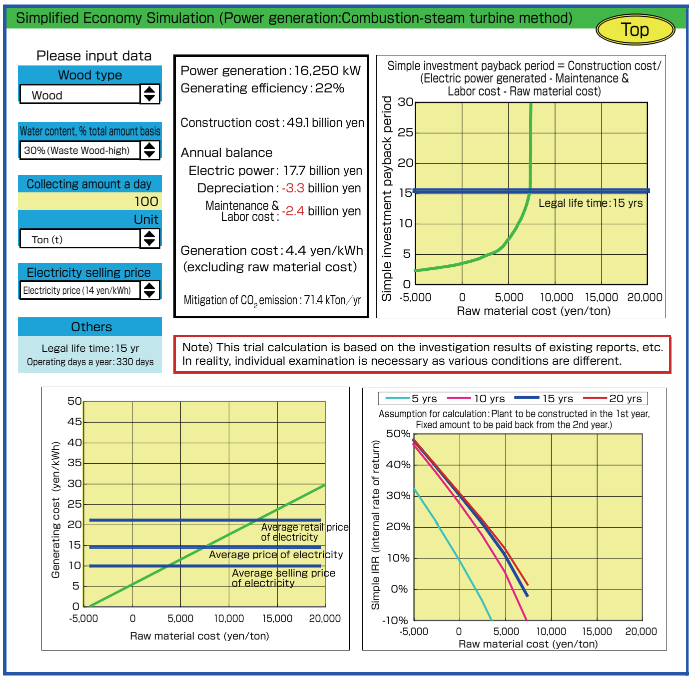
In order to promote popularization of biomass utilization, a supporting technology to simply assess the economy and the environment is needed. Based on biomass database we made separately, we have released on a website a simple economy simulator of three current biomass utilization methods: combustion heat utilization, combustion power utilization, and methane fermentation utilization[1]. The economy is expressed in relation to raw material cost, product price, payback years of investment (construction cost). We have made improvements as adding internal rate of return (IRR) based on comments from users. With this, it is possible to compare possible locations at the introduction of biomass utilization, and to make economy comparison of newly developed technology with current or past technology.

The economy assessment of bioethanol production in Japan

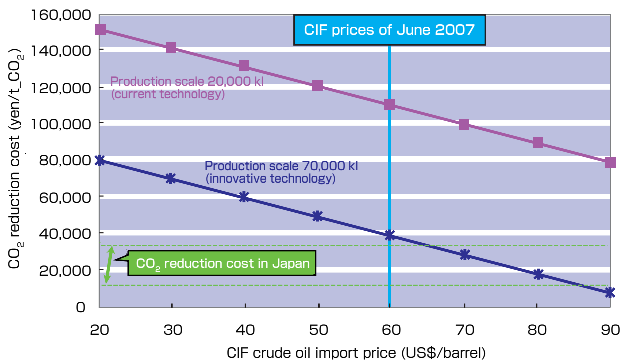
Recently, although ethanol (bioethanol) made from sugarcane and grain (corn, rice *etc.*) is drawing attention as a gasoline substitute, we, at Biomass Technology Research Center of AIST, are predominantly doing research and development of ethanol production from cellulose type biomass as wood and straw, not to compete with food supply. Ethanol made from cellulose is said to be second generation ethanol and research development is making progress all over the world. We have analyzed the production cost and carbon dioxide (CO_2) reduction cost if we produce this second generation ethanol in Japan. In the case where ethanol is produced with biomass collected within a 50 km radius, 20, 000 kl can be produced annually with the present technology, and as a method of CO_2 reduction, it becomes relatively expensive. However, with technological innovation, annual production of 70,000 kl becomes possible, and if the cost of oil exceeds $70/barrel, the cost will be the same as the energy conservation methods as other CO_2 reduction methods.

This report is released as a discussion paper[2] and all comments are welcome.

Biomass Technology Research Center
Tomoaki Minowa



Simplified Economy Simulation on display



Analysis of CO_2 reduction cost of domestically produced cellulose type biomass

Related information (in Japanese)

[1] http://unit.aist.go.jp/btrc/ci/simulation/systemteam_gaiyou

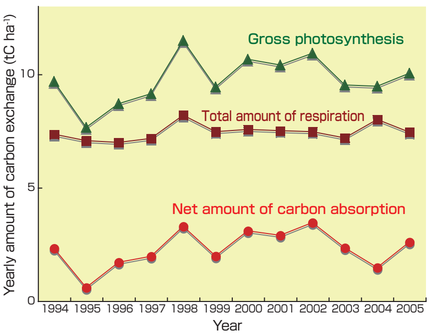
[2] http://unit.aist.go.jp/btrc/ci/research_result/documents/DISCUSSIONPAPER.pdf

Assessment of Forest CO_2 Absorption

CO_2 absorption ability of forests

Forests, when receiving sunlight, absorb carbon dioxide (CO_2) from the atmosphere by photosynthesis. At the same time, CO_2 is continually released into the atmosphere by the activities of microorganisms within the soil and the respiration of plants. The speed of forest CO_2 exchange greatly influences the atmospheric CO_2 concentration as it constantly fluctuates with the influence of weather conditions as amount of sunlight and temperature, and as large amounts of CO_2 is released in a short period of time when there is a disturbance as forest cutting and fire. The technology to accurately measure CO_2 absorption capacity of a changing forest is vital in order for future estimation of atmospheric CO_2 concentration and for a precise estimation of CO_2 emission reduction effect.

Measuring equipment of CO_2 concentration fluctuation



Change over the years of yearly gross photosynthesis of 1 ha deciduous broad-leaved forest observed in Gifu prefecture, total amount of respiration and net amount of carbon absorption (=net photosynthesis − total amount of respiration)

Observation tower in a forest

Observation network of CO_2 absorption capacity in the terrestrial ecosystem of Asia

Presently, there is established a worldwide long-term observation network of CO_2 exchange capacity in terrestrial ecosystem based on micrometeorological technique (calculating method of CO_2 absorption from the fluctuation of atmospheric CO_2 concentration and wind velocity, eddy correlation method), and the Asian network (AsiaFlux) has started its activities in 1999.

Our group, coordinating with other research institutes from home and abroad, has obtained long-term CO_2 absorption of forests in over 10 locations in Asia with eddy correlation method, and has clarified the characteristics of the topographic distribution and the change over the years. As a result, we have found that the net photosynthesis of tropical forests is 2 to 3 times that of Japan, but because the total amount of respiration is large, the net amount of absorption differs greatly by location and condition. We also found that over evergreen forests in Japan absorb 3~5 t of carbon per ha every year, and the larch forests which grow at mid to high latitudes show significantly high absorption speed only in the short summer periods.

The spread of CO_2 absorption measurement technology to Asia

Eddy correlation method requires technology in sophisticated meteorological observation and in large amounts of data processing. Therefore, in Asia, personnel training of these technologies are only done in certain research institutions of Japan and Korea. With this in mind, our group having experience so far in improving CO_2 absorption assessment technology in various ecosystems, is engaged in spreading the technology in Asian countries by organizing training courses every year.

These educational and diffusion activities of observation technology not only promote accumulation of organized observation data of CO_2 absorption in Asia and the improvement of data quality, but also are expected to contribute to strengthening coalition amongst Asian researchers and policy makers.

Research Institute for Environmental Management Technology
Nobuko Saigusa

GLOBAL WARMING – Mitigation Technology and its Assessment

Edited by
Research Coordinator for Environment & Energy Masayuki Kamimoto
Research Institute for Environmental Management Technology Masahiro Suzumura
Research and Innovation Promotion Office Taizo Sano

AIST NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

Publication Office, Public Relations Department, AIST
AIST Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8568, JAPAN
Tel:+81-29-862-6217 Fax:+81-29-862-6212 E-mail:prpub@m.aist.go.jp http://www.aist.go.jp/

The articles in this pamphlet were originally published in Japanese as the feature articles in the 2008-1 issue of AIST TODAY.
Printed in June 2008

PRINTED WITH SOY INK