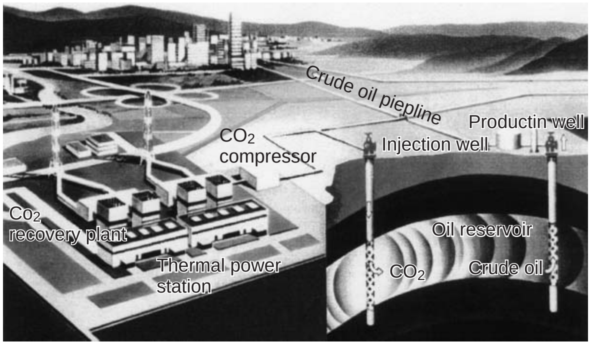

A View of Oil Resources and the Mitigation of CO_2 Emissions

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1. Introduction

While global warming is now attracting ever-greater attention in Japan, the instability of energy supplies, particularly oil, and the sudden increase in the price of natural gas in the US have become major concerns globally. This study gives a brief overview of global warming problems, energy problems closely related to global warming problems, particularly oil resources concerns, and the trends and measures being taken for both problems in the world. It concludes with a summary of what must be done in Japan.

2. Energy problems now and in the future

In the US, interest in energy has become extremely high due to major increases in the cost of gasoline and natural gas recently in that country. In Japan, however, though global warming problems are reported on by various mass media, there is very limited if any coverage given to energy problems. This difference in feeling between Japan and the U.S. may be attributable to the fact that Japan has always relied upon imports from foreign countries for almost all its energy resources such as oil and gas. The U.S., on the other hand, must now purchase greater supplies of energy resources from other countries as supplies that were once plentiful in the U.S. are now in short supply.

In recent years, the shortage of supply of oil and natural gas has been discussed in many aspects. It can be said to have first begun with a pronouncement in a paper by Dr. C.J. Campbell of Ireland stating that the production of oil would soon peak after which it will decrease never to recover to present levels. In recent years, Dr. Campbell organized an association known as ASPO (the Association for the Study of Peak Oil), arranged data on various oil fields in different countries around the world, and has offered several predictions regarding the production of oil in the future. Recently, the Oil and Gas Journal took up this problem last year, and discussion on it has been gaining greater interest ever since.

In the US, the cost of natural gas has rapidly risen during these last two to three years. In some cases, its cost has become higher than the cost of LNG purchased in Japan. In short, the US has really become a country where oil and natural gas are in short supply.

According to predictions by Dr. Campbell, the production of oil will peak around the year 2010 and then decrease, and the production of natural gas will also peak around 2020. **Figure 1** shows the amount of oil supply estimated by Dr. C. J. Campbell et al. It indicates that the amount of oil supply will decrease gradually from a peak in 2010. **Figure 2** shows the total of the amount of oil supply and the oil-equivalent amount of natural gas. It indicates that the total amounts of oil and natural gas supply will decrease gradually from a peak around 2015.

Dr. Campbell et al cited the following points as grounds for this decrease.

(1) Since the development of exploration technology, most major oil fields in the world have already been discovered and the number of untapped oil fields yet to be discovered in the future is small.

(2) Since 1981, the consumption of oil has exceeded the amount of oil discovered (oil reserves), i.e., discovered oil is assumed to be consumed before it is drilled.

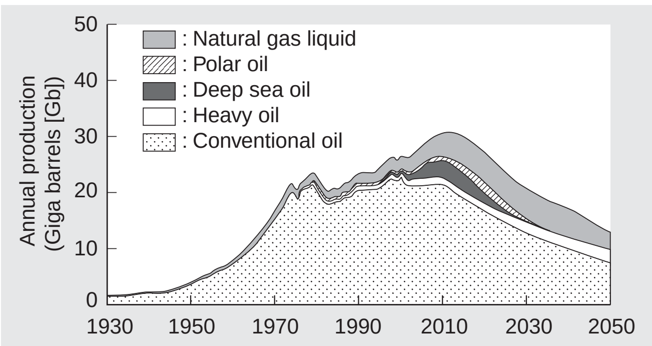

Fig. 1 Past and future estimated production of oil in the world (1)

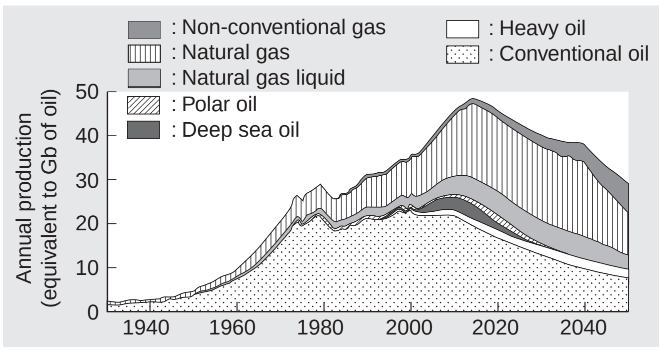

Fig. 2 Past and future estimated production of oil and natural gas in the world (1) (Natural gas is equivalent to10TCF=1Gb)

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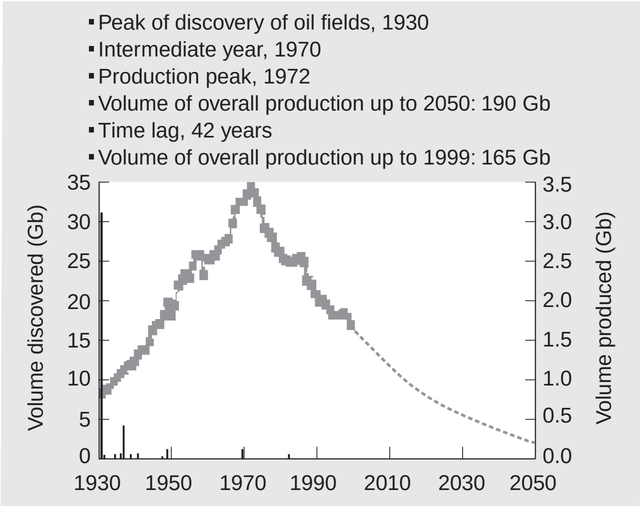

Fig. 3 Past and future estimated production of oil in the U.S. excluding Alaska [(2)]

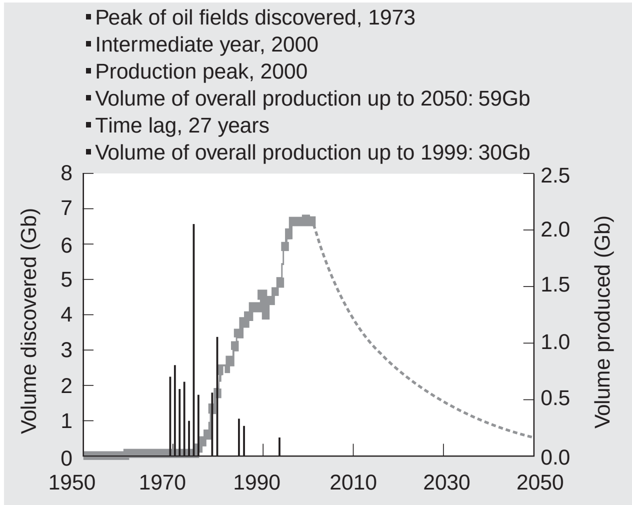

Fig. 4 Past and future estimated production of oil in the North Sea oil field [(2)]

(3) Once the peak has been passed, the production of oil will never recover the same level. A typical example of this situation is shown in **Fig. 3**, which shows the pattern of oil production in the U.S. mainland excluding Alaska.
(4) The production of oil in the North Sea oil field is currently at its peak. It will decrease markedly in the future and, by 2010, will have decreased to 40% of present production levels (**Fig. 4**).
(5) The production of natural gas will also peak around 2020.

Since the predictions of Dr. C. J. Campbell have been established based on the analysis of data from 50 000 oil fields around the world, there is a great deal of credibility attached to many of his predictions.

Considering the peak theory for the production of oil and natural gas, it is thought that coal will become more important in the future. Whereas, when considered from the perspective of global warming, more stringent and effective measures against CO_2 are essential since coal most produces the greatest amount of CO_2 per calorie amongst all fossil fuels.

3. Mitigation of CO_2 Emissions

Consideration is given here to a number of measures against CO_2 as measures against global warming. These include the following measures for reducing CO_2:

- conservation and economy of use,
- energy-saving, increase in efficiency,
- conversion to energy with lower carbon content (oil, coal → natural gas),
- Convert from fossil fuel based energy to nuclear power,
- expansion of utilization of natural energy,
- recovery and disposal (storage) of CO_2, and
- expansion of CO_2 absorbing sources such as forests.

It should be noted that hydrogen is not a primary source of energy but is a secondary energy source, like electricity, and that CO_2 cannot be reduced merely through the use of hydrogen.

An important point about the above methods for reducing CO_2 is that the recovery and storage of CO_2 has been attracting much attention recently. This interest in the recovery and storage of CO_2 began in the year 2000, when International Energy Agency (IEA) stated that under the present circumstances, it will be difficult to take suitably effective measures against global warming unless measures for CO_2 are taken that rely upon the recovery and storage of CO_2 in terms of the amount and cost of the measures.

European countries which is thinking of abolishing nuclear power and the U.S., where new site selection is no longer performed, consider that CO_2 cannot be reduced through the use of natural energy and energy-saving measures as measures against CO_2. In addition, the US cannot easily convert from oil to natural gas because the cost of natural gas is rising quickly in the U.S.

Since the Europe and U.S. are continental land masses, there are numerous thick sedimentary layers distributed underground and sufficient aquifers are present that can serve as underground storage places for CO_2. In addition, it has been pointed out that the cost for CO_2 recovery from flue gas is far lower less than the use of new energy or certain energy saving measures. Accordingly, during these three to four years, a good opportunity has swiftly arisen for the adoption of recovery and storage of CO_2 as a measure against CO_2. This is evidenced by the number of papers presented at the CHGT-6 (Green House Gas Control Technology-6) conference held in Kyoto, in October 2002. The number of papers on the recovery and storage of CO_2 amounted to 75% of all papers presented, and the number of papers on the underground storage of CO_2 comprised 50%.

The reason why the CO_2 recovery and storage have been attracting such attention and have come to be promoted is that major oil producers and OPEC understand that such measures match their profits and have thus started to make overtures to their respective government agencies. As an example, oil companies excluding Exxon Mobile among the

Majors have established an organization called the CO_2 Capture Project (CCP) which promotes research and development activities aimed at establishing storage technologies and reducing costs. Exxon Mobil established another organization in cooperation with Toyota and GE utilizing the functions of Stanford University different from the CCP.

The CCP aims at recovering CO_2 emitted from the stacks of power generation plants etc. and injecting it into the ground. When the point of injection is located in an oil field, the recovery rate of oil can be increased, and when it is located in coal seams, coal seam methane can be recovered. When such injection points are not located nearby, the CO_2 is disposed in an underground aquifer.

In November 2002, Intergovernmental Panel on Climate Change (IPCC) began to prepare a special report on the recovery and storage of CO_2 aimed at qualifying the recovery and disposal of CO_2 as a measure against global warming in 2005. The authors also participated in the preparation of this special report. Since the representatives of the countries involved mostly come from major oil companies and OPEC in the private sector and exclude government agencies and research organizations, it can be understood who promotes the recovery and storage of CO_2.

When CO_2 is recovered as a measure against global warming, the position from which CO_2 is recovered must be determined. It is very difficult to recover it from a moving vehicle such as a car, and to recover it from families and offices where small amounts of CO_2 are emitted since the recovery cost per ton of CO_2 is high. Accordingly, power generation plants and large-scale plants need to be targeted for the recovery of CO_2. Though accurate numerical values are not determined, the amount of CO_2 discharged from power generation plants and large-scale plants is said to comprise approximately 60% of the total amount of CO_2 discharged.

On the other hand, approximately 98 to 99% of the CO_2 discharged into the atmosphere is discharged from the stacks of such plants in the form of flue gas produced by the combustion of oil, gas, and coal. Considering the recovery of CO_2 as a measure against global warming, CO_2 must be recovered from these combustion flue gases.

The properties of combustion flue gases are generally characterized by the following points:

- Atmosphere
- Concentration of CO_2: 3 to 15 vol.%
- Inclusion of oxygen, SOx, NOx, and soot and dust

In the recovery of CO_2, it becomes necessary to recover a large amount of CO_2 at low cost.

The following methods for utilizing and storing CO_2 as a measure against global warming are now under examination.

(1) Methods for using CO_2
  (a) Chemical use
   - Urea
   - Methanol
   - Dimethyl ether (DME)
   - Gas to Liquid (GTL)
   - Soda ash
  (b) Enhanced Oil Recovery (EOR) method
  (c) Coal seam methane recovery method
  (d) Biological use

(2) CO_2 storage method
  (a) Underground disposal
   - Aquifers
   - Waste oil fields, gas fields
   - Coal seams
  (b) Ocean disposal

Among these CO_2 utilization and storage methods, it is the EOR method that can store and effectively use a large amount of CO_2.

Figure 5 shows the concept of a method in which CO_2 is recovered from flue gases emitted from power generation plants, which is then compressed and injected into an adjacent oil field to increase the recovery rate of oil and to store the CO_2 in the oil layers.

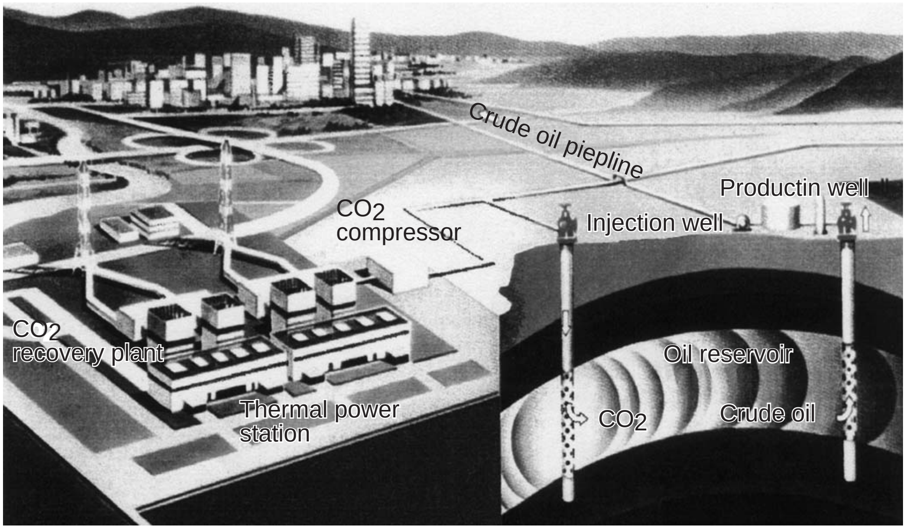

Fig. 5 Concept of system for recovering CO_2 from power plant flue gas and storing CO_2 in oil reservoir by using EOR

The CO_2 is brought into a miscible condition in which it is freely mixed with oil under high pressure to remarkably lower the viscosity of the oil, increase the flowability of the oil in the oil layers, and to markedly increase the recovery rate of the oil. This method has been adopted mainly in the Western portion of Texas in the U.S. to contribute to the production of oil. At present, however, CO_2 is produced in a nearby gas field where only CO_2 is produced and supplied to oil fields through pipelines. Accordingly, CO_2 is not reduced by this method. However, as shown in Fig. 5, it is a method of killing two birds with one stone to recover CO_2 discharged into the atmosphere and inject it into an oil field that can be taken as a measure against global warming and increase the recovery rate of oil.

In this method, however, since there are hardly any oil fields near the sources where CO_2 is discharged in advanced countries such as Japan, U.S., and Europe, CO_2 must be transported at low cost to the oil fields in order for this method to play an important role for a measure against global warming.

Figure 6 shows an example of an experiment on the disposal of CO_2 in coal seams and the recovery of methane. Methane gas is adsorbed in the coal seams, and in recent years, it is being recovered for utilization. It is, however, difficult to mine coal from deep coal seams. Instead, the methane gas adsorbed in the coal seams is attracting attention as an energy resource. Since coal adsorbs methane gas well, the methane gas cannot be sufficiently recovered from the coal.

When CO_2 is injected into the coal seams, methane gas is expelled since CO_2 tends to be adsorbed more into coal than methane gas. As a result, CO_2 can be disposed in the coal seams and the recovery of methane can be improved. Coal seams are more widely distributed than oil fields, and considered to be more effectively used for the storage of CO_2 than by the EOR method. This method may become an actuality in the future due to the soaring costs of natural gas.

Figure 7 shows the concept of the aquifer disposal of CO_2 which is already performed in Norway. The Sleipner gas field is located in the Norway-owned portion of the North Sea, and natural gas produced from this gas field contains 9 vol.% CO_2. When the natural gas is sold via pipeline, the CO_2 contained in the natural gas must be reduced to less than 1.5 vol.%. Accordingly, the CO_2 is separated from the high-pressure natural gas that is produced. In Norway, a high CO_2 tax of US$50 per ton has been imposed since the beginning of the 1990s. As a result, the CO_2 separated from the natural gas is compressed and stored in aquifers approximately 1 000 meters below ground. This project was the world's first project in which CO_2 is stored full-scale under the ground. About one million tons of CO_2 has been stored per year since 1996.

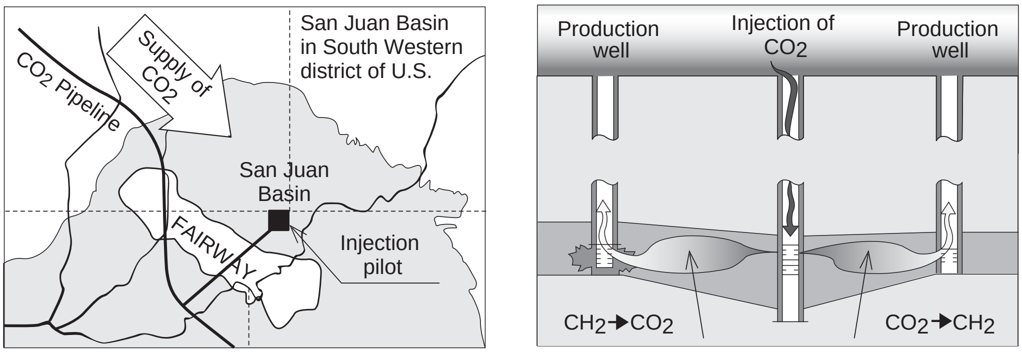

Fig. 6 Concept of experiments regarding the storage of CO_2 in coal seams and the recovery of methane[3]

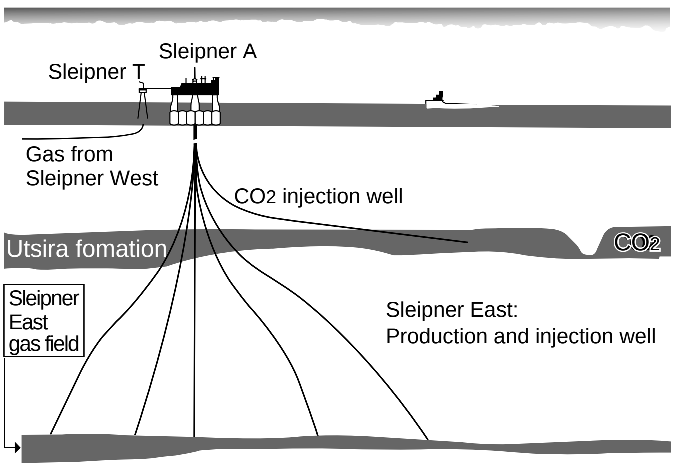

Fig. 7 Concept of storage of CO_2 in aquifers in Norway[4]

4. Chemical absorption based CO_2 recovery technology

CO_2 recovery from high-pressure natural gas and synthesis gas has been widely performed, and a large number of technologies have been put into practical use. CO_2 recovery from flue gas has not been performed so much because of the following reasons: (1) its use was limited to a very small part (such as foods in those areas where CO_2 is absent), and (2) its recovery has been technically difficult because flue gas is not pressurized and contains oxygen as well as SOx and NOx.

The technology which has been used for CO_2 recovery from flue gas uses monoethanolamine (MEA) which is said to be the most basic amine. At present, the technology is owned by Fluor Daniel Inc. and ABB Lummus Crest Inc. of the U.S. The technology has a number of shortcomings in which a large amount of energy is consumed during CO_2 recovery and there is a significant loss of absorbent in the recovery process. Mitsubishi Heavy Industries, Ltd. (MHI) has made extensive efforts to develop a new CO_2 recovery technology jointly with the Kansai Electric Power Co., Inc. Development of this new technology has been completed and already commercialized which is capable of remarkably lowering the amount of energy used to recover CO_2, remarkably reducing the loss of absorbent, and recovering CO_2 at a lower cost than existing technology based on the use of monoethanolamine.

Figure 8 shows a history of the development of technologies to recover CO_2 from flue gas. Japan first began to develop technologies for recovering CO_2 during the beginning of 1990s before anybody else in the world. As noted before, the development of technologies for recovering CO_2 from flue gas was also begun in Europe and the U.S. around the year 2000 as a measure against global warming.

The CO_2 recovery systems include the systems listed below. Among them, only the flue gas chemical absorption method is currently put into practical use. It is considered to be effective in increasing capacity while reducing costs.

(1) Recovery from flue gas
  (a) Chemical absorption method
  (b) Adsorption method
  (c) Membrane/chemical absorption method
(2) Recovery before combustion
  (a) Reforming of natural gas/separation of CO_2
  (b) Coal gasification/separation of CO_2
(3) Oxygen combustion

Fossil fuel is burned in power generation plants in order to generate high temperature and high pressure steam so as to rotate steam turbines for the generation of electric power. In general, the amount of energy contributing to power generation is 50% or less, and 50% or more of the energy is lost when the steam is condensed, and heat due to the lost energy is discarded into seas and rivers. When CO_2 is recovered using the chemical absorption method, most of the energy required may consist of low temperature heat. Accordingly, the heat discarded when the steam is condensed in a power generating system can be well utilized to recover CO_2 with less overall energy loss.

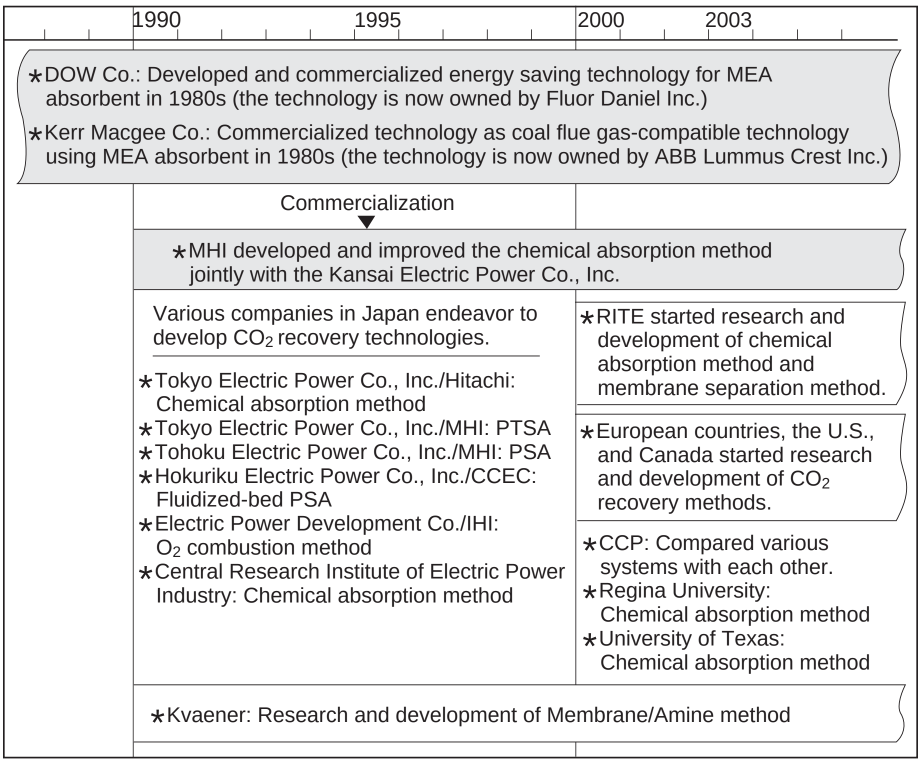

Fig. 8 History of development of CO_2 recovery technologies

Figure 9 shows that the energy discarded in a condenser can be well utilized when the energy of a boiler utilizing heat energy based on the chemical absorption method is obtained in the power generation system.

Figure 10 shows a plant that has been in operation since 1999 which recovers CO_2 from flue gas using the technology developed in the joint project of MHI and the Kansai Electric Power Co., Inc. for utilization in the production of urea.

CO_2 is needs to be recovered at minimum cost, and the chemical absorption method can increase recovery capacity. MHI has completed the trial-design of a plant with a capacity of 3 000 t/d (**Fig. 11**) so that the CO_2 recovery cost can be remarkably reduced by an increase in capacity. MHI examined the reduction in CO_2 recovery cost and an increase in capacity as a measure against global warming, and found that the currently operating maximum power generation plant was a coal-fired boiler plant of one million kilowatts which requires a CO_2 recovery rate of 18 000 t/d, and that an increase in capacity must be further pursued in the future.

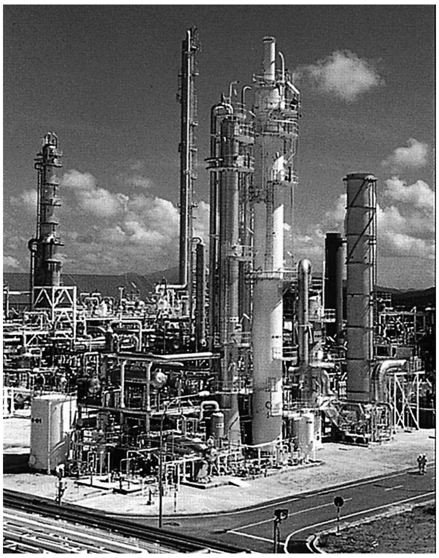

Fig. 10 CO_2 recovery plant for urea processing delivered by MHI

5. Trends in CO_2 EOR and CO_2 disposal projects in various countries

Much progress is being made in the effective use of CO_2 as well as in various storage projects in many parts of the world in addition to the CO_2 storage project in Norway mentioned earlier. **Figure 12** shows the CO_2 EOR project in the Wayburn oil field of Canada. The source of CO_2 is the off-gas of the coal gasification plant in North Dakota in the U.S. The CO_2 is fed to the Wayburn oil field in Saskatchewan of Canada via pipelines and is injected into oil reservoir as part of the EOR method. In this project, 5,000 t/d of CO_2 was first injected into oil reservoir during the fall of 2001, and it was confirmed that, in summer 2002, the production of oil was increased by 5 400 bbl/d.

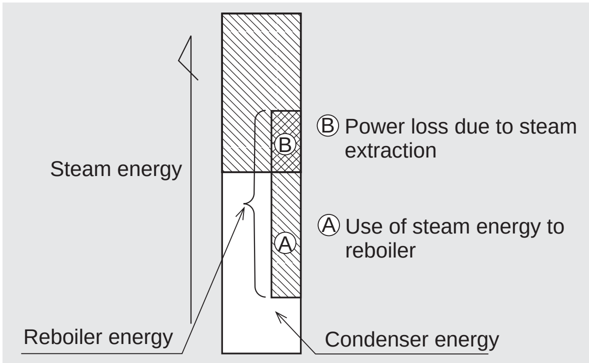

Fig. 9 Effective use of steam energy in power generation plants and CO_2 recovery plants.

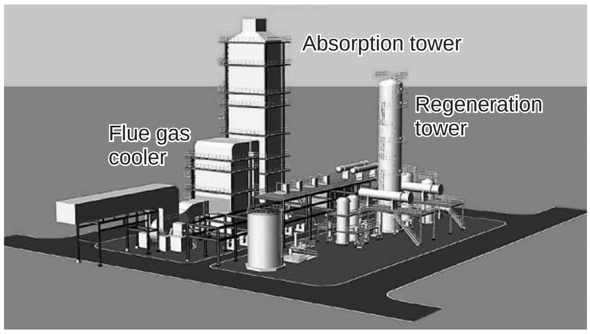

Fig. 11 Birds-eye view of 3 000 t/d plant

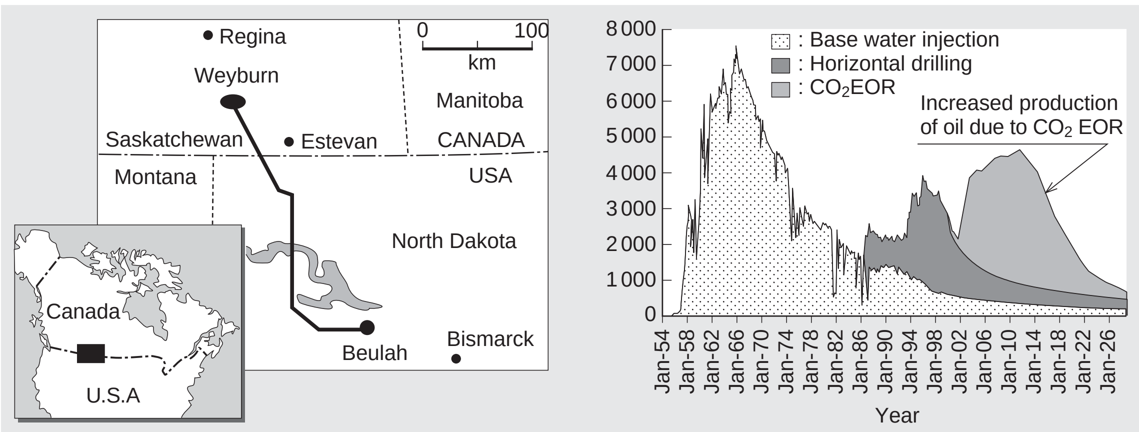

Fig. 12 CO_2 EOR project in Weyburn, Canada [5]

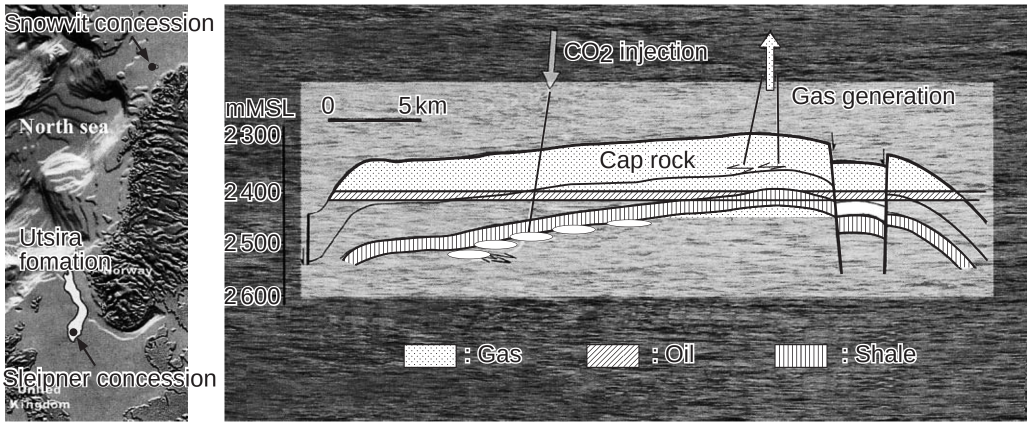

Fig. 13 CO_2 underground storage plan in Norway Snowvit LNG Project[(6)]
CO_2 is stored in the lower layers of the natural gas layers. The cost of CO_2 injection is US$100 million more than the cost of CO_2 discharge into the atmosphere.

Figure 13 shows the project for producing natural gas from the Snowvit gas field in the Sea of Norway located in the north of Norway in which the gas is delivered in the form of LNG. Since the natural gas contains CO_2, the CO_2 is separated from the natural gas and is stored in aquifers 2 500 meters underground. At present, the construction of an LNG plant has been started. The operation of the plant is scheduled to begin in 2006 with a CO_2 aquifer injection amount of 700 000 t/year.

6. Solution for global warming and energy problems

As noted in section 2, the energy problem expected to occur in the future is the shortage of oil and followed by the shortage of natural gas. It is anticipated that the rate of reliance on coal will increase from around the year 2020. Since oil is liquid, it is easiest to handle. Natural gas is the next most difficult to handle followed by coal, which is the most difficult fossil fuel to handle, respectively. As for currently completed systems, automotive vehicles already use liquid fuel, and liquid fuel is expected to be produced from natural gas as well as coal in the near future.

When the amount of coal utilized increases in the future, it is natural that the amount of CO_2 discharged will also increase. In addition, in the course of synthesizing liquid fuel or DME by gasifying coal, a large volume of CO_2 is produced. To address this problem, it is necessary to recover and store CO_2.

The CO_2 EOR can kill two birds with one stone, that is, it can cope with the shortage of oil while also reduce the discharge of CO_2. First, the method must become more widespread, and then coal gasification GTL and DME must be put into practical use as early as practicable.

Major means that can be effective in addressing the problems of global warming and energy resources can be summarized as follows:
(1) recovery and storage of CO_2,
(2) CO_2 EOR, and
(3) coal gasification GTL and DME.

Naturally, the above measures are mainly centered on the use of fossil fuel. Therefore, it is felt that not only expansion of the safe use of nuclear power, energy conservation, and an increase in efficiency but also the economy of use of fuel will become more important factors, as well.

7. Conclusion

Japan relies on 99% of its oil, natural gas, and coal on imports from overseas. It cannot help but be said that such a structure is very weak from the perspective of not only energy security but also economy.

In the future environment where the supply of oil and natural gas is considered to be insecure, CO_2 EOR is a technology that not only can produce and utilize oil resources maximally but can also contribute very significantly to controlling the discharge of CO_2. Moreover, LNG, GTL, and DME plants produce a large amount of CO_2 and, therefore, it is effective to control the emission of CO_2 in order to eliminate the emission of CO_2 from these plants.

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