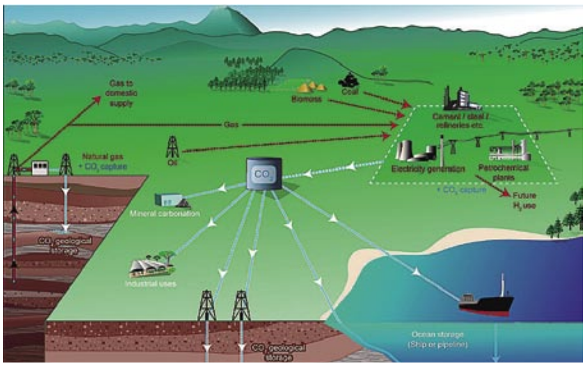

Overview of CO_2 Capture and Storage Technology; An Introduction of MHI's CO_2 Recovery Process

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Climate change is one of the most significant issues facing humanity and the global society needs to deploy immediate countermeasures against the threat posed by global warming. Yet with the current global energy structure, there are no viable energy alternatives to fossil fuels. Thus, CO_2 capture and storage (CCS) is considered as a critical and indispensable countermeasure to reduce the potentially catastrophic environmental impacts associated with this phenomenon. To improve the economic viability of CO_2 capture, power producers will need to help facilitate the practical deployment of CO_2 capture from coal-fired power plants and thus reduce the CO_2 capture cost. Mitsubishi Heavy Industries, Ltd. (MHI) has realized the significant and important role of CO_2 capture technology and is continuing research and development of effective countermeasure technologies against global warming.

1. Outline of CO_2 capture and storage

(1) Extensive climatic simulations of global warming predict a geometric increase in the number of natural disasters attributed to an average temperature rise of 2°C or more. The average global air temperature is expected to rise by 2°C if the CO_2 concentration in the air rises from its current level of 375 ppm to 450 - 475 ppm.

According to the "Special Report on Carbon Dioxide Capture and Storage"[1] produced by the IPCC (Intergovernmental Panel on Climate Change), CO_2 emissions from fossil fuel cannot effectively be reduced without CCS from stationary sources. Some 13.5 billion tons of CO_2 per year, about 60% of worldwide emissions, is generated from stationary sources (excluding those sources which produce less than 100,000 tons per year). Some 78% of the CO_2 emission from stationary sources is generated from thermal power generation facilities, and 60% of this figure originates from coal-fired power plants. Coal reserves are widely distributed and source locations are abundant. Furthermore coal is significantly cheaper than oil and natural gas. For these reasons, the quantity of coal consumed for power generation is expected to increase further, conversely with CO_2 emissions.

(2) Large amounts of energy are required for CO_2 capture and storage. The energy required for CO_2 capture and storage is highest for coal-fired power plants, due to the large CO_2 emission per kW of generated power and one of the most important challenge will be to further reduce this additional energy.

(3) Underground, geological storage of CO_2 is seen as an important means of reducing atmospheric CO_2 concentrations well into the future. The values described in **Table 1** show the potential for underground of CO_2 according to the "Special Report on Carbon Dioxide

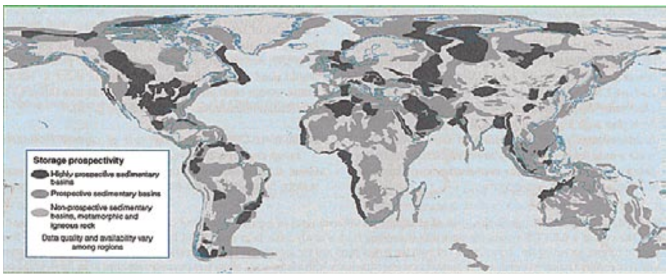

Fig. 1 Areas with potential for CO_2 underground storage

Table 1 Potential amount of underground CO_2 storage

Storage geological formations	Low CO_2 storage potential ($GtCO_2$)	High CO_2 storage potential ($GtCO_2$)
Oil and gas fields	675*	900*
Coal bed that cannot be excavated	3 - 15	200
Deep saline water aquifer	1000	10^4

Note * If a new oil and gas field is found, this value is expected to increase by 25%.

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Capture and Storage" published by the IPCC. The CO_2 emitted from stationary sources can be captured and stored for an additional 100 years, or longer, if deep saline aquifers are included in this assessment. If we consider the geographical pairing between the CO_2 emission source and storage location, aquifers in Europe and America can serve as sufficient, long term, sites for CO_2 storage (see **Fig. 1**). Japan, however, has limited storage potential due to the geological instability of the region. The experience with CO_2 capture and storage is now expanding with several commercial scale CCS projects underway. These include; Sleipner (Norway), Snohvit (Norway), In Salah (Algeria) and Weyburn (Canada).

2. Why aren't CO_2 capture and storage projects widely implemented?

As mentioned above, there are a few commercial scale CCS projects currently operating but the widespread global implementation of CCS faces several hurdles.

The CCS projects now underway seek to reduce current CO_2 emissions or to reduce future emissions. Most of these projects operate at relatively low cost. Some have been established through the provision of incentives or disincentives, such as the CO_2 tax in Norway, the use of recovered CO_2 for EOR (Enhanced Oil Recovery) in Weyburn (Canada), and so on.

To implement CO_2 capture and storage on a wide scale in the future, two issues must first be resolved.

(1) Burden of cost of CO_2 capture and storage

To implement CO_2 capture and storage as a countermeasure against global warming, incentive based mechanisms such as CO_2 emission trading and funding/subsidy instruments by central government are required.

(2) Improved knowledge of business circumstances such as storage potential surveys, further definition and regulatory certainty relating to relevant laws and ordinances, international rules, and social acceptance of CCS.

In the United States, a partnership in seven districts funded with grants from the DOE (Department of Energy) has led to the commencement of CO_2-injection experiments at a range of sites. More incentives, such as these, to promote the CO_2 capture and storage concept will be necessary in the future. Currently the revenue generating activity of EOR is expected to facilitate some early stage opportunities for CCS in key oil producing regions. Therefore, MHI has deployed a business model strategy focusing on CO_2 EOR opportunities. The following items have been identified as key areas of focus to enhance the feasibility of CO_2 capture, and MHI is further promoting research and development in these areas.

- Reduced CO_2 capture/compression energy
- Commercialization of CO_2 capture from coal-fired thermal power generation plants
- Economy of scale owing with large-capacity CO_2 capture

3. MHI's CO_2 capture technology

(1) Experiences of MHI

MHI has already delivered four commercial plants to recover CO_2 from flue gas in the chemical and fertilizer industries, with another four plants on the drawing board (3 of which are currently under construction). **Figure 2** shows a CO_2 recovery plant for a urea production facility with a CO_2 recovery capacity of 200 tonnes/day, delivered in 1999 in Malaysia. **Figure 3** shows a general-use (dry ice, beverage carbonation, welding, etc.) CO_2 recovery plant with a capacity of 330 tonnes/day, delivered in 2005

Fig. 2 Malaysia CO_2 recovery plant for urea production facility

Fig. 3 Japan CO_2 recovery plant for general use

Fig. 4 India CO_2 recovery plant for urea production

Fig. 6 Japan CO_2 recovery demonstration plant at a coal-fired power plant

Fig. 5 India CO_2 recovery plant for urea production

in Japan. **Figures 4 and 5** show CO_2 recovery plants used at urea production facilities with a capacity of 450 tonnes/day, delivered in 2006 at two separate locations in India.

(2) Strategies to reduce CO_2 capture energy

MHI began researching and developing CO_2 capture technology from the flue gas of power plants in 1990. This was undertaken jointly together with Kansai Electric Power Co., Inc. As a result of this extensive R&D, MHI has developed many proprietary items including; an energy saving absorption solution (KS-1), an energy-saving regeneration system for practical use, and a system for the optimal integration of steam between a power-generation facility and a CO_2 capture facility.

(3) CO_2 capture from coal-fired power plants

MHI has already gained considerable experience in CO_2 capture from natural gas-fired boilers. Yet the more urgent challenge today, with the advent of global warming, will be CO_2 capture from coal-fired power plants, the largest source of global CO_2 emissions. It is expected that CO_2 capture systems will be crucial in areas such as Europe and the US.

MHI responded to this challenge in 2000 by constructing and testing a CO_2 capture pilot plant with a capacity of 1 tonne/day from coal-fired flue gas at its Hiroshima Research and Development Center. Furthermore with grant funding (50% of project cost) from the Research Institute of Innovative Technology for the Earth (RITE) and cooperation from the Electric Power Development Co., Ltd., MHI constructed a demonstration plant of 10 tonnes/day at the Matsushima Power Plant of Electric Power Development Co., Ltd. The plant was constructed in 2004 and commenced demonstration testing in 2006 (**Fig. 6**). The plant successfully completed stable operation for over 4,000 hours and proved that MHI's CO_2 recovery process can be successfully applied to a coal-fired power plant.

(4) Approach for large capacity CCS implementation

The CO_2 recovery plants that MHI has already delivered for the chemical and fertilizer industries range in capacity between 200 - 450 tonnes/day. If CO_2 is captured for EOR all the flue gas from the boiler and/or gas turbines of the power plants must be treated. To capture CO_2 from a 1000 MW coal-fired power plant, for example, a large-capacity, multi-train CO_2 recovery plant of 17,000 tonnes/day will be required.

MHI has already standardized a CO_2 recovery plant of 3,000 tonnes/day and completed basic design. Further, MHI is working to realize a large-capacity plant on a scale of 5,000 - 6,000 tonnes/day.

4. Conclusion

It is not possible, with the global energy structure, to rely significantly on non-fossil fuels for energy in the foreseeable future. Thus, countermeasures for the current and future fossil fuel power generation fleet, against global warming are required urgently throughout the world. CO_2 capture and storage systems are therefore indispensable. To promote widespread, viable CO_2 capture and storage in the power generation industry, operators will need to reduce the energy required for CO_2 capture, develop economically viable commercial technologies to capture CO_2 emitted by coal-fired power plants, and aim to further reduce the CO_2 capture cost. MHI continues its efforts on a range of research and development initiatives technologies to meet these needs and develop countermeasures against global warming, to ultimately ensure humanity has a sustainable future.

Reference

1. Published 2005, IPCC Special Report on Carbon Dioxide Capture and Storage

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