

Underground storage of carbon dioxide in depleted natural gas reservoirs and in useless aquifers

Hitoshi Koide^a, Yoshiyuki Tazaki^b, Yoshikazu Noguchi^c, Masaki Iijima^d, Kazuitsu Ito^d and Yuji Shindo^e

^aGeological Survey of Japan, Tsukuba, 305 Japan

^bKanto Natural Gas Dev. Co., Mobara Japan

^cElectric Power Dev. Co., Ginza, Japan

^dMitsubishi Heavy Ind. Ltd., Japan

^eNational Chemical Laboratory for Industry, Tsukuba, 305 Japan

(Revised version accepted December 14, 1992)

ABSTRACT

Koide, H., Tazaki, Y., Noguchi, Y., Iijima, M., Ito, K. and Y. Shindo, 1993. Underground storage of carbon dioxide in depleted natural gas reservoirs and in useless aquifers. In: M. Arnould, T. Furuichi and H. Koide (Editors), Management of Hazardous and Radioactive Waste Disposal Sites. *Eng. Geol.*, 34: 175–179.

Depleted reservoirs of natural gas and petroleum can provide excellent traps for carbon dioxide. Deep aquifers, which are not used due to high salinity, can host larger amount of carbon dioxide under their high formation pressure than natural gas and oil reservoirs. Small fractions of aquifers in sedimentary basins in the world are enough to host about 87 gigaton-C of carbon dioxide.

A preliminary technical and economical survey on the carbon dioxide injection system suggests that the energy requirement for carbon dioxide injection into subterranean aquifers is about 269 kWh/ton-C and that the investment and operation costs for the system are 79 \$/ton-C. By our preliminary cost estimation in Japan, the CO₂-emission-free electricity generation may become possible with a cost increase of 35% for natural-gas-fired power stations, and of 60% for coal-fired-power station.

Introduction

In our modern industrial world, huge volumes of CO₂ are emitted by burning fossil fuels which have been extracted from underground rocks. Carbon dioxide is not extremely poisonous but may enhance the greenhouse effect. However, the enormous volumes of man-made carbon dioxide emission make the development of effective mitigation technology extremely difficult.

About 60% of the CO₂ emission in Japan comes from fixed massive sources such as electric power plants, mills, etc. With the intensive efforts for the development of recovery technology for CO₂ from flue gas of power plants and mills, we should find places for permanent or quasi-permanent storage of separated carbon dioxide. The CO₂ disposal of

the ocean is the most investigated, but is still troubled with marine environmental problems.

The carbon contained in underground rocks is almost 100,000 times that of atmospheric carbon. Fossil fuels contain a relatively small fraction of the underground carbon, but still reach about 5.5 times that of atmospheric carbon (Berner and Lasaga, 1989). This is enough to cause a significant greenhouse effect. It seems a natural solution to store the carbon dioxide, after burning of the fossil fuels, into underground rocks.

There exist many hot and cool springs of carbonated water. Some carbonated mineral waters are people's favorite drink. Rock formations can prevent carbon dioxide from an abrupt escape, as for example happened in the lake Nyos event of 1986.

Underground storage of carbon dioxide in depleted natural gas reservoirs.

If carbon dioxide is fixed in a stable form such as CaCO_3 , shallow burial is a possibility to dispose of the CO_2 . Deep underground caverns are suitable to store the "dry ice" or CO_2 hydrate. However, high excavation costs make the use of underground caverns difficult, unless natural caverns or old mine openings are available.

Natural gas and petroleum have been stored in underground reservoirs during millions of years. Depleted natural gas or oil fields provide porous and extensive reservoir rocks and trap structures that can contain gas and liquids safely. Impermeable cap rocks prevent the leakage of gas. Many depleted gas fields are used as temporary storage of natural gas in Japan and other parts of the world. It is possible to use depleted natural gas and oil fields as storage for carbon dioxide. Carbon dioxide has been injected into oil reservoirs in order to recover additional oil for the past two decades (Bonder, 1992). There exist natural gas deposits that contain a large fraction of carbon dioxide.

Fluids in underground rocks are compressed at a hydrostatic pressure that is normally comparable to the groundwater head. Deep high-pressure reservoirs can usually contain more carbon due to compression. It is expected that a depleted natural gas reservoir can safely contain gaseous carbon dioxide up to the same pressure as the primary formation pressure before the extraction of natural gas. A dry natural gas reservoir, that is, can accommodate the same volume of gaseous carbon dioxide as the volume of natural gas that has been extracted. On the other hand, burning of CH_4 produces almost the same volume of carbon dioxide under same pressure. This means that natural gas reservoirs of pure methane can store that amount of carbon dioxide that is produced by burning of the extracted natural gas.

Burning of 1 m^3 of petroleum produces about 2.2 m^3 of carbon dioxide in liquidous state. Therefore, oil reservoirs can store less than one half of the carbon dioxide that is produced by burning of the extracted petroleum. Natural gas

and oil deposits cannot provide a real sink of carbon dioxide.

Underground storage of carbon dioxide in useless aquifers

Because the circulation of groundwater is restricted to deep aquifers or aquifers which are trapped under impermeable layers, deep aquifers tend to contain old fossil water which is not suitable for drinking nor for agricultural use, mainly due to the high salinity. There are numerous, useless, deep aquifers in sedimentary basins all over the world. Oil and gas exploration drilling rarely hit economically valuable deposits but often encounter useless aquifers, containing saline groundwater. This groundwater often contains hydrocarbons such as methane. In some regions in Japan, fossil groundwater is pumped up, and the dissolved methane is extracted and used.

Carbon dioxide is much more soluble in water than methane under same temperature and pressure (Fig. 1). We can dissolve more than ten times carbon dioxide than the methane extracted from the groundwater. Carbon dioxide in groundwater may become carbonic acid but be readily neutralized reacting with carbonates and silicates in rocks to form bicarbonate. In alkaline groundwater, carbon dioxide may precipitate as carbonate,

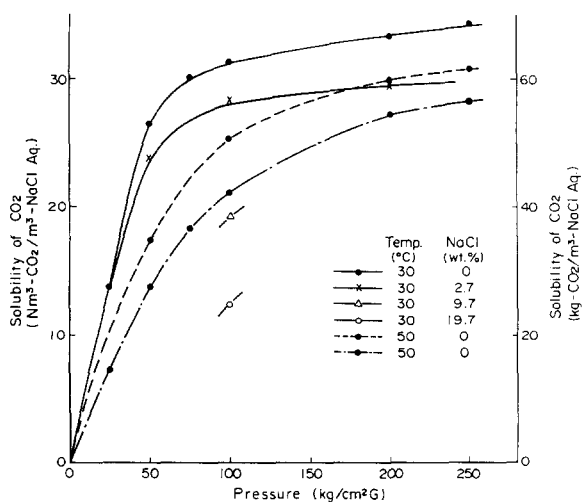


Fig. 1. Solubility of CO_2 in water (after Horixoe, 1992, pers. commun.).

although more study is necessary about the behavior of carbon dioxide and various properties of groundwater and various kinds of rocks.

Useless aquifers are commonly expected to be deep in sedimentary basins. The CO₂ storage capacity was estimated by an areal method, one of the techniques used for the calculation of oil reserves in unexplored regions (Fig. 2). This estimation assumed that the areas containing aquifers suitable for CO₂ storage comprise 1% of the areas of all sedimentary basins. This is a very conservative assumption, in view of repository siting conditions, applicable regulations and economic considerations. Assumptions for reservoirs and other parameters for calculation of CO₂ storage capacity are shown in Table 1. The solubility of CO₂ can be assumed to be 0.041 tons CO₂/m³ at the assumed temperature and pressure conditions.

TABLE 1

Reservoir parameters

Mean depth	2500 m
Formation pressure	250 kscg
Formation temperature	90°C
Effective pay thickness	300 m
Porosity	20%
Displacement efficiency	20%

Then, sedimentary basins may store 492,000 tons CO₂/km². The results of our brief estimation suggest that the CO₂ storage capacity in sedimentary basins could reach well over 320 billion tons (= 87 gigaton-C) in the world (Table 2).

The authors designed a prototype of a CO₂ injection system into useless aquifers and estimated the storage costs (Koide et al., 1992). This system

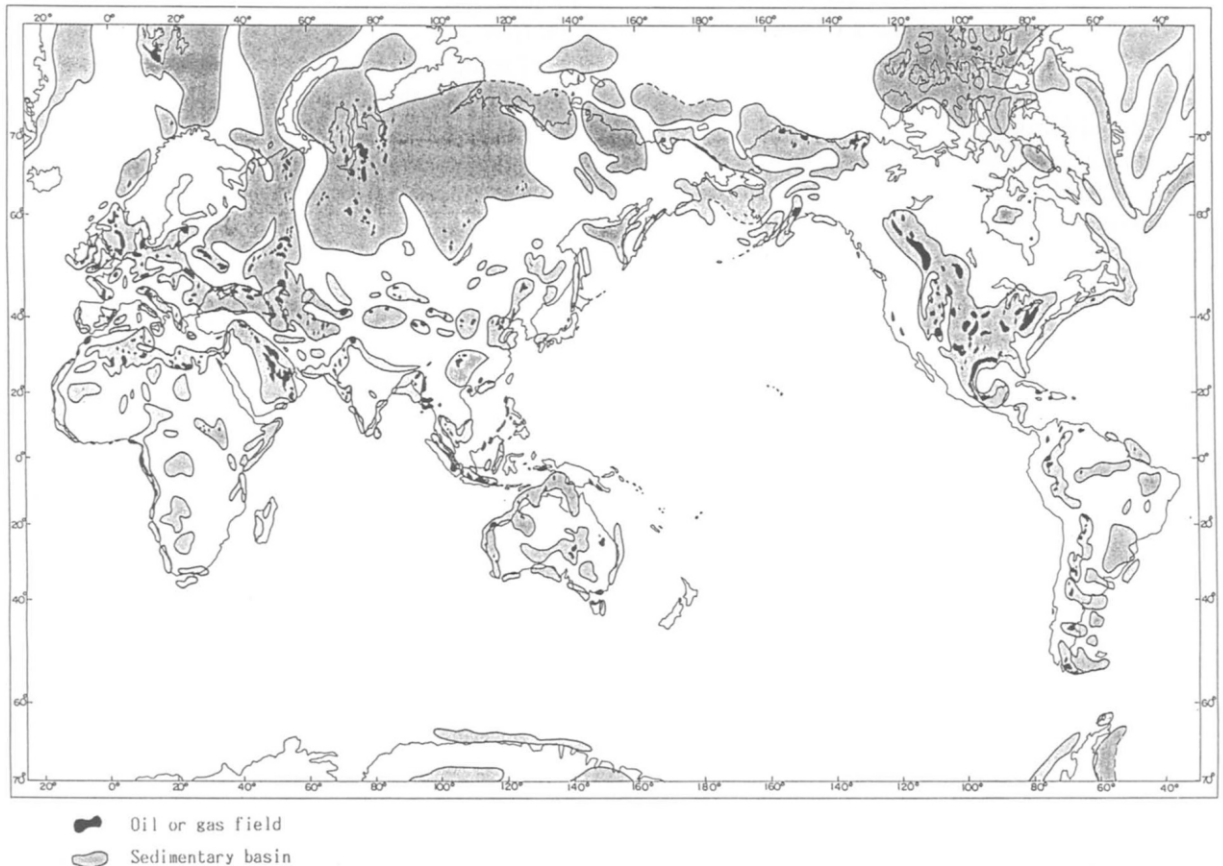


Fig. 2. Sedimentary basins in the world (after Uko Suzuki, 1992, pers. commun.).

TABLE 2

Potential of CO₂ storage

Region	Area of sedimentary basins (10 ⁶ km ²)	Potential of CO ₂ storage (gigatons-C)
East Asia	3.58	4.8
Southeast Asia	2.76	3.7
Middle East and West Asia	5.00	6.7
USSR	9.71	13.1
Europe	2.76	3.7
South America	9.07	12.2
North America	9.21	12.4
Africa	15.23	20.5
Australia and Oceania	7.47	10.1
World	64.79	87.3

assumed to inject 5000 tons of carbon dioxide per day, recovered from a fossil-fuel power plant. At the conditions listed in Table 1, approximately 80 km² of aquifer will be necessary to store 5000 tons of CO₂ per day over a period of 20 years.

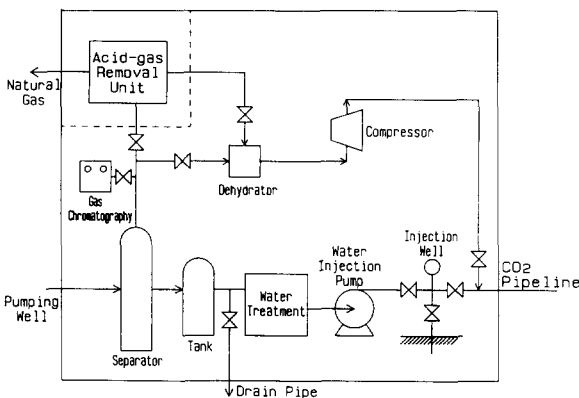
In the studied system, the CO₂ gas recovered from flue gas from the power plant is compressed to 280 kscg by a high-pressure compressor and transported through a 10-km-long pipe line to a distribution unit at the storing site. The CO₂ gas is then distributed from the distribution unit to several injection terminals and further divided among a few injection wells (Fig. 3). The CO₂ gas is injected through the injection wells into underground aquifers (Fig. 4). The injection of large volumes of CO₂ may increase the internal pressure of the aquifer. Pumping wells should be provided to lower the internal pressure of the

aquifer and to make the injection of CO₂ easier. Natural gas and carbon dioxide are separated from the recovered fossil groundwater. The carbon dioxide and part of the pumped groundwater are reinjected into the aquifer. The recovered natural gas from the groundwater is burned in the power plant to compensate for the loss of electric power necessary for the CO₂ injection. The carbon dioxide, separated from the groundwater, is reinjected into the aquifer with the other carbon dioxide. The remaining of groundwater could be discharged through a water treatment unit.

At an injection rate of 250 tons CO₂/day through a single well, 10 injection terminals, 20 injection wells and 30 pumping wells over an 8 km × 10 km injection site are necessary to inject 5000 tons of CO₂ per day.

The initial cost for this 5000 tons/day CO₂ injection system was estimated at \$328.4 million dollars. The running costs are \$23/ton-C, including wages and supplies. The total underground storing cost of CO₂ in aquifer is \$79/ton-C, excluding the separation cost of CO₂ from flue gas. This does not include electricity charge, because the recovered natural gas can compensate for the loss of electricity used for the injection system. The systems use 269 kwh of energy per ton of carbon.

Our preliminary cost estimation in Japan suggests that the CO₂-emission-free electricity generation may become possible with a cost increase of 35% for a natural-gas-fired power station and of 60% for a coal-fired power station where carbon

Fig. 3. CO₂ injection terminal.

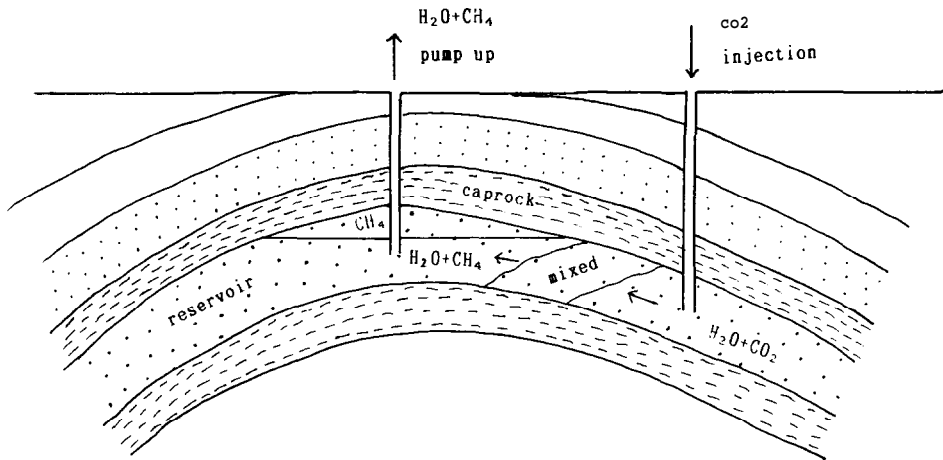


Fig. 4. Exchange from methane into carbon dioxide in aquifers.

dioxide is separated from the flue gas by amines and injected into deep aquifers.

Conclusions

Depleted reservoirs of natural gas and petroleum can provide excellent traps for carbon dioxide. They cannot, however, host more carbon dioxide than that formed by burning of produced gas and oil. Deep aquifers, which contain fossil water and can not be used due to high salinity, can host larger amounts of carbon dioxide, because their total effective volumes are larger than the total volumes of natural gas and oil reservoirs. Useless aquifers of fossil water are found around oil and gas reservoirs and occur commonly deep in sedimentary basins. Small fractions of aquifers in terrestrial sedimentary basins in the world are enough to host about 87 gigaton-C of carbon dioxide.

A preliminary technical and economical survey on the carbon dioxide injection system suggests that the energy requirement for the injection of carbon dioxide into subterranean aquifers is about 269 kWh/ton-C and that the investment and operation costs for the system are 79 \$/ton-C. By our

preliminary cost estimation in Japan, the CO₂-emission-free electricity generation may become possible with a cost increase of 35% for a natural-gas-fired power station and of 60% for a coal-fired power station.

This underground injection technology is applicable to the separation and re-injection of CO₂ from natural gas. There exists in the world huge reserves of natural gas that contain a high ratio of CO₂.

Chemical reactions of carbon dioxide with groundwater and rocks may contribute to the fixation of carbon dioxide into deep geologic formations. More investigations are necessary for the assessment of the effects of carbon dioxide injection on groundwater environments.

References

Berner, R.A. and Lasaga, AC., 1989. Modeling the geochemical carbon cycle. *Sci. Am.*, (March): 54-61.
 Bonder, P.L., 1992. Applications of carbon dioxide in enhanced oil recovery. *En. Conserv. Manage.*, 33: 579-586.
 Koide, H., Tazaki, T., Noguchi, Y., Nakayama, S., Iijima, M., Ito, K. and Shindo, Y., 1992. Subterranean containment and long-term storage of carbon dioxide in unused aquifers and in depleted natural gas reservoirs. *En. Conserv. Manage.*, 33: 619-626.