GHGT-11

Evaluation of CO₂ storage potential for feasibility study sites on Innovative Zero-Emission Coal Gasification Power Generation

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Abstract

We have investigated storage potential in a feasibility study of a CO₂ geologic storage system design. This study is a part of a research project titled “Innovative Zero-emission Coal Gasification Power Generation”.

In commercial use cases, the total amount of CO₂ storage is approximately 30 million tons, which means that the annual amount of CO₂ storage is 1.54 million tons in a 20-year injection cycle. In the case of large-scale CO₂ storage, the total amount of CO₂ storage is assumed to be 200 million tons; the annual amount of CO₂ storage is 10 million tons in a 20-year cycle.

We selected three reservoir sites—sites A, B, and C—as commercial use cases. An additional site, Site D, was selected as a large-scale CO₂ storage site. The storage capacities of aquifers distributed in 4 sites, sites A, B, and C as commercial use cases and site D as large-scale CO₂ storage case, were evaluated. Additionally, injectivity and long-term behavior were examined through numerical analyses. These results indicated the possible of sites A, B, and C as commercial use and site D as large-scale CO₂ storage.

This paper describes the site selection, geological characterization, and CO₂ storage potential of sites selected for case studies.

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Selection and/or peer-review under responsibility of GHGT

Keywords: CO₂ storage potential, feasibility study, Site characterization

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1. Introduction

This paper describes part of the results of a research project titled “Innovative Zero-emission Coal Gasification Power Generation Project,” which was conducted during fiscal years 2008–2011.

In this project, the technical and economic aspects of a feasibility study on a power generation system linked to carbon capture and storage (CCS) were examined by members of a capture and power plant group, a transport group, a geological storage group, and a comprehensive evaluation group. A task of the project involved the selection of case studies to correlate with specific plant and storage areas. As members of the geological storage group, the authors investigated the appropriate geological layer for CO₂ storage in coastal regions of Japan, evaluated the CO₂ storage volume and injectivity in the storage layer, and estimated the expenses associated with CO₂ injection.

We selected three reservoir sites—sites A, B, and C—as commercial use cases. An additional site, Site D, was selected as a large-scale CO₂ storage site. And we estimated Geological characterization, CO₂ storage potential, injectivity and long term migration of sites selected for case studies.

2. Research methods

Fig. 1 shows a workflow chart describing parameters for site selection, estimation of storage potential, injectivity, and long-term potential for case study sites.

![Workflow Chart](image)

Fig.1. The workflow on site selection, estimation of storage potential, injectivity and long term for case study sites

2.1. Site selection

The following points were mainly considered for site selection:

- In general cases, the total amount of CO₂ storage is approximately 30 million tons, which means that the annual amount of CO₂ storage is 1.54 million tons in a 20-year injection cycle.
- In the case of large-scale CO₂ storage, the total amount of CO₂ storage is assumed to be 200 million tons; the annual amount of CO₂ storage is 10 million tons in a 20-year cycle.
- The selected site may not overlap with those of other feasibility studies.
- Sedimentary basins located in marine areas were selected.
- Old formations influenced by active fold movement or fault activity were excluded.
- Formations exhibiting combinations of sealing layers (mudstones) and storage layers (sandstones) were selected.
2.2. Methodologies for estimating CO$_2$ capacity

In the first step, capacities considered for site selection were estimated at a whole basin scale. Assumed storage amounts were then examined at a regional site scale via numerical simulations. For capacity estimation at the entire basin scale, regional scale geological models created on the basis of general information were used. The obtained value was calculated by the following equation [1]:

$$ G_{CO_2} = A \times h \times \varphi \times \rho \times S_g \times S_f $$

where $A$ is the horizontal area of the aquifer; $h$ is the effective thickness of the aquifer; $\varphi$ is porosity; $S_g$ is gas saturation of supercritical CO$_2$ in pore spaces, which we assumed to be 0.5; $\rho$ is CO$_2$ density at storage depth; and $S_f$ is the storage factor that represents the ratio of CO$_2$ plume volume to total pore volume, which we assumed to be 0.25

2.3. Numerical simulation studies

In feasibility studies of CO$_2$ geological storage, it is important to evaluate the quantity that can be confined in the storage layer of the examination site over long periods.

We examined previous geological survey data and a geological model created to predict feasibility of the study sites. Storage potential of selected areas, the number of required injection wells and their arrangement, and CO$_2$ migration in the proposed site were examined through simulation with TOUGH2/ECO2N software [2].

3. Results

3.1. Basin scale assessment of CO$_2$ storage potential

(1) Site A

Site A was selected from a broad sedimentary basin composed of thick Cenozoic layers beside the Sea of Japan in eastern Japan. Stratigraphic column, geographical location and geological section for Site A were shown in Fig 2. This sedimentary basin is situated in the oil-and-gas-field region, where vast data from previous geological surveys are available, such deep drilling and refraction seismic survey information. The capacity of the basin scale is 200 million tons of CO$_2$.

Reservoirs at site A are widely distributed in the coastal regions. Two sandstone beds situated just beneath a thermal power plant hold reservoir potential and are distributed at depths of 800–900 m and 1,100–1,150 m with approximate layer thicknesses of 100 m and 50 m, respectively.

(2) Site B

For site B, we selected a sedimentary basin beside the Pacific Ocean in eastern Japan. Stratigraphic column, geographical location and geological section for Site B were shown in Fig 3. This sedimentary basin mainly consists of thick Pliocene and Miocene sediments with alternating layers of sandstone and mudstones. These layers can be considered as one thick mudstone and sandstone layer. The capacity at the basin scale is 900 million tons of CO$_2$.

As a reservoir for site B, we selected a tuffaceous sandstone layer at the base of the Pliocene series. Results of the seismic inversion method show that this approximately 50-m-thick sandstone bed may become thicker at the designated injection point 5 km from the coast. The sea water depth of the injection spot is approximately 30 m, and the depth of the reservoir is approximately 2,000 m.
(3) Site C

For site C, we selected a sedimentary basin located in a coastal region in western Japan. Stratigraphic column, geographical location and geological section for Site C were shown in Fig 4. This sedimentary basin was formed by the filling of a vast rift valley; the maximum thickness of the Pliocene layer is approximately 1,700 m. The capacity at the basin scale is 5000 million tons of CO₂.
According to log information, two predominant sandstone beds and thick silt layers lie directly above each bed. At the center of the sedimentary basin approximately 10 km from the shore, the sea water depth is approximately 120 m, and reservoirs are situated at depths of 1,200–1,600 m and 2,200–2,600 m.

(4) Site D

We chose as site D a sedimentary basin located in an offshore area of western Japan. Stratigraphic column, geographical location and geological section for Site D were shown in Fig. 5. This sedimentary basin, with a thickness of 4,000 m and an area of 1,500 km², mainly consists of sediments from the Neocene to Paleocene periods. A vast amount of previous geological survey information is available for this basin. Four holes were drilled during a refraction seismic survey conducted through about 120 survey lines with a total length of about 4,000 km.
An area with low large-scale faulting in the sedimentary basin approximately 140 km from the coast at a sea water depth of 120–150 m was selected for examination. The sandstone layer selected as a reservoir has a thickness of approximately 200–300 m and is situated at a depth of 800–2,500 m.

In order to select areas with a low leakage risks in the site D, the geological structures and faults were interpreted in detail and 4 areas where a fault does not exist closely were selected. The total of the CO₂ storage capacities of these 4 areas were estimated as 370 million ton CO₂.

Fig. 6. The 4 areas where a fault does not exist close and storage capacities of the 4 areas in Site D

3.2. Numerical simulation study

The injection rate, number of injection wells, long-term migration of the injected CO₂, and positions of injection wells were examined via numerical simulations using detailed geological 3D models created on the basis of various pieces of information such as oilfield survey data.

Considering various specifications and layouts of the injection wells, the criteria listed in Table 1 were used for the storage design concept. In this study, injection via vertical injection wells was assumed because it is considered more economical than that via horizontal injection wells. For conditions in which injection by using a single vertical injection well was judged to be difficult, a horizontal injection well with a larger CO₂ injection capacity was employed.

Table 1. Conditions considered for examination of storage design concept

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection conditions</td>
<td>- The maximum injection pressure shall not exceed the fracture pressure.</td>
</tr>
<tr>
<td></td>
<td>- CO₂ injection shall be conducted at a pressure equal to or less than the specified maximum pressure at a constant flow rate.</td>
</tr>
<tr>
<td></td>
<td>- For commercial use, operation at 80% of the entire system capacity shall be assumed.</td>
</tr>
<tr>
<td>Storage conditions</td>
<td>- Basically, the injected supercritical CO₂ shall be retained in the specified storage area.</td>
</tr>
<tr>
<td></td>
<td>- When multiple promising storage candidates exist at the same point, the uppermost storage shall be prioritized for economic reasons.</td>
</tr>
<tr>
<td></td>
<td>- Supercritical CO₂ shall not reach a large-scale fault.</td>
</tr>
<tr>
<td>Injection well conditions</td>
<td>- The type of injection well shall be vertical or horizontal.</td>
</tr>
<tr>
<td></td>
<td>- The maximum horizontal length of a horizontal injection well shall be determined after consideration of comments from the wellbore drilling company.</td>
</tr>
</tbody>
</table>
Rock properties used for the numerical model, the number of the injection wells defined on the basis of the numerical analysis results, and the spreading parameters of supercritical CO₂ are summarized in Table 2. Figure 7 shows the increase in pressure of the injection wells for Site A, Site B, Site C, and Site D during a 20-year injection period. This results presents that the maximum injection pressure does not exceed the fracture pressure. Figure 8 shows the numerical analysis results for Site D and presents that the injected supercritical CO₂ is retained in the specified storage area.

Table 2. Summary of rock properties and numerical results

<table>
<thead>
<tr>
<th>Objective</th>
<th>Item</th>
<th>Unit</th>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
<th>Site D</th>
</tr>
</thead>
<tbody>
<tr>
<td>site scale</td>
<td>water depth</td>
<td>m</td>
<td>0</td>
<td>15</td>
<td>120</td>
<td>120-150</td>
</tr>
<tr>
<td>reservoir depth</td>
<td>m</td>
<td></td>
<td>900</td>
<td>1800</td>
<td>1500</td>
<td>1300-1800</td>
</tr>
<tr>
<td>thickness</td>
<td>m</td>
<td></td>
<td>20-50</td>
<td>410</td>
<td>200-400</td>
<td></td>
</tr>
<tr>
<td>porosity</td>
<td>%</td>
<td></td>
<td>40</td>
<td>27</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>permeability (k)`</td>
<td>m d</td>
<td></td>
<td>1.23</td>
<td>0.16</td>
<td>0.29</td>
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<tr>
<td>entry pressure</td>
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<td>17</td>
<td>33</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>storage area</td>
<td>ha</td>
<td></td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig. 7. Numerical results for injectivity.
4. Discussion

In this study, the storage capacities of aquifers distributed in 4 sites, sites A, B, and C as commercial use cases and site D as large-scale CO₂ storage case, were evaluated. Additionally, injectivity and long-term behaviour were examined through numerical analyses. These results indicated the possibility of sites A, B, and C as commercial use and site D as large-scale CO₂ storage.

On the other hand, many uncertainties were included in the geological model used for these studies. Therefore, it is necessary to estimate the influence of the uncertainties and examine the effectively investigation to decrease uncertainties.

Since many aquifers are distributed around Japan[3], the investigations of the location and characteristic of large aquifers around Japan are important for realization of large reduction of CO₂ emissions by a coal-fired power plant with CCS.

Acknowledgements

This study is a part of a research project titled “Innovative Zero-emission Coal Gasification Power Generation” which was funded by the New Energy and Industrial Technology Development Organization of Japan (NEDO).

References

