EU GeoCapacity

Assessing European Capacity for Geological Storage of Carbon Dioxide

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CO\textsubscript{2} Capture and Storage – Response to Climate Change
2\textsuperscript{nd} CO\textsubscript{2}\textit{net} east Regional Workshop for CE and EE Countries
Bratislava, Slovakia, 3-4 March 2009
The work in GeoCapacity comprised:

• Full assessment of countries not previously covered
• Update of GESTCO and CASTOR countries
• Inventory of major CO₂ emission point sources and infrastructure
• Assessment of regional and local potential for geological storage of CO₂ in:
  • deep saline aquifers
  • hydrocarbon fields (incl. EOR/EGR)
  • coal fields (incl. ECBM)
• Technical site selection criteria and methodology for ranking
• Contribution to guidelines for assessment of geological storage capacity
• Analysis of source – transport – sink scenarios and economical evaluations
• Further development of mapping and analysis methodologies (GIS/DSS)
• Collaboration with China and other CSLF countries e.g. India and Russia
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26 Project partners from 20 countries

- Geological Survey of Denmark and Greenland
- University of Sofia
- University of Zagreb
- Czech Geological Survey
- Institute of Geology at Tallinn University of Technology
- Bureau de Recherce de Geologie et Miniere
- Institute Francais du Petrole
- Bundesanstalt für Geologie und Rohstoffen
- Institute for Geology and Mining Engineering
- Eötvös Loránd Geophysical Institute of Hungary
- Isituto Nazionale Oceanografie e Geofisica Sperimentale
- Latvian Environment, Geology & Meteorology Agency
- Institute of Geology and Geography

- Geological Survey of the Netherlands
- Ecofys
- Academy of Science (MEERI)
- Geophysical Exploration Company
- GeoEcoMar
- Dionyz Stur State Geological Institute
- GEOINZENIRING
- Instituto Geologico y Minero de Espana
- British Geological Survey
- EniTecnologie (Industry Partner)
- ENDESA Generacion (Industry Partner)
- Vattenfall Utveckling AB (Industry Partner)
- Tsinghua University
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GeoCapacity Project Organisational Structure

Steering Committee
One representative from each partner
The SC meets twice per year

Project Management
GEUS
assisted by 2 WP leaders
and a financial officer

End-User Advisory Group

WP 1
BGS leader

WP 2
GEUS leader

WP 3
IFP leader

WP 4
GEUS leader

WP 5
TNO leader

WP 6
BRGM leader

WP 7
GEUS leader

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Mapping of emission sources and infrastructure

Stationary sources exceeding 100 kt CO$_2$ / year

Data sources:

– annual reports for the EU ETS
– national allocation plans
– qualified estimations where data not available

Existing pipelines
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CO₂ Sources & Sinks
- CO₂ Sources
- Sedimentary Basins
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Pipelines

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Mapping of storage sites

Initial screening for sedimentary formations

3 main types of storage considered
  – aquifers
  – hydrocarbon fields
  – unmineable coal seams

Application of site selection criteria

Storage capacity estimations

Collection of data for GIS and project DSS
Basic site selection criteria

• Sufficient depth and storage capacity
  • supercritical CO₂ below 700-800 m (rule of thumb)
Variation in density with depth assuming hydrostatic pressure, geothermal gradient of 25°C/km and surface temperature of 15°C.

Great change in density / volume at ~ 800 m
Basic site selection criteria

• Sufficient depth and storage capacity
  • supercritical CO$_2$ below 700-800 m (rule of thumb)
  • porosity may deteriorate below 2500-3000 m
One of the regional Danish reservoir sandstones

Decreasing porosity with depth

Decreasing permeability with decreasing porosity

In practice this means a depth window of 800-2500 m
Basic site selection criteria

• Sufficient depth and storage capacity
  • supercritical CO₂ below 700-800 m (rule of thumb)
  • porosity may deteriorate below 2500-3000 m
  • trap type / areal extent / thickness
Stratigraphical trapping; porous layer bounded by tight seal

Structural trapping; porous layer topped by tight seal

Structural trapping; porous layer in fault contact with seal
Basic site selection criteria

- Sufficient depth and storage capacity
  - supercritical CO₂ below 700-800 m (rule of thumb)
  - porosity may deteriorate below 2500-3000 m
  - trap type / areal extent / thickness
  - storage capacity
Areal distribution and thickness of reservoir

Pore space in the reservoir

CAP ROCK

Reservoir rock
Basic site selection criteria

• Sufficient depth and storage capacity
  • supercritical CO₂ below 700-800 m (rule of thumb)
  • porosity may deteriorate below 2500-3000 m
  • trap type / areal extent / thickness
  • storage capacity

• Sufficient injectivity to be economically viable
  • permeability (as a rule of thumb > 200 mD)
  • reservoir lithology
  • heterogeneity of reservoir

• Integrity of seal
  • seal lithology and permeability
  • seal capillary pressure and pore entry pressure
  • faulting / tectonic activity / fracture pressure
Aquifers
Hydro carbon fields & Coal fields
Capacity calculations

Methodological resources:

• CSLF Task Force on CO$_2$ Storage Capacity Estimation

• Modeling work by TNO

• US DOE methodology by the Geologic Working Group of the US Regional Carbon Sequestration Partnership Program

Uncertainties for aquifers!
General considerations for saline aquifers

- Distinguish between estimates for bulk volume of regional aquifers and estimates for individual structural or stratigraphic traps.

- For estimates based on the bulk volume of regional aquifers, we suggest a storage efficiency factor of 2% based on work by US DOE.

- For trap estimates, the choice of storage efficiency factor depends on whether the aquifer system is open, semi-closed, or closed.

- For traps in open or semi-closed aquifer systems, we suggest a rule-of-thumb approach with values for the storage efficiency factor in the range between 3% and 40% for semi-closed low quality and open high quality reservoirs, respectively.

- For traps in closed aquifer systems, we suggest an approach based on trap to aquifer volume ratio, pore and water compressibility, and allowable average pressure increase, with typical values for the storage efficiency factor in the range between 1% and 20%.

- Storage capacity estimates should always be accompanied with information on assumptions and approach for storage efficiency factor.
### Terms included in the CO₂ storage efficiency factor:

<table>
<thead>
<tr>
<th>Term</th>
<th>Symbol (range)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terms used to Define the Entire Basin/Region Pore Volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net to total area</td>
<td>A_r / A_b (0.2-0.8)</td>
<td>Fraction of total basin/region area that has a suitable formation present.</td>
</tr>
<tr>
<td>Net to gross thickness</td>
<td>h_r / h_b (0.25-0.75)</td>
<td>Fraction of total geologic unit that meets minimum porosity and permeability requirements for injection.</td>
</tr>
<tr>
<td>Effective to total pore volume ratio</td>
<td>e / A_r (0.5-0.65)</td>
<td>Fraction of total porosity that is effective, i.e. interconnected.</td>
</tr>
<tr>
<td>Terms used to Define the Pore Volume Immediately Surrounding a Single Well CO₂ Injector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areal displacement efficiency</td>
<td>E_r (0.5-0.8)</td>
<td>Fraction of immediate area surrounding an injection well that can be contacted by CO₂; most likely influenced by areal geologic heterogeneity such as faults or permeability anisotropy.</td>
</tr>
<tr>
<td>Vertical displacement efficiency</td>
<td>E_v (0.6-0.9)</td>
<td>Fraction of vertical cross section (thickness), with the volume defined by the area (A) that can be contacted by the CO₂ plume from a single well; most likely influenced by variations in porosity and permeability between sublayers in the same geologic unit. If one zone has higher permeability compared with others, the CO₂ will fill this one quickly and leave the other zones with less CO₂ or no CO₂ in them.</td>
</tr>
<tr>
<td>Gravity</td>
<td>E_g (0.2-0.6)</td>
<td>Fraction of net thickness that is contacted by CO₂ as a consequence of the density difference between CO₂ and in situ water. In other words, 1-lg is that portion of the net thickness not contacted by CO₂ because the CO₂ rises within the geologic unit.</td>
</tr>
<tr>
<td>Microscopic displacement efficiency</td>
<td>E_d (0.5-0.8)</td>
<td>Portion of the CO₂-contacted, water-filled pore volume that can be replaced by CO₂. Ed is directly related to irreducible water saturation in the presence of CO₂.</td>
</tr>
</tbody>
</table>

The range of values for each parameter is an approximation to reflect various lithologies and geologic depositional systems that occur throughout the Nation. The maximum and minimum are meant to be reasonable high and low values for each parameter.

**US DOE estimation of storage efficiency factor**

- \( P_{15} : S_{\text{eff.}} = 1 \% \)
- \( P_{50} : S_{\text{eff.}} = 2 \% \)
- \( P_{85} : S_{\text{eff.}} = 4 \% \)
Conceptual model for open aquifers

- Storage space is generated by displacing existing fluids and distributing pressure increase in surrounding aquifer system.
- Storage volume = \( A \cdot \text{height} \cdot \frac{N}{G} \cdot \phi \cdot S_{\text{eff}} \)
- \( S_{\text{eff}} \) depends on connectivity to surrounding aquifer.
- \( S_{\text{eff}} = \) Used space/Available space

• From Filip Neele, TNO
Storage efficiency factor for open and semi-closed aquifers

Storage coefficient (by the rule-of-thumb) $S_{eff}$

<table>
<thead>
<tr>
<th></th>
<th>1*</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>High quality reservoir</td>
<td>40 %</td>
<td>20 %</td>
<td>10 %</td>
<td>3–5 %</td>
</tr>
<tr>
<td>Low quality reservoir</td>
<td>20 %</td>
<td>10 %</td>
<td>5 %</td>
<td>&lt;3 %</td>
</tr>
</tbody>
</table>

*Volume of bulk reservoir shall be 5-10 times the volume of the reservoir

--- Fault
• Affected space is full! (rock and water for aquifers)
• More space only via pressure increase and compressibility
• Storage volume = $A \cdot \text{height} \cdot N/G \cdot \phi \cdot (C_w + C_p) \cdot \Delta p_{avg}$
• $\Delta p_{avg}$ = allowed average pressure increase in affected area

From Filip Neele, TNO
Storage efficiency factor for closed aquifers

\[ S_{\text{eff}} = \frac{V_{\text{CO}_2}}{(\phi \cdot V_{\text{trap}})} \]

\[ V_{\text{CO}_2} = c \cdot \Delta p \cdot \phi \cdot V_{\text{aquifer}} \]

- **Storage efficiency**
  - As function of \( \frac{V_{\text{aquifer}}}{V_{\text{trap}}} \) (between 1 and 100)
  - As function of depth
  - In table: percentage of trap pore space filled with \( \text{CO}_2 \)

- **Pressure increase 10%**
- **Compressibility**
  - Pore: typical value \( 6 \cdot 10^{-5} \text{ bar}^{-1} \)
  - Water: \( 4 \cdot 10^{-5} \text{ bar}^{-1} \)
  - Total: pore + water = \( 10 \cdot 10^{-5} \text{ bar}^{-1} \)

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.10</td>
<td>0.5</td>
<td>1.0</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1500</td>
<td>0.15</td>
<td>0.8</td>
<td>1.5</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>2000</td>
<td>0.20</td>
<td>1.0</td>
<td>2.0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2500</td>
<td>0.25</td>
<td>1.3</td>
<td>2.5</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>3000</td>
<td>0.30</td>
<td>1.5</td>
<td>3.0</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>3500</td>
<td>0.36</td>
<td>1.8</td>
<td>3.6</td>
<td>18</td>
<td>36</td>
</tr>
</tbody>
</table>

**Key parameter, site specific**

\[ \frac{V_{\text{aquifer}}}{V_{\text{trap}}} \rightarrow \]

**NOTE:** numbers refer to trap, but depend on entire aquifer volume!

- From Filip Neele, TNO
Top:
**Practical** capacity with economic and regulatory barriers applied to effective capacity and with matching of sources and sinks: Case studies

Middle:
**Effective** capacity with technical/geological cut-off limits applied to theoretical capacity: site specific/regional estimates in GIS

Bottom:
**Theoretical** capacity including large uneconomic/unrealistic volumes: regional estimates without storage efficiency

**Techno-Economic Resource-Reserve pyramid**
Preliminary pan-European storage capacity estimate

<table>
<thead>
<tr>
<th>Emissions from big stationary sources (Gt CO2)</th>
<th>Storage capacity (Gt CO2)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aquifers</td>
<td>Hydrocarbon fields</td>
</tr>
<tr>
<td></td>
<td>Effective capacity</td>
<td>Conservative estimate</td>
</tr>
<tr>
<td>2</td>
<td>350</td>
<td>100</td>
</tr>
</tbody>
</table>
North Sea area
North East Europe
South East Europe
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South West Europe

GeoCapacity maps of Sources & Sinks
Case studies

Geological part

• selected structures with potential for pilot / demonstration projects

Economic part

• utilisation of Decision Support System (DSS)
Economic tool Overview

Start

1: Web application

1. Select sources, sinks
2. Edit sources, sinks
3. Source – sink match? N Y
4. Compute pipeline network
5. Define capture, compression
6. Define scenario parameters
7. Monte Carlo run
8. View results

2: Local application
WP 6.1
Initiation of technology transfer to China

Focusing on one province with large CO₂ point sources and investigate the storage potential.

WP 6.2
Framework for international cooperation

Establish communication links between GeoCapacity and CSLF countries to initiate the technology transfer.
Main project achievements:

• CCS inventory of Europe incl. GIS (base for future CO$_2$ storage atlas of Europe ?)

• Contribution to guidelines for assessment of geological storage capacity, site selection criteria and methodology for ranking

• Pioneering CCS work in many countries
Assessing European Capacity for Geological Storage of Carbon Dioxide

Project website: www.geocapacity.eu

http://www.geocapacity.eu