Carbon Capture and Storage: Technology, Economy and Social Attitudes
- an introduction -

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### Fossil fuel consumption & occurrences

<table>
<thead>
<tr>
<th></th>
<th>~ 390 EJ</th>
<th>~ 27 Gt CO$_2$</th>
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</thead>
<tbody>
<tr>
<td><strong>World fossil fuel consumption in 2005</strong></td>
<td>(80% of TPES)</td>
<td></td>
</tr>
<tr>
<td><strong>Fossil fuel consumption 1860 – 2005</strong></td>
<td>~ 16.000 EJ</td>
<td>~ 1300 Gt CO$_2$</td>
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<tr>
<td><strong>Fossil fuel reserves</strong></td>
<td>47.000 EJ</td>
<td>3.600 Gt CO$_2$</td>
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<tr>
<td><strong>Fossil fuel resources</strong></td>
<td>235.000 EJ</td>
<td>20.500 Gt CO$_2$</td>
</tr>
<tr>
<td><strong>Additional occurrences</strong></td>
<td>975.000 EJ</td>
<td>55.000 Gt CO$_2$</td>
</tr>
</tbody>
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Mainly based on: World Energy Assessment, 2004
Global CO$_2$ emissions from fossil fuels
(in 2002, forecast for 2030)

Source: IEA, WEO, 2004
Distribution of CO$_2$ Sources

Source: IPCC, SR-CCS, 2005
DECARBONISATION OF FOSSIL FUELS TO ELECTRICITY AND HYDROGEN

Courtesy of Statoil
CO₂ Capture and Storage (CCS)

- **CO₂ capture (from static sources):**
  - Natural gas sweetening (> 50 Mt CO₂/year)
  - Industry (e.g. refineries, ammonia, steel)
  - Power plants (coal, oil, gas, biomass)
  - Hydrogen plants

- **Transport:** by pipeline or tanker.

- **Storage/disposal:**
  - (Depleted) oil/gas fields (with EOR/EGR)
  - Deep unminable coal beds (with ECBM)
  - Deep saline aquifers
  - Mineral carbonation
  - Ocean (in research phase)
**CO₂ capture options**

**Major approaches:**
- Post-combustion
- Pre-combustion
- Oxyfuel combustion

**Separation technologies:**
- Absorption (e.g. amines)
- Adsorption (e.g. Selexol)
- Cryogenic
- Membrane

*CO₂ capture plant* (ABB Lummus Crest)
Energy penalty CO$_2$ capture

Reference Plant

CO$_2$ avoided

CO$_2$ captured

Plant with CCS

CO$_2$ produced (kg/kWh)
Typical energy penalties CO$_2$ capture
(increase fuel use per kWh produced, due to CO$_2$ capture)

<table>
<thead>
<tr>
<th>Power Plant</th>
<th>Today</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Coal</td>
<td>24-40 %</td>
<td>15-20 %</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>11-24 %</td>
<td>8-11 %</td>
</tr>
<tr>
<td>Advanced Coal</td>
<td>14-25 %</td>
<td>9-12 %</td>
</tr>
</tbody>
</table>
CO₂ geological storage capacity

Global capacity: at least 2,000 GtCO₂
Cost: 0.5-8 US$/tCO₂

Remarks:
- Figures are based on theoretical studies.
- Also other options need (further) attention.

Source: IPCC, SR-CCS, 2005
Potential environmental risks of underground storage

- Abrupt leakage (e.g. through injection well failure)
- Gradual leakage of CO$_2$ from the reservoir (what is an acceptable annual leakage rate?)
- Seismicity: (micro) earth tremors caused by the injection.
- Ground movement due to pressure changes.
- Displacement of brine to other formations caused by injection in open aquifers.
“With appropriate site selection, a monitoring program to detect problems, a regulatory system, and appropriate use of remediation methods (...), the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas”

IPCC Special Report on CCS
September 2005
CCS is already happening worldwide

- Sleipner, Norway
  1 Mt/yr since 1996

- Permian Basin, US
  70+ projects, total of 500 Mt stored

- In Salah, Algeria
  1.1 Mt/yr since 2004

- Weyburn, Canada
  2 Mt/yr since 2000

- K12B, Netherlands
  some 100kt/yr since 2004

Now need to upscale, reduce costs and test the full CO₂ chain and the range of storage options

Source: Nick Otter, ZEP Platform Europe, 2008
CO₂ transport

- About 4000 km CO₂ pipelines (for EOR; transport more than 45 Mt/yr).
- High-pressure (50-140 bar).
- Long-distance transport by tanker less costly
  - offshore > 1000 km
  - onshore > 1600 km
A system analysis for the Netherlands

Source: Kay Damen, Utrecht University, 2007
Production costs of electricity *)

<table>
<thead>
<tr>
<th>Power plant system</th>
<th>Natural Gas Combined Cycle (US$/kWh)</th>
<th>Pulverized Coal (US$/kWh)</th>
<th>Integrated Gasification Combined Cycle (US$/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without capture (reference plant)</td>
<td>0.03-0.05</td>
<td>0.04-0.05</td>
<td>0.04-0.06</td>
</tr>
<tr>
<td>With capture and geological storage</td>
<td>0.04-0.08</td>
<td>0.06-0.10</td>
<td>0.05-0.09</td>
</tr>
</tbody>
</table>

*) Gas prices: 2.8-4.4 US$/GJ; Coal prices: 1-1.5 US$/GJ

Source: IPCC SR-CCS, 2005
“CO₂ emission targets cannot be achieved without CCS”

By 2030, emissions are reduced to some 23 Gt, a reduction of 19 Gt compared with the Reference Scenario.
“In most scenarios for stabilization of atmospheric greenhouse gas concentrations between 450 - 750 ppmv CO$_2$ and in a least-cost portfolio of mitigation options, the economic potential of CCS would amount to 220 - 2,200 GtCO$_2$ cumulatively”

“This would mean that CCS could contribute 15 - 55% to the cumulative mitigation effort worldwide until 2100”

IPCC Special Report on CCS
September 2005
“Energy and economic models indicate that the major CCS system’s contribution to climate change mitigation would come from deployment in the electricity sector.”

“Most modeling suggests that CCS systems begin to deploy at a significant level when CO$_2$ prices begin to reach 25-30 US$/tCO$_2$”

IPCC Special Report on CCS
September 2005
CCS & public support

Major requirements for public support:

• Fair and open communication.
• Legal frame works, national and international.
• Proper monitoring and risk management.
• Leakage less than 0.01 - 0.1 %.
• CCS as a third option, after (1) efficiency improvement and (2) renewables.
• Cost of CCS should be paid by the polluter (eventually).
Thank you!