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Global Warming... Where are we?–Why CO$_2$ Sequestration

Acknowledgement: Schlumberger
Global warming–link to \( \text{CO}_2 \)

**The Greenhouse Effect**

- Some solar radiation is reflected by the earth and the atmosphere.
- Solar radiation passes through the clear atmosphere.
- Most radiation is absorbed by the earth’s surface and warms it.
- Infrared radiation is emitted from the earth’s surface.

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the earth’s surface and the lower atmosphere.

_Barnola et al._

\[
\text{Sun} \quad T_e \quad 255 \quad \rightarrow \quad 288 \text{ K} \quad \text{GHG}
\]
Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Petit, Jouzel et al... Nature, June 1999
Greenhouse gases

IPCC
Climate forcing

Hansen et al (2000,1)

Gas | GWP
---|---
CO₂ | 1
CH₄ | 23
N₂O | 296
Scientific Status

- Climate Science is progressing quickly
- Early evidence for anthropogenic emissions being responsible for part of the current warming.
- **No Regret Policy**: We should start now
Storage Volume

Assumed Advances In
- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

Carbon capture & disposal

13 Gt/y $\text{CO}_2 \approx 280$ MBbl/day
25 Gt/y $\text{CO}_2 \approx 540$ MBbl/day
Oil: 77 MBbl/d Oil Prod (2003)

(Edmonds, 2004)
Coal consumption

China

- Asia Pacific
- Africa
- Middle East
- Europe
- South America
- North America
## Comparison of fuels

<table>
<thead>
<tr>
<th>Source</th>
<th>Price / Std unit</th>
<th>Cost / emit. CO(_2) $ / ton CO(_2)</th>
<th>E / kg CO(_2) MJ/ kg CO(_2)</th>
<th>Price $ / GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>50 / Bbl</td>
<td>122</td>
<td>14.8</td>
<td>8.2</td>
</tr>
<tr>
<td>N. Gas</td>
<td>7 / Mscf</td>
<td>123</td>
<td>19.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Coal (Bit)</td>
<td>26.2 / ton</td>
<td>10.7</td>
<td>11.2</td>
<td>1</td>
</tr>
<tr>
<td>Electricity</td>
<td>50 / MW-hr</td>
<td>155</td>
<td>-</td>
<td>13.8</td>
</tr>
</tbody>
</table>

- Sequestration cost must be $15 / ton CO\(_2\) or less
$\text{CO}_2$ and relevance to oil and gas

- Separation / Capture
- Piping
- Site Selection
- Field Development
- Injection/post injection

- Reservoir evaluation
  - Capacity
  - Injectivity

- Simulation
  - Economics
  - Safety
  - Well design
  - Completion

- Optimization
  - Safety
  - Audit
  - Monitoring
  - Simulation

- Process Selection
- Process Engineering
- Optimization
- Surface facilities
Worldwide projects

Alberta

Weyburn EOR

E Texas Trial

Battelle Trial

Sleipner

Ketzin

InSalah

underway
More details for N. America

- Weyburn CO2-EOR
- PCOR: U. of North Dakota
- BIG SKY: Montana State U.
- SW: N.Mex. Inst. of Mining & Tech
- MRCSP: Battelle
- Consol ECBM
- Mountaineer CO2 SA
- SE: Southern States Energy Bd.
- GCCC
- Frio CO2 SA

Regional Partnerships: 9 Saline Aq. 5 EOR 4 Combo 5 ECBM 1 Acid Gas
Seismic
Sleipner CO2 store project 1994-2002
Reservoir Evaluation
The Mountaineer Plant

- 1.3 GW pulverized-coal unit
  - By barge/rail
- 8 Mton/y of CO₂
- NOₓ removal installed
- SOₓ removal planned for future
St Peters Sandstone
Rose Run Sandstone
Lower Marysville Dolomite & Sandstone
Can we monitor CO$_2$?

- Change in acoustic velocities, impedance < 8%
FRIO - monitoring experiment
DOE sponsored project

- Parties involved
  - BEG, Lawrence Berkeley, Sandia Technologies, NETL, ORNL
  - Schlumberger

- A test injection experiment, E. Texas
  - Frio formation
  - 5000 - 6000’
  - Monitoring well

- Real time monitoring
- Sampling while monitoring (USGS)

www.beg.utexas.edu
The location

High sand trend in the Frio

Power plants
Industrial sources

Pilot site

BRINE PILOT LOCATION

Bureau of Economic Geology

Houston

20 miles
Very modern facilities
TOUGH2 Model

Doughty, LBNL

New dip

Old dip
Pulsed Neutron Monitoring

Sigma vs CO2 Saturation at 100ppk Brine

Hydrogen Index vs CO2 Saturation at 100ppk Brine
Sigma increase after 5.run → salinity equalization (fresh completion water with saline formation water)

Run 5&6: constant temperature

Borehole salinity: run 1 high, run 5&6 fresh water

6.run: pressure gradient in borehole: water gradient

1-6 Time Lapse
Monitoring vs. Simulation

LBNL + Schlumberger
Safety
Area Well Data (Meigs County)
Portland cement reactions with CO$_2$

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} & \rightleftharpoons \text{H}_2\text{CO}_3 & \rightarrow \text{H}^+ + \text{HCO}_3^- \\
\text{Ca(OH)}_2 + \text{H}^+ + \text{HCO}_3^- & \rightarrow \text{CaCO}_3 + 2\text{H}_2\text{O} \\
\text{C-S-H phase} + \text{H}^+ + \text{HCO}_3^- & \rightarrow \text{CaCO}_3 + \text{amorphous silica gel} \\
\text{CO}_2 + \text{H}_2\text{O} + \text{CaCO}_3 & \rightarrow \text{Ca(HCO}_3)_2 \\
\text{Ca(HCO}_3)_2 + \text{Ca(OH)}_2 & \rightleftharpoons 2\text{CaCO}_3 + \text{H}_2\text{O}
\end{align*}
\]
Portland cement is unstable thermodynamically (moist CO$_2$).
Industry specifications—lacking
Development of standard testing conditions
Reaction Fronts

N-280-44

[Image: Microscopic images showing reaction fronts with labels: Carbonation Front, Dissolution Back Front, Unaltered Cement, Dissolution Front. Scale bars indicate 750 μm.]
Simulation
Trapping mechanisms for CO$_2$

- Geologic trapping
- Solution trapping
- Mineral trapping
- Residual gas, multiphase flow trapping
Contour plots of CO2 saturation contd

14 days

213 days

1.05 years

6.1 years
External Participation

- GCEP at Stanford, CA, USA
- IPGP, France
  - Mineral sequestration
- CO2CRC, Australia
  - Field Projects
  - Consortium
- TxEC
Can the Oil and Gas Industry Help

- Planning and operation is analogous to oil & gas
  - Upstream and downstream roles are reversed

- Size and scope of CO$_2$ sequestration is vast
  - Cost reduction is essential

- Safety and public trust is vital

- How is it going to be paid?
  - Trading based on caps?
  - Carbon tax?