Key technologies and solutions in providing reliable and efficient CO2 geological storage services

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CO2 Capture and Geological Storage

CO2 Streams
- Coal and Gas Power Plants
- Associated gas production
- LNG process
- Gas-to-Liquid process
- Heavy Oil production
- Coal-to-Liquid process
- Hydrogen
- Refineries
- Heavy industry
  - Steel mills
  - Cement factories
  - Aluminum mills

Saline Aquifers

Oil and Gas Production

CO2 Injection

Cap Rock

CO2 Separation

N2

Other Pollutants

Oil and Gas Reserves

Deep Coal Bed
# The CCS Cost (or Value!) Chain

<table>
<thead>
<tr>
<th>Capture</th>
<th>Transport</th>
<th>Storage</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>$20 - 50/t CO₂</td>
<td>$1 - 10/t CO₂</td>
<td>$2 - 10/t CO₂</td>
<td>$0.1 - 0.3/t CO₂</td>
</tr>
</tbody>
</table>

### IPCC Estimations:
- NGCC $44/t CO₂
- PC $29/t CO₂
- IGCC $20/t CO₂

**Sensitive to Energy prices**

### Distance dependent
- IPCC: (500km)
  - Ships $10/t CO₂
- Hydro: (250km)
  - Pipeline: 230M$  
  - University of Newcastle  
  - Pipeline 570M$/y

### Sensitive to Reservoir quality
- IPCC: Aquifer  
  - $0.5 - 8/t CO₂  
  - Pöyry: Aquifer  
    - $2/t CO₂  
    - Gas or oil field  
    - $9.5/t CO₂

### Remediation not included
- IPCC: $0.1 - 0.3/t CO₂  
- Benson et Al 2006  
  - $0.16/t CO₂  
- Remediation not included
An Integrated Solution to CO2 Storage

Site Selection | Site Characterization (SCP) | Field Design

Pre-Operation Phase
- ~ 2-5 years

Operation Phase
- ~ 10-50 years

Post-Injection Phase
- ~50-100+ years

Performance & Risk Management System (PRMS)
Communication and Public Acceptance

Site Construction / Site Preparation

Injection
- Monitoring (M&V)
  - Operation
  - Verification

Site Retirement Programme (SRP)
- Environmental
Performance & Risk Management System

Performance & Risk Assessment
- Functions / Stakes:
  - Capacity
  - Injectivity
  - Containment

Risk Treatment
- Prevention Remediation:
  - Cost
  - Environment
  - Health & Security
  - Image

Measurement for Characterization

Modeling

Monitoring Measurements
- Construction Technologies & Interventions

Regulatory Framework

Risk Treatment
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Regulatory Framework
Initial Assessment – Site Characterization

- Geophysics / Geology
- Petrophysics / Mineralogy
- Geomechanics
- Fluid Properties
- Well Integrity

Data Collection & QC

Sequence, Stratigraphy & Property Model
Dynamic Modeling
(flow, geomechanics, geochemistry)

Injectivity  Capacity  Containment

From CO2CRC – Latrobe Valley Study
Model needs to include overburden
CO2 Injection Dynamic Modeling

- Thermodynamics
- Geochemistry
- Thermal Modeling
- Geomechanics Simulator

ECLIPSE – E300
Calibration on monitoring measurements (History match)

3D Full Compositional Flow Simulator

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Capacity – Measurements

Structure

- High-Resolution Seismic, VSP’s and Sonic

Properties

- Borehole imagers
- Mineralogy
- Formation Evaluation
Injectivity

- Permeability
  - Core
  - Logs
  - Formation testers
  - Well tests

- Injection induced near-wellbore effects
  - Dry-out
  - Salt precipitation – Carbonate dissolution

- Optimization
  - Injection well design, placement and number
  - Hydraulic fracturing
Injectivity - Measurements

- Permeability from Wireline Logging
- Permeability from Well Testing
Containment

- **Caprock & Overburden**
  - Hydrostratigraphy
  - Composition
  - Mechanical properties
  - Flow properties

- **Faults**
  - Transmissibility
  - Mechanical Properties

- **Wells**
  - Completions state
  - Isolation issues
  - Degradation mechanisms

Importance of reservoir **geomechanics** and evaluation of **wells**

(from Latrobe Valley study, CO2CRC, 2005)
Along the wellbore trajectory:

**Elastic**
- Young’s Modulus
- Poisson’s Ratio

**Strength**
- UCS
- Friction Angle

**Earth Stress & Pore Pressure**
- Stress
- Stress Direction
- Regional Trend
An Integrated Solution to:
- Leakage and Degradation Modeling
- Leakage scenarios
- Risk criticality estimation

Can we re-use existing wells?
More data needed?
Probability of leakage
Type of leakage to expect

Conclusions

Sensitivity analysis
Risk mitigation options
Cost / Benefits ranking

Data & input
- Characterisation
  - Cement logs
  - Drilling reports
  - Well geometry

Dynamic model
- Cement degradation
- Casing corrosion
- CO2 migration
- Limit conditions

Leak amount & probability

Stakes
- Level
  - Minor
  - Weak
  - Middle
  - High
  - Critical

Consequence grid & transfer function

Detection
Evolution

Risk mitigation options
Cost / Benefits ranking
Containment – Integrity of Wells (2)

**Prevention**
- Good drilling practices
- Optimal Well Placement
- Cement job planning

**Materials**
- Metallurgy
- CO2-Resistant cement

**Evaluation**
- Sonic Scanner
- Isolation Scanner

**GeoSteering**
- Stonefish

**WellCLEAN**
- 2 days
- 1 week
- 6 weeks
# Monitoring and Verification during CO2 Injection

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<th>Geophysical techniques:</th>
<th>Seismic, VSP’s, EM techniques, microseismicity</th>
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<td>Logging:</td>
<td>Saturation (Resistivity, Sigma), Well integrity (Casing corrosion, cement bond)</td>
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<tr>
<td>Sampling:</td>
<td>Pressure, Fluid properties, CO2 concentration</td>
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<td>Permanent sensors:</td>
<td>Pressure, Temperature</td>
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*Schlumberger Carbon Services*
CO₂ Displacement from Seismic - Sleipner

- Interpretation of flow patterns (CO₂ displacement and trapping)
- Verification of cap rock integrity

CO₂ Injection Start: Sept 1996
4D Seismic Survey

Baseline Survey

CO₂ Injector Well
CO₂ below shale layers

Courtesy of Statoil
Well Logging for CO2 Breakthrough – Frio

CO₂ saturation measurement along a monitoring well
Frio brine experiment in Texas: Changes of Σ from time lapse logs

Injection start: Oct 4th,
Injection duration: 10 days

(*) Sakurai et al., SPWLA 46th – June 26-29th - 2005
Cap Rock & Fault Integrity

Microseismicity events are micro cracks occurring in the formation due to pressure increase

Listening to these cracks is a powerful monitoring technique

- Detection, Location in 3D and Classification of Microseismicity Events
- Control of Pumping Rate to Avoid Fracturing the Cap Rock
- Detection of Fault Reactivation
Schlumberger involved CO2 Storage Projects
Conclusions

• Key Technologies focus on:
  • Capacity-Injectivity-Containment
  • Long term storage integrity

• Key Technologies are
  • Measurement (surface and downhole in wells)
  • Modeling (static-dynamic-predictive)
  • Well Construction (drilling, cementing, completions, remediation)

• The Technology is ready!
  • But continuous investment in Engineering and Learning While Doing
Thank You!