CO₂ Sequestration Market Development

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Comparative Scope

• Inject 41 MtCO₂/yr for enhanced oil recovery
  • Output of six 1000-Mw coal-fired plants
  • Moved safely hundreds of miles via pipeline
• 50 U.S. oilfields that produce >150,000 bbl fluid per day
  • Output of a 1000-Mw coal-fired plant
• No huge technical barriers to geologic storage of CO₂
  • But...EOR experience has been focused on the oil, not the CO₂
• Non-technical challenges, on the other hand, are huge
### Similarities / Differences with Oilfield

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injectivity</td>
<td>Seal</td>
</tr>
<tr>
<td>Containment</td>
<td>Closure</td>
</tr>
<tr>
<td></td>
<td>Source</td>
</tr>
<tr>
<td></td>
<td>Timing</td>
</tr>
<tr>
<td></td>
<td>Access</td>
</tr>
</tbody>
</table>

### Other Similar Settings

<table>
<thead>
<tr>
<th>Natural gas storage</th>
<th>UIC / Acid Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller volumes</td>
<td>Regulation built to protect potable water</td>
</tr>
<tr>
<td>Shorter term focus</td>
<td>Regulated by EPA, not O&amp;G</td>
</tr>
<tr>
<td>Losses accepted</td>
<td>No verification required</td>
</tr>
<tr>
<td>Use eminent domain</td>
<td>Limited “area of influence”</td>
</tr>
</tbody>
</table>
Performance and Risk Management

- Regulatory Framework
- Performance & Risk Assessment
  - Capacity
  - Injectivity
  - Containment
- Risk Treatment
  - Cost
  - Environment
  - Health & Security
  - Image
- Actions
  - Functions / Stakes
    - Cost
    - Environment
    - Health & Security
    - Image

Measurement for Characterization → Modeling → Monitoring Measurements

CO2 Injection Dynamic Modeling

- Improved fluid-fluid / fluid-rock interactions
- Accurate description of mutual solubilities
- Dry-out / salting-out effect
- Salt precipitation
- Swelling and shrinkage

ECLIPSE – E300

Upscaling

Calibration on monitoring measurements (History match)

Thermodynamics
Geochemistry

Thermal Modeling

Geomechanics Simulator

3D Full Compositional Flow Simulator
### Commercial-Scale Storage Timeline

<table>
<thead>
<tr>
<th>Possible site</th>
<th>Probable site</th>
<th>Proven site</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data</strong></td>
<td><strong>acquisition</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Detailed</strong></td>
<td><strong>characterization</strong></td>
<td></td>
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<tr>
<td>Design</td>
<td></td>
<td></td>
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<tr>
<td>Monitoring</td>
<td></td>
<td></td>
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<tr>
<td>Validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection &amp; monitoring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model update</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equalization</td>
<td></td>
<td></td>
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<tr>
<td>Long term Environmental monitoring</td>
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</tr>
</tbody>
</table>

#### Performance & Risk

Functions: Capacity, Injectivity, Containment >>> Stakes: HSE, Cost, Image

- **High**
- **Low**

#### Time

- 1 yr
- 2-3 yrs
- 5-7 yrs
- 30 yrs
- 50 yrs
- 100+

#### Total cost & uncertainty

- Prelim. study
- Detailed characterization
- Data acquisition
- Construction
- Includes time for plant construction
- Detailed characterization
- Data acquisition
- Validation
- Injection & monitoring

### What Resources Will Be Needed?

#### People & Technology

- Geology
- Reservoir Engineer
- Petrophysics
- Geomechanics
- Hydrogeology
- HSE
- Project Management
- Geophysics
- Drilling Engineer
- Completion Engineer
- Geochemistry
- Economics
- Injection
- Tools for Team Integration

#### CO2 Technology

- Seismic Services
- Wellbore Integrity Evaluation
- Drilling & Completion
- Cementing
- Logging, Testing & Sampling
- Lab Analysis
- Data Processing
- Modeling & Prediction
- Data Management
- Monitoring
Non-Technical Needs

- Carbon value
- Pore ownership ruling
- Regulatory environment
  - Defined area of review
- Long-term liability
  - Insurance framework

Education Needs

- Sources
  - Comfort with the “risk” element
  - Coordinated timing on siting decisions
  - Working with PUCs
  - Parasitic load
- Public
  - What happens to the water?
  - Other long-term dangers
  - Value to them vs. cost
  - Communication methodology
Conclusion

- Good technology is available today
- Technology choices can impact risk
- High quality modern data sets need to be gathered prior to injection
- The integration of technologies with modeling tools is a skill
- Modeling tool selection is an important consideration

Keys to Success

- Pick the Right Site
  - Non-complex, depth, porosity, perm, extent, structure, caprock...
  - Some existing wells, but not too many
  - Access and capability for: 3-D seismic acquisition, logs, core, fluids, background
- Use the Right Technology
  - Proper density, resolution, noise limits, area of review
  - Value equivalent uncertainty reduction
  - Has impact on performance and risk
- Properly Integrate the Data
  - Requires an experienced, skilled, multi-disciplinary team
  - Unified modeling environment
  - Shared earth model, easily updatable - “Living”
Going Forward

- Non-technical factors are the key to progress
- Clear regulatory guidelines and long-term liability protection are needed for commercial involvement
- Resource requirements will be large
- Uncertainties can be managed with technology
- Expertise and technology must be valued and respected
- Thorough assessment and baseline characterization is the key to reducing cost
  - number of wells
  - frequency of monitoring
  - public acceptance