Cost Analysis Associated with Capture, Transport, Utilization, and Storage of CO$_2$

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• Introduction
• Current Models
  – FE/NETL CO₂ Saline Storage Cost Model (CO₂ Storage Cost Model)
  – FE/NETL CO₂ Transport Cost Model (CO₂ Transport Cost Model)
• Carbon Capture, Utilization, and Storage (CCUS) Modeling
• Life Cycle Analysis
• Models Under Development
• Ongoing Initiatives (Analogs, Economics, Geology)
• Conclusions
Carbon Capture Utilization & Storage

• Current Active Models
  – FE/NETL CO$_2$ Saline Storage Cost Model
  – FE/NETL CO$_2$ Transport Cost Model

• Model Development
  – FE/NETL Offshore CO$_2$ Saline Storage Cost Model
  – FE/NETL CO$_2$ Prophet
  – FE/NETL CO$_2$-EOR Cost Model
    - Will be adapted for offshore application

• Life Cycle Analysis Models
  – CO$_2$-EOR Life Cycle (CELiC) Model

• Ongoing Work
  - Analysis with or without use of models
• Introduction
• **Current Models**
  – CO$_2$ Storage Cost Model
  – CO$_2$ Transport Cost Model
• CCUS Modeling
• Models under development
• Life Cycle Analysis
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• Ongoing Initiatives (Analogs, Economics, Geology)
• Conclusions
Current Models

- **CO₂ Storage Cost Model**
  - Designed to meet Class VI regulations, estimate cost of compliance
  - Geologic database representative of geologic section in numerous basins
  - Can model storage costs for a single reservoir or multiple reservoirs
  - Model assumes successful operations

- **CO₂ Transport Cost Model**
  - Point-to-point transport cost modeling
## 

### CO₂ Storage Cost Model

<table>
<thead>
<tr>
<th>Site Screening</th>
<th>Site Selection &amp; Characterization</th>
<th>Permitting &amp; Construction</th>
<th>Operations</th>
<th>PISC &amp; Site Closure</th>
<th>Long-Term Stewardship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>UIC Class VI Regulations</td>
<td>Class VI Permit</td>
<td>Developing state regulations</td>
</tr>
<tr>
<td>0.5 to 1 year</td>
<td>3+ years</td>
<td>2+ years</td>
<td>30 to 50 years</td>
<td>10 to 50+ years</td>
<td>Rest of civilization</td>
</tr>
</tbody>
</table>

- **Gather existing data; develop several prospects**
  - Select a site; acquire new data (drill wells, shoot seismic); prepare permitting plans
  - Permit awarded to drill/test injection wells; final approval to begin injection; install MVA network
  - Inject CO₂; remediate existing wells as needed; new monitoring wells as needed; conduct MVA
  - Monitor site per plan; maintain financial responsibility; establish non-endangerment; close and restore site

- **Assemble acreage block (surface access/pore space)**
  - Secure financial responsibility upon permit application; as required, maintain financial responsibility through operations and PISC

- 25% success rate assumed
- Pay $/tonne fees* 
- Negative cash flow
- Positive cash flow
- Negative cash flow
- Covered by fee paid during ops

*Per tonne cost associated with several cost items: long-term stewardship (state sets rate), insurance to cover emergency & remedial response (financial responsibility), a per/tonne “royalty” to pore space owner
CO$_2$ Storage Cost Model

Cost Drivers:

- **Reservoir quality**
- **Areal extent of plume**
  - Area of review
  - Drives monitoring costs
    - Monitoring wells
    - Seismic
  - Corrective action
  - Financial responsibility
- **Injection**
  - Annual mass of CO$_2$ injected
  - Number of injection wells
  - Class VI permit
CO₂ Storage Cost Model

- Storage resource potential exists across continental United States
- Geo-database: 87 formations in 36 basins across 27 states
- Quality of these potential reservoirs is variable
CO₂ Transport Cost Model

- Two pipeline networks: dedicated pipeline system and trunkline pipeline system
  - Straight line segments routed through modeled storage sites
  - Trunkline hubs 30 mi (48 km) from storage sites
- CO₂ Transport Cost Model was used to estimate all pipeline transportation costs
  - Cost based on mass of CO₂ transported, transport distance, and elevation at each end of the pipeline
  - Pipeline diameter and number of booster pumps were determined by the model
  - Five trunkline capacities with pipe diameters of 12 in to 36 in were modeled

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CCUS Modeling

Four Basin Study

- Provide storage and transport costs for CCUS modeling
- Source using local coal

CCUS Modeling
Four Basin Study

- Increased percentage of cost during permitting for Red River and Madison due to increase in drilling and completion costs for a deeper reservoir.
- Madison reservoir is deepest of the four modeled here, plus it requires more than double the injection wells.
CCUS Modeling
Four Basin Study

- Cumulative storage potential cost supply curve for each basin
- CO₂ capture curve for electric and industrial sources suggests sufficient potential storage

Pipeline configuration
- 3.2 Mt/yr CO₂
- 100 km (62 mi) distance
- 2,200 psig inlet, 1,200 psig outlet

**Table**

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<thead>
<tr>
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<tbody>
<tr>
<td>Midwest</td>
<td>Illinois</td>
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<tr>
<td>Texas</td>
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<td>Williston</td>
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<td>Powder River</td>
<td>22.72</td>
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<td>25.00</td>
<td>25</td>
</tr>
</tbody>
</table>

CCUS Modeling
Dedicated Pipeline System vs. Trunkline Pipeline System

CCUS Modeling
Dome Structure

- MS6 low cost CCS for both pipeline systems
- Dedicated pipeline lowers cost to Mt. Simon over trunkline – by $1-$2
  - Dedicated 254 mi (408 km)
  - Trunkline 512 mi (824 km)
- Source at W200 has storage options
  - Multiple reservoirs at small cost difference


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Storage Activity Life Cycle Analysis
July 2017 to July 2018 Accomplishments

- Outreach – Presentations at LCA conference on *Net Energy Analysis of CO₂-Enhanced Oil Recovery (EOR)* and *CO₂-Enhanced Methane Recovery* (October 2017)

- A public version of the CO₂-EOR Life Cycle (CELiC) Model will be finalized (September 2018)

- Expanded life cycle inventories for two models: saline aquifer storage and CO₂-EOR
Storage Activity Life Cycle Analysis (cont’d)

Upcoming Work

- Abstract accepted for LCA XVIII – Ft. Collins, CO – the life cycle interactions of saline aquifer characteristics and location
- Variability of environmental impacts of anthropogenic CO$_2$-EOR due to variability in EOR reservoirs and changing U.S. electricity generation mix
- Environmental impacts of transition from anthropogenic CO$_2$-EOR to saline aquifer storage (Class II to Class VI)
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FE/NETL Offshore CO₂ Saline Storage Cost Model

- **Water Depth**
  - More steel

- **Distance from Shore**
  - Longer pipeline
  - Travel distance

- **Plume area**
  - Place onshore challenges under water

- **Injection wells**
  - Directional drilling

- **DOI (BOEM/BSEE)**
  - Regulatory oversight
FE/NETL CO₂ Prophet Model

- Simplified pattern-oriented streamline / stream tube black oil reservoir simulation program originally developed by Texaco E&P for DOE in early 1990s
  - Very fast, can simulate 30 years of CO₂ EOR operations in 5 to 20 seconds per pattern
  - Uses too little CO₂ to produce a barrel of oil (too efficient) and, consequently, stores too little CO₂
- Program recently updated so CO₂ needed to extract oil is more realistic
- Currently completing calibration of key variables using field data from 25 CO₂ EOR sites
FE/NETL CO₂ EOR Model

<table>
<thead>
<tr>
<th>Regional evaluation for a specific site</th>
<th>Site selection &amp; characterization</th>
<th>Permitting</th>
<th>Operations</th>
<th>Post-Injection Monitoring</th>
<th>Long-term Stewardship</th>
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</table>

| 0.5 to 1 year | 3+ years | 2+ years | 30 to 50 years | 10 to 50+ years | Rest of Civilization |

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<tr>
<th>Prospect Screening</th>
<th>Facility/Field Design</th>
<th>Facility/Field Construction</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical and economic: - Reservoir &amp; recoverable oil - Facilities &amp; costs</td>
<td>Wells, processing plant, pipelines, pattern development, etc. Permitting, unitization, Contract for CO₂.</td>
<td>Drill/workover wells, build plant, install pipelines, connect with CO₂ source, etc.</td>
<td>Begin injection of CO₂. Production of oil, gas, CO₂ and water; Gas processing, separation. Recycling of CO₂, purchase new CO₂. Recycle/dispose of prod water as needed. O&amp;M. Closeout. P&amp;A wells at end.</td>
</tr>
</tbody>
</table>

| 1 to 2 years | 20 to 50 years |

FE/NETL CO₂ EOR Cost Model
- Uses Input-Output from CO₂ Prophet
- Field level cash flow analysis
- Brownfield or Greenfield (ROZ) analysis
- Eval up to 10 oil prices & 5 CO₂ cost values at each of the oil cost values
- Break-even cost of oil for a specific cost of CO₂
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Ongoing Work

• Analog Studies
  – Natural Gas Storage
  – Class I Injection
  – CO$_2$-EOR Leakage

• Co-Model with NRAP
  – NsealR

• ROZ Reservoir Data
  – Permian Basin
    • San Andres
    • Greyburg
  – Other Basins

• Water Withdrawal
  – Multi-basin
  – Update technology

• Economic Analysis
  – FutureGen2, Petra Nova
  – LaBarge/Shuttle Creek
  – Anthropogenic Sources
  – Investment preference

• Offshore modeling
  – Assess infrastructure
  – Initial assessment of costs

• Beta-testing EOR models
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• **NETL CCUS modeling is providing insight into the strengths and weaknesses of CCUS**
  – Four Basin study, CCS network analysis
  – LCA analysis

• **Other analysis provides knowledge on other factors that can impact CCUS**
  – Economic analysis of large scale project, CO₂ sources
  – Developing geologic data: for ROZ, for storage cost model (onshore & offshore)

• **Publicly available models are utilized by others to assess their own projects**
  – Expands CCUS analytical capabilities
  – Provides NETL feedback on models
Acknowledgements

• **NETL Research & Innovation Center**
  – Kristin Gerdes – Associate Director Systems Engineering & Analysis (SEA) Division
  – Peter Balash – Energy Systems Analysis Team (ESAT) Supervisor
  – Traci Rodosta – Environmental Sustainability in Science & Technology Strategic Plans & Programs

• **Mission Execution and Strategic Analysis (Contractors)**
  – KeyLogic Systems, Inc.
  – Leidos
  – Deloitte
  – Advanced Resources International (ARI)
Questions
Resources

• Link to FE/NETL CO₂ Saline Storage Cost Model

• Link to FE/NETL CO₂ Transport Cost Model

• Recent Publications: