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

Timothy Grant
DOE/NETL Energy Systems Analysis Team
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– Introduction
– CCS modeling in Northeast and Central United States
– Conclusions
– Other analyses/research
  • Onshore CO₂ storage
  • Offshore CO₂ storage
  • CO₂ storage economics modeling
  • Life cycle analysis
  • CO₂ storage efficiency factors refining
– Conclusions
Introduction

- Widespread deployment of CCS is crucial to manage/reduce emissions from anthropogenic sources
  - Large-scale CCS deployment is goal but only few fully-integrated projects are underway
- Individual projects are going to be “first movers” for CCS deployment; however, each project has its own unique business situation
- CCS network modeling can help but need network that considers site-specific challenges
  - NETL has capabilities to model these unique situations
- Completed CCS network analyses across areas of United States to evaluate integrated CCS costs ($/tonne) for different source, transportation, and storage scenarios
  - Capture costs: NETL’s Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, revisions 3 and 4 reports and Cost of Capturing CO\textsubscript{2} from Industrial Sources report
  - Transport costs: FE/NETL CO\textsubscript{2} Transport Cost Model
  - Storage costs: FE/NETL CO\textsubscript{2} Saline Storage Cost Model (CO\textsubscript{2} Storage Cost Model)
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Grant et al., 2018
Assess low-cost storage and transport options for CO₂ sources in northeastern United States and storage reservoirs within Appalachian, Gulf Coast Onshore, and Illinois basins using two transportation networks to evaluate integrated CCS costs

Guinan et al., 2020 (in development)
Assess low-cost storage and transport options for CO₂ sources in central United States (via 3 regional impact areas – Central, Northwest, and Gulf) using two transportation networks to evaluate integrated CCS costs
### CO₂ Sources – Both Studies

- **Northeast study**
  - 6 sources
  - 4 source locations near Rose Run 3 or Rose Run 4 reservoirs

- **Central study**
  - 4 sources
  - 7 source locations

- Source types provide range of capture rates and costs

<table>
<thead>
<tr>
<th>Study</th>
<th>CO₂ Source</th>
<th>Net Power or Product Output</th>
<th>CO₂ Captured (Mt/yr)</th>
<th>Capture Costs (2011/tonne Northeast, 2018$/tonne Central)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>NGPP</td>
<td>500 MMscf/d</td>
<td>0.65</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Cement plant</td>
<td>992,500 tonnes/yr</td>
<td>1.14</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>SCPC plant</td>
<td>550 MWₚₑₚ</td>
<td>3.58</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>482 MWₚₑₚ</td>
<td>3.14</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 MWₚₑₚ</td>
<td>2.60</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Steel plant</td>
<td>2.54 Mt/yr</td>
<td>3.90</td>
<td>99</td>
</tr>
<tr>
<td>Central</td>
<td>NGPP</td>
<td>500 MMscf/d</td>
<td>0.55</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Ethanol plant</td>
<td>50 Mgal/yr</td>
<td>0.12</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>SCPC plant</td>
<td>650 Mwₚₑₚ</td>
<td>4.33</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Cement plant</td>
<td>992,500 tonnes/yr</td>
<td>0.97</td>
<td>106</td>
</tr>
</tbody>
</table>

- Source locations provide range of transport distances and storage options for each source
CO$_2$ Storage Reservoir Quality

- Less disparity in storage reservoir quality in Central study compared to Northeast study
- High-quality storage reservoirs provide low storage costs
  - Highest quality – Lance 1 (LA1) (Central) and Frio 3a (FR3A) (Central and Northeast))
  - Lowest quality – Maha 01 (MA01) and Minnelusa 2 (MI2) (Central), Rose Run 4 (RR4) (Northeast)
- Storage reservoir quality provides possible trade-off in quality vs. proximity to source when selecting cost-effective storage reservoir
Economies of Scale – Pipeline/Trunkline

- Unit cost of transportation decreases with increasing mass of CO₂ transported
- As trunkline diameter increases, unit cost decreases
- Unit cost of transportation increases with distance for specific mass of CO₂ transported
- For specific pipeline/trunkline diameters, more booster pumps needed for increasing mass of CO₂ transported
Economies of Scale Benefit Large Sources

- Large capture rate helps decrease CCS costs across CCS value chain
- SCPC plant at same location as ethanol plant can save up to 83% on overall CCS costs in dedicated network and 58% in trunkline
- On average, cost savings in dedicated and trunkline networks are $501/tonne and $123/tonne, respectively
- CCS costs are more economical for larger sources than smaller sources if no local storage reservoirs
Local Storage Sometimes Best

- Local storage is sometimes favored over farther, better quality reservoirs
- Maha 01 (MA01) is farthest reservoir from cement plant in Northwest Impact Area at $172/tonne
  - $175/tonne for cement plant in Kansas to Frio 3a (FR3A), farthest reservoir in Gulf Impact Area
- Costs are comparable within each local impact area, so it is not economical for cement plant to travel to Gulf, even though there are inexpensive, better-quality reservoirs
- By staying local, lower quality and more expensive storage options become viable
Illinois Basin Optimal Storage Site

- Whether a source is in northeastern or central United States, Illinois Basin provides low CCS cost options
  - High-quality reservoirs that provide low storage costs

Northeast study – SCPC plant – Dedicated – Dome (E200)

Northeast study – NGPP – Dedicated – Dome (W200)

Central study (Central Impact Area) – NGPP – Dedicated – Dome

Central study (Gulf Impact Area) – SCPC plant – Dedicated – Dome

- Source location determines which Mt. Simon reservoir provides lowest CCS cost option
Location Can Be Important

- CCS cost for W200 location to Mt Simon 10 (MS10) with dedicated pipeline is cheaper than trunkline to Mt Simon 6 (MS6)
  - Decision for source on building dedicated pipeline or belonging to trunkline network
  - MS6, better quality reservoir and lowest cost in trunkline network, is only $1/tonne more than storing in MS10 in dedicated network
- Trunkline provides lower cost CCS for other storage sites
Conclusions (Part 1)

– CCS an important strategy to reduce greenhouse gas emissions while providing affordable and reliable energy
  • Large-scale deployment critical
  • Unique scenarios of each project provide challenges
– Economies of scale important but only go so far – there are limits in distance of transportation
  • Lowering cost of capture and/or storage can increase transport distance to optimal storage
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Onshore CO₂ Storage

- QGESS: CO₂ Transport and Storage
- SMART Task 5: Virtual Learning Platform
- Water production assessment
- CO₂ intermediate storage: overview and economic analysis
- Python conversion of CO₂ Storage Cost Model
- Modeling CO₂ EOR and associated storage

Permian Basin Stratigraphy

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>SERIES</th>
<th>PERMIAN BASIN - NORTHWEST SHELF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper Guadalupian</td>
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<tr>
<td></td>
<td></td>
<td>Ochoan</td>
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<tr>
<td></td>
<td></td>
<td>Tansill, Yates, Seven Rivers, Queen, Grayburg</td>
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<tr>
<td></td>
<td></td>
<td>Lower Guadalupian</td>
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<tr>
<td></td>
<td></td>
<td>San Andres</td>
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<tr>
<td></td>
<td></td>
<td>San Andres Upper, Lower</td>
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<tr>
<td></td>
<td></td>
<td>Glorieta/ San Angelo</td>
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<td></td>
<td></td>
<td>Lower Leonardian</td>
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<td></td>
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<td>Wolfcamp, Wolfcamp</td>
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<td></td>
<td></td>
<td>Aba</td>
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</tbody>
</table>

Impact of 45Q in NW Impact Area

- Co-modeling with NRAP
- 4-, 8-, 7-, 10-, and 12-county appraisals in San Andres and Grayburg ROZ in Permian Basin
- Evaluating impact of 45Q tax credit on CCS network costs
- Basin-scale modeling
Offshore CO₂ Storage

- Offshore CO₂ EOR case studies
  - Cognac, Petronius, Horn Mountain
- Offshore CO₂ EOR cost model development
- Multi-criteria CCUS screening framework of GoM outer continental shelf for high-priority storage regions
- Offshore CO₂ transportation assessment

Favorable Geology – Saline Storage Scenario
CO₂ Storage Economics Modeling

- Impact of NETL R&D and Tax Incentives on Price of CO₂: accepted for presentation at Annual Meeting of the Southern Economic Association, New Orleans, LA November 21-23, 2020
- Competitive Analysis of EOR for U.S. O&G Investment
- Economics of Offshore CCUS in GoM: met with Advisian O&G SMEs, Houston, TX, October 21-22, 2019

Economics of offshore CCUS in GoM

<table>
<thead>
<tr>
<th>CO₂ Capture (Onshore Only)</th>
<th>Transport (Onshore)</th>
<th>Coastal Staging</th>
<th>Transport (Offshore)</th>
<th>CO₂ Injection</th>
<th>CO₂ Monitoring</th>
<th>Oil Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Identification &amp; Concept Selection</td>
<td>Pipeline Construction (permitting, pipeline construction)</td>
<td>Compression Station (compression equipment)</td>
<td>Shipping (vessel cargo)</td>
<td>Surface Infrastructure Node (platform expansion / reduction, injection and production equipment)</td>
<td>Subsurface Monitoring (monitoring wells)</td>
<td>Oil separation / processing operations (CPFX only)</td>
</tr>
<tr>
<td>Capture &amp; Process (refining, purification)</td>
<td>Transport (CO₂, processing tanks, storage tanks, monitoring)</td>
<td>Pipeline Construction (permitting, pipeline construction)</td>
<td>Shipping (vessel cargo)</td>
<td>Surface Infrastructure Node (platform expansion / reduction, injection and production equipment)</td>
<td>Subsurface Monitoring (monitoring wells)</td>
<td>CO₂ Recycling Operations (CPFX only)</td>
</tr>
<tr>
<td>Capture &amp; Process (refining, purification)</td>
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</tr>
</tbody>
</table>

CO₂ price impact
Life Cycle Analysis

- **Completed work**
  - Machine-learning optimization of refinery products from Petroleum Refinery Life Cycle Model (PRELIM) to support CO₂ EOR modeling

- **Upcoming work**
  - Understanding variability in field level performance of CO₂ EOR operations on environmental results
  - Assessing CO₂ EOR consequential impacts with CO₂ EOR Life Cycle (CELiC) Model
  - Offshore saline aquifer storage LCA
CO₂ Storage Efficiency Factors
Refining

Challenge
– Storage efficiency values based on data prior to 2009; based on limited data set of relative permeability and residual saturation

Approach
– NETL-generated data from CO₂BRA will be used as inputs in TOUGH to estimate new CO₂ storage efficiency factors
– TOUGH, PetraSIM, and CO2-SCREEN will be implemented to update storage efficiency factors

Value
– Improved saline formation efficiency factors based on experimental data for targeted storage environments that support future versions of Carbon Storage Atlas
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Conclusions (Part 2)

– There are multiple ways to lower the cost of CCS and meet the challenge of deployment
  • E.g. Storage efficiency, better economics, LCA
  • Understand the magnitude of the task
    – Cost: capture, storage, transport
    – Economics: funding (45Q, etc.)

– Decision makers need to understand/see how to take advantage of economic and physical opportunities.
  • What does the challenge look like?
  • What opportunities present themselves?

– Research/analysis provides clarity
Acknowledgements

**NETL Research & Innovation Center¹**

Peter Balash – Acting Associate Director, Systems Engineering & Analysis Directorate
Luciane Cunha – Supervisor, Energy Systems Analysis Team (ESAT)
Mark McKoy – Detail, Environmental Sustainability in Science & Technology Strategic Plans & Programs
Justin Adder, NETL SubCLIN 202 Contracting Officer’s Representative
Donald Remson, NETL SubCLIN 205 Contracting Officer’s Representative
Angela Goodman, NETL Technical Project Monitor
David Morgan, NETL Technical Project Monitor
Chris Nichols, NETL Technical Project Monitor
Timothy Skone, NETL Technical Project Monitor
Marty Webler, BMS Technology Development & Integration Center

**Mission Execution and Strategic Analysis (Contractors)**

Elizabeth Basista²  
Joseph Chou²  
Greg Cooney²  
Allison Guinan³  
Amanda Harker-Steele²  
Rachel Hoesly²  
Arun Iyengar²  
Matt Jamieson²  
Yash Kumar²  
Vello Kuuskraa⁵  
Shangmin Lin⁴  
Elise Logan⁴  
Annie Oudinot⁵  
Aileen Richardson⁴  
Chung Yan Shih³  
Alana Sheriff²  
Merril Stypula⁴  
Derek Vikara²  
Matthew Wallace⁵  
Travis Warner²  
Anna Wendt²  
Connie Zaremsky²

¹NETL; ²KeyLogic Systems, LLC; ³Leidos; ⁴Deloitte; ⁵Advanced Resources International
Questions?
Resources and Recent Publications

Public Reports
- CO₂ Leakage During EOR Operations - Analog Studies to Geologic Storage of CO₂
  https://www.netl.doe.gov.energy-analysis/details?id=2893
- Cognac Offshore Oil Field Case Study
  https://netl.doe.gov.energy-analysis/details?id=bb6c34f2-e9d3-4a5f-8ec3-674f18872ac4
- Comparative Analysis of Transport and Storage Options from a CO₂ Source Perspective
  https://www.netl.doe.gov.energy-analysis/details?id=2894
- Horn Mountain Offshore Oil Field Case Study
  https://netl.doe.gov.energy-analysis/details?id=d225d48f-670d-4928-91a1-4a8f1939b492
- Petronius Offshore Oil Field Case Study
  https://netl.doe.gov.energy-analysis/details?id=859368e8-26b9-46c8-8b3a-b701b0a0e6d8
- Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies
  https://netl.doe.gov.energy-analysis/details?id=3743
- UIC Class I Injection Wells - Analog Studies to Geologic Storage of CO₂
  https://www.netl.doe.gov.energy-analysis/details?id=2892
- Underground Natural Gas Storage - Analog Studies to Geologic Storage of CO₂
  https://www.netl.doe.gov.energy-analysis/details?id=2867

December 2019 News Release
- NETL Develops Flexible Carbon Capture, Utilization and Storage Analysis Tools and Resources
  https://netl.doe.gov/node/9384

Papers
- Assessing Key Drivers Impacting the Cost to Deploy Integrated CO₂ Capture, Utilization, Transportation, and Storage (CCUS) – USAEE (2018)
  https://www.iaee.org/proceedings/conference/101
- Comparative analysis of transport and storage options from a CO₂ source perspective – IJGHGC (2018)

Models/Tools
- FE/NETL CO₂ Saline Storage Cost Model
  https://www.netl.doe.gov.energy-analysis/details?id=2403
- FE/NETL CO₂ Transport Cost Model
  https://www.netl.doe.gov.energy-analysis/details?id=543
- StrmtbFlow Fortran Program (FE/NETL CO₂ Prophet Model)
  https://netl.doe.gov.energy-analysis/details?id=1d610037-b606-4434-8d77-256ea4b267ce
- StrmtbGen Fortran Program (FE/NETL CO₂ Prophet Model)
  https://netl.doe.gov.energy-analysis/details?id=c9dd82f2b0854c69-a517-372a5e6c3843