Cost Analysis Associated with Capture, Transport, Utilization, and Storage (CTUS) of CO_2

Timothy Grant

DOE/NETL Energy Systems Analysis Team

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage

2020 Virtual Project Review Meeting

September 8-11, 2020

Disclaimer

These studies were prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed therein do not necessarily state or reflect those of the United States Government or any agency thereof.

All images in this presentation were created by NETL, unless otherwise noted.

- **Introduction**
- CCS modeling in Northeast and Central United States
- Conclusions
- Other analyses/research
  - Onshore CO_2 storage
  - Offshore CO_2 storage
  - CO_2 storage economics modeling
  - Life cycle analysis
  - CO_2 storage efficiency factors refining
- Conclusions

Introduction

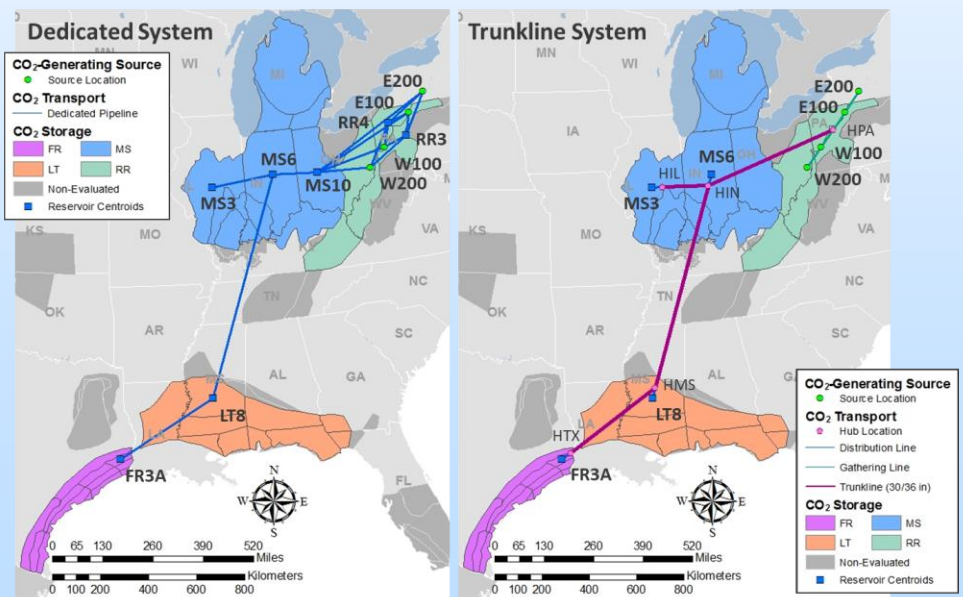
- Widespread deployment of CCS is crucial to manage/reduce emissions from anthropogenic sources
  - Large-scale CCS deployment is goal but only few fully-integrated projects are underway
- Individual projects are going to be "first movers" for CCS deployment; however, each project has its own unique 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_2 from Industrial Sources report
  - Transport costs: FE/NETL CO_2 Transport Cost Model
  - Storage costs: FE/NETL CO_2 Saline Storage Cost Model (CO_2 Storage Cost Model)

- Introduction
- **CCS modeling in Northeast and Central United States**
- Conslusions
- Other analyses/research
  - Onshore CO_2 storage
  - Offshore CO_2 storage
  - CO_2 storage economics modeling
  - Life cycle analysis
  - CO_2 storage efficiency factors refining
- Conclusions

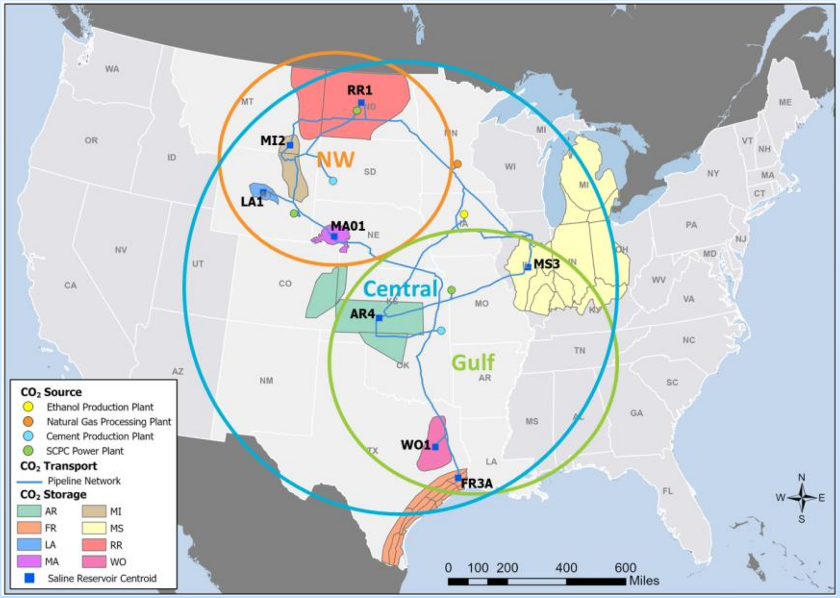
CCS Network Analyses

Grant et al., 2018
Assess low-cost storage and transport options for CO_2 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 CO_2 sources in central United States (via 3 regional impact areas – Central, Northwest, and Gulf) using two transportation networks to evaluate integrated CCS costs



Northeast study



Central study

CO_2 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

Study	CO_2 Source	Net Power or Product Output	CO_2 Captured (Mt/yr)	Capture Costs (2011/tonne Northeast, 2018$/tonne Central)
Northeast	NGPP	500 MMscf/d	0.65	18
	Cement plant	992,500 tonnes/yr	1.14	100
	SCPC plant	550 MW_{net}	3.58	58
		482 MW_{net}	3.14	59
		400 MW_{net}	2.60	61
	Steel plant	2.54 Mt/yr	3.90	99
Central	NGPP	500 MMscf/d	0.55	21
	Ethanol plant	50 Mgal/yr	0.12	35
	SCPC plant	650 Mw_{net}	4.33	66
	Cement plant	992,500 tonnes/yr	0.97	106

- Source types provide range of capture rates and costs
- Source locations provide range of transport distances and storage options for each source

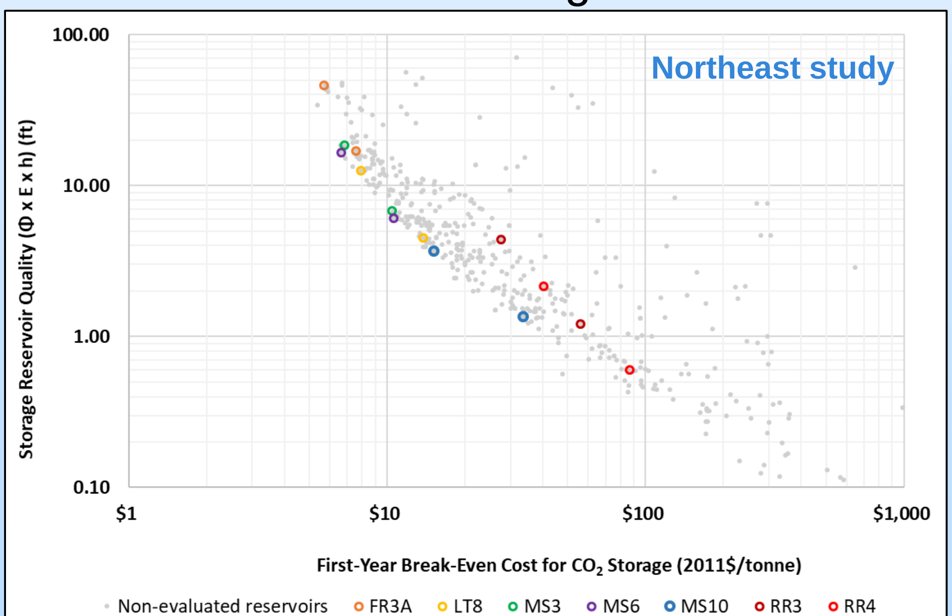
CO_2 Storage Reservoir Quality

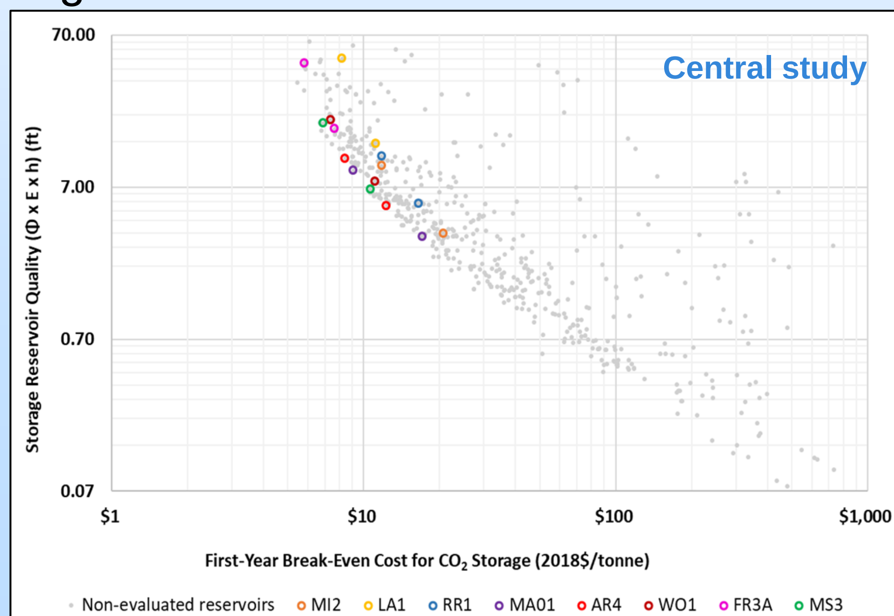
– Less disparity in storage reservoir quality in Central study compared to Northeast study

– 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)

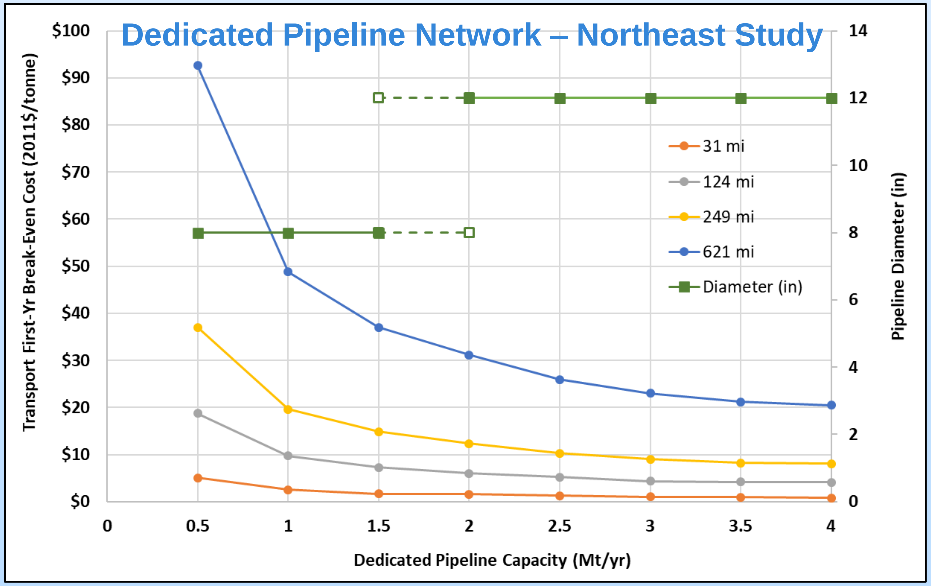
– Storage reservoir quality provides possible trade-off in quality vs. proximity to source when selecting cost-effective storage reservoir

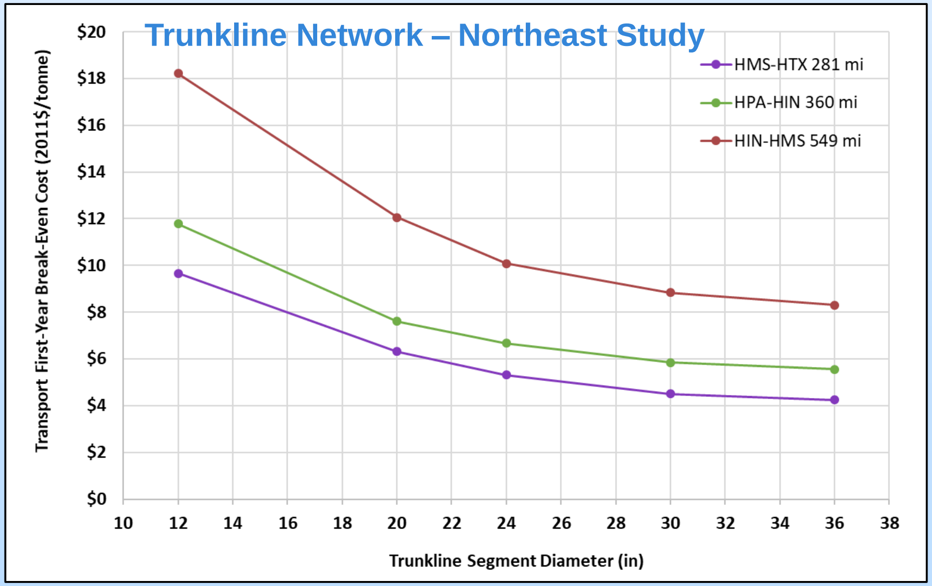




Economies of Scale – Pipeline/Trunkline

- Unit cost of transportation decreases with increasing mass of CO_2 transported
- As trunkline diameter increases, unit cost decreases
- Unit cost of transportation increases with distance for specific mass of CO_2 transported
- For specific pipeline/trunkline diameters, more booster pumps needed for increasing mass of CO_2 transported

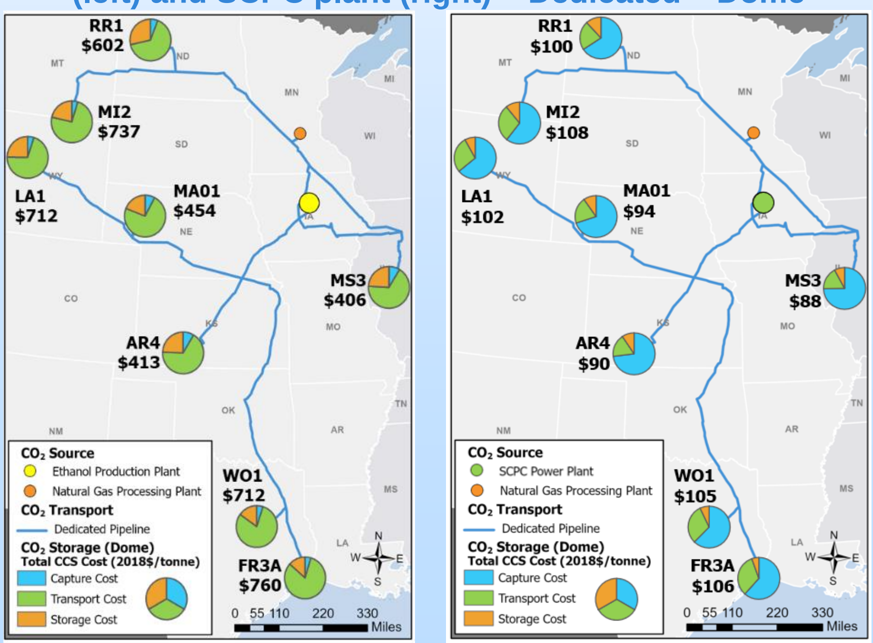




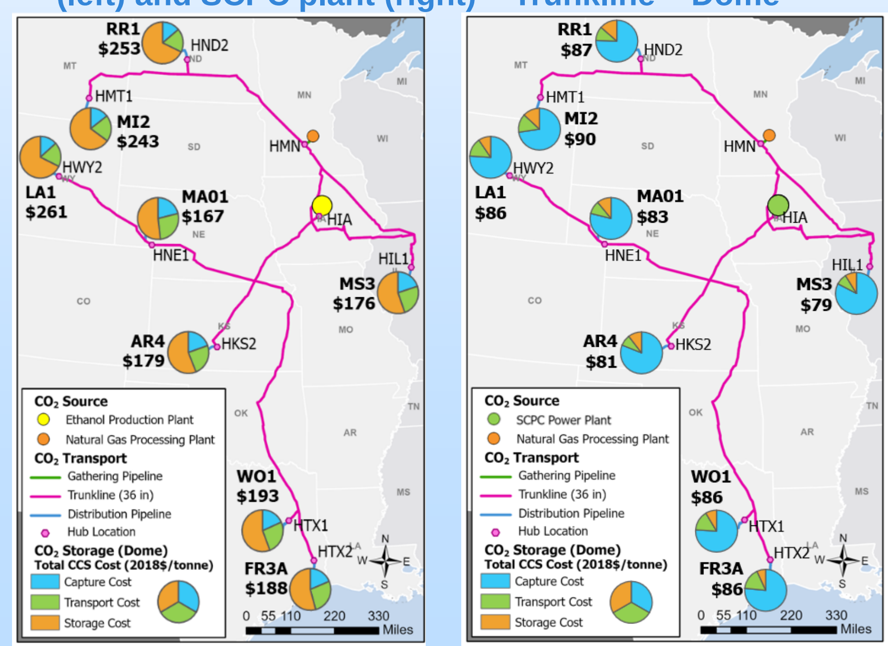
Economies of Scale Benefit Large Sources

- 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

Central study (Central Impact Area) – Ethanol plant (left) and SCPC plant (right) – Dedicated – Dome

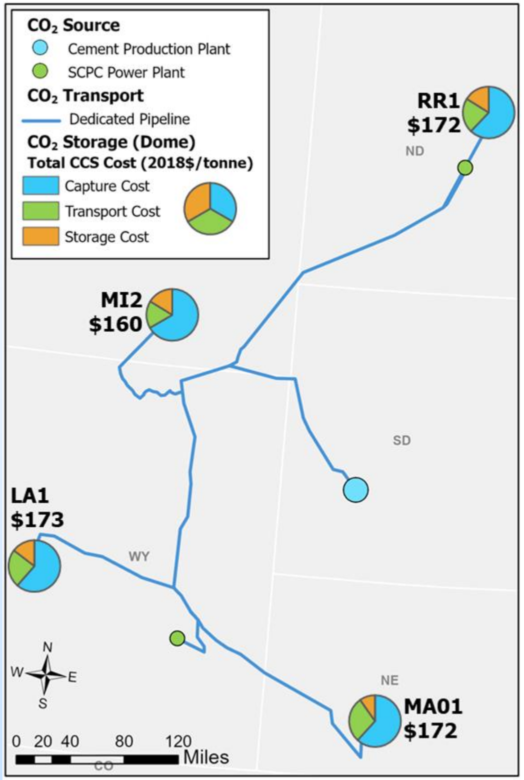


Central study (Central Impact Area) – Ethanol plant (left) and SCPC plant (right) – Trunkline – Dome



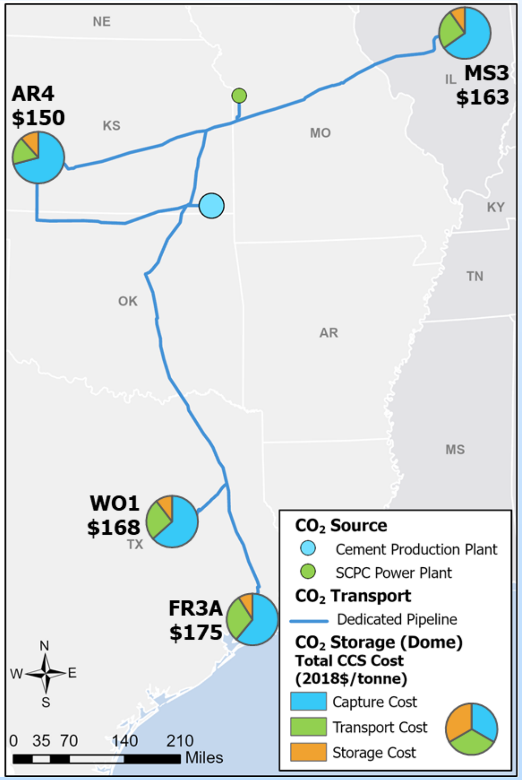
Local Storage Sometimes Best

- 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



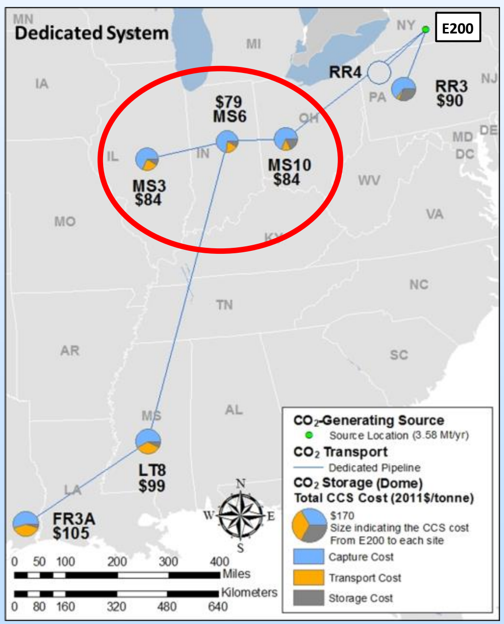
Central study (Central Impact Area) – Cement plant – Dedicated – Dome

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

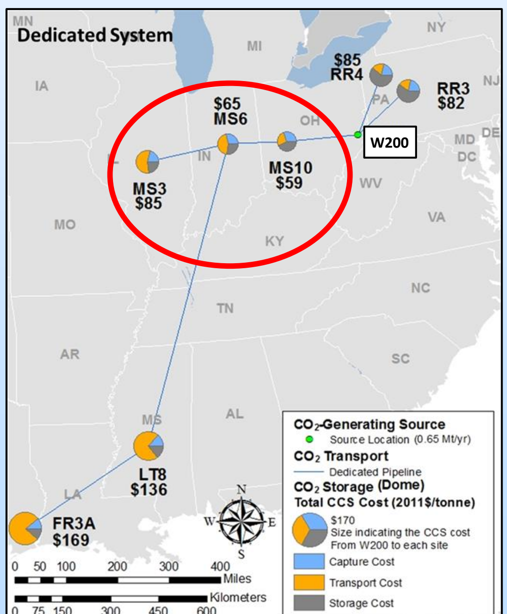


Illinois Basin Optimal Storage Site

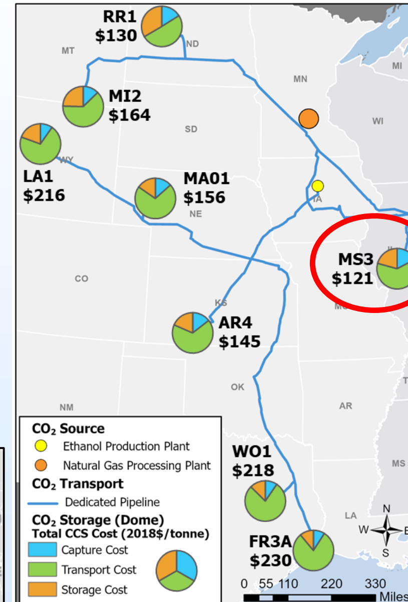
– Whether a source is in northeastern or central United States, Illinois Basin provides low CCS cost options
  - High-quality reservoirs that provide low storage costs



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

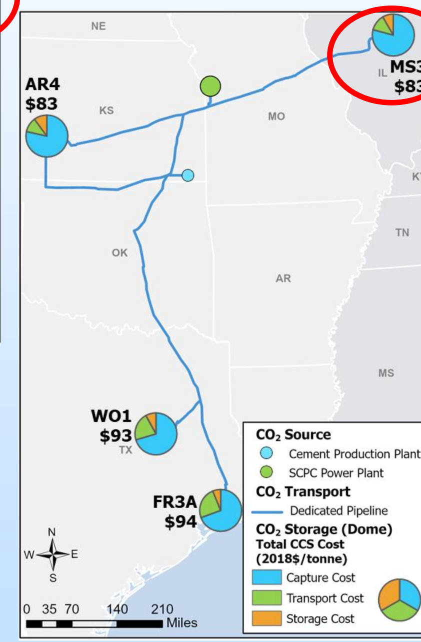


Northeast study – NGPP – Dedicated – Dome (W200)



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

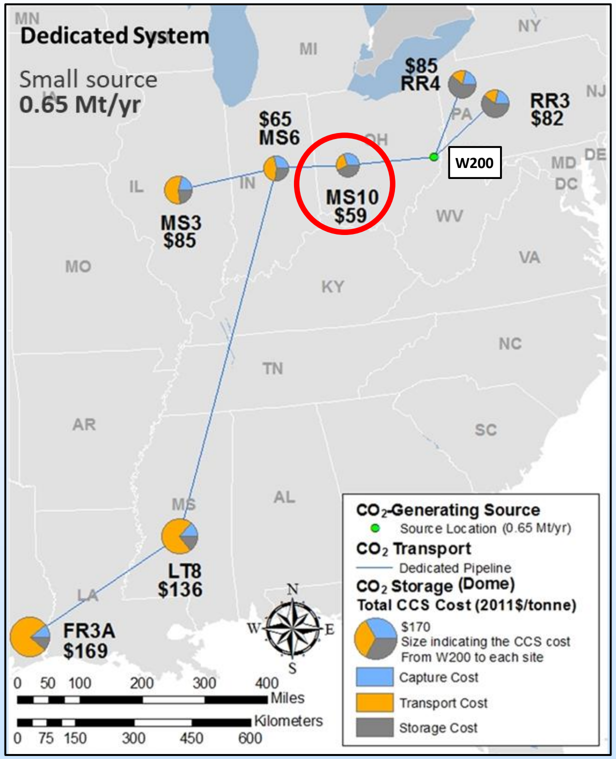
Central study (Gulf Impact Area) – SCPC plant – Dedicated – Dome



– Source location determines which Mt. Simon reservoir provides lowest CCS cost option

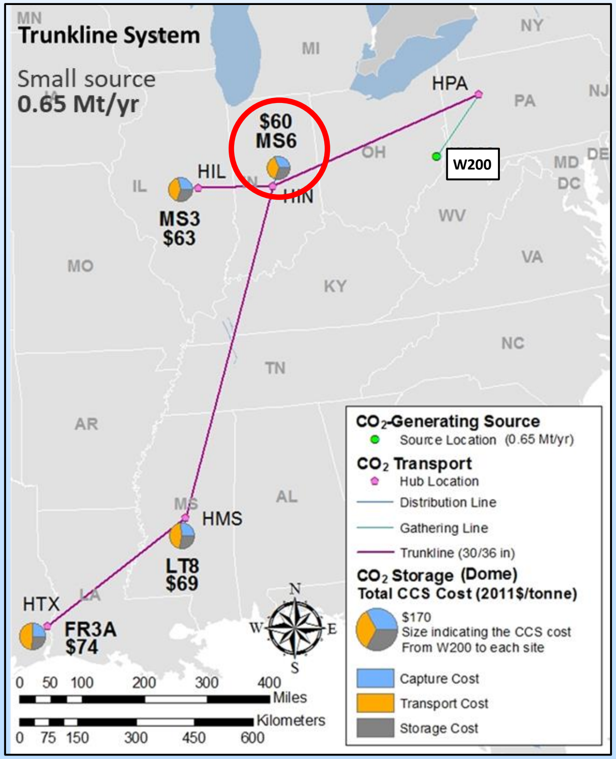
Location Can Be Important

- 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



Northeast study – NGPP – Dedicated – Dome (W200)

Northeast study – NGPP – Dedicated – Dome (W200)



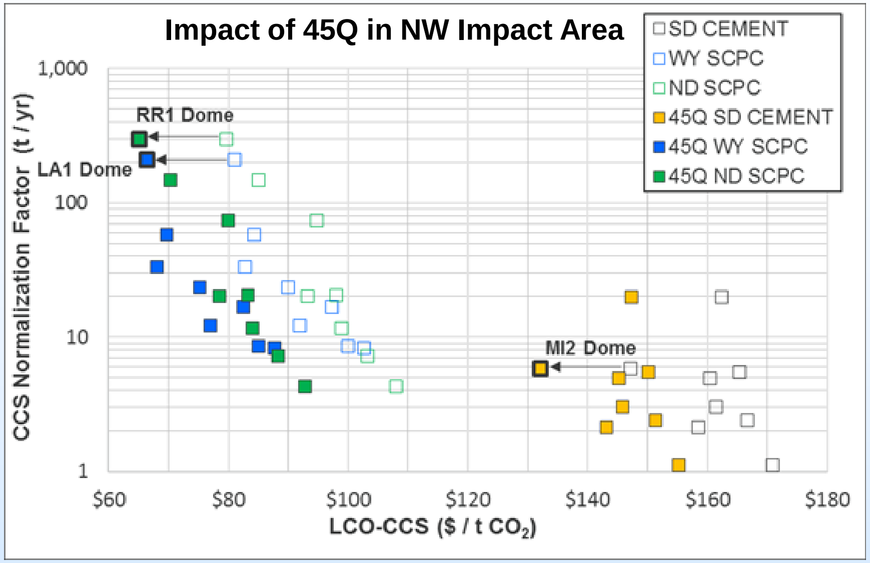
Conclusions (Part 1)

- 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

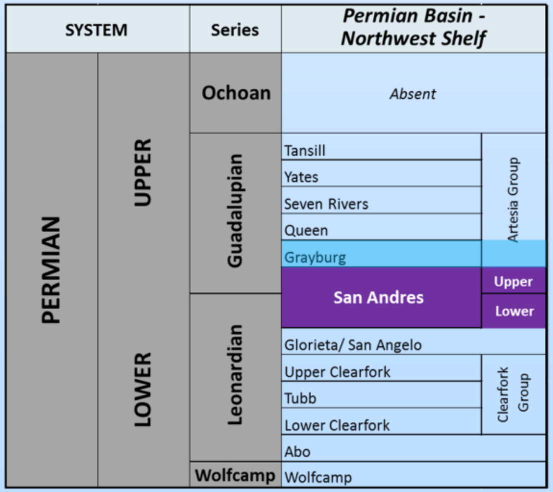
- Introduction
- CCS modeling in Northeast and Central United States
- Conclusions
- **Other analyses/research**
  - Onshore CO_2 storage
  - Offshore CO_2 storage
  - CO_2 storage economics modeling
  - Life cycle analysis
  - CO_2 storage efficiency factors refining
- Conclusions

Onshore CO_2 Storage

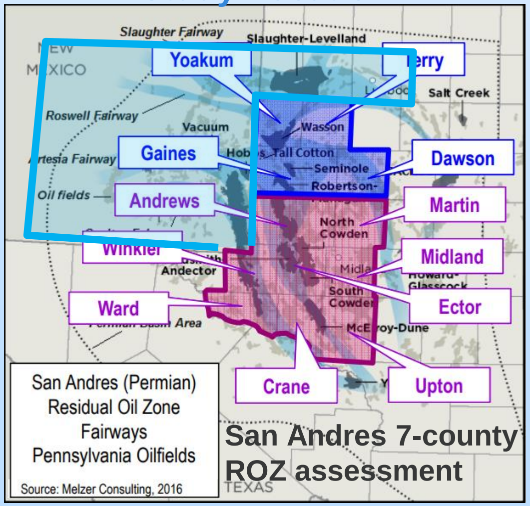
- QGESS: CO_2 Transport and Storage
- SMART Task 5: Virtual Learning Platform
- Water production assessment
- CO_2 intermediate storage: overview and economic analysis
- Python conversion of CO_2 Storage Cost Model
- Modeling CO_2 EOR and associated storage



Permian Basin Stratigraphy



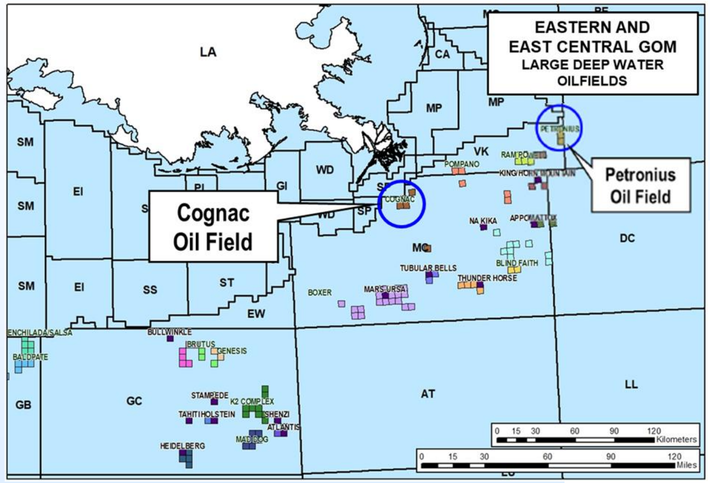
Study Location



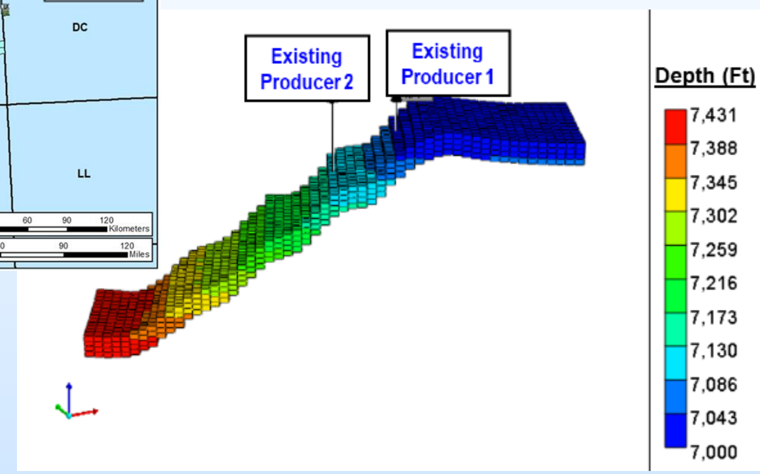
- Co-modeling with NRAP
- 4-, 8-, 7-, 10-, and 12-county appraisals in San Andres and Grayburg ROZ in Permian Basin
- Evaluating impact of 45Q tax credit on CCS network costs
- Basin-scale modeling

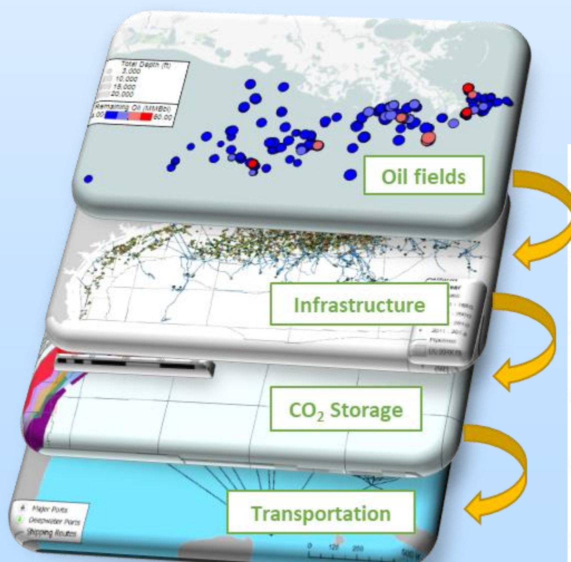
Offshore CO_2 Storage

- Offshore CO_2 EOR case studies
  - Cognac, Petronius, Horn Mountain
- Offshore CO_2 EOR cost model development
- Multi-criteria CCUS screening framework of GoM outer continental shelf for high-priority storage regions
- Offshore CO_2 transportation assessment

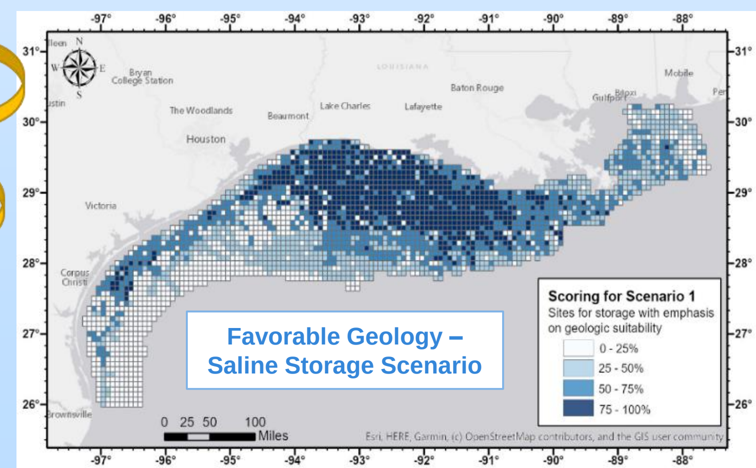


CO₂ EOR case studies





Multi-criteria framework



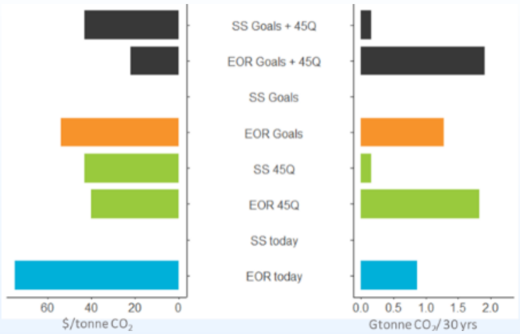
CO_2 Storage Economics Modeling

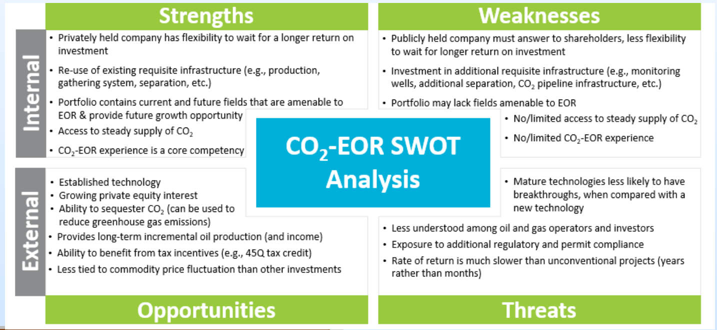
– Impact of NETL R&D and Tax Incentives on Price of CO_2: **accepted for presentation at Annual Meeting of the Southern Economic Association, New Orleans, LA November 21-23, 2020**

– Competitive Analysis of EOR for U.S. O&G Investment

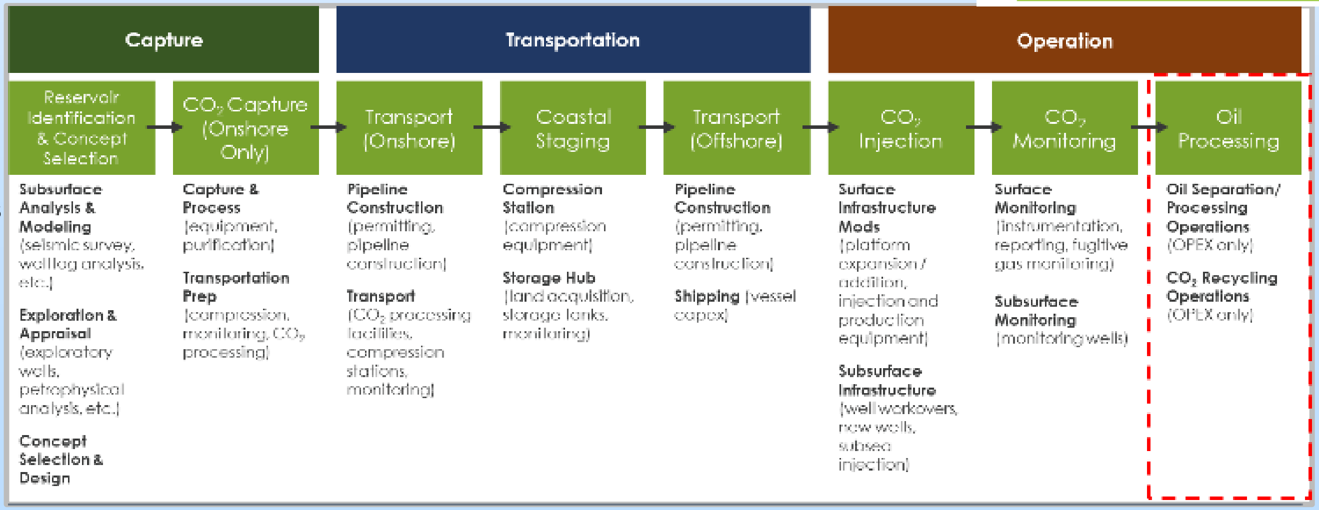
– Economics of Offshore CCUS in GoM: **met with Advisian O&G SMEs, Houston,TX, October 21-22, 2019**

CO_2 price impact





EOR competitive analysis

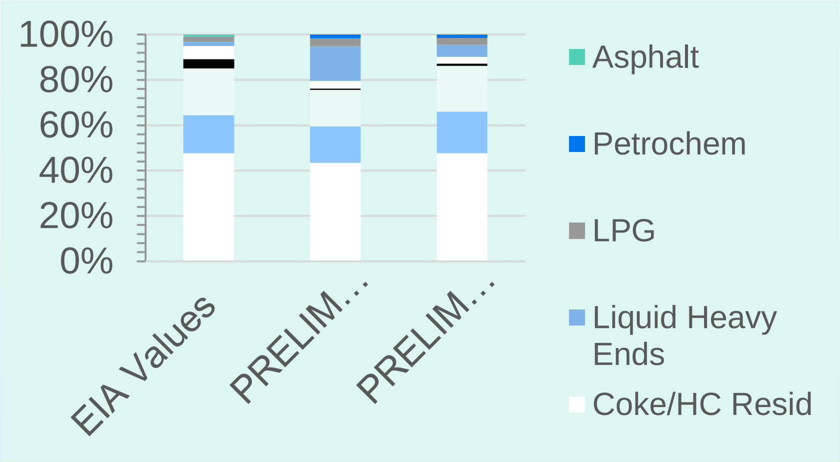


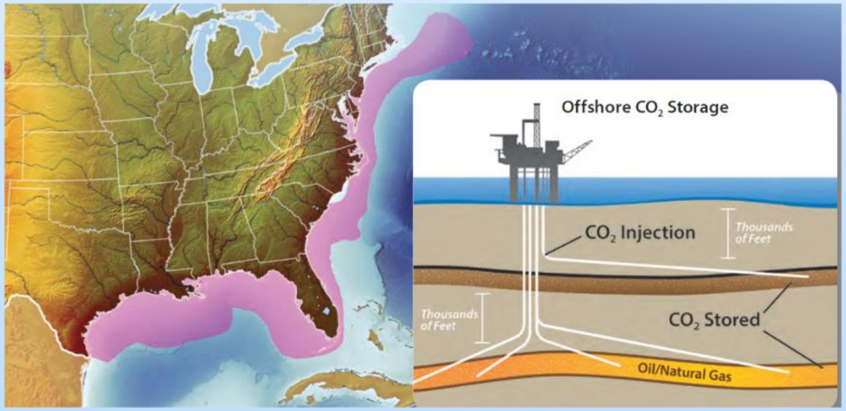
Economics of offshore CCUS in GoM

Life Cycle Analysis

– **Completed work**
  - Machine-learning optimization of refinery products from Petroleum Refinery Life Cycle Model (PRELIM) to support CO_2 EOR modeling
– **Upcoming work**
  - Understanding variability in field level performance of CO_2 EOR operations on environmental results
  - Assessing CO_2 EOR consequential impacts with CO_2 EOR Life Cycle (CELiC) Model
  - Offshore saline aquifer storage LCA

Comparison of Product Output – EIA and PRELIM





CO_2 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

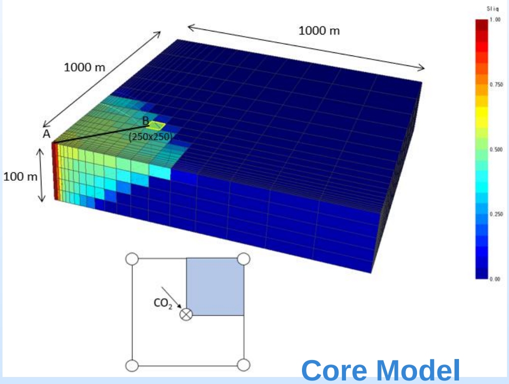
- NETL-generated data from CO_2BRA will be used as inputs in TOUGH to estimate new CO_2 storage efficiency factors
- TOUGH, PetraSIM, and CO2-SCREEN will be implemented to update storage efficiency factors

Value

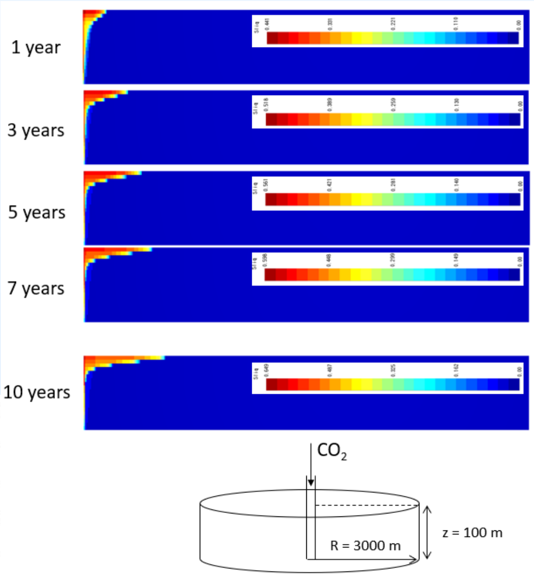
- Improved saline formation efficiency factors based on experimental data for targeted storage environments that support future versions of Carbon Storage Atlas

Initial TOUGH results to model CO_2 migration

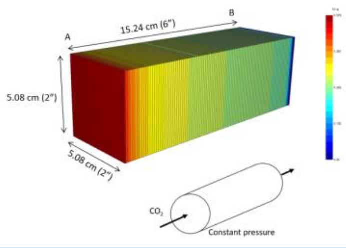
5-spot Model



Radial Model



Core Model



- Introduction
- CCS modeling in Northeast and Central United States
- Other analyses/research
  - Onshore CO_2 storage
  - Offshore CO_2 storage
  - CO_2 storage economics modeling
  - Life cycle analysis
  - CO_2 storage efficiency factors refining
- **Conclusions**

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 Center[1]

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 Basista[2]
Joseph Chou[2]
Greg Cooney[2]
Allison Guinan[3]
Amanda Harker-Steele[2]
Rachel Hoesly[2]

Arun Iyengar[2]
Matt Jamieson[2]
Yash Kumar[2]
Vello Kuuskraa[5]
Shangmin Lin[4]
Elise Logan[4]

Annie Oudinot[5]
Aileen Richardson[4]
Chung Yan Shih[3]
Alana Sheriff[2]
Merril Stypula[4]
Derek Vikara[2]

Matthew Wallace[5]
Travis Warner[2]
Anna Wendt[2]
Connie Zaremsky[2]

[1]NETL; [2]KeyLogic Systems, LLC; [3]Leidos; [4]Deloitte; [5]Advanced Resources International

Questions?

Resources and Recent Publications

Public Reports

CO_2 Leakage During EOR Operations - Analog Studies to Geologic Storage of CO_2
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 CO_2 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 CO_2
https://www.netl.doe.gov/energy-analysis/details?id=2892

Underground Natural Gas Storage - Analog Studies to Geologic Storage of CO_2
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 CO_2 Capture, Utilization, Transportation, and Storage (CCUS) – USAEE (2018)
https://www.iaee.org/proceedings/conference/101

Comparative analysis of transport and storage options from a CO_2 source perspective – IJGHGC (2018)
https://www.sciencedirect.com/science/article/pii/S1750583617307
120

Models/Tools

FE/NETL CO_2 Saline Storage Cost Model
https://www.netl.doe.gov/energy-analysis/details?id=2403

FE/NETL CO_2 Transport Cost Model
https://www.netl.doe.gov/energy-analysis/details?id=543

StrmtbFlow Fortran Program (FE/NETL CO_2 Prophet Model)
https://netl.doe.gov/energy-analysis/details?id=1d610037-b606-4434-8d77-256ea4b267ce

StrmtbGen Fortran Program (FE/NETL CO_2 Prophet Model)
https://netl.doe.gov/energy-analysis/details?id=c9dd82fa-8085-4c69-a517-372a5e6c3843