Assessing Factors Influencing CO_2 Storage Capacity and Injectivity in Eastern Gas Shales

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Developing the Technologies and Building the Infrastructure for CO_2 Storage

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Presentation Outline

- Program Benefits
- Goals and Objectives
- Technical Status
- Accomplishments to Date
- Summary
- Appendix

Benefits to the Program

- Program Goals Addressed
  - Develop technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.
- Project Benefits
  - More secure storage, since most of the injected CO_2 will re-adsorb on the shales following the desorption of methane, providing a potentially more secure CO_2 storage option than merely injecting CO_2 into saline aquifer formations
  - Ability to more cost-effectively geologically store CO_2 , since revenues from gas production can offset, at least to some extent, the costs of storage
  - Utilization of a very large capacity storage option in a region of the country with a large concentration of large CO_2 emission sources, particularly coal-fired power plants, but where finding other suitable geologic sites for CO_2 storage is proving to be challenging.

Goals and Objectives

- Acquire, analyze, and synthesize data on reservoir properties for selected eastern gas shales -- through collaboration with state geological surveys, universities, and operators -- to help guide efforts in *site assessment and selection*.
- Develop better understanding of shale characteristics impacting *sealing integrity, storage capacity, and injectivity*.
- Verify this understanding through a targeted, *highly monitored*, small-scale CO_2 injection test.
- Test a new technology for *monitoring* the movement and fate of CO_2 in gas shales -- a smart particle early warning concept.
- Characterize potential constraints to economic CO_2 storage in gas shales, as a function of specific shale characteristics.
- Develop an *updated characterization of the CO_2 storage capacity and injectivity* of selected eastern shales, focusing on reservoir characteristics affecting CO_2 storage capacity and injectivity.

Stratigraphic Correlation Chart for the Marcellus Shale

		New York	Pennsylvania	West Virginia	Eastern Ohio
Upper Devonian	West Falls Group	West Falls Fm/ Rhinestreet Shale	Brallier Fm./ Rhinestreet Shale	Rhinestreet Shale	West Falls Fm/ Rhinestreet Shale
	Sonyea Group	Middlesex Shale	Harrel Fm./ Middlesex Shale	Cashaqua Sh./ Middlesex Sh.	
	Genesee Group	Geneseo Shale	Geneseo/ Burkett Sh	Burkett Shale	
MIDDLE DEVONIAN	Hamilton Group	Tully Limestone	Tully Limestone	Unnamed Limestone	Hamilton Group, undivided
		Moscow Shale (Tichenor LS)	Hamilton Group / Mahantango Fm.	Hamilton Group, undivided	
		Ludlowville Shale (Centerfield LS)			
		Skaneateles Shale		Mahantango Formation	
		Stafford LS	Stafford LS		
		Oatka Creek Shale	Upper Marcellus	Marcellus Shale	Marcellus Shale
		Cherry Valley LS	Purcell & Cherry Valley LS		
		Union Springs Shale	Lower Marcellus		
Lower Devonian	Tri States Group	Onondaga Limestone	Onondaga LS	Onondaga LS/ Huntersville Chert	Onondaga LS
			Huntersville Chert/ Needmore Shale	Needmore Sh	
		Oriskany Sandstone	Oriskany Sandstone	Oriskany Sandstone	Oriskany Sandstone

Marcellus Shale Target Formation

JAF028406.PPT

Sources: New York State Museum, Ohio Geological Survey, Pennsylvania Department of Conservation and Natural Resources, United States Geological Survey, West Virginia Geological Survey.

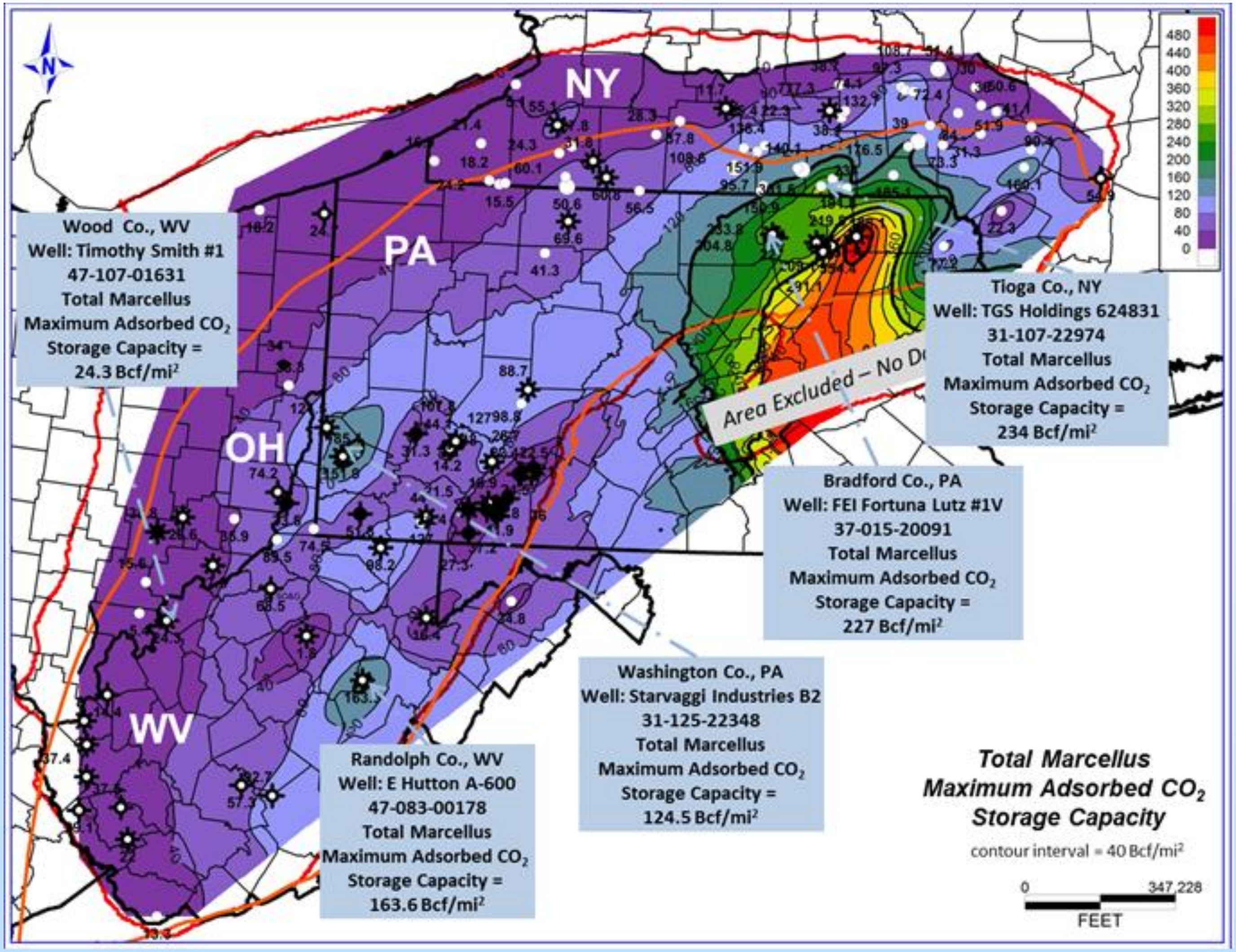
Methodology for Assessing CO_2 Storage Potential in Marcellus

- Objective is to estimate theoretical methane gas in-place and maximum CO_2 storage capacity within the study area at depths to the organic-rich lower Marcellus > 3,000 ft.
- Theoretical maximum CO_2 storage assumes 100% of calculated methane in-place, both as adsorbed and non-adsorbed ‘free’ gas, is replaced by injected CO_2.
  - Clearly, not all of this pore space will ultimately be accessible
  - Accessible storage capacity will be determined in subsequent analyses
- Data set includes:
  - digital well logs for 122 study wells
  - New York State Museum TOC data for core, cuttings and outcrop
  - CH_4 and CO_2 adsorption isotherms from three New York wells.

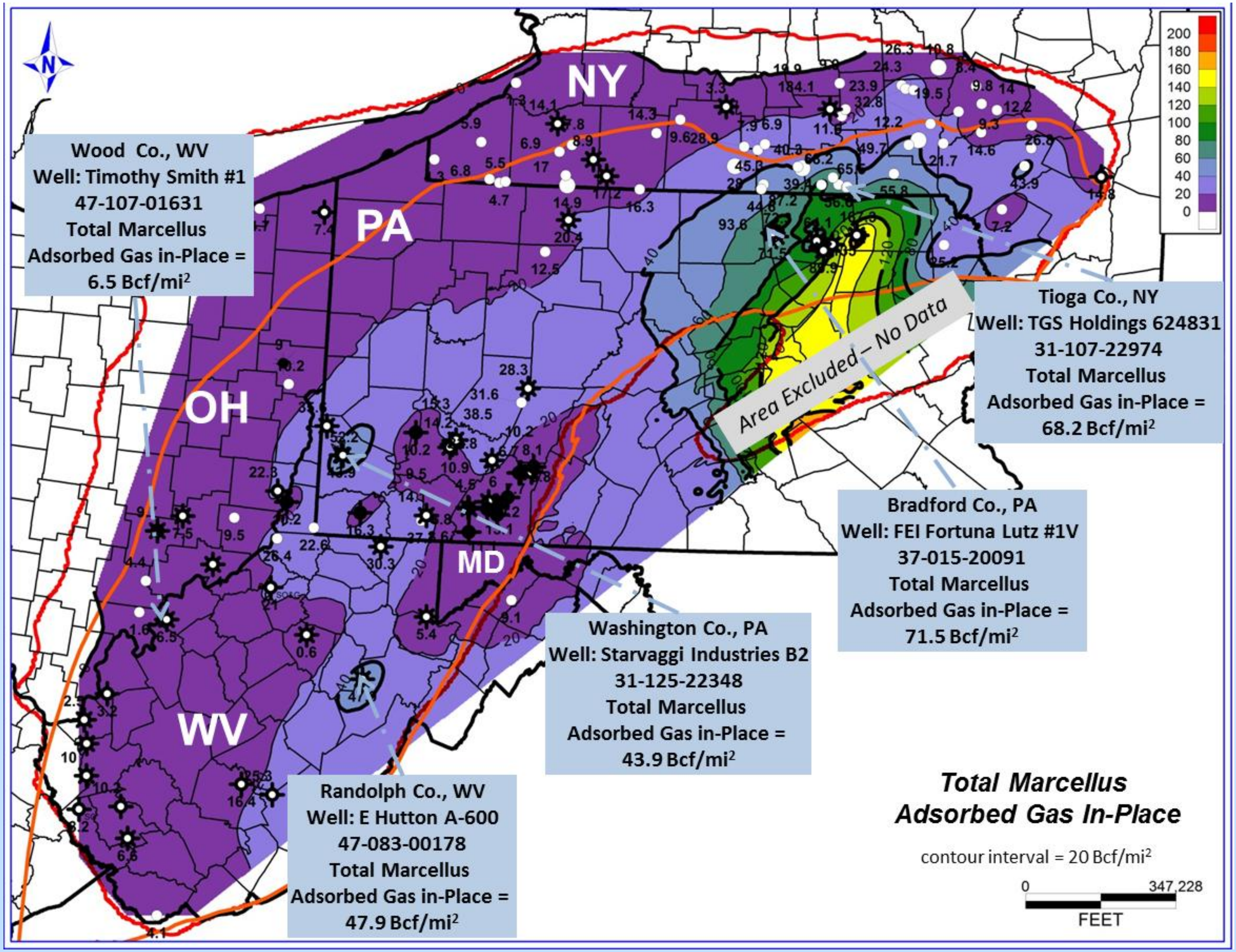
Methodology for Assessing CO_2 Storage Potential in Marcellus (cont.)

- Marcellus attributes calculated from digital logs wells:
  - Vertical thickness
  - Total organic carbon, TOC
  - Gamma-ray and/or density log ‘cut-off’ to estimate the organic-rich shale ‘pay’ zone for adsorption of methane and CO_2
  - Adsorbed methane gas in-place in Mcf/ acre-ft., and total adsorbed methane in-place in Bcf/ sq. mile, as well as theoretical maximum CO_2 storage capacity by adsorption.
  - Density porosity (corrected for TOC content)
  - Effective (gas-filled) pore volume, (which assumes water saturation calculated using a *Simandoux* algorithm, is immobile)
  - Estimated ‘free’ (non-adsorbed) methane gas in-place
  - Theoretical maximum CO_2 storage capacity as ‘free’ gas (non-adsorbed).
- Adsorbed CH_4 and CO_2 calculated using Langmuir coefficients based on the available isotherm data and estimated T & P based on depth.
- Pressure gradient was based on a map of Marcellus reservoir pressure gradients, so that over-pressured areas can be incorporated

Maximum Non-Adsorbed (Free) CO_2 Storage Capacity for Marcellus, Bcf/ sq. mile



Lower Marcellus, Adsorbed Gas in-Place, Bcf/ sq. mile



Estimated Total Gas In-Place and Maximum CO_2 Storage Capacity for Marcellus Study Area for Depth > 3,000 ft.

Estimated Gas In-Place and Theoretical Maximum CO_2 Storage Capacity for Marcellus in Eastern Gas Shale Study Area	New York	Pennsylvania	West Virginia	Ohio	Maryland	Total Study Area
Potential CO_2 Storage Area (depth>3,000 ft; R_o >1.0), acres	3,438,253	14,285,086	10,571,010	753,333	508,290	29,555,973
Potential CO_2 Storage Area (depth>3,000 ft; R_o >1.0), $mile^2$	5,372	22,320	16,517	1,177	794	46,181
Adsorbed Gas In-Place, Bcf	157,968	793,415	286,080	12,338	6,141	1,255,942
Non-Adsorbed Gas In-Place, Bcf	555,997	2,500,671	539,538	14,889	11,595	3,622,689
Total Gas In-Place, Tcf	714	3,294	826	27	18	4,879
Maximum CO_2 Storage, Adsorbed, Bcf	461,282	2,323,259	848,400	36,706	19,061	3,688,707
Maximum CO_2 Storage, Non- Adsorbed, Bcf	294,867	1,199,064	260,451	6,885	5,401	1,766,467
Total CO_2 Storage Capacity, Tcf	756	3,522	1,109	44	24	5,455

Sources of Uncertainty Re Gas in-Place and CO_2 Storage Capacity Estimates

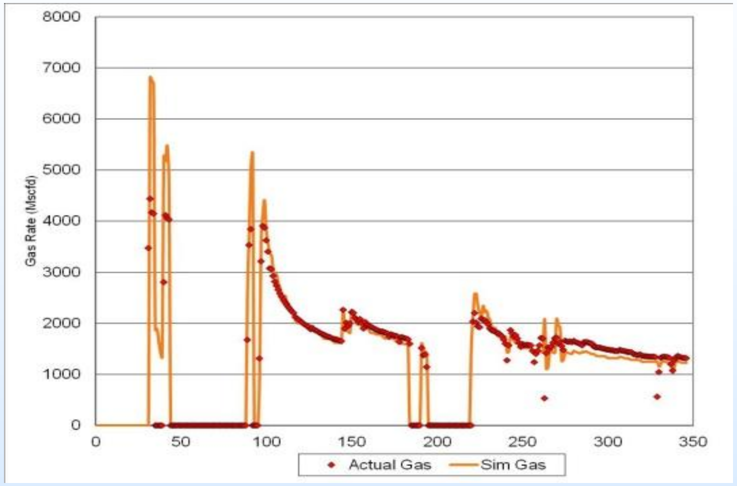
- Limited CO_2 and methane isotherm data
- Lack of access to reservoir test data and sustained production data for calibration of the reservoir simulation
- Representation of reservoir matrix and fracture properties in the reservoir simulation
  - Fracture density and spacing, fracture permeability, dominant fracture trends
- Refining and expanding this analysis needs to focus on reducing or eliminating these uncertainties
  - Acquiring additional reservoir and engineering data to improve the reservoir characterization
  - Industry input on possible development scenarios

Small-Scale CO_2 Injection Test in the Devonian Ohio Shale

- Baseline logging was completed for the field test at well in Johnson County, KY.
- Baseline logging included the reservoir saturation tool (RST), PBMS (pressure and temperature), a Spinner log, and a multi-finger caliper (PMIT) log.
- Start of the injection test planned in late August
- Up to 300 tons of CO_2 to be injected in “huff and puff”
- Two subsequent logging runs are anticipated;
    - During the test
    - After the test

CO_2 Injection Scenarios and Results

Production History Match for a Pennsylvania Horizontal Marcellus Well



Simulation Inputs

Shale Depth	5,670	ft.
Shale Thickness	125	ft.
Pay Zone Thickness	15	ft.
Matrix Permeability	100	nD
Matrix Porosity	7	%
Water Saturation	35	%
Initial Pressure Gradient	0.58	psia/ft.
CH_4 Langmuir Volume	90	scf/ton
CH_4 Langmuir Pressure	1,000	psia
CO_2 Langmuir Volume	172	scf/ton
CO_2 Langmuir Pressure	416	psia

Enhanced Recovery & CO_2 Storage as Function of Distance Between Injection and Production Wells

Distance Between Wells	No Injection Case (MMscf)	Injection Case (MMscf)			
	Cum CH_4 Produced	Cum CH_4 Produced	Cum CO_2 Injected	Cum CO_2 Produced	Stored CO_2
50 ft.	6.4 (85.1%)	7.2 (95.3%)	38.6	25.5	13.1
100 ft.	9.4 (83.0%)	10.6 (93.3%)	28.0	9.9	18.1
150 ft.	12.2 (80.4%)	13.6 (89.5%)	25.4	3.9	21.5
200 ft.	14.7 (77.5%)	16.1 (85.0%)	24.3	1.2	23.1
250 ft.	16.9 (74.5%)	18.3 (80.3%)	23.6	0.2	23.4
300 ft.	19.0 (71.5%)	20.0 (75.2%)	22.6	0.0	22.6
400 ft.	22.4 (65.6%)	22.9 (67.1%)	21.2	0.0	21.2
500 ft.	25.0 (60.1%)	25.3 (60.7%)	19.7	0.0	19.7
750 ft.	29.3 (48.3%)	29.3 (48.4%)	16.6	0.0	16.6

Smart Particle Early Warning Concept

- Conducted by researchers at Cornell University (lead: Larry Cathles)
- Objective -- develop the methods to infer the uniformity of CO_2 injection into shale based on the inter-diffusive mixing of CO_2 and methane and nanoparticle tracers.
  - Demonstrate basic principles with laboratory Hele Shaw experiments and develop nanoparticles compatible with supercritical CO_2 that could be deployed in a field demonstration.
  - Develop a streamline-based interpretive model.
- Status
  - Apparatus has now been constructed
  - Efforts to successfully manufacture CO_2-dispersable, detectable, nanoparticles are being pursued.
  - Work underway to demonstrate the use of these particles to measure the uniformity of flow in the laboratory

Accomplishments to Date

- Acquired, analyzed, and synthesized data on reservoir properties for the Marcellus and Utica gas shales
- Developed preliminary characterization of the potential theoretical maximum CO_2 storage capacity in the Marcellus Shale
    - Next step is to determine “accessible” capacity
- Performed preliminary reservoir simulation to develop better understanding of shale characteristics impacting *sealing integrity, storage capacity, and injectivity*.
    - To be revised based on results of small scale injection test and additional proprietary data acquired from operators
- Prepared site for small scale CO_2 injection test in KY shales, to take place in late August/early September

Summary

- **Key Findings**
  - Theoretical maximum CO_2 storage capacity in Marcellus as adsorbed CO_2 is 3,689 Tcf, which assumes that all adsorbed methane is replaced by CO_2.
  - The theoretical maximum CO_2 storage capacity as non-adsorbed CO_2 replacing methane is 1,766 Tcf, approximately half the estimated volume of free gas in-place.
- **Lessons Learned**
  - Limited CO_2 and methane isotherm data, lack of access to reservoir test and sustained production data limit ability for calibration of the reservoir simulation
- **Future Plans**
  - Complete similar assessment of the Utica Shale, including geologic characterization and reservoir simulation
  - Update previous assessments based on field test results and operator data
  - Conduct KY CO_2 injection test; after some delays
  - Finish efforts to characterize constraints to economic CO_2 storage in gas shales.
  - Update characterization of the CO_2 storage capacity and injectivity of selected eastern shales (Marcellus, Utica, Ohio)

Appendix

Project Participants

NYSERDA
New York State Energy Research and Development Authority

Kentucky Geological Survey
UNIVERSITY OF KENTUCKY

CORNELL

UB
University at Buffalo
The State University of New York

Schlumberger

Roles of Key Participants

- Advanced Resources International – Overall Project Lead
  - Michael Godec -- Principal Investigator & Project Director
- NYSERDA serving in project advisory capacity, along with providing substantial financial support.
- KGS leading assessment of the Devonian Ohio shale and the small-scale injection test in KY, leveraging state funds.
- University at Buffalo characterizing the spacing, geometry and intersection field data for fractures in Marcellus shale settings.
- Cornell University investigating capability of monitoring CO_2 injection into shale through a proposed smart particle early warning concept.
- Schlumberger Carbon Services -- contributing cost-share for logging program conducted for the KY small scale CO_2 injection test

Gantt Chart


Task Name
, 2010 | Qtr 4, 2010 | Qtr 1, 2011 | Qtr 2, 2011 | Qtr 3, 2011 | Qtr 4, 2011 | Qtr 1, 2012 | Qtr 2, 2012 | Qtr 3, 2012 | Qtr 4, 2012 | Qtr 1, 2013 | Qtr 2,
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
Task 1 Project management and Planning
Milestone: Initial PMP
11/8
Milestone: Update PMP for No-Cost Extension
9/15
Milestone: Update for Continuation Application
5/25
Deliverables: Quarterly Reports
Task 2 Acquire, Analyze, and Synthesize Geologic Data
Deliverable: Progress report on efforts to acquire, analyze and synthesize data: plan for using data for the development of the reservoir models and simulators in Task 3.0.
4/20
Deliverable: Progress report on further efforts to acquire, analyze and synthesize data (especially that for the Ohio Utica Shale), for use in refining and updating the reservoir models and simulators.
8/15
Task 3 Develop Reservoir Models of the Geological CO2 Storage Potential
Deliverable: Progress report on efforts to develop the preliminary reservoir models and reservoir simulation activities.
12/22
Task 4 Acquire Additional Data From One CO2 Injection Test to Validate Reservoir Models
Deliverable: Progress report summarizing efforts and results from the small-scale injection test in KY
8/15
Task 5.0 – Test Innovative Technology for Monitoring CO2 Flow Behavior
Deliverables: Progress report summarizing efforts and results associated with the bench-scale tests of the smart particle early warning concept using nanotracers.
7/15
Deliverables: Progress report summarizing efforts and results associated with the modeling of the smart particle early warning concept using nanotracers.
10/15
Task 6.0 – Refine Reservoir Models Based on Results from Injection Test and Additional Data Acquisition
Deliverables: Progress report summarizing efforts refine the reservoir models and reservoir simulation activities to characterize the potential for both CO2 storage and EGR in the targeted shales, based the field tests results and additional Task 2 data
12/15
Task 7.0 – Characterize Potential Constraints to Cost-Effective CO2 Storage, and Propose and Evaluate Options to Overcome Constraints
Deliverables: Progress report on the potential constraints to economic CO2 storage in gas shales, and potential development and production options that may help to overcome these constraints.
12/15
Task 8.0 – Update Basin-Level Geological Characterizations of CO2 Storage Potential
Deliverables: Progress reports describing updated, basin-level geological characterization of CO2 storage and EGR potential of the Marcellus and Utica Shales, the Ohio Shales
12/15
Task 9.0 – Document Findings in Draft and Final Reports
Deliverables: Draft and final reports summarizing all of the work reported in the previous progress reports
1/30
3/30

Bibliography

No peer reviewed publications have yet been generated from this project