Midwest Regional Carbon Sequestration Partnership

DOE/NETL cooperative agreement # DE-FC26-05NT42589

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Battelle Memorial Institute

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY | BATTELLE

U.S. Department of Energy

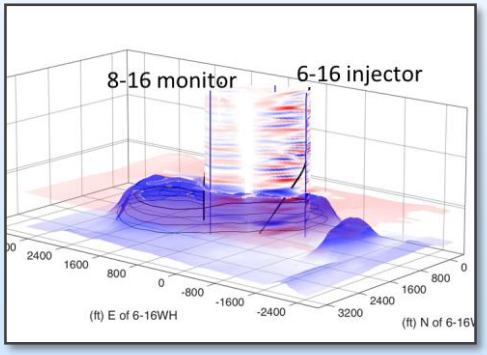
National Energy Technology Laboratory

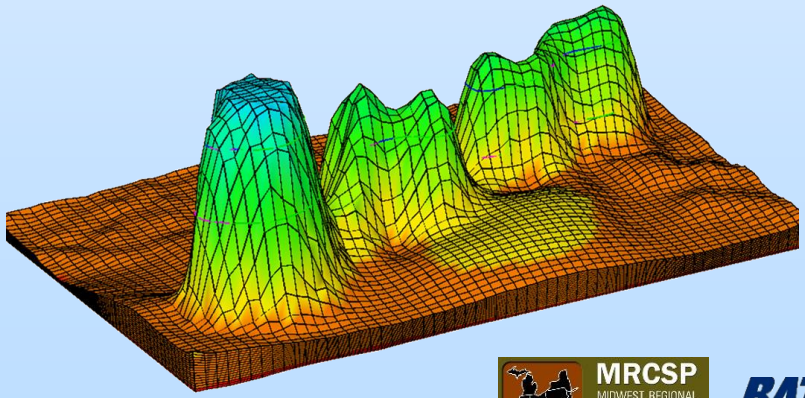
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

September 8-11, 2020

Presentation Outline

- Introduction
- Technical Status
  - Monitoring/Modeling
  - Accounting/LCA
  - Regional Impact
- Summary
  - Accomplishments
  - Lessons learned
  - Synergy Opportunities





MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

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Acknowledgements

Battelle's MRCSP Current Contributors – Mark Kelley, Srikanta Mishra, Matt Place, Lydia Cumming, Sanjay Mawalkar, Charlotte Sullivan, Priya Ravi Ganesh, Autumn Haagsma, Samin Raziperchikolaee, Amber Conner, Glenn Larsen, Joel Main, Isis Fukai, Ashwin Pasumarti, Manoj Kumar Valluri, Laura Keister, Andrew Burchwell, Rebecca Wessinger, Jackie Gerst, and many others

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Ohio Development Services Agency's **Ohio Coal Development Office**

MRCSP's technical **partners, sponsors, and host sites since 2003**

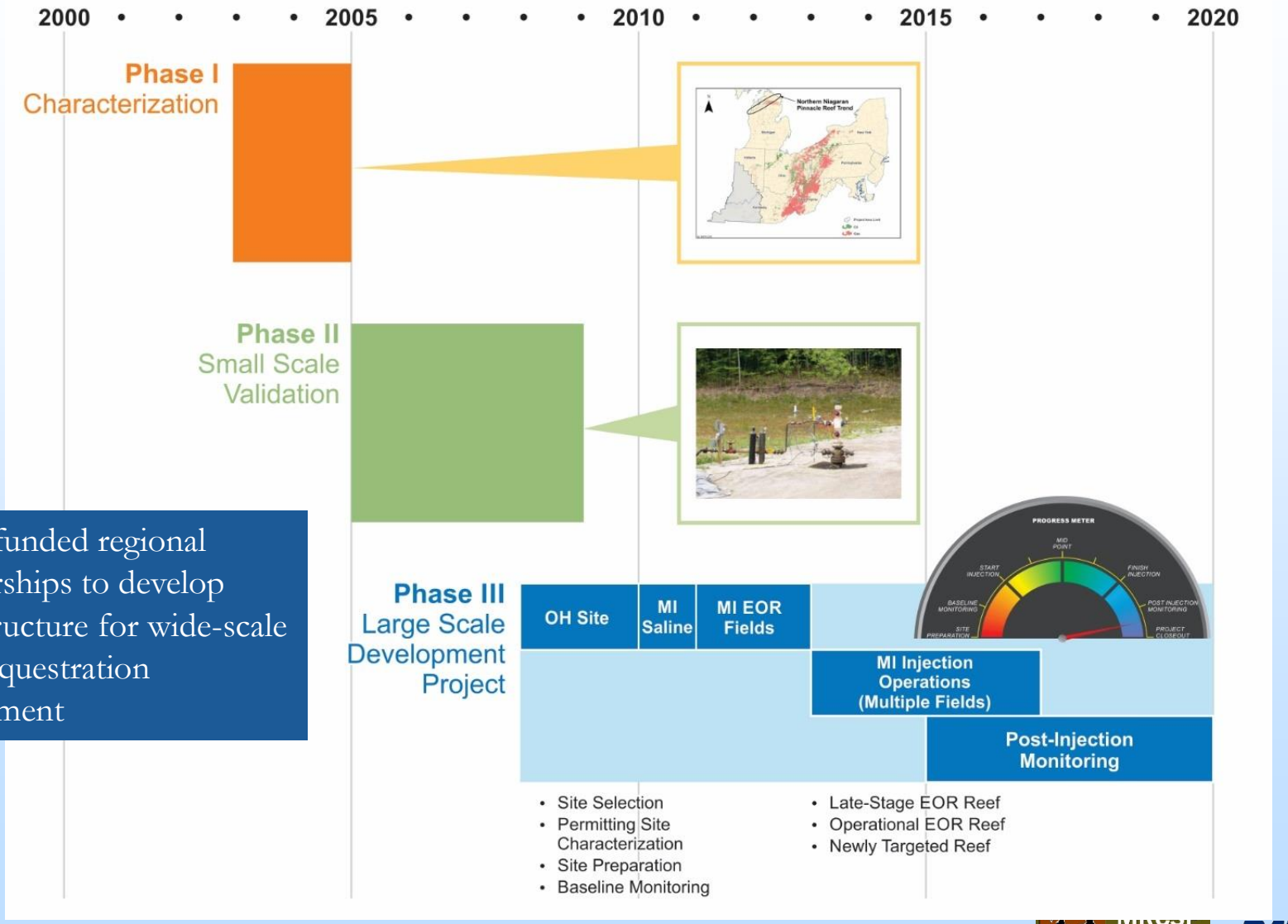
The MRCSP Region's State **Geology Survey and University team members**

Acknowledgements – MRCSP Lead Contributors over Time

- DOE Project Managers – Charlie Byrer, Lynn Brickett, Traci Rodosta, Dawn Deel, Andrea McNemar
- DOE Technology Managers and Directors – Kanwal Mahajan, Sean Plasynski, John Litynski, Traci Rodosta, Darrin Damiani
- Battelle Project Managers – Ron Cudnik, Dave Ball, Darrell Paul, Caitlin Holley, Rebecca Wessinger, and several supporting PMs
- MRCSP Geology Team Leads – Larry Wickstrom, Chris Perry, Kris Carter, and John Rupp
- MRCSP Phase I and II Terrestrial Storage Lead - Dr. Rattan Lal, Ohio State University
- Past Key Technical Contributors – Phil Jagucki, Charlotte Sullivan, Lydia Cumming, Rod Osborne

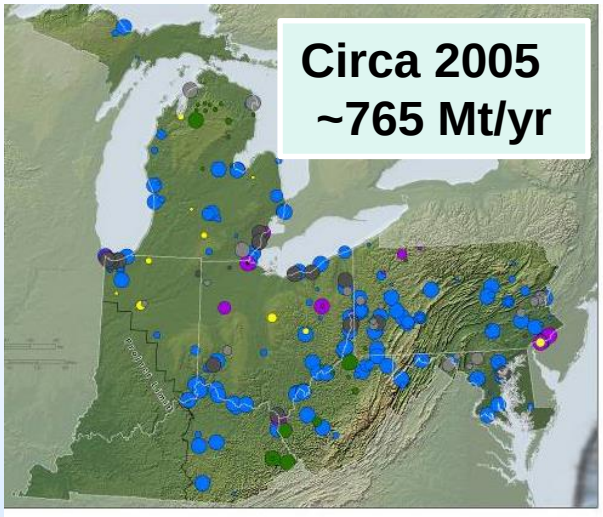
Partners over 17 years have helped make MRCSP successful

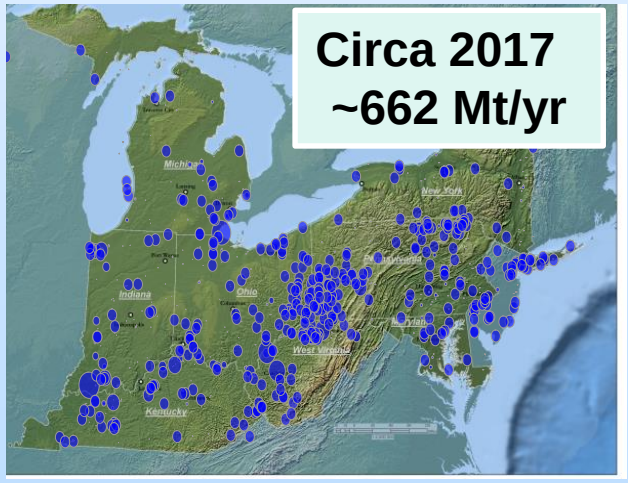
Historical Snapshot of MRCSP – 17 Years of CCUS Innovation



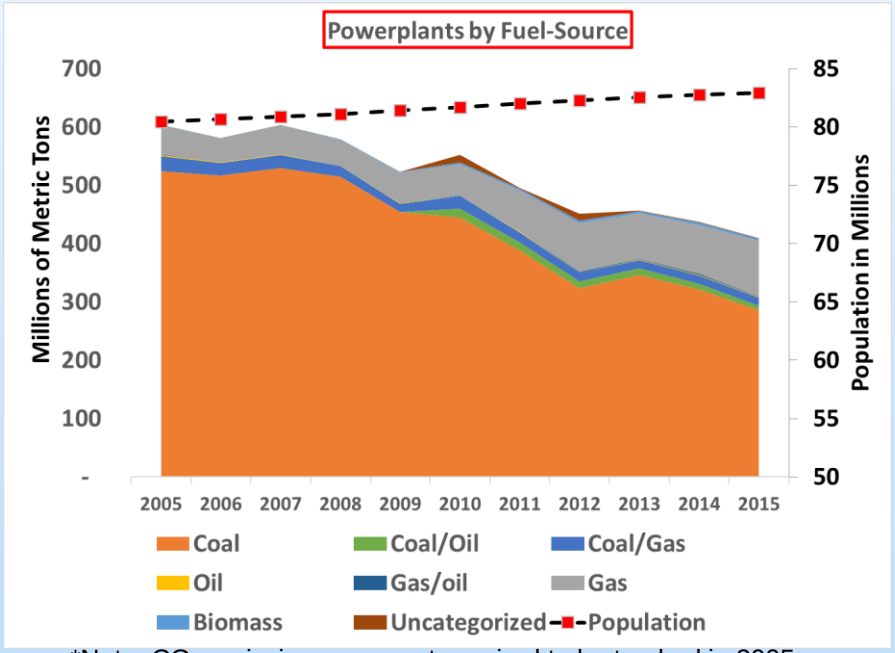
- DOE-funded regional partnerships to develop infrastructure for wide-scale CO_2 sequestration deployment

Historical Snapshot of MRCSP – 17 Years of CCUS Innovation





- Emissions from large sources down 10-15% since 2005*
- Fewer coal-fired plants, more natural gas power plants
- Shale gas boom
- Regulatory fluctuations and anticipation



*Note: CO_2 emissions were not required to be tracked in 2005.

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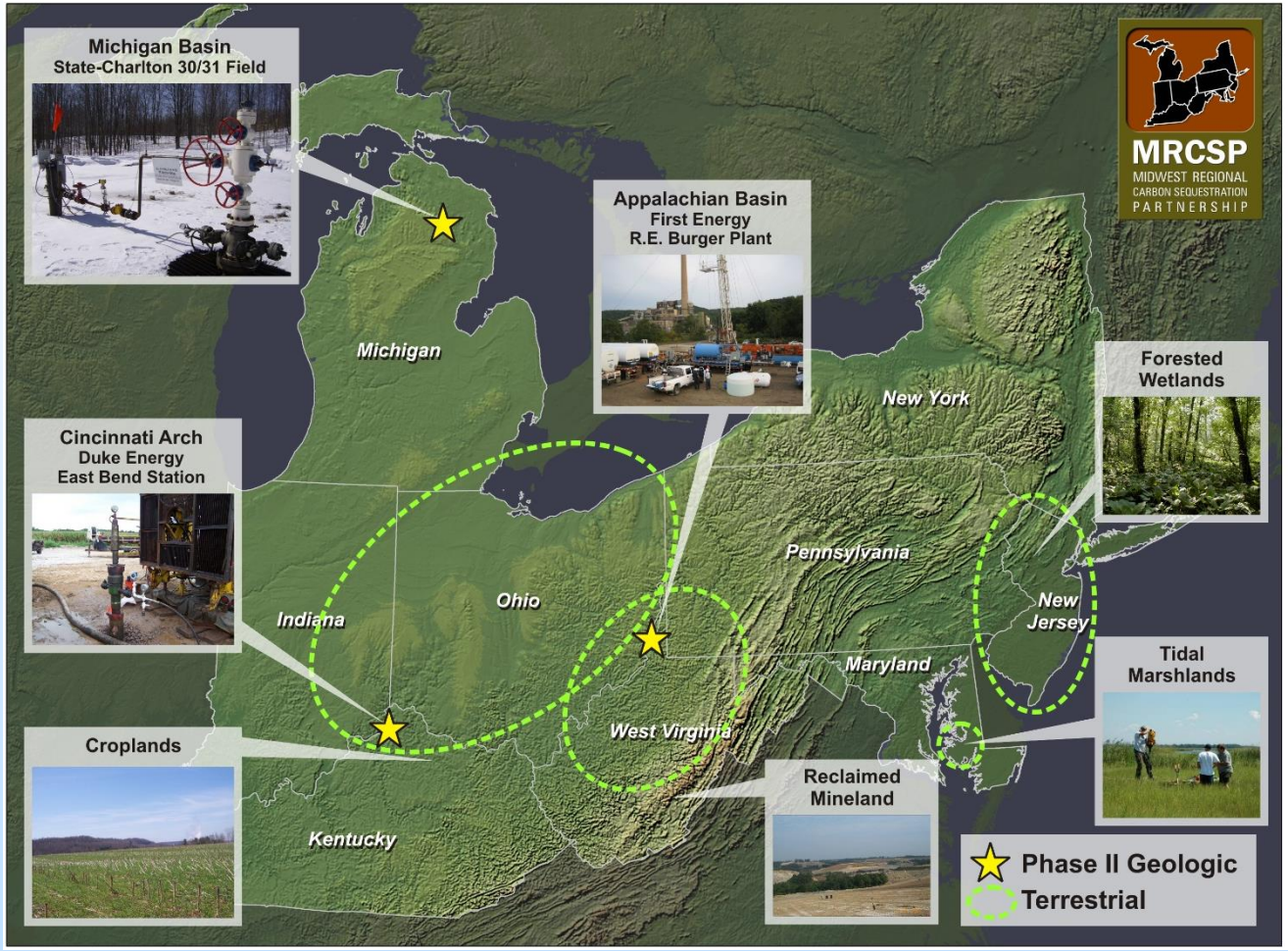
Phase II Demonstrated the Feasibility of CCUS in the MRCSP Region

- 3 geologic storage tests in different settings
- 4 terrestrial storage tests in croplands, mine lands, tidal and forested wetlands



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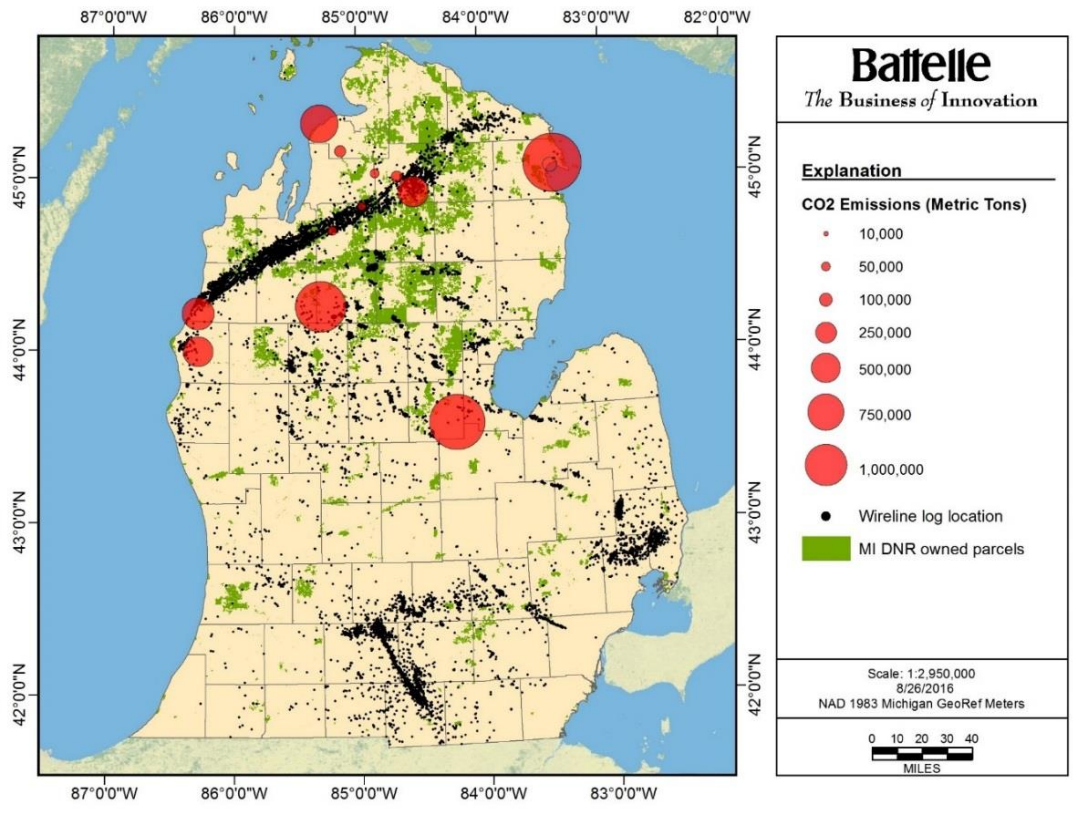
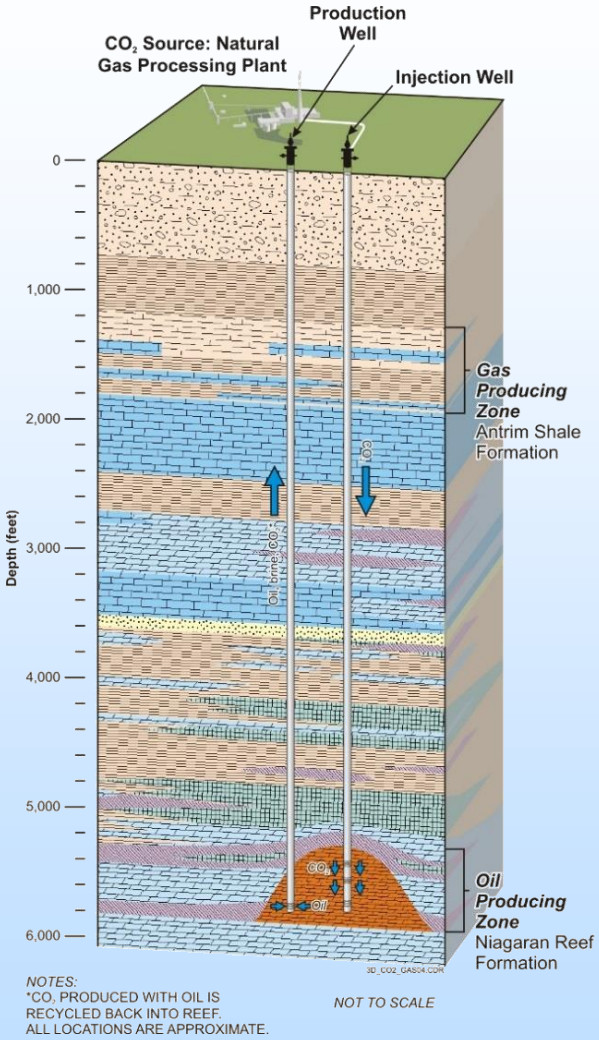
Prof. Ratan Lal MRCSP Terrestrial Lead gets Japan Prize (2019) and World Food Prize (2020)

MRCSP Phase III Basin Large-Scale Injection

- Objective – Inject/monitor +1 million metric tons of CO_2 in collaboration with EOR operations.
- Evaluate CO_2 injectivity, migration, containment
- Evaluate regional storage resources
- Outreach and knowledge share





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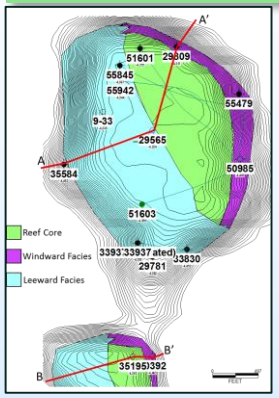
Large-scale Injection Test

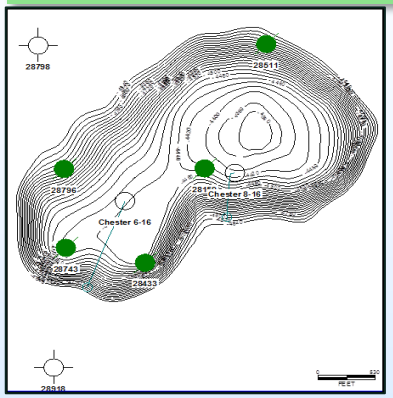
Key Reefs Vary in Setting and Operational History

Late-Stage Reef: Dover 33



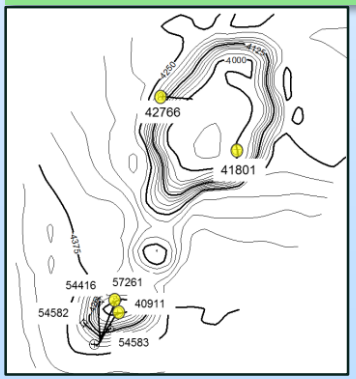
1 Lobe
Operational since 1974
Primary + CO_2-EOR
MRCSP Injection since 2013
- 1 CO_2 Injection Wells
- 2(+1) Mon./ Prod. Wells

Chester 16



2 Lobes
Operational since 1971
Primary + Water Inj.
MRCSP Injection since 2017
- 1 CO_2 Injection Well
- 1 Monitoring Well

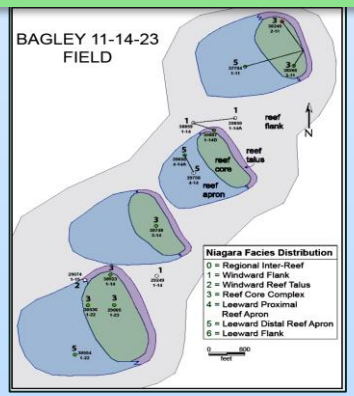
Charlton 19



2 Lobes
Operational since 1988
Primary Production
MRCSP Injection 2015-2017
- 1 CO_2 Injection Wells
- 2 Monitoring Wells

Currently in CO_2-EOR

Bagley



4 Lobes
Operational since 1973
Primary Production only
MRCSP Injection since 2015
- 3 CO_2 Injection Wells
- 4 Monitoring Wells

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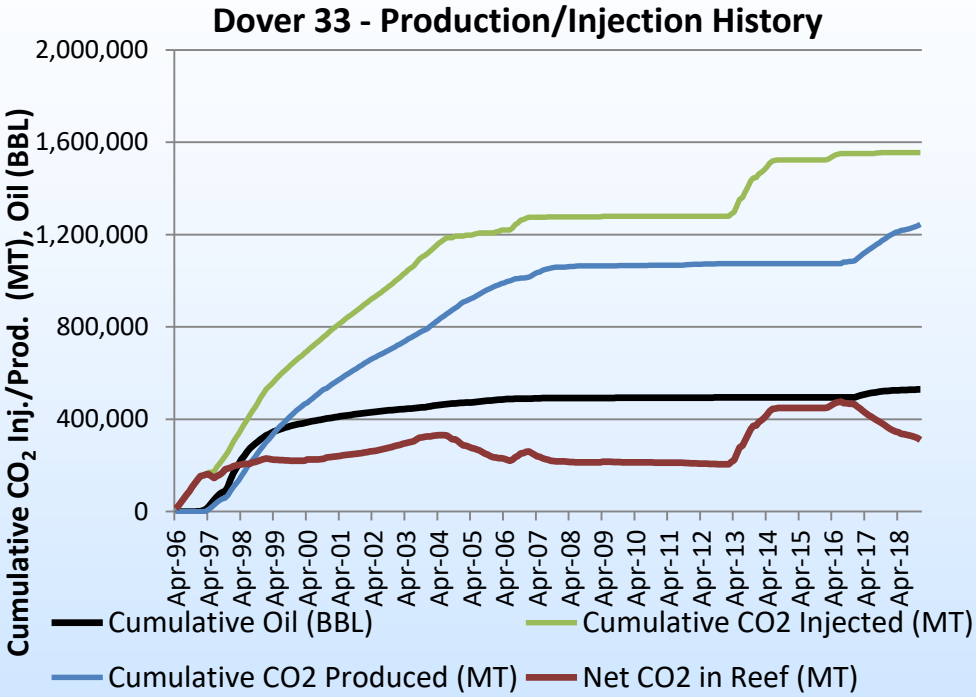
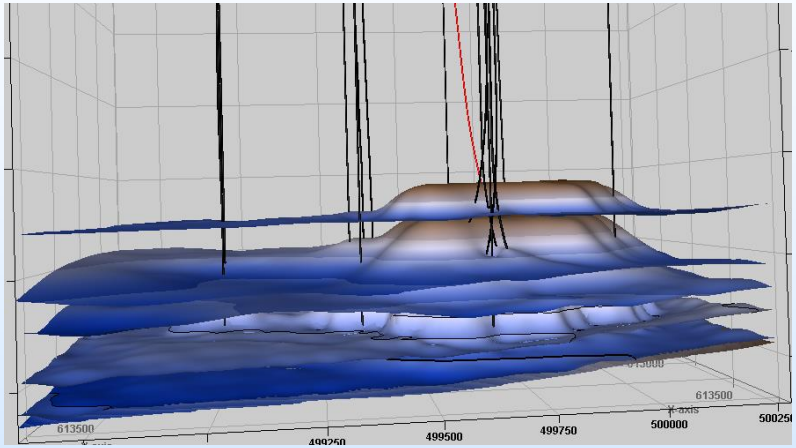
The Late State Reef –

R&D at Various Stages in the EOR Lifecycle





1974 Primary production

1996 CO_2 injection and EOR begins

2003 MRCSP Phase III

2012 InSAR began Baseline Geochem, PNC

2013 Baseline microseismic, VSP, borehole gravity, PNC

Level I&II Models

2014 Geochem ended

2015 InSAR ended

2016 Repeat VSP. Borehole gravity, microseismic, PNC

2016 New Well Characterization

2018 Repeat PNC, borehole gravity

2019 **>275K tons of CO_2 stored**

Level III Model

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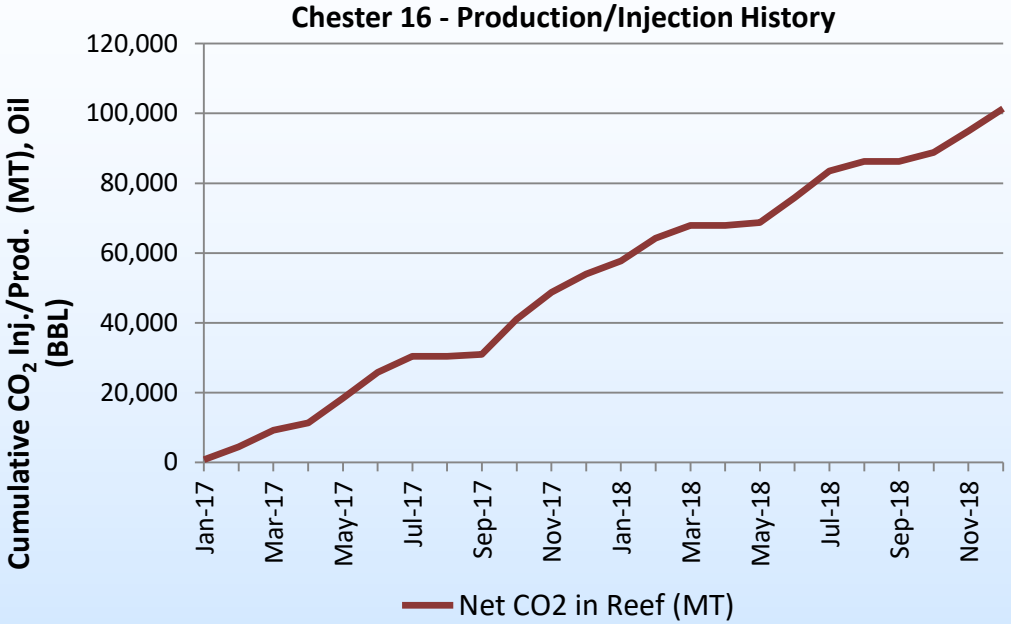
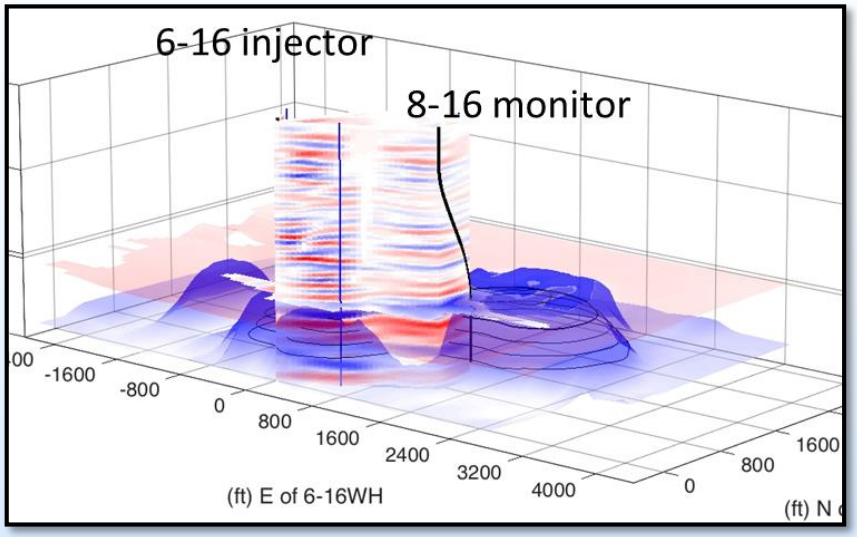
Chester 16 Reef – New EOR Flood used to Test New Technology and Methods





1971
Primary production

1983
Water Injection Began

1990
Water Injection Ended

2016
Injection well drilled
Fiber optics installed
Fluid sampling baseline
PNC baseline

2017
Monitoring well drilled
Fiber optics installed
PNC, DAS VSP baseline

Model Development

Geomechanical Tests

2018
DAS VSP repeat
Cross well seismic
Seismic attribute analysis

2019
>100K tons of CO_2 stored

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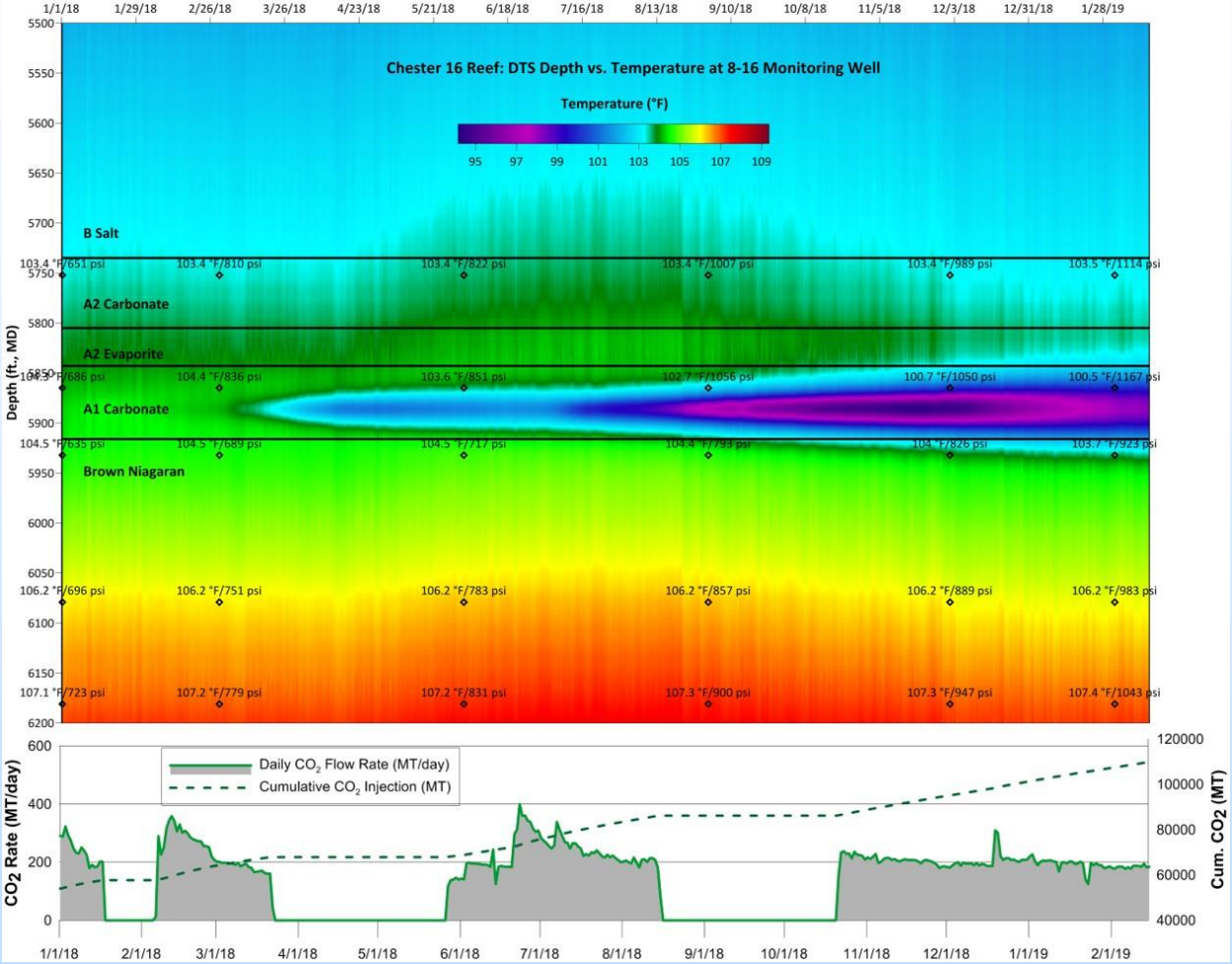
Objective-Based Monitoring Portfolio

	Monitoring Objective				Monitoring by Reef				
Monitoring Technology	Mass-Balance Accounting	Leak Detection/ well integrity	CO_2 plume tracking/ interaction	Induced seismicity, uplift	Dover 33	Charlton 19	Chester 16	Bagley	Other reefs
CO_2 injection/ production	X				X	X	X	X	X
Reservoir Pressure			X		X	X	X	X	X
Temperature (DTS)		X	X				X		
PNC logging		X	X		X	X	X	X	
Borehole gravity			X		X				
Geochemistry			X		X	X	X	X	
Vertical seismic profile – geophone		X	X		X				
Vertical seismic profile – DAS		X	X				X		
Cross-well seismic			X				X		
Microseismicity				X	X				
InSAR (Satellite radar)				X	X				

Discerning CO_2 Migration with DTS

CO_2 Moves to the top of reef in Obs. Well

Chester 8-16 Waterfall Plot



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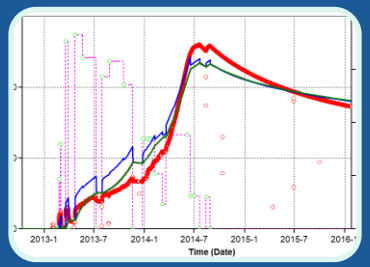
Modeling and Analyses

Reservoir properties and performance from CO_2 injection data

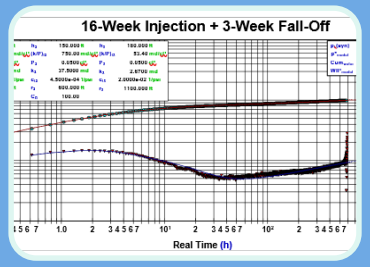


Static and dynamic modeling

- Integrate G&G data; constrain reservoir properties; evaluate reservoir performance for future scenarios
- Dover-33; Chester-16; Bagley; Charlton-19

Capacitance-resistance modeling

- Simplified estimation of reservoir capacity and injectivity; simplified analysis of future scenarios
- Charlton-19; Bagley



Transient pressure and rate analysis

- Estimate reservoir properties; synthesize results from multiple types of analysis; validate dynamic model
- Dover-33; Bagley; Chester-16; Charlton-19

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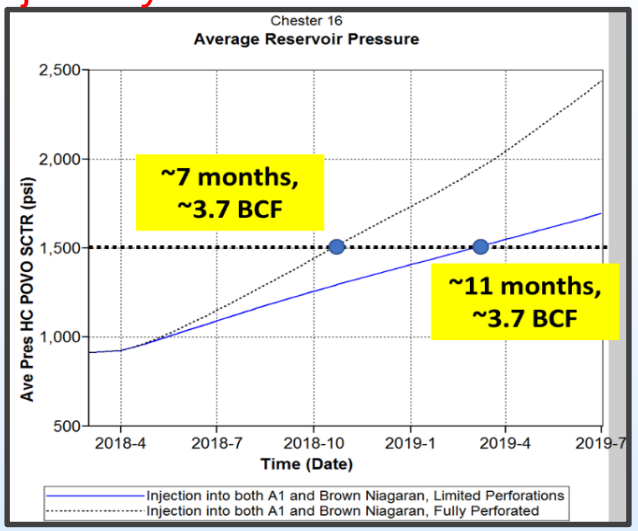
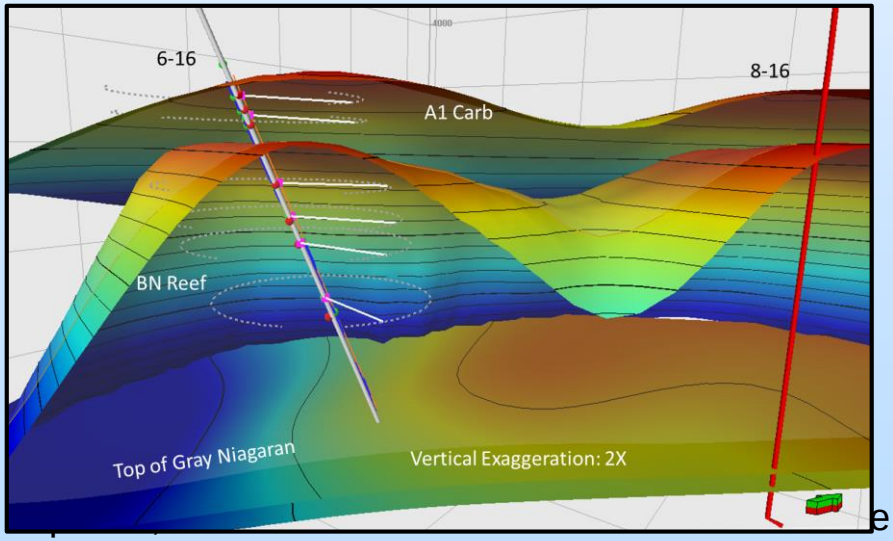
Using Models to Test Alternate Injectivity Scenarios

- Increasing the number of perforations provides only marginal improvement
- Drilling radial “tunnels” is more effective; performs similar to a horizontal well

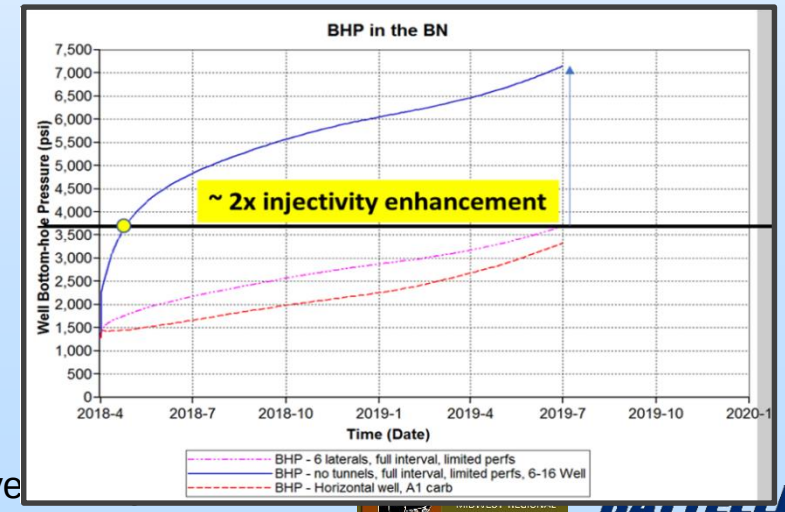
Injectivity with Increased Perforations



Radial Tunnels are small open boreholes drilled laterally from existing well



Injectivity with Radial Tunnels



MRCSP Large-Scale Injection Test

- **>1,732,500** metric tons of CO_2 stored
- **>1,167,000** barrel of oil production monitored

- Removal of **374,295** passenger cars for a year
- Amount stored by **2,262,565** acres of forest
- Switching **65,816,966** incandescent lights to LEDs

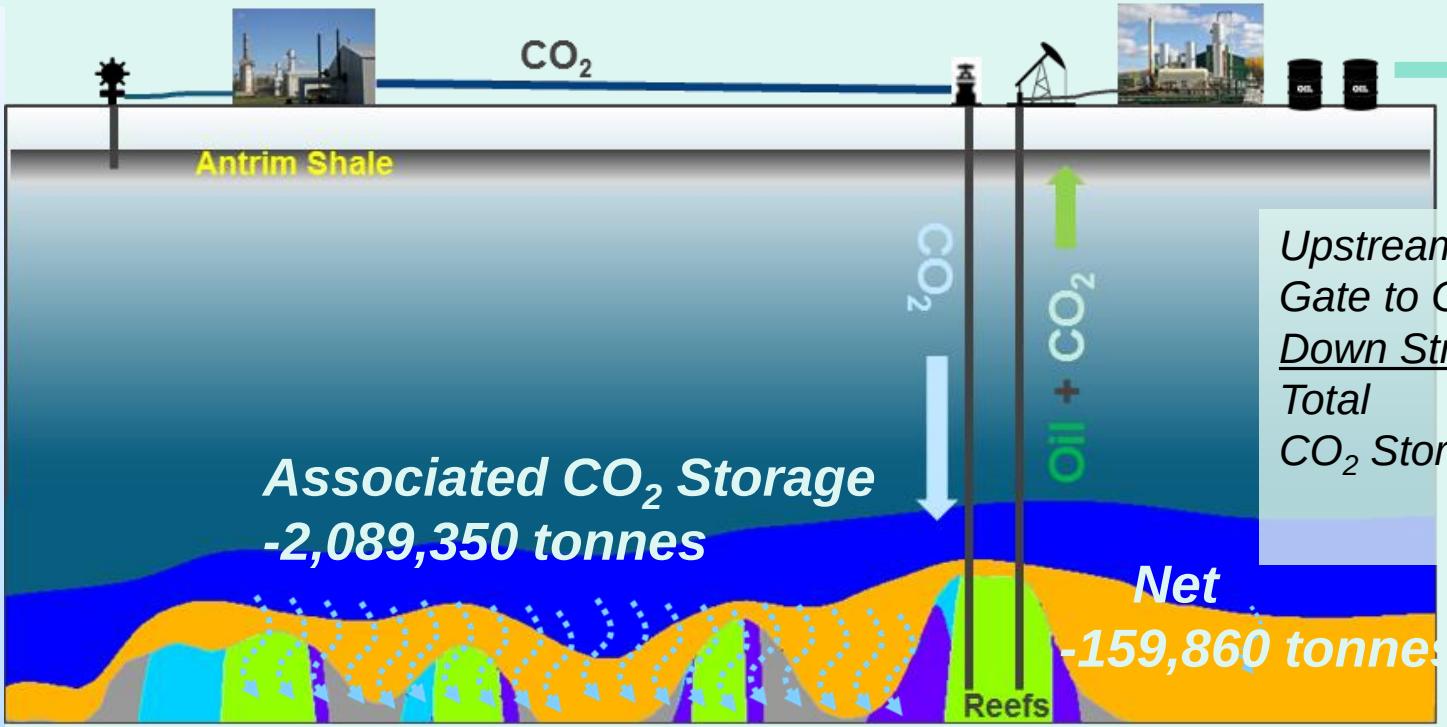
- **532** jobs yielding more than **$22.4 M** in income
- **$77.5 M** goods and services
- **$8.1 M** in other taxes and royalties

Life Cycle Analysis for 22 Years of EOR shows Net-Negative Emissions

Upstream
CO_2 Capture Plant Operations
478,476 tonnes
CO_2e Generated

Gate to Gate
(compression, EOR, & gas processing)
374,147 tonnes
CO_2e Generated

Downstream
1,076,867
tonnes CO_2e
Generated



Upstream	*+478kt*
Gate to Gate	*+374kt*
Down Stream	*+1,077kt*
Total	*1,929kt*
CO_2 Stored	*-2,089kt*
Net	*-160kt*

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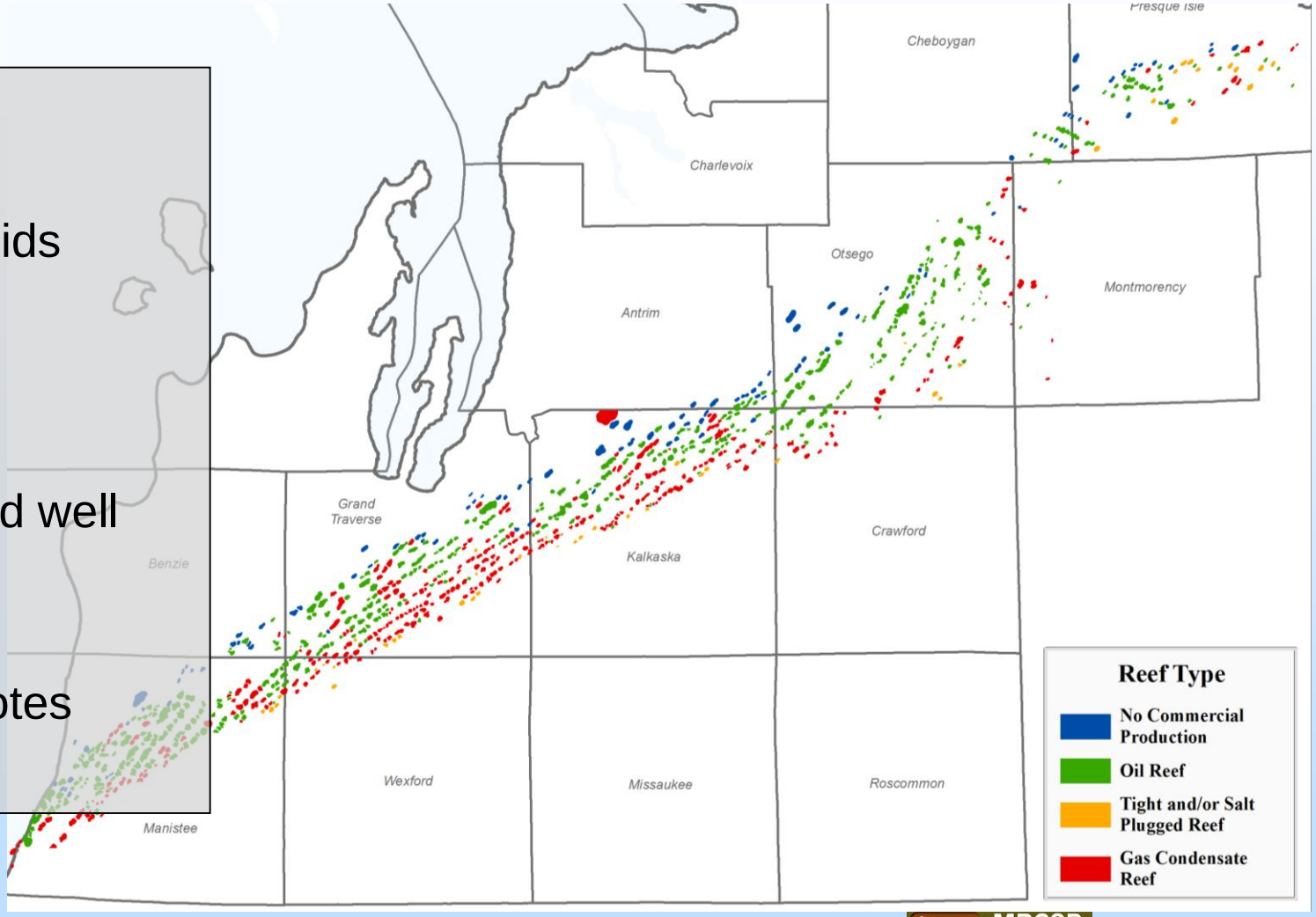
Development of a Reef Atlas – Regional CCUS Scale-up

- Type
- Status
- Produced fluids
- Pressure
- OWC
- Reef height
- # of wells and well IDs
- Operators
- Additional notes



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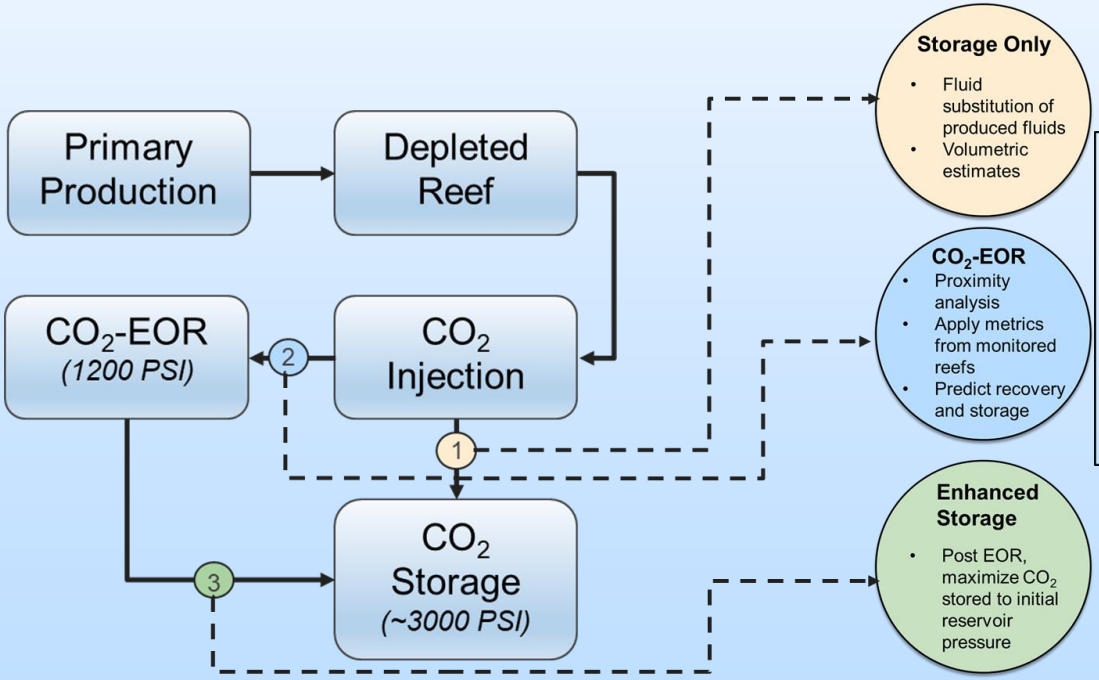
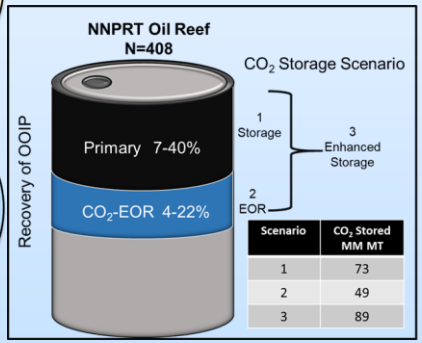
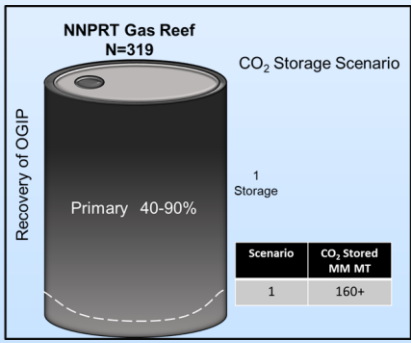
Regional Scale up to Entire NNPRT

- Regional reef atlas used to estimate CO_2 resources and EOR potential
- > 250 million metric tons of storage possible
- >100 million STB oil recoverable via CO_2-EOR







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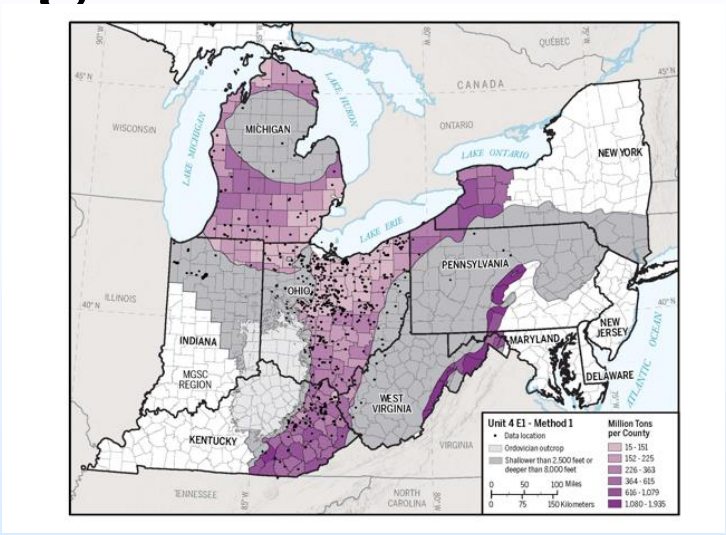
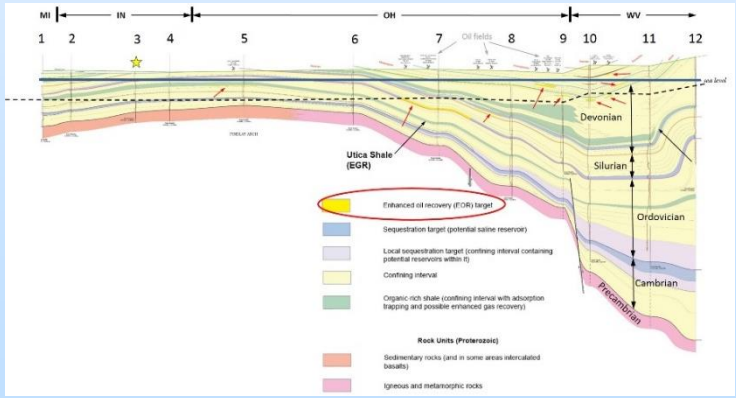
MRCSP Continued Regional Characterization During Phase III

Establish fundamentals for CO_2 storage within the ten-state region and to qualify what volumes, how and where

- Assess the potential reservoirs and seals in the region, including offshore
- Determine the type of storage (saline, EOR or EGR reservoirs)
- Quantify the potential storage resources
- Generate products essential for siting, performance modeling, MVA



Storage resource estimate map



Regional cross section

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MRCSP Conducted Extensive Outreach

Summary of 17 years

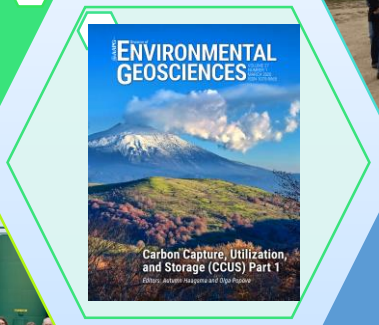
Annual partners meetings held in various locations to engage stakeholders

Papers, books, and targeted CCUS special issues

Annual Partners Meetings

Field Site Tours

Peer Reviewed Publications



Technical Workshops

Presentations

STEM Outreach

100s of oral and poster presentations at leading technical conferences. MRCSP special sessions and invited talks

Numerous technical workshops and site visits

AAUW, BeWISE STEM camp

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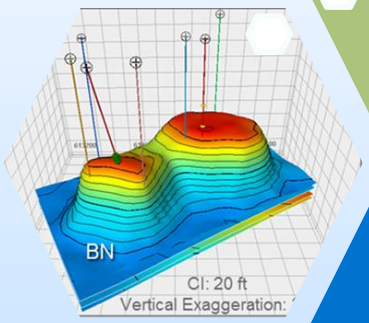
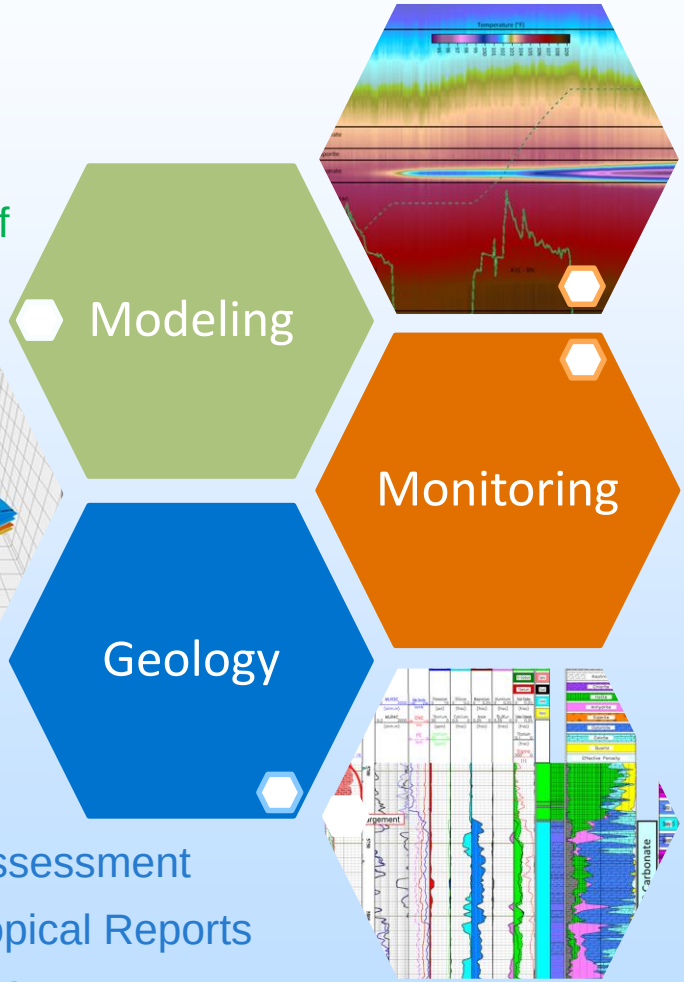
Extensive Final Reports Under Review

Final Technical Report and Papers

- Chester 16 Reef
- Dover 33 Reef
- Bagley Reef
- Charlton 19 Reef





- Monitoring, Reporting, Verification Plan (MRV)
- Life Cycle Assessment
- Borehole Gravity
- Geochemistry
- INSAR
- VSP / DAS-VSP
- Cross Well Seismic
- Microseismic
- Mass Balance Accounting
- Distributed Temperature Sensing (DTS)
- Pressure Analysis
- Pulsed Neutron Capture
- EOR Performance Dashboard

- Phase III Geologic Assessment
- Geo Team Partner Topical Reports
- Reef Trend Regional Assessment

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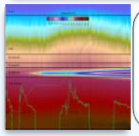
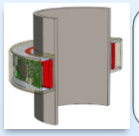
MRCSP has Spawned Numerous Synergistic Projects in the US and Abroad

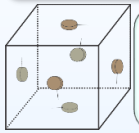
Technology Development


Machine Learning / Data Analytics

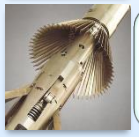
NETL Research Support and S.M.A.R.T. Initiative


Microsensors System to Monitor Deep Subsurface

CCUS Research

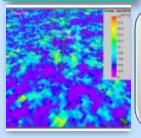

Non-Invasive Approach for in-Situ Stress for CO_2 Storage

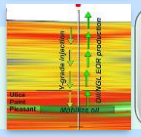

Mid-Atlantic Offshore CO_2 Storage Resource Assessment


Wellbore Integrity Assessment

Pilot Projects


Mid-Continent CarbonSAFE


Chemically Enhanced CO_2-EOR in Southern Michigan


Y-Grade NGL Treatment for Unconventional Oil Recovery

International Development


World Bank South Africa CO_2 Storage Pilot

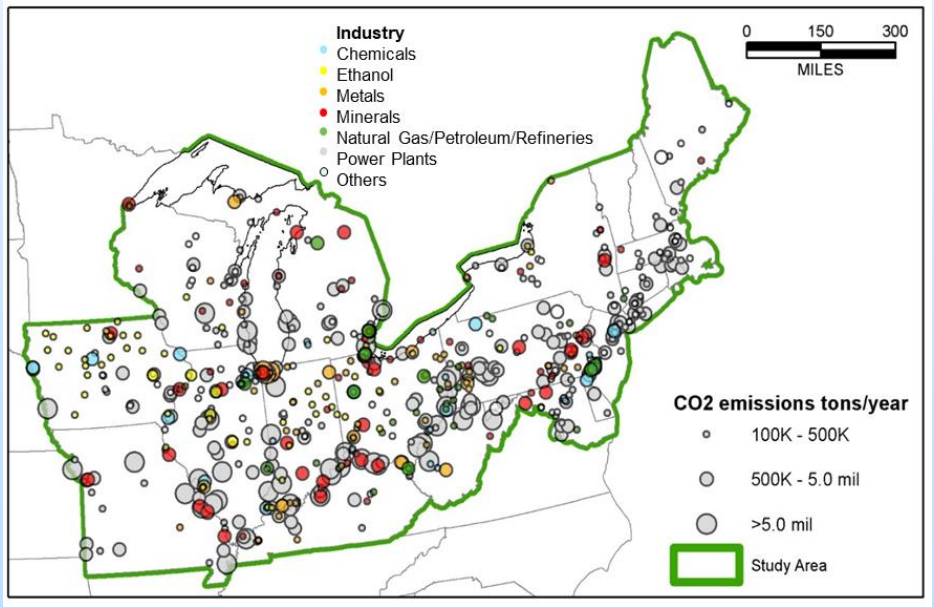

Asian Development Bank Indonesia CCUS Projects


World Bank China

Midwest Regional Carbon Initiative

- New initiative led by Battelle and Illinois State Geological Survey
- Combines MRCSP and MGSC
- Diversity of CO_2 sources in the region
- Multiple geologic basins and provinces provide variety of storage solutions
- New initiative is advancing CCUS research through four main tasks:
  - ✓ Addressing key technical challenges
  - ✓ Obtaining and sharing data to support CCUS
  - ✓ Facilitating regional infrastructure planning
  - ✓ Performing regional technology transfer

MRCI
Midwest Regional Carbon Initiative



MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
BATTELLE

MRCSP has Accomplished All its Goals

- >1.7M MT net stored under MRCSP monitoring, >2.8M MT stored since start of EOR in 1996
- Completed monitoring at main test bed in late-stage reef
  - Micro-seismic, Post-injection PNC, microgravity, and VSP completed, Post-injection test well drilled and characterized
  - Returned to normal EOR operations, with selected monitoring continued
- Added new EOR reefs with complex geology to monitoring
  - Distributed temperature and Acoustic Monitoring
- Advancements in static and numeric modeling processes for CCUS
- MRV Plan and Life-Cycle Analysis completed
- Support commercialization with 45Q Partnership by Core Energy, LLC

Lessons Learned

- Surrounded by salt and low permeability carbonates, reefs are excellent containers for CO_2
- CO_2 **measurement/accounting** can be performed with high level of confidence in an inter-connected multi-field EOR complex
- Storage in **closed reservoirs** evaluated, for – EOR to storage transition
- **Geologic complexity** in reefs affects CO_2 injection, migration, and storage
- **Pressure monitoring** remains the mainstay for managing injection operations and monitoring reservoir response
- **Advanced monitoring** technologies still require testing/validation for confident assessment of plume development in different geologic settings
- **Characterization-monitoring-modeling** loop requires more research for cross-validation over the life-cycle
- A well-developed CO_2-EOR **regulatory/policy framework** with financial incentives essential for enhanced associated storage

Project Summary

- MRCSP Large-Scale Test 100% completed with diverse EOR field setting and variety of monitoring options
- Field research included a strong combination of characterization, monitoring, and modeling
- Multiple monitoring options were tested
- Both monitoring and modeling were essential for understanding performance – imperative to be able to do much with limited data
- Regional characterization helped identify new storage zones and estimate storage resources – setting stage for commercial scale CCS
- Results will contribute to developing standards and best practices, NRAP tools, CO_2 capacity estimation tools

Appendix

Benefit to the Program

MRCSP Approach/Benefit	DOE Program Goal
Geologic characterization, reservoir assessment and models correlated with field monitoring combined with MRCSP regional mapping.	Predict CO_2 storage capacity in geologic formations to within ±30%
Operational accounting for CO_2 during EOR Monitoring options to track and image plume, and monitor CO_2 storage and retention	Demonstrate that 99% of CO_2 remains in the injection zones
Test in EOR fields in various stages of their life cycle and examine effective strategies for utilizing the pore space created by the oil production	Improve reservoir storage efficiency while ensuring containment effectiveness
Contribute to BPMs through large-scale test and regional analysis across MRCSP	Development of Best Practices Manuals (BPMs)

Project Overview

Goals and Objectives

RCSP Goal	MRCSP Success Criteria
Goal 1 – *Prove Adequate Injectivity and Available Capacity*	• Success measured by injecting 1 million tonnes of CO_2 in CO_2-EOR fields within permitted pressures • Pressure analysis and modeling used to evaluate and validate capacity
Goal 2 – *Prove Storage Permanence*	• Seismic and well data used to evaluate storage and containment zones • Monitoring wells used to measure containment over time within the reef and immediate caprock • Reservoir modeling to evaluate storage mechanism
Goal 3 – *Determine Aerial Extent of Plume and Potential Leakage Pathways*	• Monitoring portfolio employed to image and track the lateral and vertical plume migration. Success measured by using monitoring data to compare to and validate plume models

Project Overview

Goals and Objectives

RCSP Goal	MRCSP Success Criteria
Goal 4 – *Develop Risk Assessment Strategies*	• Risk assessment for events, pathways, and mitigation planning • Success will be measured by comparing predicted to actual field experience for all stages of the project
Goal 5 – *Develop Best Practices*	• Phase III builds on Phase II best practices in siting, risk management, modeling, monitoring, etc. • Key emphasis is on operation and monitoring and scale-up to commercial-scale
Goal 6 – *Engage in Public Outreach and Education*	• Extensive outreach efforts for both Phase II and Phase III sites as well as technology transfer and sharing • Phase III lessons learned contribute directly to the RSCP Best Practice Manual updates

Organization Chart

DOE/NETL
Andrea McNemar
MRCSP Program Manager

Battelle
The Business of Innovation

Prime Contractor
Neeraj Gupta, PI/PM
M. Kelley, Characterization/Monitoring
A. Haagsma, Outreach & Regional Geology
A. Haagsma and A. Conner, Geology
S. Mishra, P. Ravi Ganesh, and A. Pasumarti Modeling
C. Duffy (PM), A. Burchwell, (Dep. PM)
A. Conner Fieldwork

Pacific Northwest NATIONAL LABORATORY

Charlotte Sullivan
Alain Bonneville
Characterization Monitoring Support

Kentucky Geological Survey UNIVERSITY OF KENTUCKY
Michigan Basin Core Research Laboratory
MARYLAND GEOLOGICAL SURVEY
WVGES
New York State Museum
RUTGERS

Kris Carter, PA Geo Survey
Regional Characterization Task Coordinators

WADE

Sarah Wade
Outreach Working Group Coordinator

THE OHIO STATE UNIVERSITY

David Cole
Geochemical Monitoring
LLNL

CORE ENERGY, LLC

Robert Mannes
Rick Pardini
Large-Scale Test Host

MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
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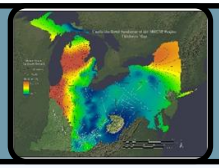
MRCSP Scope of Work Structured Around Six Tasks



Task 1

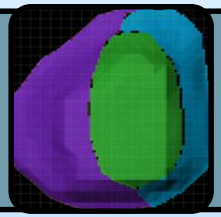
Regional Characterization: *Develop a detailed actionable picture of the region's geologic CO_2 storage resource base*

Task 2

Outreach: *Raise awareness of regional CO_2 storage opportunities and provide stakeholders with information about CO_2 storage*

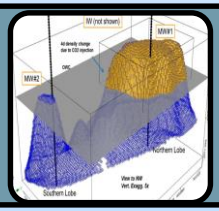
Task 3

Field Laboratory Using Late-Stage EOR Field: *Pressurize a depleted oil field with CO_2 injection to test monitoring technologies and demonstrate storage potential*



Task 4

CO_2 Storage Potential in Active EOR Fields: *Monitor CO_2 Injection and recycling in active EOR operations with different scenarios*



Task 5

CO_2 Injection in New EOR Field(s): *Monitor CO_2 injection into an oil field that has not undergone any CO_2 EOR to test monitoring technologies and demonstrate storage potential*

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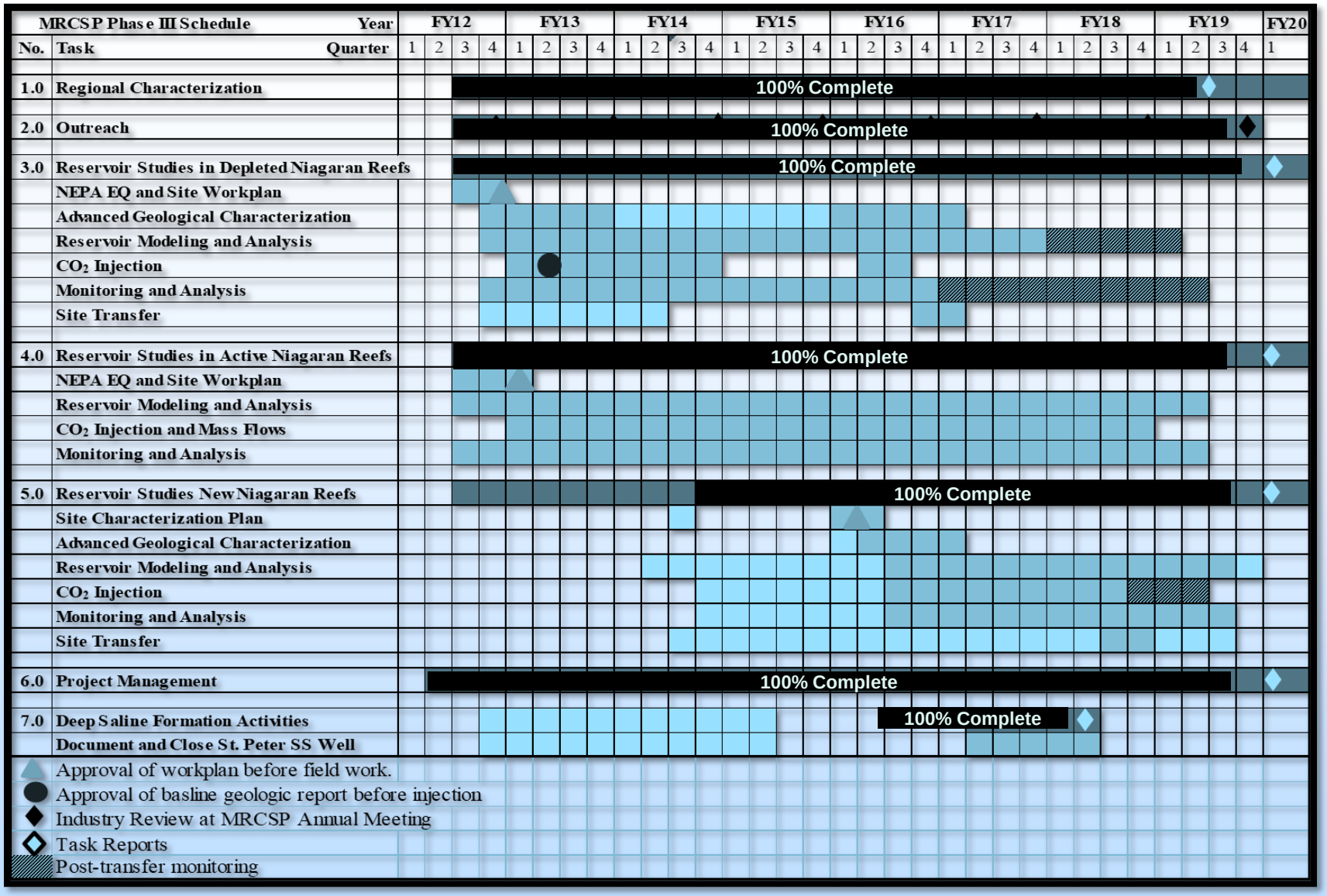
Task 6

Program Management

Gantt Chart



MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

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