Importance of Field Projects and Regional Mapping to Demonstrate Geologic Storage Potential in the Midwestern United States*

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Abstract

This presentation will provide information on the work being undertaken by the Midwest Regional Carbon Sequestration Partnership (MRCSP) to test and demonstrate the commercial viability of carbon capture, utilization, and storage in the Midwestern region of the United States. The MRCSP Michigan Basin Large-Scale Injection Project is part of a larger national carbon storage research program headed by the United States Department of Energy. Since injection operations began on February 3, 2013, MRCSP has successfully injected and monitored the net storage of more than 300,000 metric tons of carbon dioxide. The goal of the project is to inject one million metric tons of carbon dioxide into depleted oil and gas fields during a span of roughly four years. Large-scale injection projects like the Michigan Basin test are needed to reduce the uncertainty with geological storage, demonstrate technical and economic feasibility, and increase public acceptability. A variety of approaches are being implemented to collect and analyze data on monitoring, injectivity, capacity, and safety. In addition to the large-scale test, MRCSP research team is also evaluating carbon dioxide storage potential in the Appalachian Basin and other areas of the Midwest through regional mapping and exploratory site characterization in collaboration with the oil and gas industry. This presentation will provide an overview of the key findings of the MRCSP program and how this information may be applied to future commercial storage sites.

Acknowledgement

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A Mid-Term Status Update on MRCSP

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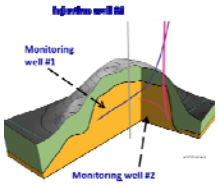
DOE/NETL Cooperative Agreement # DE-FC26-0NT42589

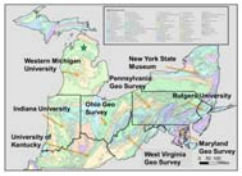
AAPG Eastern Section, Indianapolis, Sept 20-21, 2015

MRCSP Field Tests and Regional Characterization
Presentation Outline

About the MRCSP



Large Volume CO_2 Injection Test



Regional Characterization

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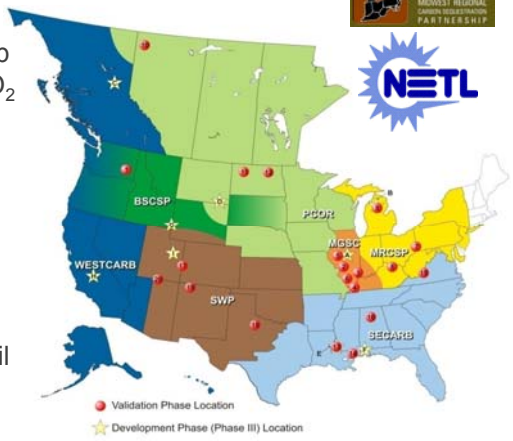
The MRCSP is assessing viability of carbon sequestration

- One of seven DOE-funded regional partnerships to develop infrastructure for wide-scale CO_2 sequestration deployment
- Characterization phase (2003-2005) and validation phase (2005-2010) completed
- MRCSP Development phase (2010-2019) focused on CO_2 utilization/storage in depleted oil fields in Michigan
  - Late-stage EOR reef
  - Operational EOR reef
  - Newly targeted reef



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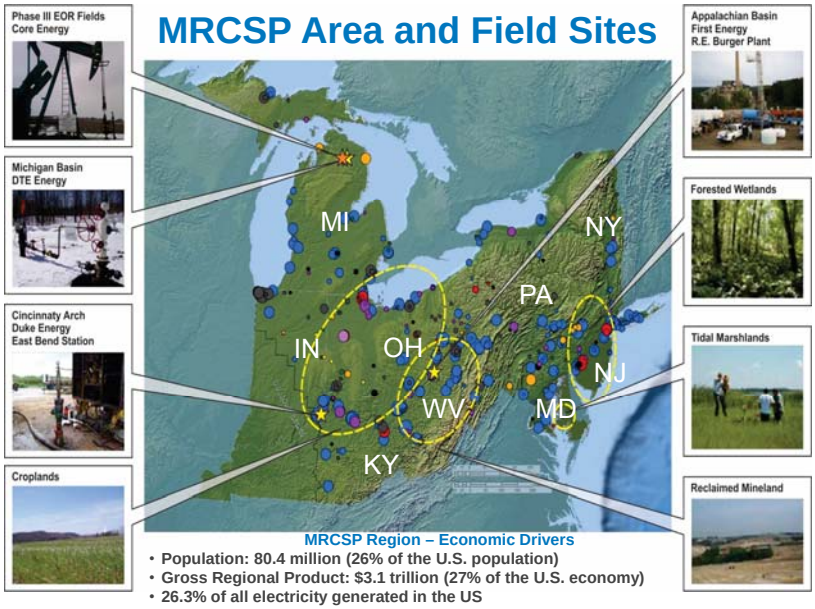
MRCSP Area and Field Sites



MRCSP Region – Economic Drivers

- **Population: 80.4 million (26% of the U.S. population)**
- **Gross Regional Product: $3.1 trillion (27% of the U.S. economy)**
- **26.3% of all electricity generated in the US**
- **75% of electricity generated in the region is generated by coal**

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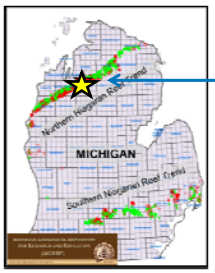
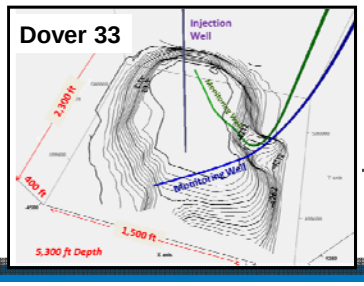
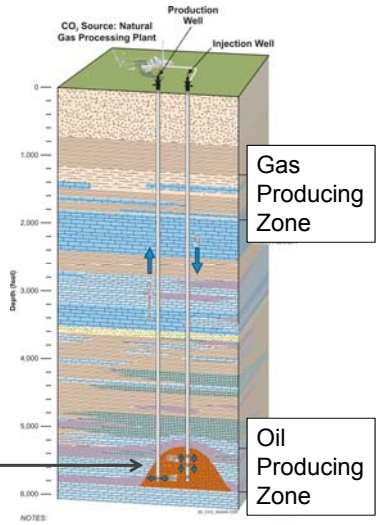
MRCSP Large-Scale Injection Test

Late-stage reef is the main test bed







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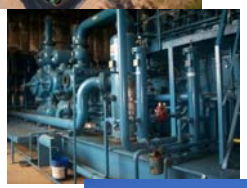
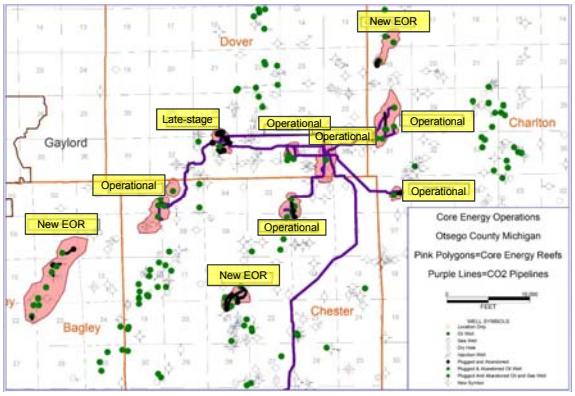
MRCSP Large-Scale Test Site – Leveraging CO_2-EOR Infrastructure





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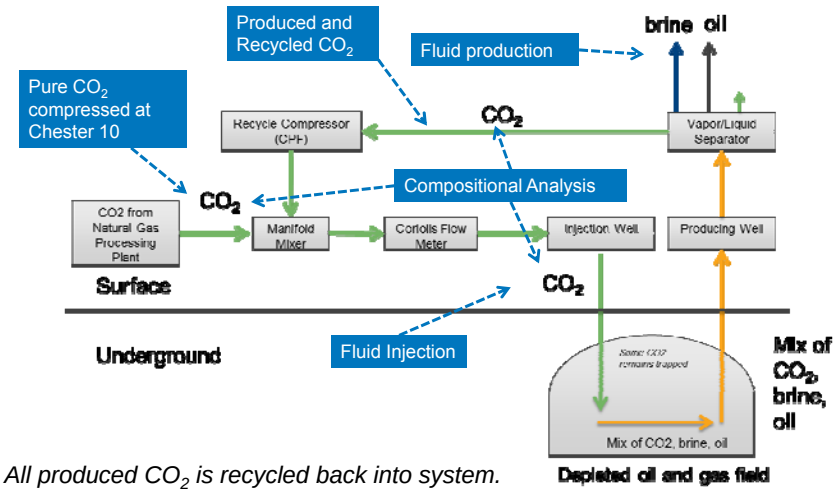
Closed Loop System for CO_2 EOR Cycle

Monitoring and Accounting for the CO_2



All produced CO_2 is recycled back into system.

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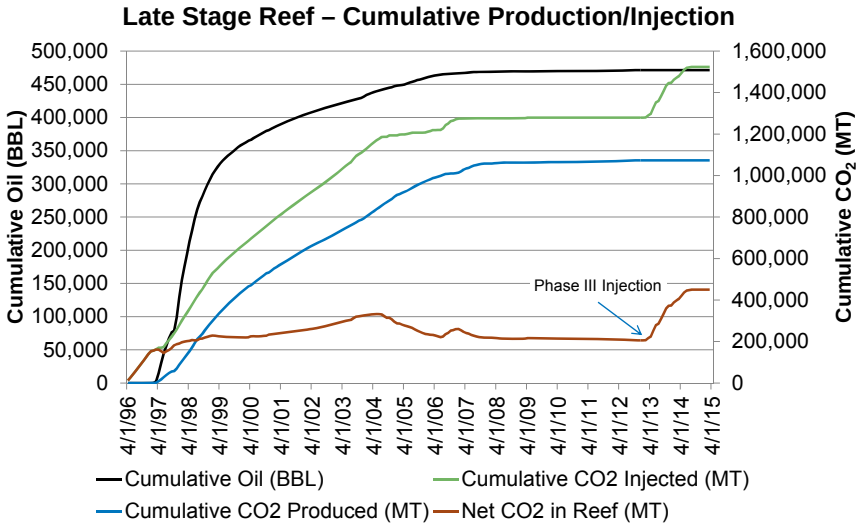
Historical and Recent CO_2 Injection Data

Late Stage Reef EOR Operations



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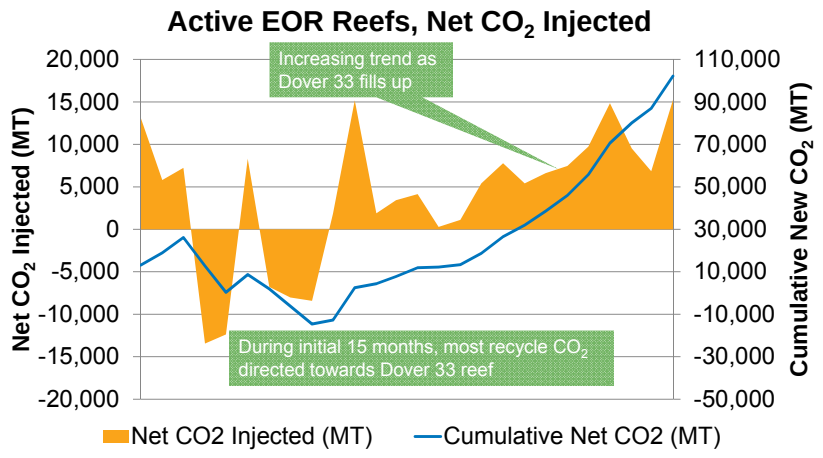
Recent CO_2 Injection Data: Active EOR Reefs

Tracking net retention over time and across multiple fields



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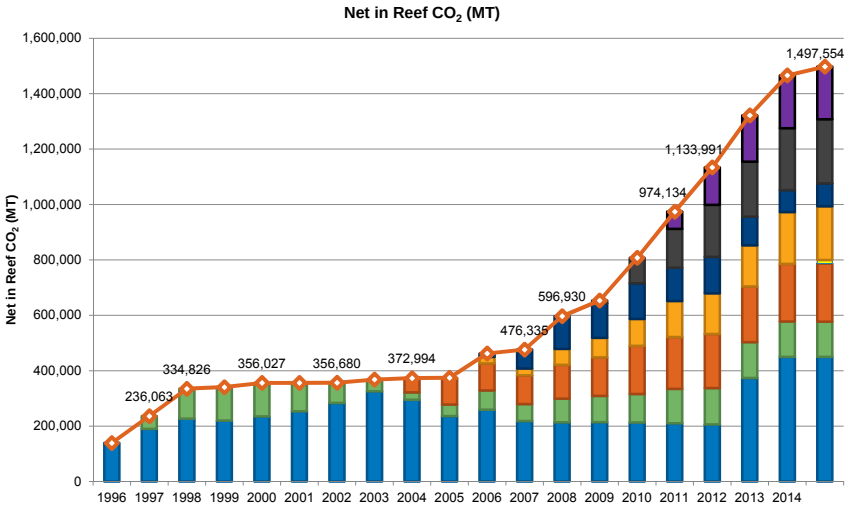
Net CO_2 Stored in All Reefs Over Time

~1.5M metric tonnes retained since 1996



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Monitoring Status for Late Stage Reef

A portfolio of technologies is being tested

Activity	Before Injection	Early Injection	Mid Injection	Late Injection	After Injection
CO_2 flow		X	X	X	
Pressure and temperature		X	X	X	X
Wireline logging	X		X		X
Borehole gravity	X				X
Fluid sampling	X		X		X
Vertical seismic profile	X				X
Microseismic	X			Under planning	
Satellite radar	X	X	X	X	X

Lessons learned will be applied to design the MVA plan for the newly targeted field

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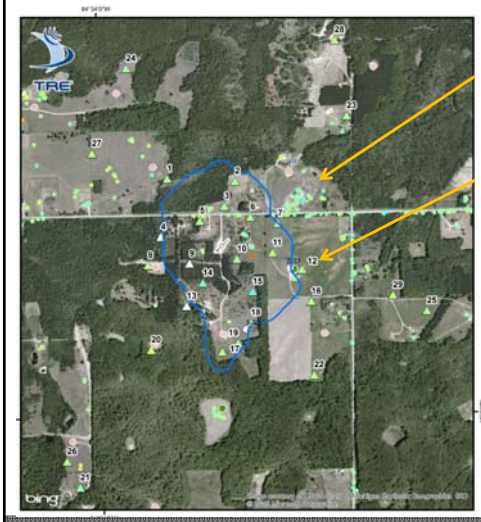
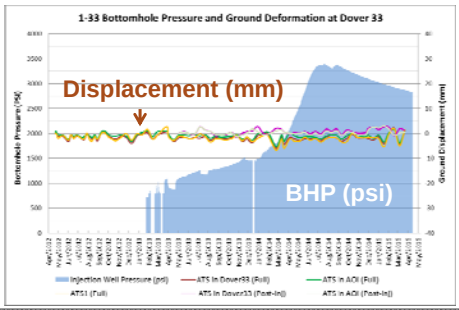
INSAR Monitoring for Surface Changes:

No perceptible change Seen due to injection



- Vegetation and snow are challenging for radar, but there were a reasonable number of natural reflectors
- Artificial reflectors augmented the data for injection monitoring



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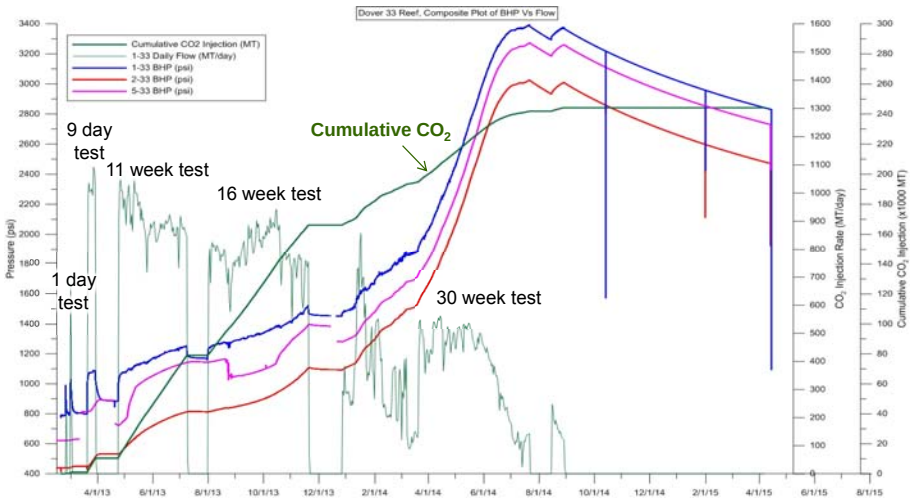
Pressure Monitoring in Late-Stage Reef

Slow, long-term decline 9 months after injection



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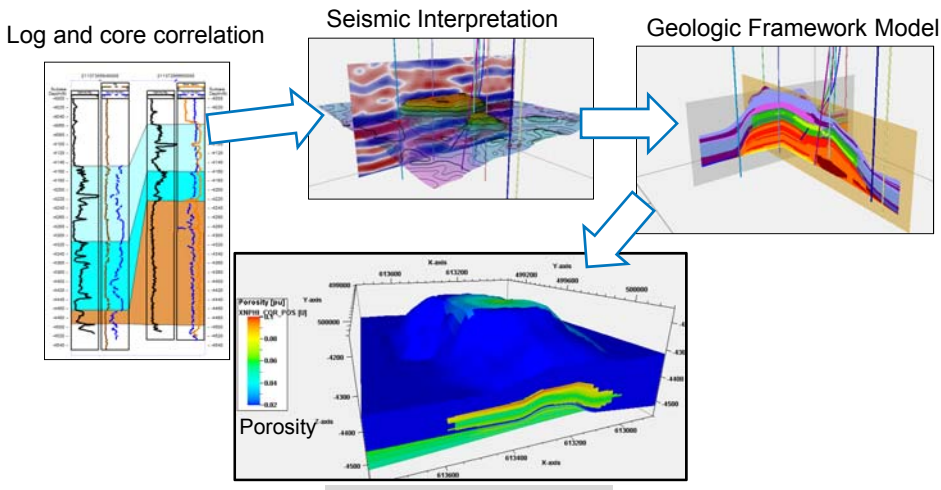
Geologic and Reservoir Model Development



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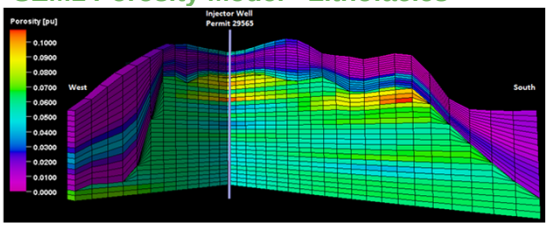
Modeling Reef Geologic Complexity

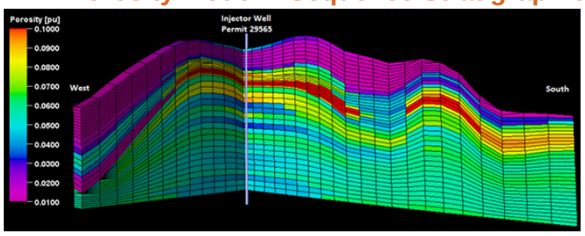
Static earth models built in various levels of geologic detail

SEM1 Porosity Model - Lithofacies



- Limited data available in late-stage reef (few wells and no core data)
- Heterogeneous geology
- Internal architechure difficult to model precisely

SEM2 Porosity Model – Sequence Stratigraphic



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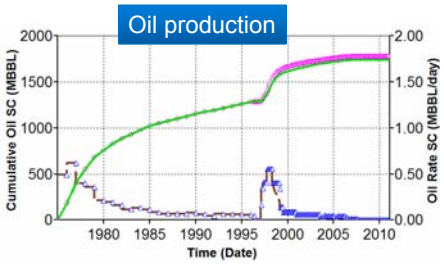
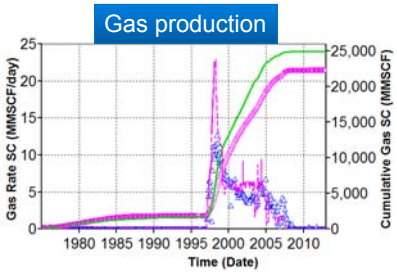
Simplified Compositional Model History-Match

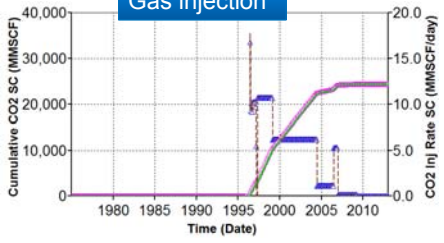
Oil production



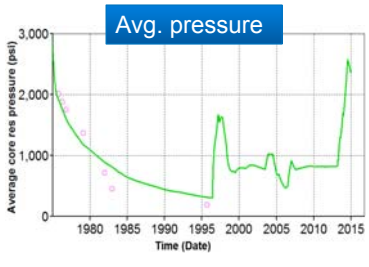
Gas production



Gas injection



Avg. pressure



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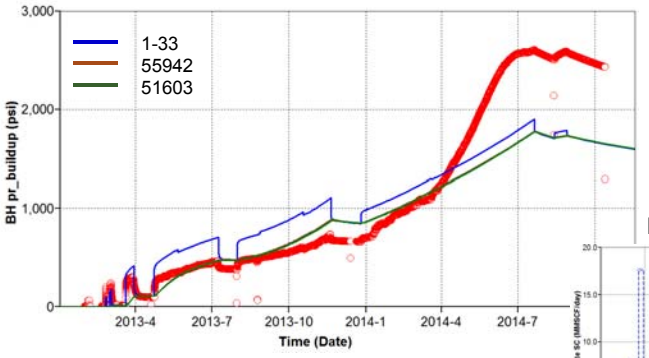
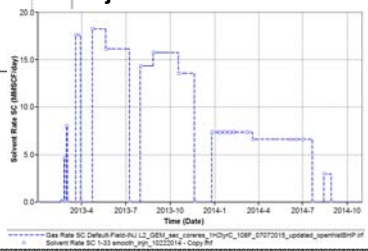
Modeling Pressure Response

Equivalent Homogeneous Compositional Reservoir Model
MRCSP Injection Response Validation



Injection Schedule



Reasonable match except near the end of injection

Further model calibration is in progress

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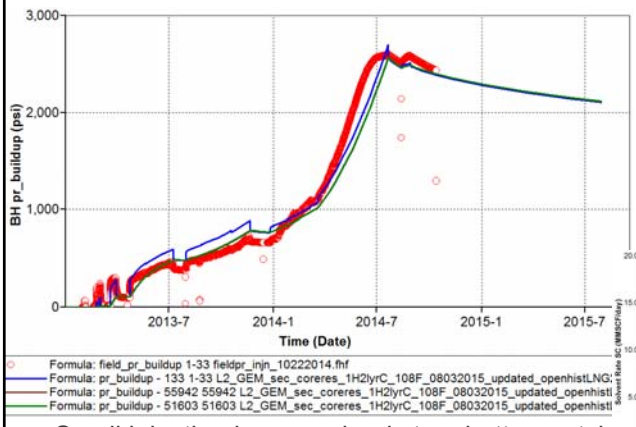
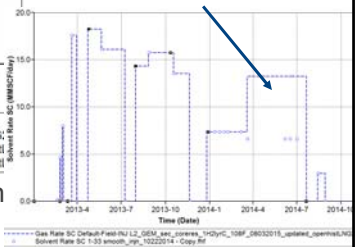
Modeling Pressure Scenarios

Sensitivity to injection rates



Hypothetical "what-if" higher injection scenario

Modified MRCSP Injection rate schedule



- Small injection increase leads to a better match
- Current model within range of uncertainty?

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Simulated CO_2 Distribution within the Reef

Migration into reef flanks over time

At beginning of MRCSP Injection

At end of MRCSP Injection @10/2014

Post-MRCSP Injection @06/2015

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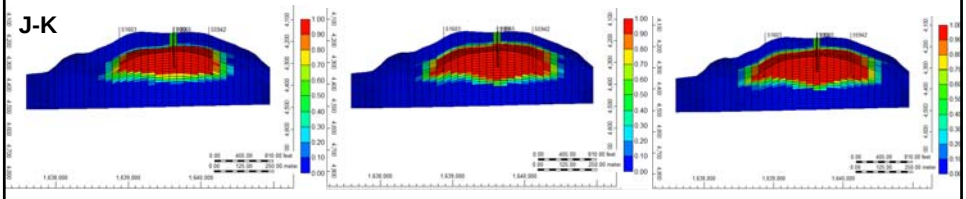
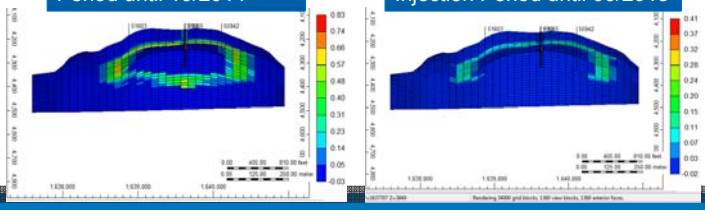


Difference Maps

For MRCSP Injection Period until 10/2014

Fall-off post MRCSP Injection Period until 06/2015



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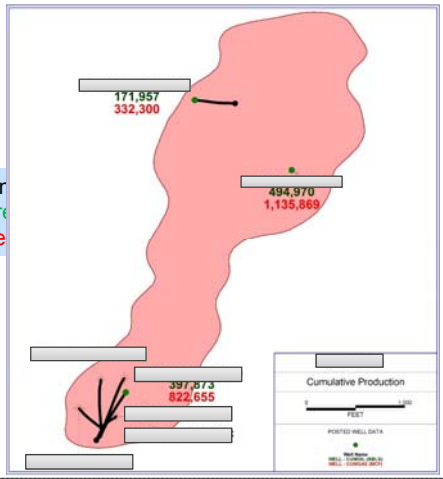
New EOR Reef Layout and Production History

- Initial saturation (oil, water, gas) = 88.65%, 11.35%, 0% (no initial gas cap)
- Original Oil In Place = 2.634 MMSTB



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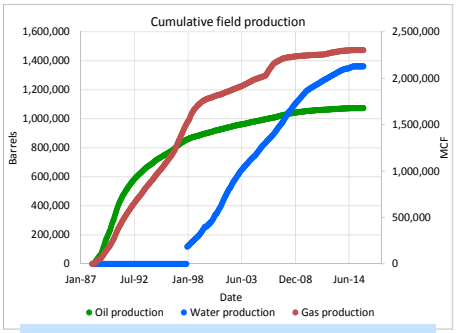

Cumulative Production

- 1.074 MMSTB oil (40.7% of OOIP)
- 2303 MMSCF gas

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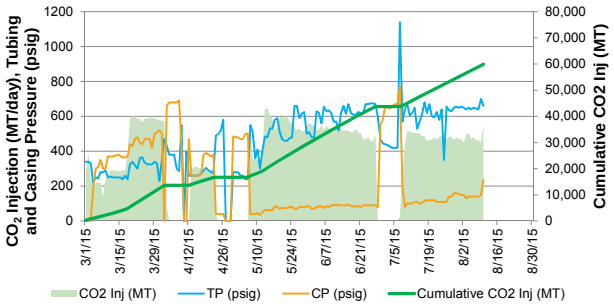
CO_2 Injection in a New EOR Flood



- CO_2 injection began on March 1st, 2015
- ~60K metric tons of CO_2 injected to date
- Rates ranged from 150 to 645 MT/day
- Two operational interruptions used to obtain pressure fall-off data for analysis

Daily and Cumulative CO_2 Injection at a new EOR Reef March to August, 2015

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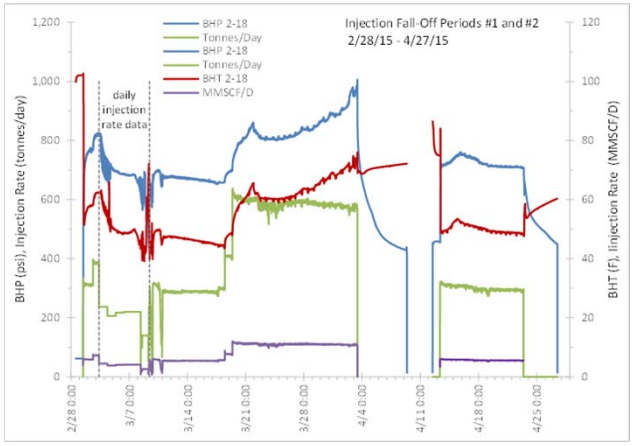
New EOR Reef
Injection Well Pressure/Temperature Response



- Pressure increases by several hundred PSI
- Temperature appears to follow pressure trend (gauge issue?)
- Two fall-offs conducted

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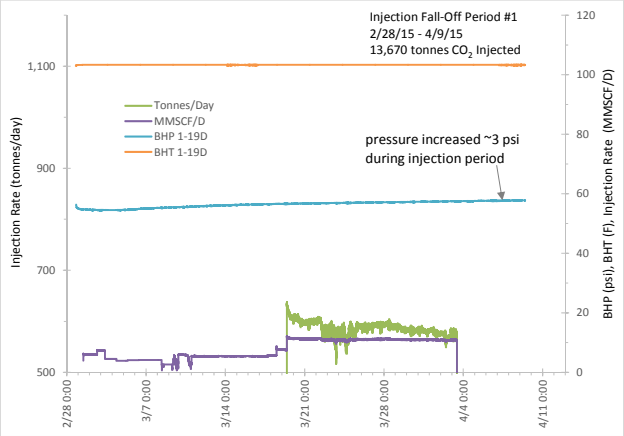
New EOR Reef – Monitoring Well Pressure Response)



- Well is only partly connected to main reef lobe
- Only a small pressure response observed (~3psi)
- Demonstrates a slight hydraulic connection between the north and south parts of the reef

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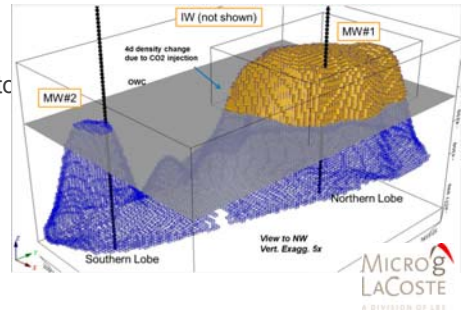
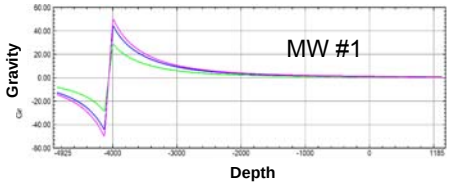
Borehole Gravity Meter Survey Assessment

Modeling exercise for the New EOR Reef

- Battelle provided well logs, formation top picks, and structure contour grids to Micro-g LaCoste
- Built 3D reservoir model (in Oasis Montaj) and profile (2-½D) reservoir model
- Modeling methods estimated total change in formation density for 3 injection scenarios
- Preliminary modeling predicted detectable signal response in north/center of new EOR reef but low response in MW#2
- *MW#1 had to be plugged, so the gravity survey performed in this reef*





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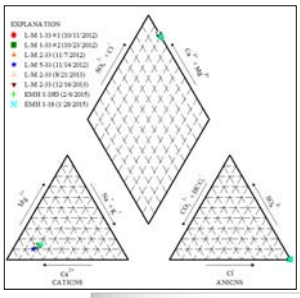
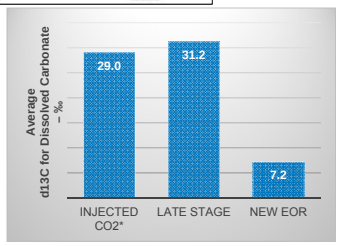
Geochemical Studies: Stable Isotope as Tracers

Late-Stage reef shows impact of CO_2 relative to new reef

- Collected gas and brine samples from a new EOR reef, which has not received CO_2.
- General brine chemistry is similar between new EOR reef and late-stage reef with very high TDS.
- Isotopically, the brines are different. Differences in the $\delta^{13}C$ for dissolved carbonate suggest the brine chemistry is altered by the injection of CO_2.
- Note: the $\delta^{13}C$ value has been corrected for fractionation resulting from dissolution and dissociation.





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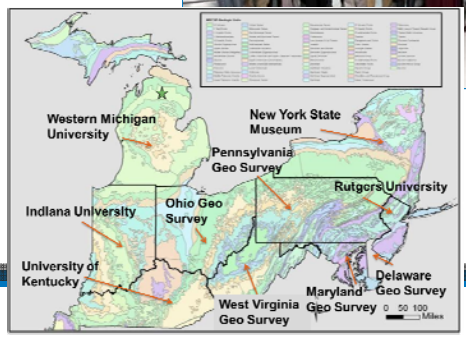
Regional Characterization - An Integrated Geologic Storage Potential Mapping Collaboration

State geological surveys are:

- Compiling/interpreting data
- Developing common terminology for formations across state boundaries
- Creating maps and other tools

MRCSP's geology team



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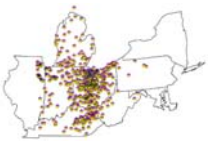
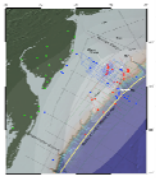
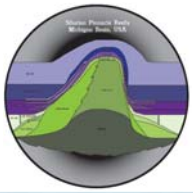
Selected Regional Geology Team Activities



Cambro-Ordovician Storage Potential
Led by Indiana

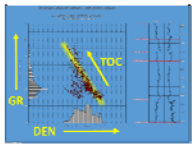


East Coast Offshore and Onshore Storage Targets
Led by Rutgers

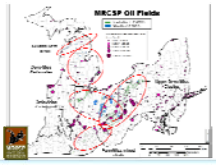


Silurian Pinnacle Reef Reservoirs
Led by W. Michigan University

CCUS Opportunities in Appalachian Basin
Led by Pennsylvania



Storage and Enhanced Gas Recovery for Organic Shale
Led by Kentucky



Reservoirs for CO_2-EOR, EGR, and other Commercial Uses
Led by West Virginia

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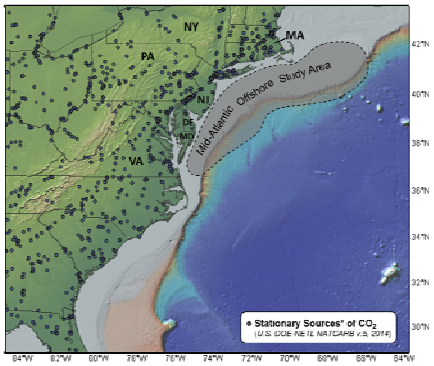
Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project New Project (DOE FOA 1246)



- Project Team includes Battelle; geological surveys of MD, DE, and PA; USGS; Rutgers; Harvard; and Columbia

Example of existing core material, COST G2 well

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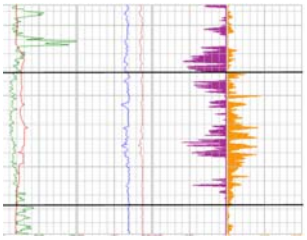
Defining CO_2 Storage in Upper Ohio River Valley

- Create "Road Map" for CO_2 sequestration in saline reservoirs in the Upper Ohio River Valley area.
  - Determine extent of potential reservoirs, such as the Copper Ridge and Conasauga/Rome
  - Characterize potential caprocks, both in terms of petrophysical and geomechanical properties
  - Map relevant parameters: porosity, permeability, injectivity, capacity
  - Continue gathering new data through piggyback opportunities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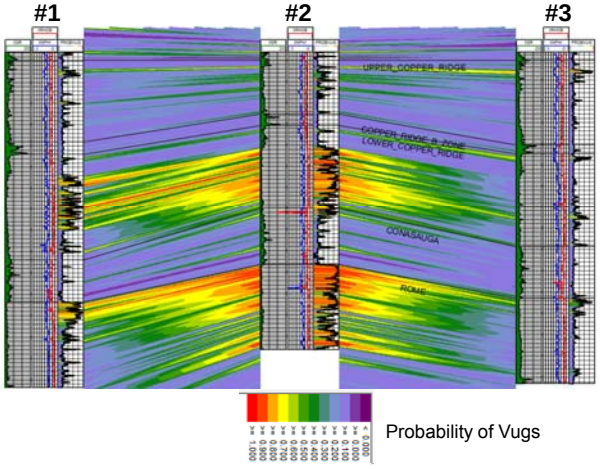
Characterizing Storage Zones

Learning from Brine Injection Wells

Vug Probability in Lower Copper Ridge and Rome Dolomites

- Local view of vug probability across three closely spaced wells
- There is better probability of vugs and potential connectivity between Wells 1 and 2
- Properties improve understanding of fluid flow



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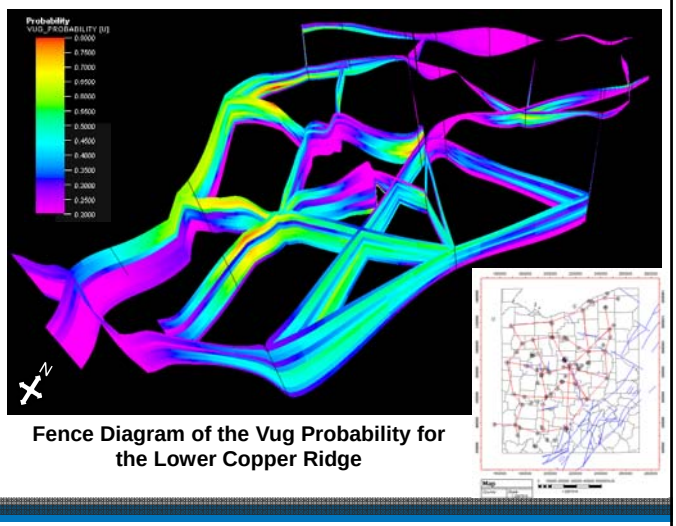
Characterizing New Storage Candidates

Vuggy Dolomite Probability Mapping in Copper Ridge

- Apply methods to a regional scale
- Identify areas of high probability of vug development
- Identify areas of best reservoir potential



Fence Diagram of the Vug Probability for the Lower Copper Ridge

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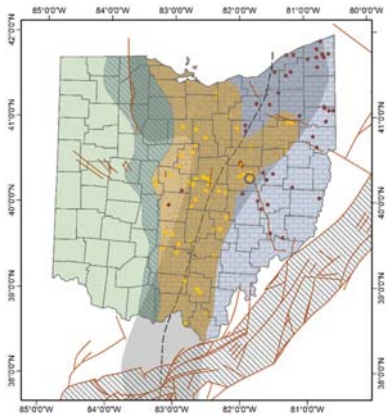
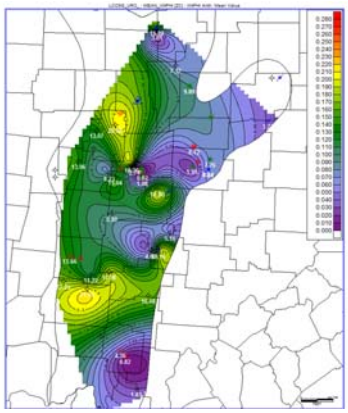
Regional Mapping of Storage Targets

Sandy Facies Map for Conasauga Group



Extent of the sandy facies in the Conasauga (orange) and how it relates to known structure



Porosity map of the sandy facies showing high porosity (yellow) in the center.

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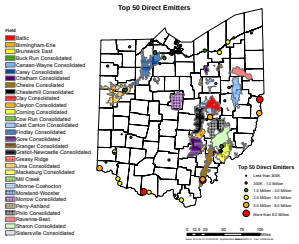
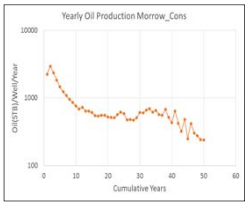
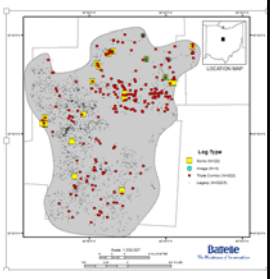
CO_2 Utilization for EOR and Geologic Storage in Ohio's Depleted Oil Fields

- **Research goals**
  - Develop process understanding and evaluate technical and economic feasibility of CO_2 utilization and storage in Ohio's depleted oil fields
  - Focus on Clinton sandstone and Knox dolomite formations (under-pressured, low permeability reservoirs with poor primary recovery)



- **Current focus**
  - Source-sink matching
  - Production history assessment
  - Geologic model development
  - Fluid property characterization
  - Reservoir simulation





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CO_2-EOR/Storage Assessment

Fluid Property Prediction Tool for oil-gas-water-CO_2 Systems

Inputs:

Shadding Indicates Needed Input		
Input Bubble Point Property		
Select Known Bubble Point Property :	Pressure	
Pressure, pB	2017.0	psia
Additional Reservoir Properties		
Oil gravity, γ_{API}	43.6	API
Gas gravity, γ_g	0.76	-
Reservoir Temperature, T	108	°F
Single Point Pressure of Interest Evaluation at right		
Pressure, p	1250	psia
Pressure Range of Interest See next sheets for tables and plots		
Maximum Pressure	2894	psia
Min Pressure	15	psia
Brine-Gas Calculations		
Calculate Brine-Gas Properties?	Yes	
If Yes, Salinity =	1.2	Weight % Solids
CO_2 Calculations		
Calculate Pure CO_2, CO_2-Oil and CO_2-Brine Properties?	Yes	
*Pure CO2 properties only available for 100psia ≤ p ≤ 3600psia and 0°F ≤ T ≤ 350°F		
*CO2-Oil and CO_2-Brine Calculations assume dead oil		
If Yes, Avg. Oil Molecular Weight (MW) =	220	lb/lbmol
If Yes, Salinity =	1.5	Weight % Solids

Outputs at Single Point of Pressure:

At:	Pressure, p	1250	psia
	Bubble Point Pressure, p_b	2017	psia
	Solution Gas Oil Ratio at Bubble Pt, R_{sob}	774	SCF/BBL
Oil-Gas	Formation Volume Factor, B_o	1.21	RB/STB
	Solution Gas Oil Ratio, R_{so}	439.2	SCF/BBL
	Viscosity, μ_o	0.466	cP
	Compressibility, c_o	3.41E-04	1/psi
	Density, ρ_o	45.2	lbm/ft3
Gas	Formation Volume Factor, B_g	0.0103	ft3/SCF
	deviation factor, Z	0.802	-
	Viscosity, μ_g	0.014	cP
	Compressibility, c_g	9.57E-04	1/psi
	Density, ρ_g	5.64	lbm/ft3
Brine-Gas	Formation Volume Factor, B_w	1.0097	RB/STB
	Solution Gas Water Ratio, R_{sw}	15.31	SCF/BBL
	Viscosity, μ_w	0.64	cP
	Compressibility, c_w	5.04E-05	1/psi
	Density, ρ_w	62.29	lbm/ft3
Pure CO_2	Formation Volume Factor, B_{CO2}	0.01	ft3/SCF
	Viscosity, μ_{CO2}	0.03	cp
	Density, ρ_{CO2}	21.88	lbm/ft3
	Compressibility Factor, Z_{CO2}	0.43	-
CO_2 - Oil	CO_2-Oil Solubility, Sol	0.60	mole fraction
	Solution CO2 Oil Ratio, R_{so-CO2}	740.8	SCF/STB
	CO_2-Oil Swelling, SF	1.29	-
	CO_2-Oil Viscosity Ratio, μ_{oCO2}/μ_{oi}	0.23	-
CO_2 -Brine	Solution CO_2-Water Ratio, R_{sw-CO2}	142.3	SCF/STB

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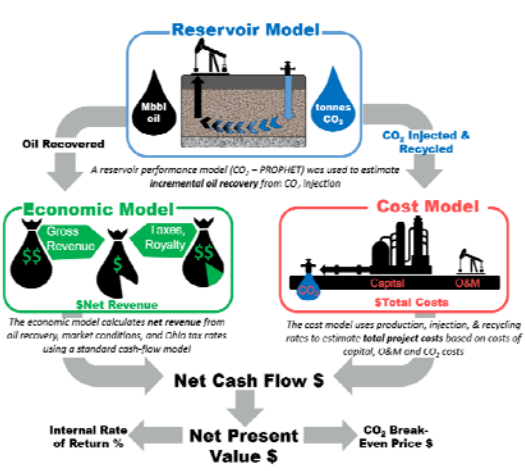
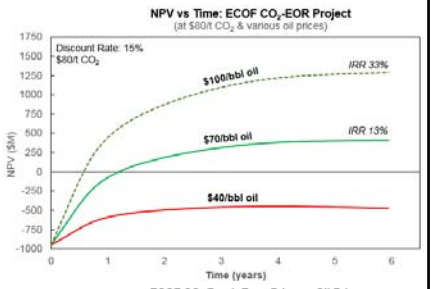
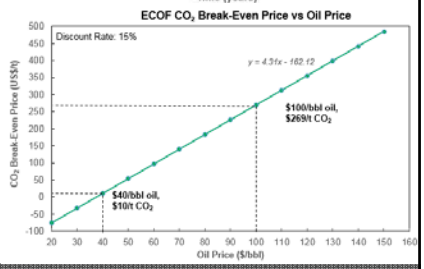
CO_2-EOR/Storage Assessment

Cost-Benefit Analysis Tools







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Summary of Recent Progress

- Large-scale Test in Michigan
  - Completed baseline monitoring and site preparation for multiple reefs
  - ~244,000 metric tonnes injected in late state reef
  - >125,000 metric tonnes net CO_2 in active EOR reefs
  - Operational and subsurface monitoring underway
  - Reservoir analysis shows closed reservoir conditions
  - Phase changes and compressibility affect pressure
  - Initial static and reservoir models prepared
  - Injection in a second new EOR reef likely to start in late 2015
- Regional mapping/characterization across ten states
- Initiated detailed storage and EOR assessment in Ohio

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Acknowledgements

Battelle's MRCSP team members for work shown here

DOE/NETL for primary funding of MRCSP

Core Energy, LLC as the host site and CO_2 supplier for 10 years under MRCSP Phase II and Phase III

The **Ohio Coal Development Office** for consistent and significant cofunding for the regional characterization efforts of the MRCSP

MRCSP's **industrial partners and sponsors**

The State **Geology Surveys and Universities** for integrated regional storage potential assessment

Please visit www.mrcsp.org

Questions?

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