Midwest Regional Carbon Sequestration Partnership Phase III Development Phase Injection Test

RCSP Annual Meeting
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Acknowledgement

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Performed by Battelle and MRCSP Research Team

- *Geology Teams from nine states*
- *Key Stakeholders in Michigan (Core Energy, DTE, and Western Michigan University)*
- *Major contributions from MRCSP members who attend key meetings and provide feedback and guidance*

MRCSP Membership - Progress through Collaboration

Battelle
The Business of Innovation

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

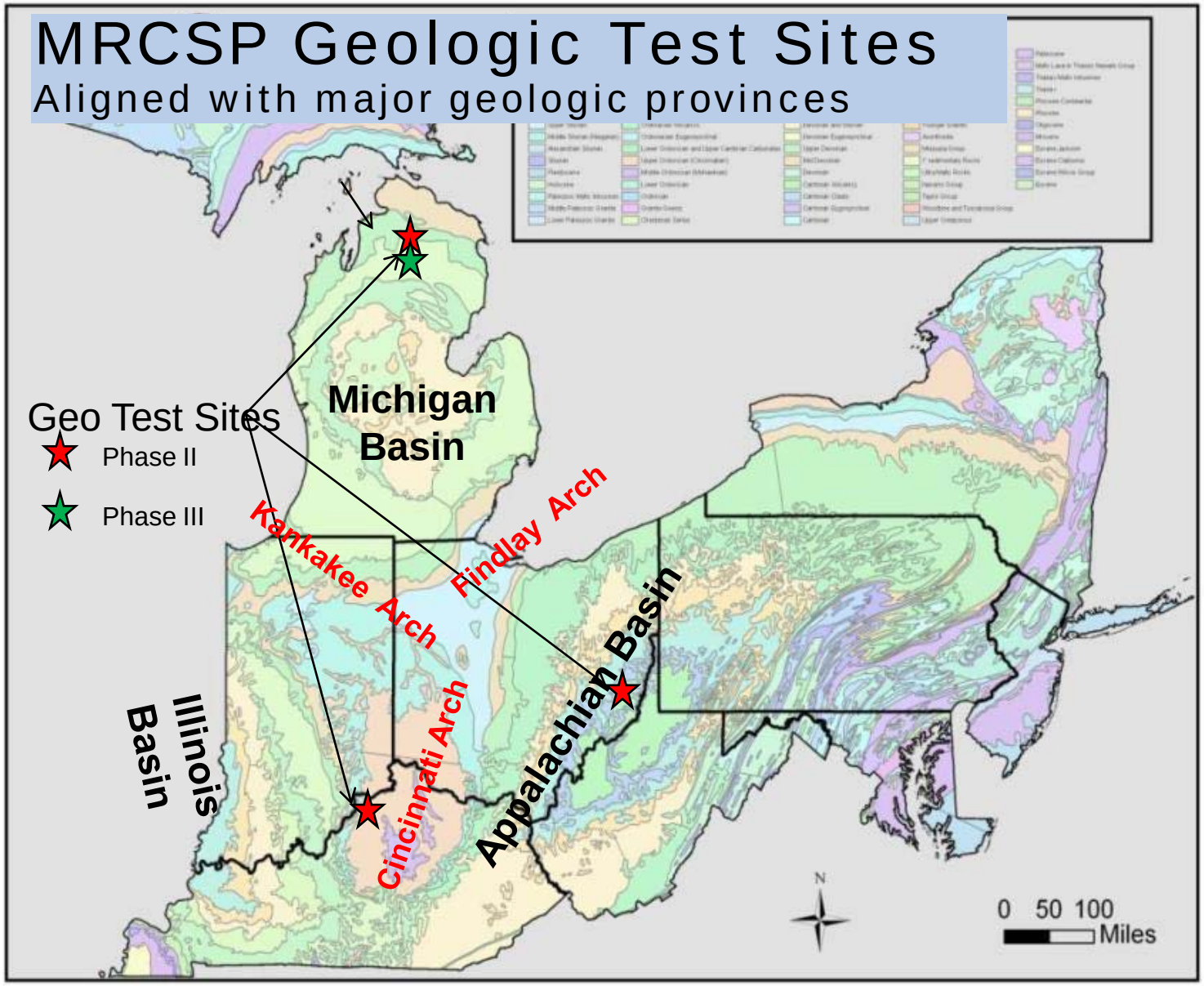
ArcelorMittal
Indiana Geological Survey 1837 Indiana University
bp
Leland Stanford Junior University 1891
AEP
West Virginia University Where Greatness is Learned
OUCC Indiana Office of Utility Consumer Counselor
Office of the Ohio Consumers' Counsel
CONSOL ENERGY
The Keystone Center
Kentucky Geological Survey University of Kentucky
AJW Inc.
CEED Center for Energy and Economic Development
The Ohio State University
O.D.N.R. Geological Survey
Making Ohio Coal the Clean Choice
Pennsylvania Geological Survey Est. 1836
National Rural Electric Cooperative Association A Touchstone Energy Cooperative
PRAXAIR
CCX Chicago Climate Exchange
FirstEnergy
NETL
DTE Energy
West Virginia Geological Survey
Schlumberger
Duke Energy
MISource
Consumers Energy Count on Us
Ohio Environmental Council Keep Watch, Take Action, Make Change
University of Maryland 1856
Soy Ohio Ohio Soybean Council
Ohio Corn Marketing Program
B&W
AMP Ohio
Dominion It all starts here.
Core Energy, LLC
RWE
NYSERDA New York State Energy Research and Development Authority
Department of Geosciences Michigan Geological Repository for Research and Education (MGRRE)
財團法人中興工程顧問社
New York State Museum
Constellation Energy
Pacific Northwest National Laboratory Operated by Battelle for the U.S. Department of Energy

Major MRCSP Activities

- Regional Overview and Characterization
- Outreach Activities
- Large Volume CO_2 Injection Test
  - St. Peter Sandstone Site Development
  - Injection and Monitoring in Depleted Oil Fields

MRCSP Geologic Test Sites

Aligned with major geologic provinces



States in MRCSP Region

Michigan
Indiana
Kentucky
Ohio
West Virginia
Pennsylvania
New York
Maryland
New Jersey

MRCSP Phase II Reports Released Publically by Battelle on Nov. 15, 2011 on www.mrcsp.org

Risk Screening Completed For St. Peter

- Features, Events, and Processes (FEP) performance and safety screening to identify possible risk items.
- Activity based analysis used to identify leakage pathways and other risks to receptors in the area.
- Risk matrix prepared.

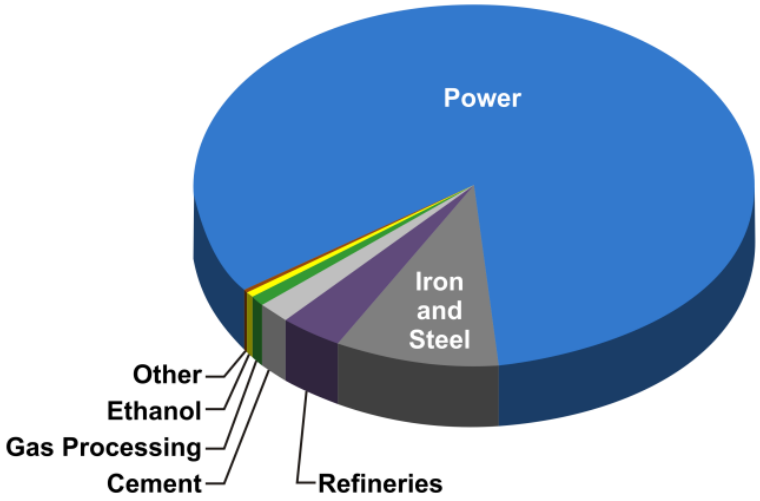
- Node 1: Pre-Drill Planning
- Node 2: Drilling / Monitoring Injection Well
- Node 3: Well Completion
- Node 4: CO_2 Pipeline Transport
- Node 5: Injection
- **Node 6: Site / Well Closure**
- Node 7: Post Injection Containment
- Node 8: Project Management
- Node 9: Maintenance and Workover Programs

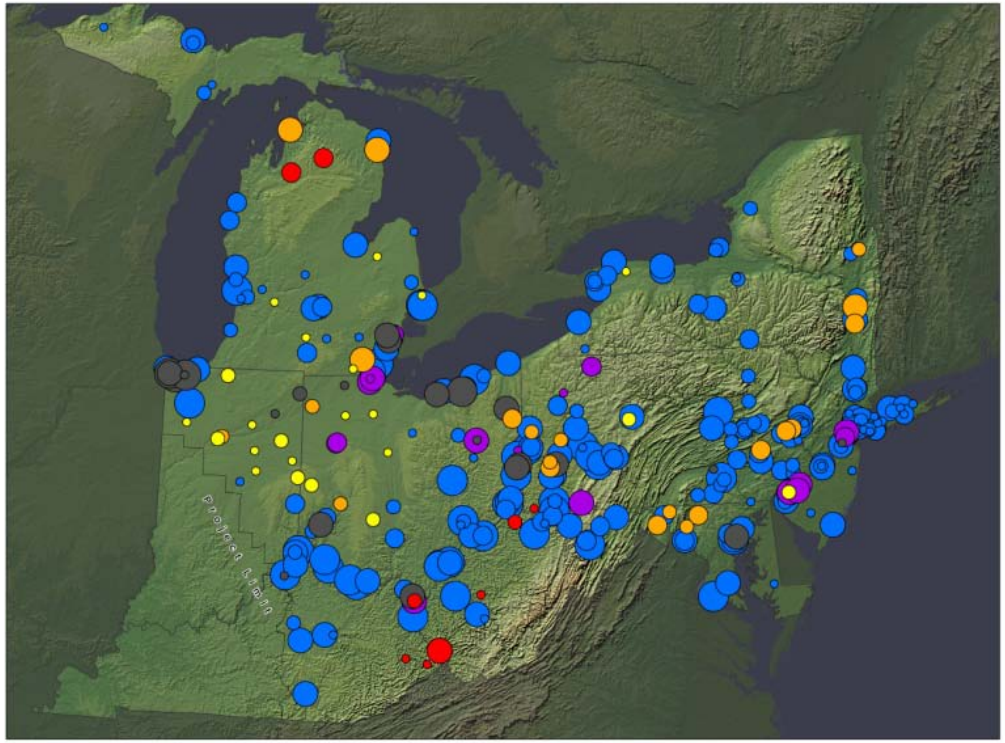
		Likelihood				
		Frequent	Probable	Occasional	Remote	Improbable
Severity		A	B	C	D	E
Catastrophic	I	High (A-I)	High (B-I)	High (C-I)	Serious (D-I)	Medium (E-I)
Critical	II	High (A-II)	High (B-II)	Serious (C-II)	Medium (D-II)	Medium (E-II)
Marginal	III	Serious (A-III)	Serious (B-III)	Medium (C-III)	Medium (D-III)	Medium (E-III)
Negligible	IV	Medium (A-IV)	Medium (B-IV)	Low (C-IV)	Low (D-IV)	Low (E-IV)

CO_2 Sources in the MRCSP Region Will Change in the Near Future

- Currently about 85% of emissions from coal-fired power plants.
- New EPA Regulations will cause some plants to close
- Utica and Marcellus gas plays will create new opportunities

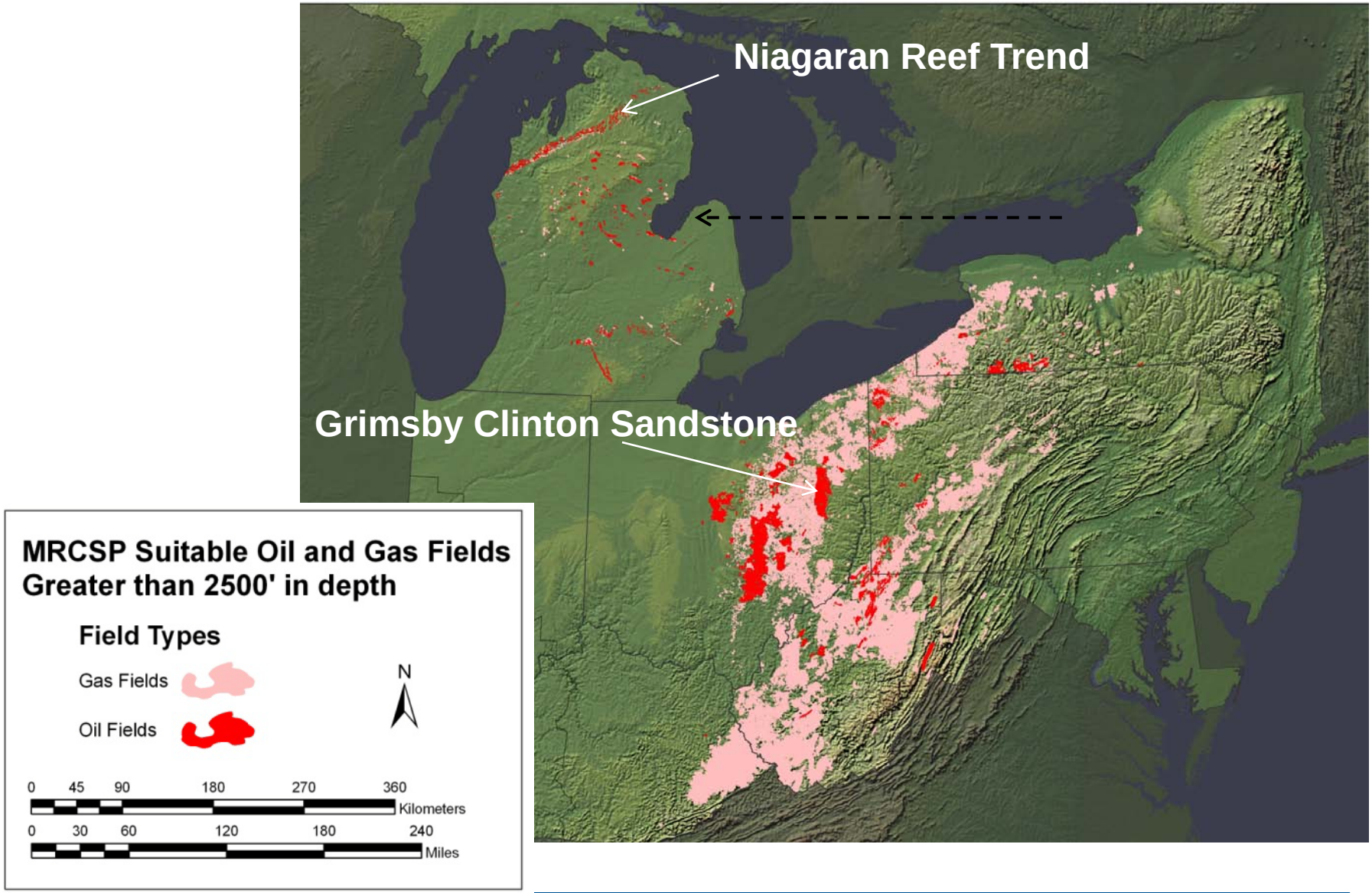
MRCSP is examining the likely implications of shifts in the CO_2 sources within our region





Map showing locations of large point sources.

Key Oil and Gas Fields in MRCSP Potential Targets for CO_2 Utilization



Role of State Geological Surveys

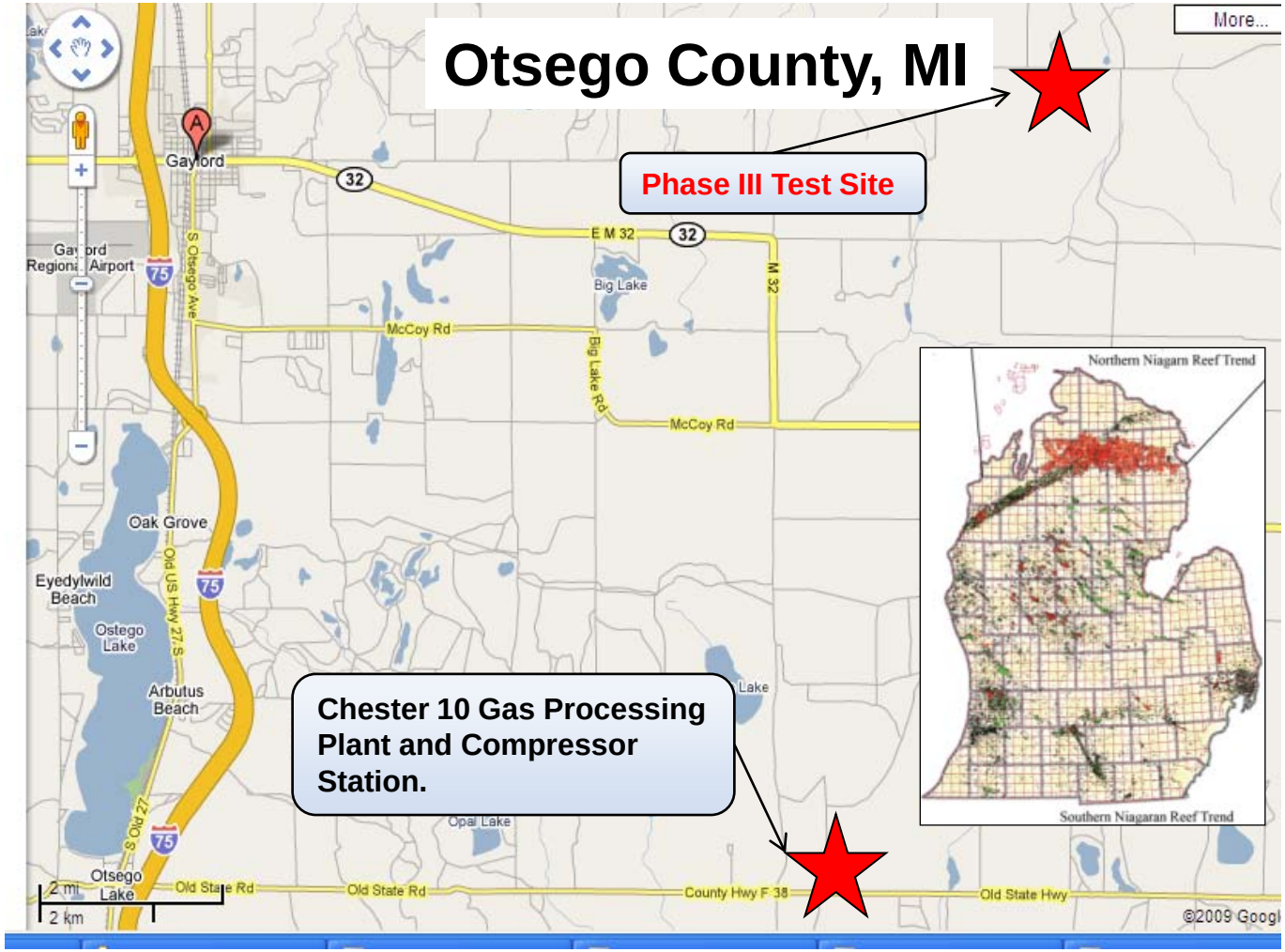
Phase III project will also continue integrated effort by geological surveys and teams from all nine states to:

- **Refine the mapping (GIS)** for sources and sinks
- **Help translate the results** of field testing into actionable strategies for the stakeholders in our region.
- **Identify promising reservoirs** for geological storage including off shore areas along the east coast.
- **Identify opportunities** for potential piggy-backing operations (logging, coring, and/or seismic) to collect geological data that would otherwise be lost

Large Volume Injection Test Objectives

- **Inject 1,000,000 metric tons of CO_2** into the Niagaran Reef Trend in Northern Michigan in conjunction with Core Energy's enhanced oil recovery operations
- **Determine how much CO_2 is safely retained** or produced and recycled with oil recovery through innovative approaches as to when and how CO_2 is injected into the reefs and examining how CO_2 migrates through the geological formation
- **Perform reservoir modeling**, augmented by hydraulic, geophysical, and system monitoring, to demonstrate the CO_2 storage process, determine mechanisms that affect permanent sequestration, and assess regional commercialization potential
- **Translate the results** of this project to a regional volume by integrating results into NATCARB, participating in technical working groups to develop and document CCS best practices, and communicating results to MRCSP members.

Phase III Large Volume CO_2 Injection



Location: Chester Township, Otsego County MI

Source of CO_2: Processing of natural gas from Antrim Shale (~15% CO_2)

Permitting: UIC from EPA Region 5

Drilling and surface use from Michigan Dept. of Environmental Quality

Field Partner in Michigan is Core Energy EOR Operator with CO_2 Source

Combination is well suited to Phase III test in addition to geological considerations

Gas Processing Plants

Compressor

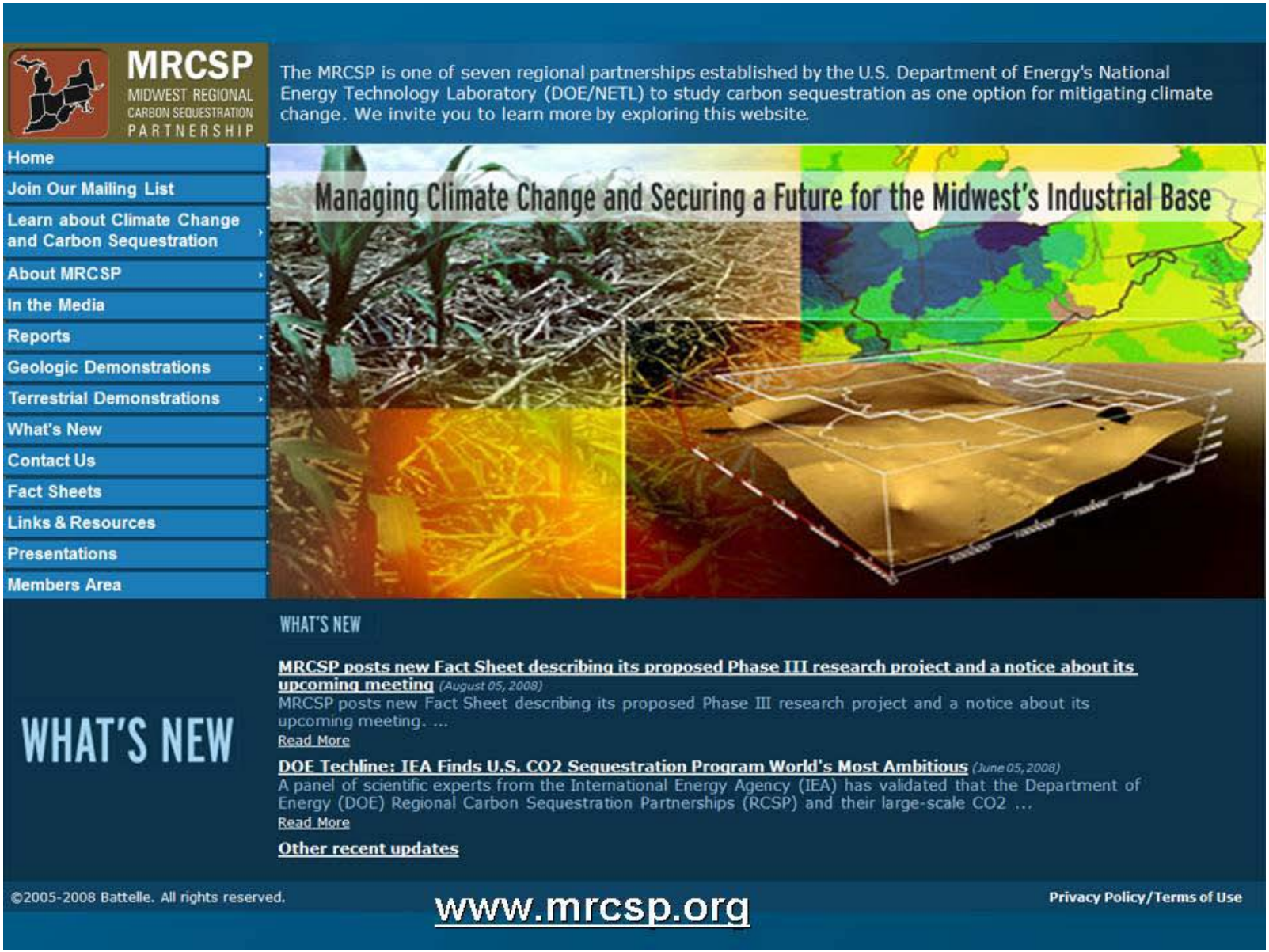
Schedule

	MRCSP Phase III Schedule	2012				2013				2014				2015				2016	2017	2018	2019
	Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4				
1.0	Nine State Geo Survey Teams																				
2.0	Niagaran Reef Injection Tests																				
	Advanced Geo Characterization																				
	CO_2 Injection																				
	Post Injection Monitoring																				
	Reservoir Modeling and Analysis																				
3.0	Outreach Activities																				
	Maintain and Enhance Website																				
	Partnership Communications																				
	Industry Review Panel																				

MRCSP Outreach Activities

- **Support the large volume injection test**
  - Monthly teleconference with key stakeholders during key periods
- **Maintain reputation of MRCSP** as a neutral and credible source of scientific information on CCUS
  - Over 20 Topical Reports available
  - Over 30 Presentations and Briefings available on MRCSP Website
- **Improve public understanding** and acceptance of carbon capture, utilization, and sequestration
  - Hosting site visits for key groups and local officials
- **Increase public understanding** of enhanced oil recovery, subsurface activities, and their role in the larger energy mix
  - Speaking at conferences and meeting with trade associations

Visit MRCSP.ORG



MRCSP Partnership Meeting September 8-9, 2011, Baltimore

- Keynote Address by DOE/NETL
- Large Scale Injection Test Update
- Regional Geological Assessment Update
- Topical Briefings – New Jersey, Michigan, Mountaineer, EOR, Modeling, Tracers, Regulations, National Policy, etc.)
- Phase II Wrap-Up
- Outreach Activities and
- Industry updates

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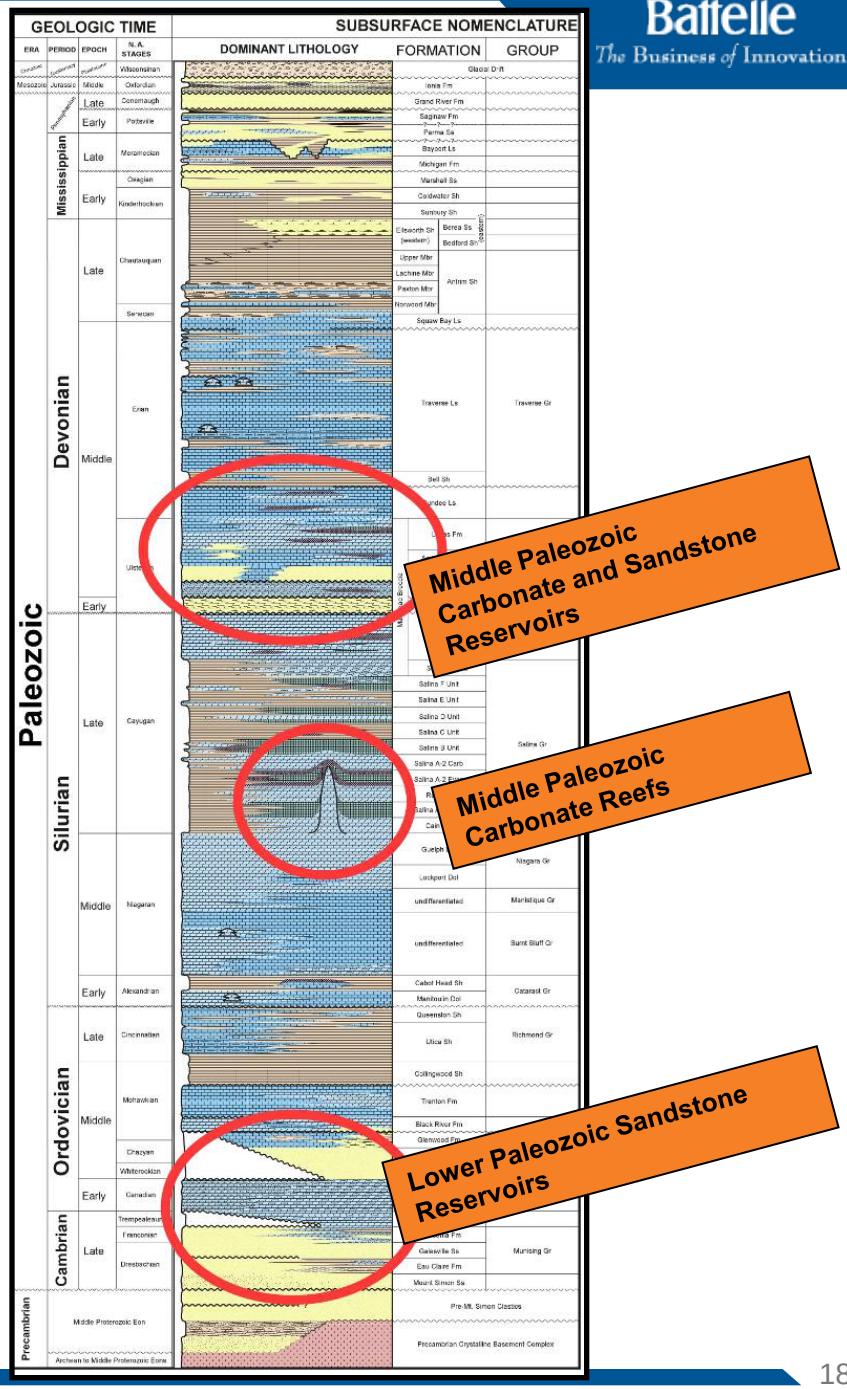
MRCSP Geologic Storage Progress

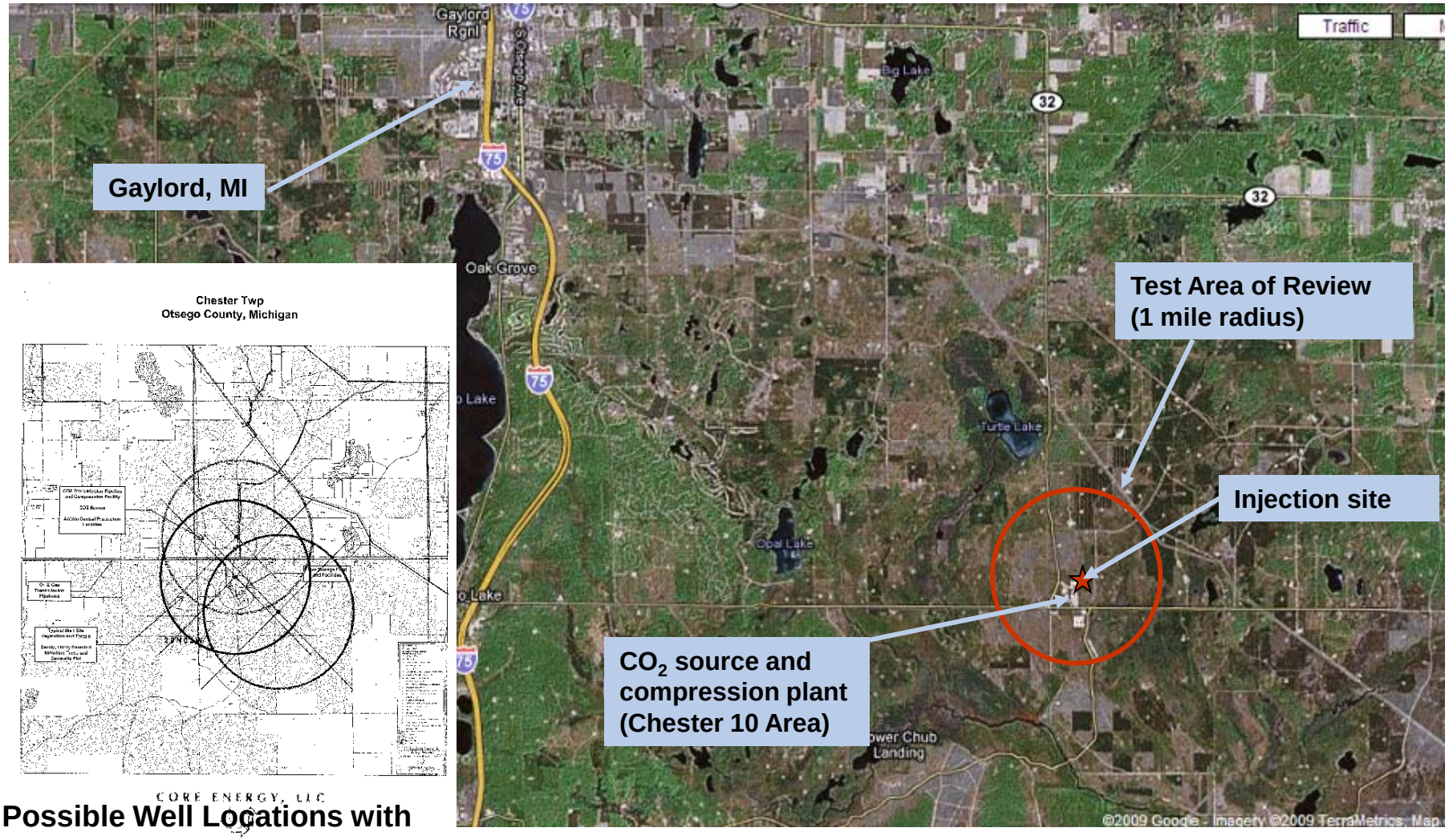
- St. Peter Saline Reservoir Test – Significant effort completed before the test was suspended
- Northern Michigan Niagaran Reefs – Large Scale Test Planning is well underway with potential for accelerated start
- MRCSP Regional Characterization and associated projects

Michigan's Deep Reservoir Formations

- As much as 16,000 ft of Paleozoic sedimentary rock strata
- Multiple potential storage opportunities in saline and oil-bearing formations



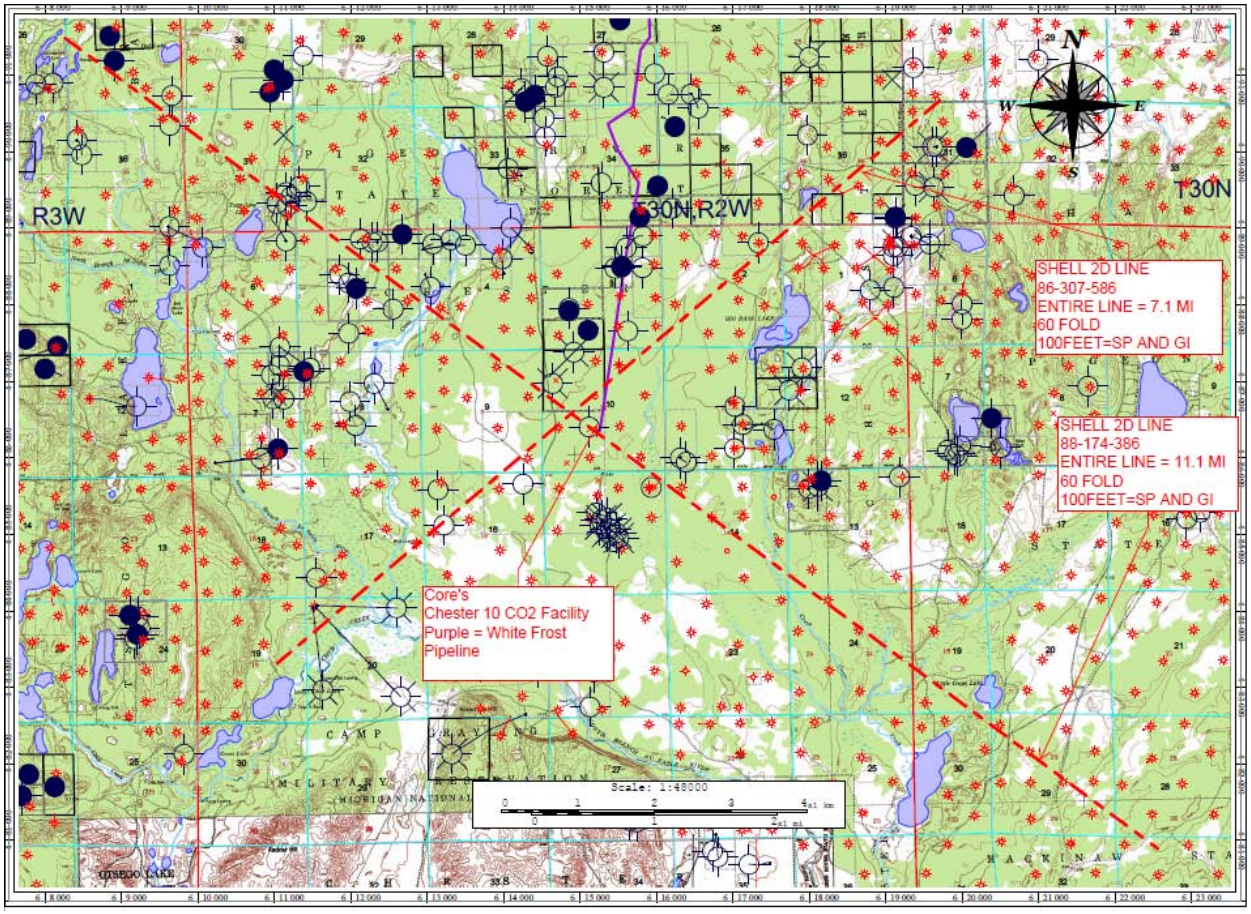
St. Peter Sandstone Area of Review (AOR) State Land and Away from populated areas



Possible Well Locations with AOR of 1 mile within state land

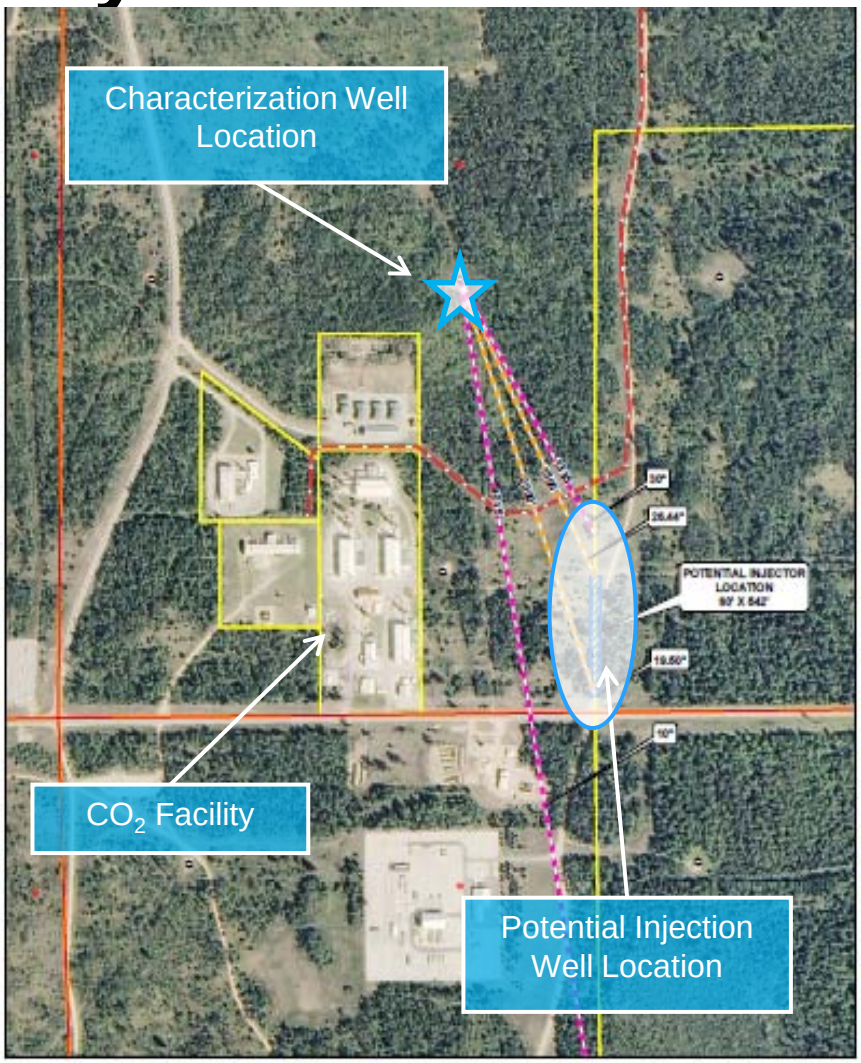
Existing 2D Seismic Data – Procured and Reviewed

- More than 20 miles of existing seismic data was purchased from Brokers and analyzed.
- No significant features of concern were detected at the resolution of 2D seismic.
- A 3D seismic survey design mostly completed



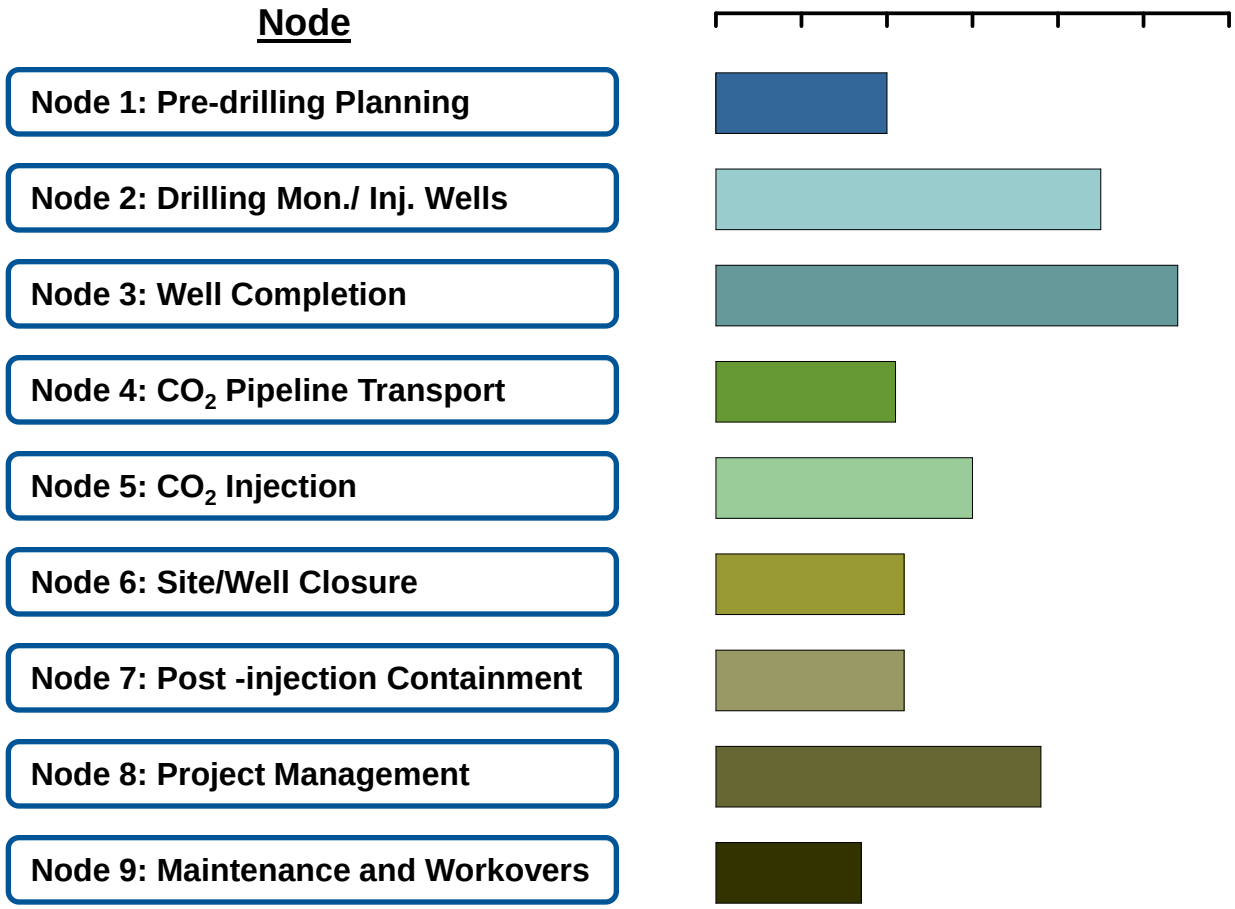
St. Peter Tests - Potential Well Locations and Site Layout

- The characterization well located north of the CO_2 handling facility.
- The potential injection well location would have been between 1000 and 2000 ft to the south east (down dip).
- A third well monitoring well was anticipated at a location to be determined.



MRCSP Activity Based Analysis Example

- Project life span divided into 9 nodes
- Each node was deliberated by group of field personnel and others.
- Total of 269 scenarios identified.



Example Results - Node 6: Site/Well Closure

- Varying levels of risks and consequences, but not major show-stoppers

Failure to depressurize the pipeline – exposure to high pressure, worker injury

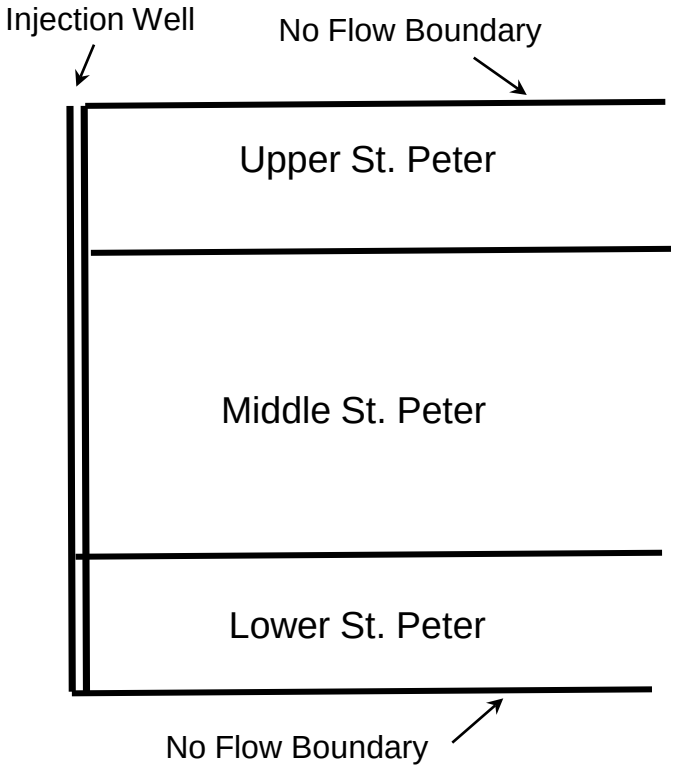
Natural gas and/or H_2S leaking near well – potential exposure, fire and/or explosion, schedule delay, additional costs

Can't get tubing or cement retainer down to needed depth – delay with additional costs

Scenario Number	What If	Cause	No Safeguards					Potential Safeguards to Consider		With Safeguards			
			Prob	Consequence	Severity	RAC		Admin	Engineering	Prob	Severity	RAC	
Pipeline Decomissioning							?						
N06-01	Workplace injury from heavy equipment		C – Occasional	Personnel injury/fatality; equipment damage	III – Marginal	C-III	Medium	- PPE, Tailgate meetings, Safe Work Practices	- Normal heavy equipment safeguards	C – Occasional	IV – Negligible	C-IV	Low
N06-02	Did not purge the pipeline		C – Occasional	Potential exposure to CO2	IV – Negligible	C-IV	Low	- Safe work practices	- pressure guages on pipeline, safety relief valves	D – Remote	IV – Negligible	D-IV	Low
N06-03	Did not depressurize the pipeline		D – Remote	Potential exposure to high pressure	III – Marginal	D-III	Medium	- Safe work practices	- Pressure gages on pipeline	E – Improbable	III – Marginal	E-III	Medium
N06-04	Concentration of CO2 in a low spot or pipeline trench		D – Remote	Potential exposure to high concentration of CO2	IV – Negligible	D-IV	Low		- CO2 monitoring in low spots - Ventillation in the trench	E – Improbable	IV – Negligible	E-IV	Low
Wellhead Decommissioning							?						
N06-05	Workplace injury from heavy equipment		C – Occasional	Personnel injury/fatality; equipment damage	III – Marginal	C-III	Medium	- PPE		C – Occasional	IV – Negligible	C-IV	Low
N06-06	The well starts to flow		B – Probable	Potential exposure to high concentration of CO2, high pressure/high flow of brine	IV – Negligible	B-IV	Medium	- PPE - Well control procedures	- Well head pressure guages	C – Occasional	IV – Negligible	C-IV	Low
N06-07	Natural gas and/or H2S is leaking near the well		C – Occasional	Potential exposure to natural gas and/or H2S - toxic, fire and/or explosion if ignition source; Schedule delay	II – Critical	C-II	Serious	- Procedures which include warning about natural gas and/or H2S - Ignition source control	- Personal multi-gas detection meters - Well design	D – Remote	III – Marginal	D-III	Medium
N06-08	High pressure at well head	Pressure gage fails	D – Remote	Potential exposure to high pressure	IV – Negligible	D-IV	Low	- Safe work practices	- Redundant gages	E – Improbable	IV – Negligible	E-IV	Low
N06-09	High pressure at well head	Fail to depressurize	C – Occasional	Potential exposure to high pressure	IV – Negligible	C-IV	Low	- Safe work practices	- Pressure gages on pipeline	D – Remote	IV – Negligible	D-IV	Low
N06-10	High pressure at well head	Unable to depressurize it		Potential exposure to high pressure		-	?	- Safe work practices	- Pressure gages on pipeline			-	?
N06-11	Wellhead bolts locked (can't be remove (stuck))	Corrosion	A – Frequent	Delay (fairly routine scenario)	IV – Negligible	A-IV	Medium	- Proper well maintenance		C – Occasional	IV – Negligible	C-IV	Low
Plug and Abandon							?						
N06-12	The well starts to flow		D – Remote	Potential exposure to high concentration of CO2, high pressure/high flow of brine	III – Marginal	D-III	Medium	- Safe work practices	-shut-off valves, pressure relief valves	D – Remote	IV – Negligible	D-IV	Low
N06-13	Natural gas and/or H2S is leaking near the well		C – Occasional	Potential exposure to natural gas and/or H2S - toxic, fire and/or explosion if ignition source	II – Critical	C-II	Serious	- Procedures which include warning about natural gas and/or H2S	- Personal multi-gas detection meters	D – Remote	III – Marginal	D-III	Medium
N06-14	Can't get the tubing or cement retainer down the depth you need	Collapse or deformity in the casing	C – Occasional	Delay. May need to mill it out.	III – Marginal	C-III	Medium	-well design and materials	- Gage ring	D – Remote	III – Marginal	D-III	Medium
N06-15	Bad cement job		C – Occasional	Delay. Drill out bad cement and re-cement	III – Marginal	C-III	Medium	-well design and materials	- Gage ring, cement bond log	D – Remote	III – Marginal	D-III	Medium
N06-16	Tools or equipment stuck in the well		C – Occasional	Delay. Fish, drill, and/or mill it out.	IV – Negligible	C-IV	Low	- Safe work practices	-tool guide arms, cable tension monitors	D – Remote	IV – Negligible	D-IV	Low
N06-17	Cannot get site closure permit	No causes identified	C – Occasional	Need to continue to address issues until closure permit is granted.	III – Marginal	C-III	Medium	-proper permit procedures		D – Remote	III – Marginal	D-III	Medium
Site Restoration							?						
N06-18	Workplace injury from heavy equipment		C – Occasional	Personnel injury/fatality; equipment damage	III – Marginal	C-III	Medium	- PPE, safe work practices	- Normal heavy equipment safeguards	D – Remote	IV – Negligible	D-IV	Low
N06-19	Pit not properly stabilized		D – Remote	Potential for heavy equipment and/or farm machinery to get stuck; Poor foundation for future construction activities	IV – Negligible	D-IV	Low	-safe work practices	-materials testing	D – Remote	IV – Negligible	D-IV	Low
N06-20	Substantial erosion		D – Remote	Potential for heavy equipment and/or farm machinery to get stuck; Poor foundation for future construction activities	IV – Negligible	D-IV	Low	Erosion control plan	Implement Erosion control plan	E – Improbable	IV – Negligible	E-IV	Low
Document Transfer							?						
N06-21	In the future regulators ask for documents/records for the site		C – Occasio	Possible regulatory issue/fines/liabilities	IV – Negligible	C-IV	Low	- Formally hand over all records to the EPA		D – Remote	IV – Negligible	D-IV	Low

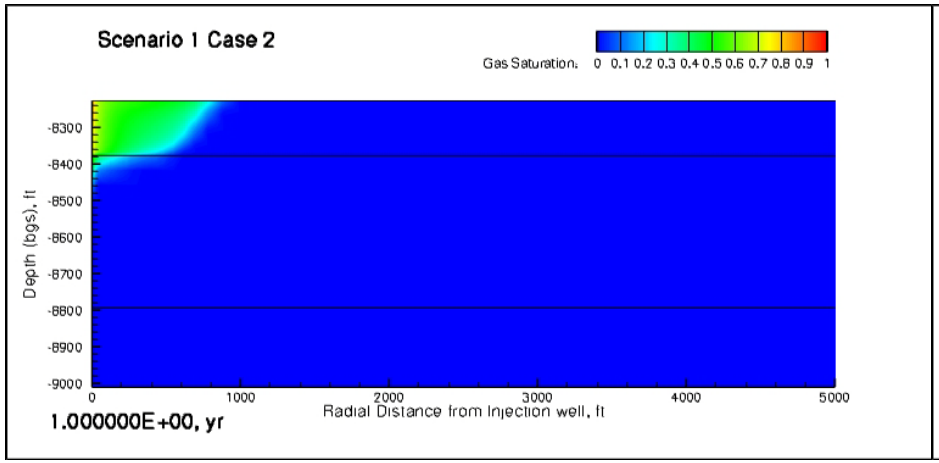
Conceptual Screening Model St. Peter Sandstone Reservoir

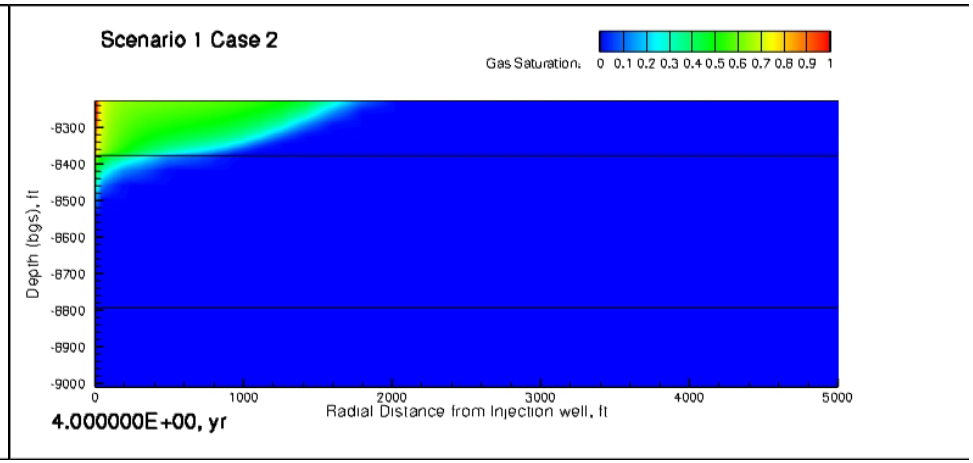
- The saline St. Peter sandstone reservoir occurs between depths 8227 and 9010 ft bgs. and is divided into 3 zones.
  - Upper St. Peter = 150 ft thick, moderate k
  - Middle St. Peter = 400 ft thick, low k
  - Lower St. Peter = 183 ft thick, moderate k
- Radial symmetry extending to 10,000.
- The east (outer) boundary condition is hydrostatic pressure
- STOMP-WCSE simulator with isothermal conditions and salt precipitation
- 250,000 MT/year injection for 4 years with maximum pressure limit ~5938 psi
- Injection in upper St. Peter only and across entire thickness
- Reactive transport and geomechanical simulations will be conducted after drilling

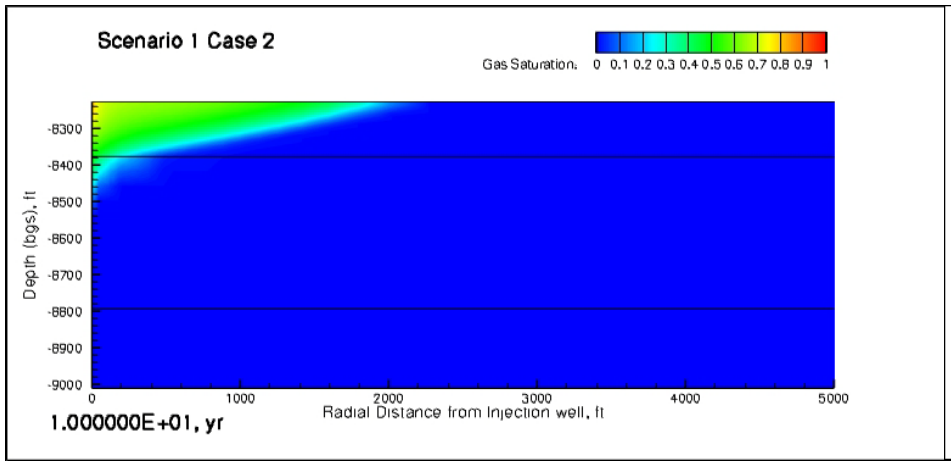


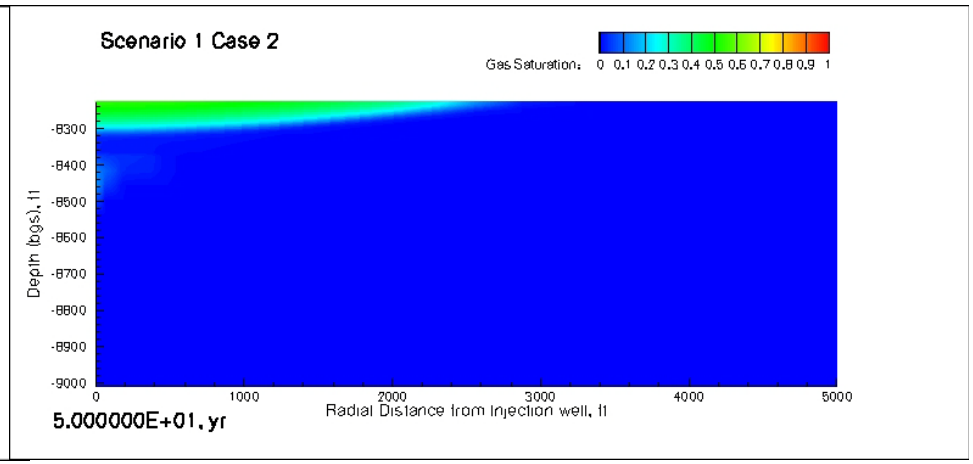
Scenario 1 (Upper St. Peter) Case 2 (50 mD,7%)

Gas Saturation (1, 4, 10, 50 years)



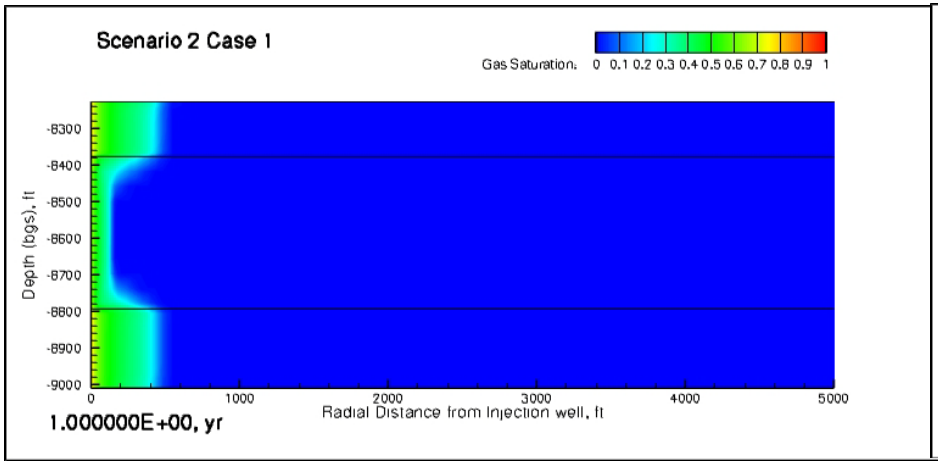


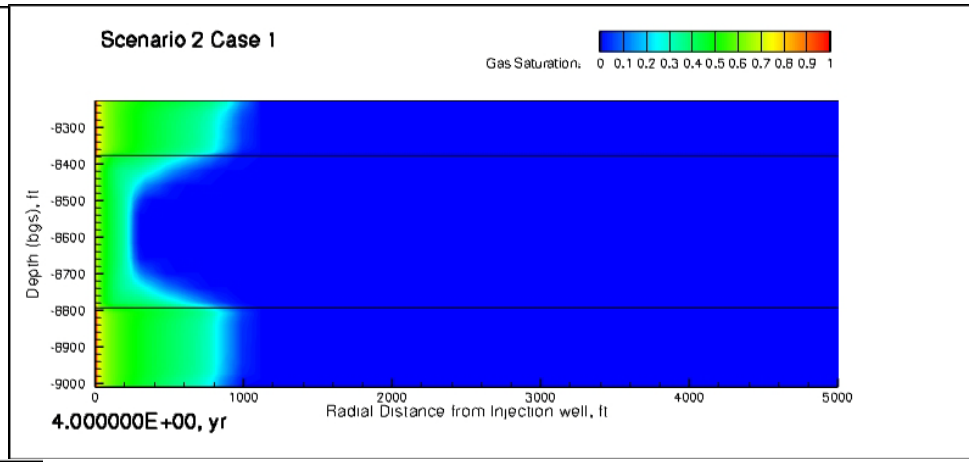


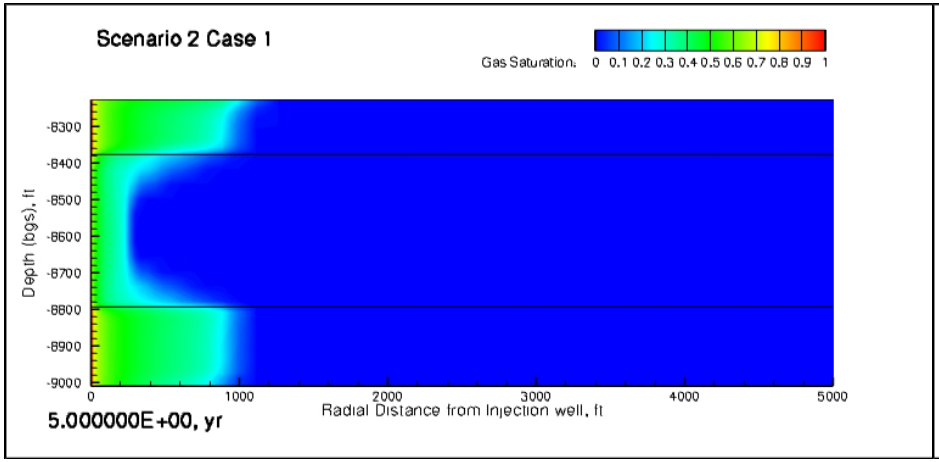


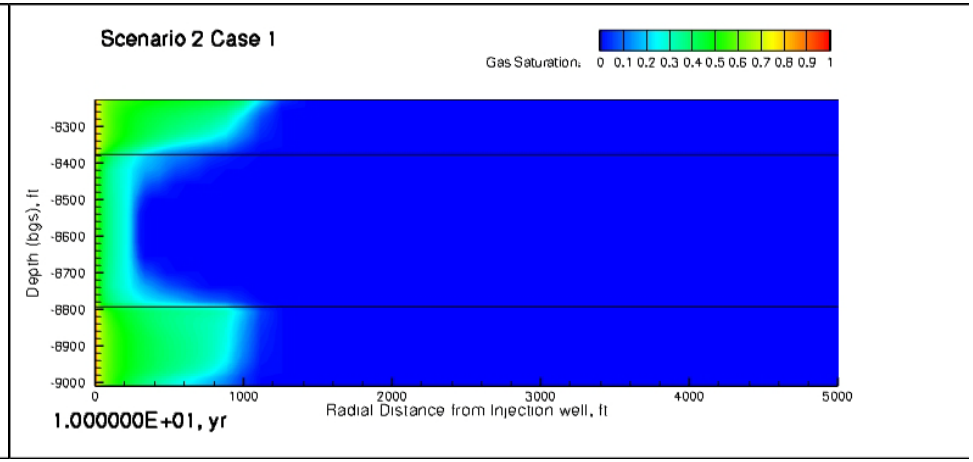
Scenario 2 (Full St. Peter Injection Case 1

Gas Saturation (1,4, 5, 10 Years)







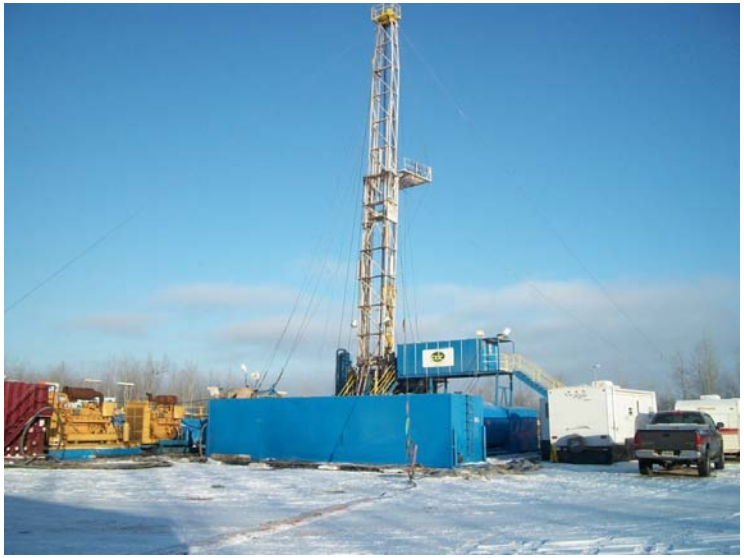


EPA Class VI UIC Regulations Add Considerable Time and Costs Uncertainty

Item	Battelle Plans	Class VI Specs	Class VI Multiplier
Post Injection Monitoring	4 years	50 years default	12X
Post Injection Financial Assurance Required	4 years	50 years default	12X
Potential Requirement for Stainless Steel Casing	L80	13CR precedent	4x

Plans for injecting into the Niagaran Reefs by piggy-backing on Core Energy's EOR Operations (UIC Class II)

Characterization Well Drilling March 2011 Suspended in Spring 2011



- Drilling with site access and drilling permit from Michigan Dept. of Natural Resources and Environment (MI DNRE)
- Independent rig inspection and safety oversight
- Above ground management of drilling waste without mud pits
- Completed logging and sidewall coring of two intermediate casing strings
- Well currently in temporary abandonment

Transition to Niagaran Reef Depleted EOR Fields

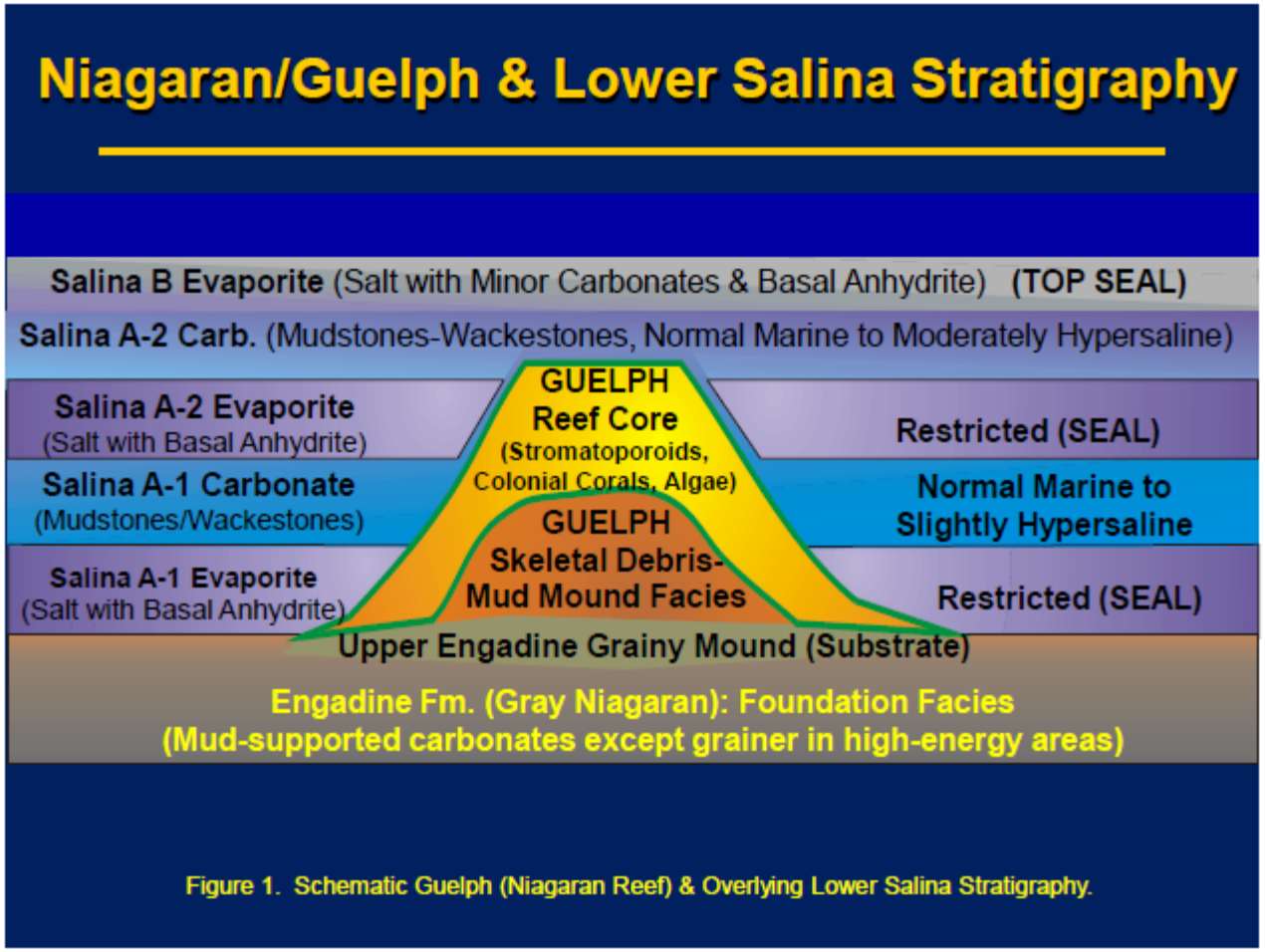
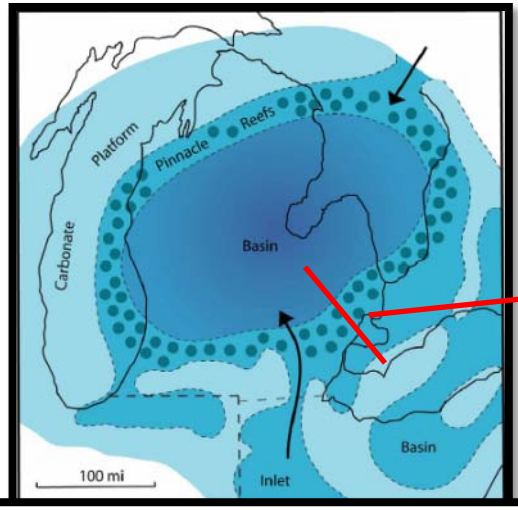
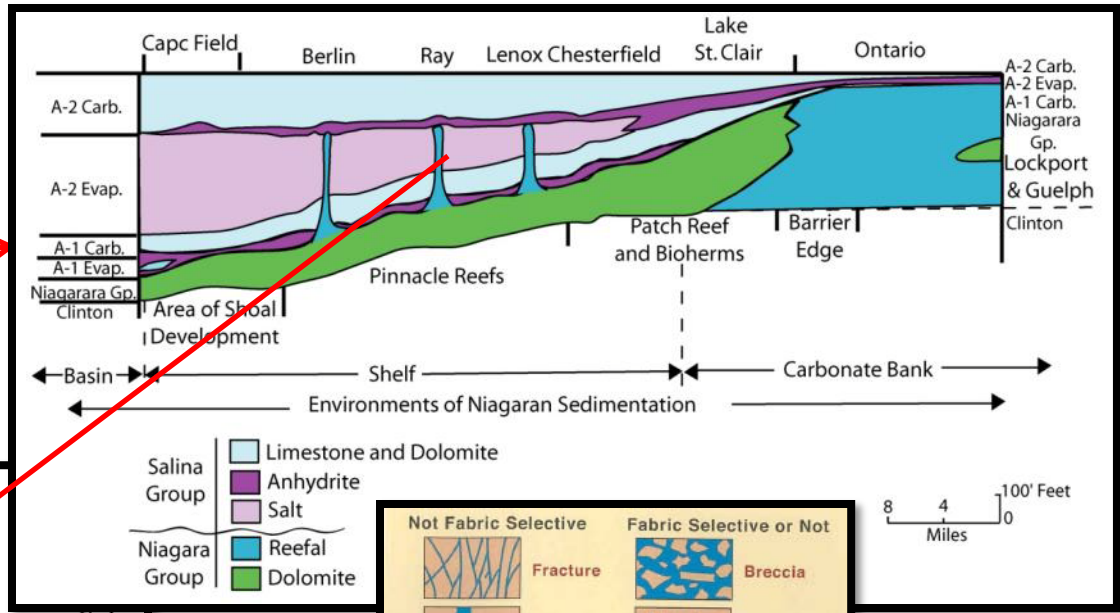
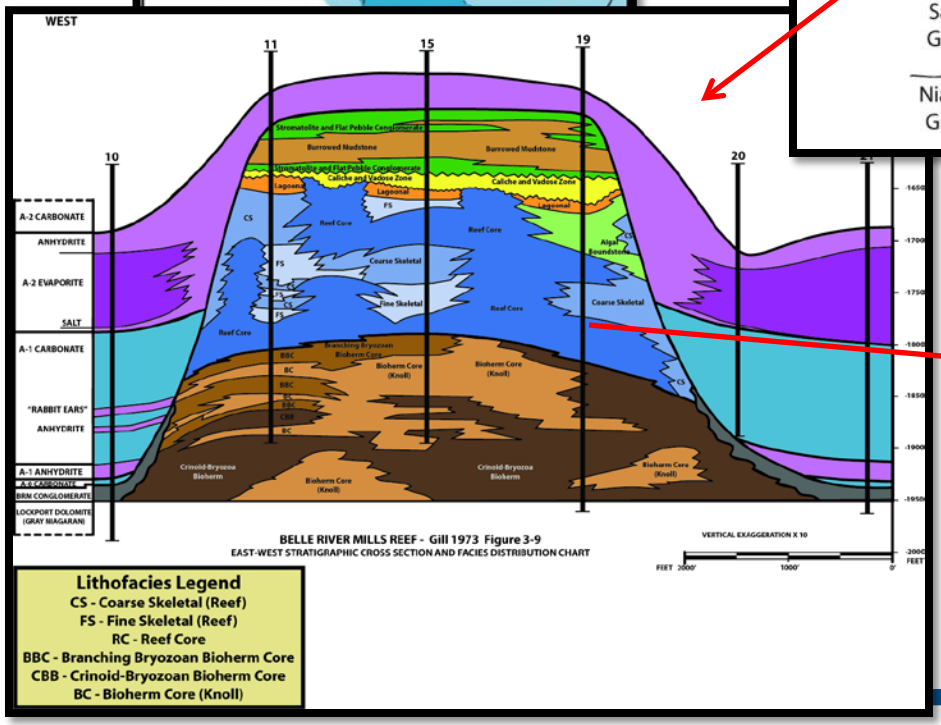


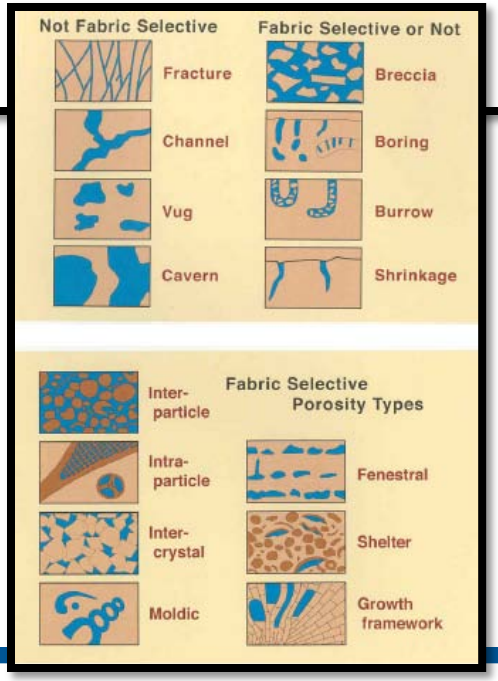
Figure 5. Niagaran Reef and Overlying Lower Salina Stratigraphy

Niagaran Pinnacle Reef Oil Fields

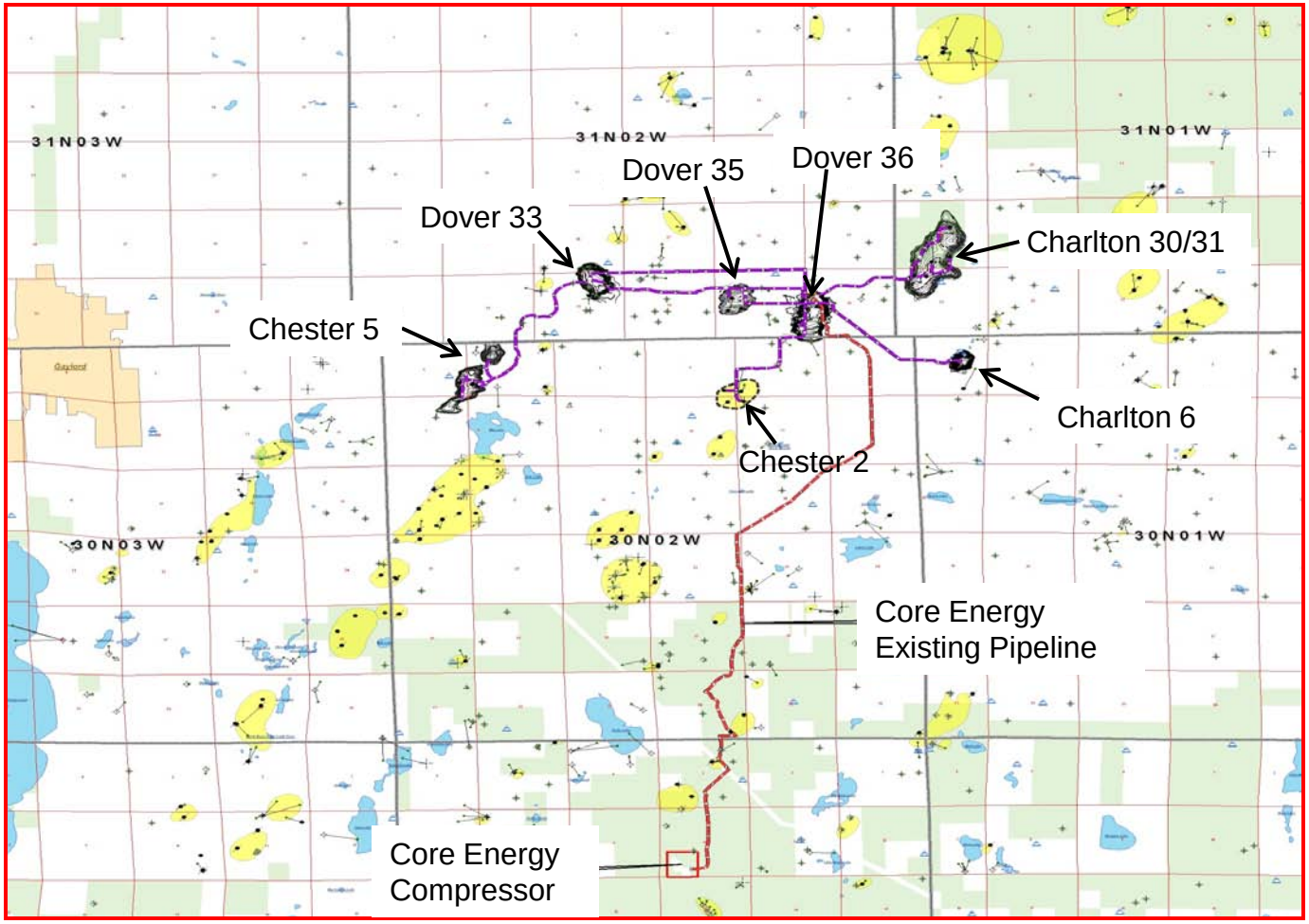








Core Energy has EPA UIC Class 2 Permits for almost all Reefs of Interest to MRCSP



Core Energy has tentatively agreed to let MRCSP monitor several reefs to develop scientific knowledge concerning reef geology, capacity, injectivity, etc.

Types of Niagaran Reefs for Evaluation

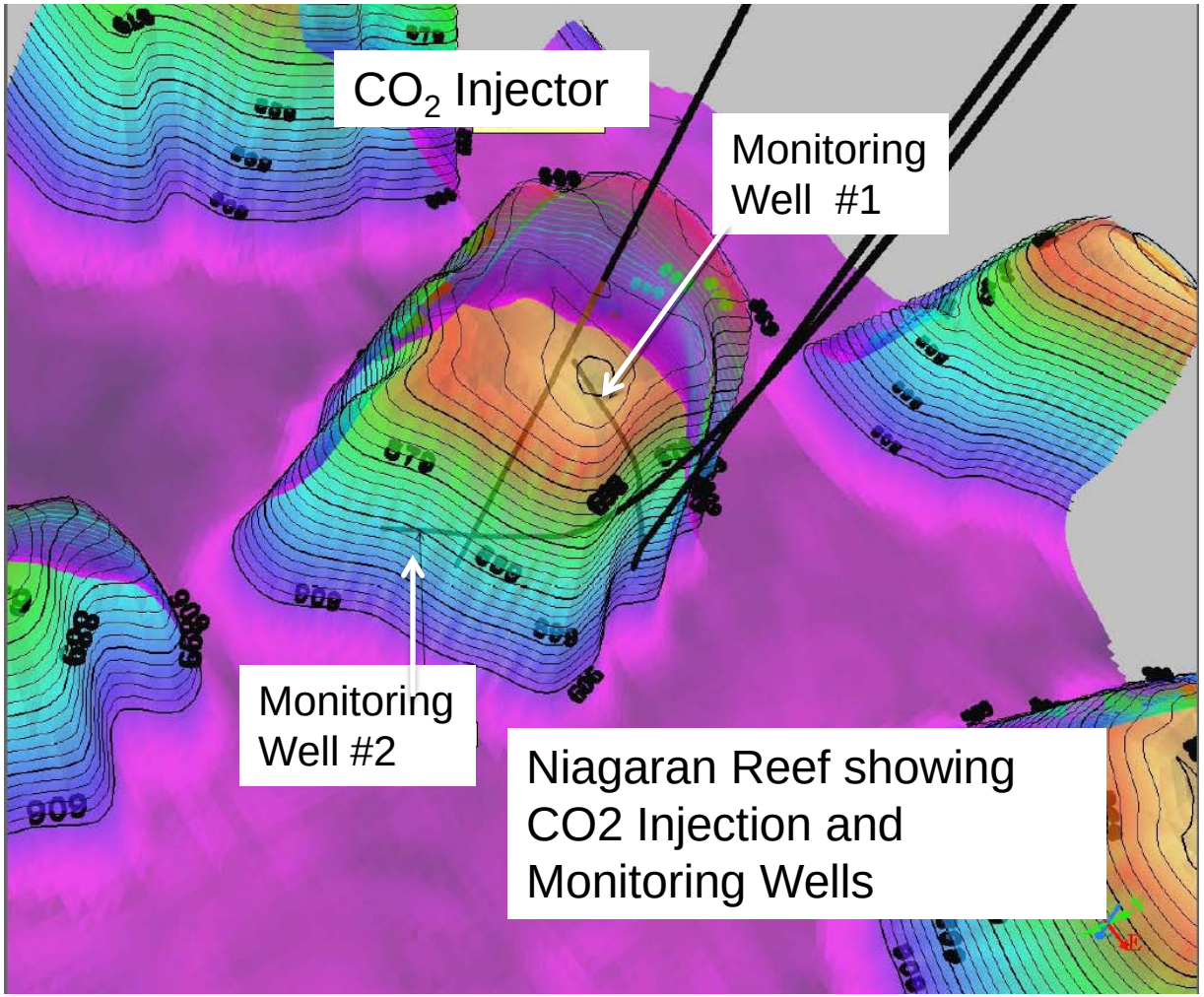
Category 1. Late-stage EOR Reef (e.g. Dover 33): These reefs have undergone extensive primary and tertiary oil recovery, and are mostly depleted of oil.

Category 2. Operational EOR Reef (e.g. Chester 2 and 5; and Charlton 6 and Charlton 30/31): These reefs have finished primary oil recovery and are currently undergoing secondary oil recovery using CO_2.

Category 3. Newly Targeted Reef: These reefs have undergone primary oil recovery, but no tertiary oil recovery using CO_2 has been attempted.

Category 4. Untapped Primary Reef: reefs that may be discovered and evaluated for accelerated CO_2 injection

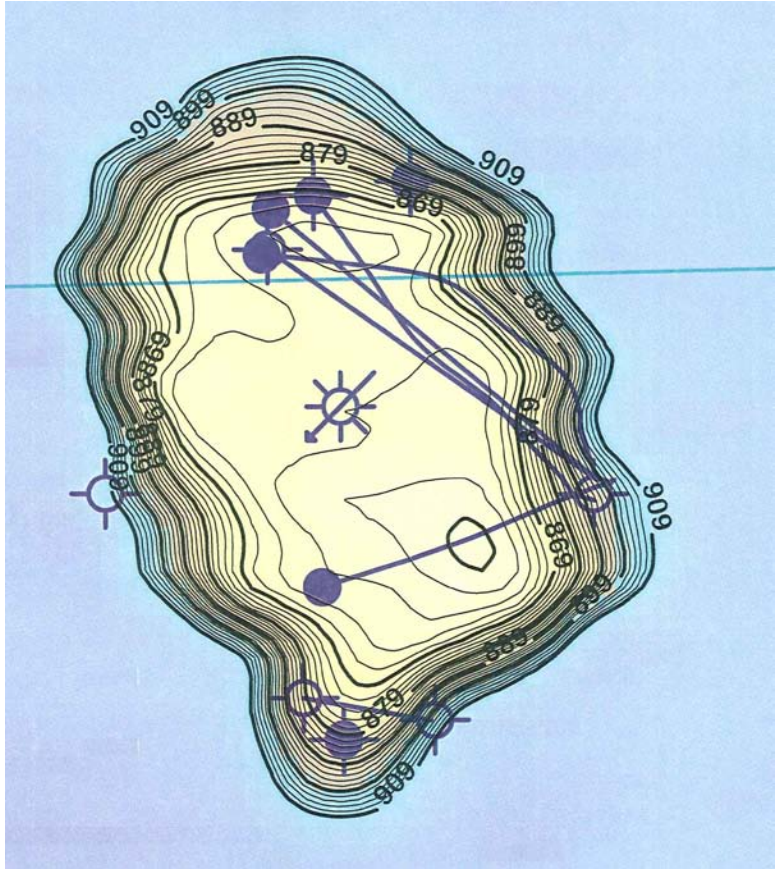
Three Component 3D Seismic Acquired



MRCSP has piggybacked on Core Energy's seismic survey (Over 30 Sq. Miles) by collecting three component geophone data over several reefs targeted for study.

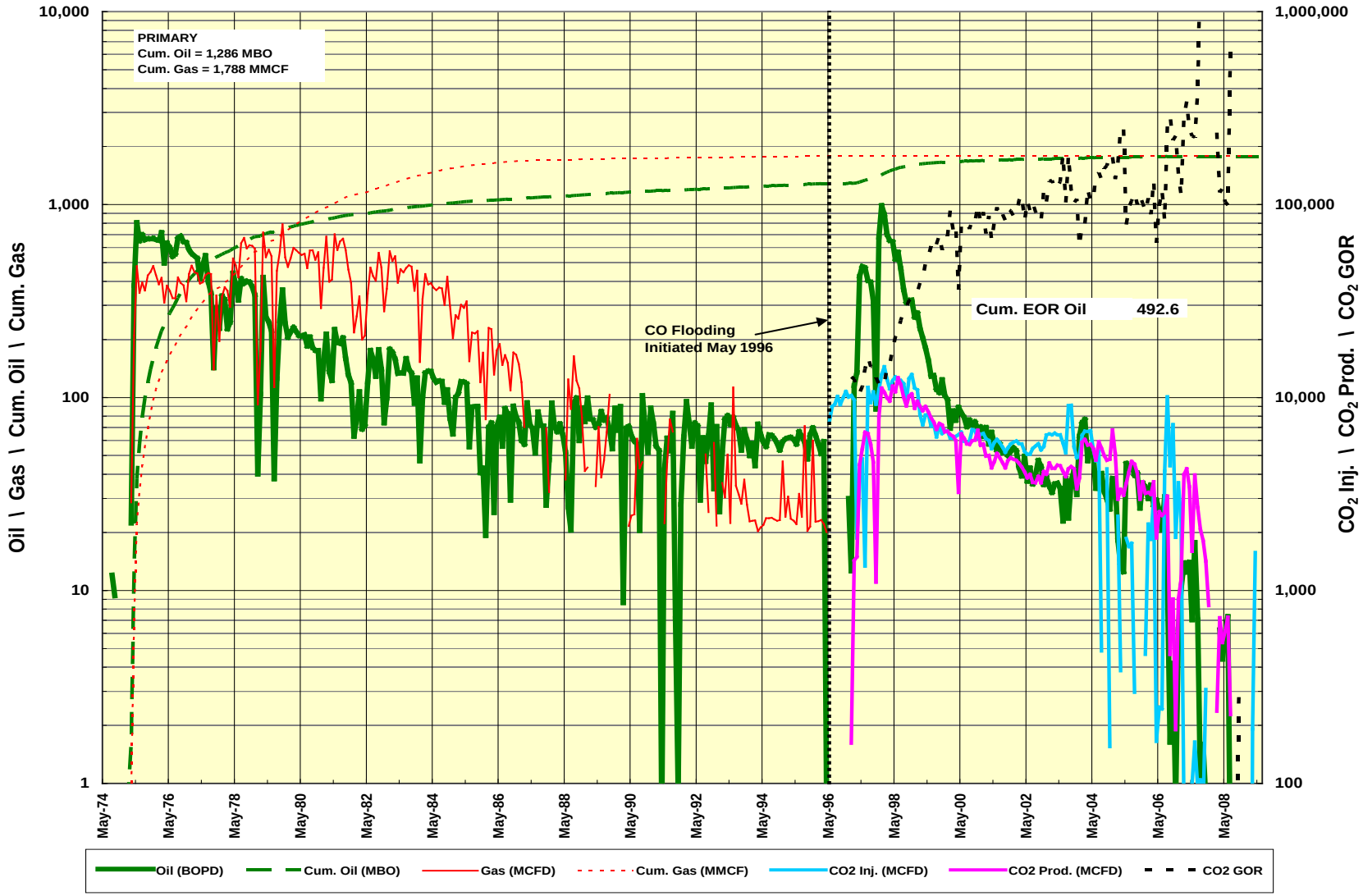
This data will be a key contribution in developing detailed models of the CO_2 behavior inside the Niagaran Reefs.

Dover 33 Late-stage EOR Reef – Test Bed for Monitoring and Operational Assessment



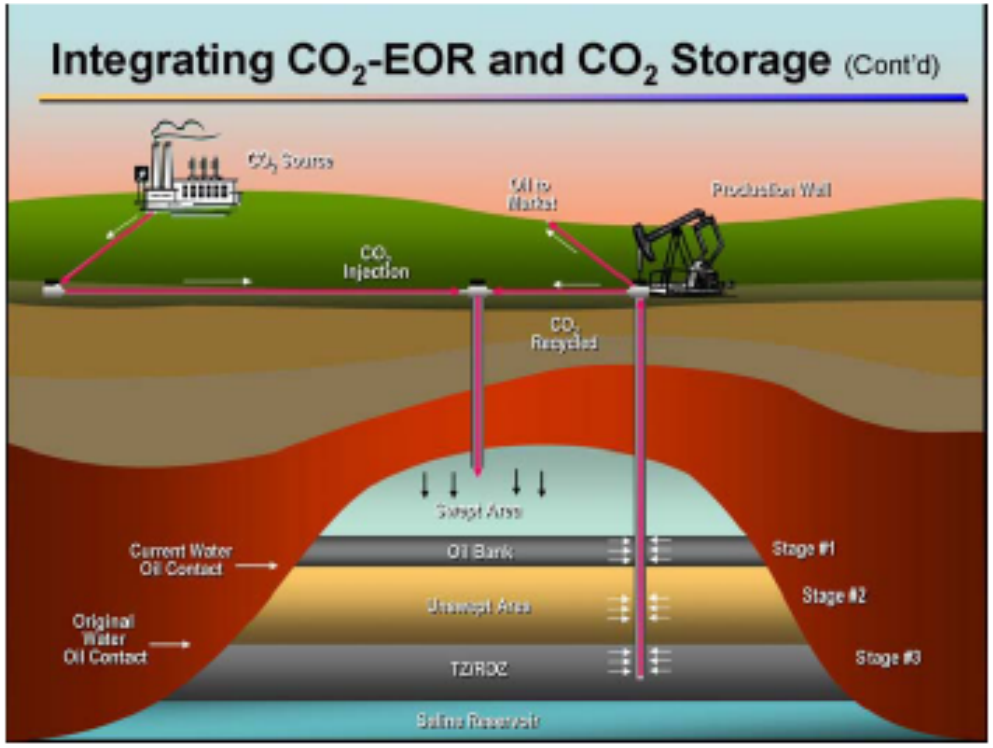
- **Geological characterization:** logging, coring, seismic data
- **Reservoir models:** validation using pressure tests, multi-fluid sampling, injection rate and volume, etc.
- **Operational models:** reef capacity as a function of geology, well locations, operational history, displaced fluids; geochemical reactions, etc. Pressurize beyond discovery pressure, residual zone
- **Monitoring techniques and equipment:** CO_2 plume migration, reef stability, geochemical reactions, multi-fluid interactions, mechanical integrity, etc.
- Alternative well designs for storage/EOR optimization

CO_2 Injection and Oil Production History is Used in Reservoir Models



Optimizing EOR and CO_2 Geologic Storage – Developing New Operational Paradigms

- Evaluate CO2 injection, migration, and oil recovery in the residual oil zone, below oil-water contact
- Within the constraints of existing Class II permits,



Monitoring Technologies will be Distributed Across Different Reefs in Phased Approach

A comprehensive MVA plan is **under development** :

- Portfolio of options distributed based on life-cycle stage, infrastructure, and technology readiness
- Monitoring of CO_2 fate and transport in reservoir, outside reservoirs, and interactions in adjacent reservoirs
- Selective collaboration with other researchers
- MVA Objectives include, but not limited to:
  - Injection systems (pressure, temperature, composition, flow rates)
  - Mechanical integrity, corrosion, cement conditions
  - Hydraulic, geochemical and geomechanical changes
  - CO_2 distribution and migration in the reefs

Candidate Monitoring Technologies

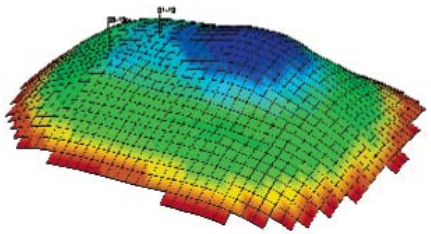
- Several technologies are under considerations
  - Extensive down hole pressure, temperature gauges
  - CO_2 injection/production and composition
  - Surface or borehole (VSP, X-Well, CSSM)
  - Microseismic (borehole or surface)
  - Tiltmeter and remote sensing (INSAR?)
  - Gravity (surface and/or borehole)
  - Wireline logs (PNC, Sonic, Resistivity, CBL)
  - Tracer injection and fluid sampling
  - Corrosion coupons, sidewall cement cores
- Use of surface detection, soil gas, groundwater are unlikely as they may be affected by CO_2 from shallower Antrim Shale wells

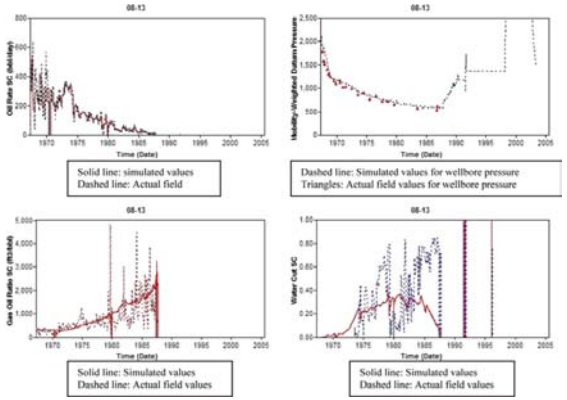
Data Needs for Geological Characterization and Modeling of the Niagaran Reef Trend

- **Geology**
  - Lithology
  - Stratigraphy
  - Facies distribution
  - Seismic - well log correlation
  - Static model
- **Fluid properties**
  - Formation volume factor (gas, oil)
  - Viscosity (gas, oil,brine)
  - Solution GOR
  - Minimum miscibility pressure (MMP)
  - CO_2-oil phase equilibrium data
  - CO_2-oil-brine equilibrium data
- **Rock-fluid properties**
  - Water/oil relative permeability
  - Gas/oil relative permeability
- **Production data**
  - Oil, water, gas – rate + cum prod
  - Injection volumes
  - Reservoir pressures
- **Geo-mechanical data**
  - Stress orientation and magnitude
  - Fracture pressure
  - Stress profiles
- **Geo-chemical data**
  - Formation fluid chemistry
  - Mineralogy and geochemistry of reservoir

Reservoir Simulation

- Full accounting for (1) reservoir geology and (2) compositional phase behavior
- Requires detailed information about (1) rock / fluid properties and (2) production history
- Can be used for all phases of history matching, flood design and production forecasting
- Partial or full coupling of flow, geochemistry, and geomechanics
- **GEM** (Computer Modeling Group) will used to model multiphase flows common to CO_2-EOR systems





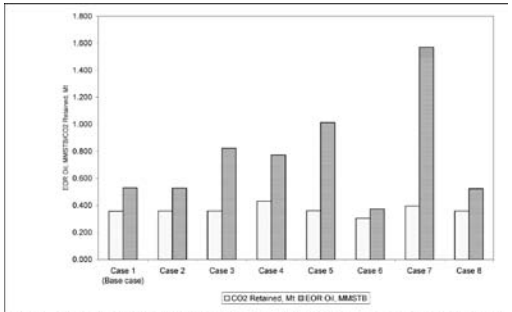


Figure 11: Comparison of the ultimate oil recovery and CO_2 storage capacity for the eight cases presented.

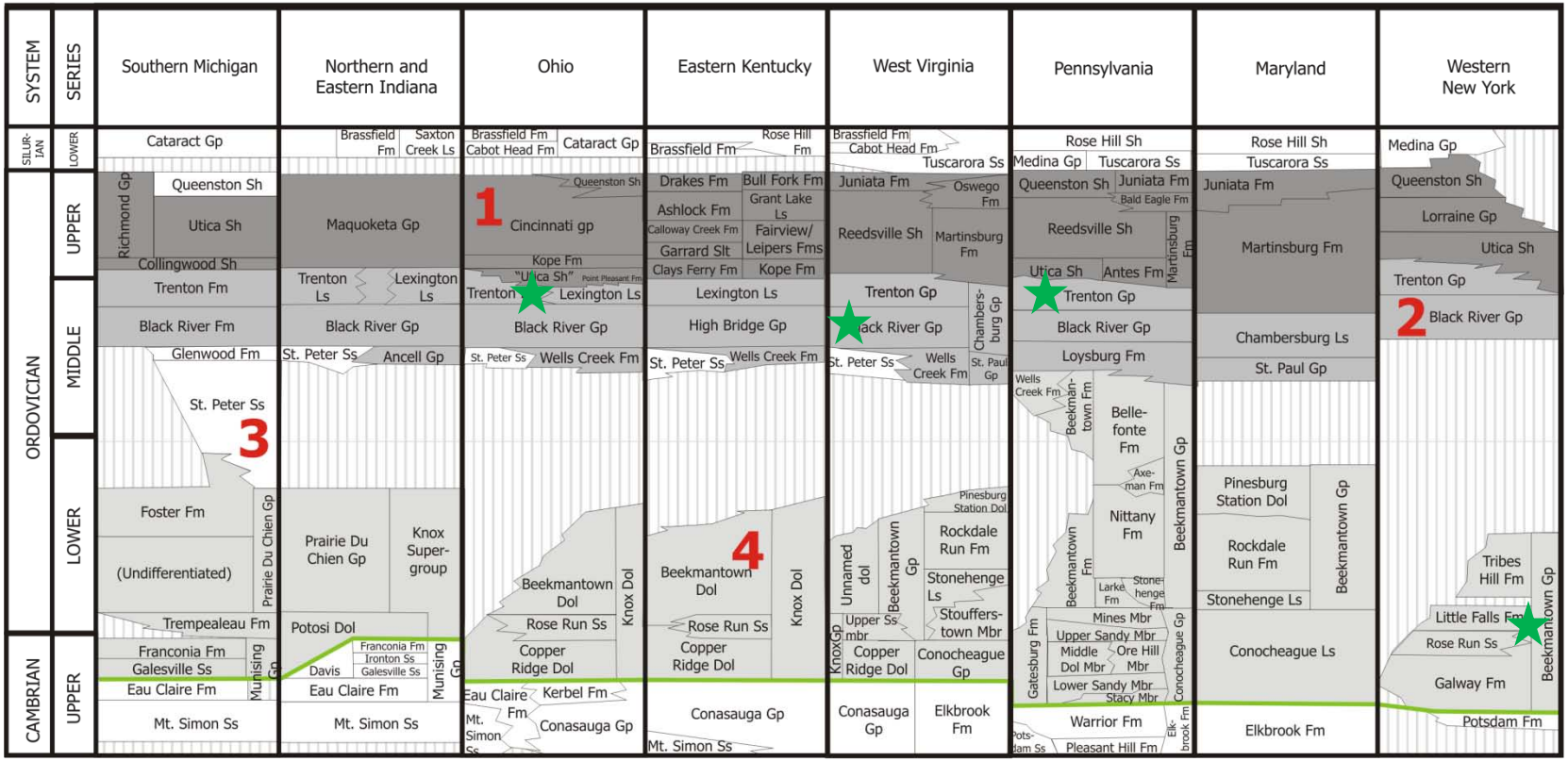
Regional Geologic Characterization

Collaboration between 9 States Continues

MRCSP GeoCharacterization Phase III							
DOE Budget Period 3							
MRCSP Task I							
Distribution of workload by subtask and state							
	Subtasks						
	1.1	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**
	Geo-Char	Off shore	GIS	Oil&gas	Geostats	Fracture	Regional
State							
Indiana	XX		XX		X	X	X
Kentucky	XX		X	XX	X	X	**XXX**
Maryland	X	XX	X	X	X	X	X
Michigan	XX*		X	**XXX**	X	X	X
New Jersey	XX	**XXX**	X		X	X	X
New York	XX	XX	X	XX	X	**XXX**	X
Ohio	XX	X	**XXX**	XX	**XXX**	X	XX
Pennsylvania	**XXX**		XX	XX	XX	X	X
West Virginia	XX		X	XX	X	X	X
	X	State will participate in this task					
	XX	State will play a major role in developing and completing this task					
	XXX	State will take a leadership role developing and completing this task					

Example of Regional Geologic Mapping

Cambro-Ordovician Carbonates, Sandstones, and Shale Storage and Containment



1 Upper Ordovician Confining Seal Units

2 Middle Ordovician Trenton-Black River and Equivalent Reservoir Units

3 Middle Ordovician St. Peter Sandstone - Reservoir Unit

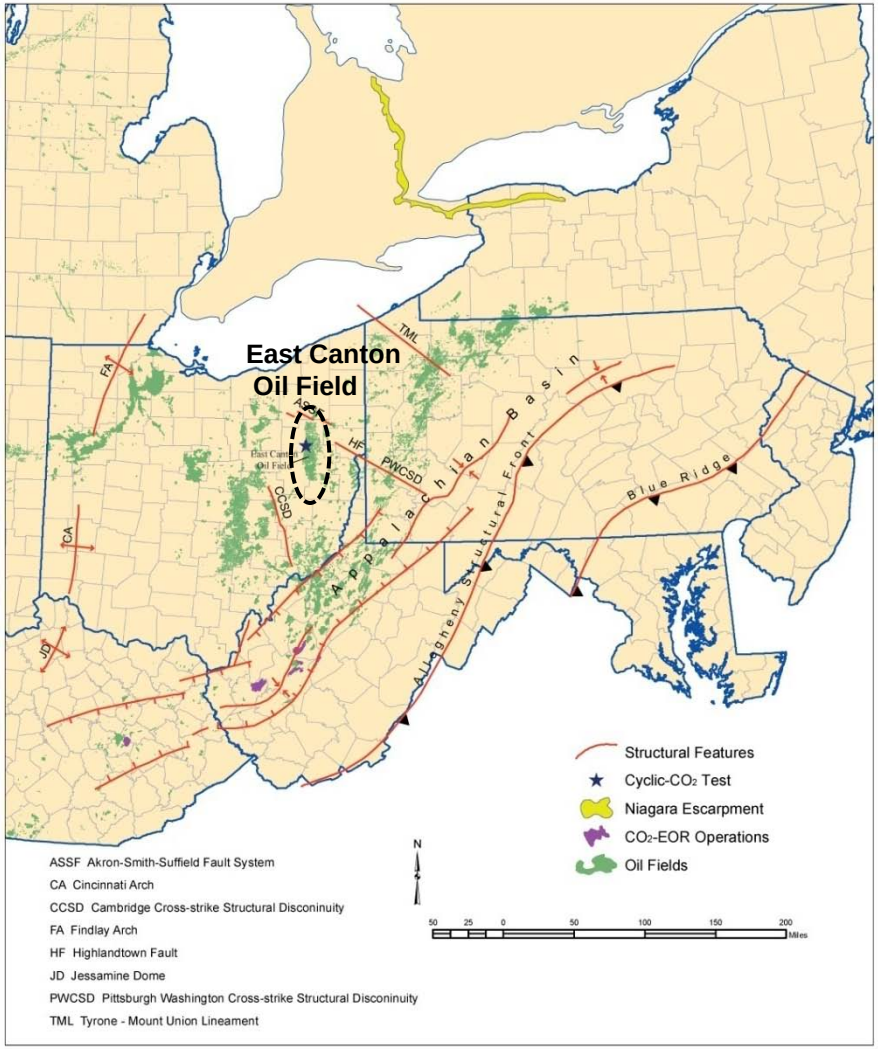
4 Cambro-Ordovician Beekmantown-Knox Group and Equivalent Reservoir Units

Unconformity

Base of Mapped Units

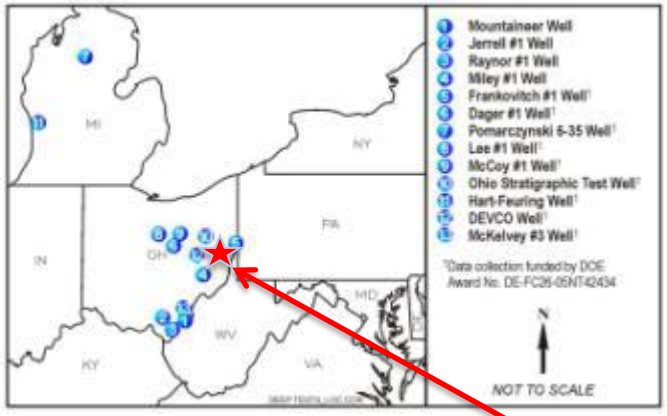
Testing Geologic Storage Potential in Clinton Sandstone (East Canton Oil Field)

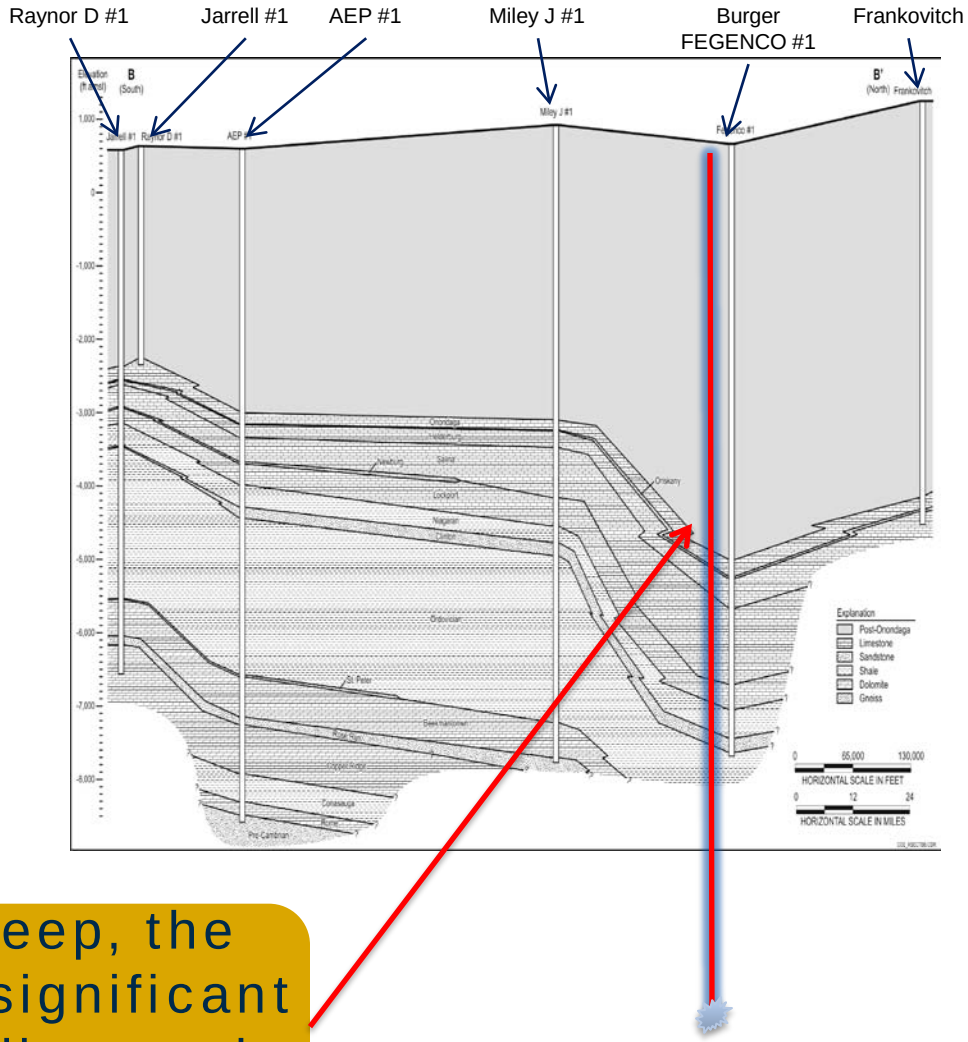
- Discovered in 1947, field has produced approximately 95 million barrels of oil from the Silurian “Clinton” sandstone.
- The original oil-in-place for this field is ~1.5 billion bbl of oil. There current recovery is <10%
- Reservoir simulations indicate cumulative production for the central producer in the pilot area varied from 12,000 to 42,000 bbl of oil over 5 years
- Determining injectivity and economic viability are key challenges



Upper Ohio Valley Characterization – Leveraging with Oil and Gas Activities

- **Funded by Ohio Coal Development Office**
- Partnering with local oil/gas and brine-disposal company
- Location in Upper Ohio Valley, near a large-fraction of coal-fired generation

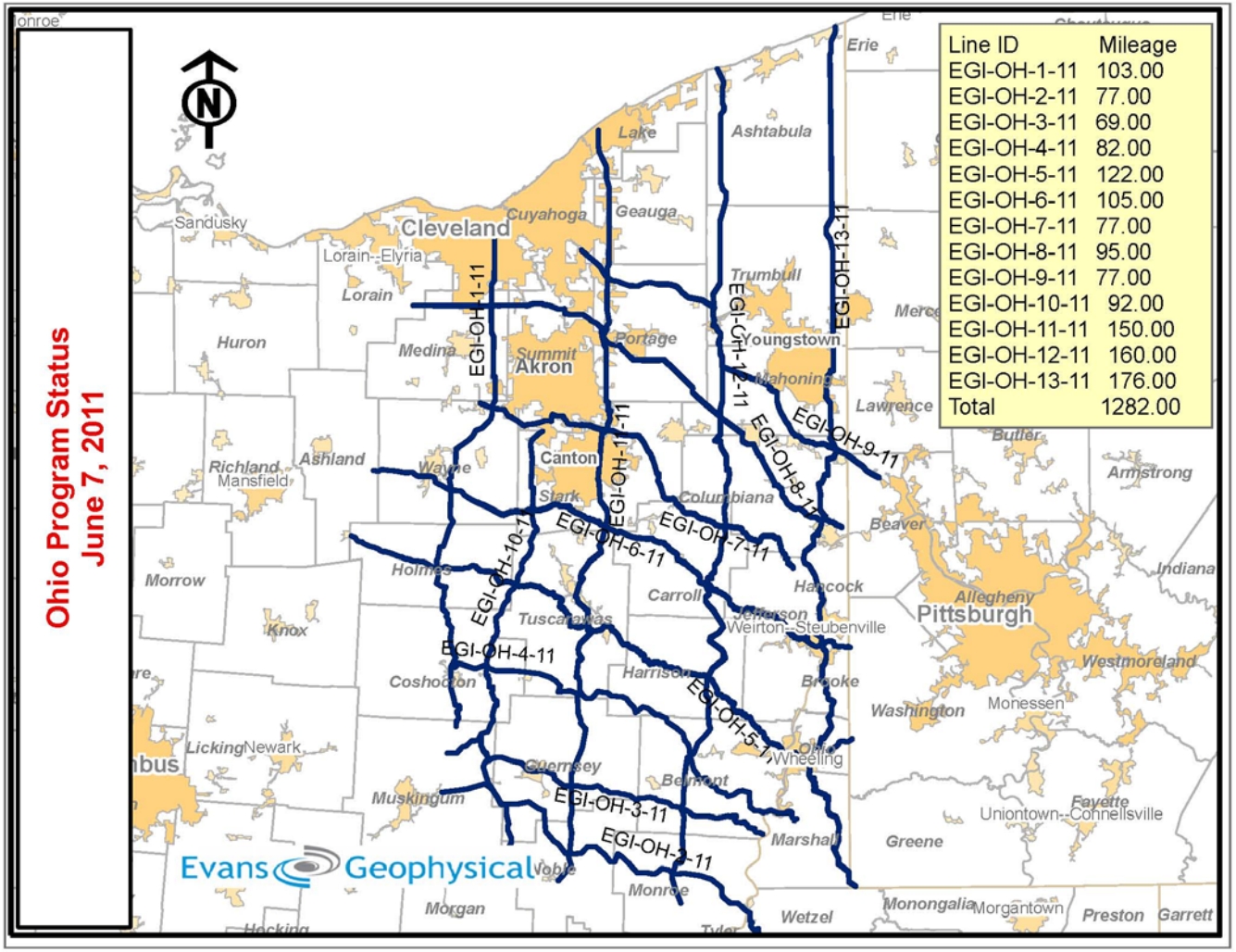




GM #1 is ~14,000 feet deep, the deepest in Ohio. It adds significant new data on the deep sediments in the Ohio Valley

~250 Miles New 2D Seismic Data for Appalachian Basin Characterization

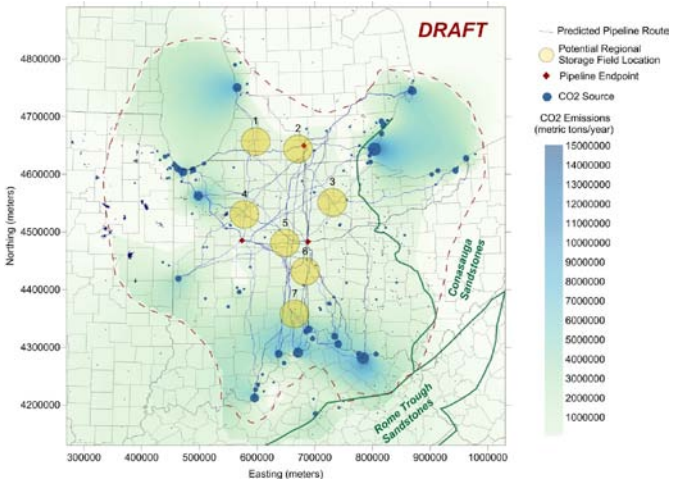
A *Co-benefit from Gas Shale Boom*

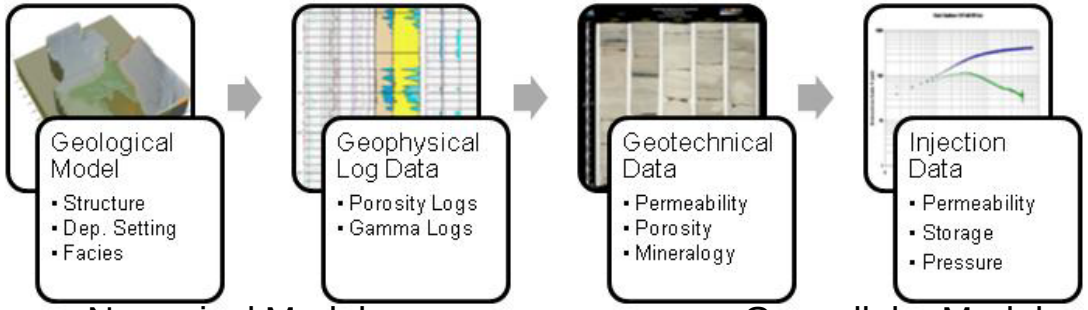


Purchased Using Ohio Coal Development Office Funds

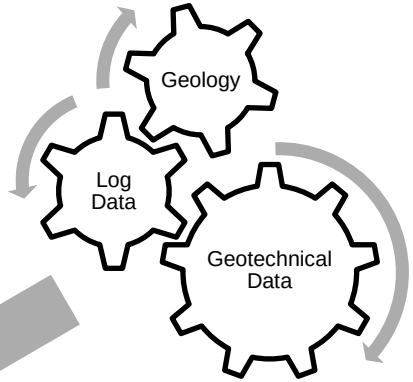
Arches Province Mt. Simon Sandstone Regional CCS Deployment Simulation

- Regional geologic model for the Mt. Simon Sandstone along the Arches province to determine the infrastructure issues for large-scale CO_2 storage
- Geologic characterization, pipeline routing analysis, and reservoir simulations completed
- **Funded separately by US DOE and Ohio Coal Development Office**



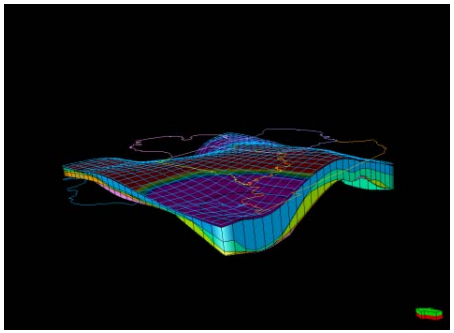


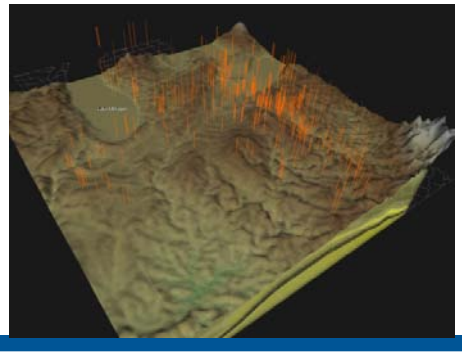
Geostatistical Analysis



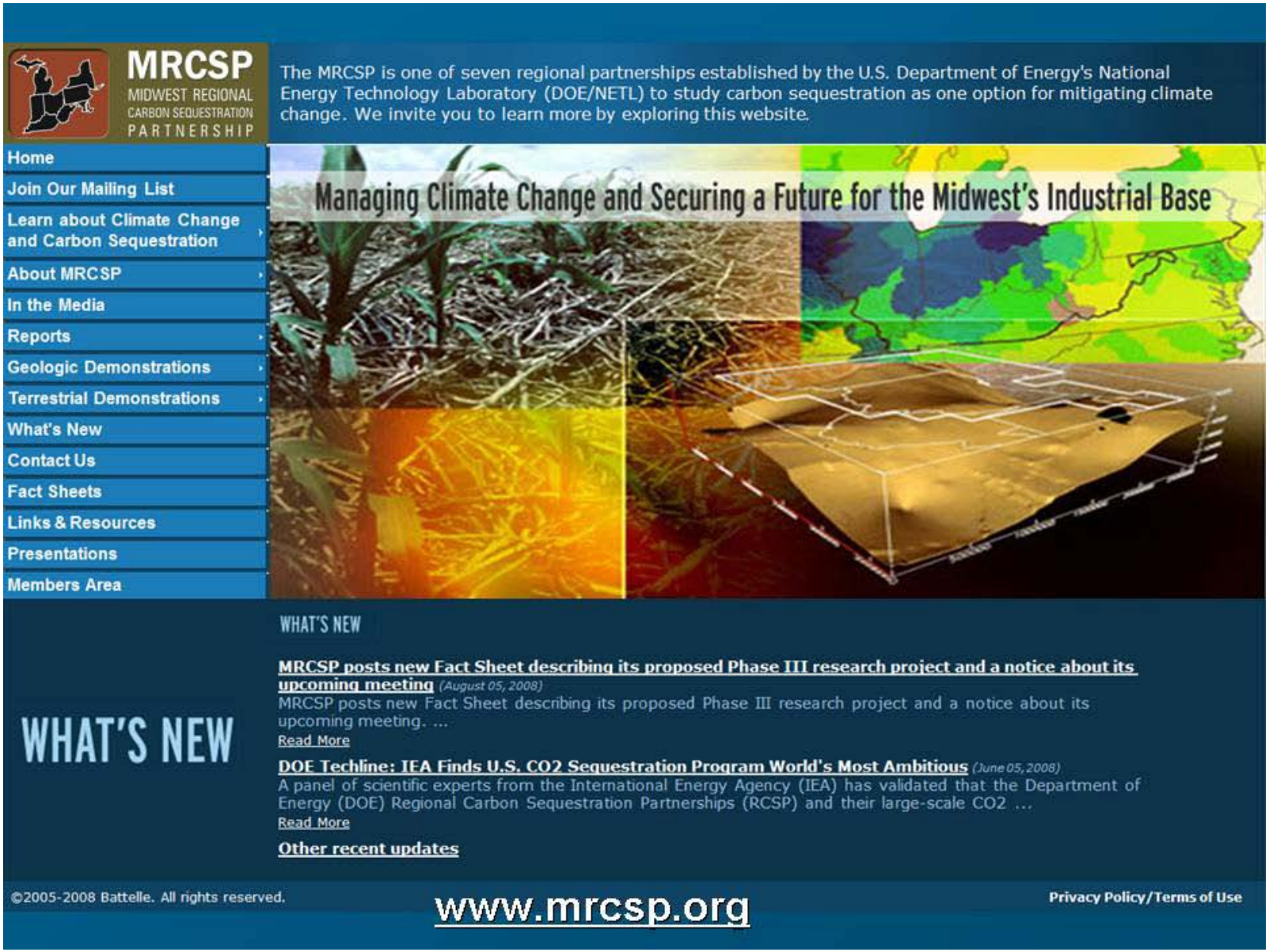
Numerical Model

Geocellular Model





Thank You!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