CO_2 Utilization and Storage Technology Update

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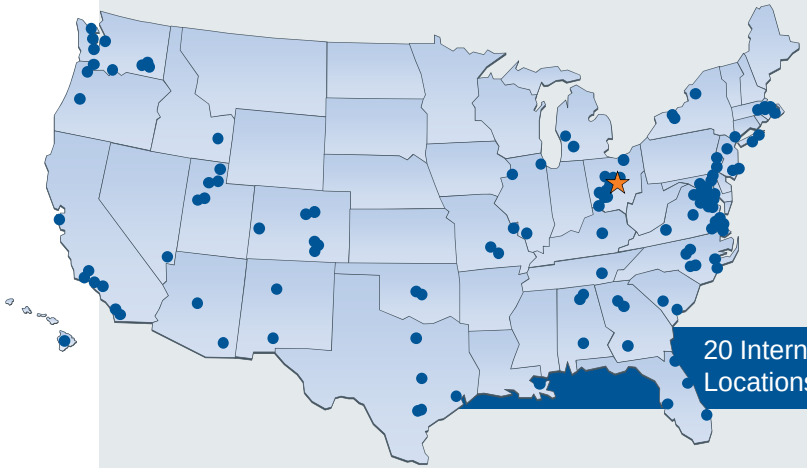
Work Presented here has been Funded by USDOE, AEP, Ohio Coal Development Office, & Many Other Sponsors and Performed by Battelle and MRCSP Research Team Members from Across Midwestern USA

McIlvaine Hot Topic Webinar, May 24, 2012

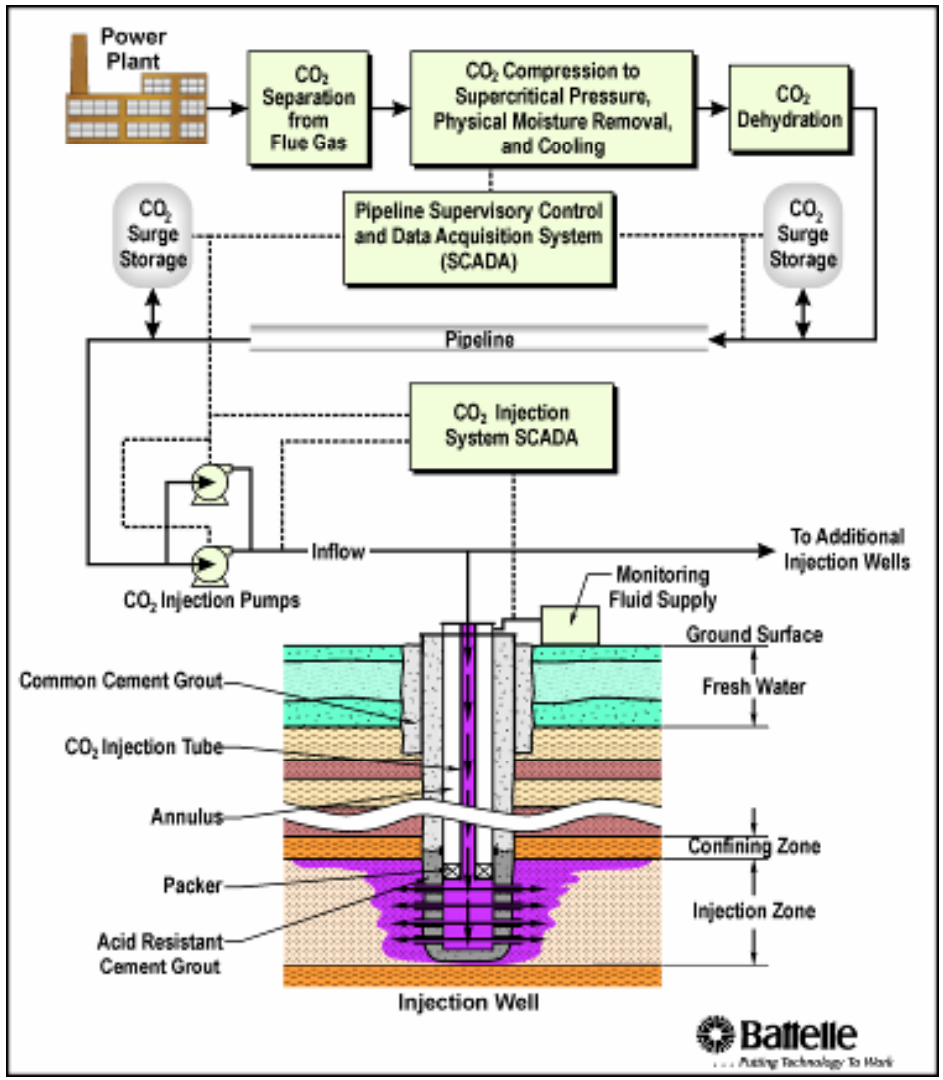
What We Are

- Global enterprise
  - Applying science and technology to real-world problems
  - Managing machinery of scientific discovery and innovation
  - Creating commercial value by bringing new technologies to international marketplace
- Non-profit, charitable trust formed by Will of Gordon Battelle in 1925

- Generates $6.5 billion annually in global R&D
- Oversees over 22,000 employees in 130 locations worldwide



Major Components of CCS Value Chain



Enterprise Strategic Planning
- Carbon foot print analysis
- Source reduction analysis
- Asset opportunity screening

Capture
- Development of new capture concepts
- Applications screening
- Process optimization and integration

Surface Transport
- Analysis of CO_2 transport properties
- Process optimization and integration
- System design support
  - Compression and processing
  - Pipeline transport
- Monitoring (inspection, corrosion analysis etc.)

Subsurface and Injection
- Site characterization
- Permitting and NEPA
- Well field design and implementation
- Injection operations

Measurement Mitigation and Verification
- MMV design, implementation and operation
- Data analysis

Battelle Carbon Management – Involved in Major Public-Private and Other CCS Efforts

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AEP Mountaineer – 3 Projects over 9 Years

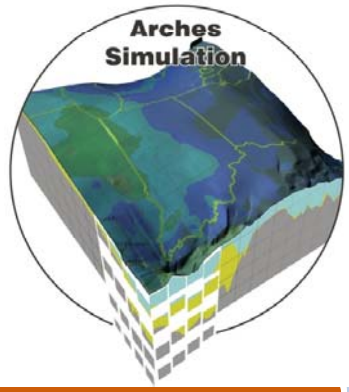
DOE Regional Partnerships Program

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

BIG SKY CARBON SEQUESTRATION PARTNERSHIP
(Basalt Demonstration)

FutureGen and FutureGen 2.0

FutureGen™ ALLIANCE



Regional Characterization and Basin-Scale Modeling

Direct Industry Projects Examples

- Consulting projects for domestic and international utilities, oil, gas, coal, steel, and infrastructure companies

FutureGen 2.0

Commercial-scale, Leading Edge

- Oxy-Combustion Repowering with pipeline transport to Morgan County, Illinois site
- Storage in the Mt. Simon Sandstone up to 5000' depth
- Initial pipeline routing study completed
- Conceptual storage and monitoring design completed

FutureGen 2.0, Test Well, October 5, 2011

- Characterization well drilling and testing 2011-12 to confirm site suitability and develop permitting and design parameters
- Extensive stakeholder involvement to build technology support
- Battelle is the geologic storage contractor for the FutureGen Alliance

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CCS history of AEP at Mountaineer

Location: Mountaineer Power Plant, New Haven, West Virginia

- 1,300 MW coal fired power plant.
- Operated by Appalachian Power Company (a subsidiary of AEP)

CCS Projects:

- 2003, Ohio River Valley Project.
- 2007, Product Validation Facility (PVF).
- 2010, Commercial Scale Project (CSP-2)

Site Selection

- Suitable Power Plant.
- Available Property.
- AEP's coal fired generation fleet in this region.

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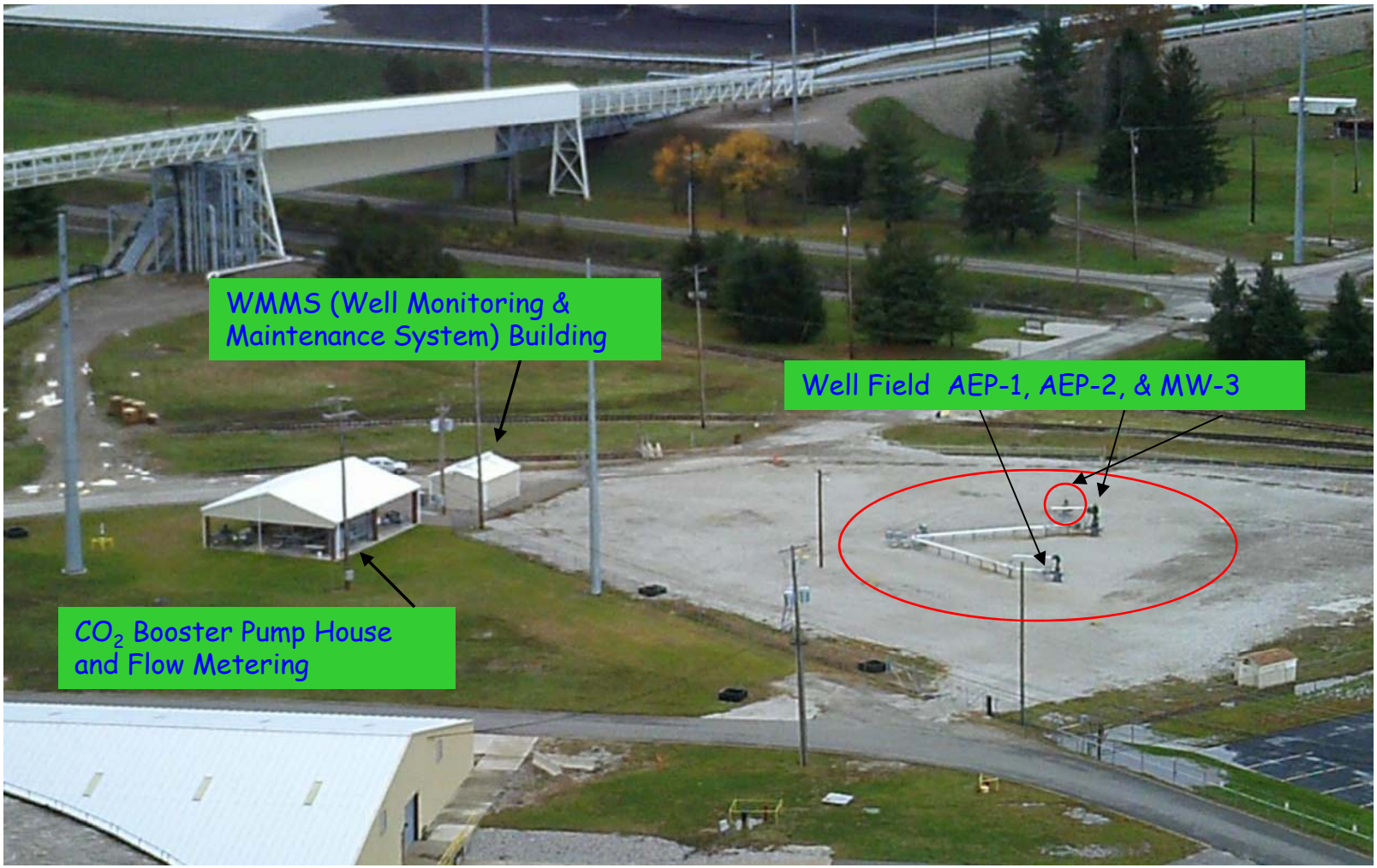
CO_2 Sequestration at Mountaineer Plant

~150,000 man-hours of safe drilling, completion, and workover operations. Extensive subsurface monitoring program



- Approximately 37,000 tonnes CO_2 injected, with majority of injection in the Copper Ridge zone, which showed very good injectivity

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Mountaineer Commercial Scale Project

Scale: Full commercial demonstration
~235 MWe Slipstream

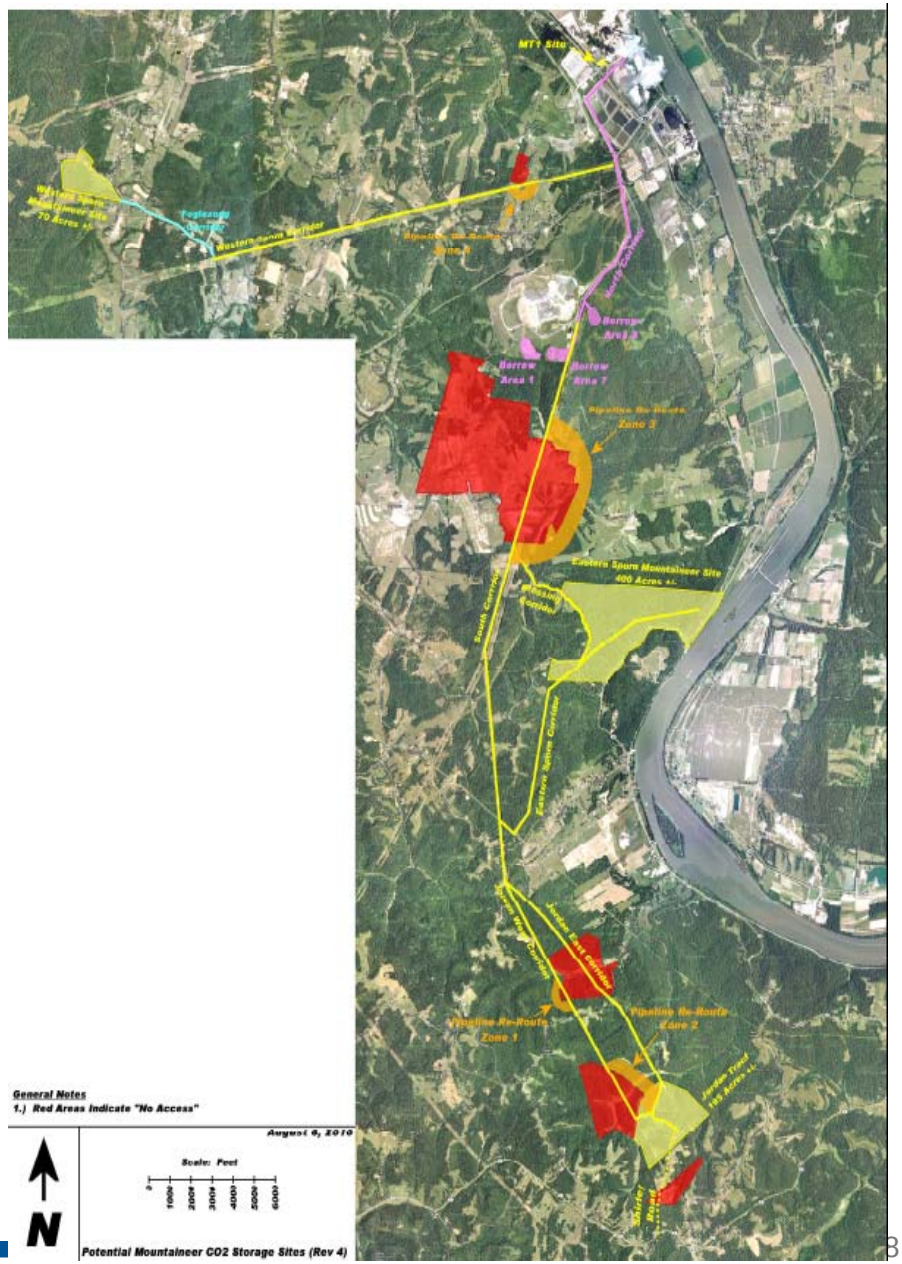
Funding: CCPI Round III Selection

Capture: Alstom Chilled Ammonia Process
~90% CO_2 capture rate

Sequestration: Battelle as Storage Contractor
Deep saline reservoirs
~1,500,000 tons CO_2 per year
~1.5 miles below the surface
Pipeline system with off-site wellheads

Geologic Experts Advisory Group:
Battelle, CONSOL, MIT, Univ. of Texas, Ohio State, WVU, Virginia Tech, LLNL, WV Geo. Survey, OH Geo. Survey, WV DOE, NETL, RWE, & CATF

Status – Suspended after Project Definition Phase



AEP Mountaineer CSPII - Project Definition Phase

Test well drilled in 2011 to evaluate geologic continuity in the area

Well logs, cores, and reservoir testing results consistent with PVF injection tests, however, more regional characterization is needed

Preliminary design, monitoring program, costs, and schedule for developed for all phases

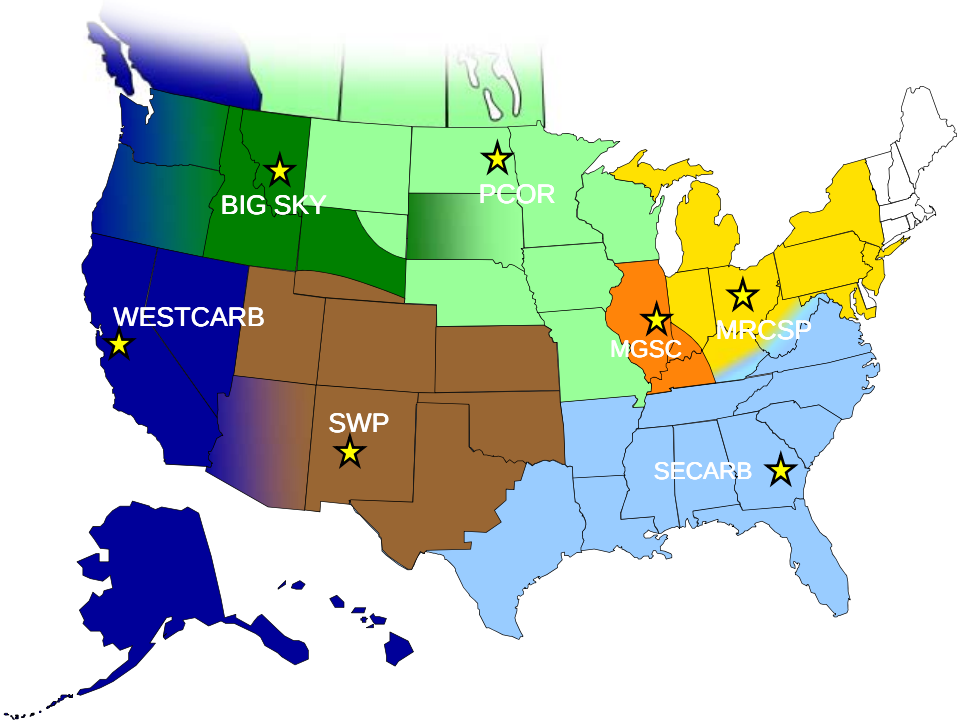
Preliminary design estimates indicated that 2-3 wells in Copper Ridge Dolomite may be sufficient for CSPII scale injection project,

Regional Carbon Sequestration Partnerships

Developing the Infrastructure for Wide Scale Deployment (Source : US DOE)

Seven Regional Partnerships

400+ distinct organizations, 43 states, 4 Canadian Provinces



- Engage regional, state, and local governments
- Determine regional sequestration benefits
- Baseline region for sources and sinks
- Establish monitoring and verification protocols
- Address regulatory, environmental, and outreach issues
- Validate sequestration technology and infrastructure

Characterization Phase (2003-2005)

Search of potential storage locations and CO_2 sources	Found potential for 100's of years of storage

Validation Phase (2005-2010)

20 injection tests in saline formations, depleted oil, unmineable coal seams, and basalt

Development Phase (2008-2017+)

9 large scale injections (over 1 million tons each)	Commercial scale understanding	Regulatory, liability, ownership issues

Battelle Plans to Issue 17 MRCSP Phase II Reports in Nov. 2011

MRCSP Membership - Progress through Collaboration

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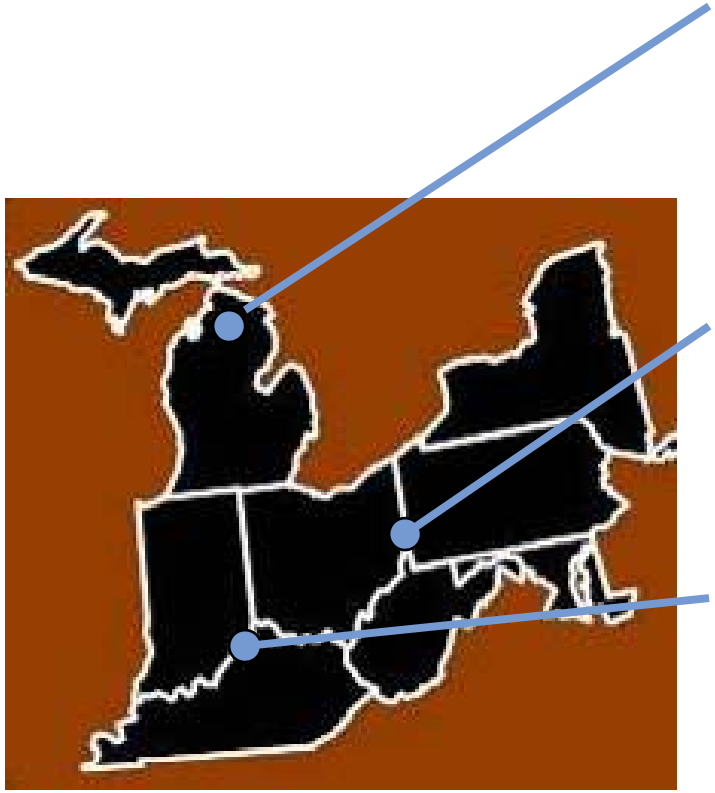
MAKING OHIO COAL
THE CLEAN CHOICE

CORE ENERGY, LLC

MRCSP Geologic Test Sites*



Michigan Basin: DTE and Core Energy gas and oil operations, Gaylord, Michigan

- Permitting: EPA Region 5, Class V, Granted Jan 2007.
- Target: Bass Islands Dolomite, ~3500 ft
- Status: Injected 10,000 tonnes 2008. Additional 50,000 tonnes injected February-July 2009
- Several monitoring technologies tested at the site

Appalachian Basin: FirstEnergy's RE Burger Power Plant, Shadyside, Ohio

- Permitting: Ohio EPA, Class V, Granted Sep 2008
- Target: Oriskany, Salina, and Clinton, 6500-8000 ft
- Status: Injection testing indicate low injectivity at this site

Cincinnati Arch -- Mount Simon: Duke's East Bend Power Station, Rabbit Hash, Kentucky

- Permitting: EPA Region 4, Class V, Granted Feb 2009.
- Target: Mt. Simon Sandstone, 3,500 ft
- Status: Drilling Jun 2009, Injection completed Sep 2009

Large Scale (1 million tonnes of CO_2) Phase III Site, Otsego County, Michigan

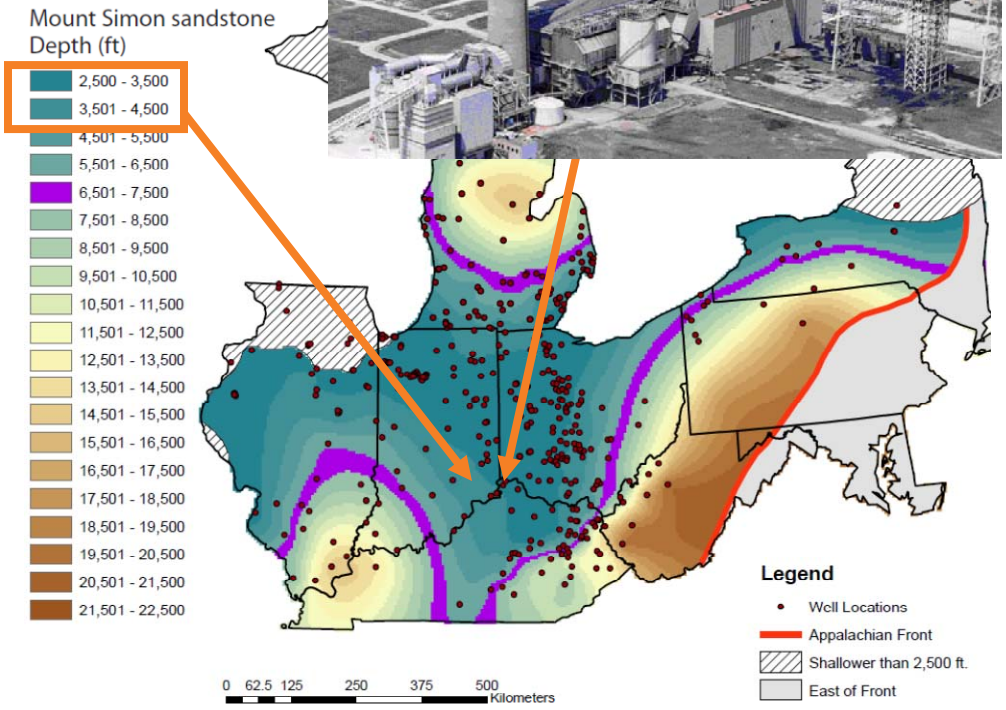
- Project transitioning to EOR due to UIC Class VI requirements for deep saline reservoirs

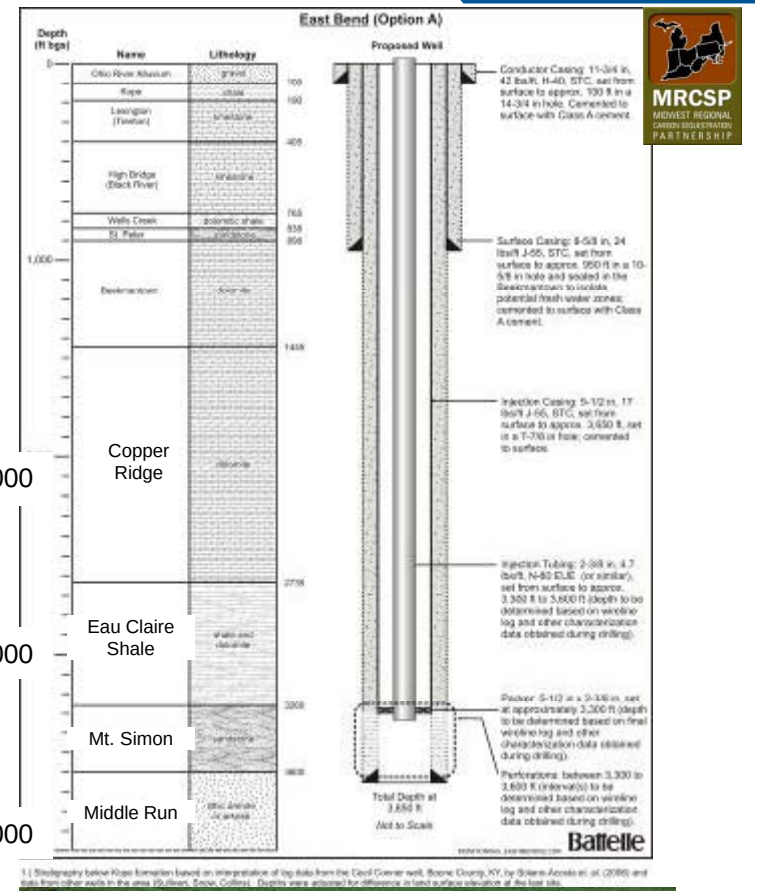
* All deep saline tests

Cincinnati Arch Site

East Bend Station, Duke Energy

1,000 tonnes CO_2 injected in 2009.





Michigan Basin Phase II Injection Test

Leveraging Existing EOR Infrastructure

Gas processing plant, source of pure CO_2

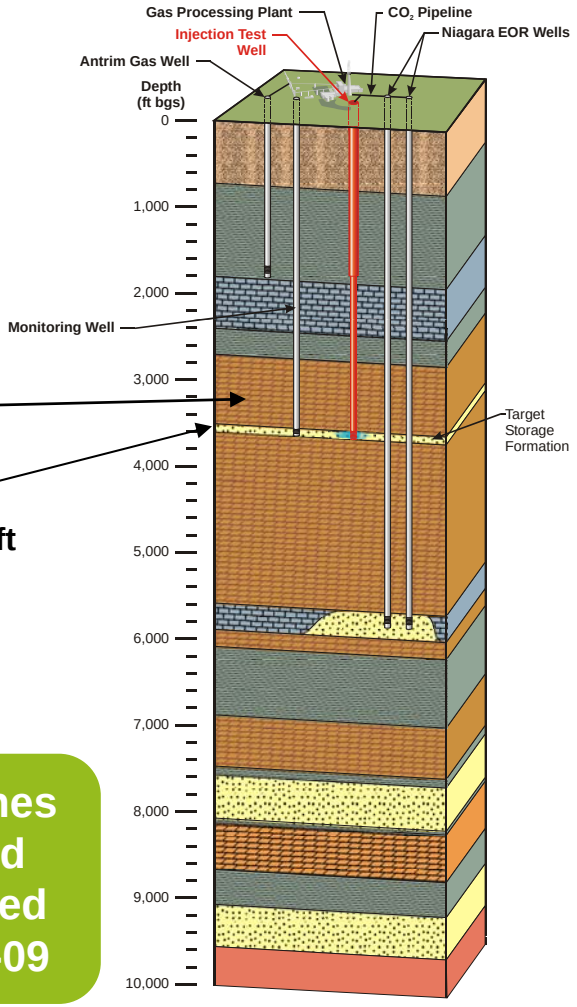
600 T/d Compressor

5000 Foot Deep Test Well
Drilled in November 2006

180 feet of core taken

Injection well head

~60,000 Tonnes CO_2 injected and monitored during 2008-09



Confining Layer:
Amherstburg Limestone

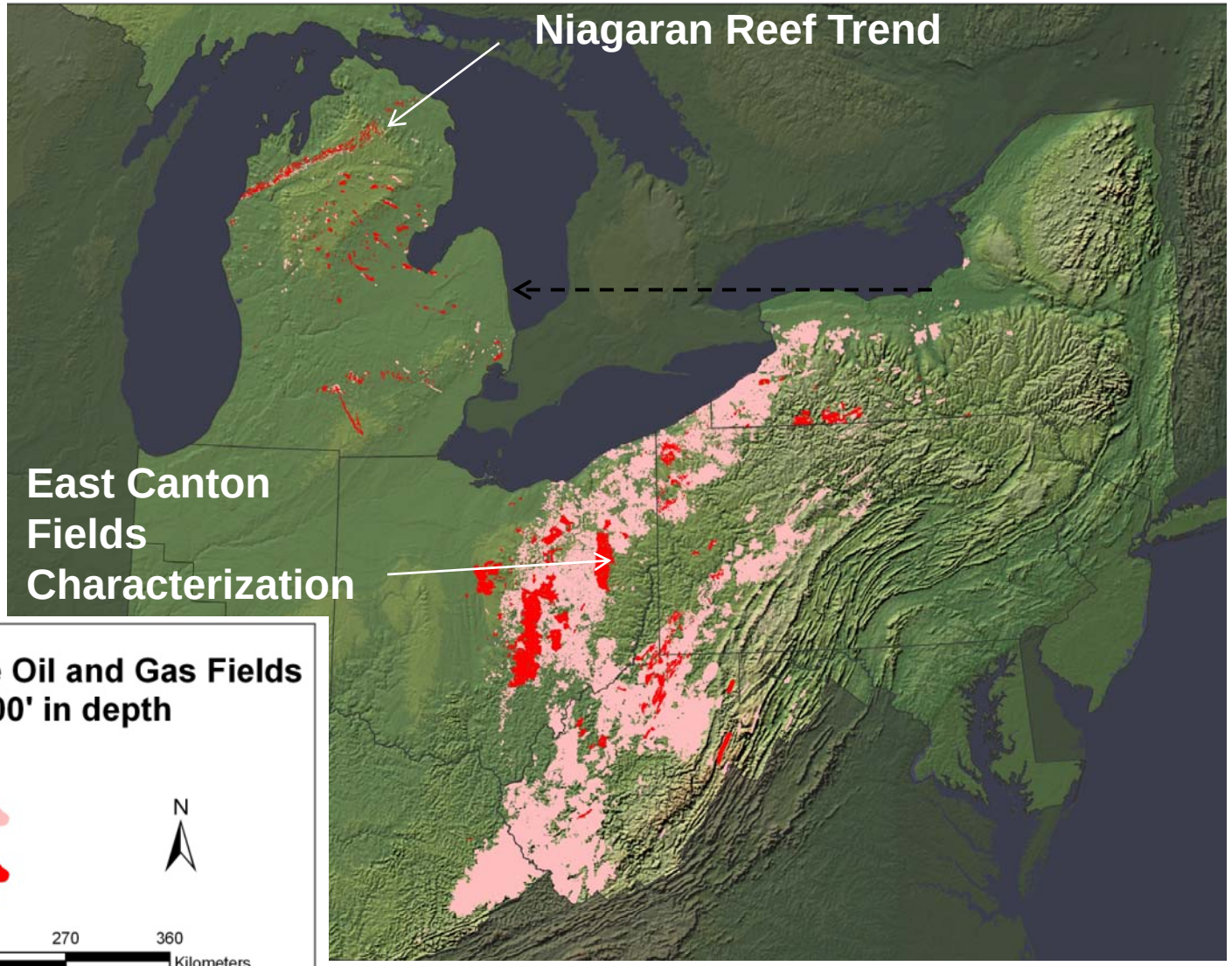
Injection Target:
Bass Islands Dolomite 3,500 ft

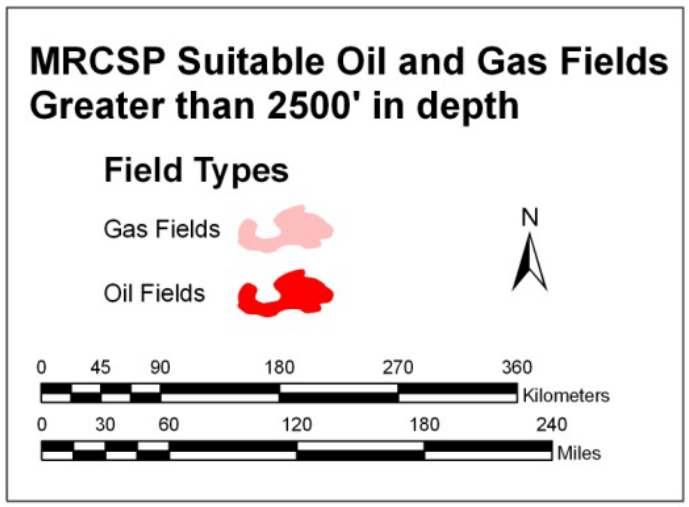
Well Column

MRCSP Phase III Saline Formation Characterization Well Drilling – March 2011

- Drilling with site access and drilling permit from Michigan Dept. of Natural Resources
- However, Class VI UIC requirements for post-injection monitoring and financial assurance are difficult for demonstration projects.
- Therefore a new strategy is needed to meet the objectives of CCS deployment

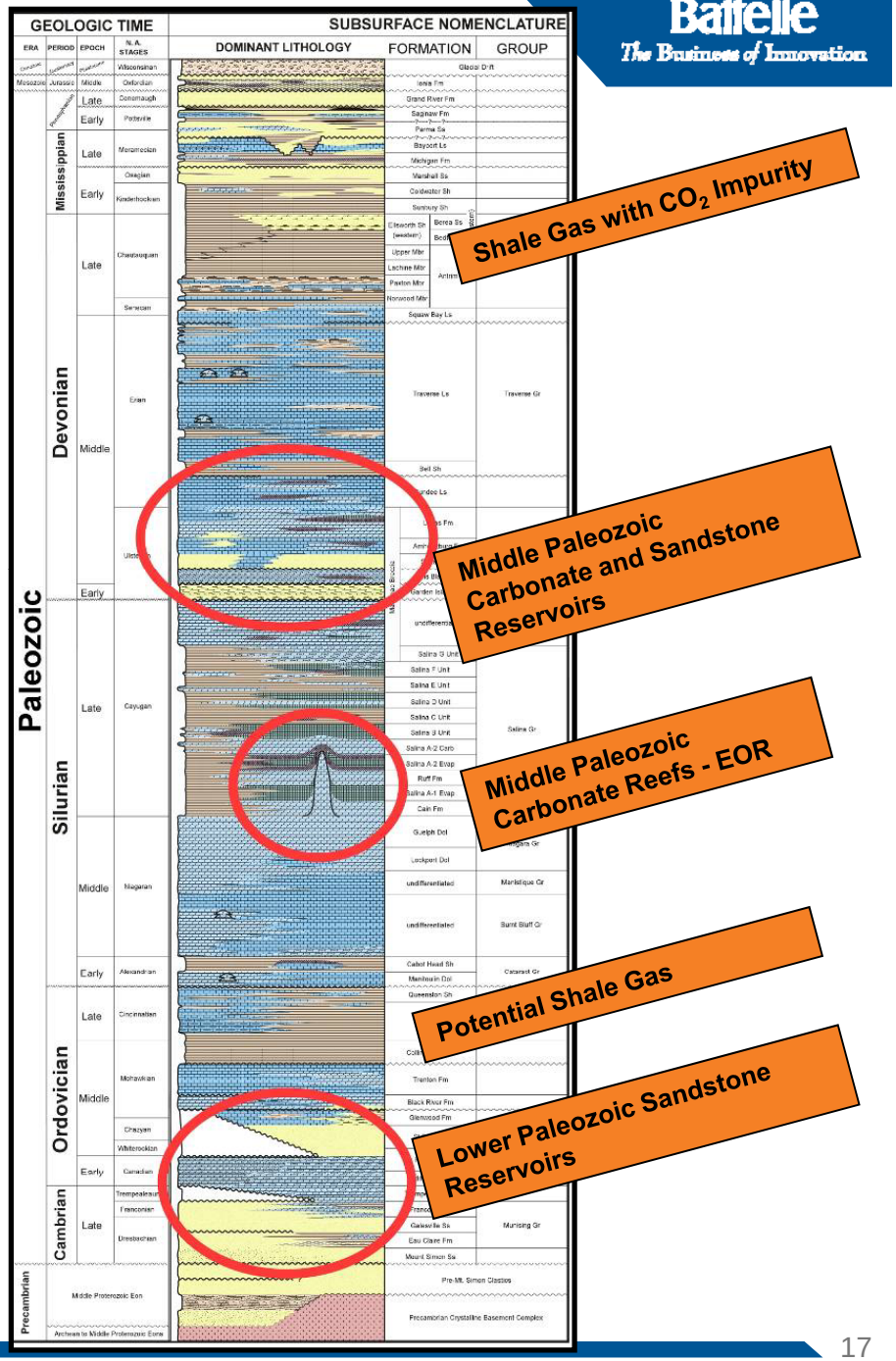
MRCSP – Leveraging EOR Infrastructure in Oil Fields for CCS Research



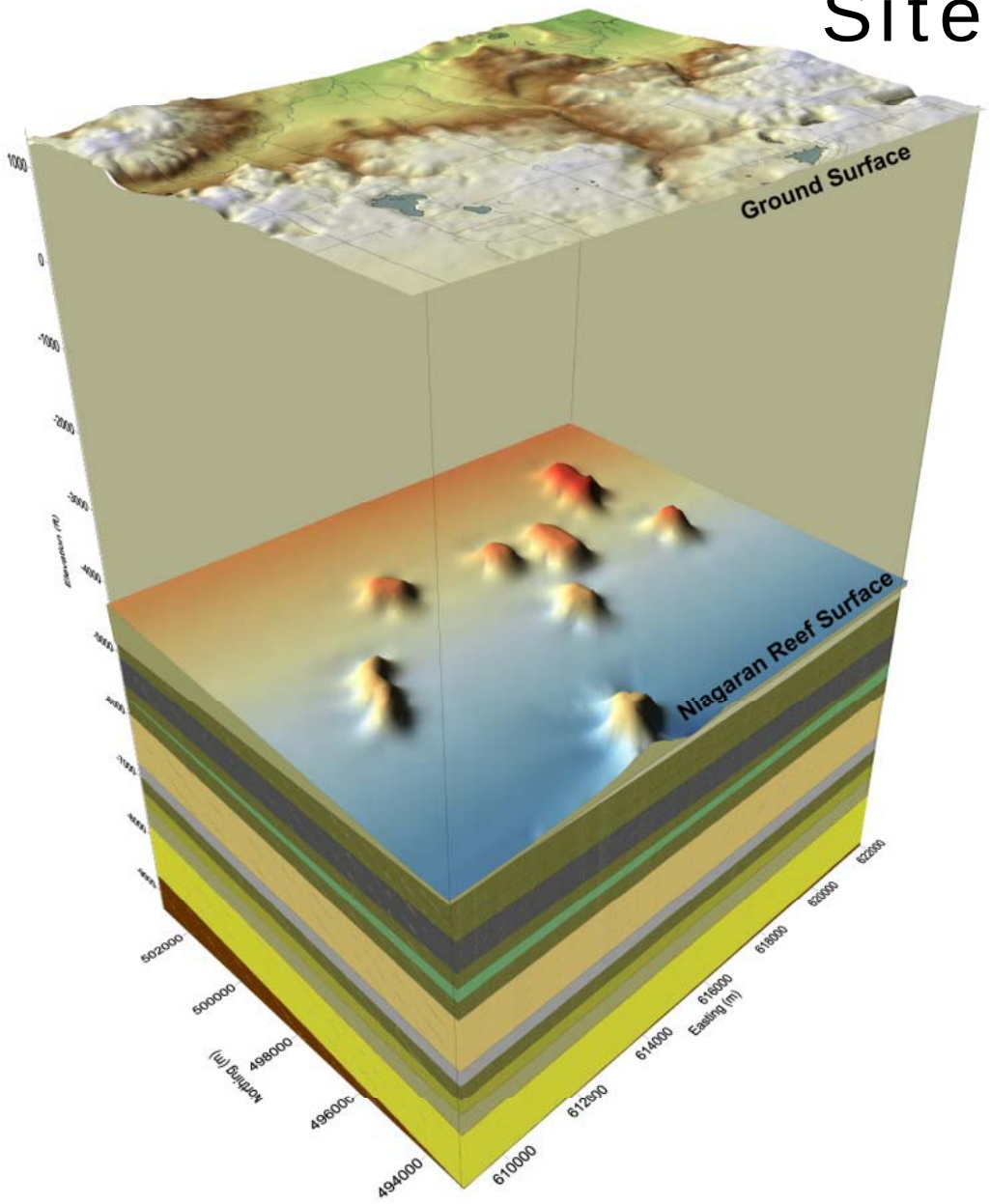


Michigan's Geologic Resource Example

- ~16,000 feet of sedimentary layers with multiple uses across geologic column
  - Conventional shale gas
  - Conventional oil
  - CO_2-EOR
  - Brine Disposal
  - Potential deep shale gas
  - Potential CO_2 storage
- Is this a possible analogue for eastern Ohio?



Site Description



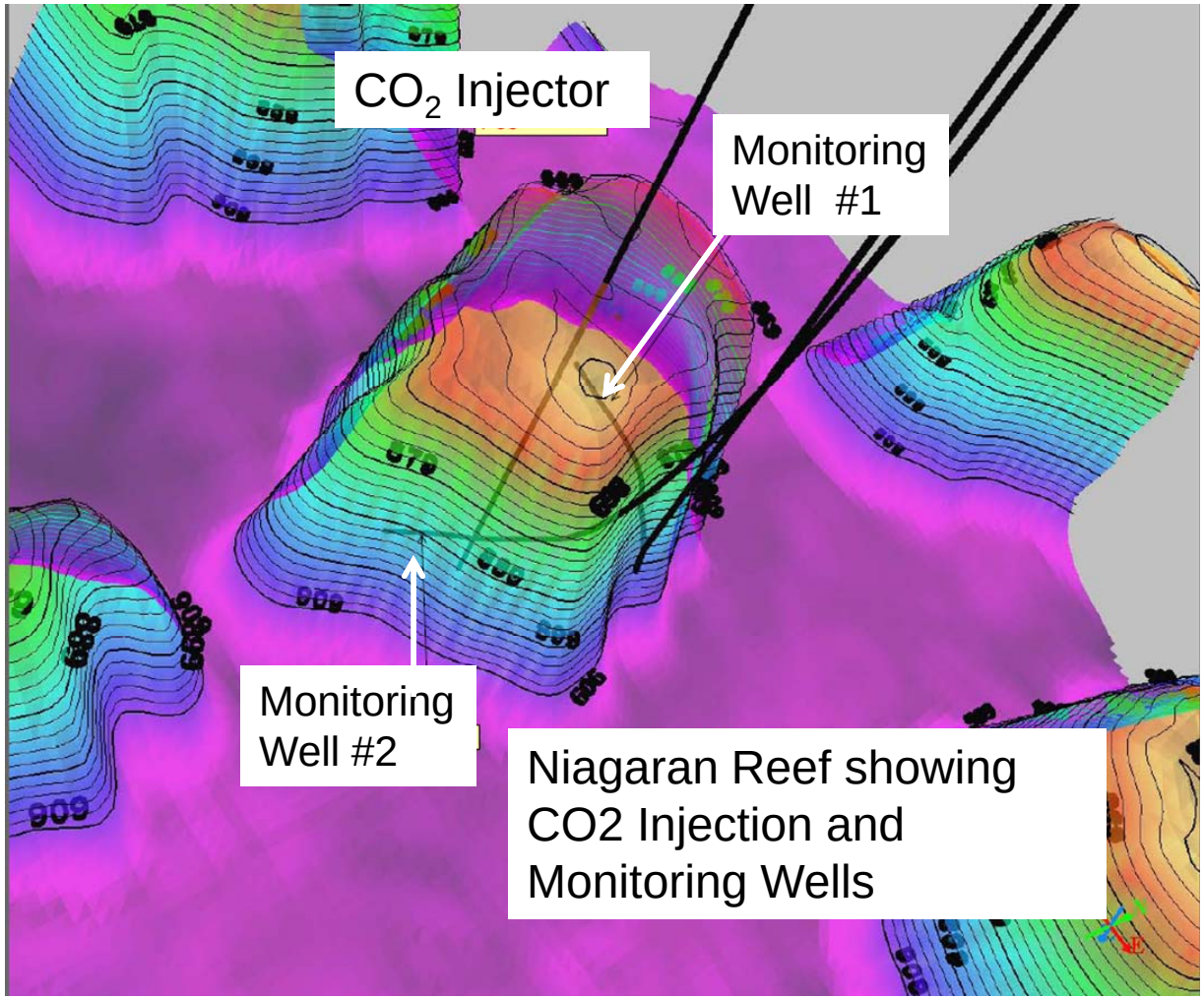
Location:
Otsego County, Michigan

Source of CO_2:
Local Natural Gas Processing Plant (Antrim Shale Gas ~15% CO_2 content)

Reservoir Type:
Closely-spaced, highly compartmentalized oil & gas fields located in the Northern Michigan Niagaran Reef Trend

Permitting:
U.S. EPA Region 5 UIC Class II permits already in place for EOR operations

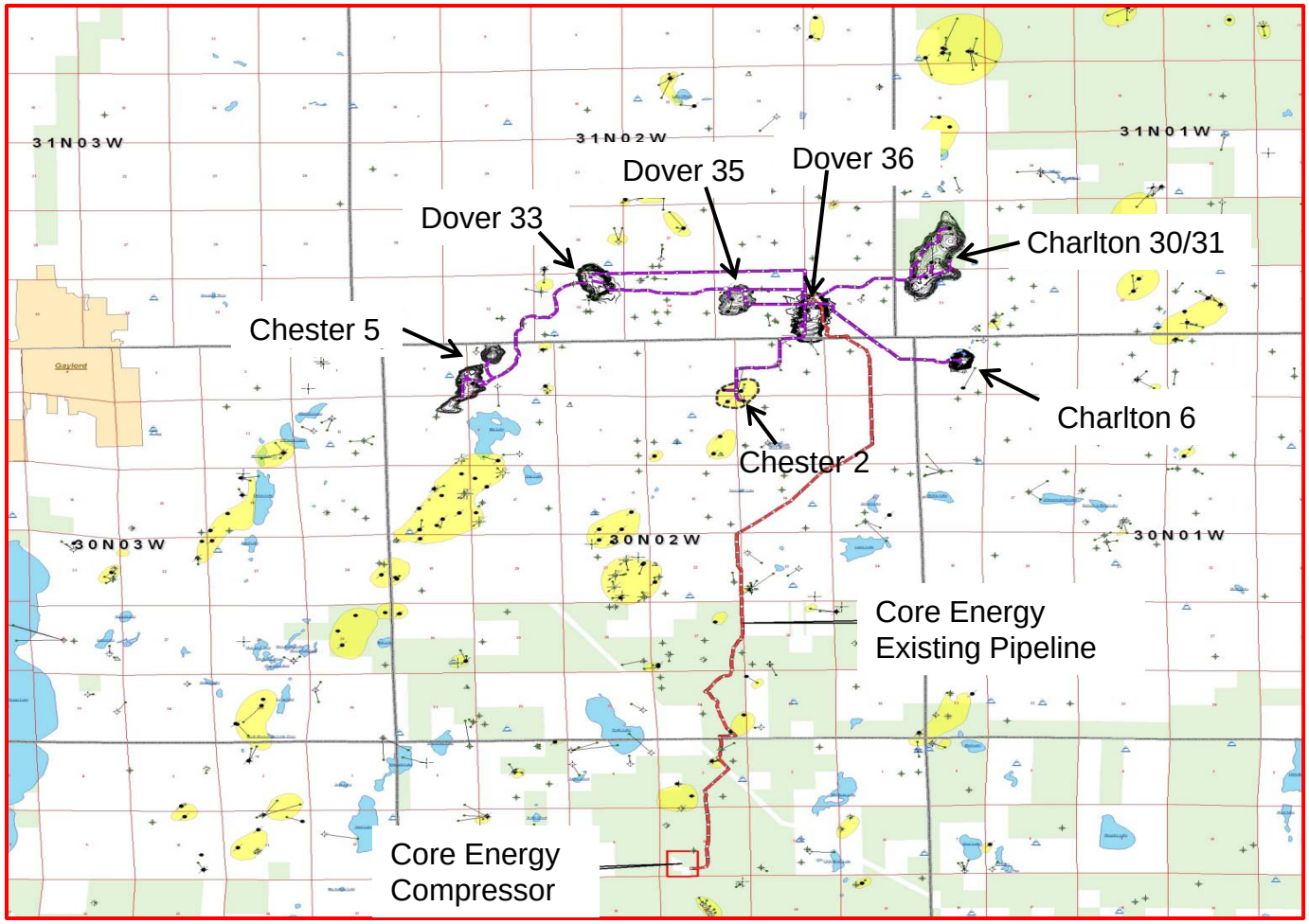
3D Seismic View of the Reefs



3D Seismic is a key technological tool for effective exploration, production, and monitoring

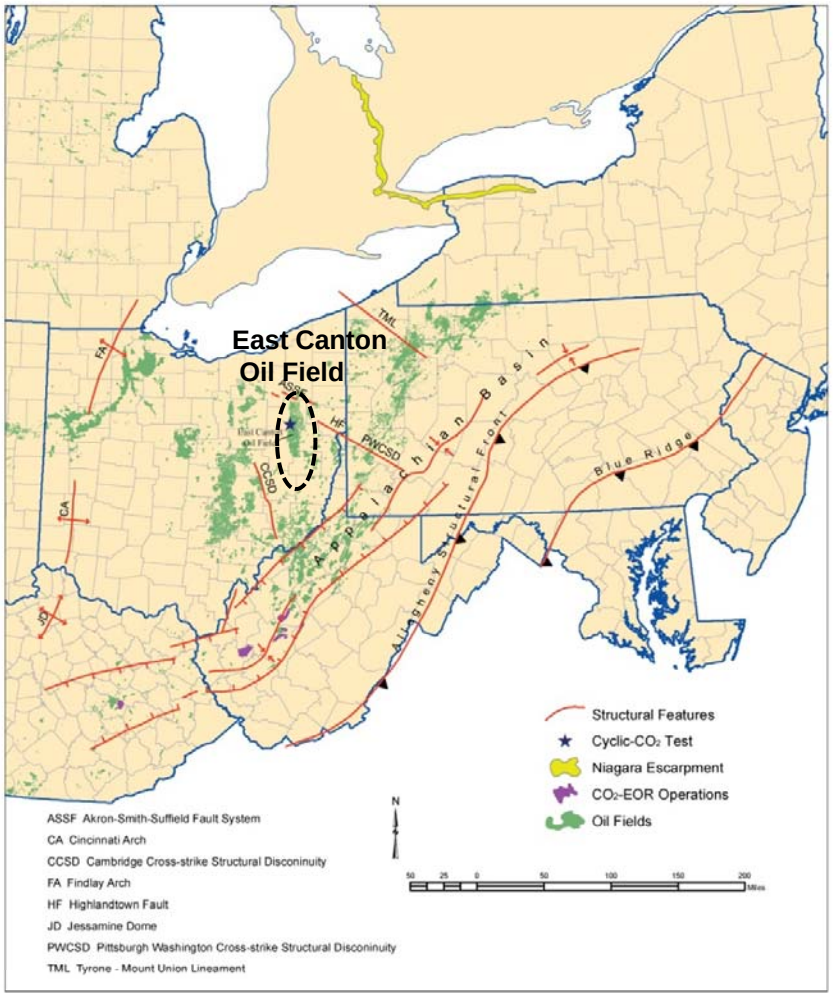
This data will be a key contribution in developing detailed models of the CO_2 behavior inside the Niagaran Reefs.

Existing EOR Infrastructure allows MRCSP to Meet its Scientific Goals



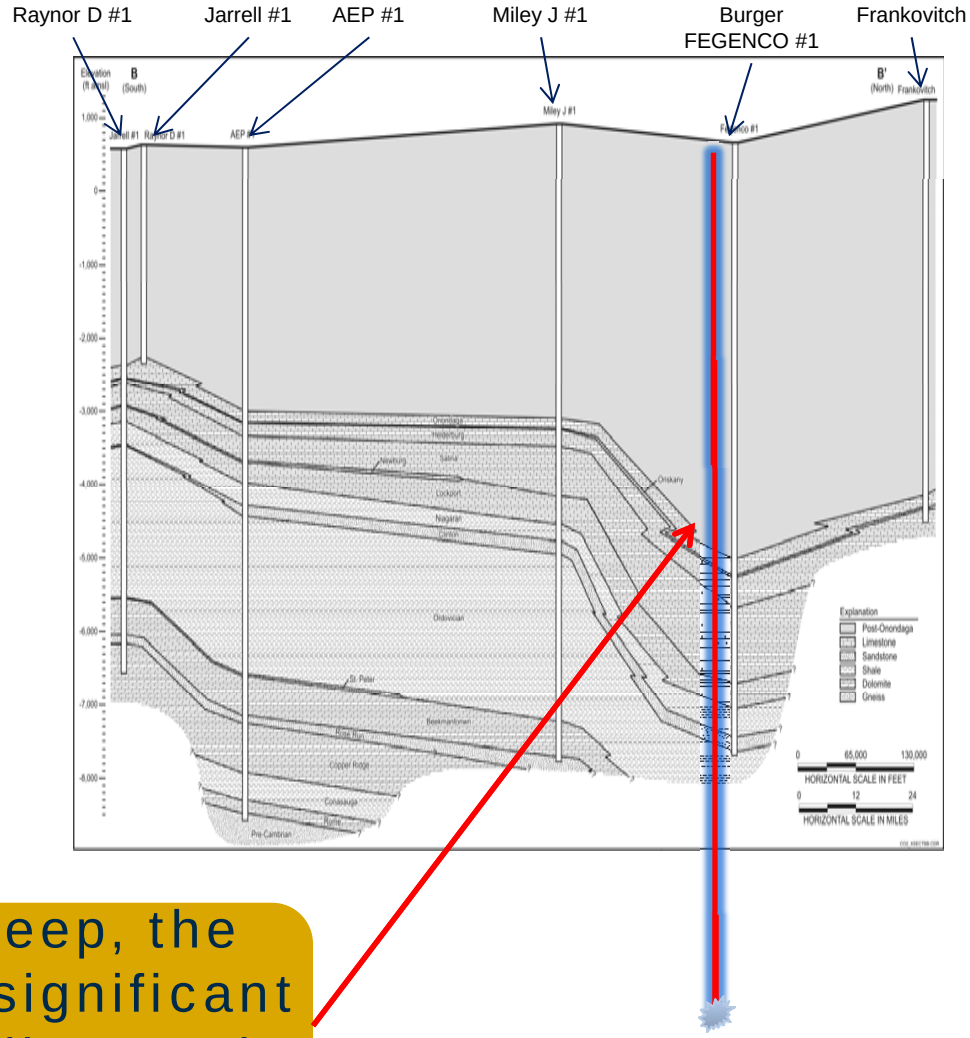
Potential Testing EOR/CO_2 Storage Potential in East Canton Oil Field Clinton Sandstone

- Discovered in 1947, the ECOF in northeastern Ohio has produced approximately 95 million barrels (MMbbl) of oil from the Silurian "Clinton" sandstone.
- Encompassing 175,000 reservoir acres with more than 3,100 current or past producing wells, this is the most significant, actively producing oil field in Ohio.
- The original oil-in-place (OOIP) for this field is estimated to be approximately 1.5 billion bbl of oil.
- ***Additional testing is needed to determine EOR viability in such fields.***



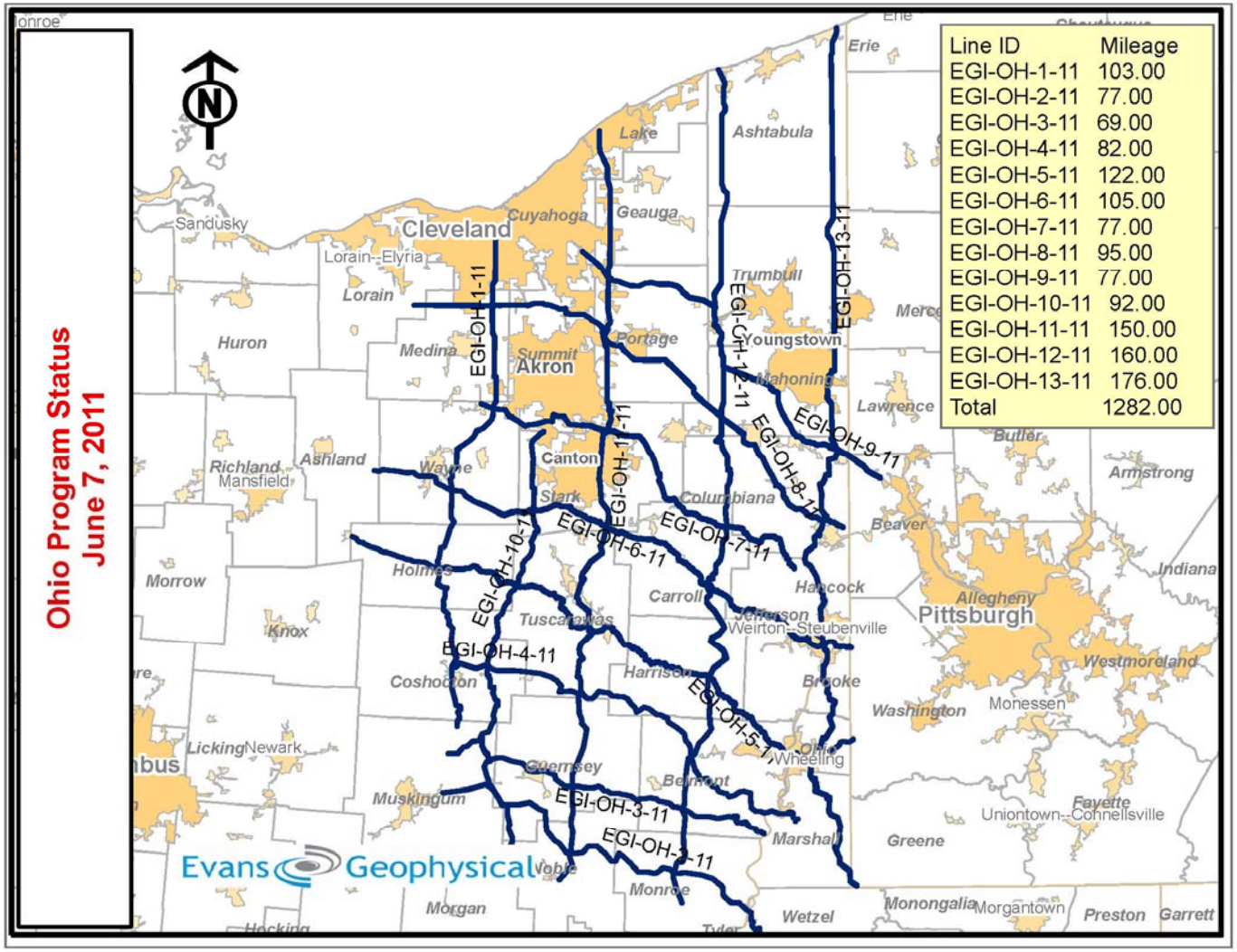
Upper Ohio Valley Characterization – Leveraging with Oil and Gas Activities

- 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

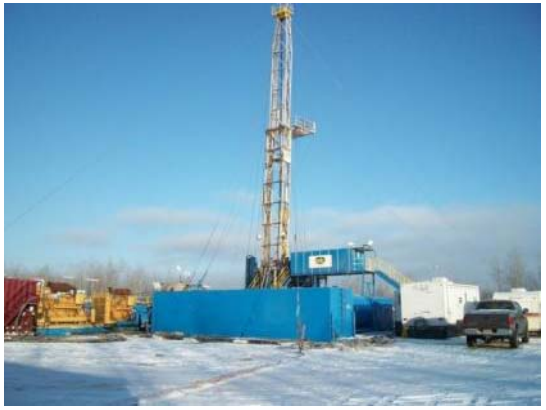


GM #1 is ~14,000 feet deep, the deepest in Ohio. It adds significant new data on the deep sediments in the Ohio Valley

New 2D Seismic Data in Appalachian Basin
Co-benefit from Gas Shale Boom



Summary – Assessing Geologic Storage Options in Midwest



Battelle/MRCSP Test Well Drilling, Northern Michigan, March 2011

- Executed drilling of more than 10 CO_2 storage test wells in the Region
- Several geologic storage injection permits completed and closed
- Experience gained in operation and monitoring technologies
- CO_2 storage work at AEP Mountaineer site, from site characterization to operations, including discovery of new storage targets of regional significance
- Developing regional geologic framework through piggyback testing in the region
- CO_2-EOR is proving to be a bridge to large-scale CO_2 Storage in saline formations. This will require collaboration between coal and oil/gas interests

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Back-up Slides
Battelle Overview
Geologic Site Illustrations

May 08, 2012

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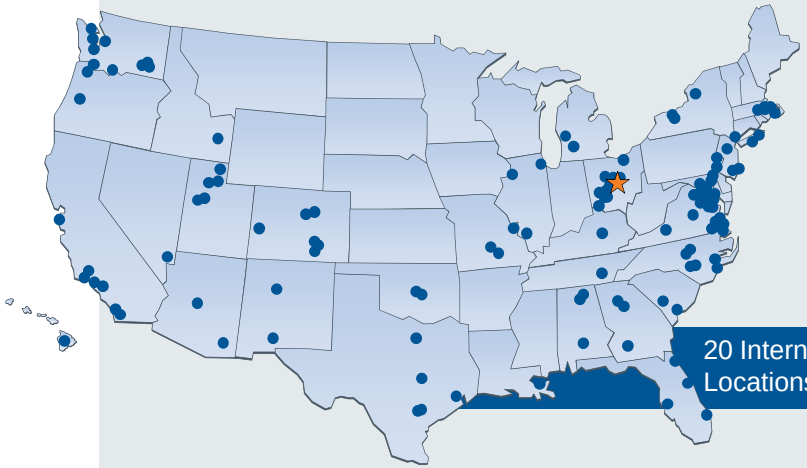
What We Are

- Global enterprise
  - Applying science and technology to real-world problems
  - Managing machinery of scientific discovery and innovation
  - Creating commercial value by bringing new technologies to international marketplace
- Non-profit, charitable trust formed by Will of Gordon Battelle in 1925

- Generates $6.5 billion annually in global R&D
- Oversees over 22,000 employees in 130 locations worldwide



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Battelle Has a History of Creating First of a Kind Innovations

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- Earned 20 R&D 100 Awards in 2008, total of 191 since 1969
- Velocys-FT: advanced reactor technology which greatly reduces the size and cost of second-generation biofuel facilities

- International fiber optic venture (PIRI) formed by Mitsubishi, NTT and Battelle
- Compact disc technology
- Universal Product Code and cut-resistant golf balls developed
- Officer copier (Xerox) entered the market
- Battelle began operations
- Battelle founded by the Will of Gordon Battelle

2000

Innovation Valley Partners

BATTELLE | VENTURES

- New venture companies launched in medical, pharmaceutics, electronics and software fields

1980

- Breakthrough medical research to protect against blood clots

- Astronaut nutrition work for NASA

1960

1940

- Developed fuel for U.S. Navy's first nuclear-powered submarine, the *Nautilus*

- Developed the first generation of nuclear fuel rods for nuclear reactors

1920

27

Nine Major Labs in the US Provide a Broad Base of S&T Capabilities

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Pacific Northwest

Idaho

Columbus

West Jefferson

Brookhaven

Lawrence Livermore

NBACC

Oak Ridge

National Renewable Energy Lab

BEST Center

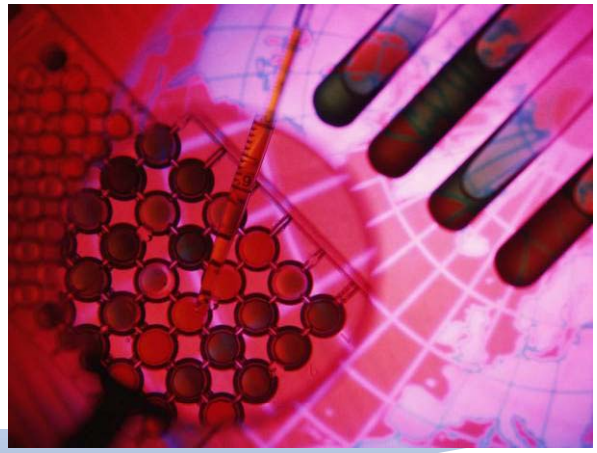
$6.5 billion R&D volume
22,000 staff
31 scientific user facilities

Battelle is Organized Around Three Global Businesses

Energy, Environment & Material Sciences

National Security

Health & Life Sciences



Battelle's mission matches the challenges and scientific opportunities of our time

- Battelle manages or co-manages DOE and DHS National Laboratories
- Battelle operates subsidiaries, such as Bluefin Robotics

Energy Systems Product Line

Making transformational impacts across the energy conversion supply chain by providing economically viable technology-based solutions, products, and services to Oil and Gas, Electric Grid, and Alternative Energy markets

Exploration and CO_2 Sequestration

Geologic characterization; reservoir modeling; drilling and field services; measurement, monitoring, and verification analysis

Infrastructure Integrity and Risk Assessments

Pipeline integrity management, failure analysis, service life predictions, and in-line inspection tool development and evaluation

Process and Systems Engineering

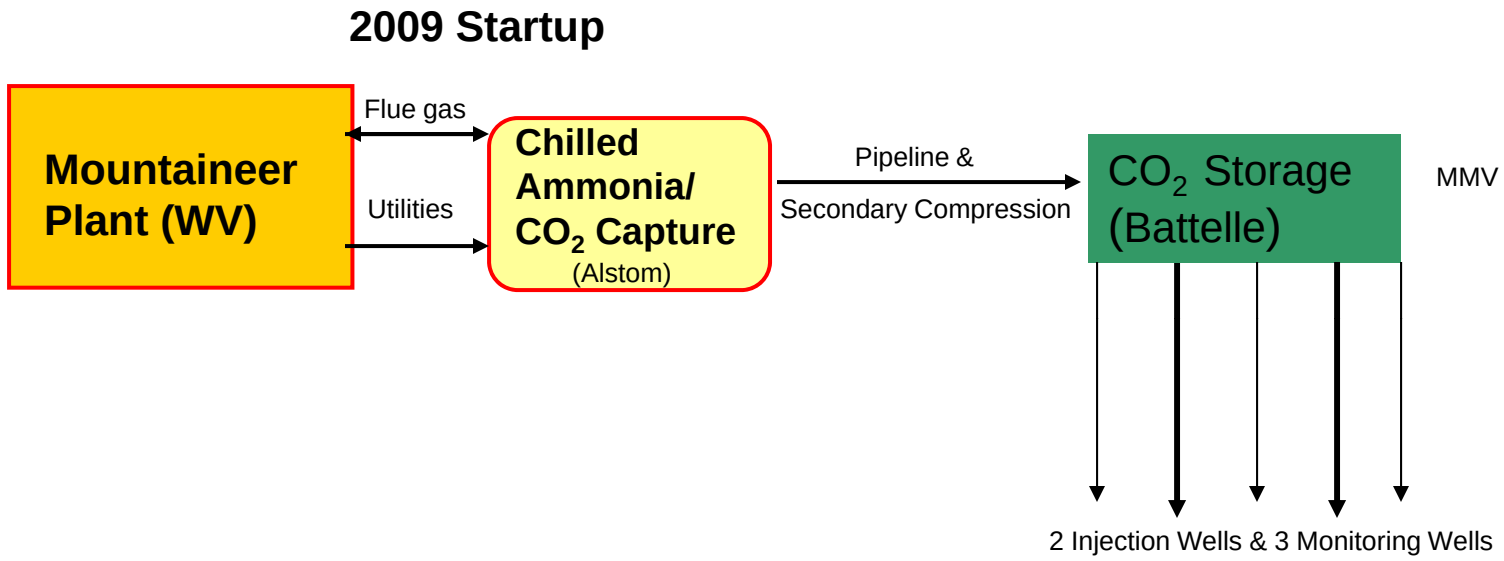
Process modeling, new product development, equipment testing and evaluation, systems integration, process scale-up and demonstration, industrial process improvement and technology insertion, sustainability and life cycle evaluations

AEP Mountaineer Plant

1,300 MW Generator

Project Location
New Haven, WV

Product Validation Facility (PVF) at AEP's Mountaineer Plant



- 20 MW (electric) slip stream from FGD outlet
- System capacity >100k tonnes/year of CO_2
- Started engineering, planning, and permitting in Sep 07
- Started construction 2Q 2008, in operation ~ 1 Sep 09
- Major workover and monitoring in late 2010
- Injection completed during mid-2011

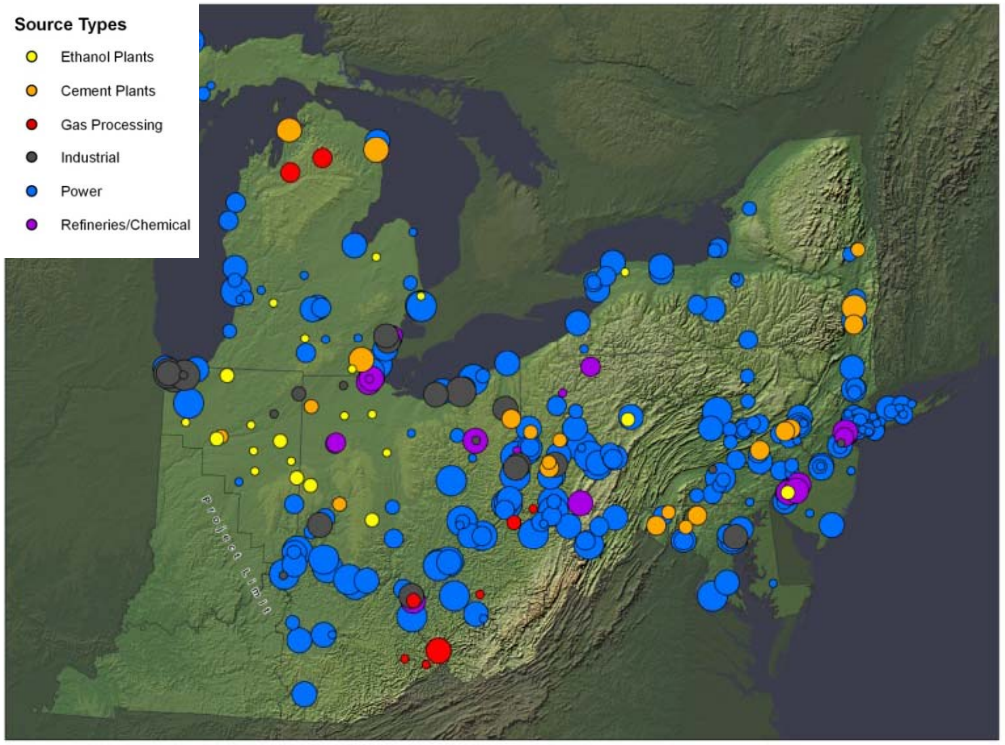
Vuggy Dolomite in Copper Ridge in AEP Test Well - Very High Permeability Zones Match with High Injectivity Observed in PVF Well

8370

8345

About the Midwest Regional Carbon Sequestration Partnership

- Formed in 2003 as a public/private consortium
- Consists of nearly 40 members (industry, universities, geosurveys, NGOs), led by Battelle
- Includes 9 states
- Region emits nearly 700 million metric tons CO_2 each year
- CCS is viewed as a key emissions reduction technology for our industrial base



This map shows locations of large point sources – power generators, iron and steel manufacturing, refineries, cement plants, gas processing, and other industry.

MRCSP's mission: be the premier resource for sequestration knowledge in its region

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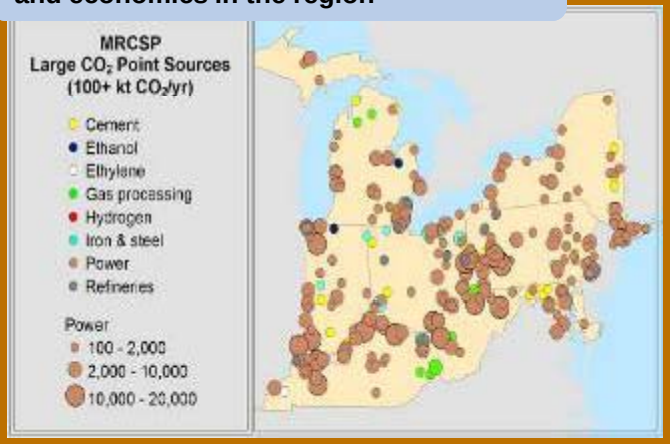
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Characterization, Phase I, 2003 - 2005

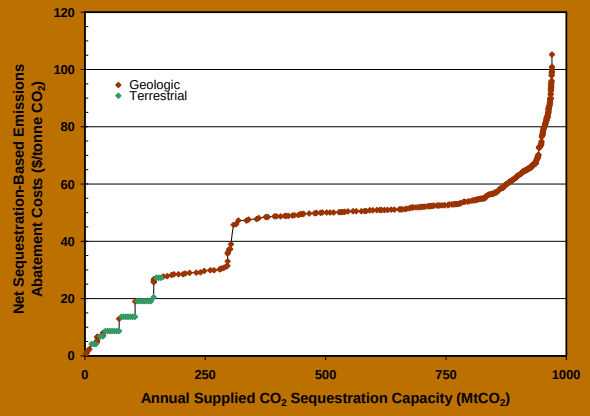
Quantifying CO2 sources, demographics and economics in the region



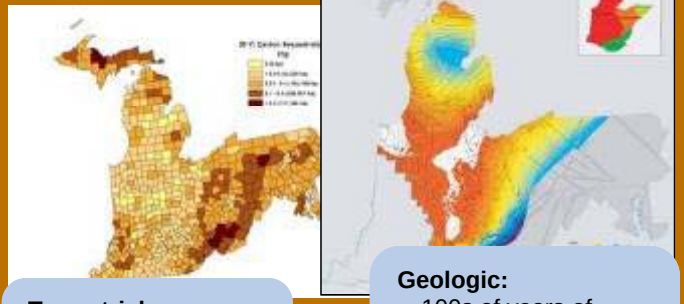
Reaching Out To and Educating Stakeholders

www.mrcsp.org

Developing a Regional Model of the Economics of Sequestration



Quantifying CO_2 Sinks in the Region



Terrestrial:
- Potential for 20% annual offset for large point sources

Geologic:
- 100s of years of capacity for large point sources in deep saline alone

Validation, Phase II, 2005 - 2009

Implementation

Geological

Terrestrial

Duke Energy East Bend Station

650 MW coal-burning power plant situated on1,800 acres along the Ohio River

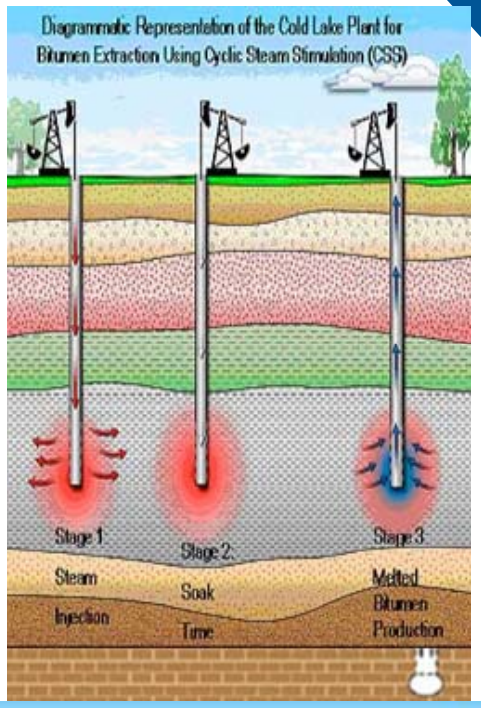
Monitoring program primarily included pressure and temperature, along with shallow groundwater and baseline VSP

Drilling Operation – Summer 2009

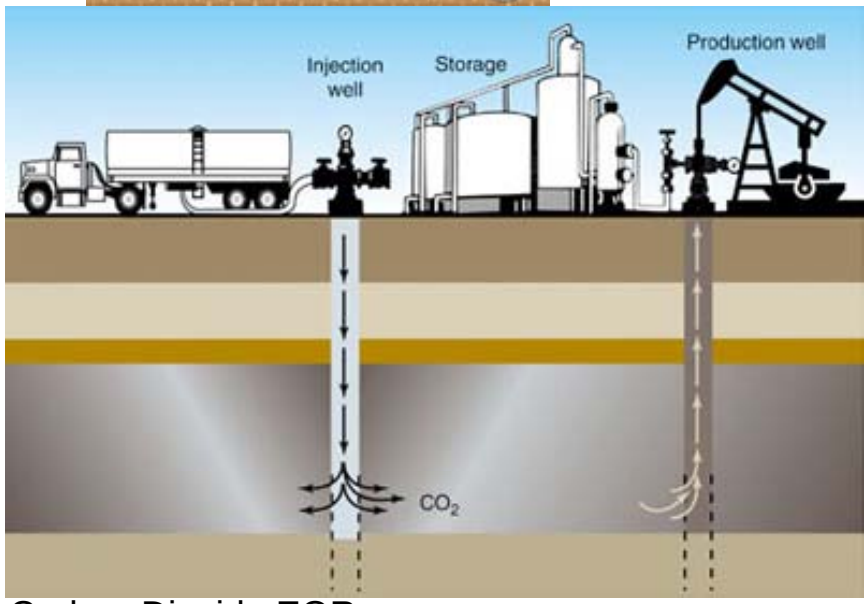
Proactive Outreach was Key to Successful Execution at Each Site

Potential Opportunity
Enhanced Oil Recovery

- Primary and secondary production typically tap only about 25% of oil in place
- EOR technologies can help increase oil recovery substantially, especially in tight fields such as East Canton Field in Ohio
- CO_2-EOR has potential benefit for greenhouse gas mitigation, but this will require changes to injection systems to minimize recycling.
- Supply and price of gases such as CO_2 is a significant constraint in expanding EOR use. In addition, EOR requires significant capital expense and technical expertise, not currently accessible to smaller producers.



Thermal Recovery EOR



Carbon Dioxide EOR