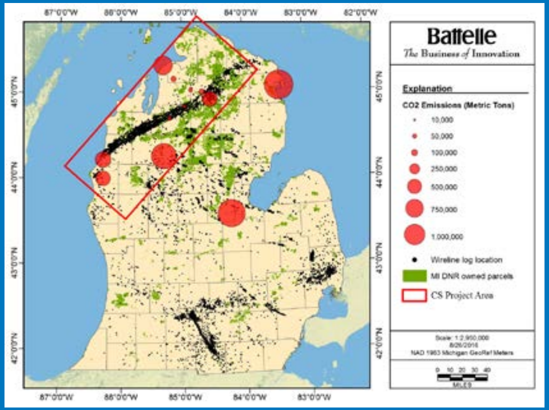


Carbon Safe- Michigan DE-FE0029276

Neeraj Gupta

Battelle Memorial Institute

U.S. Department of Energy

National Energy Technology Laboratory

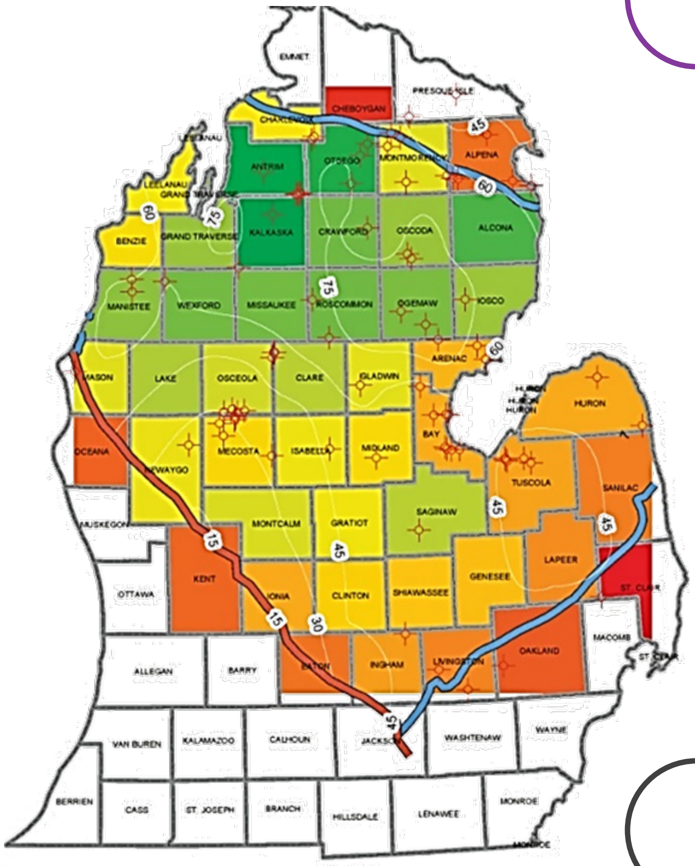
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 1-3, 2017

Organizational support project team

- Battelle - Project leader with substantial CCUS experience
- Core Energy, LLC – Primary project development partner; 12 years of collaboration with Battelle
- PKM Energy Consulting, LLC – Evaluate financial/economic factors, liability management options
- PNNL/LANL/LLNL- Application of select NRAP tools
- Wade LLC – Outreach coordination and planning
- Loomis Law - Advice on mineral rights, permitting, land access, and liability issues.
- Western Michigan University – Geologic Research Partner
- Advisors – GE, MHIA, Tondu Corp. etc.

Presentation outline

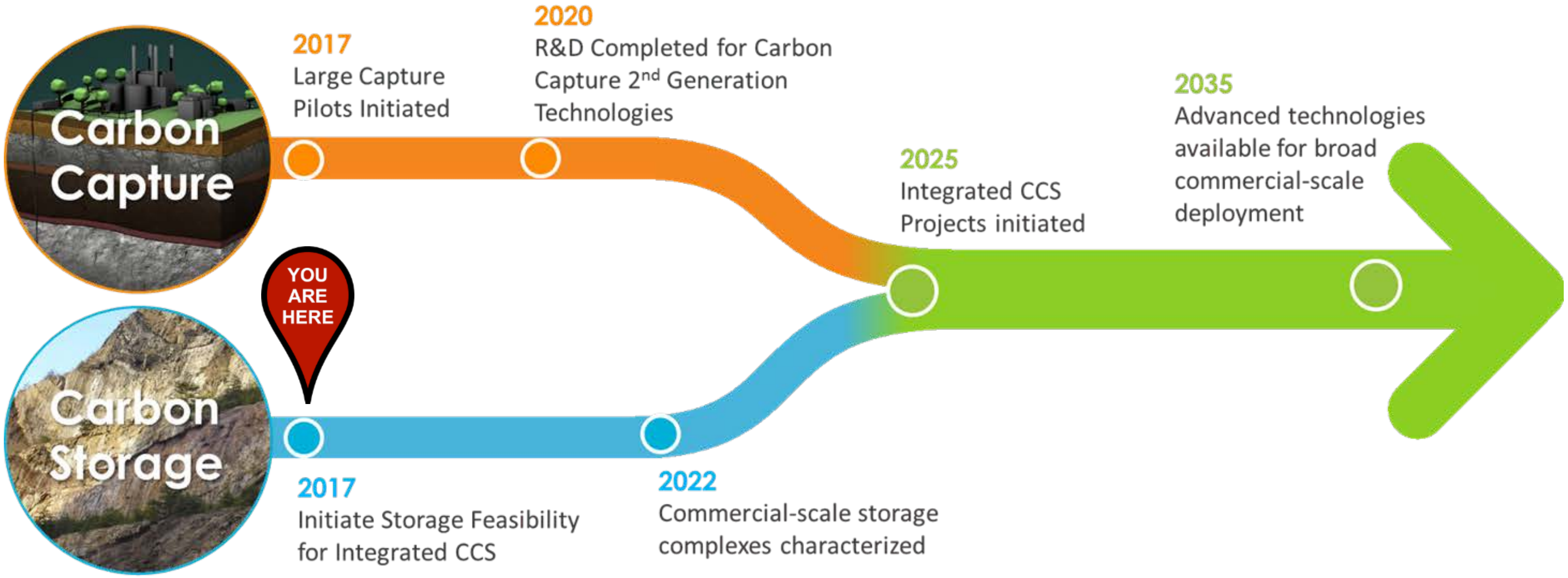


- Technical Status
- Accomplishments
- Lessons Learned
- Synergy
- Project Summary
- Appendix

Project Overview: Goals and Objectives

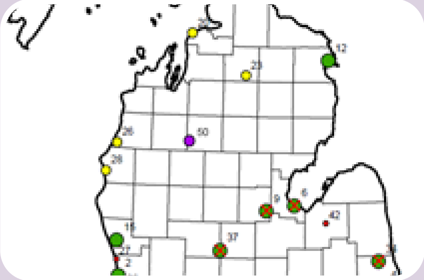
DOE-NETL is funding projects over four sequential phases:

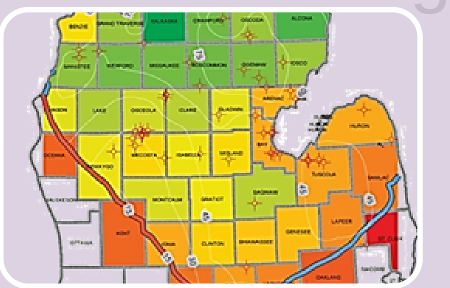
- Phase I: Integrated CCS Pre-Feasibility
- Phase II: Storage Complex Feasibility (2 years)
- Phase III: Site Characterization (2 years)
- Phase IV: Permitting and construction of storage complex (3.5 years)

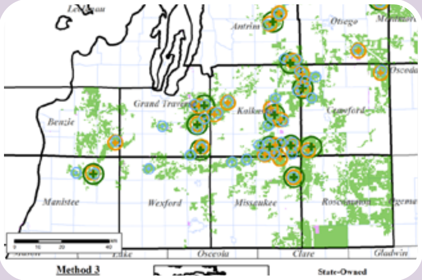


Technical status

Technical updates grouped into four categories







1
Carbon Source Evaluation

2
Geologic Storage Assessment

3
Integration

4
Team Building

Carbon source evaluation

- Locate major existing and potential CO_2 sources in the Lower Peninsula
- Determine emission type and first order estimate of CO_2 capture cost
- Identify potential partners based on findings

flight
Facility
Level
Information on
GreenHouse gases
Tool

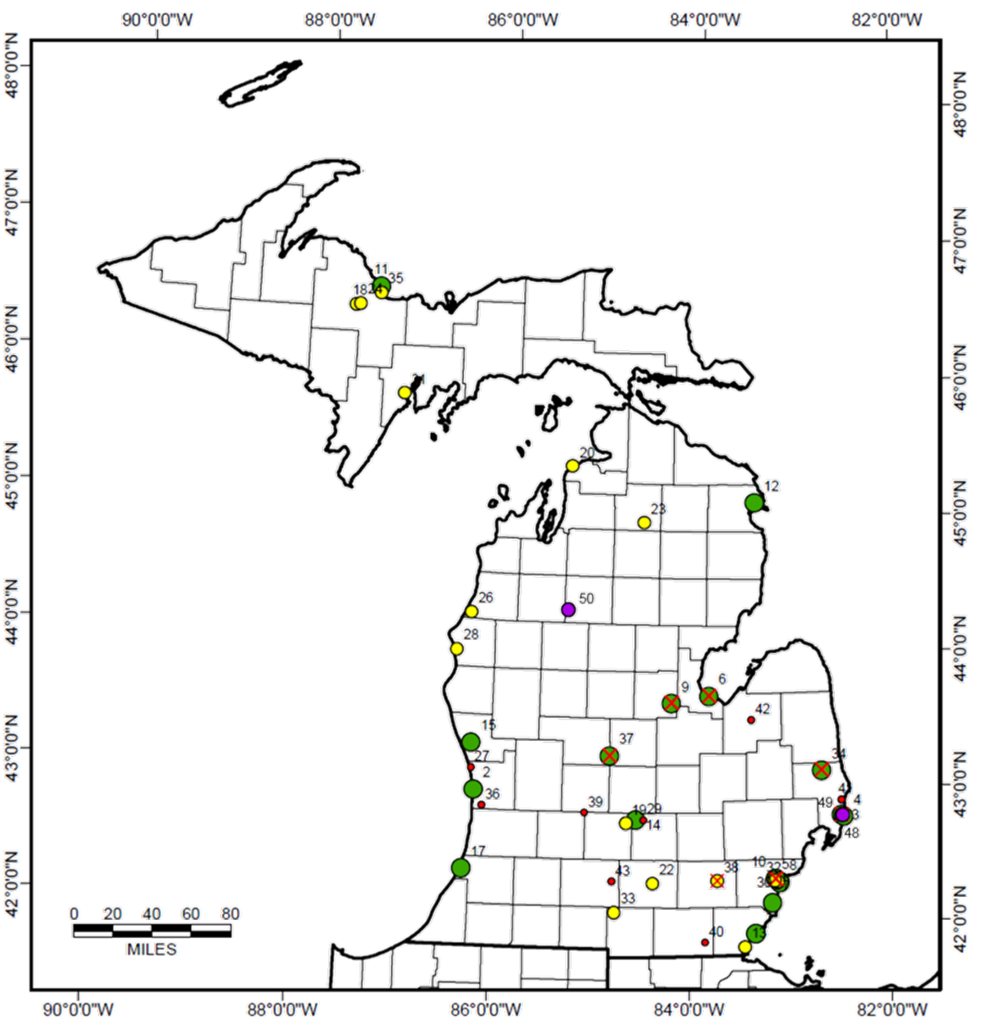
eia
Independent Statistics & Analysis
U.S. Energy Information
Administration

DEQ
Department of
Environmental Quality

Carbon source evaluation

- **Dan E Karn** – Two units running on coal, low capture cost compared to the other available sources. CMS (Consumers Energy) is the operator.
- **TES Filer City Station** – Two units running on coal, lower emissions ~300k tpy
- **LaFarge Cement** – Emits almost 2.3 million tpy CO_2, higher capture costs
- **St. Mary's Cement** – Emits about 1 million tpy CO_2.
- **Ludington CoGen Plant** –Emits about 600k tpy CO_2.

Michigan likely to require significant new generation in coming years.



Geologic storage assessment three main goals

Reservoir Characterization

- Identify formations of interest
- Depth, thickness, porosity, permeability
- Overburden influence
- Prospective storage resources (P10, P50, P90)

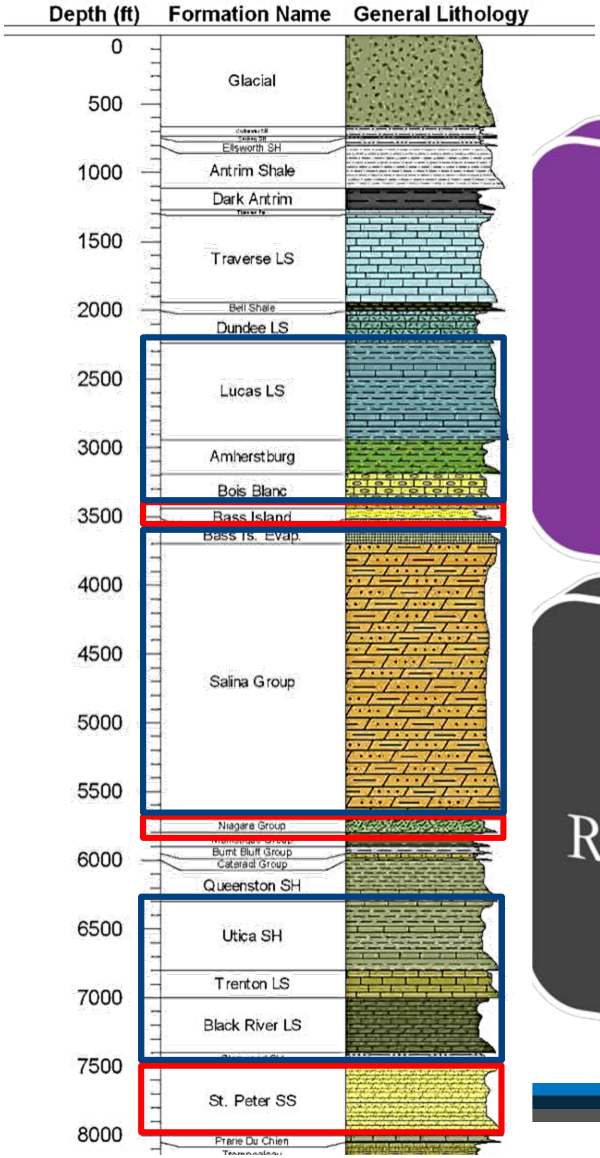
Caprock/Trapping Assessment

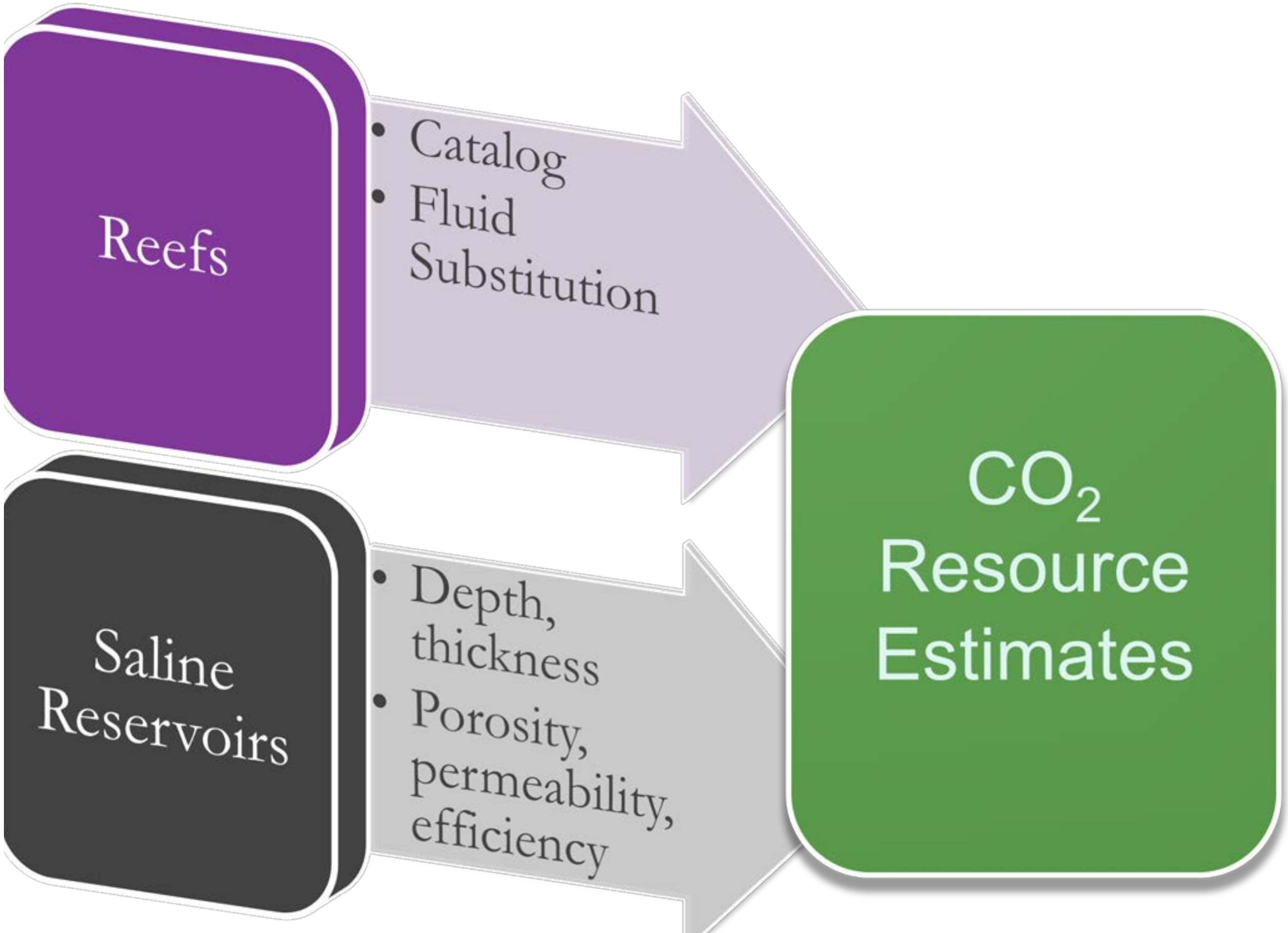
- Extent, thickness, and integrity
- CO_2 migration potential and sealing effectiveness
- Any structural concerns

Geohazard Risk Assessment

- Surface and subsurface geohazard assessment
- Site analysis using NRAP
- Documentation of wellbores, which penetrate confining zones, etc

Geologic storage assessment different approaches for each reservoir





Reefs

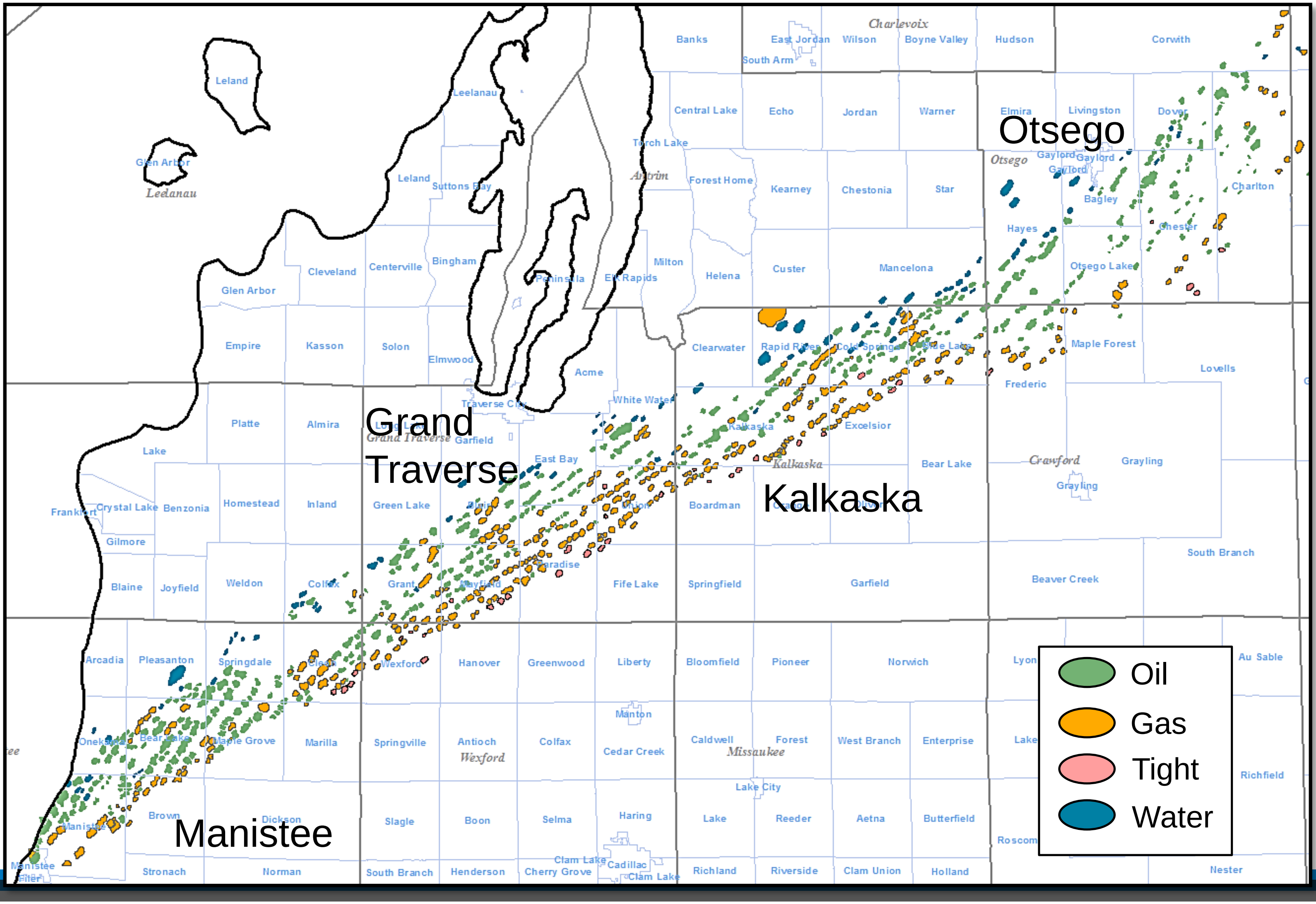
- Catalog
- Fluid Substitution

Saline Reservoirs

- Depth, thickness
- Porosity, permeability, efficiency

CO_2 Resource Estimates

Geologic storage assessment Niagaran reef catalog



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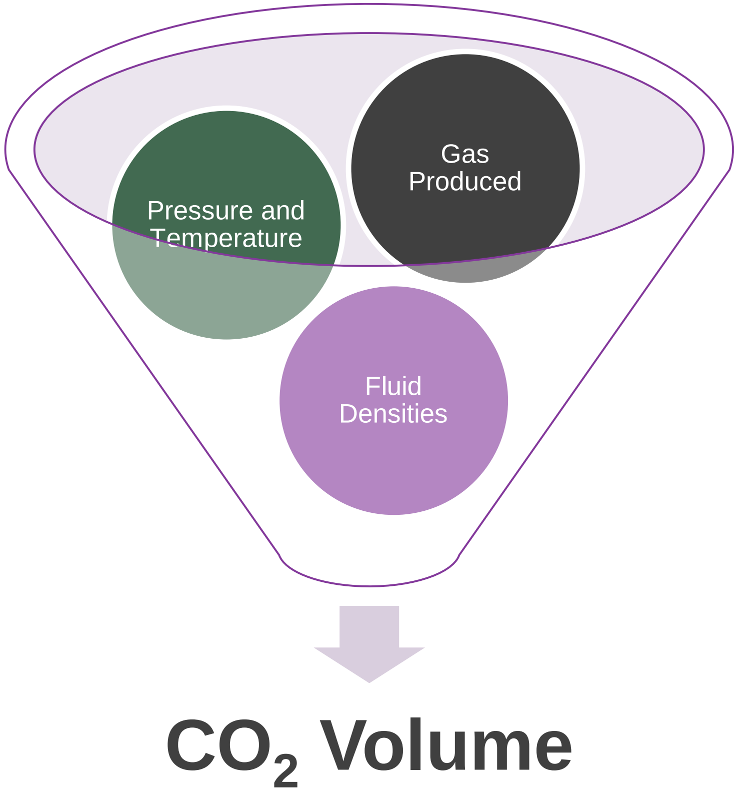
Geologic storage assessment Niagaran reef resource estimates

- Fluid substitution method
- Calculates volume of CO_2 based on volume of fluids produced

$$B_g = \frac{V_R}{V_{SC}} = 0.02828\frac{ZT}{P}$$

$$M_{CO2} = V_{sc} * B_g * \rho_{CO2}$$

B_g =Gas Volume Formation Factor (reservoir cubic feet/standard cubic feet)
V_R=volume at reservoir P & T (reservoir cubic feet)
V_{SC}= volume at Standard P&T (standard cubic feet)
Z= gas compressibility factor
T= reservoir temperature (°R)
P= reservoir pressure (psi)
M_{CO2} = Mass CO2 (tonnes)
ρ_{CO2}= density CO2 at reservoir P&T
CF= 1 tonne/2200 lbs



CO_2 Volume

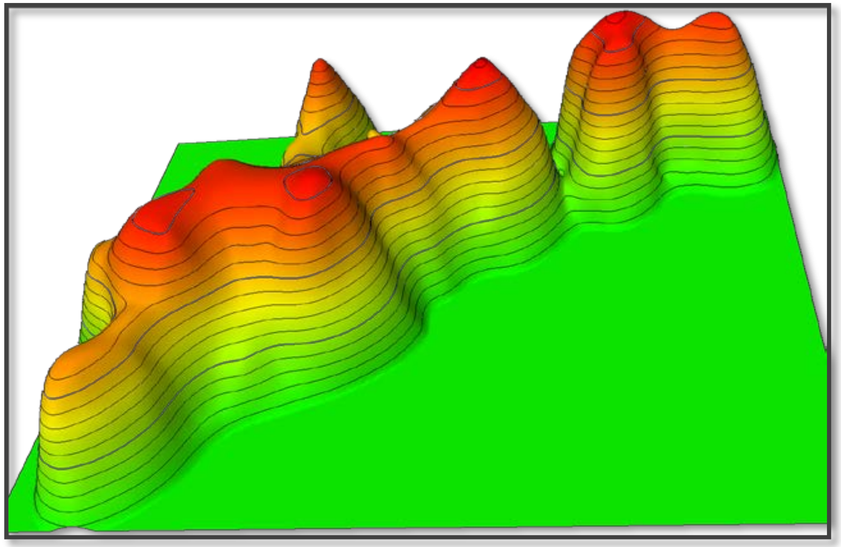
Geologic storage assessment example gas storage reef

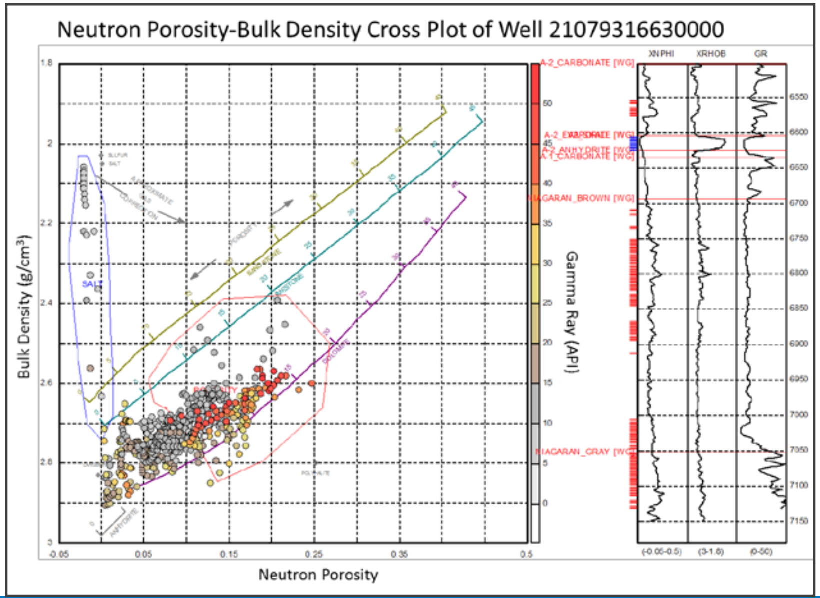
- Building SEMs for example reefs
  - Blue Lake 18A currently a gas storage reef

Cumulative Oil (BO)	Cumulative Gas (MCF)
1,486,598	35,859,831

Calculated CO_2 Volume

2.2-4.4 Million Tonnes





Neutron Porosity-Bulk Density Cross Plot of Well 21079316630000

Geologic storage assessment saline reservoir CO_2 resource estimates

- Three evaluation methods:
  1) Homogeneous- using averages for high level preliminary values
  2) Heterogeneous- CO2-SCREEN tool to calculate a 2D grid
  3) Modeling

$$\underset{\textit{Mass of } CO_2 \textit{ stored}}{G_{CO2}} = \underbrace{A_t\, h_g\, \phi_{tot}}_{\textit{Pore volume}}\, \underbrace{\rho_{CO2}}_{\textit{fluid properties}} \underbrace{E_{saline}}_{\textit{storage efficiency}}$$

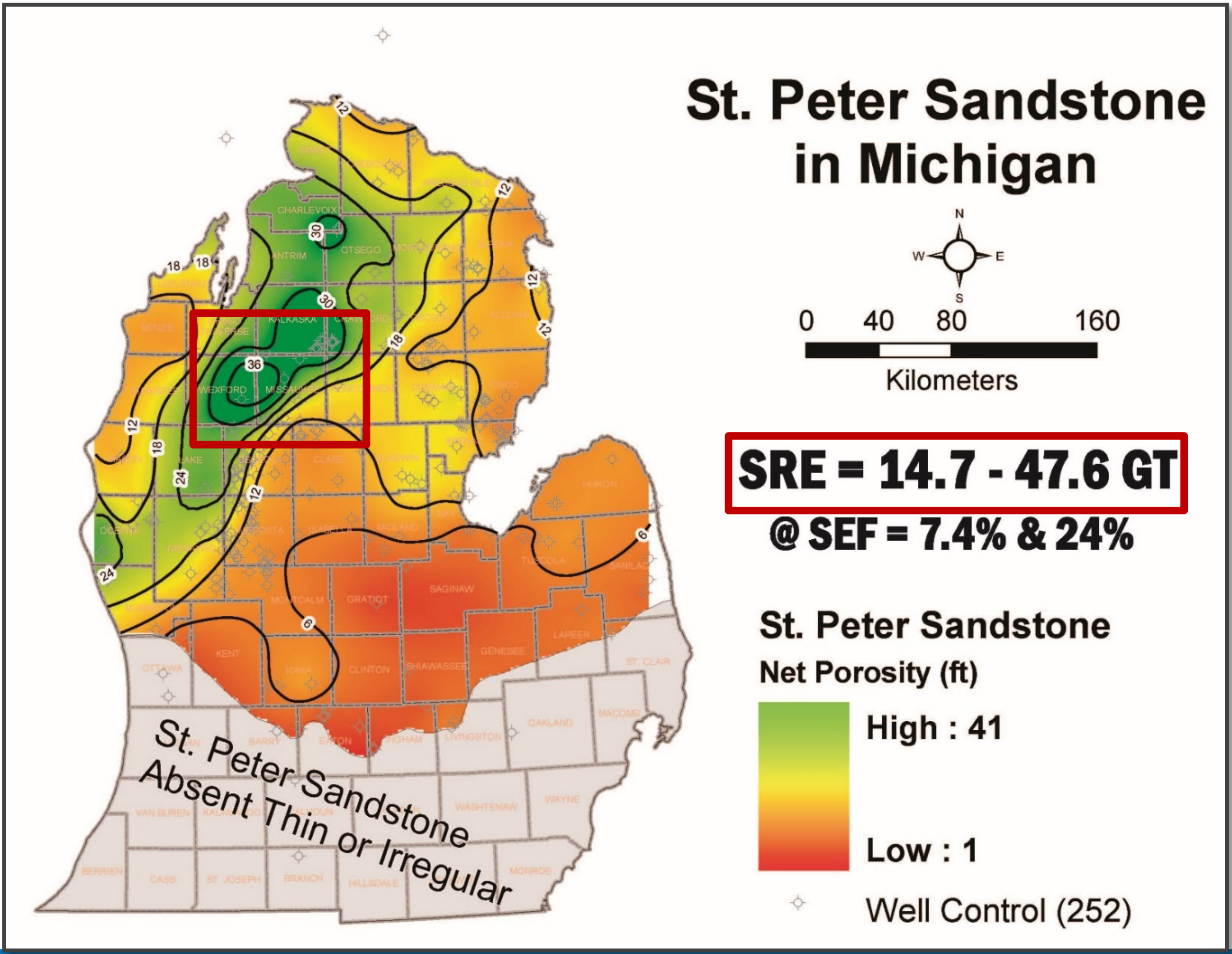
A_t = Total formation area
H_g = gross formation thickness
ϕ_{tot} = total porosity

ρ_{CO2} = density of CO_2 at reservoir conditions
E_{saline} = CO_2 storage efficiency

$$E_{saline} = E_{An/At}\, E_{hn/hg}\, E_{\phi e/\phi t}\, E_v\, E_d$$

$E_{An/At}$ = Net to total area
$E_{hn/hg}$ = net to gross thickness
$E_{fe/ft}$ = effective to total porosity
E_V = volumetric displacement
E_d = microscopic displacement

Geologic storage assessment - saline reservoir CO_2 resource - St. Peter

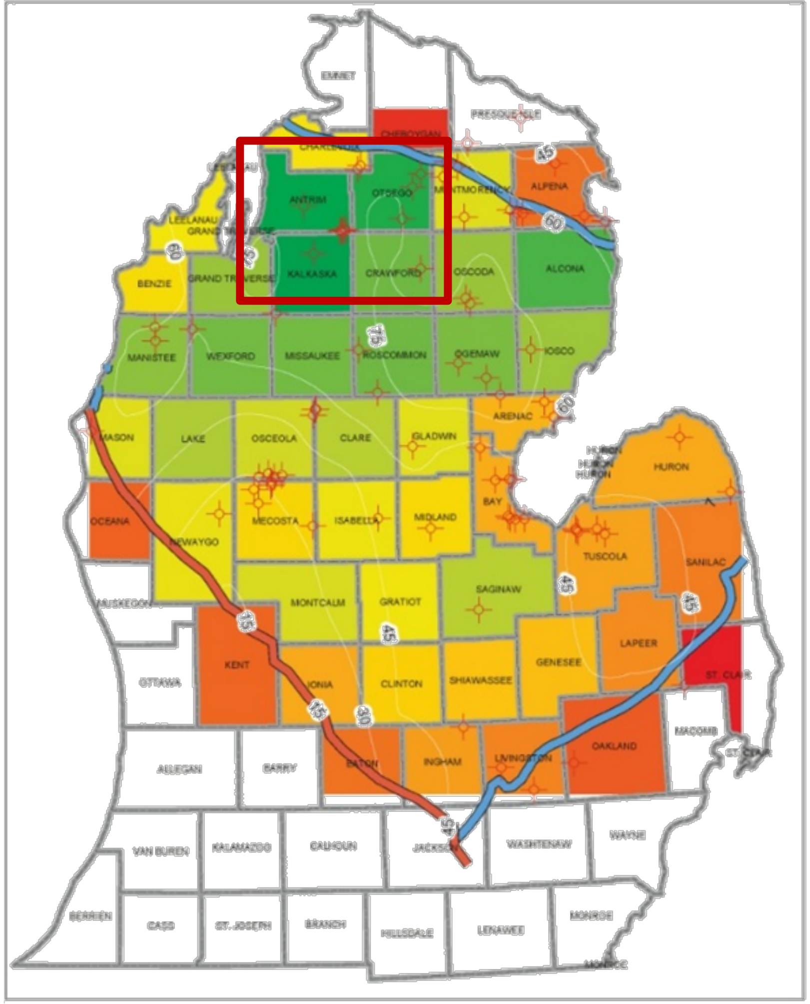


St. Peter Sandstone in Michigan

SRE = 14.7 - 47.6 GT

@ SEF = 7.4% & 24%

Geologic Storage Assessment Saline Reservoir CO_2 Resource - Bass Islands



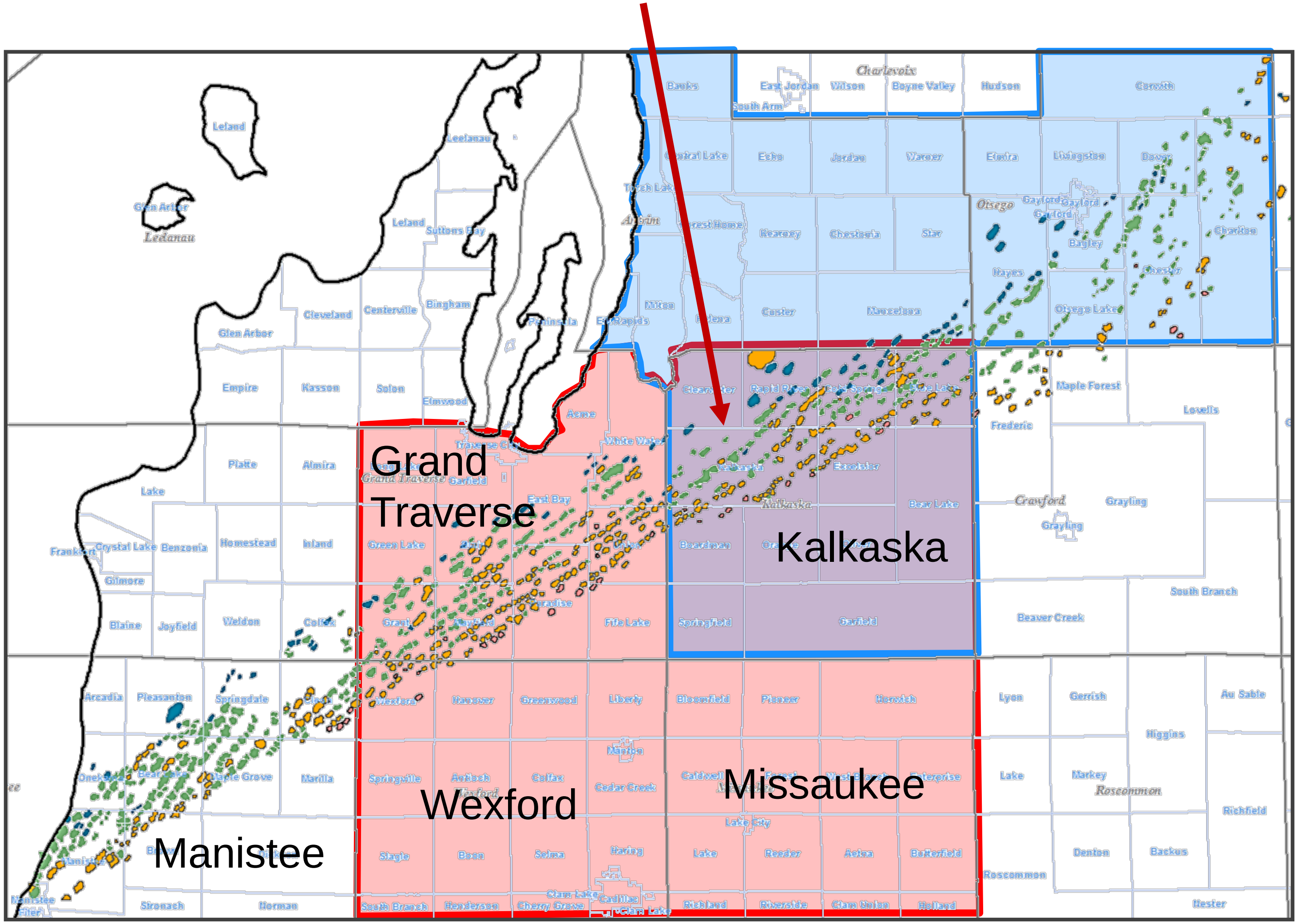
Bass Islands dolomite (BILD) Storage Capacity in Michigan

1.45 billion metric tonnes

(@ 4% storage efficiency)

Geologic Storage Assessment

Overlap In Highest Reservoir Potential- Kalkaska County



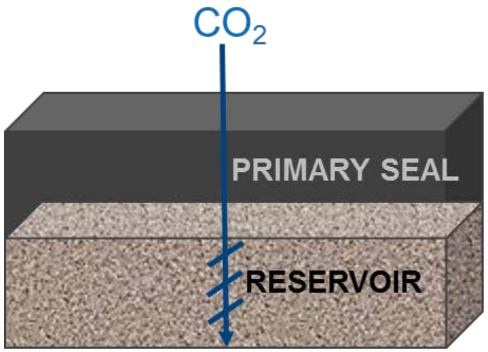
Geologic Storage Assessment with Multiple Storage Scenarios

A St. Peter

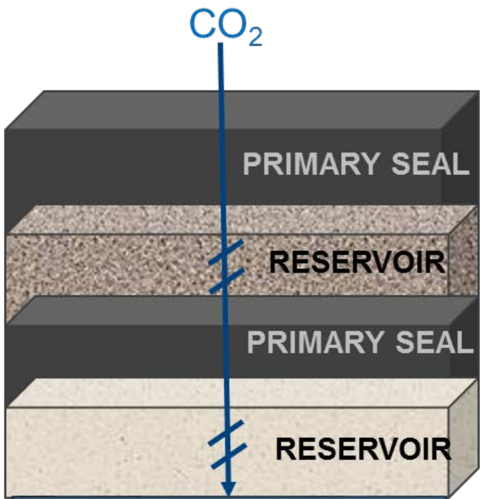
B Bass Island

C Niagaran Reefs

D Stacked Reservoirs



Single Formation Injection Type



Stacked Formations Injection Type

Geologic Storage Assessment Quick-look Well Integrity Mapping Tool

- Developed as stand-alone application using Google Maps API
  - Can easily be integrated into existing web sites and applications
- **FEATURES**:
  - Simultaneously select and compare potential sites on the fly
  - Draw the spatial boundaries and select the associated confining layer
  - Calculates integrity score and presents information pertaining to the score
  - Presents data for individual wells
  - Exports data on selected wells for further investigation outside the tool
  - Presents reports that summarize results for sites under investigation

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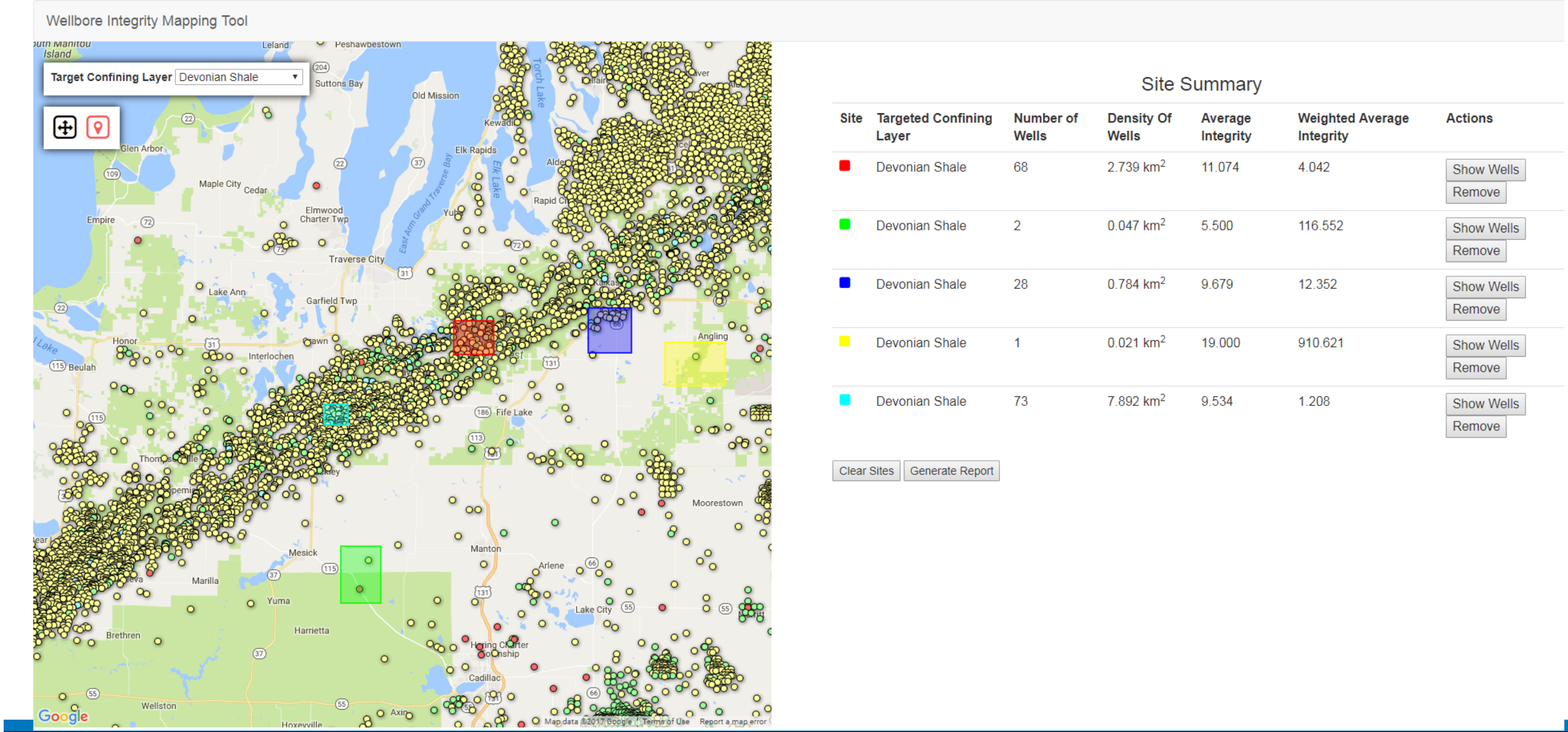
Geologic Storage Assessment
Quick-look Well Integrity Mapping Tool

Select confining layer and potential sites

Calculates and compares integrity scores for potential sites based on CL



Wellbore Integrity Mapping Tool

Target Confining Layer Devonian Shale ▾

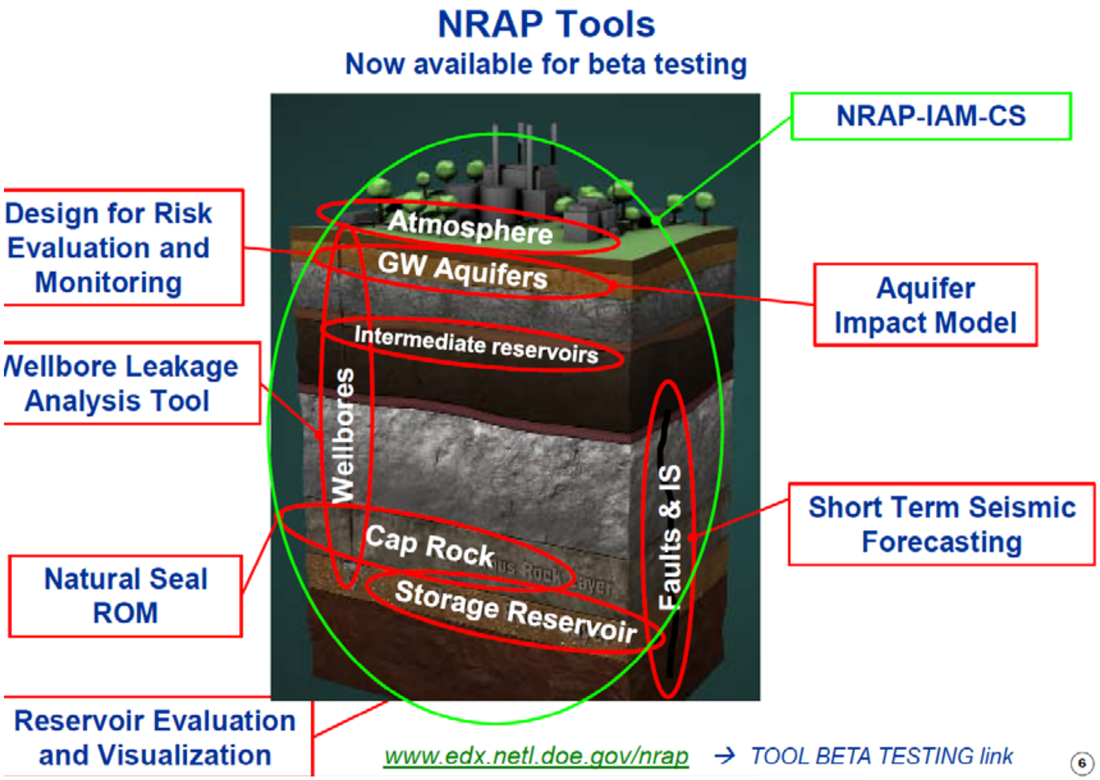
Site Summary

Site	Targeted Confining Layer	Number of Wells	Density Of Wells	Average Integrity	Weighted Average Integrity	Actions
🟥	Devonian Shale	68	2.739 km^2	11.074	4.042	Show Wells Remove
🟩	Devonian Shale	2	0.047 km^2	5.500	116.552	Show Wells Remove
🟦	Devonian Shale	28	0.784 km^2	9.679	12.352	Show Wells Remove
🟨	Devonian Shale	1	0.021 km^2	19.000	910.621	Show Wells Remove
■	Devonian Shale	73	7.892 km^2	9.534	1.208	Show Wells Remove

Clear Sites Generate Report

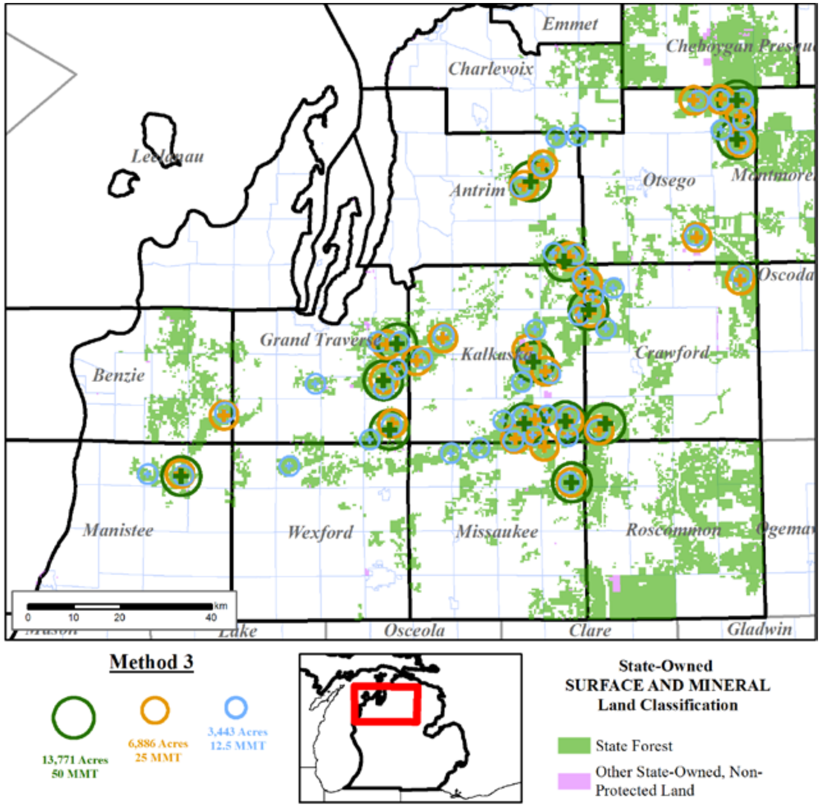
Geologic Storage Assessment Using NETL NRAP Tools For Geohazard Risk Assessment

- Integrated Assessment Model (IAM-CS)
  - Simulate injection, migration, and impacts
  - 100s-1000s of years simulations using Monte Carlo
  - Storage reservoirs, wells, seals, and groundwater
- Designs for Risk Evaluation and Management (DREAM)
  - Optimal monitoring program to detect leakage
  - Time it takes to detect leakage
- Seismicity and Induced Seismicity
  - Data limitations
  - Predict induced seismicity from injection



Integration
Site Selection - St. Peter Example

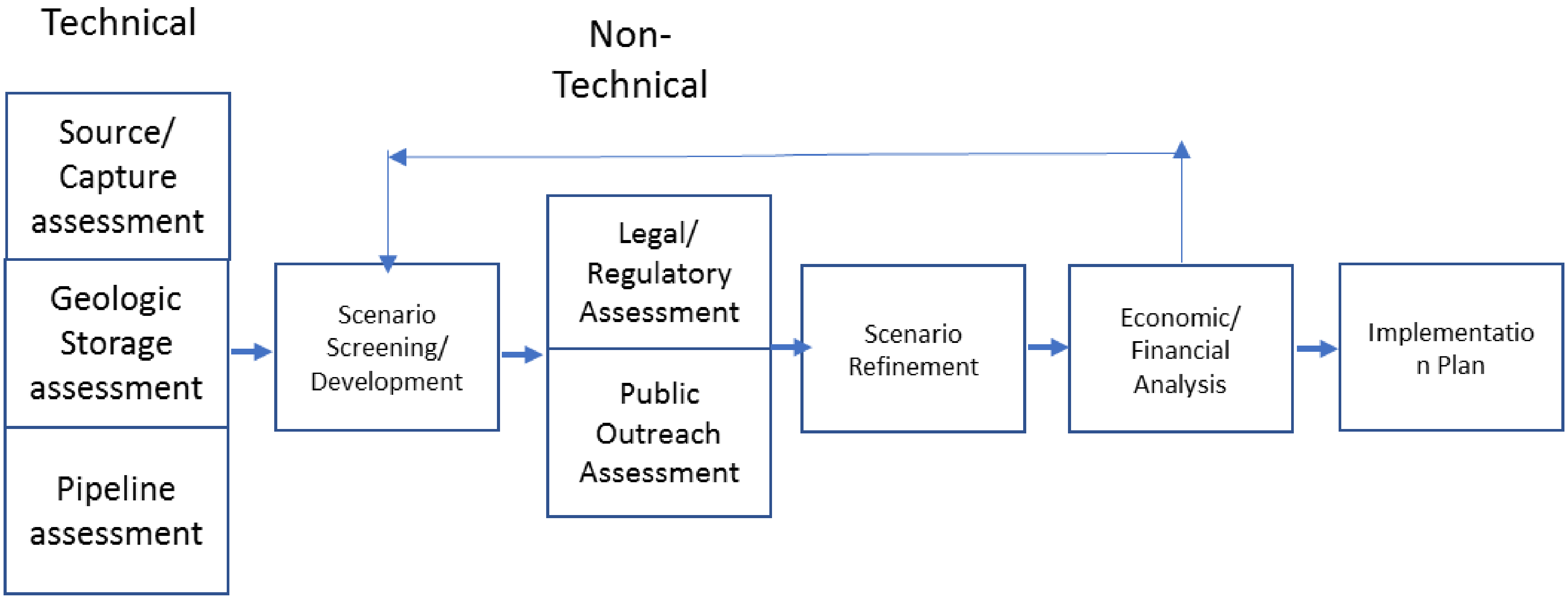
Site size based on storage estimates → Land ownership → Overlap of geology and land owners



Potential St. Peter Storage Sites

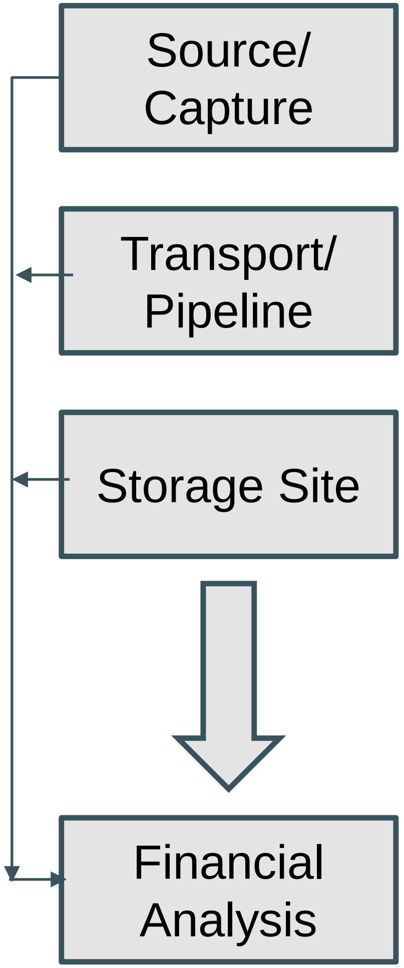
- Locations limited to state forest land with *surface and mineral* rights controlled by state and large enough to accommodate CO_2 plume
- Plume area(s) based on Reservoir Facies Method, p50 estimate (Barnes et al., 2017):
  - Single storage site (50 MMT plume) = XX acres
  - 2 storage sites (25 MMT plume) = ½ XX acres each
  - 4 storage sites (12.5 MMT plume) = ¼ XX acres each

Integration-
Overall Workflow For Final Site Selection



Scenario = source + transport + land (surface, pore space, mineral rights) +storage/EOR

Integration- Cost Estimating Methodology



Literature

FE/NETL CO_2 Saline Storage Cost Model

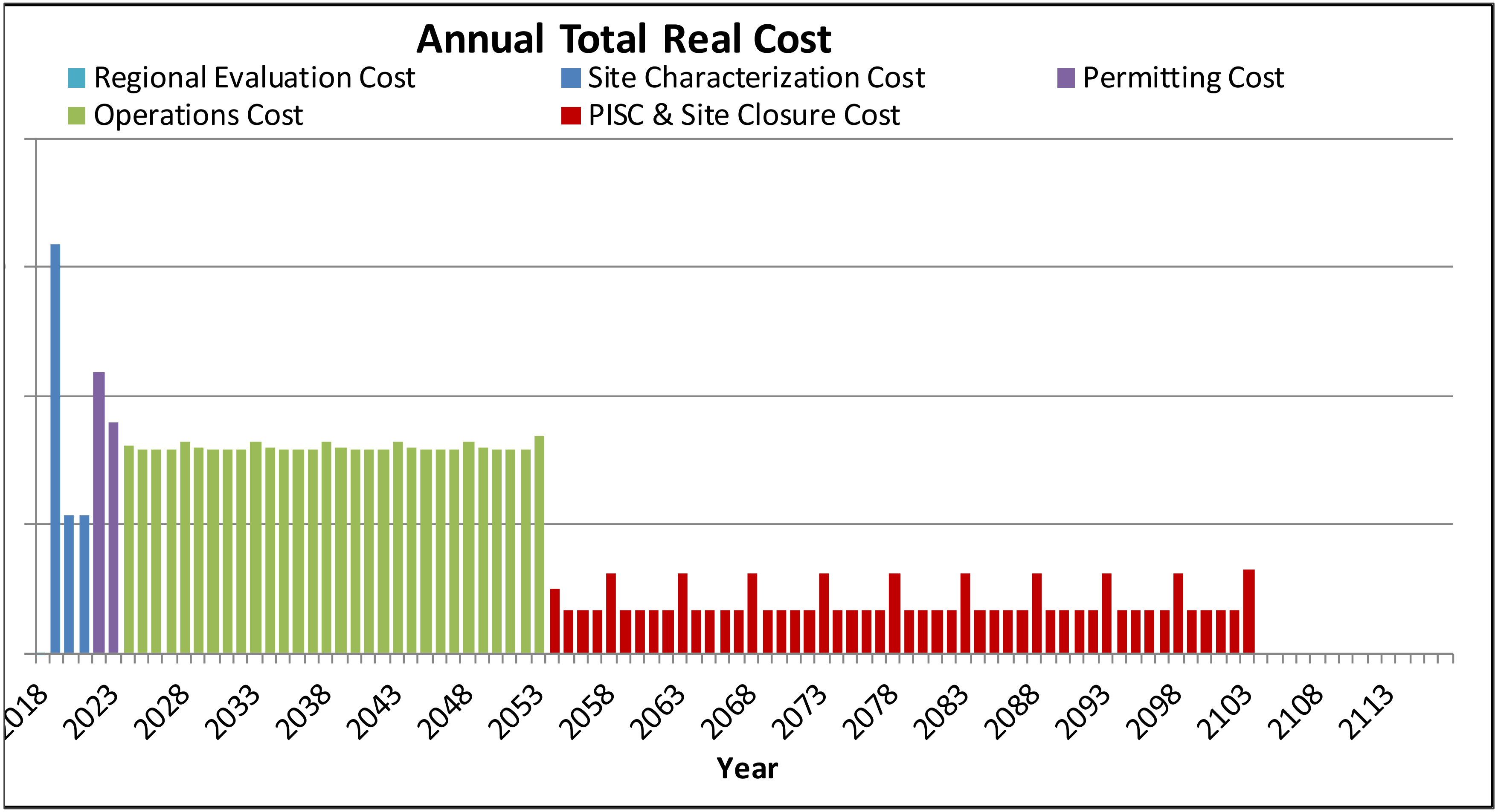
DOE/NETL CO_2 Transport Cost Model

DOE/NETL CO_2 Saline Storage Cost Model; historical in-house costs

Capitalization
Financial Responsibility Funding and Payments
Revenues
Debt
Cash Position
Debt Principal, Interest and Re-payment
Taxes

Cash Flow Available to Owners
Costs of Different Components of Financial Responsibility
Real Costs
Escalated Costs
First Year Break-Even Price of CO2 ($/tonne)

Integration
Cost Estimating Methodology - St. Peter Scenario



Potential CCS Business Structures Rate Regulated Entities

Generation Asset(s)

Dedicated

Permanent

Source

Transport

Storage

Figure 1

Generation Asset(s)

Dedicated

Non-Regulated Permanent / EOR

Source

Transport

Storage

Figure 2

Potential Ccs Business Structures (2) Power / Industrial Entities

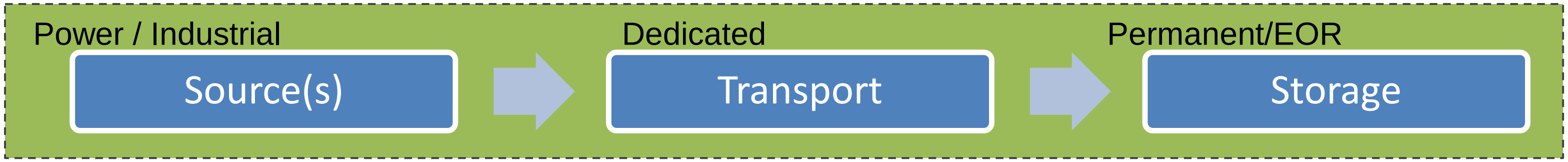


Figure 3

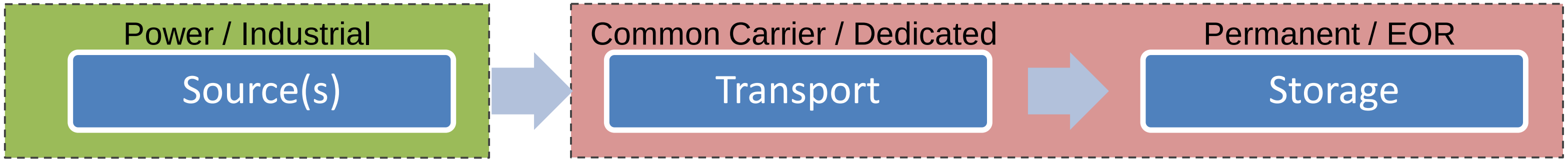


Figure 4

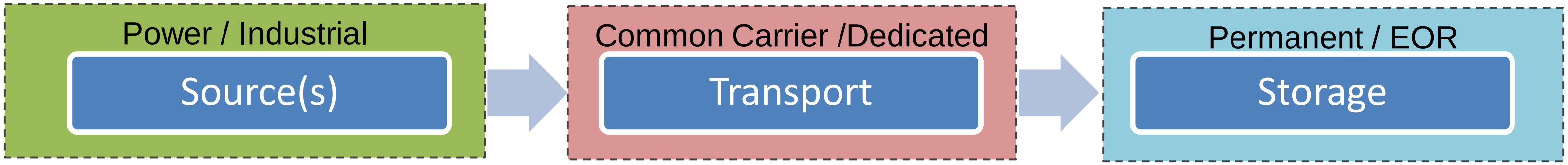


Figure 5

Social Characterization Study

- Social characterization and descriptions of counties
- Rank counties based on political and economic indicators

County	Rank	Total
Leelanau	1	5
Grand Traverse	2	8
Charlevoix	3	12
Emmet	4	13
Benzie	5	21
Otsego	6	23
Antrim	7	24
Cheboygan	8	25
Manistee	9	28
Alpena	10	29
Presque Isle	11	30
Wexford	12*	34
Crawford	12*	34
Kalkaska	13	35
Montmorency	14	44

POLITICAL SNAPSHOT

- All counties voted for President Trump. Mostly with margins of close to 60/40 or better for Trump. Much closer in Grand Traverse and Leelanau
- “Michigan is purple state that goes red under the right circumstances, but in no sense is this a layup for Rs”* (Saul Anuzis, former rep chr)
  - Elections 2018 –

Governor – 14 R/D candidates declared (as of June)

US Sen. Debbie Stabenow (D) up

ECONOMIC SNAPSHOT

- Generally stable size of labor force
- Steady decline in jobless rate over last 5 years
- Major growth occupations:
- Health care (RN, Aides, Home Health)
- Food service
- Construction / landscaping / carpentry
- Truck drivers
- Seasonal population / tourism a major

Policy and regulatory landscape

- **Existing Policy/Regulatory Landscape** – There are several existing policies that support the development of energy related businesses and infrastructure
    - MDEQ familiar with CO_2-EOR projects and processes in area
    - Governor supports growing energy industry
    - Pore space rights researched and updated
    - Existing CO_2-EOR infrastructure
- **Changes to Existing Policy/Regulation**– There are several changes that will be necessary or could be beneficial to the regulatory landscape
    - CO_2 specific legislation and regulations

Accomplishments

- Major CO_2 sources have been evaluated
- Geology team collaboration has produced:
  - Methodology for evaluating reservoirs
  - Geologic databases
  - preliminary geologic “sweet spots”
  - Geohazard risk assessment tools
- Identification of storage scenarios and methodology for evaluations
- Social characterization completed for key counties
- Pore space rights and policy/regulations reviewed

Lessons learned

- Multiple storage and EOR options available – stacked storage solution should be preferred.
- Geology largely conducive to storage – no significant risk factors
- Lack of policy on CCS is an issue in developing projects
- Some regulatory/policy gaps still to be filled
- Clarity needed regarding capture sources – wait for next generation or provide a source with capture in Phase I

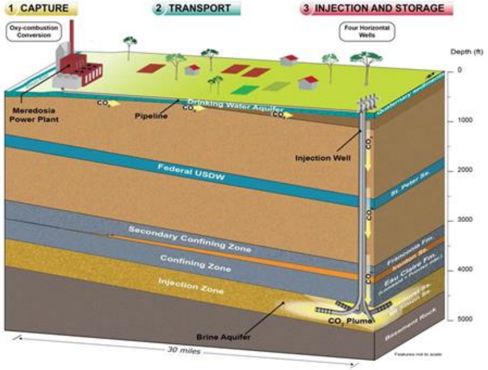
Synergy opportunities

Project builds on past and current projects to enable CCS technology development in Northern Michigan and across Midwest

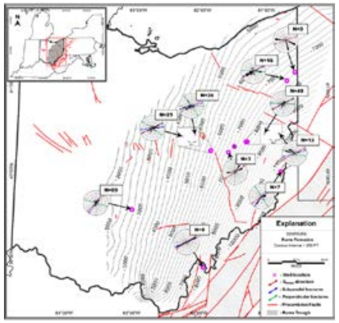
MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

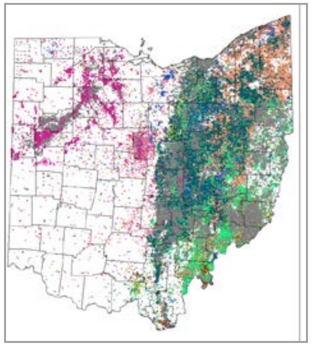
Midwest Regional Carbon Sequestration Partnership

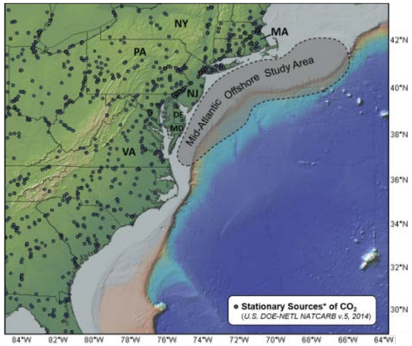
AEP Mountaineer CCS Project Experience



FutureGen Project Experience (closed)







Project summary

- The Northern Michigan Basin CarbonSAFE builds on 12 years of MRCSP work in the study area
- Established collaboration with Core Energy – a key industry partner for MRCSP II and III
- Close to existing and potential future CO_2 sources
- In an area of active oil, gas, CO_2-EOR, and brine disposal – local public familiarity
- Builds on past geologic assessments in saline formations and EOR fields
- Includes key partners for assessment of risk, safety, deployment and economic factors
- Business model could combine EOR and storage.

Appendix

Benefit To The Program
DOE Program Goals

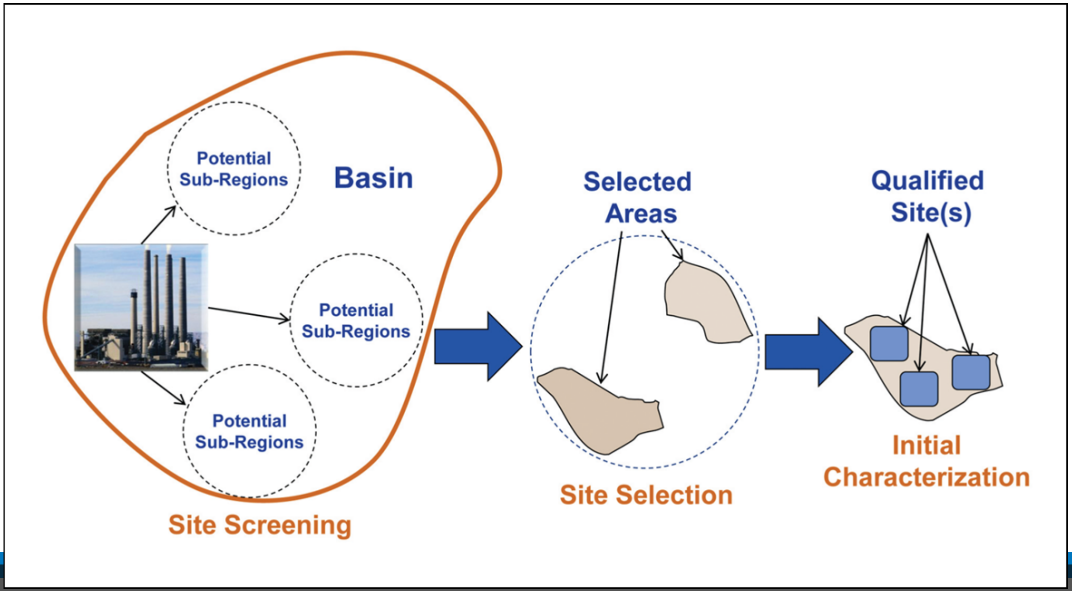
- Develop and validate technologies to ensure 99% storage permanence
- Develop technologies to improve storage efficiency while ensuring containment effectiveness
- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent
- Develop Best Practice Manuals for MVA; site screening, selection, and initial characterization; outreach; well management activities; and risk analysis and simulation.

Benefit to the program

The project design involves integrating storage with existing and emerging CO_2 sources in an area containing power plants, natural gas processing facilities, and other industry through the completion of a CarbonSAFE pre-feasibility plan for the Northern Michigan Basin.

Project overview: goals and objectives

- Develop pre-feasibility for a commercial-scale CO_2 geological storage complex
- Demonstrate that the storage site(s) within the complex has the potential to store CO_2 emissions safely, permanently and economically.



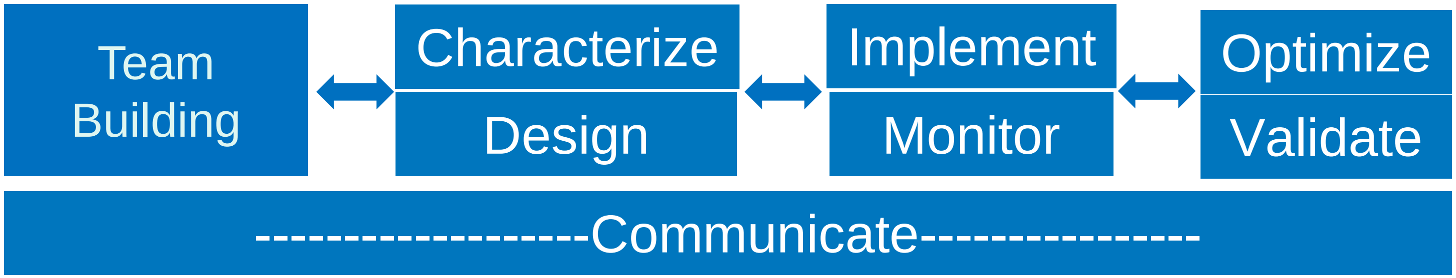
Project overview
project context

- The Northern Michigan Basin CarbonSAFE Integrated Pre-Feasibility Project is located in the northern portion of the Lower Peninsula of Michigan
- Northern Michigan Basin is rich in data due to oil and gas exploration and ongoing CO_2 operations.
- This region is home to two successful CCS projects under the Midwest Regional Carbon Sequestration Program (MRCSP).
- The presence of large CO_2 emitters near geologic sinks offers a favorable environment. Large CO_2 point sources with total emissions of 8 million metric tons per year. Ongoing CO_2-EOR operations use about 300,000 metric tons of CO_2 per year from a natural gas processing facility provide a case study for integrating CCS.

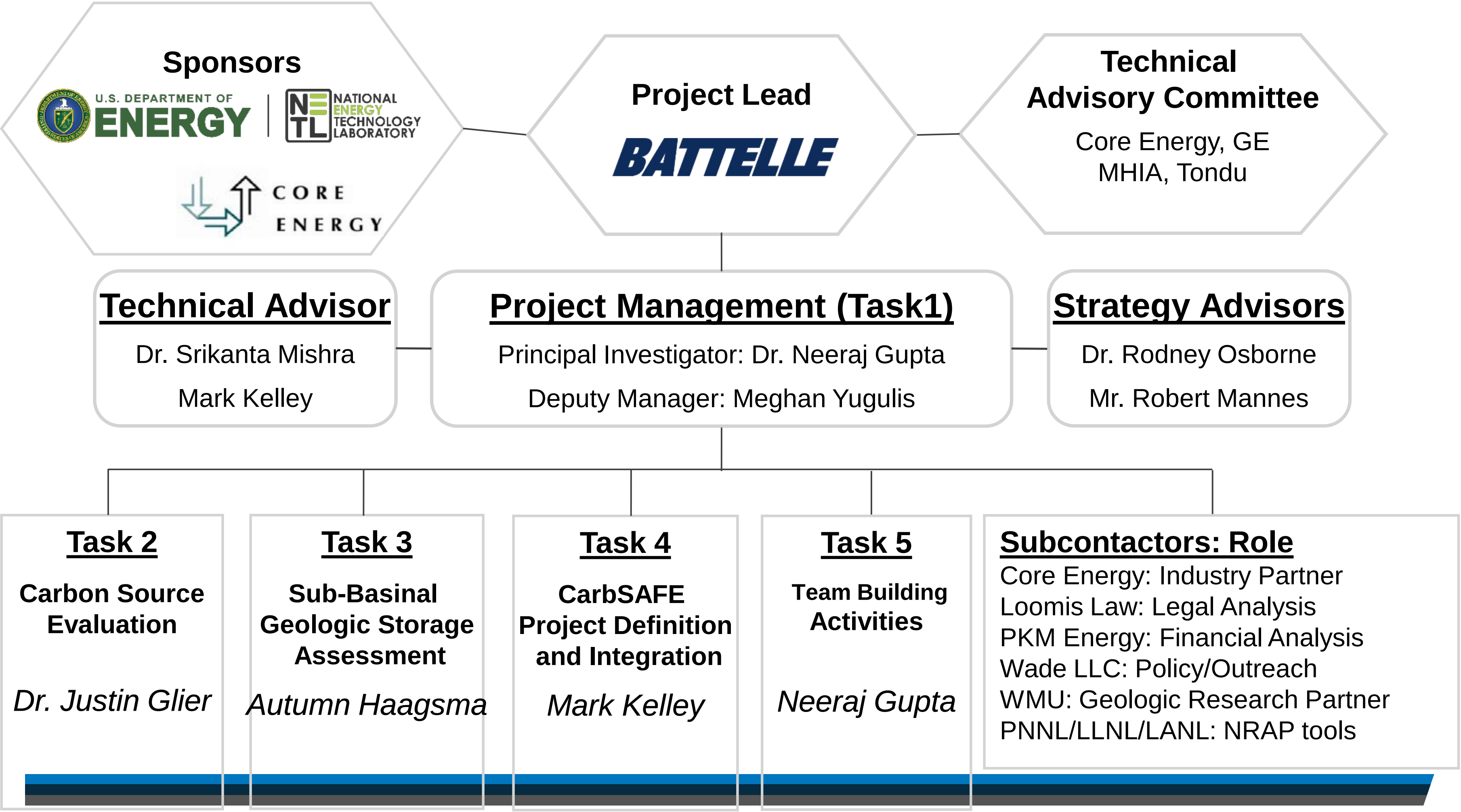
Project overview goals and objectives

Research Objectives

- Form a CCS coordination team capable of addressing technical and non-technical aspects
- Conduct technical evaluation of sources and sinks for developing an integrated commercial CO_2 storage complex in the 2025 time frame
- Develop a plan that encompasses technical as well as non technical requirements (economic feasibility, legal aspects, public acceptance, etc.)



Organizational Support:
Organization Chart



Sponsors

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

CORE ENERGY

Project Lead

BATTELLE

Technical Advisory Committee

Core Energy, GE
MHIA, Tondu

Technical Advisor

Dr. Srikanta Mishra
Mark Kelley

Project Management (Task1)

Principal Investigator: Dr. Neeraj Gupta
Deputy Manager: Meghan Yugulis

Strategy Advisors

Dr. Rodney Osborne
Mr. Robert Mannes

Task 2

Carbon Source Evaluation

Dr. Justin Glier

Task 3

Sub-Basinal Geologic Storage Assessment

Autumn Haagsma

Task 4

CarbSAFE Project Definition and Integration

Mark Kelley

Task 5

Team Building Activities

Neeraj Gupta

Subcontactors: Role

Core Energy: Industry Partner
Loomis Law: Legal Analysis
PKM Energy: Financial Analysis
Wade LLC: Policy/Outreach
WMU: Geologic Research Partner
PNNL/LLNL/LANL: NRAP tools

Organizational support project team

- Battelle - Project leader with substantial CCUS experience
- Core Energy, LLC – Primary project development partner; 12 years of collaboration with Battelle
- PKM Energy Consulting, LLC – Evaluate financial/economic factors, liability management options
- PNNL/LANL/LLNL- Application of select NRAP tools
- Wade LLC – Outreach coordination and planning
- Loomis Law - Advice on mineral rights, permitting, land access, and liability issues.
- Western Michigan University – Geologic Research Partner
- Advisors – GE, MHIA, Tondu Corp. etc.

Proposed schedule

- Tasks aligned with key outcomes
  - Project Manangement
  - Source Evaluation
  - Sub-Basinal Geological Storage
  - Project Definition
  - Team Building
- Will be updated for Feb 2017 start

Task Name	2017				2018			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Project Management & Planning	▨ ●	▨	▨	▨	▨	▨ ●		
1.1 Update Project Mgmt. Plan	▨ ◆							
1.2 Project Management	▨	▨	▨	▨	▨	▨		
1.3 Progress Reporting	▨	▨	▨	▨	▨	▨		
1.4 Project Controls	▨	▨	▨	▨	▨	▨		
1.5 NEPA Reporting	▨							
Task 2: Carbon Source Evaluation	▨ ●	▨ ●						
2.1 Carbon Source Analysis	▨							
2.2 Source-Sink Routing and Feasibility	▨							
2.3 Capture and Storage Integration		▨ ◆						
Task 3: Sub-Basinal Geologic Storage Asmt		▨ ●	▨	▨ ●				
3.1 Reservoir Characterization		▨						
3.2 Caprock/Trapping Assessment			▨					
3.3 Geohazard Risk Assessment				▨ ◆				
Task 4: CarbonSAFE Project Definition		▨ ●	▨	▨	▨ ●			
4.1 Project Dimensions Definition		▨						
4.2 Infrastructure Definition		▨						
4.3 Property Rights/Mineral Rights Plan			▨					
4.4 Site Screening			▨					
4.5 Reg/Pol/Tech/Perm Planning				▨				
4.6 Public Outreach Review/Planning				▨	▨			
4.7 Liability Assessment				▨	▨ ◆			
Task 5: Team Building Activities	▨ ●	▨	▨	▨	▨	▨ ●		
5.1 Technical Advisory Meetings & Review	▨	▨	▨					
5.2 Teaming Planning & Siting Review	▨	▨	▨					
5.3 Commercialization Plan				▨	▨			
5.4 Path Forwar					▨	▨		