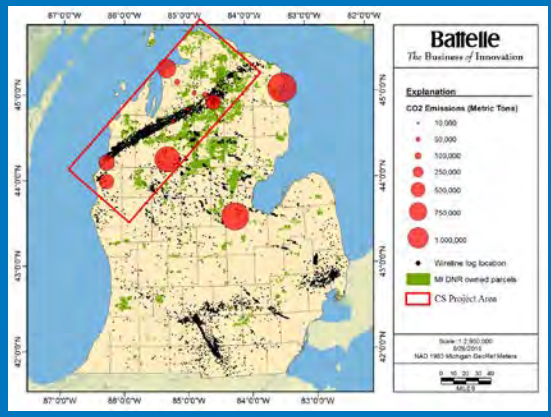
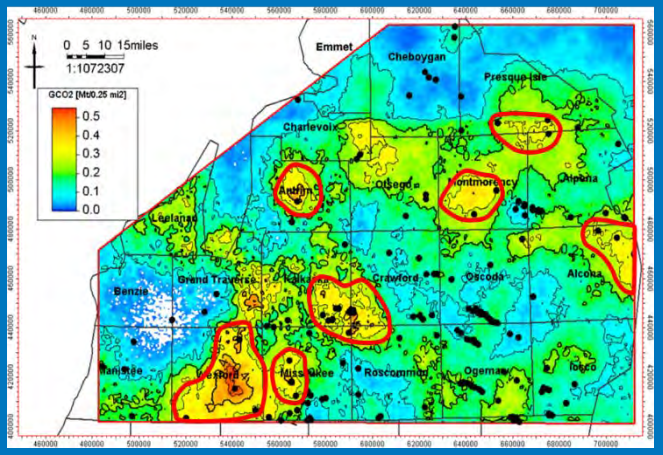
Northern Michigan Basin CarbonSafe Integrated Pre-Feasibility Analysis





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 13-16, 2018

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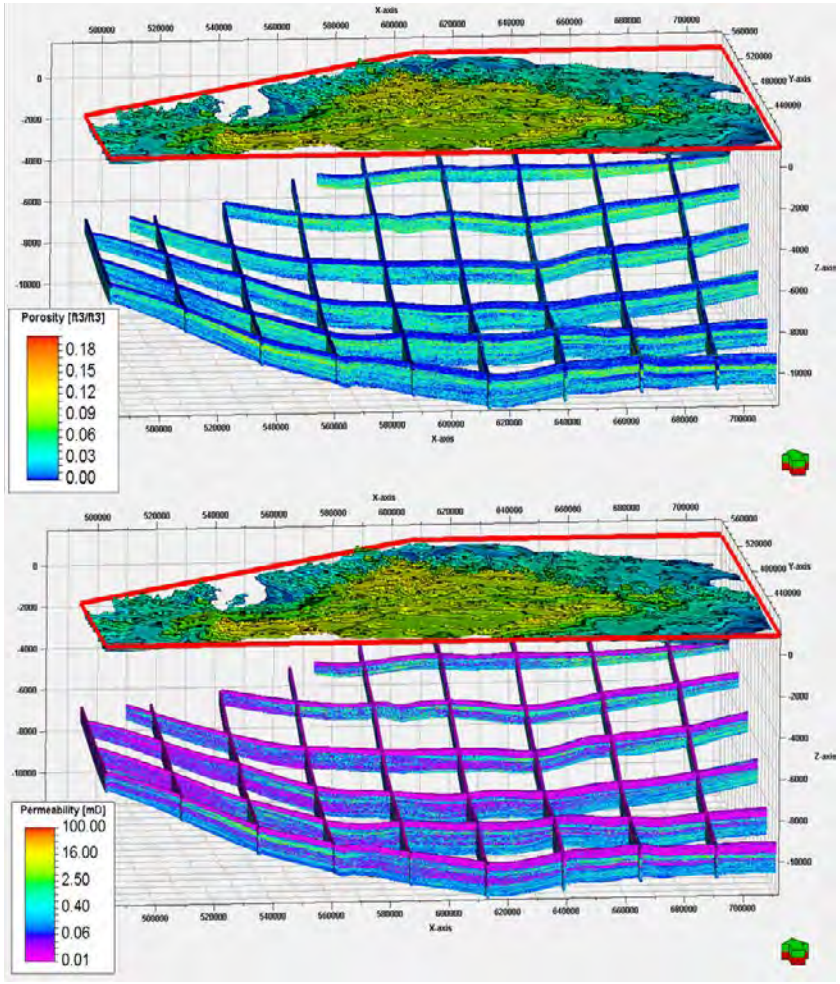
Presentation Outline



- Project Overview
- CO_2 Source Assessment
- Geologic Storage Options
- Project Integration
- Summary
- Appendix

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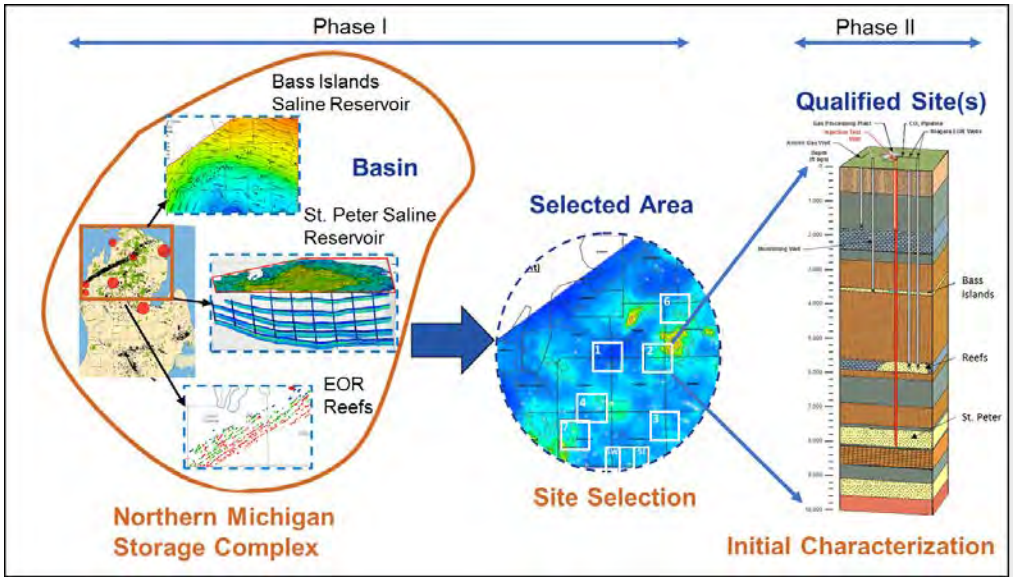
Organizational Support - Project Team

- Battelle - Project leader with substantial CCUS experience
- Core Energy, LLC – Primary project development partner; 13 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 – New Steel, Inc., GE, MHIA, Tondu Corp. etc.

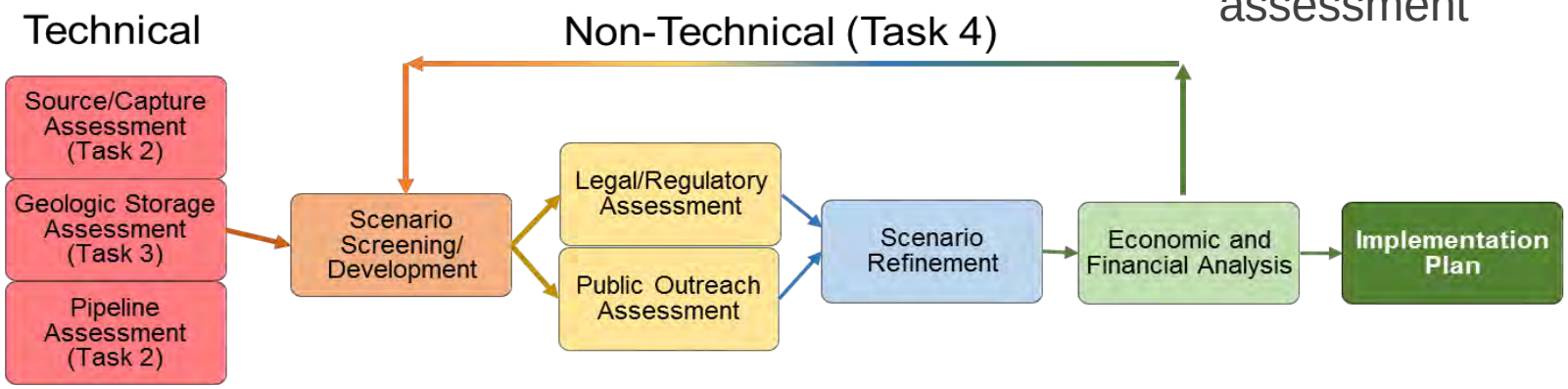
Project Overview: Goals and Objectives



*Modified after NETL Best Practices Manual

Main Objectives:

- CO_2 Source Assessment
- Geologic Storage Assessment
- Pipeline Assessment
- Project Integration
  - Site selection
  - Public outreach
  - Economic and financial analysis
  - Legal/regulatory assessment



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

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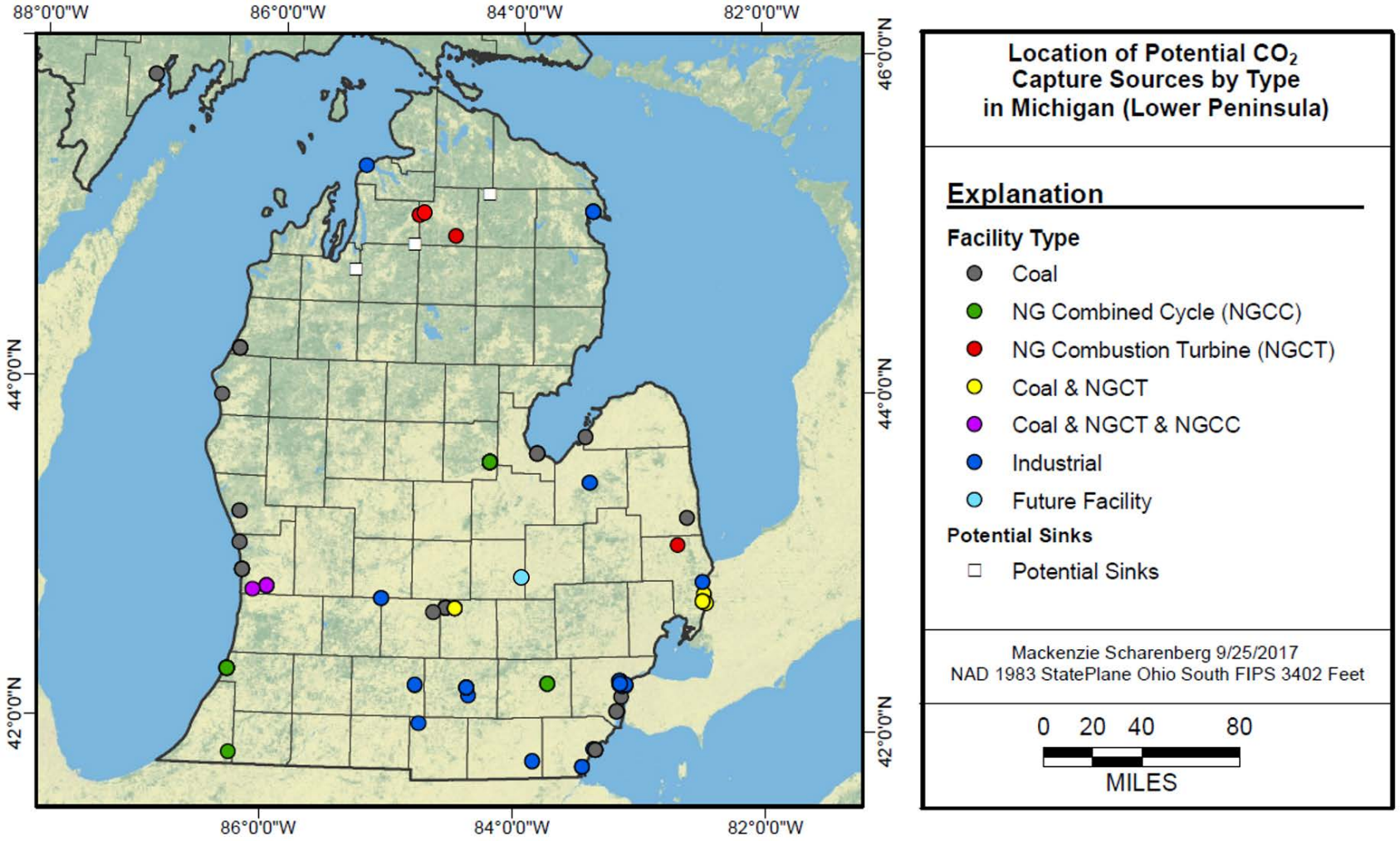
CO_2 Source Assessment– Objectives

Analyze the nature of large carbon point sources in the Northern Michigan Basin

- **Carbon Source Analysis**
  - Describe the location, size, gas stream, and impurities for the Northern Michigan Basin's sources and capture feasibility
  - Assess the gas composition, flow rates, technical readiness, capital costs, operational costs, capture facility impact on existing industrial operations, and incentives
- **Source-Sink Routing and Feasibility**
  - Analyze the location of CO_2 sources, sinks, and pipeline routes
  - Identify economic, environmental, and construction factors related CO_2 pipelines

CO_2 Source Assessment - Multiple Potential Sources



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Screened Regional CO_2 Sources

Facility Name	Ownership	Facility Type	Potential Emissions (MMtpy)
LaFarge Cement	LaFarge North America	Cement	2.3
St. Mary's Cement	Votorantim Cimentos N.A.	Cement	1.0
DCP Midstream Partners - White's Landing	DCP Midstream Partners	Petroleum and Natural Gas	0.4
Dan E Karn	CMS Energy	Coal-fired power	4.4
TES Filer City	CMS Energy, KCR Power	Coal, Biomass Cogen	0.4
Ludington CoGen	Arclight Capital	NG Cogen	0.6
Midland Cogen Venture	Midland Cogen Venture	NGCC	2.8
J H Campbell	CMS Energy	Coal-fired	10.4

Potential Sources

Facility Name	Levelized Capture Cost ($/tonne)	Potential Emissions (MMtpy)	Electrical Output (MWNet)	Technology	County
Alpine Combined Cycle	72	1.9	~600	NGCC	Otsego
Project TIM	TBD	large		Iron/Steel	Shiawassee

Geologic Storage Assessment - Three Main Goals

Reservoir Characterization

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

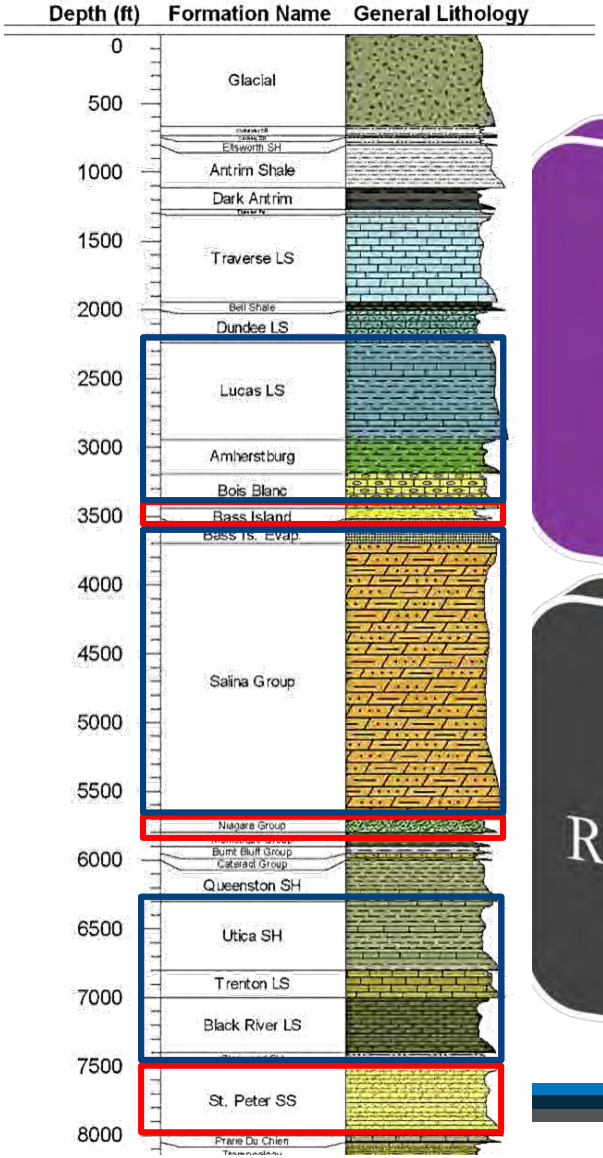
Caprock/Trapping Assessment

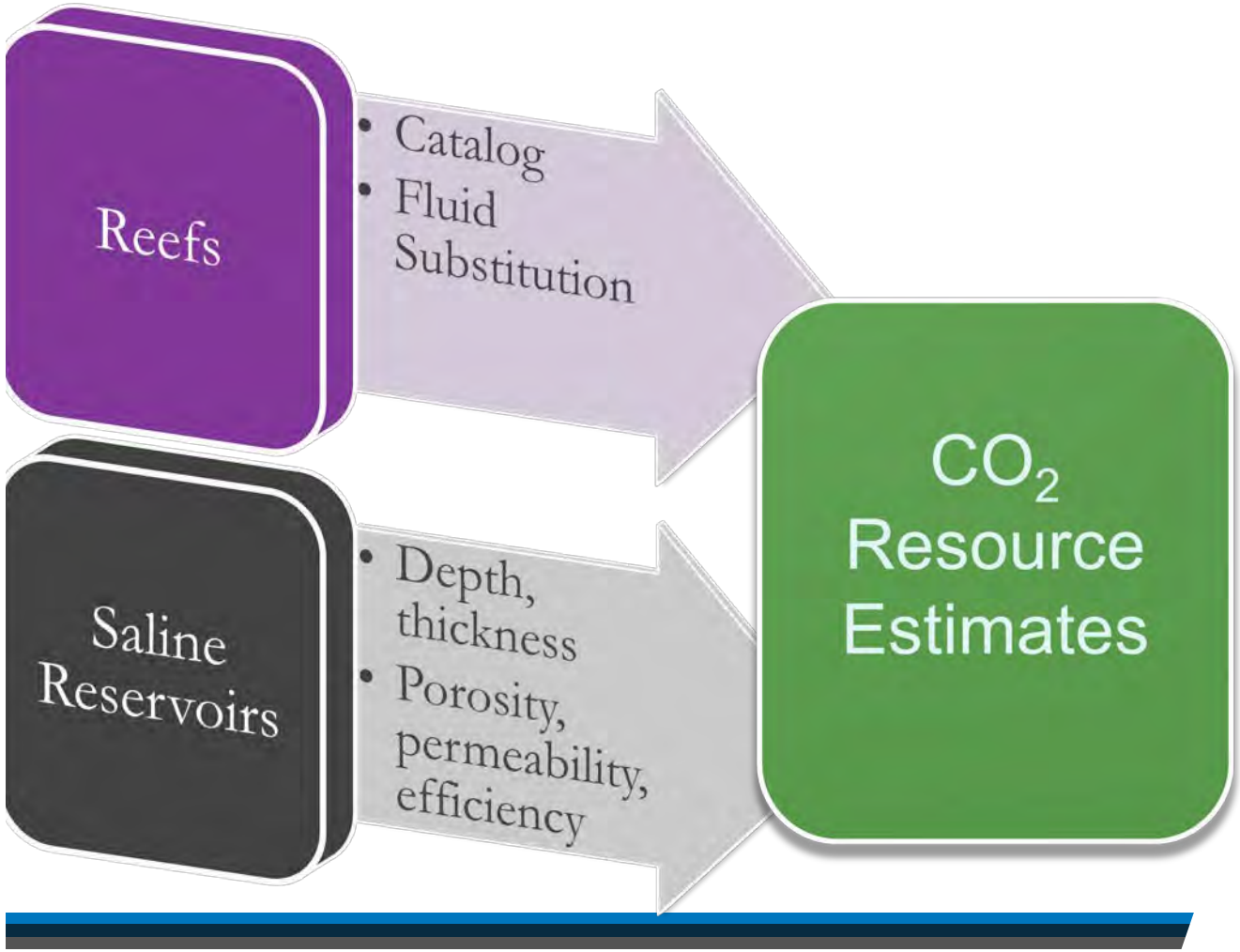
- Extent, thickness, and integrity
- CO_2 migration potential and sealing effectiveness
- Any structural concerns

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





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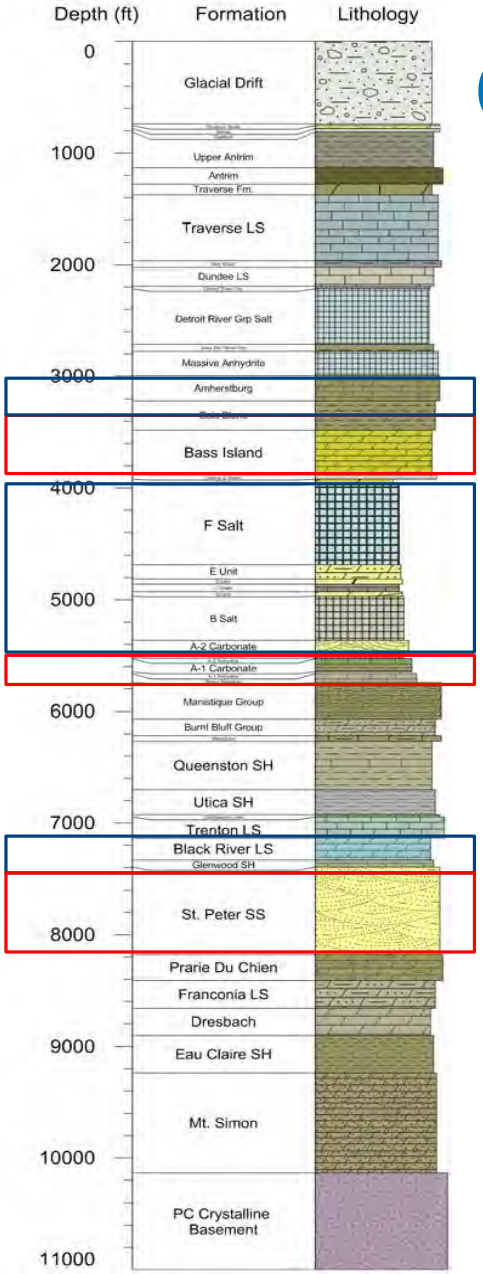
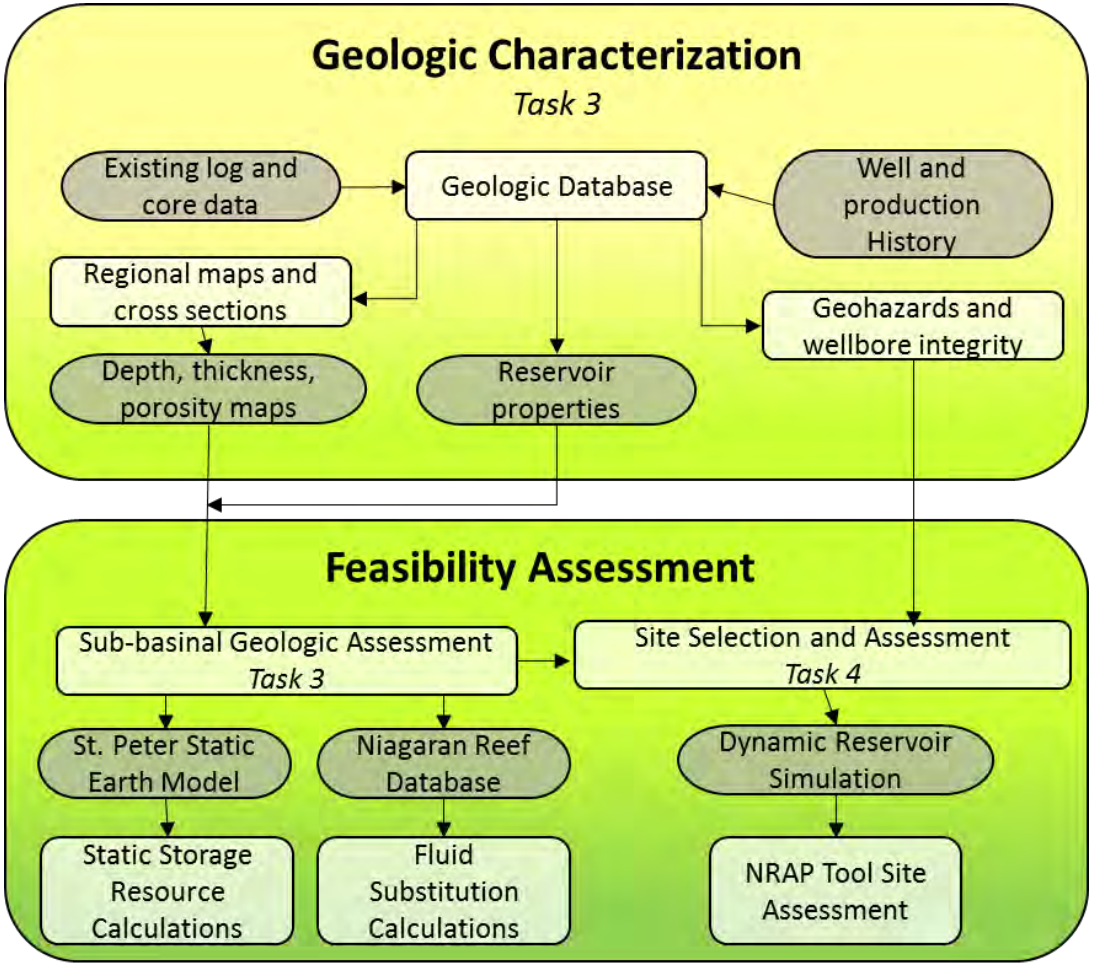
Candidate Storage Reservoirs



Secondary Saline

EOR

Primary Saline



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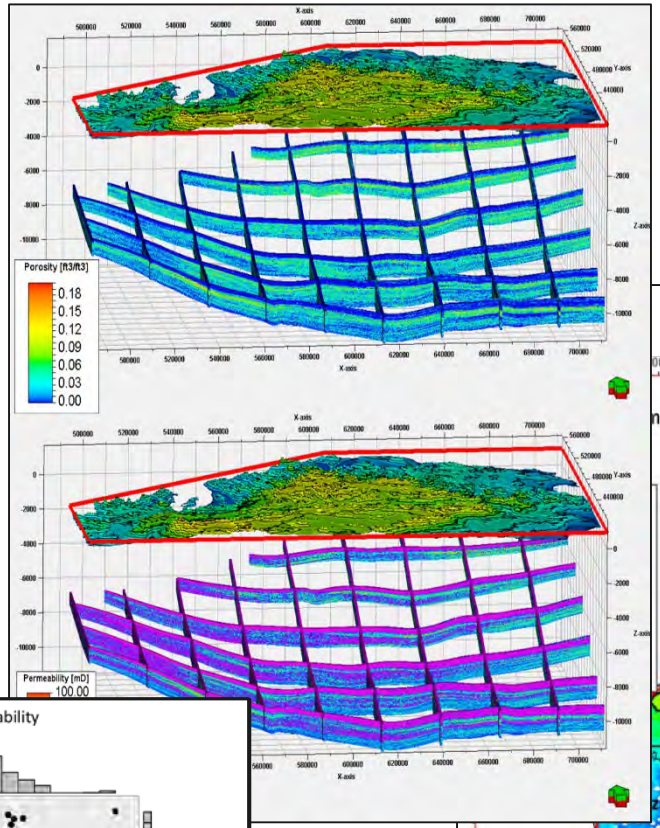
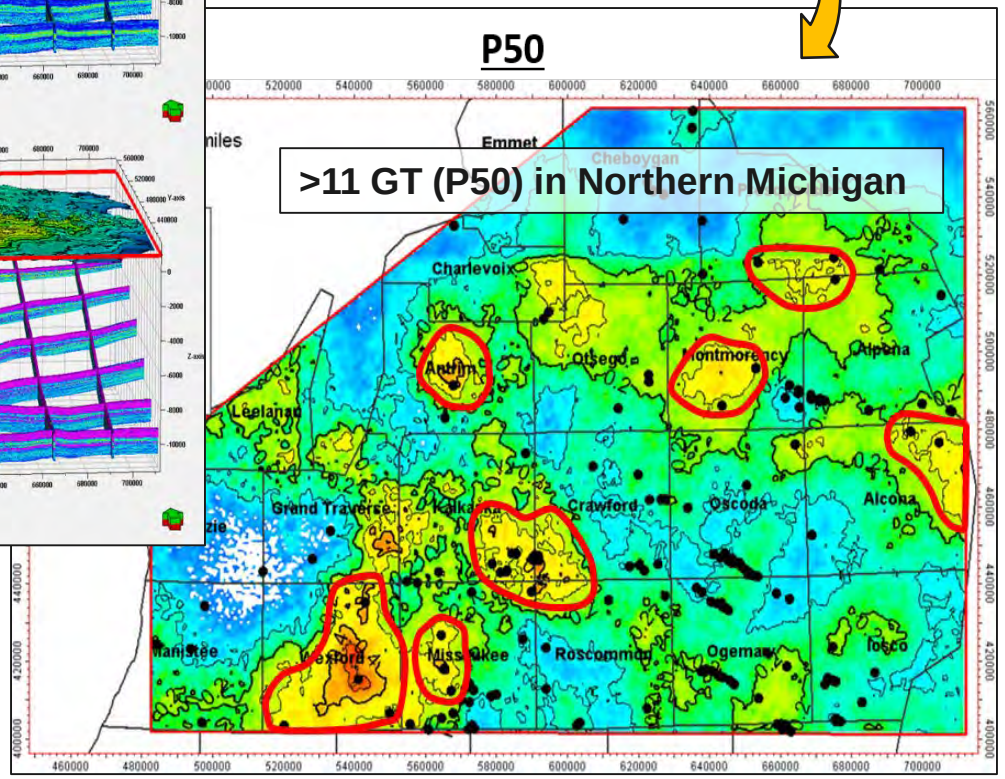
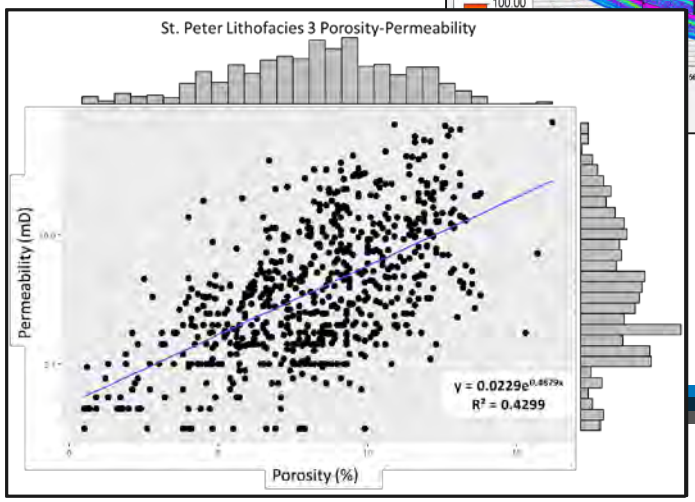
St. Peter Storage-Resource Estimate: Volumetric Calculations from a Sub-Regional Static Earth Model



$$G_{CO2} = A_t \, h_g \, \phi_t \, \rho_{CO2res} \, E_{saline}$$





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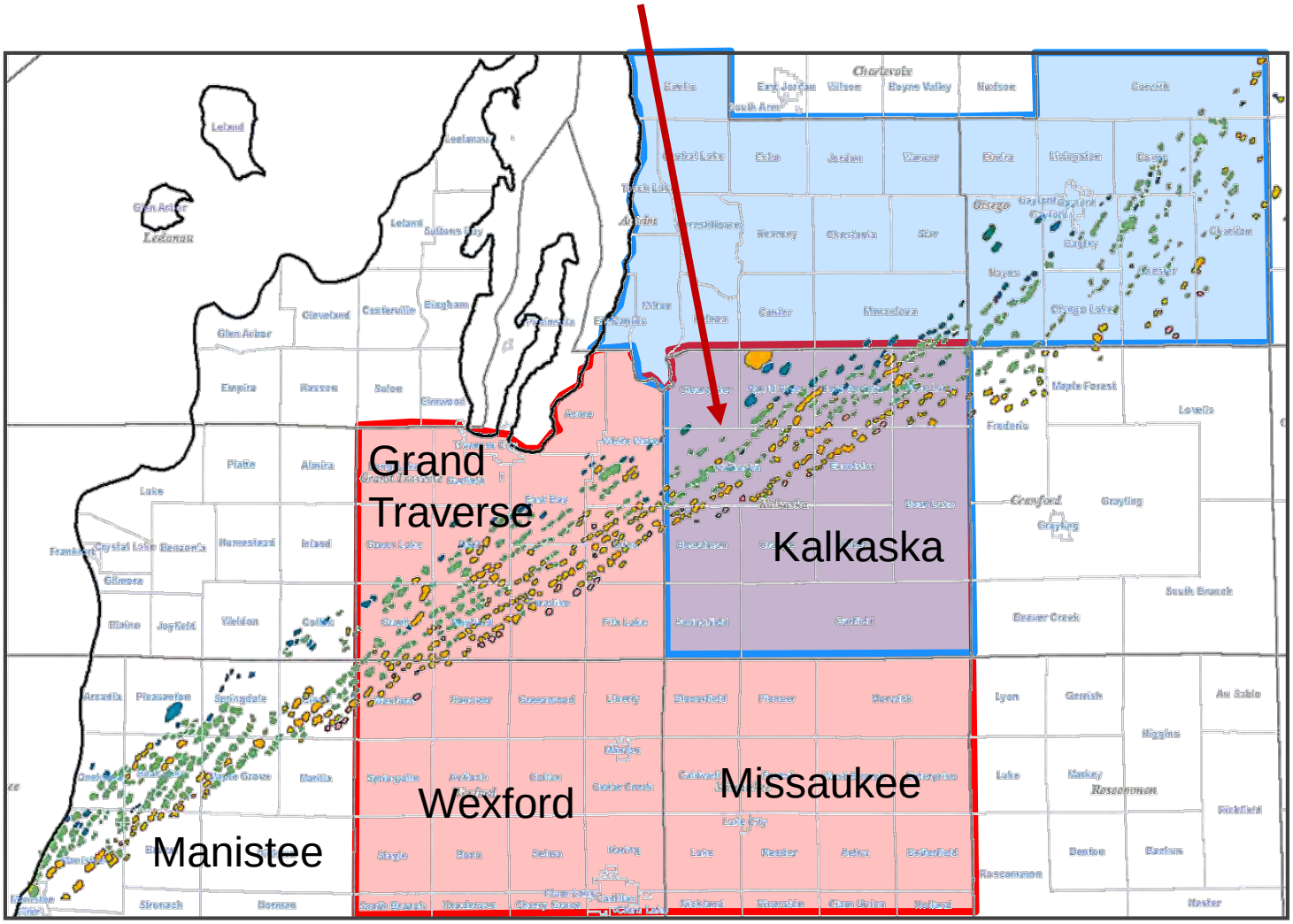
Geologic Storage Assessment

Overlap In Highest Reservoir Potential- Kalkaska County



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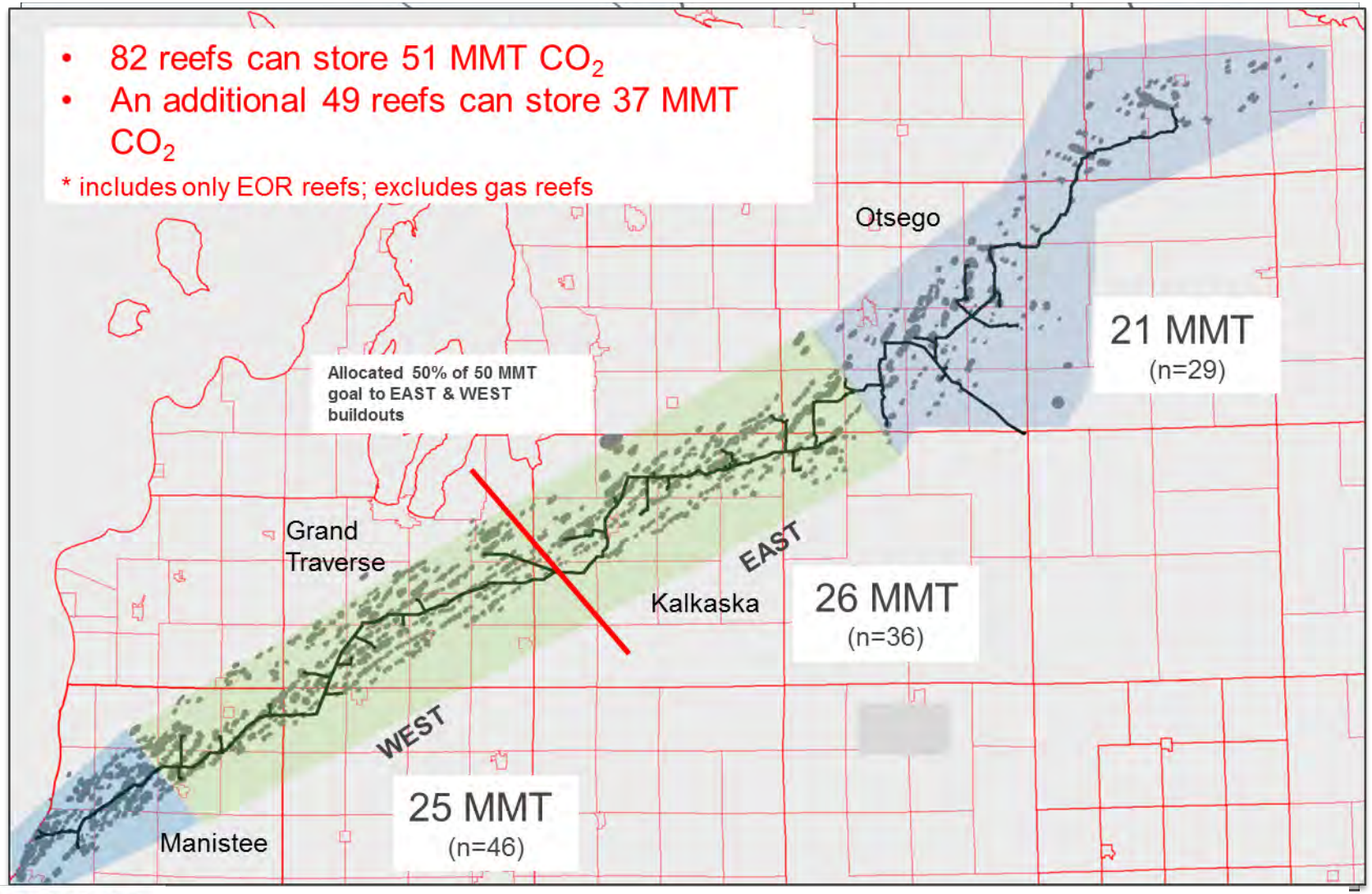
Storage Capacity of (selected) EOR Reefs



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Geologic Storage Assessment
Quick-look Well Integrity Mapping Tool

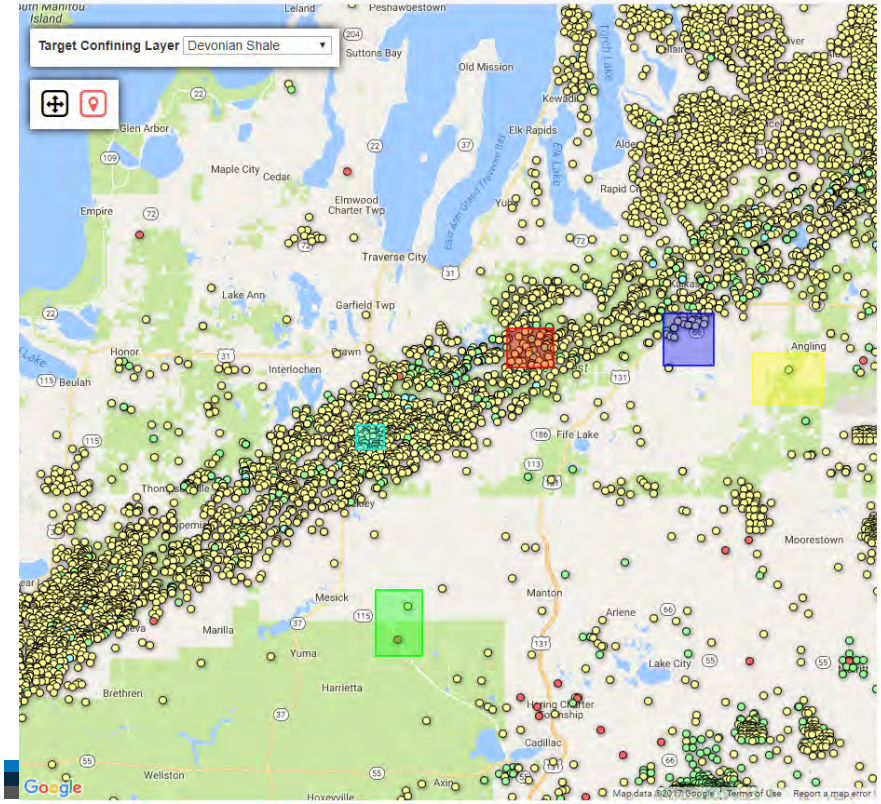
- Developed as stand-alone application using Google Maps API
  - Can easily be integrated into existing web sites and applications
- **FEATURES**:
  - Simultaneously select and compare potential sites on the fly
  - Draw the spatial boundaries and select the associated confining layer
  - Calculates 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

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



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

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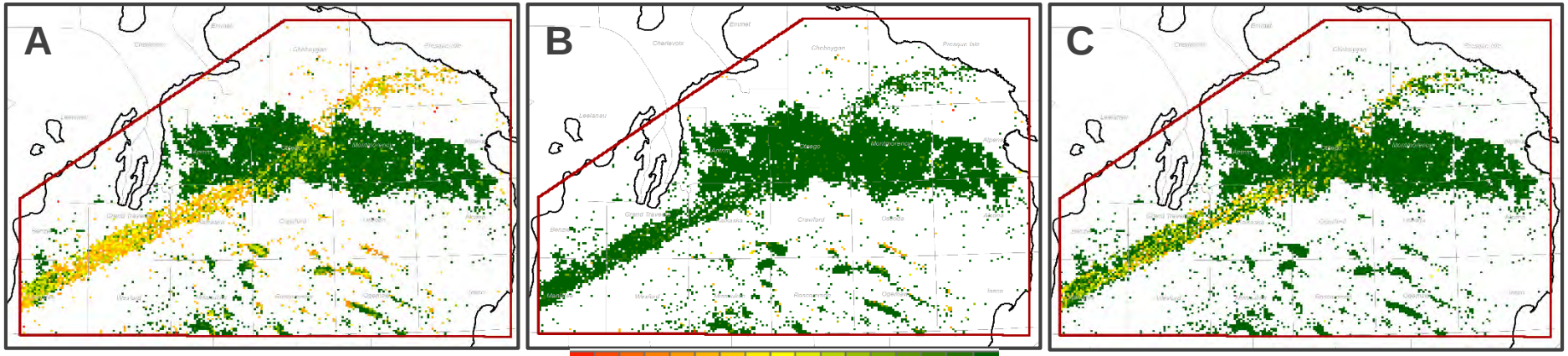
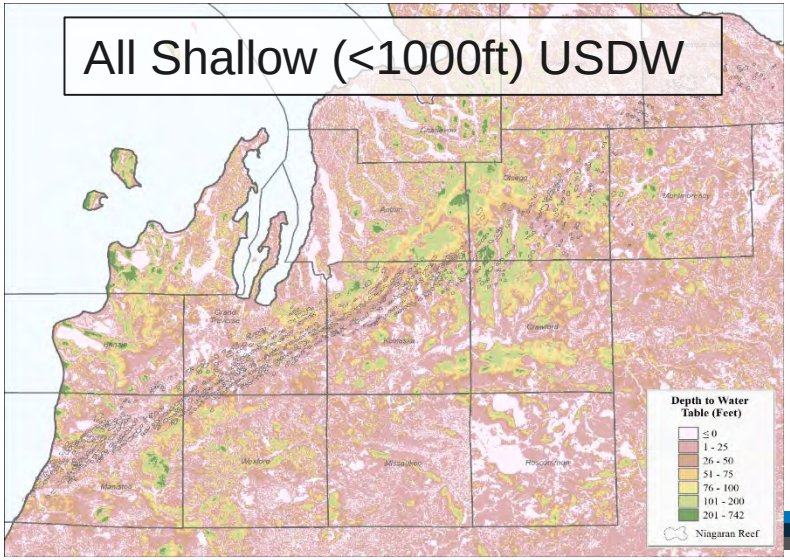
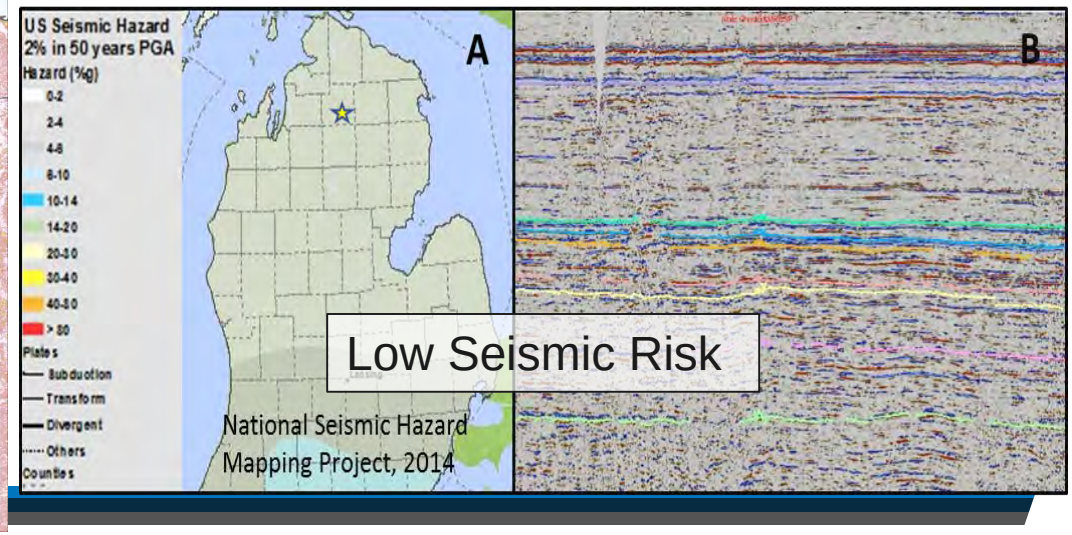
Geohazard Risk Assessment

Reefs | St. Peter | Bass Islands



Low (0) — High (19)





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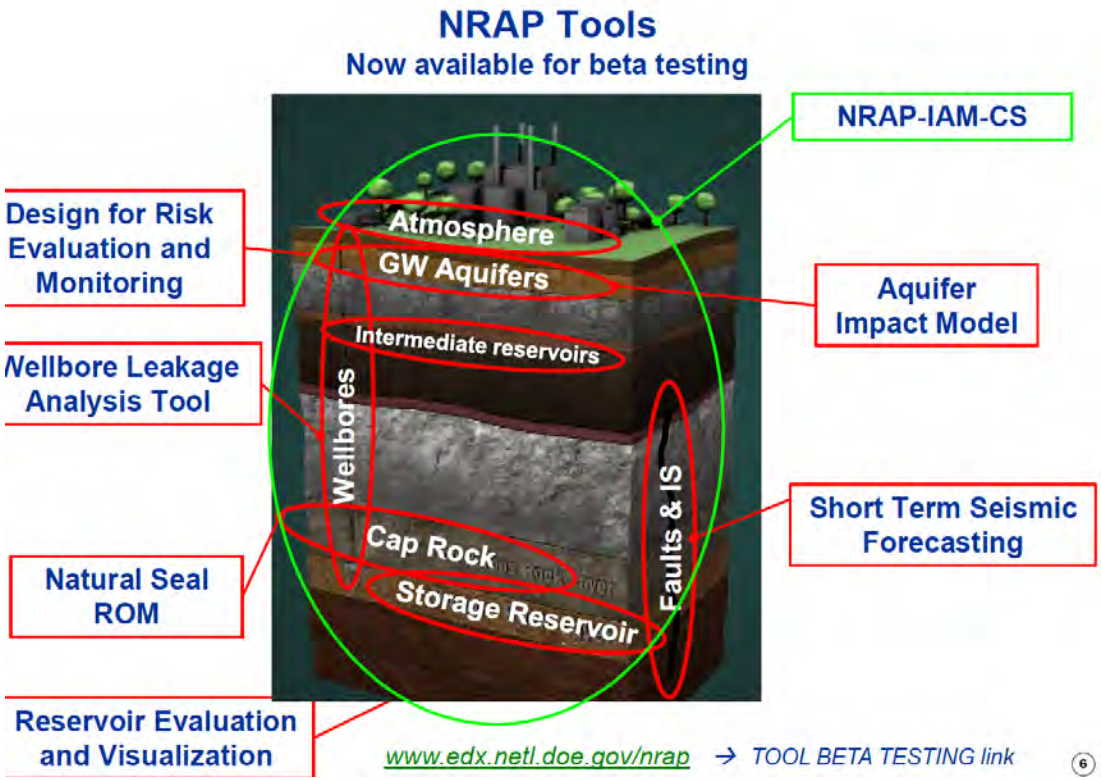
Geologic Storage Assessment - Using NETL NRAP Tools

- 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



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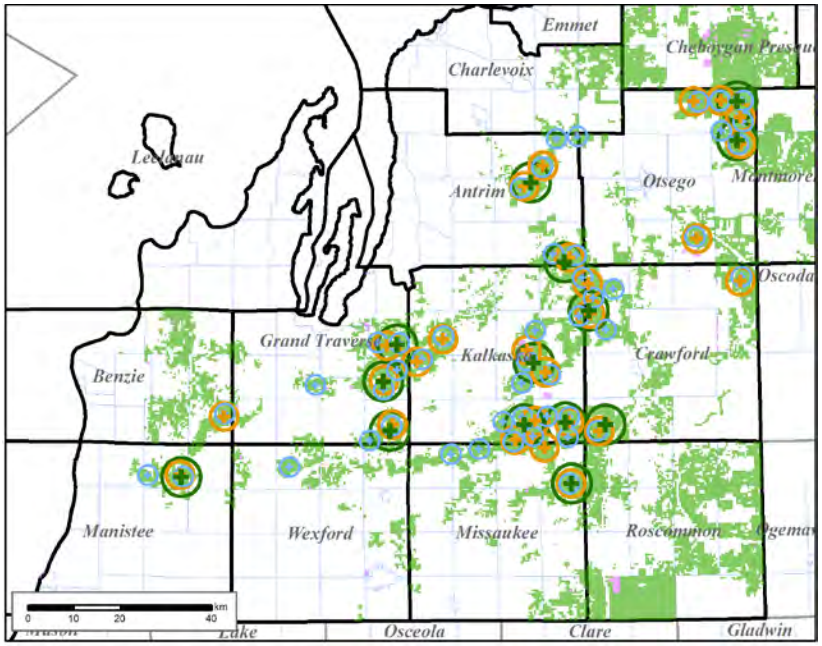
Integration - Site Selection - St. Peter Example

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

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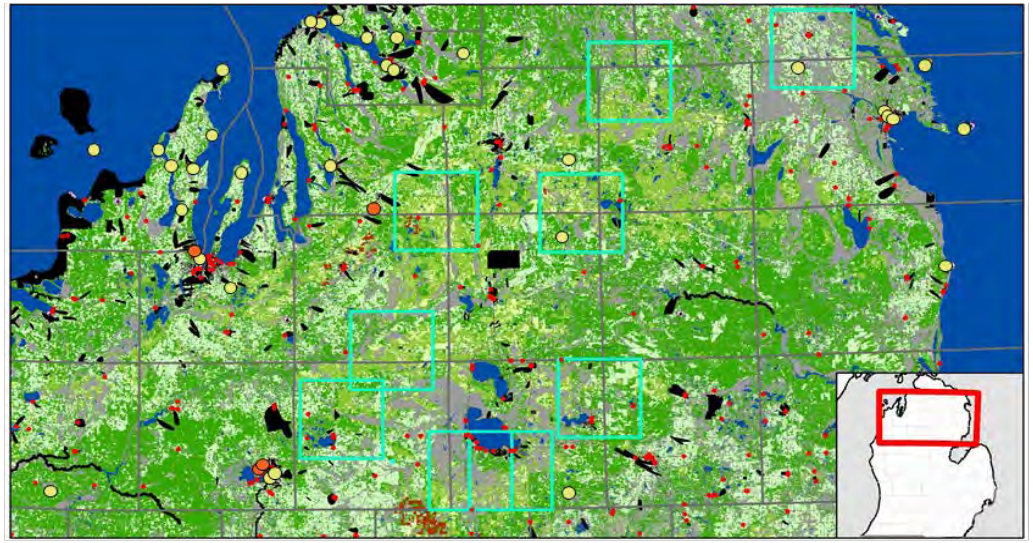
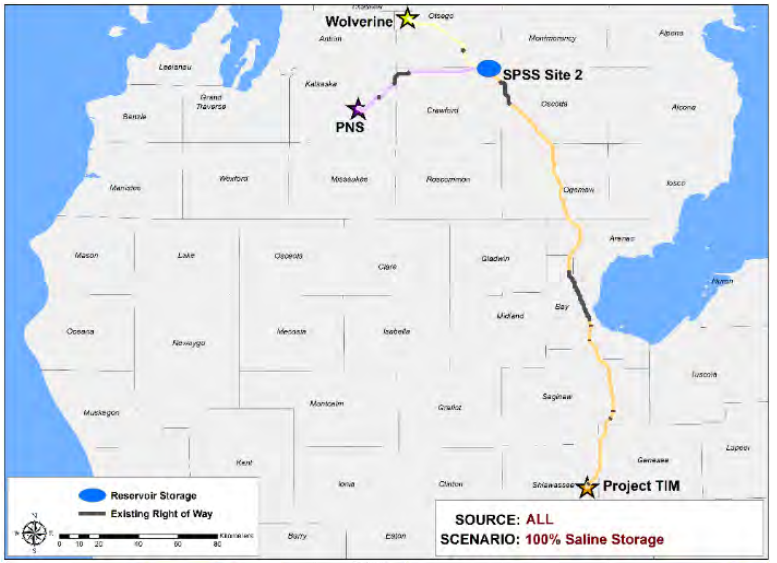
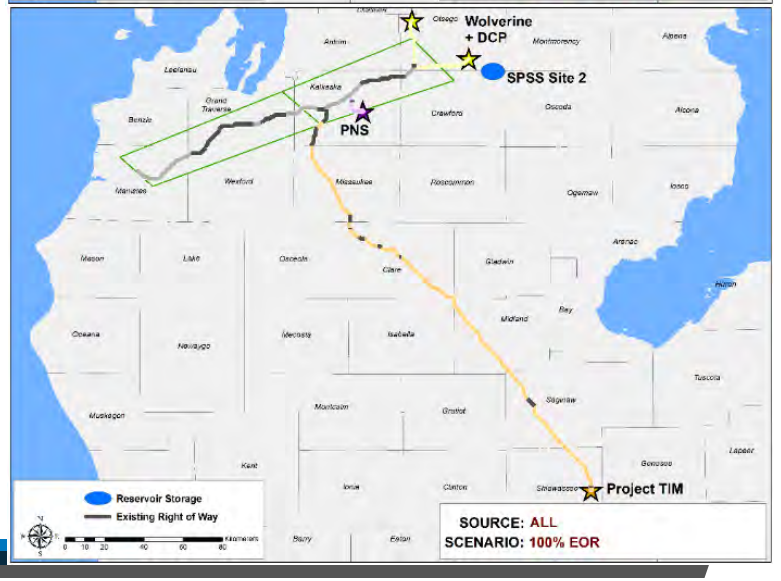
Project Integration- Site Selection and Pipeline Routing







- Potential sites selected based on geology, land ownership, obstacles, etc.
- Multiple pipeline scenarios generated to link source to sink

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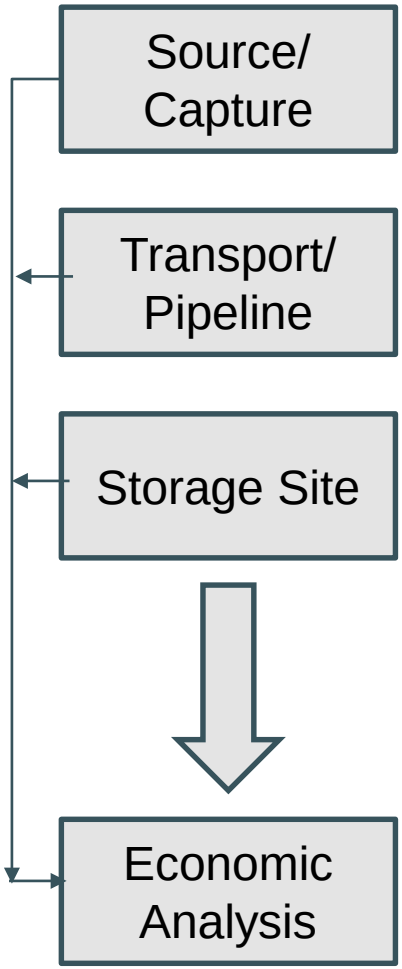
Project Integration- Cost Estimating Methodology



Literature

FE/NETL CO_2 Saline Storage Cost Model

DOE/NETL CO_2 Transport Cost Model

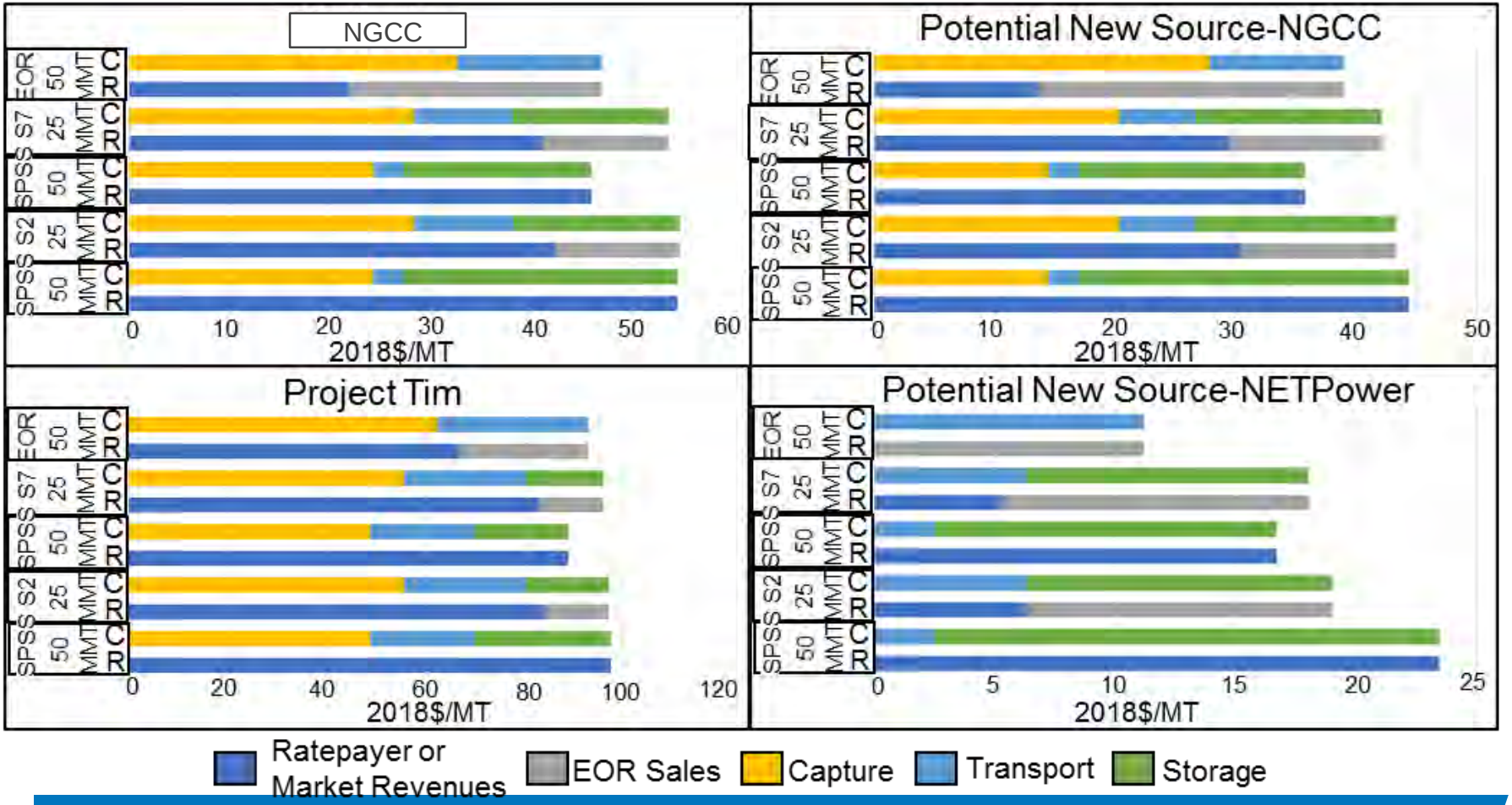
DOE/NETL CO_2 Saline Storage Cost Model; historical in-house costs

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 CO_2 ($/tonne)

Project Integration – Economic Analysis

- 20 scenarios analyzed for different source→ sink options
- New technologies, EOR economic benefits, and financial mechanisms are key



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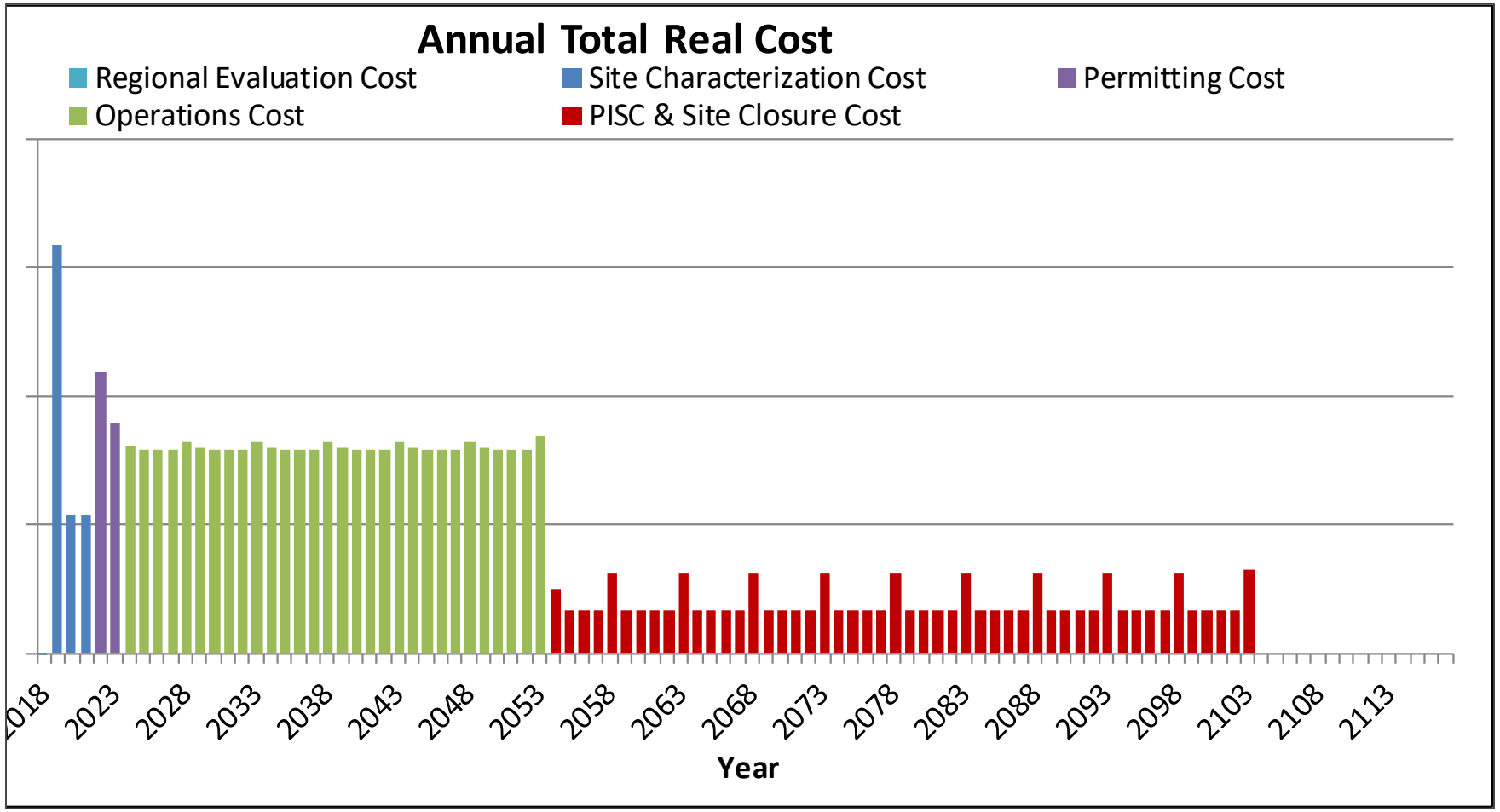
Integration - Cost Estimating Methodology - St. Peter Scenario



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Project Integration - 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** supports 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
- **Needed changes to existing policy/regulation mainly related to updating current mechanisms to include CO_2**

Accomplishments

- Major CO_2 sources have been evaluated
- Strong support from selected primary source
- Geology team collaboration has produced:
  - Methodology for evaluating reservoirs
  - Geologic databases
  - Geologic “sweet spots”
  - Geohazard risk assessment tools
- Storage scenarios and methodology for evaluated
- Social characterization completed for key counties
- Pore space rights and policy/regulations reviewed

Lessons learned

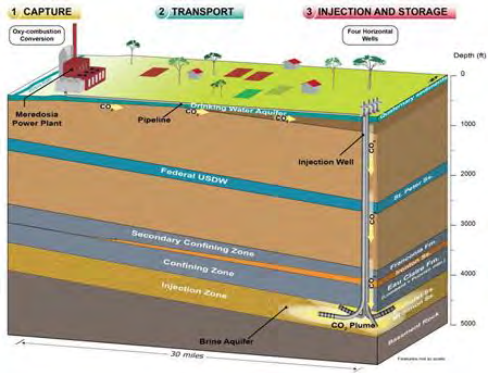
- CarbonSAFE projects require a strong collaboration with industry and a business focused strategy
- Collaboration with oil/gas companies and strong host site support is critical
- Multiple storage and EOR options available – stacked storage solution should be preferred
- Geology conducive to storage – no significant risk factors
- Fitting CO_2 storage within existing regulatory instruments is favored
- Clarity needed regarding capture sources – wait for next generation or provide a source with capture in Phase I

Synergy opportunities

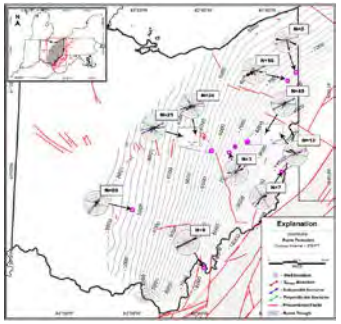
Project builds on past and current projects to enable CCS technology development in Northern Michigan and across Midwest

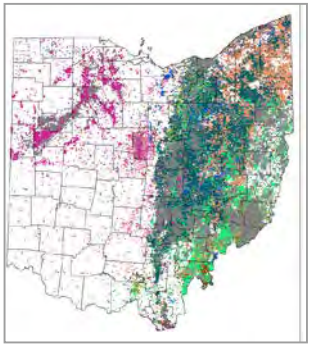
Midwest Regional Carbon Sequestration Partnership

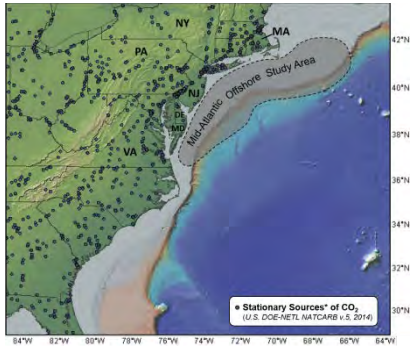
AEP Mountaineer CCS Project Experience



FutureGen Project Experience (closed)







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Project summary

- The Northern Michigan Basin CarbonSAFE builds on 13 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

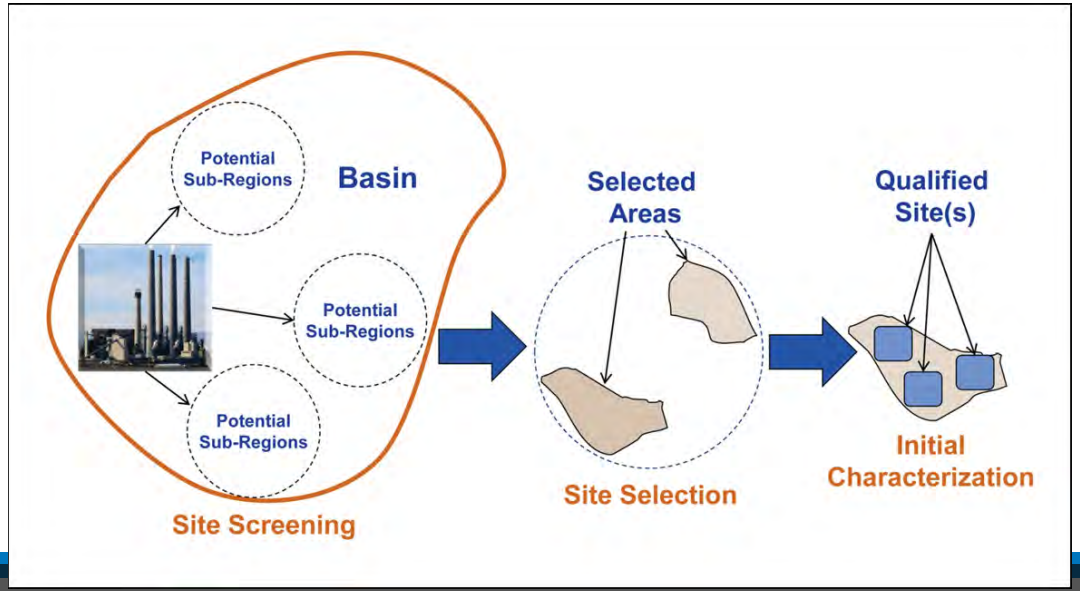
The project design involves integrating storage with existing and emerging CO_2 sources in an area containing power plants, natural gas processing facilities, and other industry through the completion of a CarbonSAFE pre-feasibility plan for the Northern Michigan Basin.

Project overview: 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

- 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.



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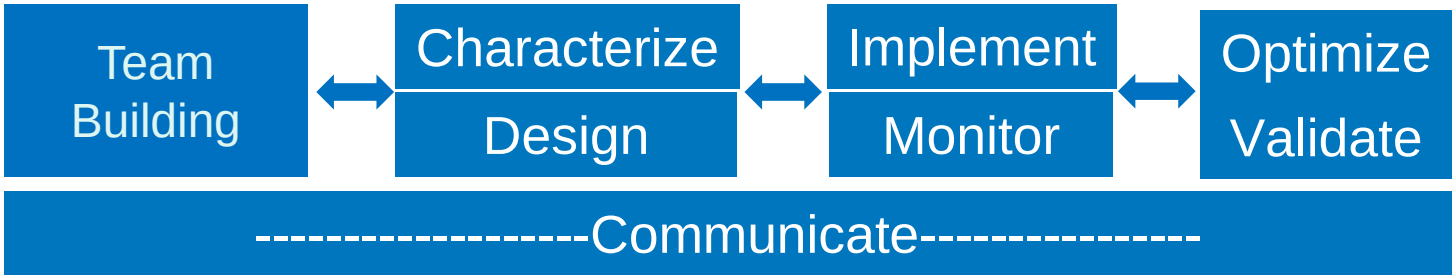
Project overview: goals and objectives

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.)



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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

$$G_{CO2} = A_t\, h_g\, \phi_{tot}\, \rho_{CO2}\, E_{saline}$$

Mass of CO_2 stored — *Pore volume* — *fluid properties* — *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

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

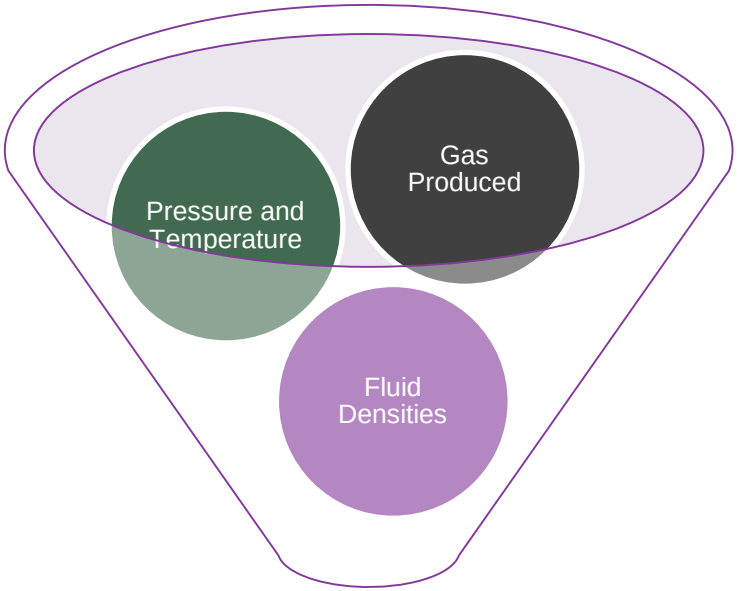
$E_{An/At}$ = Net to total area
$E_{hn/hg}$ = net to gross thickness
$E_{fe/ft}$ = effective to total porosity
E_V = volumetric displacement
E_d = microscopic displacement

Geologic storage assessment Niagaran reef resource estimates

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

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

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



CO_2 Volume

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

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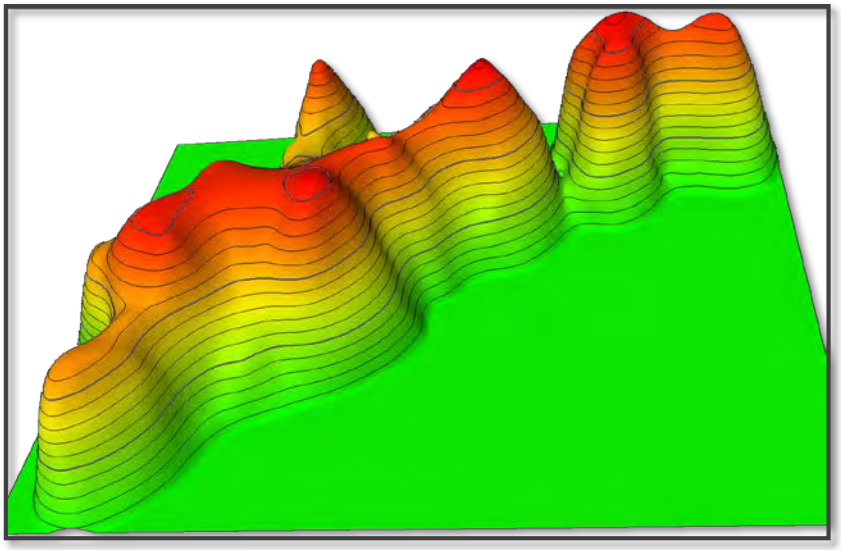
Geologic storage assessment example gas storage reef

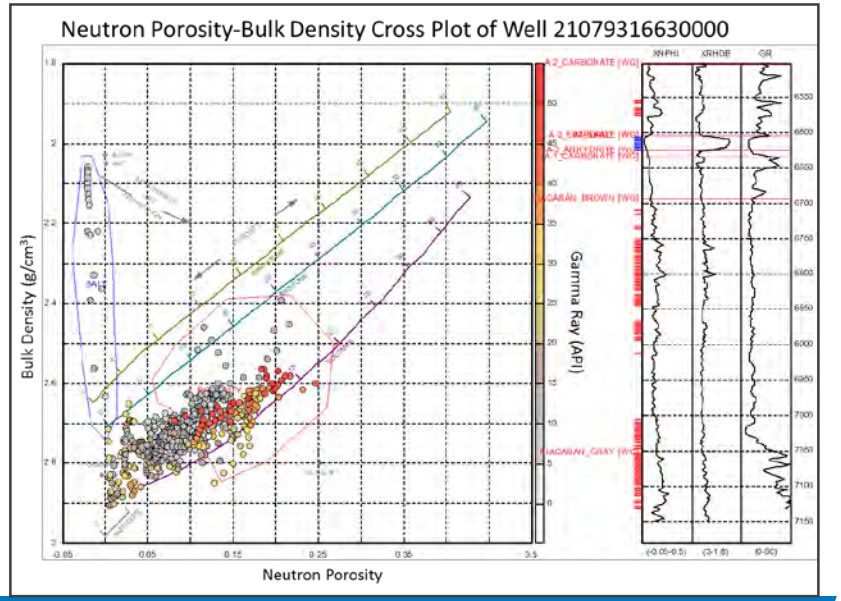
- Building SEMs for example reefs
  - Blue Lake 18A currently a gas storage reef

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

Calculated CO_2 Volume

2.2-4.4 Million Tonnes





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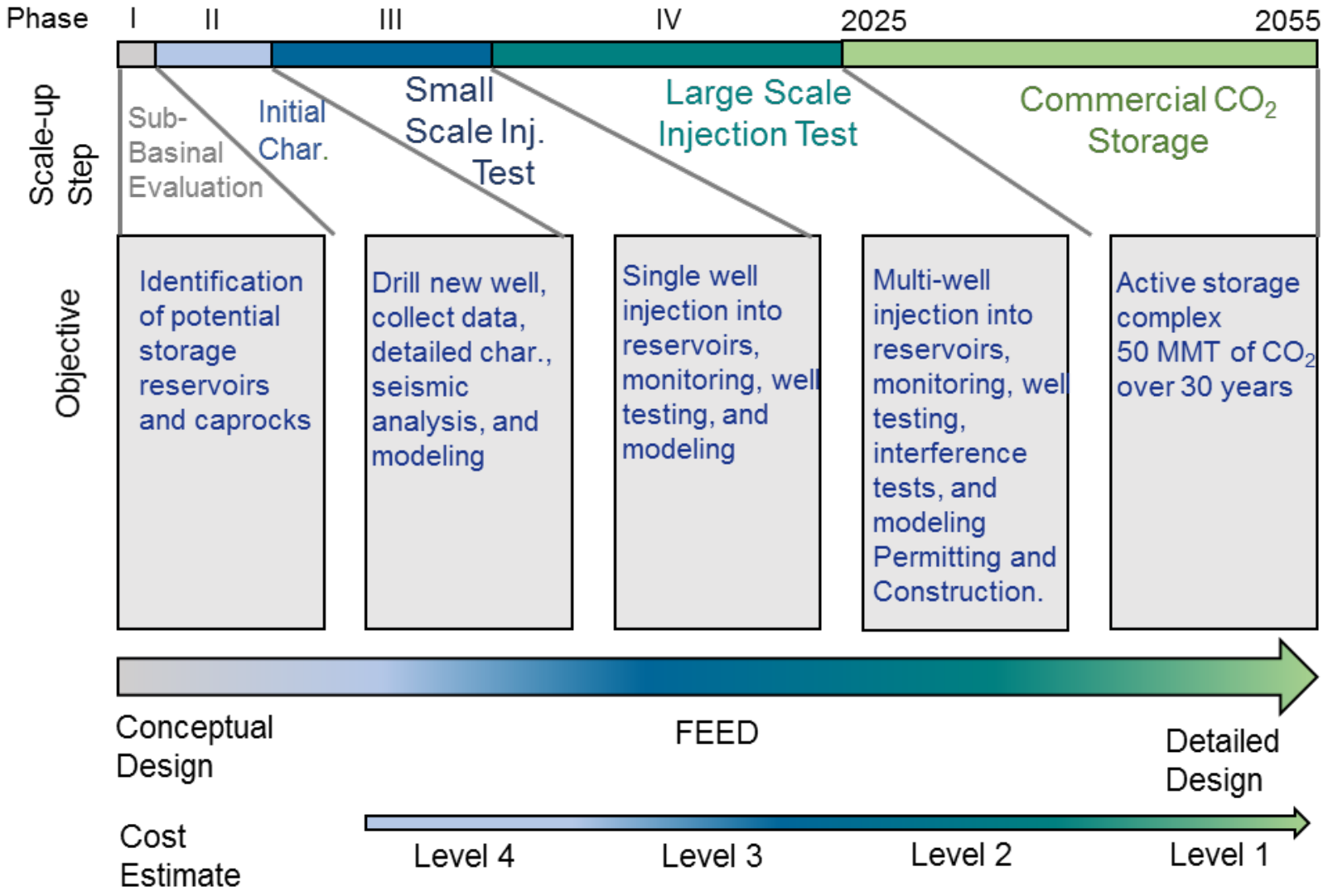
Looking Forward- Scaling up



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Potential CCS Business Structures Rate Regulated Entities

Figure 1

Figure 2

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Potential Ccs Business Structures (2) Power / Industrial Entities

Figure 3

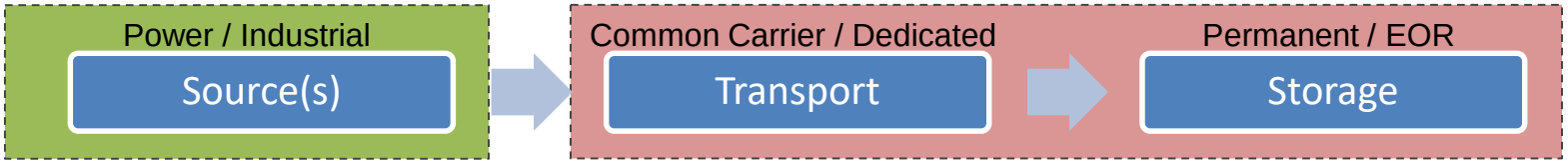

Figure 4

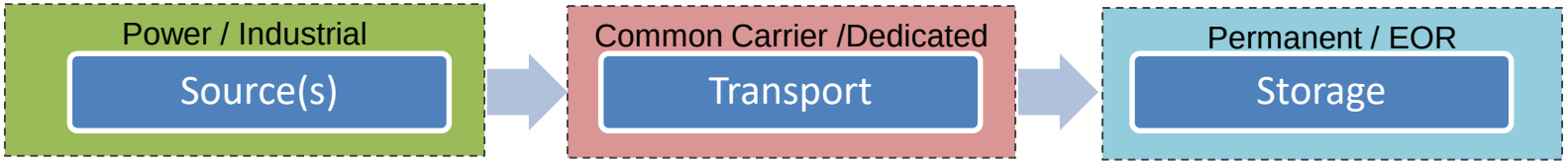

Figure 5

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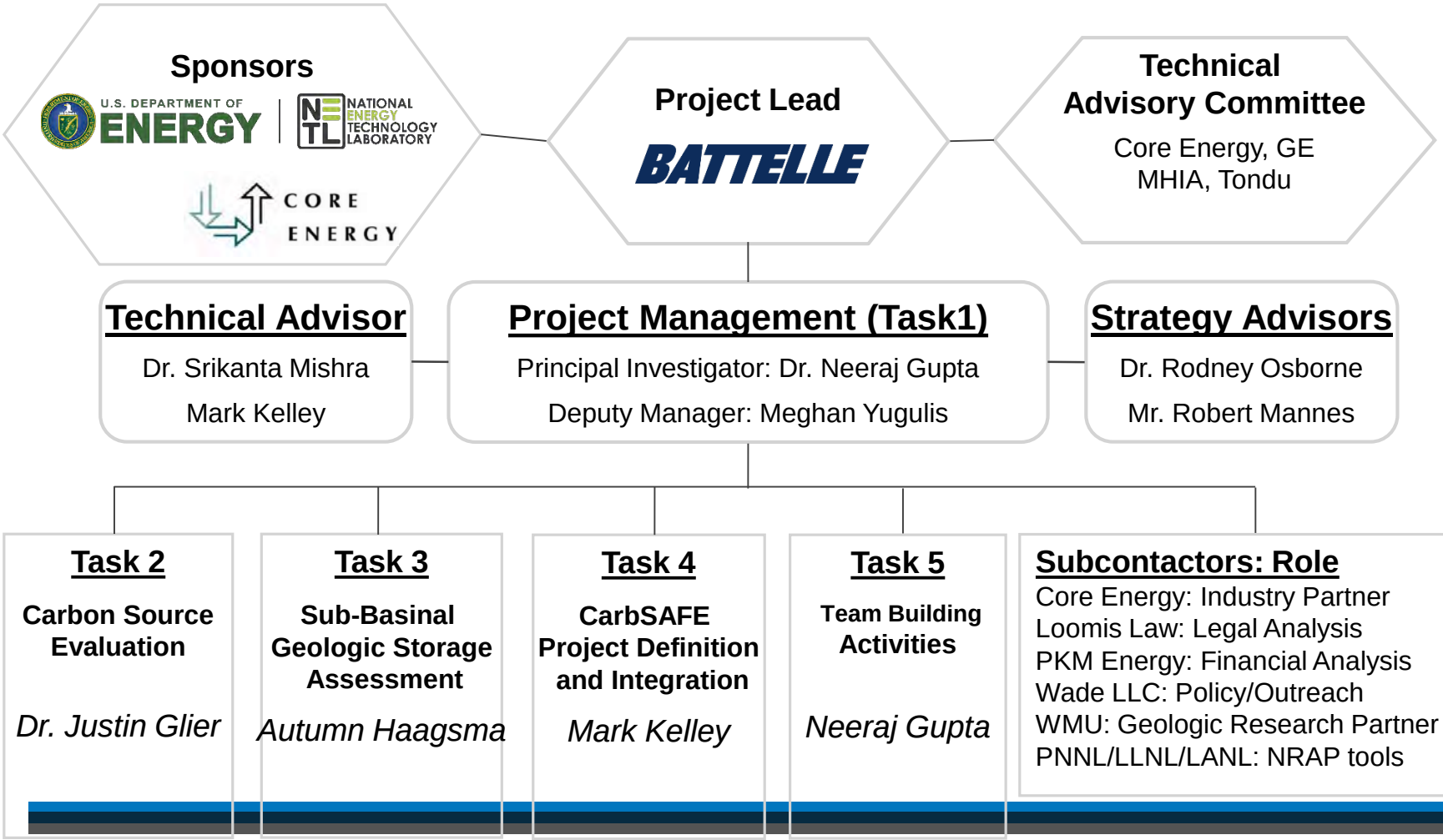
Organizational Support:
Organization Chart



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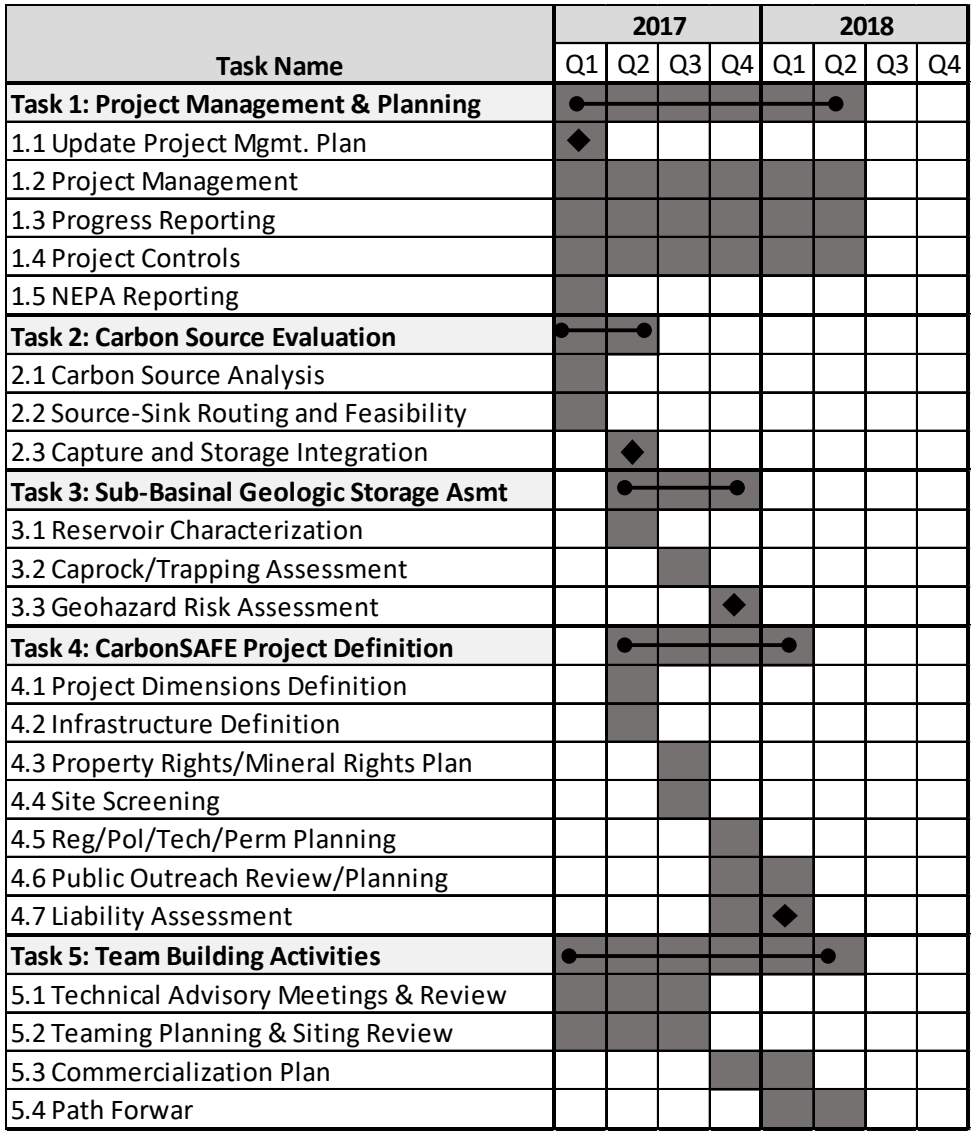
Organizational support project team

- Battelle - Project leader with substantial CCUS experience
- Core Energy, LLC – Primary project development partner; 13 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 – New Steel, Inc., GE, MHIA, Tondu Corp. etc.

Proposed schedule

- Tasks aligned with key outcomes
  - Project Management
  - Source Evaluation
  - Sub-Basinal Geological Storage
  - Project Definition
  - Team Building



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