Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment

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National Energy Technology Laboratory
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Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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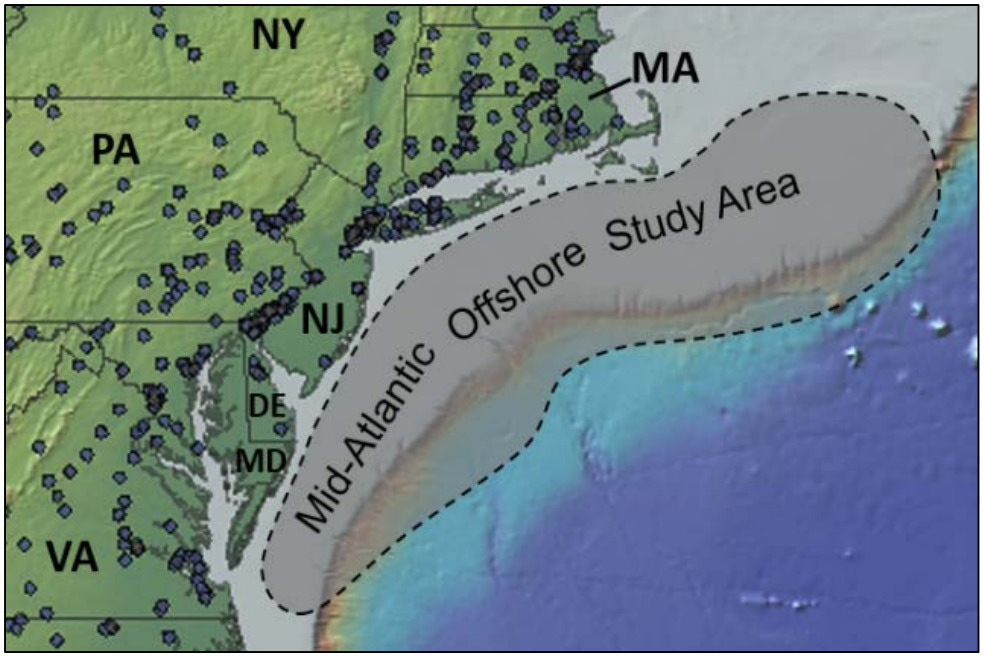
Presentation outline

- Project Overview & Organization
- Technical Status
- Accomplishments To-Date
- Lessons Learned
- Synergy Opportunities
- Project Summary



MID-ATLANTIC U.S. OFFSHORE
CARBON STORAGE RESOURCE
ASSESSMENT PROJECT

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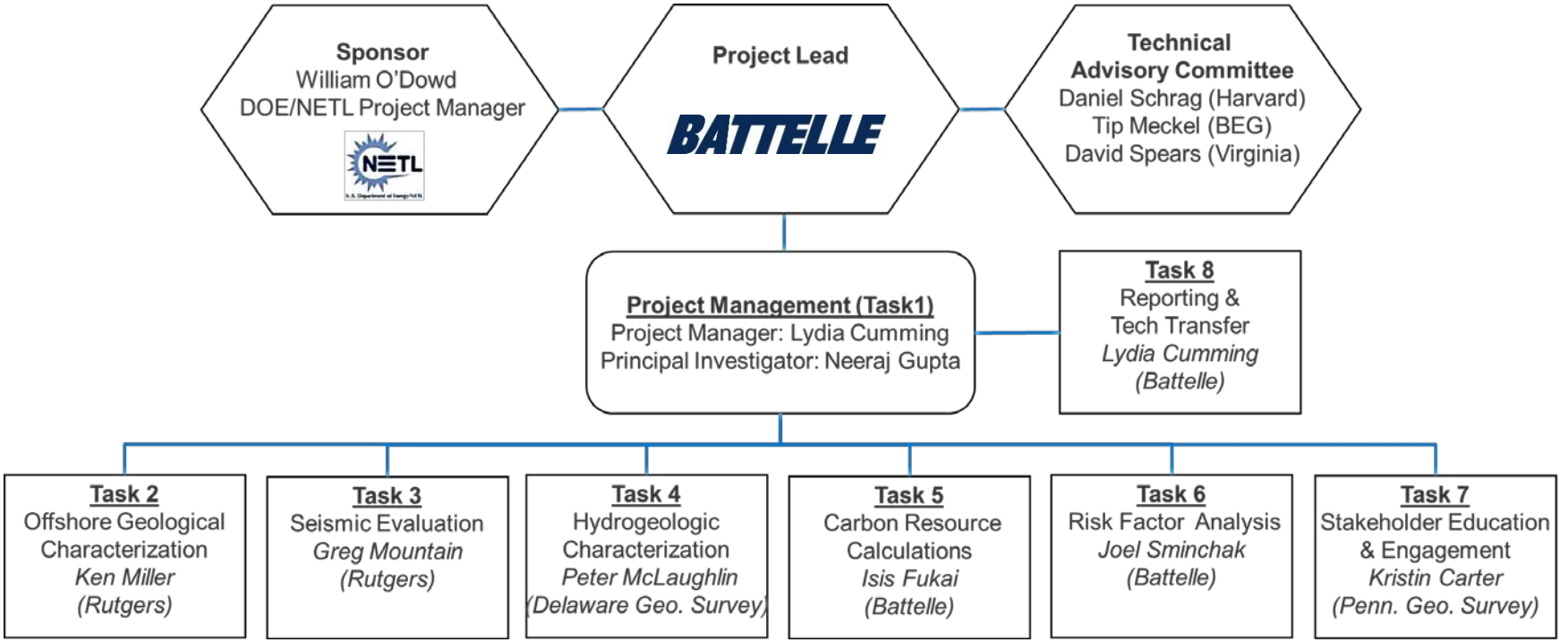
Project overview goals and objectives

Objective: Complete a systematic Carbon Storage Resource Assessment of the U.S. Mid-Atlantic offshore coastal region (Georges Bank Basin - Long Island Platform - Baltimore Canyon Trough)

U.S. Mid-Atlantic Offshore Project Objectives	Carbon Storage Program Goals	
	Support industry's ability to predict storage capacity	Develop Best Practice Manuals
Define geologic characteristics of deep saline formations and caprocks in the Mid-Atlantic offshore study area	✓	✓
Better define continuity of potential storage zones and caprocks via use of seismic data	✓	✓
Catalog hydrologic properties of offshore deep saline formations and caprocks	✓	✓
Estimate Prospective Storage Resource and Storage Efficiency of candidate storage reservoirs	✓	✓
Examine risk factors associated with CO_2 storage in the Mid-Atlantic study area	✓	✓
Engage stakeholders to guide future projects		✓

Project organization and team members

The project consists of 8 tasks, with a diverse team of experts responsible for project implementation



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Project team – a seamless collaboration across multiple institute

- **Lamont Doherty Earth Obs.** - Dave Goldberg, Angela Slagle, Will Fortin
- **Delaware Geol. Surv.** - Pete McLaughlin, Moji KunleDare, June Hazewski, Noam Kessing, David Wunsch
- **Rutgers Univ.** - Greg Mountain, Ken Miller, Stephen Graham, Alex Adams, John Schmelz, Kim Baldwin, David Andreasen, Chris Lombardy (deceased)
- **Maryland Geol. Surv.** - David Andreasen, Andy Staley, Katie Knippler, Richard Ortt
- **Pennsylvania Geol. Surv.** - Kristin Carter, Brian Dunst, Morgan Lee, Ryan Kassak, Danial Reese
- **US Geol. Surv.** - Guy Lang, Uri ten Brink
- **Battelle** - Lydia Cumming, Neeraj Gupta, Martin Jimenez, Andrew Burchwell, Joel Sminchak, Isis Fukai, Jit Bhattacharya, Kathryn Johnson, Judith Straathof, Bryan O'Reilly
- **Advisors** – Daniel Schrag (Harvard), Tip Meckel (TX BEG), David Spears (VA Geo. Surv.)

Technical status

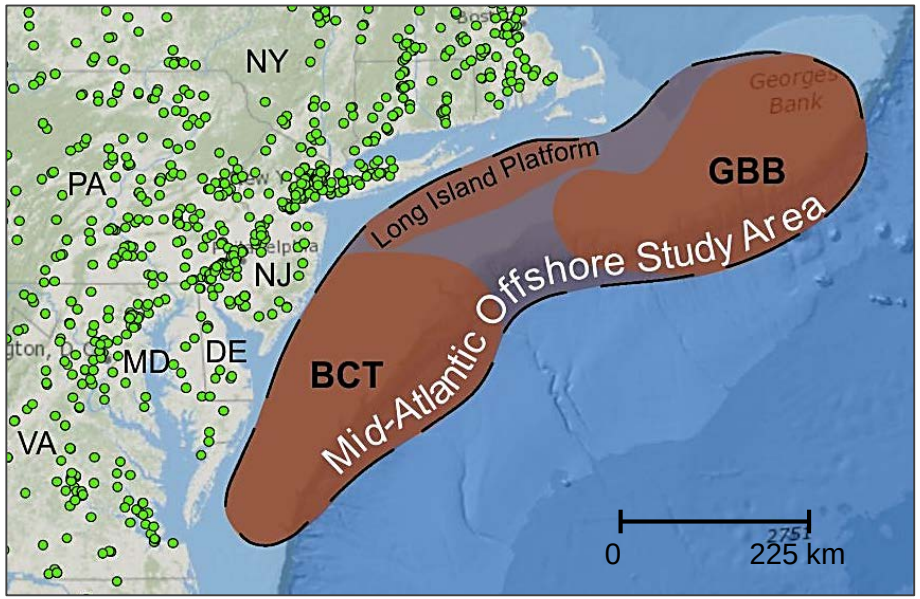
Problem: Geologic resources available for CO_2 storage are not well defined in U.S. State and Federally regulated offshore areas

Solution: Characterize the Prospective Geologic CO_2 Storage Resource of deep saline formations in the U.S. Mid-Atlantic offshore region

- Near numerous CO_2 point sources in northeast U.S. w/few onshore storage options
- Reduced risk to heavily populated areas and underground sources of drinking water

Study Area: ~170,993 km^2

- Three sub-regions: GBB, Long Island Platform, BCT
- Storage potential in Cretaceous sands interbedded with and overlain by shale*



BCT Baltimore Canyon Trough **GBB** Georges Bank Basin

Stationary Sources of CO_2 (U.S. DOE-NETL NATCARB v. 1502)

*Smith et al., 1976; Amato and Bebout, 1980; Slater, 2010; MRCSP, 2011

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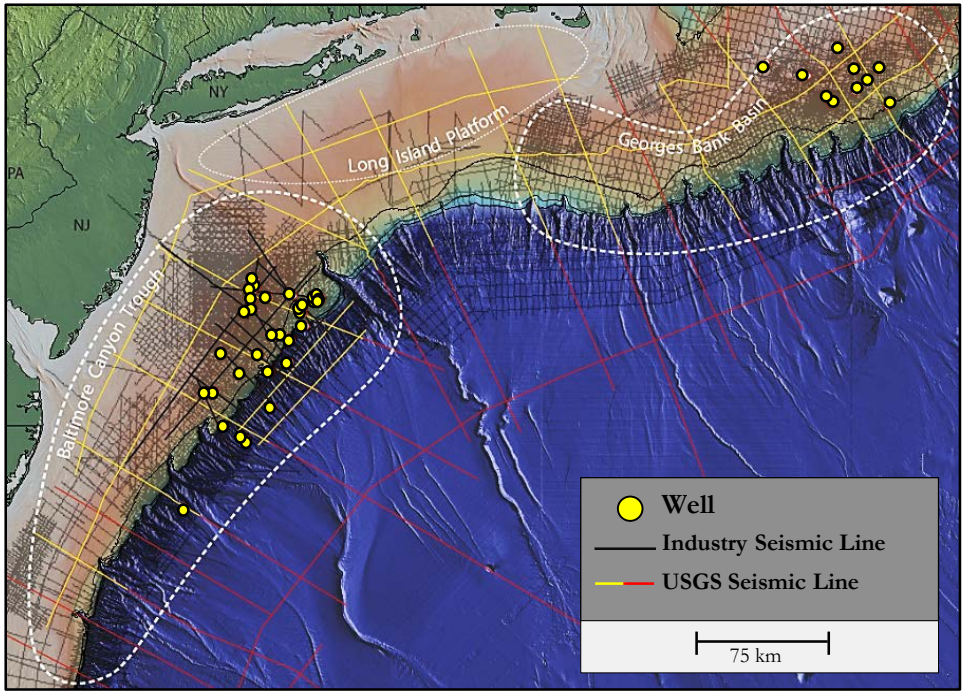
Technical Status: Task 2

A large coordinated group effort was undertaken to categorize & preserve offshore samples and data for geologic characterization

Study area sample inventory & database content:



Sample Inventory

- ~2,300 core samples
- ~5,000 thin-sections
- ~97,000 drill cuttings

Data Compilation

- ~2,500 log files
- >1,000,000 ft. of log data digitized
- 5,973 porosity & 5,729 permeability core data points* from 184 existing reports and publications

*Includes all raw and derived entries reported at all depths for 41out of 44 wells in the study area

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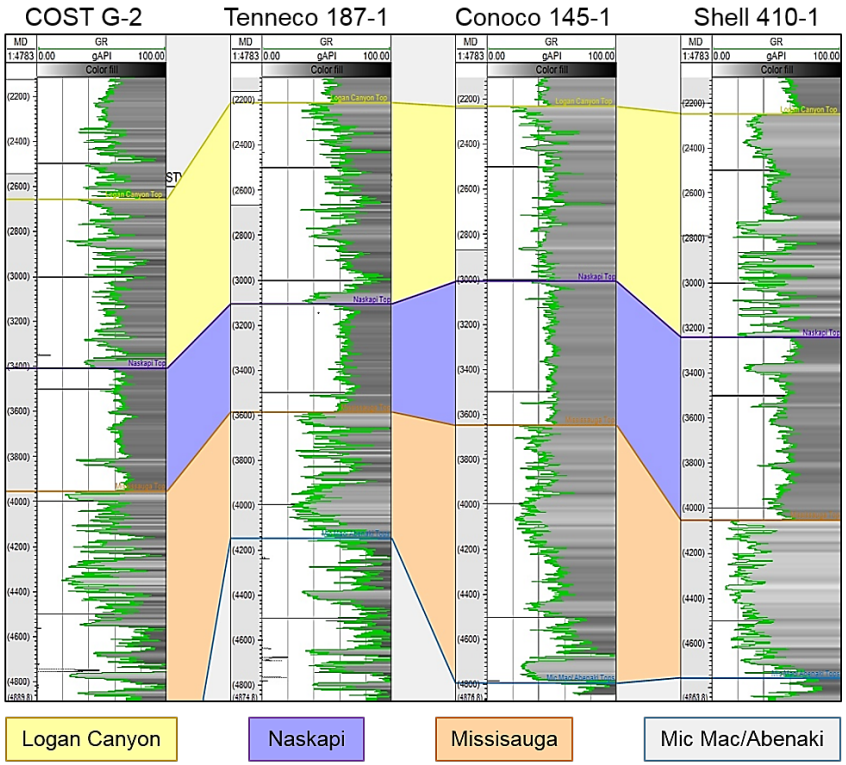
Technical status - Task 2

Geologic characterization of deep saline formations & caprocks is underway to define the geologic storage framework of the region

Lithostratigraphic and sequence stratigraphic approaches integrated to define storage zones



Identified **three** potential storage targets and **four** regional caprocks

Age	Seal or Reservoir	Formation Name*	Depth (ft.)	Thickness (ft.)
Upper Cretaceous	Seal	Dawson Canyon	996 – 6,831	556 – 3,128
	Reservoir	Logan Canyon	2,208 - 9,561	174 - 2,227
Lower Cretaceous	Seal	Naskapi	3,022 – 10,557	49 – 1,481
	Reservoir	Missisauga	3,583 - 10,639	553 - 4,542
Upper Jurassic	Seal	Mic Mac	4,116 - 13,591	331 - 13,591
	Reservoir	Mohawk	4,924 - 15,082	5,274 - 7,742
	Base/Seal	Mohican/Iroquois	≥ 9738	-

Tops picked for all 44 wells in study area

*Based on Libby-French (1984)

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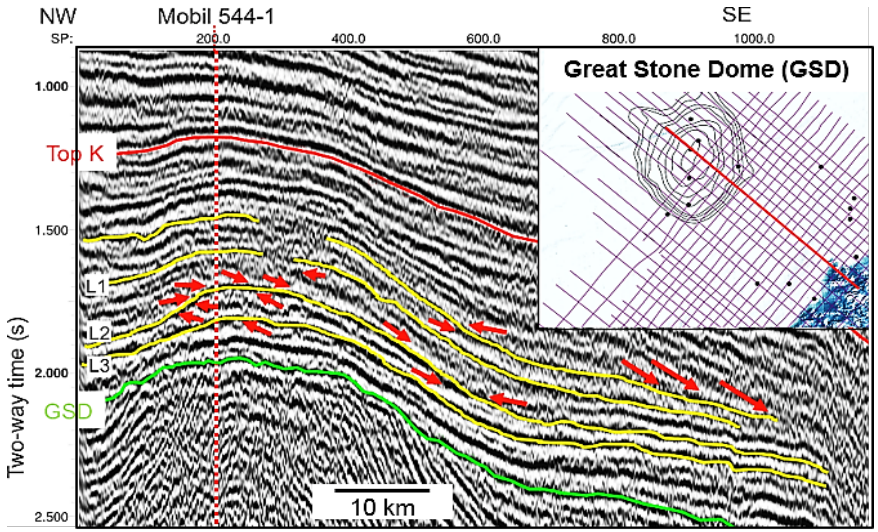
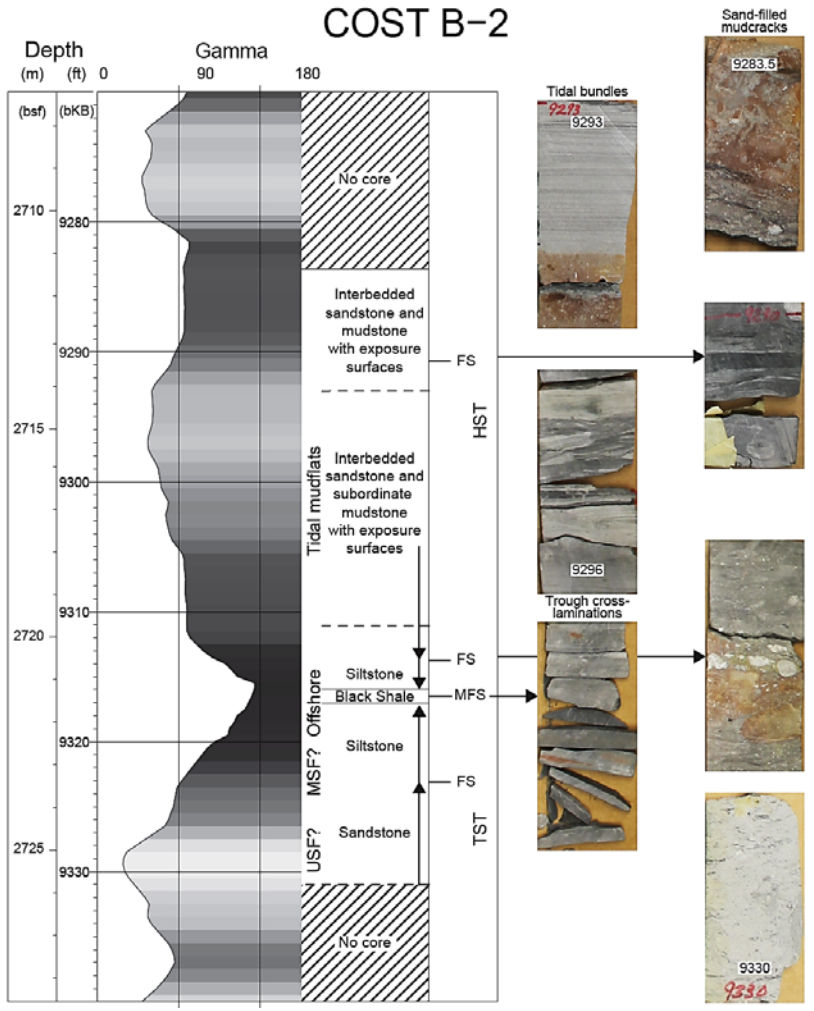
Technical status - Task 2

Subtidal, supratidal, & deltaic deposition of Cretaceous sequences corroborated by core, log, and seismic data

Four sequence boundaries identified in mid-Cretaceous sediments in northern BCT; **thick (≥10 m) sand units well-defined and predictable**



Interpreted seismic profile through the Great Stone Dome in the northern BCT showing terminations (red arrows) and sequence boundaries (yellow lines). Inset location map shows profile as red line.



Sequence stratigraphic interpretation based on correlation of gamma ray log signatures with core facies (Miller et al., submitted)*

*FS: flooding surface; TS: transgressive surface; MFS:Maximum Flooding Surface; TST: Transgressive Systems Tract; HST: Highstand Systems Tract

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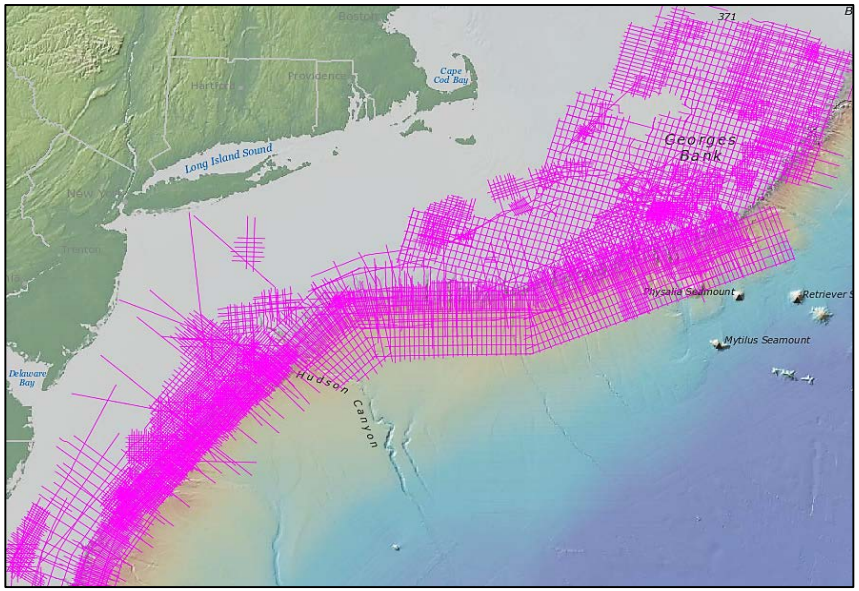
Technical status – Task 3

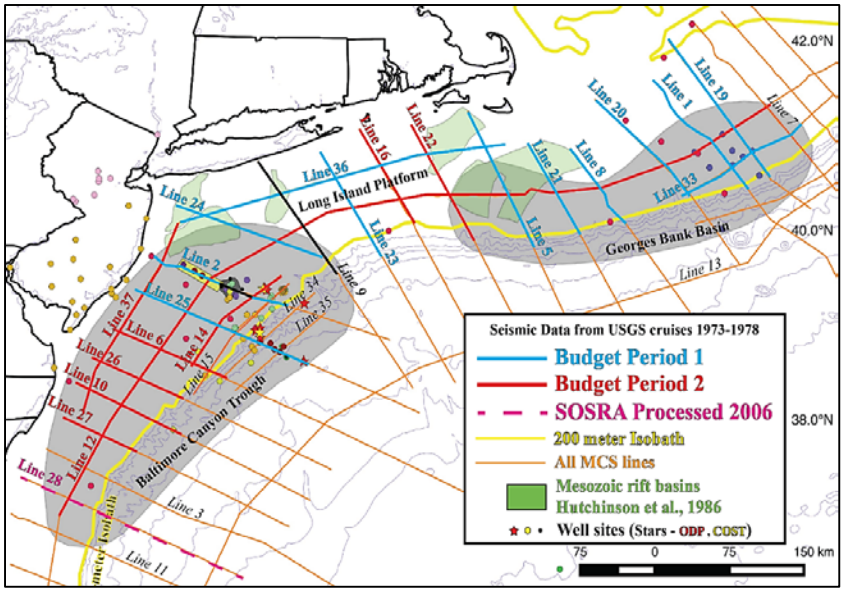
Seismic data is being reprocessed and used to constrain formation geometry, continuity, and geologic structures

Dense grid of existing USGS lines & newly released lines by BOEM & NAMSS*



Grid of newly released seismic lines (pink) available in the study area (from walrus.wr.usgs.gov/namss/search/)

Reprocessing 4,000 km of seismic with modern techniques to enhance resolution



Map showing the reprocessing plan for seismic lines in the study area. **Approximately 2,000 km have been reprocessed to-date.**

*BOEM: Bureau of Ocean Energy Management; NAMSS: National Archive of Marine Seismic Surveys

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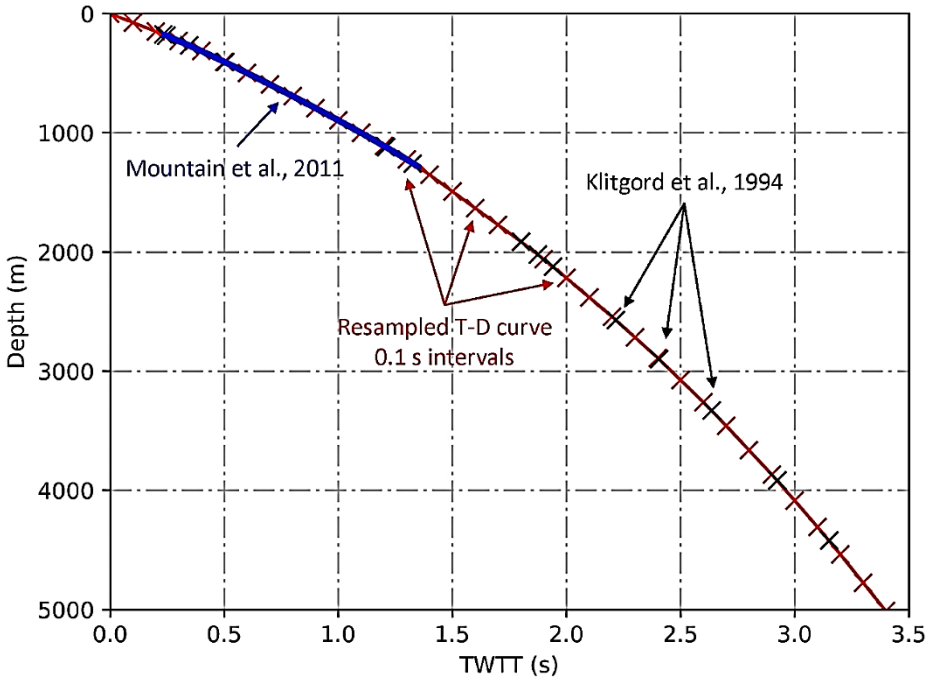
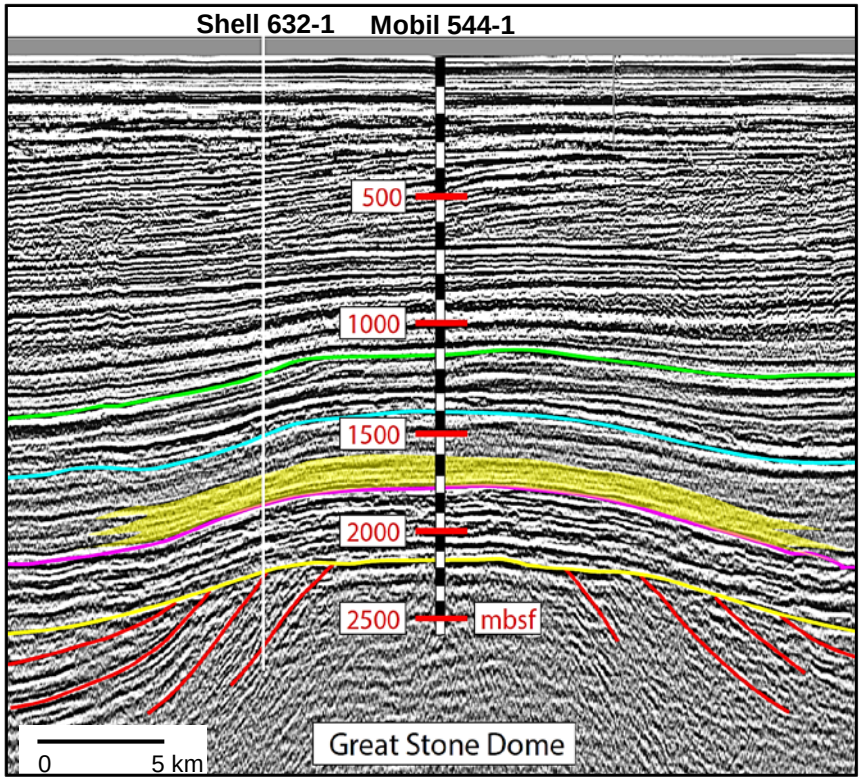
Technical status – Task 3

Time-to-depth conversions are being established via integration of seismic, log, velocity, & checkshot data from 28 wells



Plot of two-way travel time (TWTT) versus depth showing a regional velocity-depth function developed by integrating the top 800 microseconds from Mountain et al. (2010) with the deeper function of Klitgord et al. (1994).



Depth-converted seismic section interpreted across the Great Stone Dome in the northern BCT showing formation tops (colored lines) and potential Logan Canyon storage zone (yellow).

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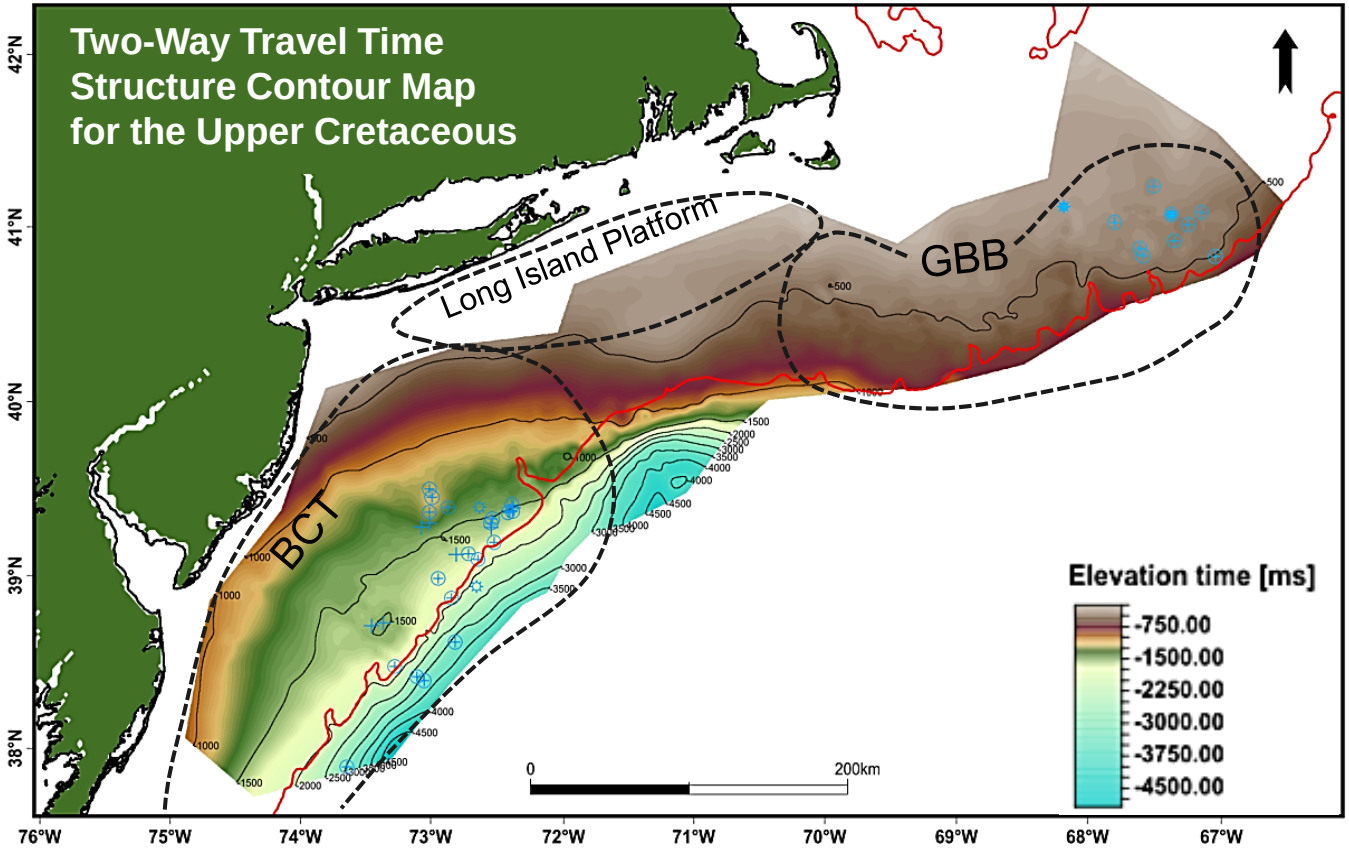
Technical status - Task 3

Maps are being generated to constrain formation geometry and continuity



Chronostratigraphic surfaces traceable across sub-regions: ~67 km in Georges Bank Basin (GBB) and ~80 km in Baltimore Canyon Trough (BCT)

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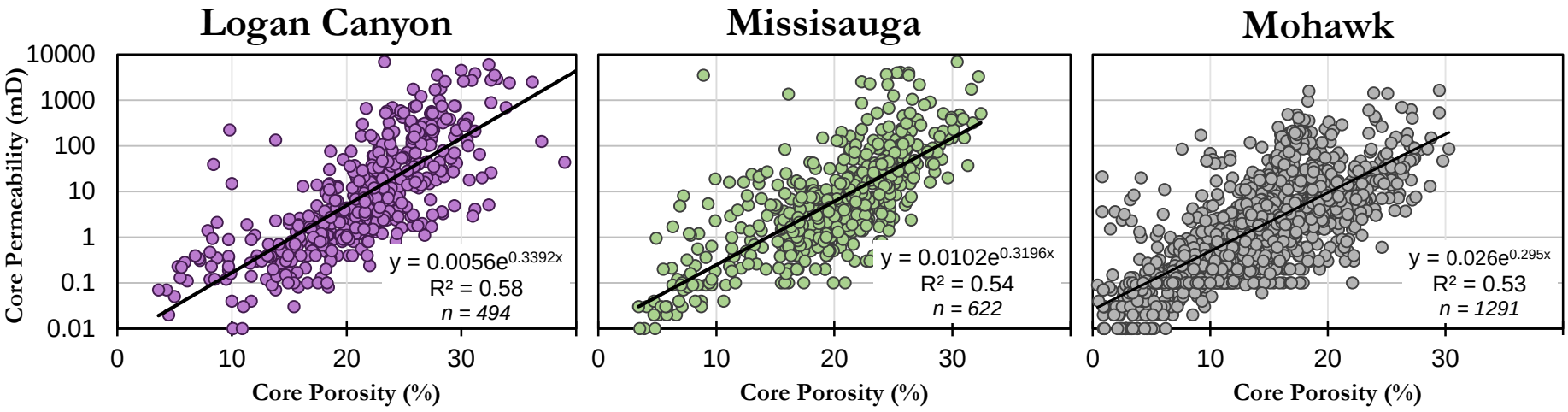
Technical status – Task 4

Hydrologic and petrophysical properties of offshore deep saline formations and caprocks are being cataloged and characterized



Core porosity and permeability data indicate offshore deep saline formations of interest have storage reservoir potential

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Technical status – Task 4

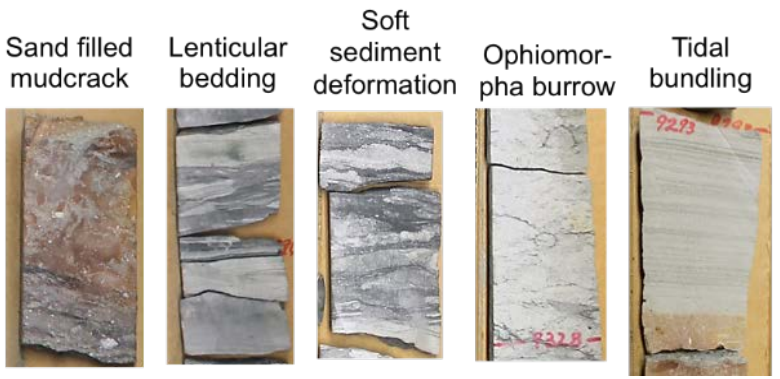
Geologic samples have been selected for laboratory analysis to augment the hydrologic property characterization dataset

Up to 100 geologic core samples selected for (re)analysis: e.g. porosity, permeability, petrography, XRD

- Address data gaps
- Verify & calibrate existing data

New and existing core data used to calibrate log data and calculate petrophysical properties for formations of interest

1: sandstone 2:mudstone



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Technical status – Task 5

Geologic, seismic, and hydrologic data will be integrated to quantify the Prospective Storage Resource and Storage Efficiency of formations

DOE–NETL Volumetric Equation[1]

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

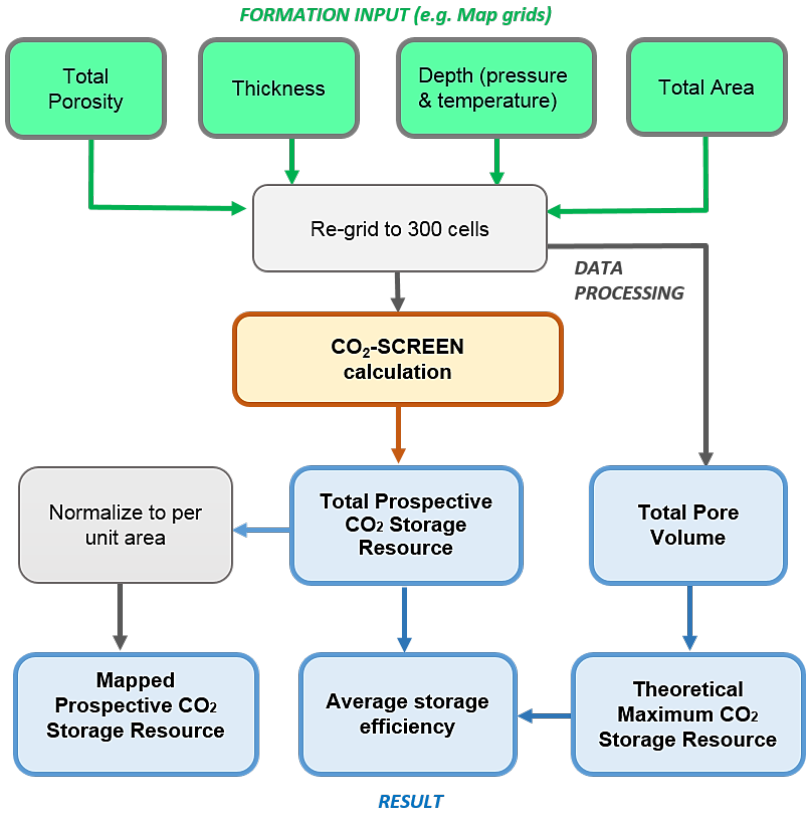
- $A_t\, h_g\, \phi_t$: Total Pore Volume
- ρ_{CO2res}: Fluid Properties
- E_{saline}: Storage Efficiency

DOE–NETL CO_2-SCREEN Tool[2]

Storage Efficiency Input	Auto-populated		User Specified	
	P_{10}	P_{90}	P_{10}	P_{90}
Net-to-Total Area	0.20	0.80	0	0
Net-to-Gross Thickness	0.21	0.76	0	0
Effective-to-Total Porosity	0.62	0.78	0	0
Volumetric Displacement	0.18	0.63	0	0
Microscopic Displacement	0.39	0.82	0	0

Grid cell #	Area* (km^2)	Gross Thickness* (m)		Total Porosity*(%	
	Mean	Mean	Std Dev	Mean	Std Dev
1	109.2	97.1	0.0	4.4	0.0
2	109.2	104.9	0.0	4.5	0.0
3	109.2	116.6	0.0	4.1	0.0
4	109.2	135.1	0.0	3.8	0.0
5	63.8	157.2	0.0	2.9	0.0
6	109.3	76.4	0.0	4.3	0.0
7	109.2	92.6	0.0	5.2	0.0
8	109.2	103.4	0.0	5.6	0.0
9	109.2	110.1	0.0	4.8	0.0
10	109.2	124.0	0.0	3.7	0.0

GCO_2 Results (Mt)			
Grid Cell #	P10	P50	P90
1	2.1	8.4	25.0
2	2.8	10.9	32.4
3	3.1	12.2	36.2
4	0.9	3.6	10.6
5	1.7	6.9	20.4
6	2.1	8.2	24.2
7	2.2	8.8	26.0
8	3.0	11.7	34.6
9	1.4	5.5	16.4
10	0.3	1.4	4.0
Summed CO_2 Total	P10	P50	P90
	564	1,873	4,517



Schematic showing workflow for Prospective Storage Resource calculations for the Mid-Atlantic offshore project

1. DOE-NETL, 2010; 2012; Goodman et al., 2011; 2016
2. Sanguinito et al., 2016; https://edx.netl.doe.gov/organization/co2-screen

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Technical status – Task 6

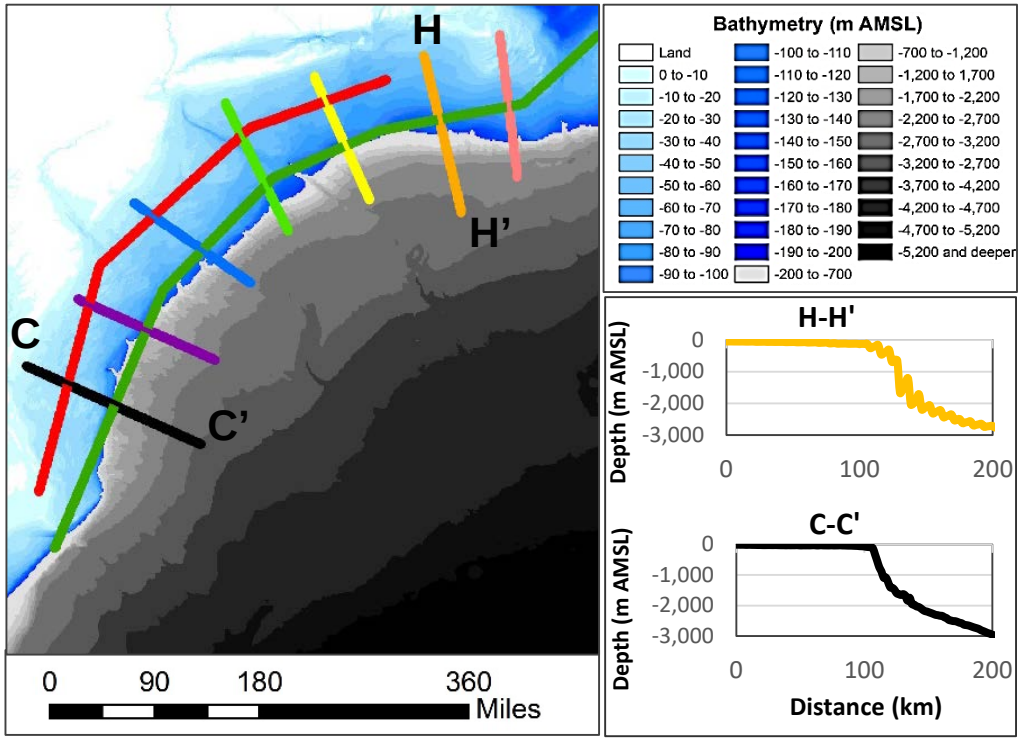
Geologic and long-term risk factors associated with offshore CO_2 storage in the Mid-Atlantic study area will be examined

Geological risk factors:

- e.g. faults, basement structures, seismic activity, slope stability
- Features to be portrayed on study area maps and geologic cross-sections

Long-term risk factors:

- Integrity of confining layers: mineralogy, thickness, hydrologic & geomechanical properties
- CO_2 migration pathways & trapping mechanisms: reverse 'Plinko' flow simulations



Bathymetry map for the study area showing cross-section profiles of the shelf-slope transition in the GBB (H-H'), & southern BCT (C-C').

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Technical status: Tasks 7 & 8

Stakeholder Outreach (Task 7)

- Developed a Project Overview Factsheet and logo
- Preparing a stakeholder list

Technology Transfer (Task 8)

- SECARB Annual Stakeholder Briefings
- CSLF International Workshop on Offshore Geologic CO_2 Storage
- Conferences: CCUS, GHGT, GSA
- Two peer-reviewed publications

MID-ATLANTIC U.S. OFFSHORE CARBON STORAGE RESOURCE ASSESSMENT PROJECT

NETL

U.S. Department of Energy NETL

Project Overview

The greatest potential for carbon storage in the northeastern United States lies in the offshore geologic formations comprising the continental shelf[1]. Offshore storage can be implemented close to large point-sources of carbon dioxide (CO_2) while avoiding many of the logistical difficulties and potential risks encountered when siting onshore projects, especially in densely populated areas of the East Coast. The technical, social and economic factors associated with offshore carbon storage have been discussed in literature[2]. Recent assessments of domestic offshore CO_2 storage suggests a majority of the storage potential is in sandstone and carbonate saline reservoirs, with less potential in depleted oil fields and enhanced oil recovery projects (e.g., Gulf of Mexico), as oil and gas development is currently prohibited in ~87% of U.S. offshore federal water[1,3]. Other potential storage formations, such as basalts, have not been comprehensively assessed, although they may become significant reservoir candidates in the Atlantic and Pacific[1,4].

Internationally, offshore CO_2 storage has been underway in Norway for the past 20 years and considerable research has been completed in countries including Japan, Australia, Brazil, and South Africa. Offshore CO_2 storage assessment and research in the United States is still in its infancy, with significant uncertainty in potential storage resources resulting from a lack of geologic/petrophysical data and other unconstrained variables, particularly in the mid- and north- Atlantic offshore area[1].

Global estimates suggest that 40% of the potential CO_2 storage resource in deep saline aquifers is located offshore in widespread porous and permeable sandstones and shelf carbonates (IEAGHG, 2009).

Given the current knowledge base and access to publicly available data, the objectives of the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project are fourfold: 1) complete a systematic carbon storage resource assessment of the mid-Atlantic Offshore coastal region from the Georges Bank Basin through the Long Island Platform to the southern Baltimore Canyon Trough; 2) define key input parameters to reduce uncertainty for offshore storage resource and efficiency estimates; 3) perform a preliminary assessment of risk factors, uncertainties and data gaps; and 4) engage industry and regulatory stakeholders through development of a road map to assist future project planning and implementation.

Image showing existing core material from the Continental Offshore Stratigraphic Test (COST) wells, which will be correlated with geophysical logs used to characterize rock properties relevant to carbon storage resource assessments

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Accomplishments to date

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CARBON STORAGE RESOURCE
ASSESSMENT PROJECT

- Completed detailed sample inventory and developed comprehensive geologic database for study area
- Characterized key geologic properties of deep saline formations and caprocks, including: depth, thickness, porosity, permeability, sequence stratigraphy
- Surveyed and selected geologic core samples for laboratory analysis to address data gaps and calibration of existing data
- Evaluated and selected legacy seismic data for advanced reprocessing
- Established velocity-depth function for seismic time-to-depth conversions and have initial structure maps of formation continuity
- Began preliminary analysis of CO_2 storage risk factors in study area
- Defined method and workflow for offshore Prospective CO_2 Storage Resource calculations
- Prepared project fact sheet for stakeholder outreach and education

Lessons learned

Research gaps/challenges: data availability & vintage

- Working with relatively old seismic and log data of varying quality and poorly recorded navigation and acquisition parameters
- Disparate reporting methods from different agencies/repositories: e.g. paleontological and sequence stratigraphic interpretations; datums and units
- Only 44 wells in the study area, with localized distribution of log and core data: e.g. Long Island Platform, western GBB, and southern BCT
- Lack of ongoing exploration and production activity in the study area

Technical disappointments: limited no. of intact/indurated cores

Changes to be made in future work: define standards, focus areas

- Standardization of reporting methods, QA/QC procedures, reference datums & units
- Refine calculations/assessment in localized areas based on availability and quality of data & samples

Synergy opportunities

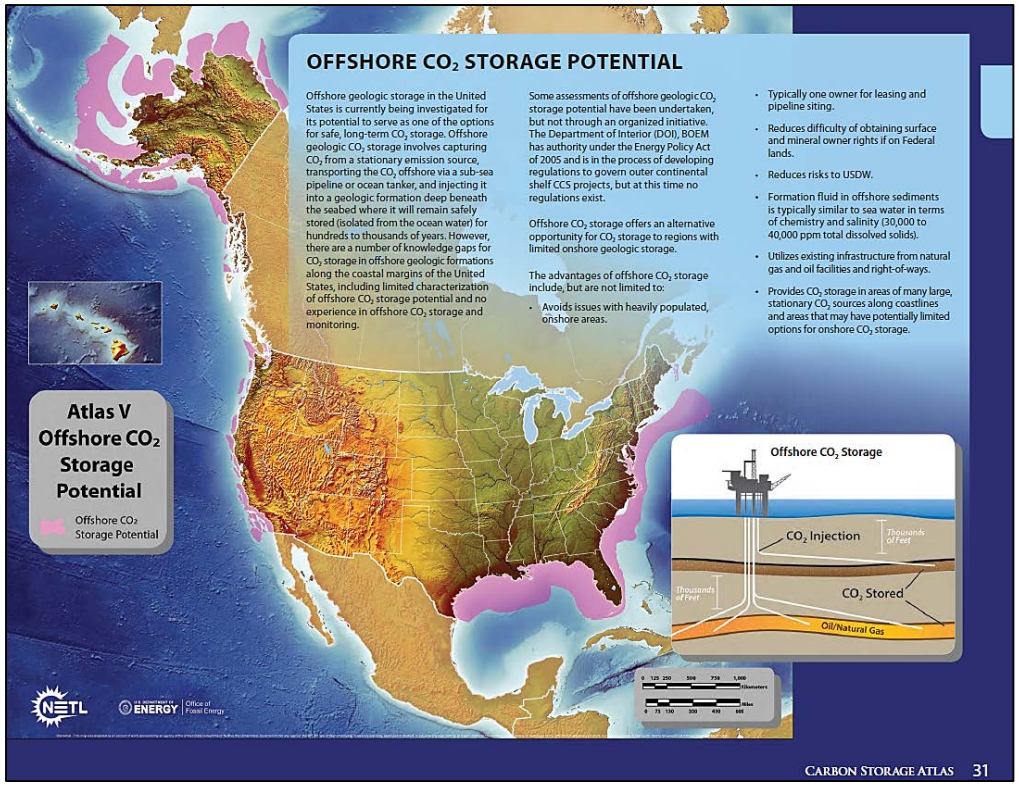
Building on preliminary offshore characterization of MRCSP Program

Collaborating with other DOE Offshore Projects

- Data sharing/exchange with SOSRA
- Project technical advisors from SOSRA & Gulf Coast Projects

Adding to the international pool of offshore CCS information

- CSLF International Offshore Geologic Storage Workshops; World Bank - South Africa



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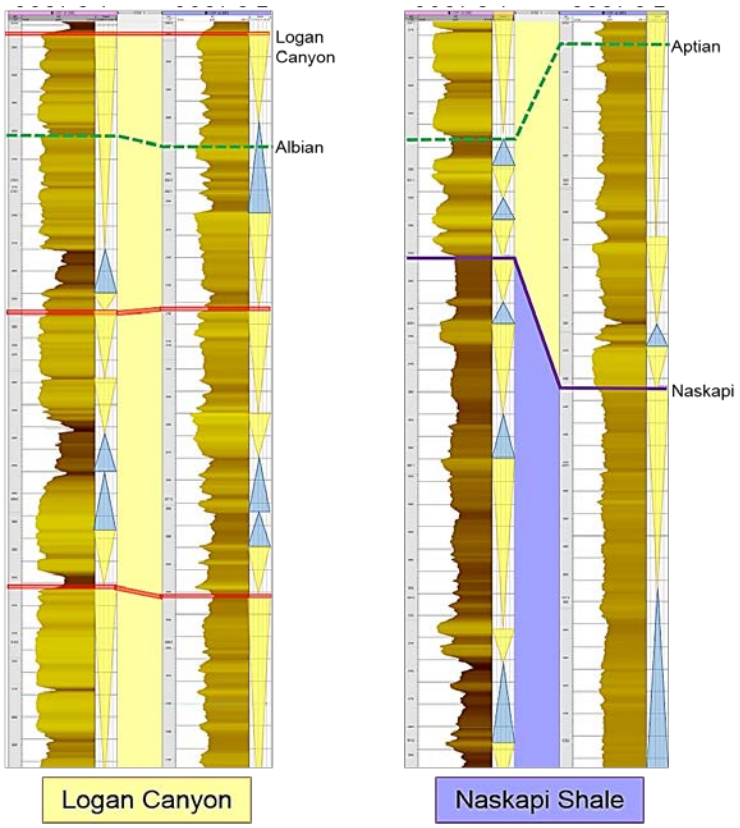
Project summary

MID-ATLANTIC U.S. OFFSHORE CARBON STORAGE RESOURCE ASSESSMENT PROJECT

Key Findings:

- Three deep saline formations and four caprocks identified for potential storage & containment
- Formations have depths, thicknesses, porosities, and permeabilities suitable for CO_2 storage
- Sequence boundaries identified that well-delineate thick sand units in mid-Cretaceous sediments
- Some stratigraphic units can be traced continuously across sub-regions

Next Steps: Risk factor analysis and regional Prospective Storage Resource calculations



Data compiled and results generated as part of this project will help guide future site screening and selection efforts in the study area, address potential technical barriers to offshore CCS, and inform stakeholders, policy & business decisions.

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Appendix

NOTE: Some of these slides are duplicated in the main presentation slide set

Benefit to the program

The project will establish a Prospective Storage Resource Assessment in offshore regions along the mid-Atlantic and northern states in the U.S. The key outcomes include: (1) a systematic carbon storage resource assessment of the offshore mid-Atlantic coastal region, (2) development of key input parameters to reduce uncertainty for offshore storage resource calculations and efficiency estimates, (3) evaluation of risk factors that affect storage resource potential, and (4) industry and regulatory stakeholder outreach to assist future projects.

Characterization of deep saline formation geologic and hydrologic properties, evaluation of risk factors, and estimation of Prospective Storage Resource at the P10, P50, and P90 percentiles for Mid-Atlantic offshore study area will contribute to the Carbon Storage Program's effort to support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent (Goal).

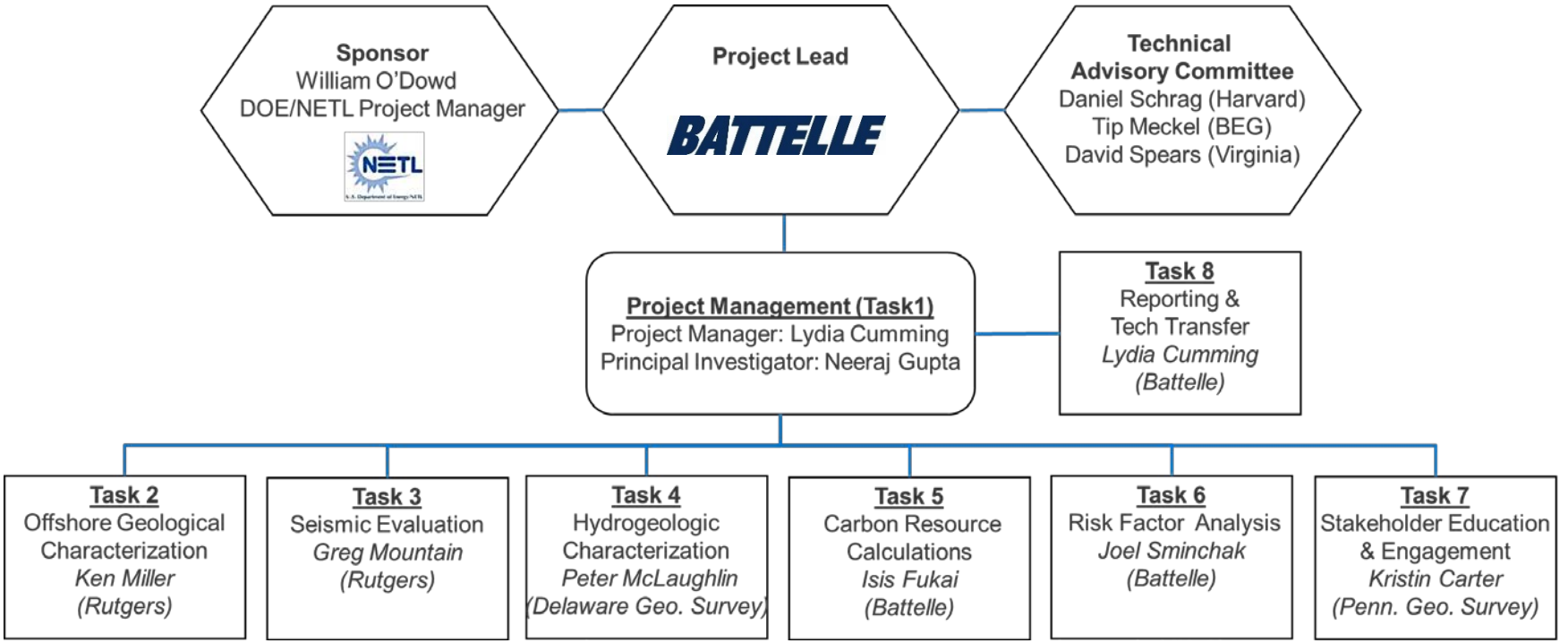
The overall workflow and results established by this project along with stakeholder outreach efforts will also aid in development of Best Practice Manuals for Site Screening, Selection, and Initial Characterization; Outreach; and Risk Analysis (Goal).

Project overview goals and objectives

Objective: Complete a systematic Carbon Storage Resource Assessment of the U.S. Mid-Atlantic offshore coastal region (Georges Bank Basin - Long Island Platform - Baltimore Canyon Trough)

DOE Carbon Storage Program Goal	U.S. Mid-Atlantic Offshore Project Objectives	Success Criteria
Support industry's ability to predict CO_2 storage capacity	Geologic characterization of potential offshore storage zones in the Mid-Atlantic study area	Constrained study to areas with realistic storage potential based on depth and thickness criteria, and presence of CO_2 containment mechanisms
	Use seismic data to better define continuity of offshore deep saline formations and caprocks	Evaluated and selected seismic data for additional processing
	Catalog hydrologic properties of offshore deep saline formations and caprocks	Surveyed available geologic cores for the study area and selected samples to undergo hydraulic tests and laboratory measurements
	Integrate data to estimate Prospective Storage Resource and Storage Efficiency of candidate storage reservoirs	Determined suitable carbon storage resource calculation method and workflow for offshore study area/formations
Develop Best Practice Manuals	Examine risk factors associated with CO_2 storage in the Mid-Atlantic study area	Provide an initial assessment of offshore geological risk factors and long-term CO_2 storage risk factors
	Engage stakeholders to guide future projects	Prepare a stakeholder list and project fact sheet for education and engagement

Organization chart



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Gantt chart

Budget Period	BP1						BP2					
Task Name	FY2016				FY2017				FY2018			
	Q1	Q2	Q3	Q4	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 Project Controls												
1.4 NEPA Reporting												
Task 2: Offshore Geologic Characterization												
2.1 Data Compilation and Synthesis												
2.2 Correlation of Seismic Data with Well Logs												
2.3 Well Log Analysis												
2.4 Formation Maps and Cross-Sections						★						
Task 3: Seismic Evaluation												
3.1 Seismic Processing												
3.2 Seismic Interpretation												
3.3 Integration of Seismic Data									★			
Task 4: Hydrologic Properties Characterization												
4.1 Hydrologic Props Data Collection & Testing												
4.2 Calibration of Logs with Test Data.												
4.3 Num. Simulation Valid. Runs for Loc.Areas									★			
Task 5: Carbon Storage Resource Calculations												
5.1 Local Resource Calculations												
5.2 Regional Resource Calculations										★		
Task 6: Risk Factors for Mid-Atlantic Offshore Areas												
6.1 Offshore Geological Risk Factors												
6.2 Long Term Storage Risk Factors											★	
Task 7: Stakeholder Education & Engagement												
7.1 Mid-Atlantic Stakeholder Education												
7.2 Industrial Stakeholder Activities												
7.3 Technology Communication Activities												
Task 8: Reporting and Tech Transfer												

- duration of task ★ - milestone - work completed to-date

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