Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment DE-FE0026087

Neeraj Gupta, Senior Research Leader

Environment & Infrastructure, Battelle

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
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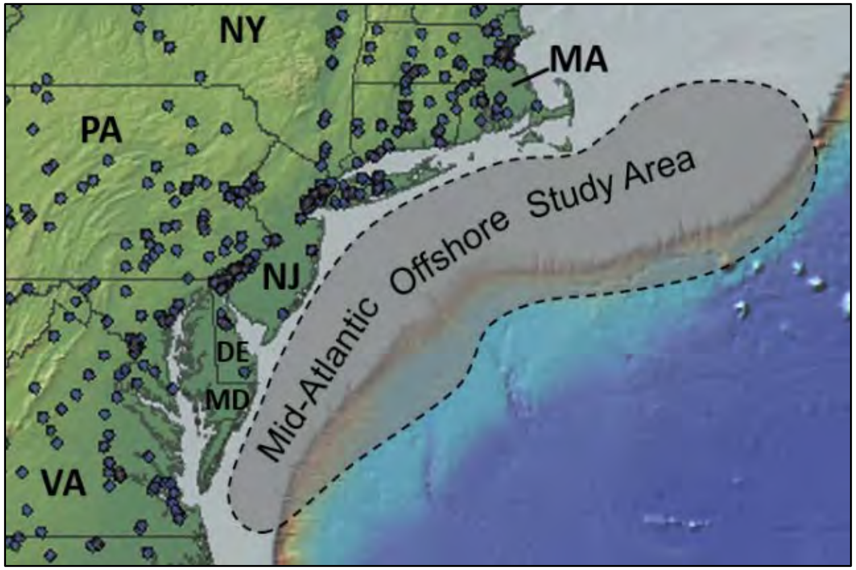
Presentation outline

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



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

Project overview goals and objectives

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		✓

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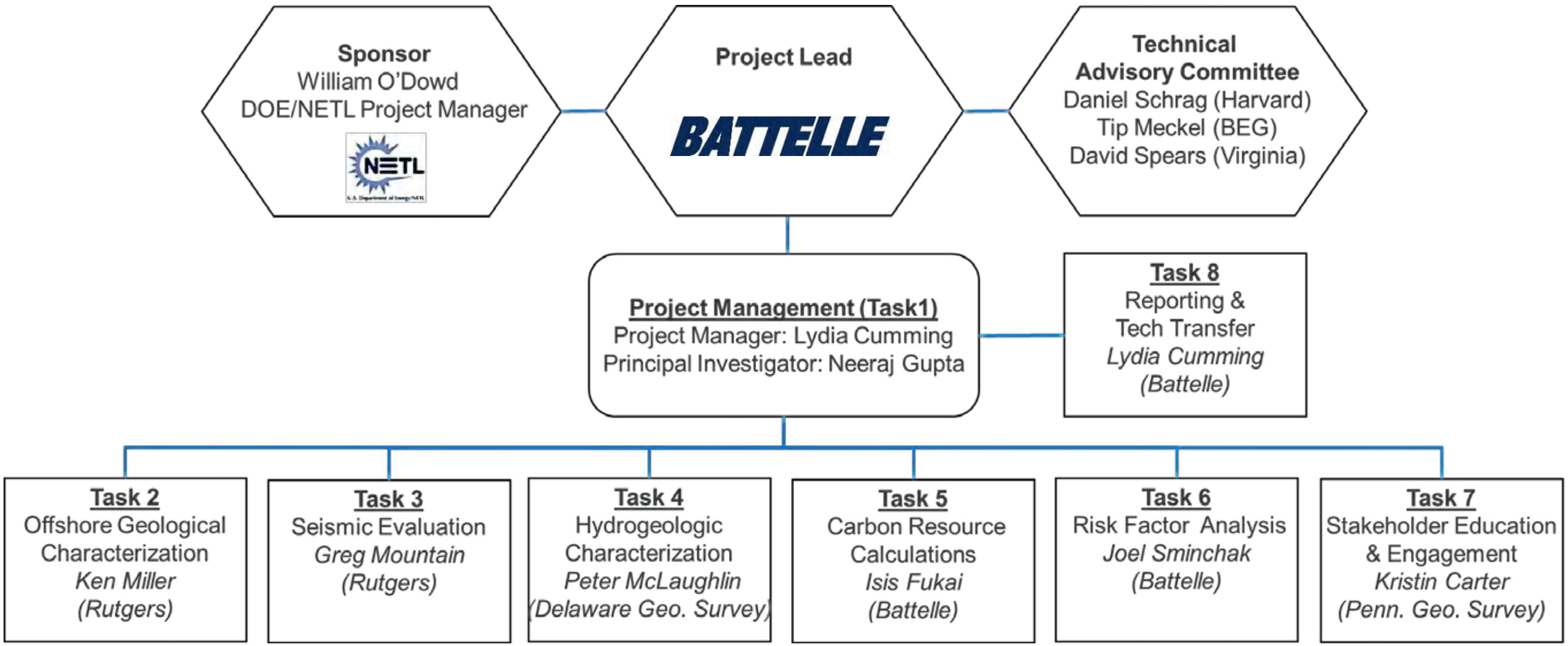
Project organization and team members

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



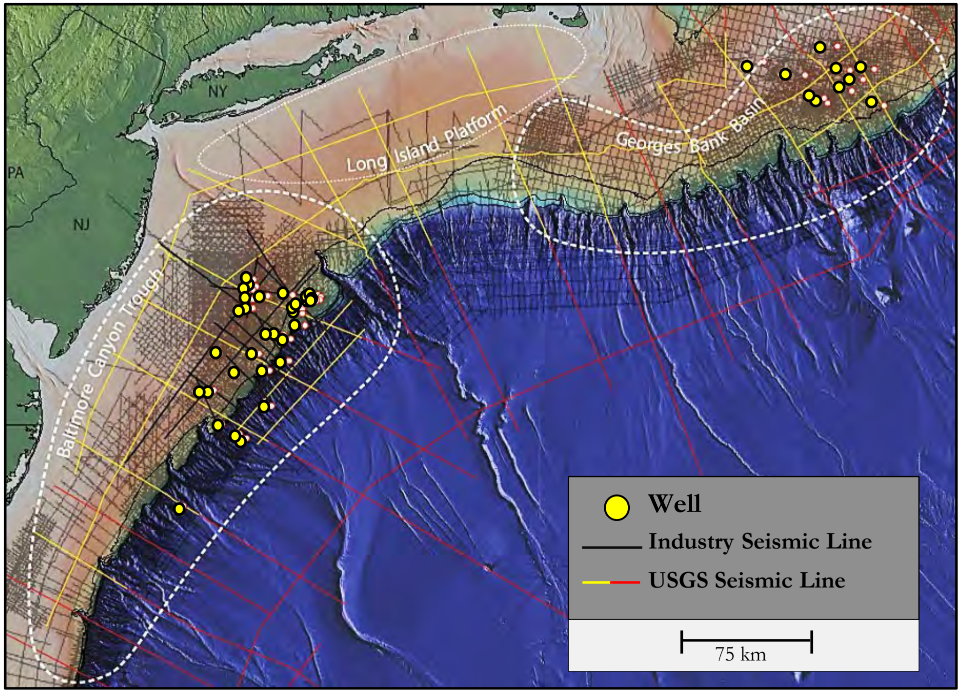
Project team – collaborating across multiple institutes

- **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.)

Task 2 - Geologic Characterization

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

Three sub-regions: Georges Bank Basin (GBB); Long Island Platform; Baltimore Canyon Trough (BCT)



Sample and data inventory:

Sample Inventory

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

Data Compilation

- ~2,500 log files
- >1,000,000 ft. 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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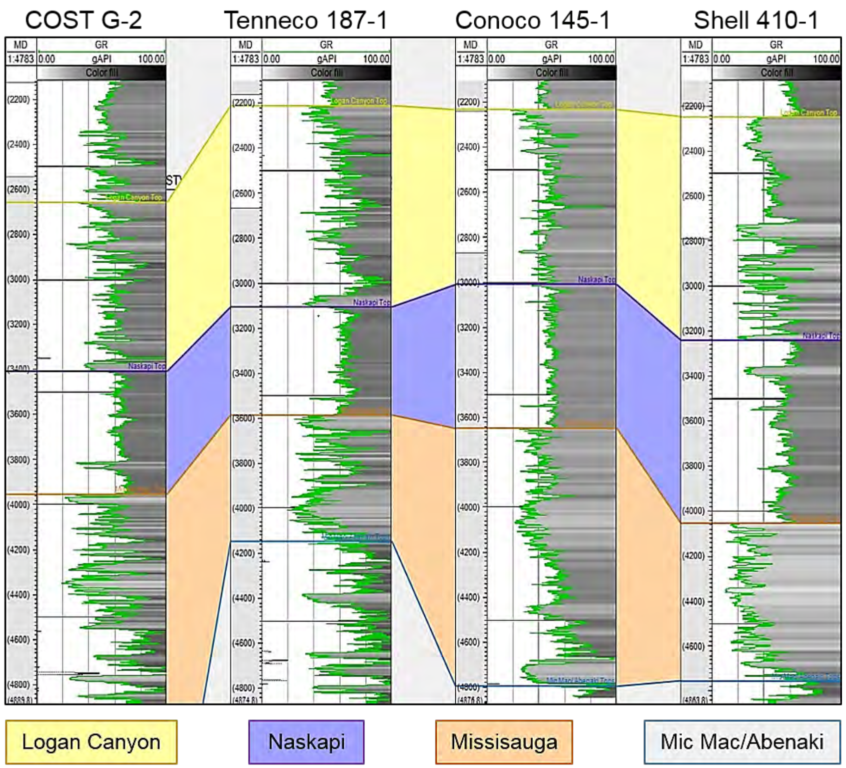
Task 2 - Geologic Characterization (cont.)

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	-

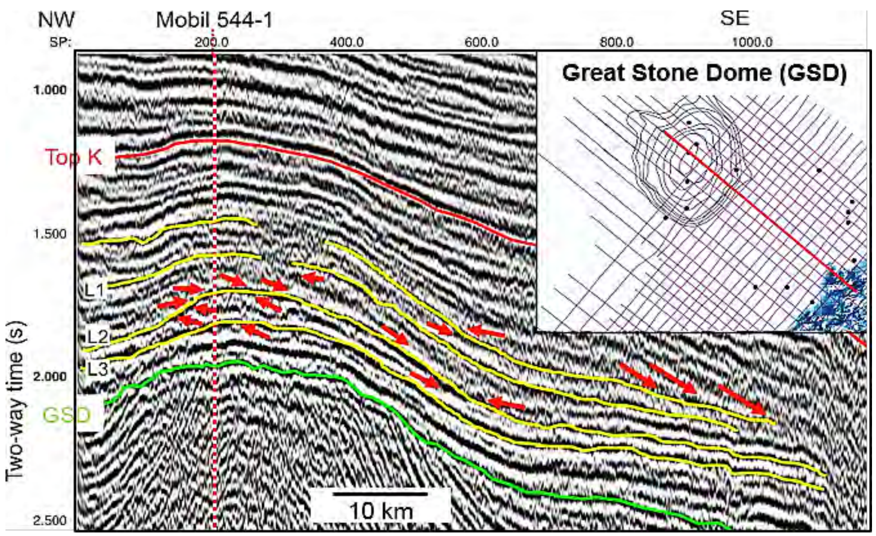
Tops picked for all 44 wells in study area

*Based on Libby-French (1984)

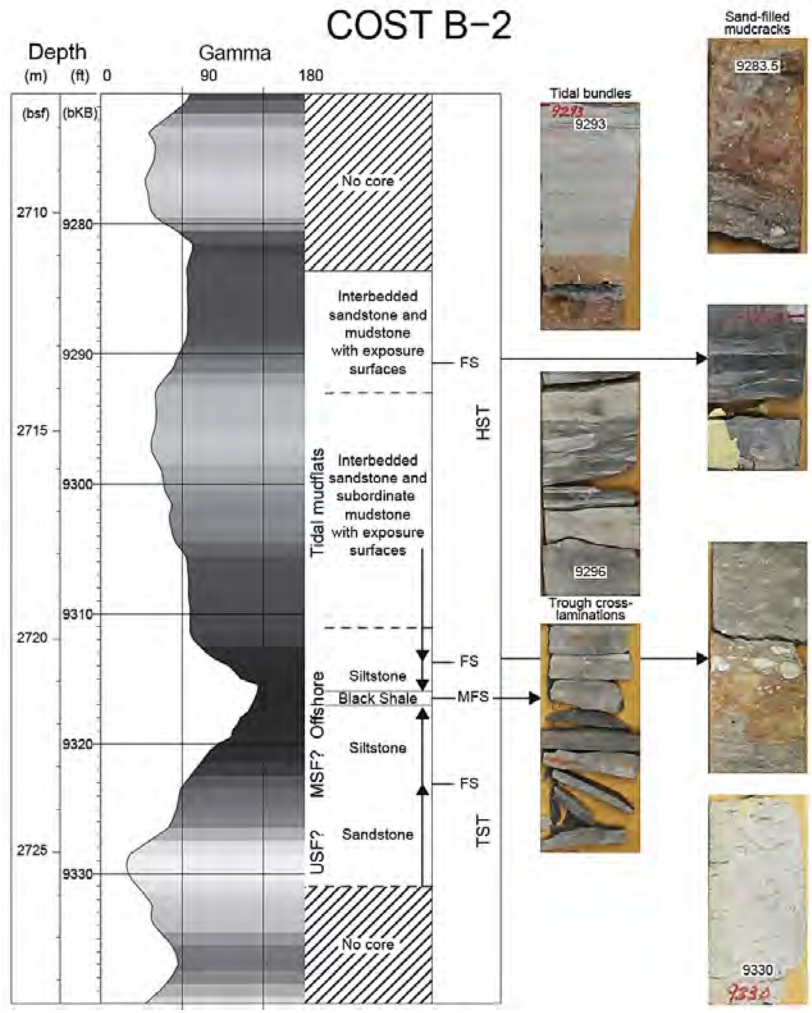
Task 2 - Geologic Characterization (cont.)

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.



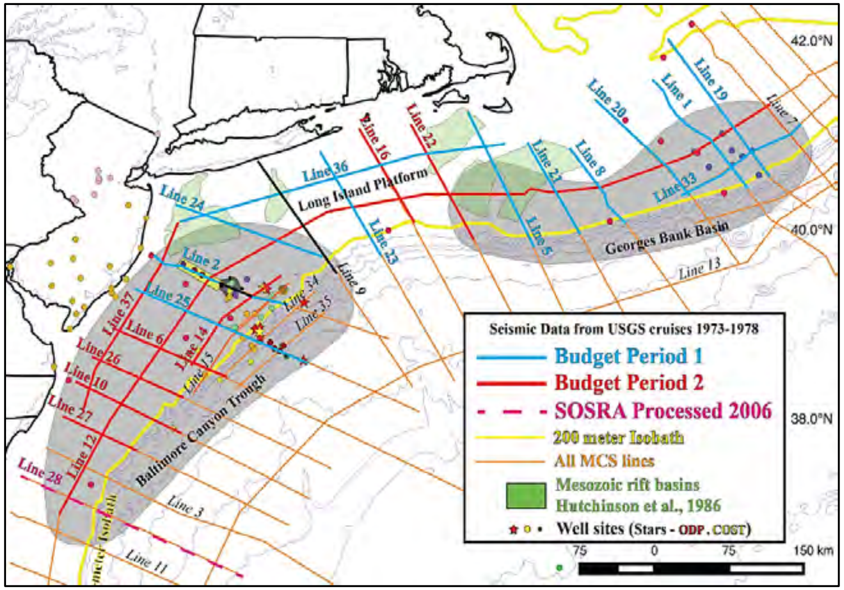
Sequence stratigraphic interpretation based on correlation of gamma ray log signatures with core facies (Miller et al., submitted)*

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

Task 3 – Seismic Evaluation

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

- Completed reprocessing 4,000 km of seismic with modern techniques to enhance resolution
- Time-to-depth conversions were established via integration of seismic, log, velocity, & checkshots
- Maps were created to constrain formation geometry and continuity (discussed further in Task 5)



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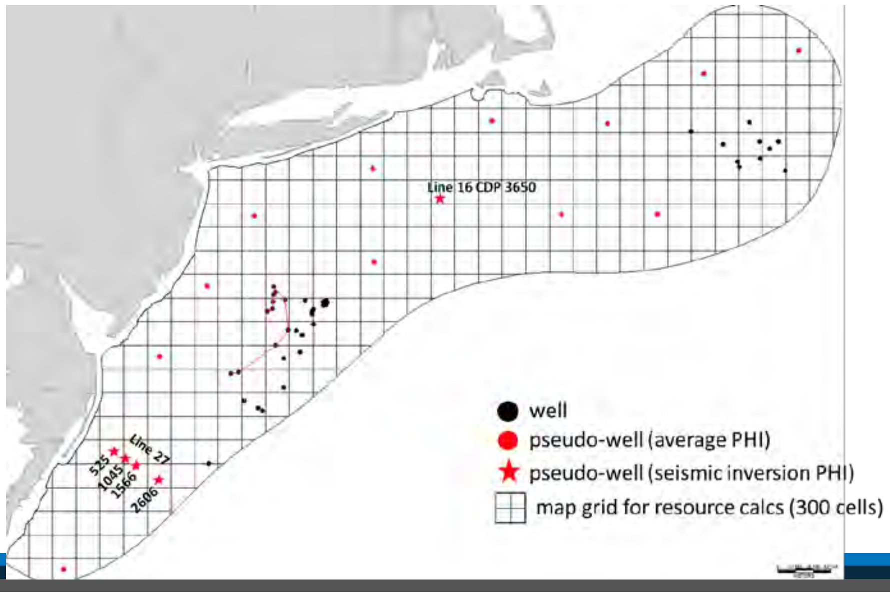
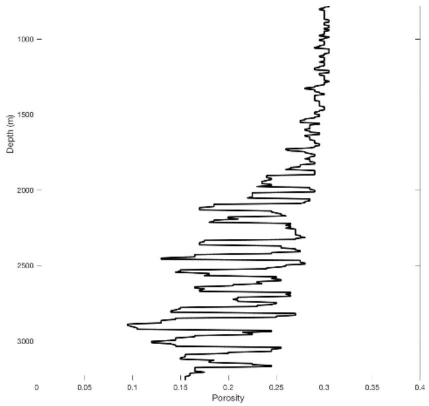
Task 3 – Seismic Evaluation (cont.)

- New data processing capabilities and seismic inversion techniques are being used to for improvements in data quality, velocity determination, and stratigraphic interpretations. May be used to:
  - Identify rift basins, and pre-rift structures between Delaware and Massachusetts (Long Island Platform)
  - Differentiate petrophysical properties and characterize the stratigraphy – pseudo-wells using seismic inversion may help fill porosity gaps for Task 5



Trial pseudo-well using seismic inversion



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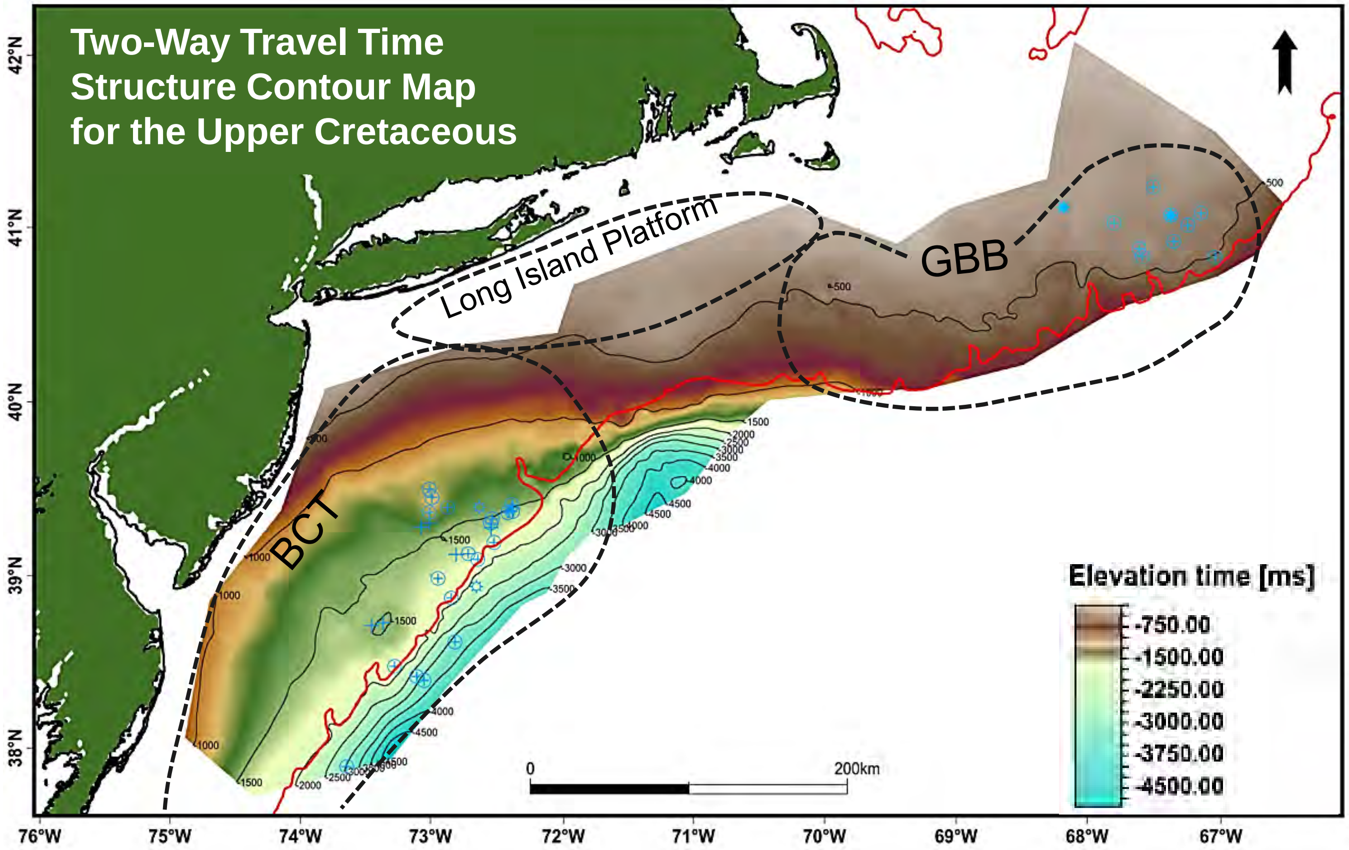
Task 3 – Seismic Evaluation (cont.)

Maps 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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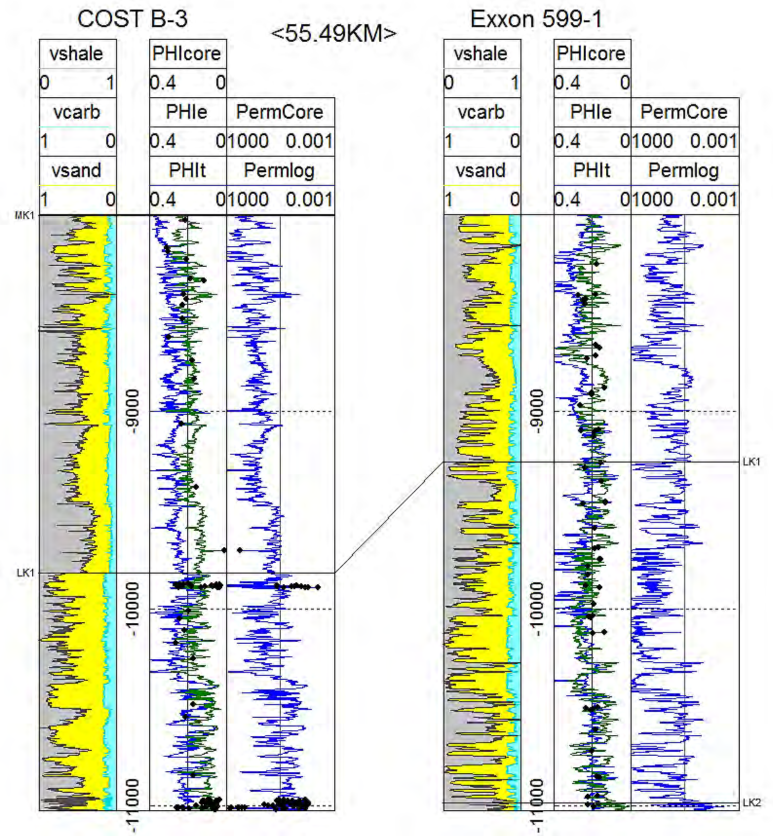
Task 4 – Hydrogeologic Characterization

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

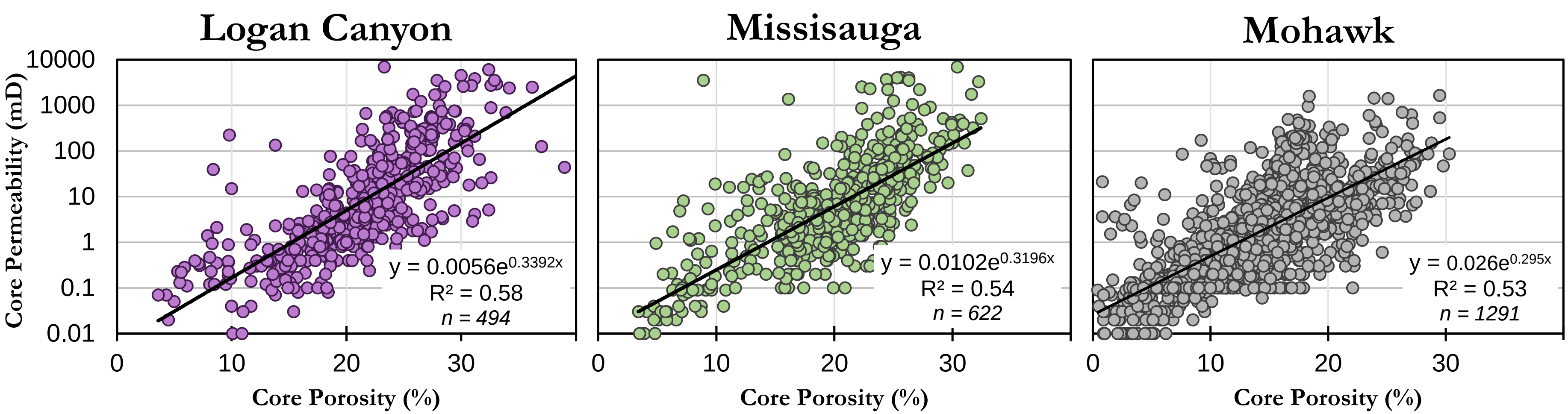
- Completed new sample analysis and prepared the Hydrologic Properties Data Package Report
  - Petrography results (76 XRF, 75 XRD, 18 SEM analysis points and 85 thin sections) as well as 40 new data for porosity, permeability and grain density were added to the legacy data
- Integrate hydrologic properties with well log analyses in Task 5



Examples total porosity (PHIt), effective porosity (PHIe), and permeability logs with core data for porosity and permeability

Task 4 – Hydrogeologic Characterization (Cont.)

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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Task 5 – Storage Resources

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

DOE–NETL Volumetric Equation

$$G_{CO2} = \underbrace{A_t\, h_g\, \phi_t}_{\text{Total Pore Volume}}\ \underbrace{\rho_{CO2res}}_{\text{Fluid Properties}}\ \underbrace{E_{saline}}_{\text{Storage Efficiency}}$$

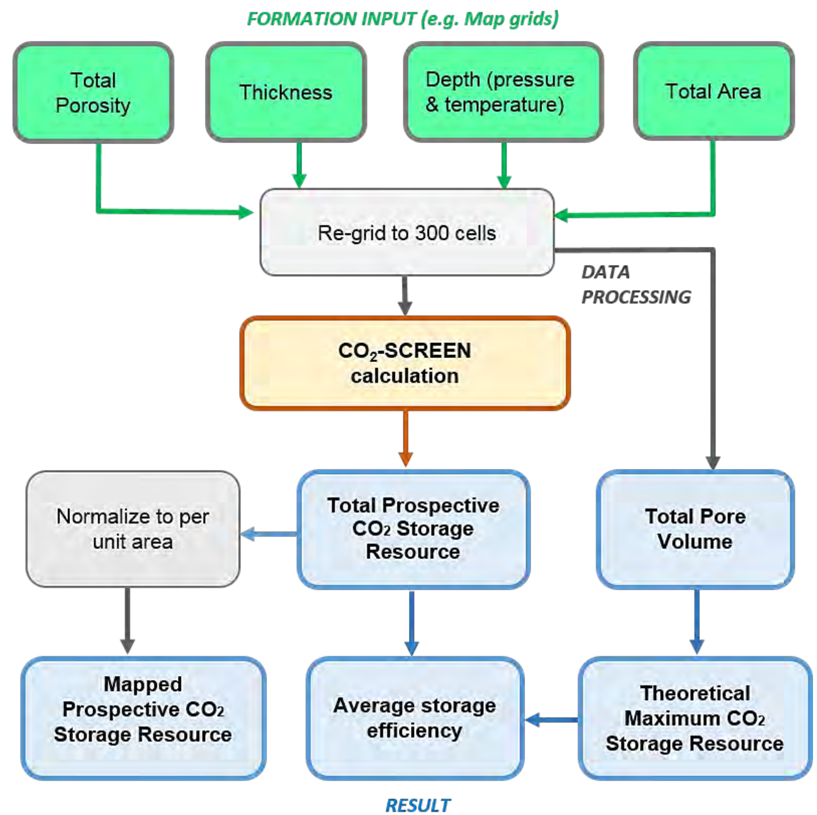
DOE–NETL CO_2-SCREEN Tool*

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

Carbon Storage Resource Assessment Workflow



*Sanguinito et al., 2016; https://edx.netl.doe.gov/organization/co2-screen

Task 5 – Storage Resources (cont.)

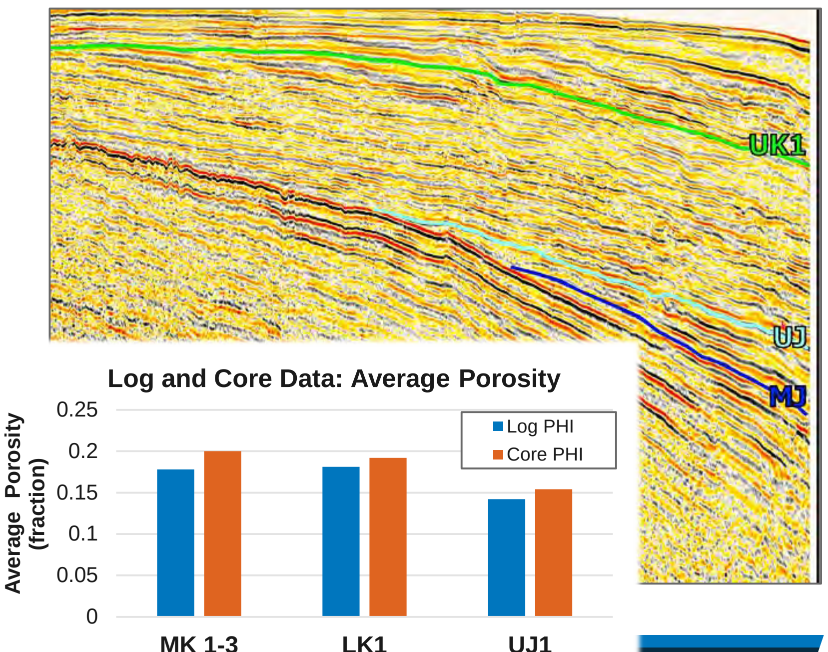
- Completed the stratigraphic correlations of tops and bases, defining three storage zones and three caprocks in the GBB, and three storage zones and two caprocks in the BCT
- Conducted thorough correlation, comparison, and integration of core, log, seismic, and bio/sequence stratigraphic data to ensure consistency and optimal usage of data

Georges Bank Basin

Period	Epoch	Stage	~Age (Ma)	Seismic Surface	Task 5 Zone	Equivalent Formation Top
Cretaceous	Late	Coniacian	86	UK1		Dawson Canyon
		Turonian			UK1	
		Cenomanian	100	MK1		Logan Canyon
	Early	Albian		*MK2*	MK 1-3	*Logan Canyon 2*
				MK3		*Logan Canyon 3*
		Aptian	126	MK4		Naskapi
					MK4	
		Barremian	129	LK1		Missisauga
						Miss 2
		Hauterivian			LK1	*Miss 3*
		Valanginian	139	LK2		Mic-Mac
		Berriasian			LK2	
Jurassic	Late	Tithonian				
		Kimmeridgian	152	UJ1		Mohawk
		Oxfordian			UJ	
	Middle	Callovian	164	MJ1		Mohawk base

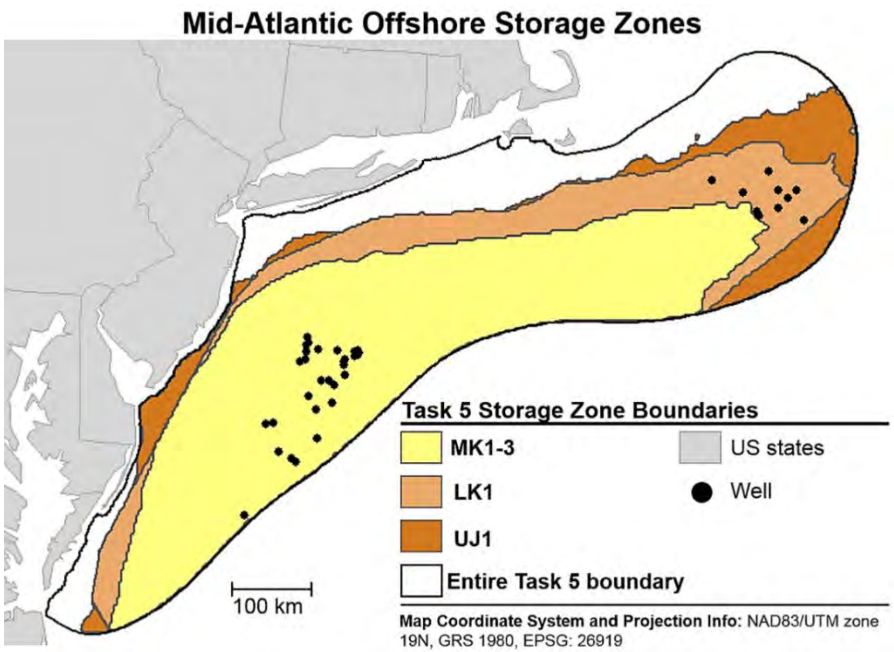
not to scale

shale - above supercritical depth
sandstone - above supercritical depth
shale/caprock
sandstone/storage zone
approximate/inferred



Task 5 – Storage Resources (cont.)

- Finalized the screening criteria to be used to provide areal and vertical constraints on the boundaries of the storage resource calculation
- Decided to conduct the storage resource estimate across the entire study region for each storage zone (rather than by sub-region/basin);



Map of the Mid-Atlantic offshore study area showing zone boundaries determined by screening criteria: Submerged Lands Act boundary, data limits, depth cut-off

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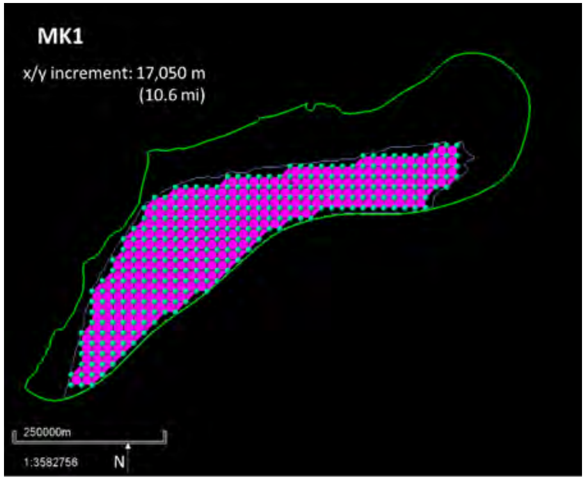
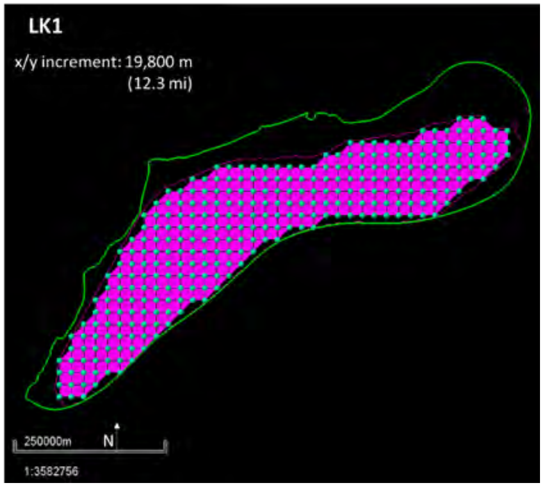
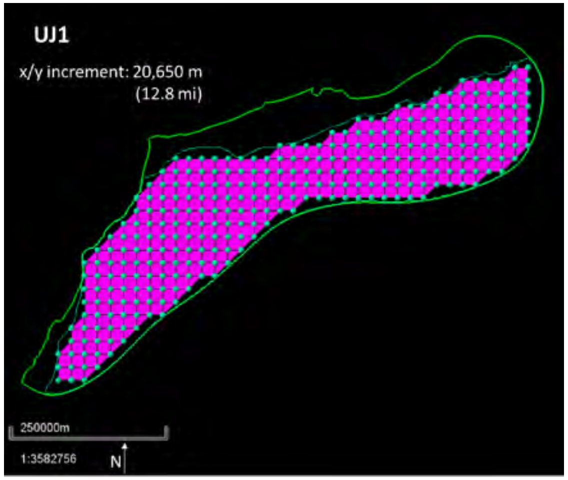
Task 5 – Storage Resources (cont.)

- Generated map grid data for storage zone calculations

Interval	Horizons		Property to export		
MK1/Logan Canyon Fm.	Top horizon	MK1	depth	thickness	porosity
	Base horizon	LK1	none		
LK1/Missisauga Fm.	Top horizon	LK1	depth	thickness	porosity
	Base horizon	UJ1	none		
UJ1/Mohawk Fm.	Top horizon	UJ1	depth	thickness	porosity
	Base horizon	MJ1*	none		



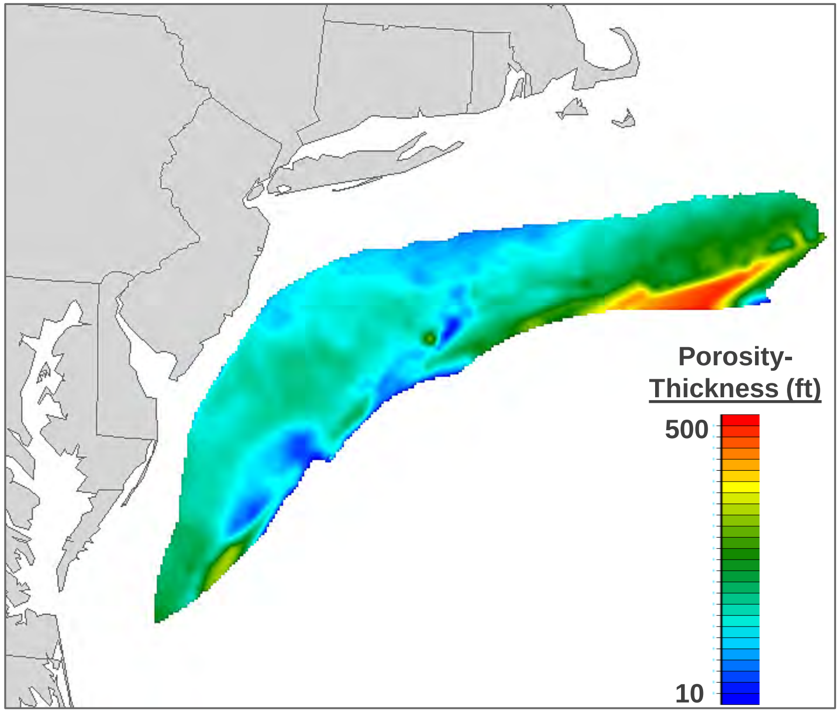




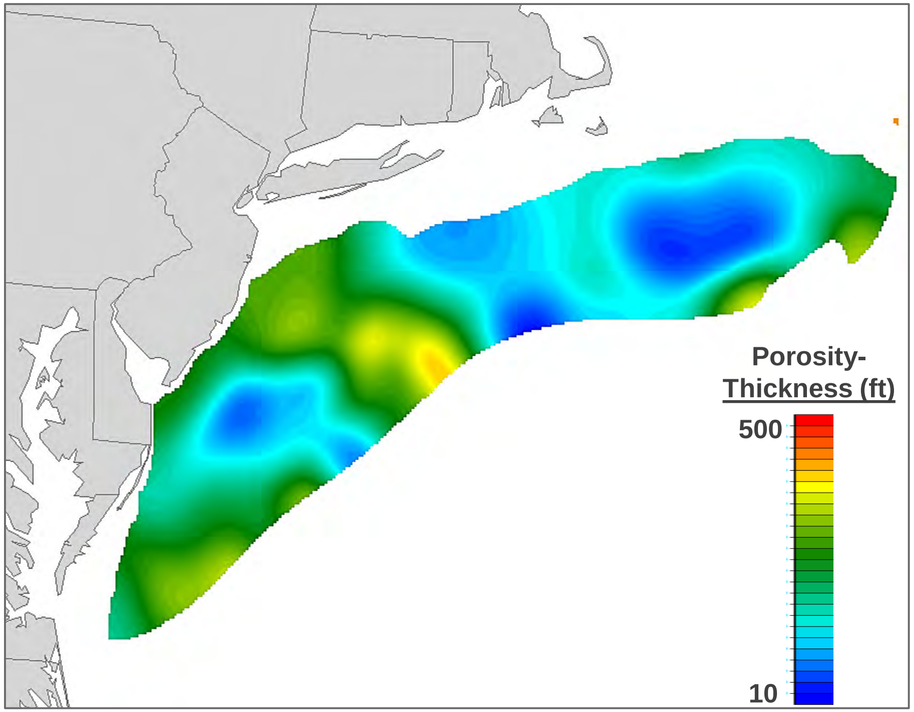
Task 5 – Storage Resources (cont.)

- Generated storage zone map grid data for volumetric calculations

MK 1-3 Porosity Thickness Map



LK1 Porosity Thickness Map



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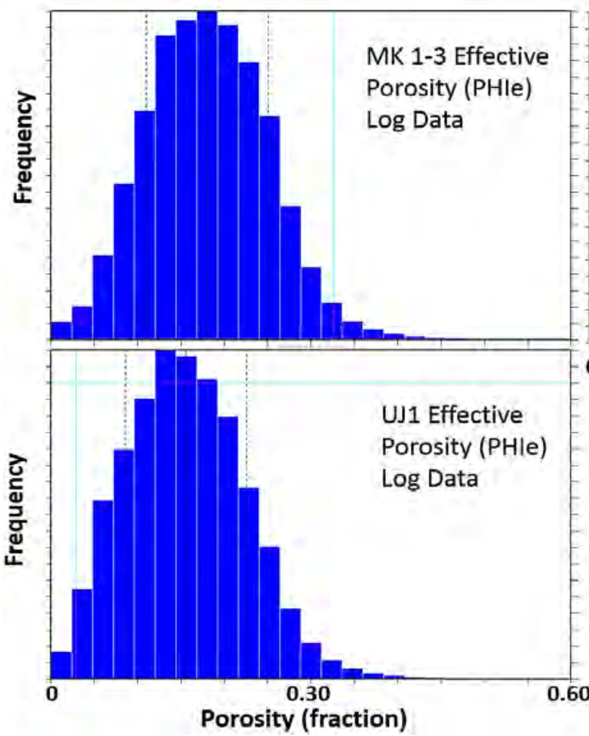
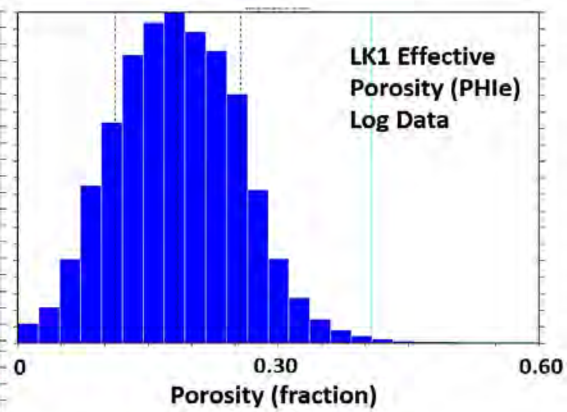
Task 5 – Storage Resources (cont.)

- Statistical distributions of effective porosity, permeability, and net thickness data were evaluated for the wells in the study area to provide input for numerical simulations of regional offshore displacement efficiencies.





Task 5 Storage Zone		MK 1-3	LK1	UJ1
Effective Porosity Log (fraction)	Mean	0.18	0.18	0.14
	P10	0.09	0.11	0.09
	P50	0.16	0.18	0.14
	P90	0.24	0.26	0.20
	SD	0.07	0.07	0.07
	Well count	43	42	39

Distributions and curve statistics for effective porosity logs used to generate porosity map grids for each storage zone and quantify efficiency parameter p-values.

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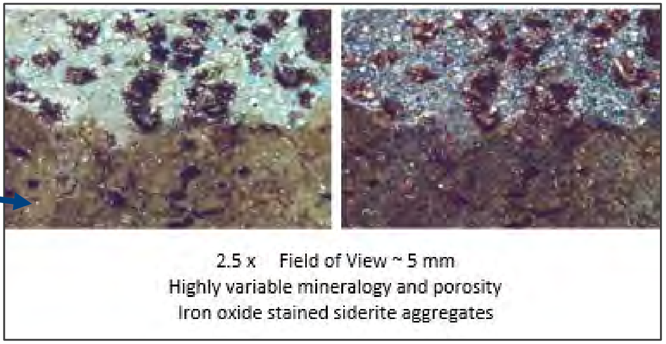
Task 5 – Storage Resource (cont.)

- Use final shapefiles and maps to derive area, thickness, porosity, and depth grids for volumetric storage calculations.
- Statistical values and distributions of net reservoir properties to define high and low probability values for geologic storage efficiency parameters ($E_{An/At}$ $E_{hn/hg}$ $E_{\phi e/\phi t}$)
- Dynamic CO_2 injection simulations to derive probability values for displacement storage efficiencies (E_v, E_d) based on results of various injectivity, injection pressure buildup, CO_2 saturation, and pore volume accessibility scenarios
- Grid data and offshore-specific storage efficiency values as input in the DOE-NETL CO_2-SCREEN tool to stochastically calculate P10, P50, and P90 estimates for offshore storage resources.

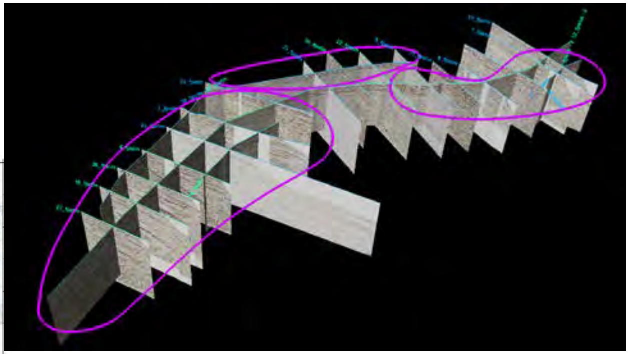
Task 6 – Risk Factors

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

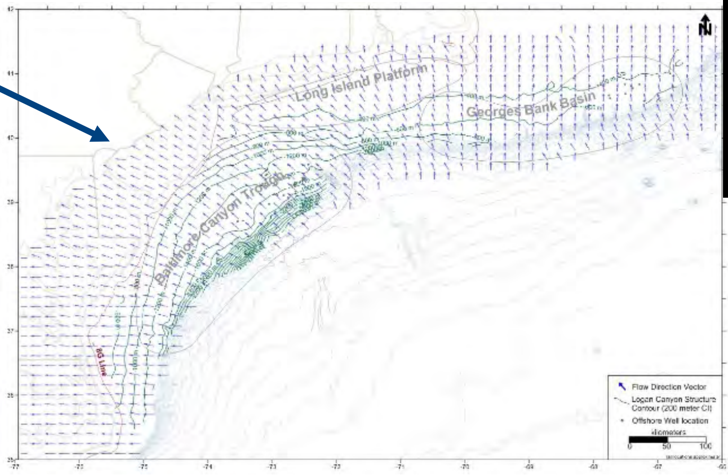
- Describing confining layers in terms of their mineralogy, lithology, thickness, hydrologic properties, make-up, etc.
- Evaluating potential for long-term CO_2 migration based on pathway analysis and trapping mechanisms
- Goal is to depict long-term processes such as CO_2 dissolution, residual saturation, and mineralization



Thin section analysis of confining zone (Pennsylvania Geological Survey)



Reprocessed legacy seismic to identify faults, structures, gas chimneys, etc.



Flow direction pathway analysis indicate hydraulic head, dissolution inhibit migration

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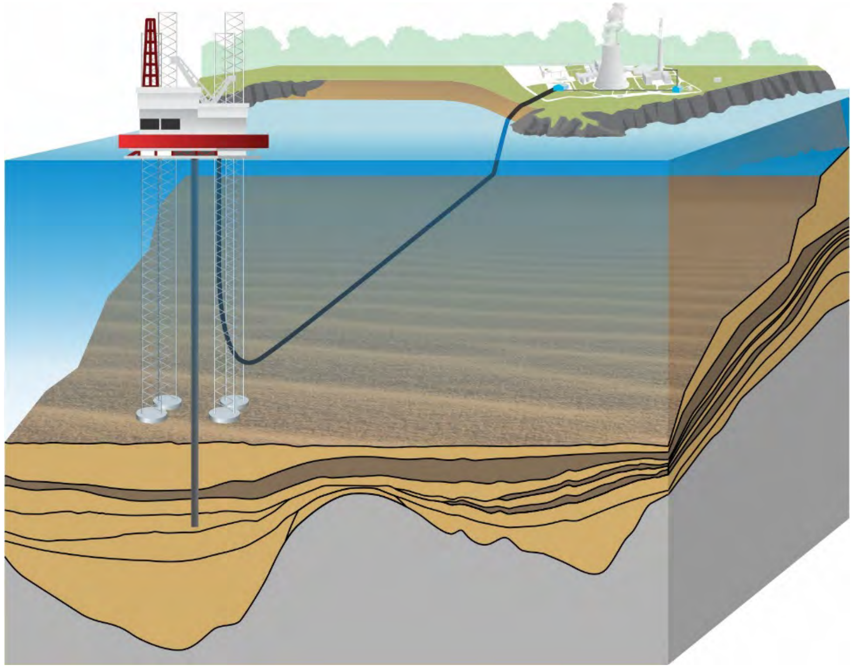
Task 6 – Risk Factors (cont.)

- Draft task summary report was submitted:
  - Area benefits from the large spatial extent, thick sequences of K- and J-age sands, scarcity of wellbores (44 P&A wells), and distance from populated development.
  - No highly critical risk factors identified that would impede CO_2 storage in study areas.
  - Moderate risks include faults and geomechanical stability along the mid-Atlantic slope and reservoir variability
  - Soft sediment deformation identified as a risk factor for semi- or unconsolidated sediments less than 1,000 m deep



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Task 7 – Stakeholder Outreach

The stakeholder outreach task will engage stakeholders about CO_2 storage resources in the offshore mid-Atlantic

- Battelle co-hosted a stakeholder workshop with Harvard at the Harvard University Center for the Environment on April 3, 2018.
- Discussed the challenges and hurdles for offshore CCS and how to overcome them.
- Stakeholders included industry (e.g., Statoil, BP), non-governmental organizations (e.g., Natural Resources Defense Council, Clean Air Task Force), Universities (MIT, UMASS Boston), and regulators (Norwegian Petroleum Directorate).
- Begun planning for a second stakeholder meeting in Annapolis, MD this November 14 and 15, with MRCSP Meeting.

Task 8 – Technology Transfer

- Technology Transfer has included:
  - Preparation of Task 2, 4, and 6 topical reports
  - Annual review meetings (2016, 2017, 2018)
  - SECARB Annual Stakeholder Briefing
  - CSLF International Workshops on Offshore Geologic CO_2 Storage (2016, 2017, 2018)
  - Conferences and meetings: 2016 CCUS, GHGT-13, GSA (multiple), AAPG (multiple)
  - Two peer-reviewed publications
- One oral and one poster will be presented at GHG-14
  - "Reprocessing of multichannel seismic data offshore the US East Coast: implications for carbon sequestration"
  - "Performing Carbon Storage Resource Assessments for Offshore Mid-Atlantic United States"

Accomplishments

- Detailed inventory and developed comprehensive database
- Characterized key properties of reservoirs and caprocks, including: depth, thickness, porosity, permeability, sequence stratigraphy
- Completed sample analysis to address data gaps and calibration of existing data
- Completed advanced reprocessing of 4,000 line km of seismic data
- Developed composite seismic lines, zone top surface maps, and zone isopach maps
- Completed analysis of CO_2 storage risk factors in study area
- Offshore Prospective CO_2 Storage Resource nearly complete
- Successful stakeholder outreach workshop with Harvard

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Lessons learned

- Important to define appropriate map projection/coordinate system for geospatial data used directly in storage calculations
- Uncertainty due to offshore data gaps and data vintage can be addressed via resource classification and use of probabilistic methods to estimate storage
- Integration and correlation of various data sets (core, log, seismic, biostrat) is time-intensive but extremely valuable for constraining statistical distributions of offshore formation properties
- Development of user-friendly tools to facilitate integration/correlation process would be worthwhile effort?
- Important to consider seismic data acquisition/quality when defining vertical limitations (e.g time/depth ranges) of seismic inversion method and corresponding porosity results

Synergy opportunities

Building on preliminary offshore characterization of MRCSP Program

Collaborating with other DOE Offshore Projects

- Project technical advisors from SOSRA & Gulf Coast Projects

Adding to the international pool of offshore CCS information

- CSLF International Offshore Geologic Storage Workshops

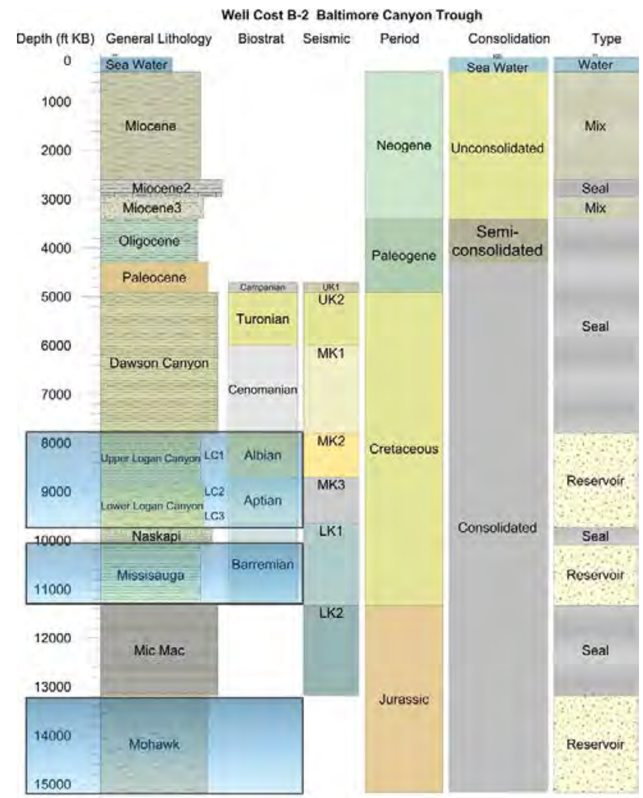
Project summary

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

Key Findings:

- Deep thick saline formations and caprocks identified for potential storage & containment
- Risk factor analysis resulted in a comprehensive list of potential sources of risk and identified site screening criteria specific to the marine environment
- Risk communication is an important element for future CCS applications.

Next Steps: Complete regional Prospective Storage Resource calculations and additional stakeholder outreach



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

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

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Organization chart

Sponsor
William O'Dowd
DOE/NETL Project Manager
NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Lead
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Technical Advisory Committee
Daniel Schrag (Harvard)
Tip Meckel (BEG)
David Spears (Virginia)

Project Management (Task1)
Project Manager: Lydia Cumming
Principal Investigator: Neeraj Gupta

Task 8
Reporting & Tech Transfer
Lydia Cumming (Battelle)

Task 2
Offshore Geological Characterization
Ken Miller (Rutgers)

Task 3
Seismic Evaluation
Greg Mountain (Rutgers)

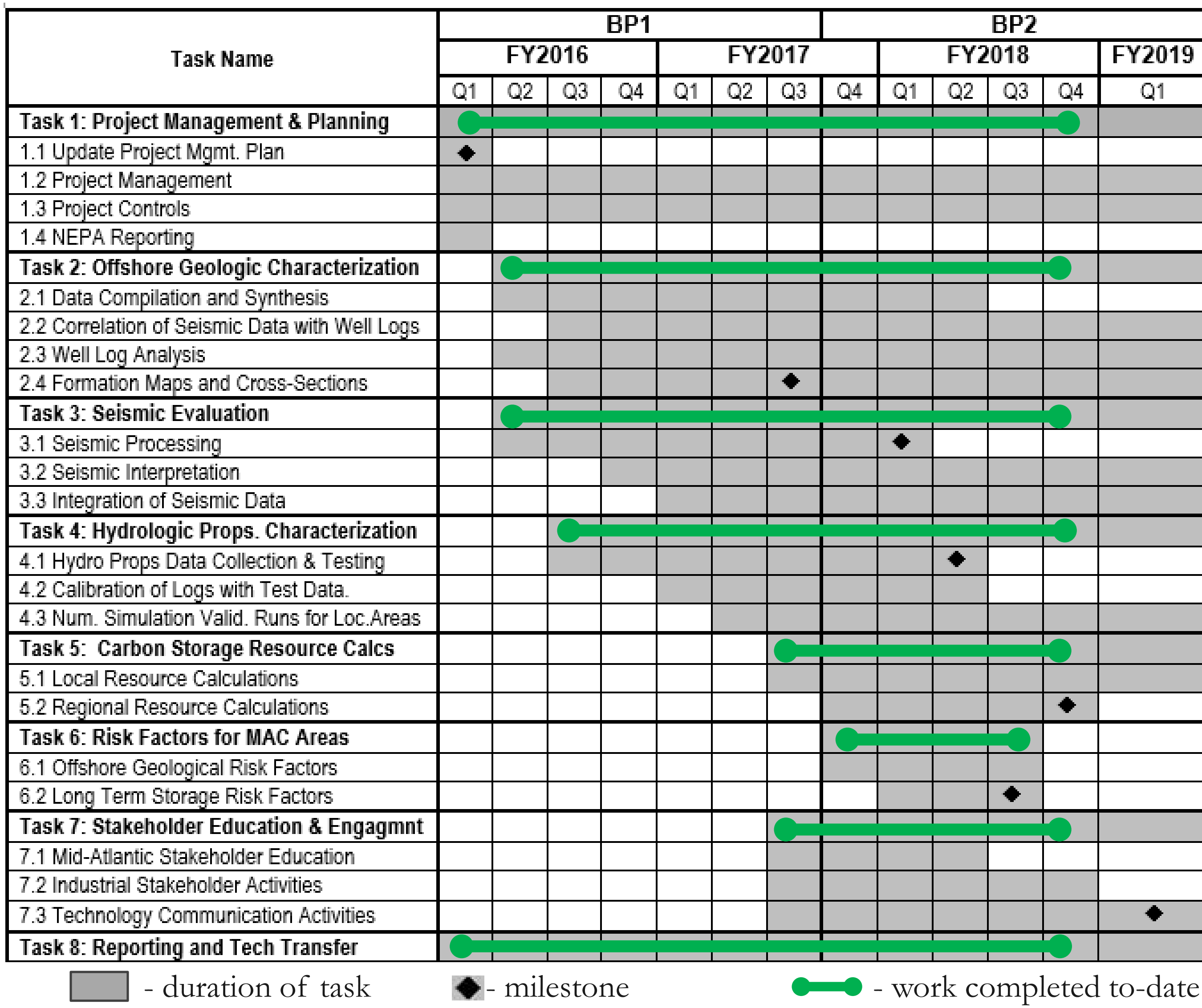
Task 4
Hydrogeologic Characterization
Peter McLaughlin (Delaware Geo. Survey)

Task 5
Carbon Resource Calculations
Isis Fukai (Battelle)

Task 6
Risk Factor Analysis
Joel Sminchak (Battelle)

Task 7
Stakeholder Education & Engagement
Kristin Carter (Penn. Geo. Survey)

Gantt chart



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- Miller, K.G., Lombardi, C., Browning, J.V., Schmelz, W.J., Gallegos, G., and Mountain, G.S., Back to basics of sequence stratigraphy: Early Miocene and Mid Cretaceous examples from the New Jersey paleoshelf. Journal of Sedimentary Research (provisionally accepted June 27, 2017).