Memorandum

To: William O'Dowd, DOE-NETL

From: Neeraj Gupta and Lydia Cumming, Battelle; Kristin Carter and Brian Dunst, Pennsylvania Geological Survey

Date: December 7, 2018

RE: Road Map for Future CCS Project Planning and Implementation offshore of the Mid-Atlantic United States: Compilation of Research and Industry Views from Stakeholder Workshops

1. Introduction

Offshore carbon capture and storage (CCS) is an important strategy for reducing industrial emissions in the northeastern U.S. Furthermore, climate change experts consider CCS to be a keystone technology in the global mitigation of climate change[1]. However, widespread deployment of carbon storage will require sustained research and development (R&D) and policy framework development. Establishing a foundation of CCS knowledge and expertise now is critical for future successes in planning and implementation. The Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project (DE-FE0026087) lays the foundation for these future CCS planning efforts by:

- identifying the number and potential carbon dioxide storage capacity of offshore reservoirs in the study area;
- developing a comprehensive digital geologic database for this area that can be consulted by future projects;
- recognizing potential risk factors associated with the deployment of offshore CCS; and
- engaging stakeholders through various technology transfer and outreach methods.

While most of the Project research has been designed to answer technical questions, stakeholder engagement is an important strategic element for technology advancement. One outcome of this Project is a road map for future CCS project planning and implementation. A road map is a useful communication tool to assist R&D programs by facilitating stakeholder input and revealing a path for achieving desired outcomes.

2. Approach for Obtaining Stakeholder Input

The primary objective for stakeholder education and engagement is to build support for future CCS projects by developing and/or maintaining relationships with government agencies, utilities, industry and other interested parties throughout the Mid-Atlantic region. The Project team reached out to stakeholders to provide educational and technical information on CO_2 storage resources in the region, as well as to gather feedback and input on short- and long-term issues regarding the potential deployment of CCS technologies in the Mid-Atlantic U.S. offshore area. This two-way communication effort was intended to facilitate a greater understanding of the benefits of CCS in an offshore setting while garnering a high-level sense of how such activities may be planned, implemented and regulated from those agencies and entities that would be involved.

[1] International Energy Agency. Energy Technology Perspectives (2015). https://www.iea.org/etp/etp2015/

Two stakeholder workshops were held to provide a streamlined approach to gather stakeholder perceptions, initiate information exchanges, identify potential project benefits, and identify potential hurdles and how to address them. Technical presentations were provided at the meetings, followed by moderated discussion. The agenda, speakers, and attendees for both workshops are in Attachment A.

3. Key Takeaways from the Workshops

3.1 Spring 2018 Stakeholder Workshop

A one-day meeting was held in Cambridge, Massachusetts, at the Harvard University Center for the Environment to ask invited organizations to provide feedback regarding the Project team's preliminary findings and offer their insight on the planning and potential application of CCS technologies in the Mid-Atlantic U.S. offshore region in the years to come. Stakeholders included industry (e.g., Statoil, BP), non-governmental organizations (NGOs) (e.g., Natural Resources Defense Council, Clean Air Task Force), universities (MIT, UMASS Boston), and regulators (Norwegian Petroleum Directorate).

The roundtable discussion centered on three major themes, including: 1) developing appropriate regulations, 2) the role of this project and science-based data in fostering communication and public acceptance, and 3) addressing risk factors associated with CCS deployment. The key inputs from the with workshop are listed below:

- **Regulatory Framework:**
    - Norway has been performing offshore storage for 20+ years and has regulations and protocols in-place that could be referenced to help develop the regulatory framework in the USA.
    - The process of ranking sites has been important to Norway. The possibility of jobs in an onshore CO_2 plant provided a positive response.
    - In the U.S., the regulatory framework for offshore CCS is not well defined. Working with regulators and industry to build protocols and regulations that enable a project to move forward in a safe and timely manner is critical for success.
- **Science/Public Acceptance:**
    - The opportunity afforded by CCS technologies to mitigate climate change is timely and significant – the 'do nothing' option is not really an option at all. Even so, the entities that will most greatly benefit from CCS implementation should be determined so that they can be engaged early and often.
    - Public outreach needs to be incorporated early and continue throughout a project development phase to develop appropriate public outreach opportunities, technical and marketing content, and plans for focused engagement.
    - Stakeholders including regulators, NGOs, coastal communities and others must be a part of the outreach plan. Both known, current stakeholders and possible future stakeholders should be engaged to ensure effective outreach during all stages of project development and maturity.
    - NGOs can assist with early stakeholder outreach and will lend credence to any proposed technical work.
    - Any project will need to demonstrate its scientific merit and potential environmental benefits versus anticipated risks, as early as possible during project development.

- A neutral party is important for soliciting stakeholder input and providing information in situations where conflicts of interest are of concern.
- Continued focus on the scientific merit, advanced technologies being used and collaborative oversight of a CCS project will allow regulators to foster support.
- Risk mitigation (by way of providing critical scientific data and documentation of project successes) will be needed for financial institutions to back CCS projects.

- **Risk:**
  - A quantitative risk analysis is needed. Stakeholder concerns require thoughtful responses and should be addressed in the risk analysis and mitigation plan.
  - Perceived risk must be reduced. The scientific community has good reason to believe CCS works, but we must bolster understanding of CCS technologies, address risks, and maintain two-way communication to prevent the spread of misinformation.
  - Effective communication of project risk to bankers and investors may be another challenge. To address this issue, the Society of Petroleum Engineer's CO_2 Storage Resources Management System[2] can be adopted to communicate project risk and commercial potential to investors using an industry-standard classification framework.

3.2 Fall 2018 Stakeholder Workshop

The Project Team hosted a one-day technical workshop to communicate the near-to-final Project results to invited industry and other interested parties in the governmental, environmental and NGO sectors. This meeting was held in conjunction with the Midwest Regional Carbon Sequestration Partnership (MRCSP) 2018 Partners Meeting to maximize research and regional industry participation at the event. A series of technical factsheets that describe important activities and findings of the Project team, as well as a draft road map, were distributed at the workshop (see Attachment B).

A facilitated discussion was held to obtain specific input on the draft CCS road map presented at the workshop, including the following components: goals, strategies, milestones and timeline.

- **Goal:**
  - There was not enough information to reach a consensus on the desired project/program scale and timeline. For discussion purposes, an "early mover project" was envisioned as the end goal – this could be a pilot scale or a commercial scale project. However, the ultimate timing of the deployment will depend on the development of regulatory framework for carbon mitigation.
  - A suggestion was made to remove the offshore surface rig from the road map graphic and instead show images of the advanced subsea technologies used in the Snøhvit project that could be used to reduce the impact of project infrastructure/operations on coastal communities and ensure the offshore aesthetic is maintained.
- **Strategies:**
  - Early stakeholder outreach is critical. Key groups (e.g., NGOs) can be partners or roadblocks. CCS projects focus on U.S. coastal waters. Coastal communities could be great allies if we listen to their issues and can offer a direct positive economic impact to their communities.

[2] https://www.spe.org/industry/docs/SRMS.pdf

- Regulatory and policy unknowns can make or break projects. Early mover CCS projects can help work towards development of appropriate regulations and establish regulatory certainty to promote investment, as well as to identify and implement policy mechanisms to facilitate targeted investment.

- **Milestones:**
  - A stakeholder outreach plan must be in place to garner offshore CCS champions by conveying key, targeted messages to coastal communities, international collaborators, NGOs and industry.
  - Establishing a practicable permitting/regulatory pathway is a necessary checkpoint to ensure success for CCS projects, and ultimately, CCS commercialization.

- **Timeline:**
  - The least cost portfolio for global climate change mitigation should be considered when developing the timeline. According to IEA (2018) scenario[3] for sustainable development, significant large-scale CCS deployment is needed by 2040.

4. Recommended Actions

Based on the stakeholder input received, the draft road map was revised and is shown in Figure 1. As shown in the road map, offshore CO_2 storage assessment and research of the mid-Atlantic U.S. is still in its early stages. This project represents an important first step by completing a high-level CO_2 storage resource assessment and building the knowledge infrastructure necessary to improve quantitative storage resource estimates. The data sets that have been curated under this project provide an opportunity to conduct R&D needed to address data gaps and reduce risk and uncertainty. Offshore characterization and validation strategies that are systematically designed to provide data and infrastructure that can be upscaled to meet commercial requirements should be developed. Recommended actions for future CCS project planning and implementation offshore of the Mid-Atlantic U.S. are listed below.

Near-Term Actions (Characterization Stage):

- As a practical next step, the Project team could use existing data sets to develop advanced static and dynamic geologic models to determine the geospatial variability of key storage parameters, complete the site screening process, and provide a better understanding of offshore subsurface storage opportunities and risks.
- Advanced reprocessing using existing seismic data and interpretation of modern seismic data from recent cruises should be performed to evaluate rift basin properties and reservoir capacity.
- A stakeholder outreach strategy to create champions for CCS R&D in the offshore region and streamline public acceptance of data collection in the marine environment should be implemented as early as possible.
- Identifying common industry and research goals for collaboration with international projects can build partnerships that lower research costs. Pursuit of onshore or analog data collection opportunities (e.g., drilling, core collection) could also help lower the cost of data collection.
- Development of regulatory certainty could be facilitated through U.S. regulator meetings with countries (e.g. Norway) where CCS is currently implemented and experiences from offshore oil and gas activities.

[3] International Energy Agency. 2018. World Energy Outlook. OECD/IEA WEO-2018. <https://www.iea.org/weo/>

Mid-Term Actions (Validation Stage):

- New data collection efforts should initially focus on addressing subsurface data gaps and requirements for qualifying potential sites, mitigating risk, and addressing potential regulatory/permit requirements.
- New data will be needed to validate caprock petrophysical properties, fracture pressure gradients, leakage risks, reservoir injectivity, and baseline geomechanical, geochemical, and hydrologic properties of storage zones and caprocks.
- Due to the higher costs and challenges associated with offshore characterization wells, a cost-benefit analysis will be needed to ensure the value of new data acquired meets the specific technical and economic requirements defined for the project.
- Appropriate monitoring methods will need to be investigated and validated prior to full-scale deployment and incorporated into the development phase plan.

Long-Term Actions (Development Stage):

- The development stage will establish and implement a detailed plan for large-scale CCS operations based on the findings of the preceding phases and the development of sufficient regulatory and pricing mechanisms to enable financially viable deployment. The progression to development also will depend on the strength of the stakeholder buy-in into the offshore CCS deployment in the mid-Atlantic area.
- The development stage activities typically include the assessment of CO_2 sources and transport, final site selection, detailed design, permitting, construction, operations, and monitoring. Advances in offshore technologies, such as advanced characterization, robotics, sub-sea structures, safety mechanisms, and remote operations over the next decade may facilitate cost-effective deployment with enhanced stakeholder confidence.
- Early mover projects in the U.S. and globally may help accelerate deployment of CCS through upscaling of technologies that reduce economic and policy barriers to commercial scale CCS.

5. Closing

This memorandum was prepared to document the results of two stakeholder workshops held to solicit input on what stakeholders, including Project team members, think should be done to advance offshore CCS research. We plan to draft a white paper to present a research path to address technical challenges in more detail. We will be glad to discuss these recommendations with you later on and follow through on any questions or suggestions you have.

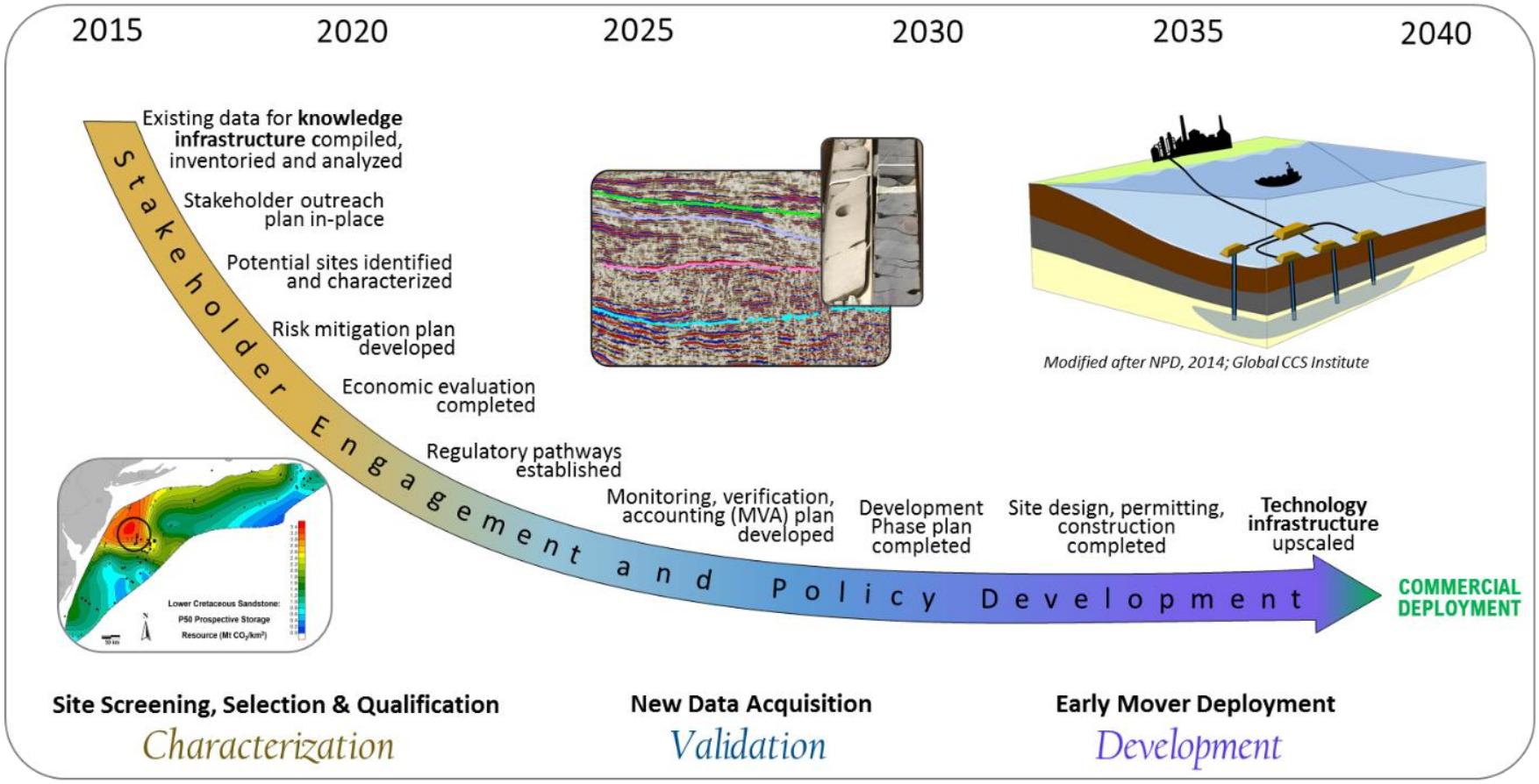

Figure 1. Draft Final Mid-Atlantic Offshore CCS Deployment Road Map

ATTACHMENT

STAKEHOLDER WORKSHOP HANDOUTS

SPRING 2018 STAKEHOLDER WORKSHOP

Stakeholder Workshop Agenda

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

Tuesday, April 3, 2018, 9:30 am to 3:30 pm
Harvard University Center for the Environment (HUCE), Cambridge Massachusetts

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Meeting Host: Dan Schrag, Harvard University and Neeraj Gupta, Battelle

Meeting Purpose: The purpose of this meeting is to reach out to stakeholders to provide information on CO_2 storage resources for the region and to gather feedback and input regarding short-term and long-term issues for the potential deployment of CCS technologies in the Mid-Atlantic U.S. offshore area. This two-way communication effort is intended to facilitate a greater understanding of the benefits and challenges of CCS in an offshore setting while garnering a high-level sense of how such activities may be planned, implemented and regulated from those agencies and entities who would be involved.

Registration and Networking 9:30 AM

Welcomes and Opening Presentations 10:00 AM

Background and Lessons from Other Locations:

- *Setting the Stage: Offshore CCS Deployment in the Mid-Atlantic US (Dan Schrag, Harvard)*
- *Statoil's Offshore CO_2 Geologic Storage Experience (Philip Ringrose, Statoil)*
- *CO_2 Geologic Storage Assessments – Gulf of Mexico (*Tip Meckel, Texas Bureau of Economic Geology)
- *Environmental Regulations of Subsea Storage - Norway* (Eva Halland, Norwegian Petroleum Directorate)

Mid-Atlantic Carbon Storage:

- *Mid-Atlantic Carbon Storage Resource Assessment Project Overview (Neeraj Gupta, Battelle)*
- *Identifying and Quantifying Potential Mid-Atlantic Offshore Storage (Ken Miller, Rutgers)*
- *Discussion*

Lunch - 12:30 PM

The Path Forward - Moderated Discussion 1:30 PM

Facilitator: Dan Schrag, Harvard

- *How offshore storage could develop in areas like the Atlantic offshore*
- *Technical Evaluation and Data Availability*
- *Regulatory Issues*
- *Stakeholder Acceptance*

Workshop Ends 3:00 PM (reception to follow)

Harvard University
Center for the Environment

Stakeholders Workshop for the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project
April 3, 2018

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Kristin Carter serves as Assistant State Geologist for the Pennsylvania Geological Survey (the Survey) and manages its Economic Geology Division. She has worked as a petroleum geologist for the Survey since 2001, and her current research efforts involve carbon capture utilization and storage, unconventional petroleum hydrocarbon reservoir characterization, storage reservoir characterization and subsurface stratigraphy. Kristin serves as the Survey's Primary Investigator in its work with the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project and the Midwest Regional Carbon Sequestration Partnership (MRCSP). She managed Pennsylvania's Carbon Sequestration Technical Assessment in 2009, an assessment of the state's subsurface geologic formations for CO_2 storage potential (prepared in accordance with Act 129 of 2008). Prior to joining the Survey, Kristin worked as a consulting hydrogeologist in the private sector, managing projects throughout the Mid-Atlantic region. In addition to her work at the Survey, she serves as an Adjunct Instructor in the Geology Department at Allegheny College (Meadville, PA) and as Eastern Region Vice President of the Potential Gas Committee (Colorado School of Mines, Golden, CO).

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David W. Cash is Dean of the John W. McCormack Graduate School of Policy and Global Studies at University of Massachusetts Boston. Dean Cash joined the McCormack Graduate School in July 2015. He has spent his career trying to understand and better harness knowledge to solve pressing policy challenges. Spending the past decade in Massachusetts state government in catalytic roles, Dean Cash helped to transform the commonwealth's energy and environmental policy and regulatory landscape. His job history includes positions in Massachusetts state government as Commissioner at the Department of Environmental Protection and

the Department of Public Utilities, and as Assistant Secretary of Policy at the Executive Office of Energy and Environmental Affairs. In these roles, he helped develop and implement nation-leading science-based environmental, climate, clean energy, water and waste management regulatory programs; innovative renewable energy and grid modernization efforts; and the development and implementation of the Regional Greenhouse Gas Initiative–the nation's first CO_2 cap-and-trade program. While working in state government positions, Dean Cash extended his efforts internationally, participating in a U.S. State Department mission to India on clean energy and climate and via USAID collaborations with regulators and policymakers in Tanzania and Ghana. Dean Cash was also a research fellow and lecturer in environmental science and public policy at Harvard University and, as a PhD student, was a White House global environmental policy intern at the Council on Environmental Quality. He has published numerous professional, peer-reviewed academic and lay articles and book chapters. He earned a PhD in public policy from the Kennedy School at Harvard University, concentrating in environment and natural resources. He also completed an MAT in science education from Lewis & Clark College and a BS in biology from Yale.

JAMES CROYLE
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James Croyle is CEO of SCS Energy and Hydrogen Energy California, the latter a project company requiring CCS to get built. Prior to HECA he was CEO of Purgen and in that capacity analyzed storing CO_2 off the coast of New Jersey. In 2011 Purgen was moved to the Central Valley in California after acquiring development rights in Kern County from British Petroleum. He has considerable experience with the regulatory and political environments related to energy project development both as a banker to the industry and an energy project developer. Mr. Croyle served as the President of the 1,200 MW Astoria Energy Project from 1999 to 2007 and previously had executive management responsibility for several large power projects. Mr. Croyle holds a PhD from Harvard University's Government Department.

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Lydia Cumming is a Project Manager at Battelle, an independent research and development organization. She has managed national and international collaborative research projects to advance carbon capture and storage (CCS) technologies through assessment of technical, risk, and other factors. She has performed outreach and project development activities for five CCS field projects in the Midwestern U.S. Her experience gained from flagship initiatives such as the Regional

Carbon Sequestration Partnerships and the Carbon Storage Assurance Facility Enterprise, as well as CCS Capacity Building Trust Fund projects in China and Mexico, has given her a deep appreciation for science driven innovation and collaboration. She is currently the project manager for the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project, which is part of the U.S. Department of Energy's Carbon Storage Program to improve the effectiveness and reduce the costs of carbon storage. Ms. Cumming earned her Bachelor's degree in Geology from The Ohio State University, Columbus, Ohio.

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Brian J. Dunst, P.G. is currently a geologist supervisor with the PA Geological Survey in Pittsburgh. He supports the Survey's oil and gas well drilling tracking system (EDWIN), the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project, MRCSP (Midwest Region Carbon Sequestration Partnership), and the recently completed Utica Shale play (2015) and ASH (Appalachian Storage Hub, 2017) studies. He is the Survey's seismicity and brine disposal (non-regulatory) contact. Prior to his current position, he worked in several regulatory programs, and has also been employed as a consultant in mining and oil and gas.

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Emre Gençer is a postdoctoral researcher in the MIT Energy Initiative since September 2016. His research interests focus on efficient and integrated process design, renewable energy conversion, multi-scale modeling and optimization. Currently, he is working on a multi-level systems analysis of carbon capture, utilization, and storage technologies and developing a novel modular life cycle analysis tool. Emre holds a PhD in Chemical Engineering from Purdue University. He received both a BSc in Chemical Engineering and BSc in Mathematics from Bogazici University in Istanbul, Turkey.

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David S. Goldberg is a Lamont Research Professor and serves as Associate Director of the Marine/Large Programs Division at the Lamont-Doherty Earth Observatory of Columbia University. His research has focused on geological carbon sequestration, marine methane hydrates, and related scientific technologies. He has published over 140 peer-reviewed articles and holds 5 patents. Goldberg has supervised field operations, engineering developments and other activities related to marine and continental drilling and mentored 11 Columbia University graduate students and 19 post-doctoral research scientists. He received B.S. and M.S. degrees in geophysics from Massachusetts Institute of Technology and a PhD degree in geophysics from Columbia University.

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Neeraj Gupta, a Senior Research Leader/Battelle Fellow at Battelle, provides technical and program development leadership for Battelle's subsurface resources work. He has over 25 years of domestic and international experience in CO_2 storage, CO_2-EOR, and other subsurface projects as a Principle Investigator, Project Manager, or technical advisor. He has led several field programs and research projects on CO_2 storage technology including leadership of the Midwestern Regional Carbon Sequestration Partnership (www.MRCSP.org), CO_2 storage pilot at the Mountaineer power plant in West Virginia, and regional assessments of CO_2 storage, Mid-Atlantic U.S. offshore carbon storage resource assessment, Enhanced Oil Recovery (EOR), and brine disposal in US. Dr. Gupta has also conducted international projects for CO_2 storage assessments in China, Mexico, Japan, Germany, and South Africa. Neeraj holds a PhD in Geological Sciences from The Ohio State Universities, an MS in Geochemistry from George Washington University, an MS and BSc in Geology from Panjab University, India.

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Eva Halland has held various positions within the Norwegian Petroleum Directorate (NPD), and has been a member of the management team for 17 years. Her responsibilities have included petroleum exploration, field development, field production, regulations and HSE. Her present position is as Project Director for the Norwegian CO_2 Storage Atlas and CO_2 storage projects in Norway. She is also Project Manager for FORCE, a co-operating forum for improved oil and gas recovery and improved exploration between 43 oil companies and authorities in Norway. She is Director of the Programme Board of CLIMIT, NORSAR and Natural History Museum in Oslo, member of the North Sea Basin Task Force and member of the bilateral CCS co-operation between Norway and USA. She is the leader of the Norwegian "CO_2 Storage Forum". She was the Norwegian project leader for the UK-Norway ministerial CCS project "One North Sea" and appointed member of the selection panel and project advisor for the appraisal of UK CO_2 storage sites. Eva is a member of the South African Pilot CO_2 Storage Project International Advisory Committee. She is an educated geologist from the University of Bergen, Norway.

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Howard J. Herzog is a senior research engineer in the MIT Energy Initiative. He received his undergraduate and graduate education in chemical engineering at MIT. He has industrial experience with Eastman Kodak (1972-1974), Stone & Webster (1975-1978), Aspen Technology (1981-1986), and Spectra Physics (1986-1988). Since 1989, he has been on the MIT research staff, where he works on sponsored research involving energy and the environment, with an emphasis on greenhouse gas mitigation technologies. He was a Coordinating Lead Author for the IPCC Special Report on Carbon Dioxide Capture and Storage (released September 2005), a co-author on the MIT Future of Coal Study (released March 2007), and a US delegate to the Carbon Sequestration Leadership Forum's Technical Group (June 2003-September 2007). He was awarded the 2010 Greenman Award by the IEAGHG "in recognition of contributions made to the development of greenhouse gas control technologies".

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Having spent twenty years in the merchant banking and commodities trading industry Jonathan moved into the geological sciences after reading for a BSc at the Birkbeck University of London and receiving a PhD from the Queensland University of Technology in Brisbane. After initial tenure as a coal geologist for the Geological Survey of Queensland he became the program manager and subsequently the director of the Queensland Carbon Geostorage Initiative jointly funded by the State and Federal governments and the Australian Coal Association. He moved to the private sector and worked for BG and Shell as a principal hydrogeologist and senior reservoir engineer before joining BP America in 2017 as a consultant CCUS Subsurface Technologist. His interests are focused across a broad spectrum of geological and reservoir engineering topics including basin analysis, petroleum hydrodynamics, geochemistry, mineral stability and reservoir management and optimization strategies.

FRANCINE KERSHAW
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As part of NRDC's Marine Mammal Protection Project and Oceans Program, Francine Kershaw identifies areas of the ocean that are crucial for marine mammals and then assesses how vulnerable those areas are to human impacts. She combines information on marine mammal behavior, genetics, and oceanography using geospatial tools to advocate for and improve marine mammal protections. Prior to joining NRDC, Kershaw worked at the United Nations Environment Programme World Conservation Monitoring Centre in Cambridge, U.K. She holds a bachelor's degree in zoology from the University of Leeds and a master's degree in biodiversity, conservation, and management from the University of Oxford. She earned her PhD in ecology and evolutionary biology from Columbia University. Kershaw is a member of the IUCN Joint WCPA/SSC Marine Mammal Protected Area Task Force (MMPATF). She works out of NRDC's New York office.

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Peter P. McLaughlin, Jr. is Senior Scientist at University of Delaware's Delaware Geological Survey and has a secondary faculty appointment as Professor in the Department of Geological Sciences. McLaughlin has been with the University of Delaware since 1999, before which he worked for 10 years in research, exploration, and management positions at a major oil company. McLaughlin was raised in Dover, Delaware and holds a BS in Geology from the University of Delaware and a PhD in Geology from Louisiana State University. McLaughlin's primary research interests are sequence stratigraphy, micropaleontology, groundwater, and clastic depositional systems. His projects utilize many of the tools and techniques used in the oil industry to address ground-water issues of importance to Delaware. He has recently developed a research interest in geologic sequestration of carbon dioxide and the carbon storage potential of subsurface geologic formations both offshore and onshore in the U.S. Middle Atlantic region.

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Dr. Tip Meckel is a research scientist investigating geologic carbon storage for the Bureau of Economic Geology at The University of Texas at Austin. During his 12 years with the Gulf Coast Carbon Center at the Bureau he has led research focusing on geologic characterization, structural geology, monitoring design, and pressure evolution for CO_2 injections. He has been directly involved with many large-scale field demonstration projects funded through the DOE-NETL Regional Carbon Sequestration Partnerships. During the past 8 years he has led the research initiative to identify offshore sequestration potential in the Gulf of Mexico with focus on capacity assessment and high-resolution 3D marine seismic monitoring technologies.

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Kenneth G. Miller is a Distinguished Professor in the Department of Earth and Planetary Sciences at Rutgers University, Co-Chair of the International Ocean Discovery Program Science Evaluation Panel, and Vice Chair, of Subcommission on Neogene Stratigraphy of the International Commission on Stratigraphy. He received an A.B. from Rutgers College (1978) and a Ph.D. from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography (1982). He was an Associate Research Scientist at Lamont-Doherty Geological Observatory from 1983-1988. A veteran of 8 scientific cruises, he has integrated offshore seismic and drilling activities with onshore drilling: since 1993, he has been Chief Scientist of the New Jersey Coastal Plain Drilling Project (Ocean Drilling Program Legs 150X and 174AX) that continuously cored sixteen sites. Author of over 100 peer-reviewed scientific papers, his most significant publications include widely cited synthesis of Cenozoic oxygen isotopes (Miller et al., 1987) and syntheses of global sea-level change (Miller et al., 1998, 2005, 2011, 2013). He was awarded the 2003 Rosenstiel Award from the University of Miami, is a two-time JOI/USSAC Distinguished Lecturer (1995, 2006) and an AAPG Distinguished Lecturer (2014-2015) and a Fellow of the American Geophysical Union and the Geological Society of America. A resident of Pennington, NJ, Ken grew up in Medford, NJ in the heart of the pine barrens and just sold his house in Waretown, NJ, the home of the sounds of the NJ pines, where he used to watch the inexorable rise in sea level from his deck 15 ft above Barnegat Bay.

STEVE MURPHY
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Steve Murphy has been working in the emerging CO_2 transportation and storage space since co-founding CO_2DeepStore in 2007. Project Acorn was one of the first project concepts that the company developed. The company was acquired by Petrofac and became a 50% partner in the 1st Goldeneye storage joint venture. The team did an MBO & formed Pale Blue Dot Energy in 2013 to provide strategy advice to clients involved in the energy transition. Steve has led many significant studies in CCS, including the Teesside ICCS project and the ETI CO_2 storage appraisal project. He is currently the Project Director for the Acorn project, which was recently awarded ~ €2.4m funding through the ACT co-fund program. Steve has degrees in Geophysics, Petroleum Engineering, and Business coupled with

around 33 years of broad experience. He describes one of his specialties as helping people make sense of complex situations and minimizing bias in strategic decision-making.

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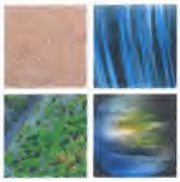
Dr. Francis O'Sullivan is Director of Research for the MIT Energy Initiative, and a Senior lecturer at the MIT Sloan School of Management. He works on topics related to energy technologies, policy and economics. His current research is focused on unconventional oil and gas resources, particularly the productivity and economics of North America's shale resources. He also studies global gas market dynamics, and how power systems are evolving to accommodate large-scale generation from renewable resources, particular solar power. He has written and spoken widely on these topics, and has made presentations to the President's Office of Science and Technology Policy, the EIA, the EPA, the Brookings Institute, the Bipartisan Policy Center, the Center for Strategic and International Studies, the National Governors' Association, the National Association of Regulated Utility Commissioners, at CERAWeek, the American Physical Society, the American Geophysical Union and to a range of other academic, policy and industry forums. He is a lead author of both the 2011 MIT Future of Natural Gas study, and the 2015 MIT Future of Solar Energy study.

Dr. O'Sullivan is a member of the U.S. National Academies' Roundtable on Science and Technology for Sustainability, and is a Senior Associate with the Energy and National Security Program at the Center for Strategic and International Studies. He has also served as a member of the U.S. Secretary of Energy's working group on methane emissions and as a member of the scientific advisory board for the Environmental Defense Fund's methane emissions campaign.



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Philip Ringrose is a specialist in CO_2 storage and petroleum geoscience at the Statoil Research Centre in Trondheim, Norway. He is also Adjunct Professor in CO_2 Storage at the Norwegian University of Science and Technology (NTNU) in Trondheim. He was elected as 2014-2015 President of the European Association of Geoscientists and Engineers (EAGE). He has BSc and PhD degrees in geology from Universities of Edinburgh and Strathclyde, Scotland, UK. He has published widely on reservoir geoscience and flow in rock media, and has recently published a textbook on Reservoir Model Design. He is Co-Editor for the journal Petroleum Geoscience.

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Daniel Schrag is the Sturgis Hooper Professor of Geology, Professor of Environmental Science and Engineering at Harvard University, and Director of the Harvard University Center for the Environment. His primary appointment is in the Department of Earth and Planetary Sciences in the Faculty of Arts and Sciences. He serves as Area Dean for Environmental Science and Engineering in the John A. Paulson School of Engineering and Applied Sciences and also co-directs the Program on Science, Technology and Public Policy at the Harvard Kennedy School with John Holdren. Dan's interests include climate change, energy technology, and energy policy. He has studied climate change over the broadest range of Earth's history, including how climate change and the chemical evolution of the atmosphere influenced the evolution of life in the past, and what steps might be taken to prepare for impacts of climate change in the future. He helped to develop the hypothesis that the Earth experienced a series of extreme glaciations, called "Snowball Earths" that may have stimulated a rise in atmospheric oxygen and the proliferation of multicellular animals. He is also interested in how we can use climate events in the geologic past to understand our current climate challenges. Dan has worked on a range of issues in energy technology and policy including advanced technologies for low-carbon transportation fuel, carbon capture and

storage, and risks and opportunities of shale gas. He was named a MacArthur Fellow in 2000 and served from 2009 to 2017 on President Obama's Council of Advisors for Science and Technology (PCAST), contributing to many reports to the President including energy technology and national energy policy, agricultural preparedness, climate change, and STEM education.

DAVID SPEARS
Virginia Department of Mines, Minerals and Energy
David.Spears@dmme.virginia.gov

David B. Spears is the State Geologist of Virginia. Based in Charlottesville, he manages the Division of Geology and Mineral Resources, which serves as the state geological survey. After earning a B.S. in Geology from Lafayette College and an M.S. in Geology from Virginia Tech, David began his professional career as a petroleum geologist for Chevron USA in 1983. With assignments in New Orleans and Lafayette, Louisiana, he developed oil and gas prospects using classical concepts of stratigraphy and structural geology, guided by geophysical well logs and seismic data. In 1993, David joined Virginia's geological survey as an economic geologist. His work there covered a wide range of topics including the mapping of abandoned mines, database management, field mapping in complexly deformed terranes, and assessment of natural gas resources in the Appalachian basin. From 2005 to 2009, David served as the Policy Manager for the state's Department of Mines, Minerals and Energy, where he led a major study that resulted in the development of Virginia's first offshore energy policy. During this time, he was selected by the Secretary of the Interior to serve on the Outer Continental Shelf Policy Committee. David was appointed State Geologist in 2009. He is a member of the Geological Society of America, the Society of Economic Geologists, the American Association of Petroleum Geologists, and is currently Past President of the Association of American State Geologists. He serves on the Committee on Earth Resources at the National Academies of Sciences, Engineering, and Medicine and recently completed a term as a member of the Geology and Public Policy Committee of the Geological Society of America. He has been a Professional Geologist (ASBOG) since 2002.

ANN WEEKS
Clean Air Task Force
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Ann Weeks is the Legal Director at the Clean Air Task Force, and in that capacity she advocates for CCS as a climate mitigation technology, and has written on subseabed CCS regulatory issues. Ann holds a JD from UNC-Chapel Hill, an SM from MIT, and a BS from Boston University.

FALL 2018 STAKEHOLDER WORKSHOP

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

Wednesday, November 14, 2018
Historic Inns of Annapolis
58 State Circle
Annapolis, MD 21401

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

8:00 – 9:00 am ***Check-in / Continental Breakfast***

9:00 – 10:45 am ***Welcomes, Project Overview, Regional Framework***

Welcomes / Introductions	Kristin Carter, PAGS
Mid-Atlantic Offshore Program Introduction	Neeraj Gupta, Battelle
Developing Structural Framework from Legacy Seismic	David Goldberg, LDEO
Hydrogeological Assessment from Log and Core Archives	Peter McLaughlin, DGS
An Integrated Geologic Storage Framework for Atlantic Offshore	Ken Miller, Rutgers

10:45 – 11:00 am *Break*

11:00 am – 12:45 pm ***Risk Factors, Storage Resources, Road Mapping***

Storage Resources in the Mid-Atlantic Continental Shelf	Isis Fukai, Battelle
Evaluating Deployment Risk Factors	Joel Sminchak, Battelle
Considering Regulatory Issues	Melissa Batum, BOEM
Global Significance of Offshore Storage – Well Known and Frontier Areas	Sue Hovorka, BEG
Developing a “Sleipner” off the East Coast	Facilitated Discussion

1:00 pm – 1:45 pm ***Combined MRCSP Annual Meeting/Workshop Networking Lunch***

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY | MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP | BATTELLE

Speakers and Facilitators

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

Melissa Batum – *Bureau of Ocean Management*

Melissa Batum, P.G. is a Senior Program Analyst for the Bureau of Ocean Energy Management, U.S. Department of the Interior.

Kristin Carter – *Pennsylvania Geological Survey*

Kristin Carter serves as Assistant State Geologist and manages the Economic Geology Division of the Pennsylvania Department of Conservation and Natural Resources (DCNR) Bureau of Topographic and Geologic Survey. She has worked as a petroleum geologist for the Survey since 2001, and her research efforts include evaluating depleted/depleting oil and gas fields as potential storage reservoirs; characterizing unconventional petroleum hydrocarbon reservoirs; tracking oil and gas exploration, production and well abandonment activity for the state; interpreting Appalachian basin subsurface stratigraphy; and mapping subsurface geologic formations. Kristin served as Project Manager for DCNR's Carbon Sequestration Technical Assessment project, which was mandated by PA Act 129 of 2008 and completed in August 2009. She serves as Primary Investigator for the Survey's participation in both the Midwest Regional Carbon Sequestration Partnership's and the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project's research. Kristin is licensed as a Professional Geologist by the Commonwealth of Pennsylvania and as a Certified Petroleum Geologist by the American Association of Petroleum Geologists**.**

Lydia Cumming – *Battelle*

Ms. Cumming is a Project Manager at Battelle, an independent research and development organization. She has managed national and international collaborative research projects to advance carbon capture and storage (CCS) technologies through assessment of technical, risk, and other factors. She has performed outreach and project development activities for five CCS field projects in the Midwestern U.S. Her experience gained from flagship initiatives such as the Regional Carbon Sequestration Partnerships and the Carbon Storage Assurance Facility Enterprise, as well as CCS Capacity Building Trust Fund projects in China and Mexico, has given her a deep appreciation for science driven innovation and collaboration. She is currently the project manager for the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project, which is part of the U.S. Department of Energy's Carbon Storage Program to improve the effectiveness and reduce the costs of carbon storage. Ms. Cumming earned her B.S. in Geology from The Ohio State University, Columbus, Ohio.

Brian Dunst – *Pennsylvania Geological Survey*

Brian J. Dunst, P.G. is currently a geologist supervisor with the PA Geological Survey in Pittsburgh. His supports the Survey's oil and gas well drilling tracking system (EDWIN), the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project, MRCSP (Midwest Region Carbon Sequestration Partnership), and the recently completed Utica Shale play (2015) and ASH (Appalachian Storage Hub, 2017) studies. He is the Survey's seismicity and brine disposal (non-regulatory) contact. Prior to his current position, he worked in several regulatory bureaus, and has also been employed as a consultant in mining and oil and gas.

Isis Fukai – *Battelle*

Isis Fukai is a geologist for Battelle's Energy Division where she currently leads various geologic characterization and CO_2 storage resource assessment efforts. Her responsibilities include assisting with field operations for characterization wells, petrophysical analysis, CO_2-EOR techno-economic analysis, and storage resource estimation. Prior to joining Battelle, Isis participated in carbon storage research as a Mickey Leland Energy Fellow and ORISE Research Associate at the U.S. Department of Energy National Energy Technology Laboratory. She is also an active committee member of the Society of Petroleum Engineer's CCUS Technical Section and contributor to the Storage Resource Management System. Isis received her Bachelor's degree from Oberlin College and her Master's degree from Louisiana State.

Speakers and Facilitators

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

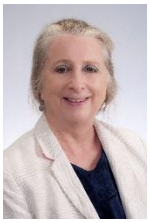
Dave Goldberg – *Lamont-Doherty Earth Observatory of Columbia University*

David S. Goldberg is a Lamont Research Professor and serves as Associate Director of the Marine/Large Programs Division at the Lamont-Doherty Earth Observatory of Columbia University. His research has focused on geological carbon sequestration, marine methane hydrates, and related scientific technologies. He has published over 140 peer-reviewed articles and holds 5 patents. Goldberg has supervised field operations, engineering developments and other activities related to marine and continental drilling and mentored 10 Columbia University graduate students and 19 post-doctoral research scientists. He received B.S. and M.S. degrees in geophysics from Massachusetts Institute of Technology and a PhD degree in geophysics from Columbia University.

Neeraj Gupta- *Battelle*

Neeraj Gupta provides technical integration and program development leadership for the Battelle's carbon management and subsurface resources work. Dr. Gupta joined Battelle in 1993 and is currently a Senior Research Leader in the Energy Group at Battelle. Dr. Gupta has been involved in CO_2 storage technology development since mid-1990s has conducted numerous US and international projects for the US DOE and industry. As the Principal Investigator and Project Manager for Midwestern Regional Carbon Sequestration Partnership, Dr. Gupta oversees a consortium for regional assessment of field projects for CO_2 storage and Enhanced Oil Recovery (EOR), including MRCSP Michigan Basin Project. His subsurface resources work includes EOR, brine disposal, geologic characterization; regional hydrogeology; reservoir simulations; geochemical modeling and experiments; seismic assessments; and costing and regulatory aspects.

Susan D. Hovorka – *Gulf Coast Carbon Center, Bureau of Economic Geology*



Susan Hovorka is a sedimentologist who works on fluid flow in diverse applications, inlcuding water resource protection, oil production, and waste storage. She has led a team working geologic storage of CO_2 since 1998, with a focus on field studies, monitoring, and capacity estimation. Projects include saline injection at the Frio Test site and Cranfield Field and EOR studies at SACROC oil field, Cranfield, Hastings and West Ranch industrial CO_2 utilization projects. She specializes in monitoring to document retention. The Gulf Coast Carbon Center is leading efforts to develop offshore storage capacity in the the US and globaly.She has a long-term commitment to public and educational outreach. She has a BA from Earlham College and a PhD in Geology from The University of Texas at Austin.

Peter P. McLaughlin, Jr – *Delaware Geological Survey*

Peter P. McLaughlin, Jr. is Senior Scientist at University of Delaware's Delaware Geological Survey and has a secondary faculty appointment as Professor in the Department of Geological Sciences. McLaughlin has been with the University of Delaware since June 1999, before which he worked for ten years in research, exploration, and management positions in the petroleum industry. McLaughlin was raised in Dover, Delaware and holds a B.S. in Geology from the University of Delaware and a Ph.D. in Geology from Louisiana State University. McLaughlin's primary research interests are sequence stratigraphy, microfossils, groundwater, and clastic depositional systems. His projects utilize many of the tools and techniques used in the oil industry to address ground-water issues of importance to Delaware. He has recently developed an interest in geologic sequestration of carbon dioxide and the carbon storage potential of subsurface geologic formations both offshore and onshore in the U.S. Middle Atlantic region.

Speakers and Facilitators

Kenneth G. Miller – *Rutgers University*

Kenneth G. Miller is a Distinguished Professor in the Department of Earth and Planetary Sciences at Rutgers University, Co-Chair of the International Ocean Discovery Program Science Evaluation Panel, and Vice Chair of Subcommission on Neogene Stratigraphy of the International Commission on Stratigraphy. He received an A.B. from Rutgers College (1978) and a Ph.D. from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography (1982). He was an Associate Research Scientist at Lamont-Doherty Geological Observatory from 1983-1988. A veteran of 8 scientific cruises, he has integrated offshore seismic and drilling activities with onshore drilling: since 1993, he has been Chief Scientist of the New Jersey Coastal Plain Drilling Project (Ocean Drilling Program Legs 150X and 174AX) that continuously cored sixteen sites. Author of over 100 peer-reviewed scientific papers, his most significant publications include widely cited synthesis of Cenozoic oxygen isotopes (Miller et al., 1987) and syntheses of global sea-level change (Miller et al., 1998, 2005, 2011, 2013). He was awarded the 2018 Laurence L. Sloss Award for Sedimentary Geology, 2003 Rosenstiel Award from the University of Miami, is a two-time JOI/USSAC Distinguished Lecturer (1995, 2006) and an AAPG Distinguished Lecturer (2014-2015) and a Fellow of the American Geophysical Union and the Geological Society of America. A resident of Pennington, NJ, Ken grew up in Medford, NJ in the heart of the pine barrens and just sold his house in Waretown, NJ, the home of the sounds of the NJ pines, where he used to watch the inexorable rise in sea level from his deck 15 ft above Barnegat Bay.

Joel Sminchak – *Battelle*

Joel Sminchak is a hydrogeologist in the Energy Division at Battelle Memorial Research Institute. He received his BSc from the University of Dayton, MSc from Ohio State University, and recently completed the Dog Training Course at Columbus Humane Society. He has been active in research on reservoir characterization, geotechnical testing, wellbore integrity, risk analysis, and performance monitoring for geologic CO_2 storage and other subsurface investigations.

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

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 linked 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.

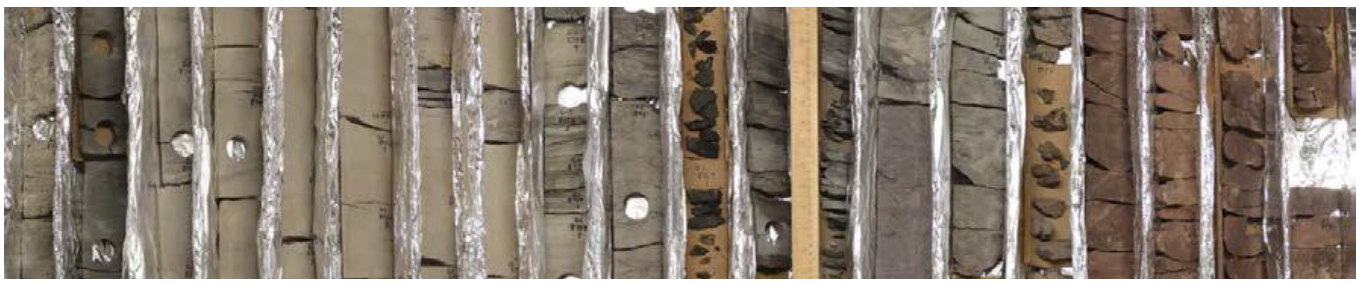
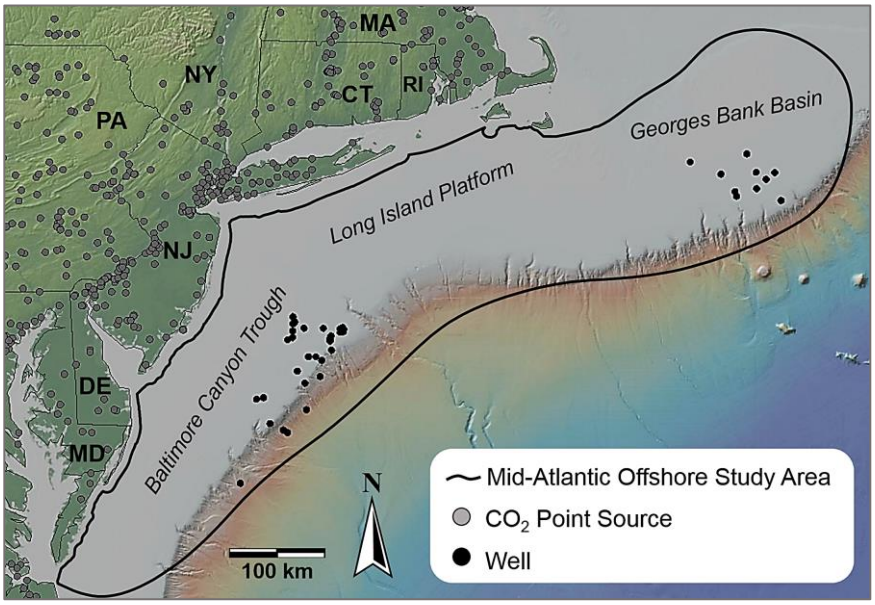


Image showing existing core material from the Continental Offshore Stratigraphic Test (COST) wells, which will be correlated with geophysical logs used to characterize rock properties relevant to carbon storage resource assessments

This project will prepare a realistic portrayal related to offshore CO_2 storage resource assessment by:

- Defining the ***geologic characteristics*** of candidate storage sites
- Using existing ***seismic data*** to better define the continuity of the storage zones and seals
- Cataloguing the ***hydrogeologic properties*** of mid-Atlantic offshore storage sites
- Calculating ***prospective CO_2 storage resources*** using net effective pore volumes and fluid displacement properties specific to offshore lithologies
- Examining ***risk factors*** related to offshore storage
- ***Communicating*** with industry and other stakeholders about the future prospects for offshore storage
- Ensuring ***technology transfer*** to industry and other stakeholders

Led by Battelle, this project is being conducted by public and private entities with expertise in offshore geology and resources for the study region, including state geological surveys of Delaware, Maryland and Pennsylvania; United States Geological Survey-Woods Hole Coastal and Marine Science Center; Rutgers University; Harvard University; and Lamont-Doherty Earth Observatory at Columbia University. This project team provides the U.S. Department of Energy with multi-disciplinary expertise to complete storage resource assessment for a broad region offshore of the U.S. East Coast, from Massachusetts to Virginia. The team will build on the success of the Midwest Regional Carbon Sequestration Partnership program (www.mrcsp.org), using a regional approach for screening and identifying candidate storage sites with the potential to deliver the most value for the East Coast. Anticipated outcomes are high-level storage resource estimates for areas not previously characterized and improved storage resource estimates for geographically expansive portions of offshore geologic units.



Map of the eastern United States coastal region showing location of the mid-Atlantic U.S. offshore study area, as well as locations of stationary CO_2 sources[3, 5]

Point of Contact

Neeraj Gupta, Battelle Principal Investigator, gupta@battelle.org.

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2 Schrag D.P., 2009. Storage of carbon dioxide in offshore sediments. Science 325, 1658-1659. DOI: 10.1126/science.1175750.

3 US-DOE-NETL, 2012. Carbon Utilization and Storage Atlas. U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory.

4 Goldberg, D.S., D.V. Kent, and P.E. Olsen, 2010. Potential on-shore and off-shore reservoirs for CO_2 sequestration in Central Atlantic magmatic province basalts, Proc. Nat. Acad. Sci., www.pnas.org/cgi/doi/10.1073/pnas.0913721107.

5 Ryan, W.B.F., S.M. Carbotte, J.O. Coplan, S. O'Hara, A. Melkonian, R. Arko, R.A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, J. Bonczkowski, and R. Zemsky, 2009. Global multi-resolution topography synthesis, Geochem. Geophys. Geosyst., 10, Q03014, doi:10.1029/2008GC002332.

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

CO_2 Storage Resource Estimation

Estimates of CO_2 storage were calculated for Cretaceous- and Jurassic-age sandstones to establish preliminary, screening-level constraints on the geologic CO_2 storage resources in the Mid-Atlantic U.S. offshore study region. The assessment was carried out using a step-wise approach that included: **(1)** data integration and mapping, **(2)** regional-scale storage resource estimates, and **(3)** local-scale dynamic injection and storage simulation.

Data Integration

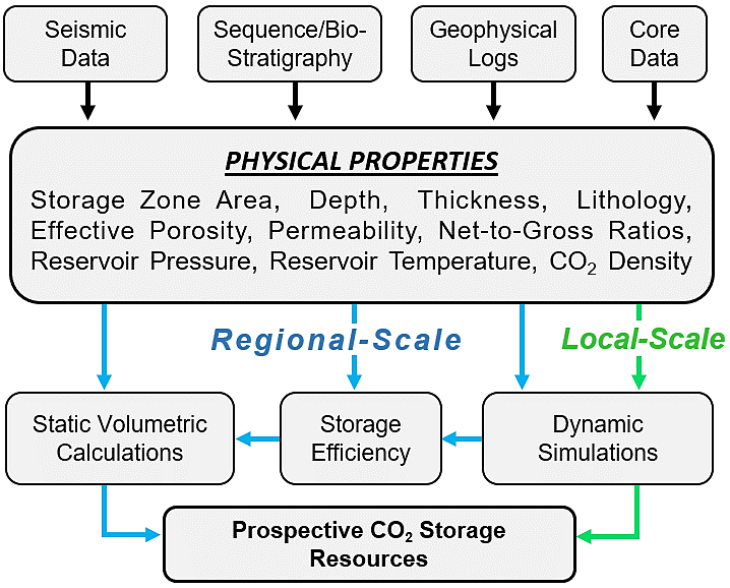
The CO_2 storage resource of offshore deep saline formations were quantified following static volumetric and dynamic methods. Static methods employ estimates of subsurface pore volumes and in-situ fluid saturations to derive an equivalent quantity of CO_2 that could occupy the pore space in a given storage reservoir. Dynamic methods use numerical models to simulate the CO_2 injection and storage performance of a reservoir under specific pressure, time, and operational constraints.

POTENTIAL OFFSHORE STORAGE ZONES

The Middle Cretaceous Logan Canyon sandstone (MK1-3), Lower Cretaceous Missisauga sandstone (LK1) and Upper Jurassic Mohawk (UJ1) units were identified as potential storage zones based on ***screening criteria derived from the risk factor analysis*** in this project and recommended best practices for onshore CO_2 storage[1].

DATASETS AND WORKFLOW

Geophysical logs from 44 existing offshore test well locations were scanned and digitized to inform interpretations of storage zone lithofacies and petrophysical properties. Seismic and well log sequence stratigraphy was used to define storage zone depth, thickness, and lateral continuity. Biostratigraphic data provided age control to help align and correlate storage zone lithofacies with sequence boundaries. ***Log data was integrated with laboratory-derived core analyses*** to better characterize effective reservoir porosity and permeability. The newly ***reprocessed seismic data provided by this project were also used to derive estimates of porosity*** in areas without well data.



Schematic showing data input and workflow used for estimating offshore CO_2 storage resources.

STORAGE EFFICIENCY AND CALCULATION METHODS

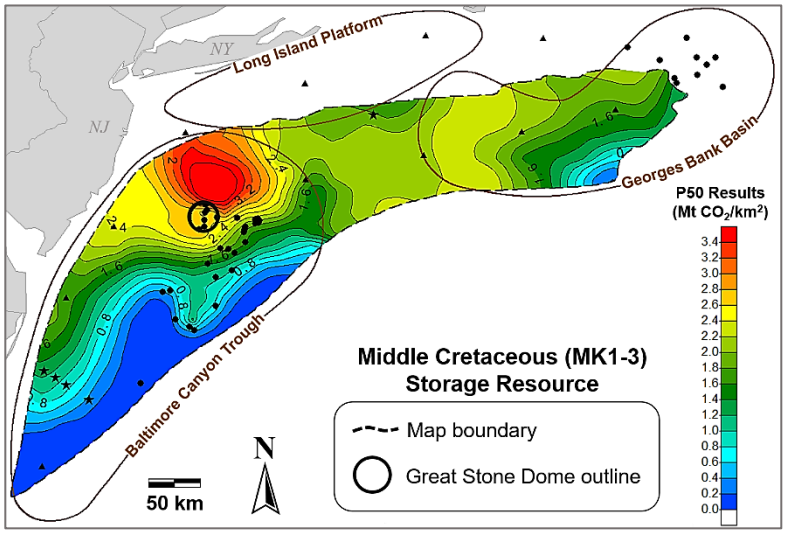
The integrated dataset was used to develop regional maps of depth, thickness, and porosity for each storage zone within an area of ~115,000 km^2. Map grids served as input for CO_2 storage resource calculations using the static volumetric methodology[2] and CO_2-SCREEN tool[3] developed by DOE-NETL for onshore deeps saline formations. CO_2 storage efficiency is generally defined as the ratio of CO_2-occupied pore volume relative to a total pore volume, and is dependent on the specific geologic and fluid properties the reservoir(s) being evaluated for storage[4]. ***Offshore-formation specific storage efficiency values were determined*** using regional statistical and geospatial distributions of net-to-gross pore volume and permeability for the three storage zones of interest. Regional results were then mapped and locations exhibiting high CO_2 storage resource per area that were also constrained by data from three or more nearby wells were selected for further evaluation using dynamic simulation.

Regional-Scale CO_2 Storage Resource

Average effective reservoir ***porosities ranging from 21- 29% and average permeabilities ranging from 45 - 339 millidarcies*** are observed in the storage zones of interest based on detailed petrophysical analysis of available well data. These values are within range of values reported for other offshore reservoirs used for commercial-scale CO_2 storage[5].

Using formation-specific probability values derived from regional data distributions in the study area, ***calculated storage efficiencies ranged from 1% to 13%,*** with median values of 5% and 3% computed for the Cretaceous sandstones and the Upper Jurassic sandstone, respectively.

Storage Zone	Avg. Net Reservoir Properties	
	Porosity (%)	Permeability (mD)
Middle Cretaceous (MK1-3)	23 -27	71 - 314
Lower Cretaceous (LK1)	26 - 29	65 - 339
Upper Jurassic (UJ1)	21 - 25	45 - 264



Map showing results of the regional prospective storage resource calculation (P50) for the Middle Cretaceous storage zone

Regional prospective storage resource estimates range from 37 to 403 gigatonnes (Gt) of CO_2, with median values of 148, 178 and 153 Gt computed for the Middle Cretaceous, Lower Cretaceous, and Upper Jurassic storage zones, respectively.

Local-Scale Dynamic Simulation

Dynamic CO_2 injection and storage simulation was conducted using a simplified three-dimensional site model in a selected area of the northern Baltimore Canyon Trough near the Great Stone Dome. The simulation was conducted for the lower sequence (51 m thick) of the Middle Cretaceous sandstones using an injection rate of 1.5 megatonnes (Mt) per year and a single injection well. The ***local-scale simulation results show 45 Mt of CO_2 can be stored over 30 years*** within the pressure constraints considered to be safe.

Regional estimates and dynamic simulation results both suggest ***a single offshore storage zone could potentially store commercial quantities of CO_2*** emitted from a nearby power plant or industrial source in the mid-Atlantic region. Additional data analysis and acquisition is needed to reduce uncertainty associated with data gaps throughout the offshore study area. Development of a three-dimensional static earth model to better characterize the variability of reservoir properties would provide valuable constraints on storage resource estimates and would aid in identification of candidate sites for further characterization, validation and development.

Point of Contact: Dr. Neeraj Gupta, Battelle Project Manager, gupta@battelle.org.

References Cited

1. DOE-NETL (U.S. Department of Energy-National Energy Technology Laboratory). 2017. Best Practices for Site Screening, Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations. DOE/NETL-2017/1844.
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3. Sanguinito, S., A. Goodman, and J.S. Levine. 2016. NETL CO_2 Storage prospeCtive Resource Estimation Excel aNalysis (CO_2-SCREEN) User's Manual; NETL-TRS-X-2016; Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, Pennsylvania, 2016; p. 31. https://edx.netl.doe.gov/carbonstorage/?page_id=914.
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Risk Factor Analysis

A risk factor analysis was conducted as part of the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project to determine whether the offshore area is suitable for geologic storage of carbon dioxide (CO_2). The analysis considered ***geologic risk factors***, ***long-term CO_2 storage risks***, and ***environmental factors*** related to the permanent storage of CO_2 in Mid-Atlantic U.S. Offshore study area.

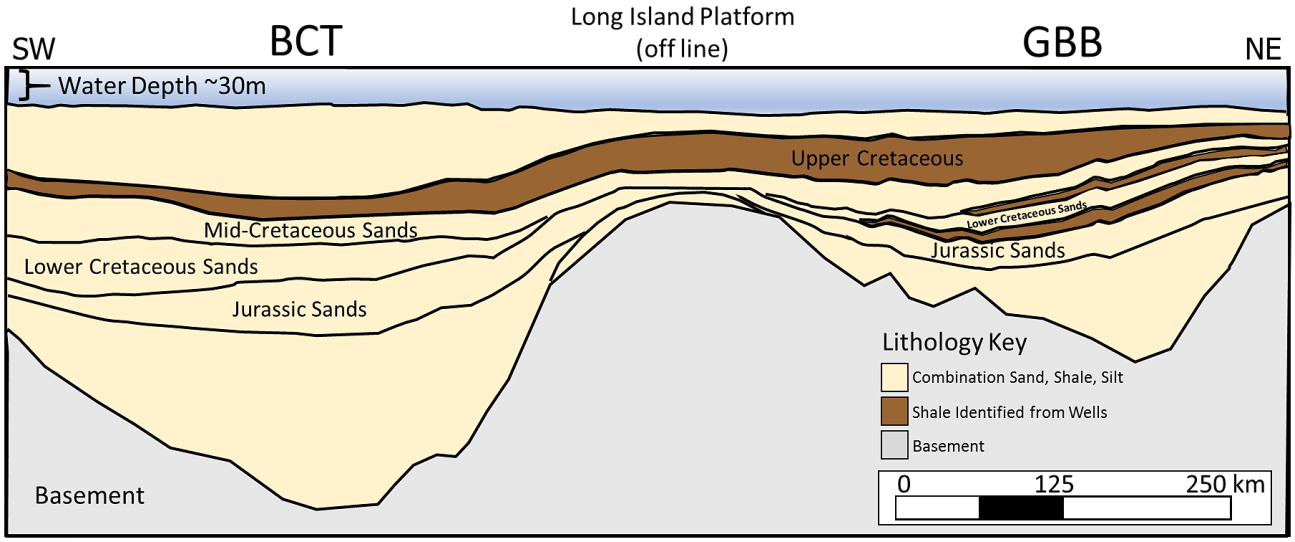
Geologic Risk Factors

CO_2 CONTAINMENT: Overlying the storage zones, thick layers of Upper Cretaceous shale and mudstone occur as ***regionally continuous caprocks*** across the study region and would prevent CO_2 migration to the surface.

SEDIMENTOLOGICAL AND STRUCTURAL FEATURES: At shallower depths (<1000 m), caprocks and storage zones may occur as unconsolidated sediments subject to soft sediment deformation and CO_2 phase changes, suggesting ***lower risk at storage depths >1000 m***. Evidence of faulting was identified in localized areas near the continental slope.

Geologic CO_2 storage risk management process defined by the U.S. DOE-NETL[1].

SEISMICITY AND GEOMECHANICS: The eastern margin of the North American continent is a passive margin, meaning tectonic plates are not actively colliding, and very few historical earthquakes have occurred in the study region. The 2014 U.S. Geological Survey National Seismic Hazard Map[2] shows a mostly low hazard probability along this margin. Faults and geomechanical stability along the continental slope present a moderate risk factor, suggesting areas near ***the slope should be avoided*** during storage.



Cross-section showing regional distribution of caprocks (shale, brown) and storage zones (sandstone, tan) defined by seismic correlation across the Baltimore Canyon Trough (BCT), Long Island Platform, and Georges Bank Basin (GBB).

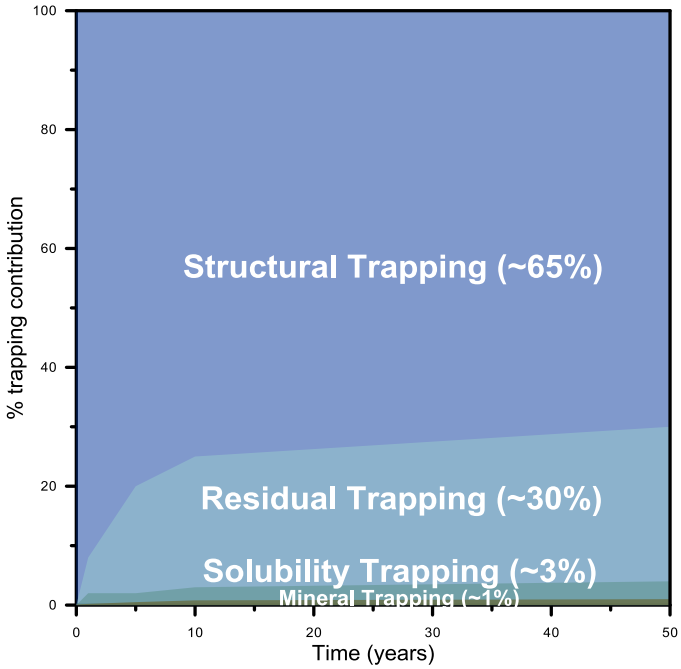
Long-Term CO_2 Storage Risks

Offshore CO_2 confinement and trapping mechanisms are important for ensuring long-term CO_2 storage security and permanence. CO_2 acts as a supercritical fluid below storage depths of about 1,000 m in the offshore study area, where it exhibits a higher density similar to liquid, but will flow more readily like gas. Stored CO_2 will be less dense than formation brine and will buoyantly rise to the top of the storage zone and become trapped by various mechanisms.

In the offshore study area, ***CO_2 trapping mechanisms were not identified as significant risk factors***. The majority of CO_2 stored is estimated to be trapped as a free-phase fluid in structural and stratigraphic traps. ***Approximately 34% of the CO_2 is estimated to be trapped in a less mobile state*** via residual trapping in intergranular pores, dissolution in formation brine, and mineral carbonation reactions.

General structural trends and analogous onshore-offshore depositional systems suggest up-dip migration inshore is restricted by inherent structural and lithographic traps.

A more detailed, local assessment of confining rock properties, CO_2 migration pathways, and trapping mechanisms should be conducted at candidate sites to address long-term risks.



Graph showing the quantity of CO_2 estimated to be trapped by four main trapping processes in the study area

Environmental Factors

Environmental factors can have a significant impact on the deployment strategy and overall success of a potential CCS project. CO_2 storage projects involve activities such as drilling, infrastructure construction and seismic surveys that may cause environmental risks or disturbances. Some environmental factors identified as important considerations for a CO_2 storage project in the mid-Atlantic offshore study area include:

- marine life migration patterns, protected and sensitive species and marine habitats
- existing infrastructure and offshore activities such as shipping lanes, submarine cables, and ocean disposal sites
- low leakage risk from the few existing wellbores (44)
- distance from population centers and CO_2 sources

No highly critical geologic, environmental, or long-term storage risk factors were identified that would preclude deployment of CCS in the Mid-Atlantic U.S. Offshore study region.

These environmental factors should be considered when determining potential storage site locations and timing of project activities in order to reduce risks and minimize impacts to marine life, marine habitats, and other environmentally-sensitive offshore features in the study area.

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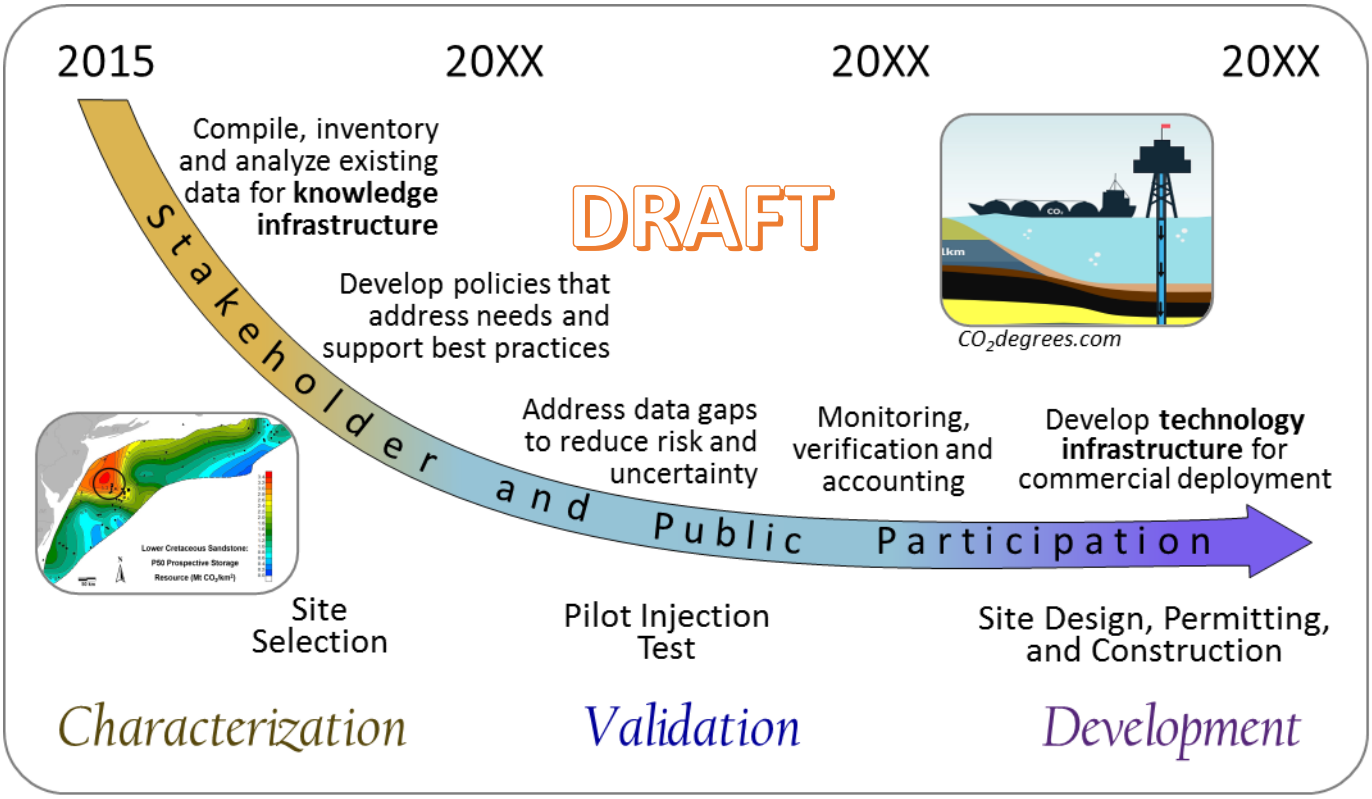
MID-ATLANTIC U.S. OFFSHORE
CARBON STORAGE RESOURCE
ASSESSMENT PROJECT

Road Map for U.S. Offshore CCS Deployment

Carbon capture and storage (CCS) is a critical technology for ensuring a range of clean energy options are available to meet current and future energy demand in the U.S. and abroad. The objectives of the Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project are to:

1) complete a systematic carbon storage resource assessment of the U.S. mid-Atlantic Offshore region
2) identify key input parameters to reduce uncertainty for offshore storage resource and efficiency estimates
3) prepare a preliminary assessment of risk factors, uncertainties and data gaps
4) engage industry and regulatory stakeholders through development of a road map to assist future project planning and implementation

The road map for full-scale development of carbon capture and storage (CCS) in the U.S. Mid-Atlantic offshore is illustrated below.



Road map for development of knowledge and technology infrastructure needed to support full-scale offshore carbon storage

Characterization: Establishing the Foundation for Knowledge Infrastructure

Over the past three years, the Project has compiled, inventoried, and assimilated various publicly available data sets to provide a strong technical basis on which future carbon storage studies and applications can be built. The knowledge infrastructure necessary to support the development of full-scale offshore carbon storage must be able to ***communicate*** our need for clean, secure energy in the context of domestic options (fuel switching, onshore storage and offshore storage); ***provide*** useful, organized data already available for the Mid-Atlantic U.S. offshore region; and ***transfer*** onshore technology knowledge in a prudent way to offshore applications.

Key Project Outcomes To-Date

SUBSURFACE DATA ANALYSIS:

- Legacy seismic, well log, core, and biostratigraphic data was digitized, reprocessed, and analyzed using modern techniques, augmenting previous characterization efforts.
- Prospective storage resource estimates suggest Mid-Atlantic U.S. Offshore formations can potentially store decades of CO_2 from industrial sources in the region.
- Advanced geologic modeling and new data acquisition are needed to address data gaps and advance CCS in key offshore areas selected for further investigation.

OFFSHORE RISK FACTORS:

- Offshore geologic risk factors include soft-sediment deformation, unit continuity, sedimentological and structural features, seismicity and hydrates.
- Carbon dioxide storage risks include inadequate seals, migration/leakage, chemical interactions leading to decreased storage
- Sensitive habitats, environmental impacts, disturbance to seafloor, and other risks need to be identified in advance of project activities and integrated into detailed mitigation plans for all project phases

STAKEHOLDER ENGAGEMENT:

- Input and participation from government, industry, and environmental groups is needed to develop the roadmap and address next steps needed for project deployment
- Early engagement and ongoing communication is key to project success

Validation: Injection Site Identification, Testing, and Verification of Storage Feasibility

The specific components of the project validation stage will be determined by stakeholder interests and concerns, injection site conditions, as well as regulatory and economic requirements. General examples of activities and milestones that could be associated with the Mid-Atlantic U.S. Offshore Storage Project include:

- ***Addressing data and technology gaps*** in areas selected for further investigation to reduce uncertainty in storage zone and caprock continuity and integrity, fault occurrence, CO_2 trapping mechanisms, pore fluid behavior and migration, geochemistry, and geomechanics.
- ***Identification of a candidate site*** for site-specific characterization to develop a well design and operational strategy in accordance with project and permit requirements
- ***Well drilling and pilot testing*** to establish injectivity, refine storage resource estimates and classification, and validate offshore CCS feasibility.
- ***Development of monitoring, verification and accounting plans*** to comply with permit/regulatory requirements, determine CO_2 fate and transport, reduce risk, and quantify storage volumes.

Development: Maturation of Knowledge and Technology Infrastructure

The project development stage will establish and implement a detailed plan for commercial offshore CCS operations, and may include activities such as: securing ***stakeholder investment and buy-in***; ongoing ***public outreach*** and communication; development of ***contingency plans*** for potential economic and technical challenges; ***upscaling*** injection and storage site infrastructure to meet project requirements and integration with CO_2 capture and transportation infrastructure; and ***implementation of monitoring, verification and accounting plans*** to provide assurance of long–term storage integrity.

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Publications and Presentations List

Peer-Reviewed Journals

Back to Basics of Sequence Stratigraphy: Early Miocene and Mid-Cretaceous Examples from the New Jersey Paleoshelf, Miller K. G., Lombardi, C. J., Browning, J. V., Schmelz, W. J., Gallegos, G., Mountain, G. S., Baldwin, K. E., Journal of Sedimentary Research, 2018, v. 88 148-176.

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Conferences, Workshops and Meetings

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Georges Bank Basin Stratigraphy: Cretaceous Gamma Log Sequences Correlated with Seismic Data, master's thesis, Rutgers University, Graham, S., 2019

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