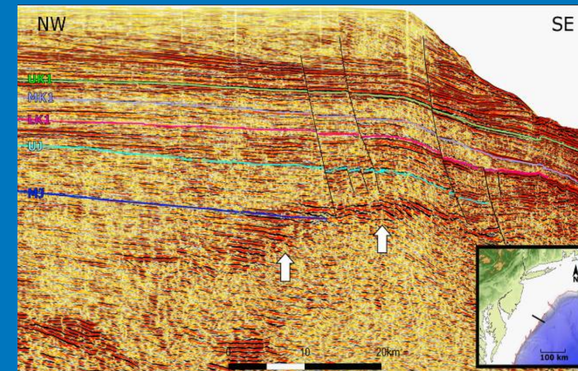
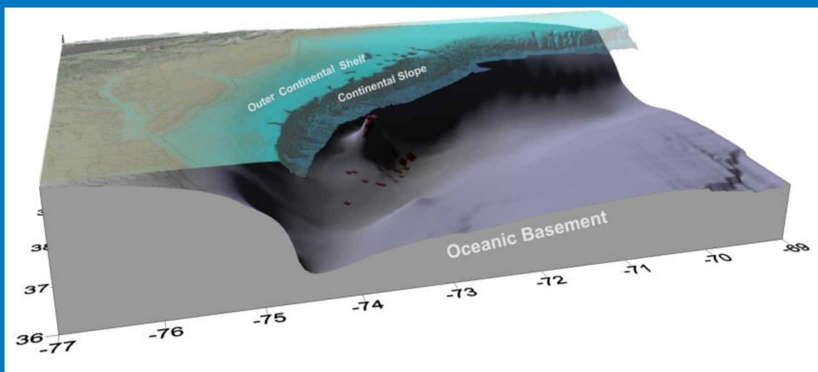
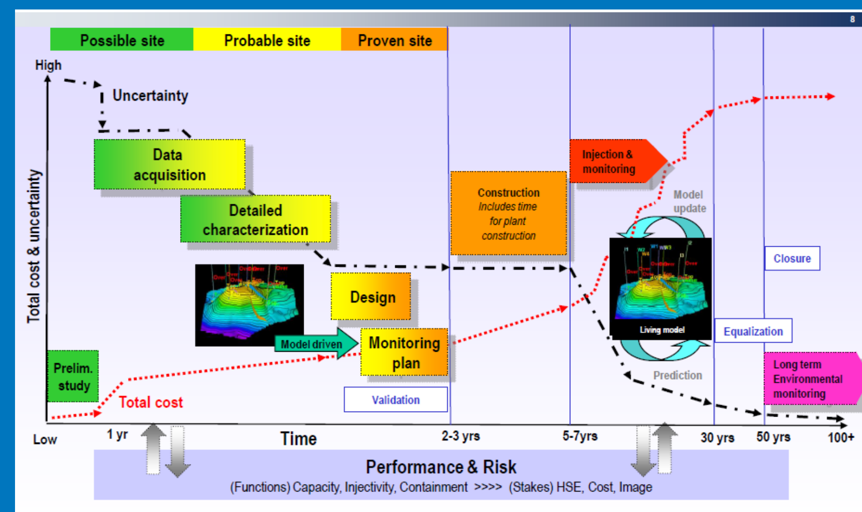
CO_2 Storage Methods







Battelle
Neeraj Gupta and
Joel R. Sminchak

Maryland Energy Administration Carbon Sequestration Workshop
November 19-20, 2019
Maritime Institute, Linthicum, Maryland

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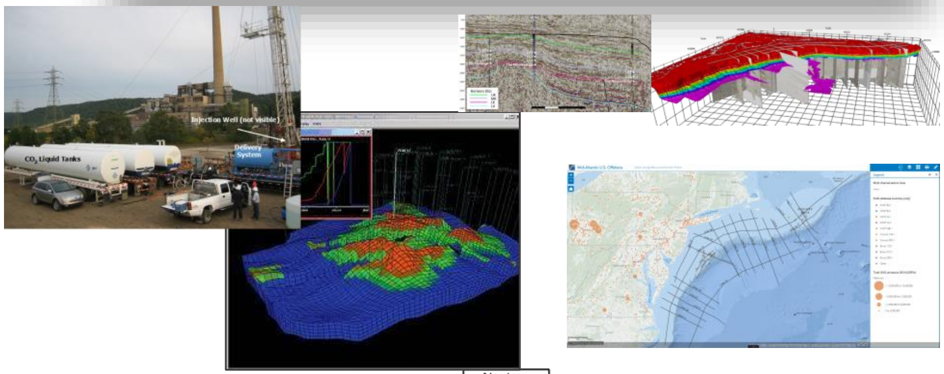
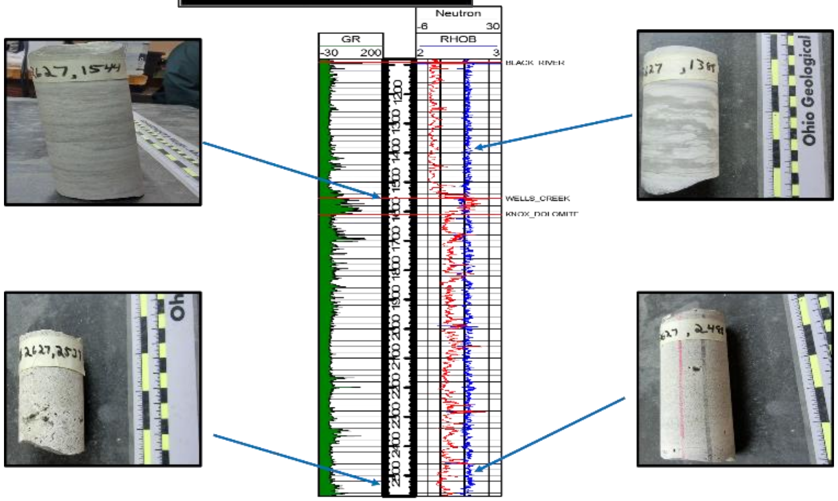
Outline

1. CCS Overview/Value Chain
2. Site Selection/Screening
3. Developing CCS projects
4. Storage Resources
5. Reservoir Modeling
6. Public Outreach
7. Terrestrial/CO_2 Utilization





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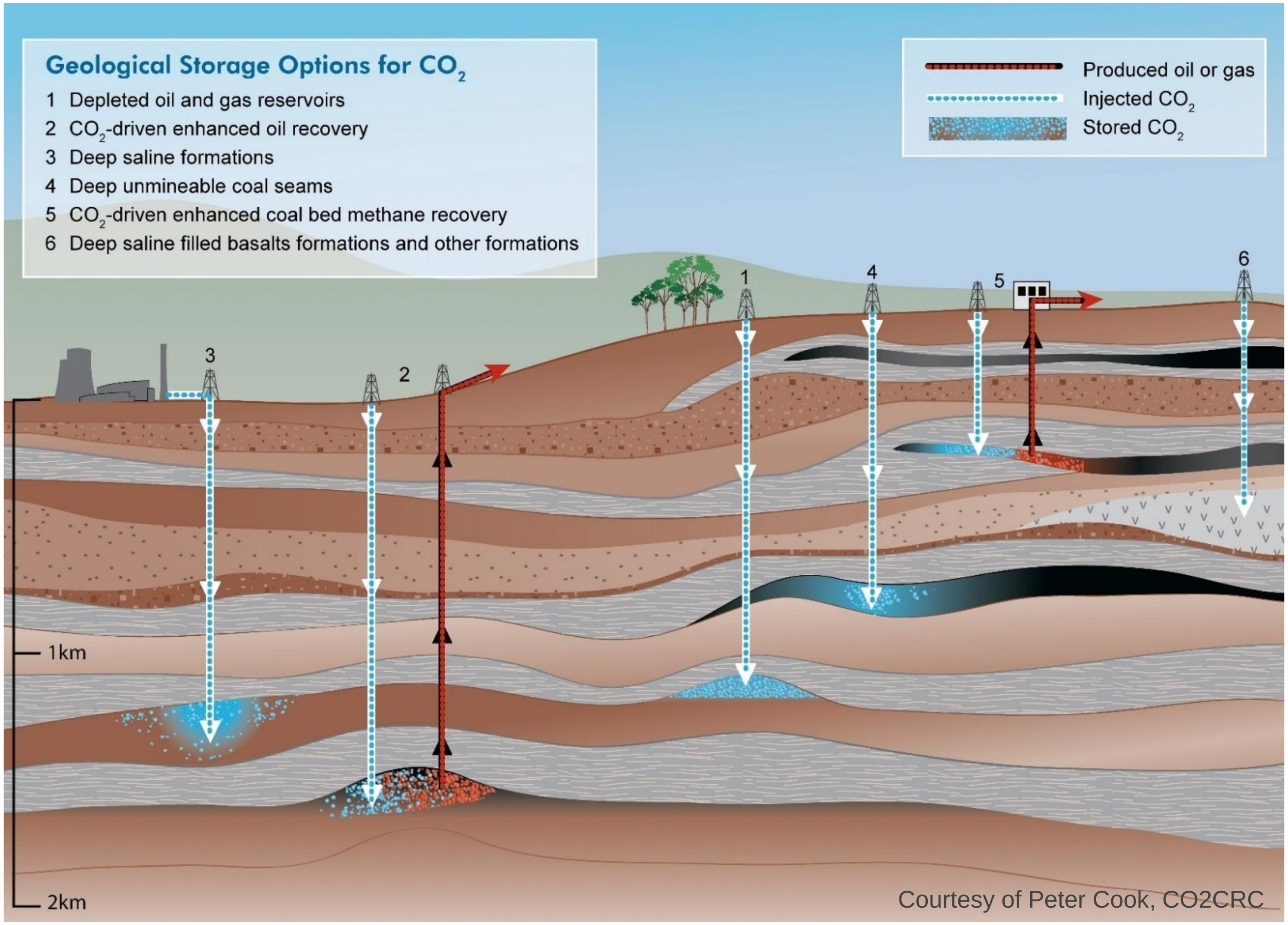
Candidate Geologic CO_2 Storage Formations

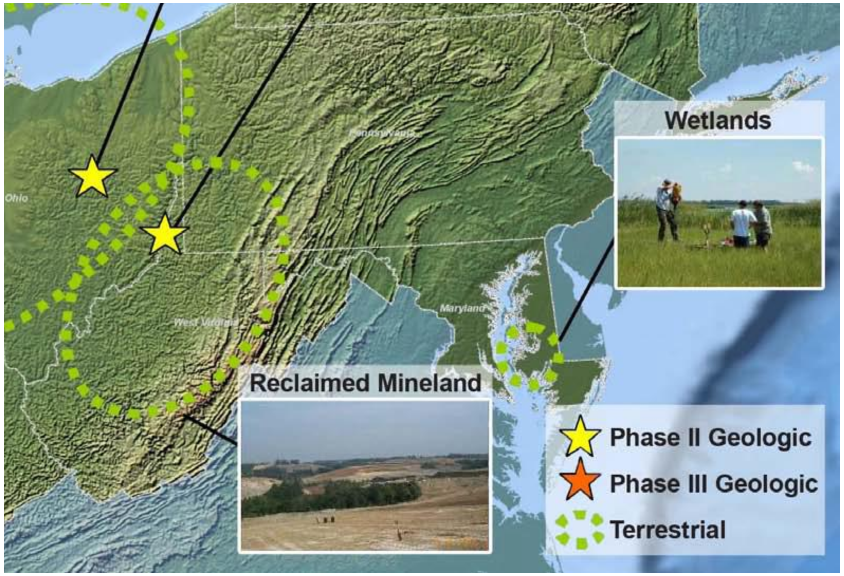
Multiple Options for CO_2 Storage



Courtesy of Peter Cook, CO2CRC

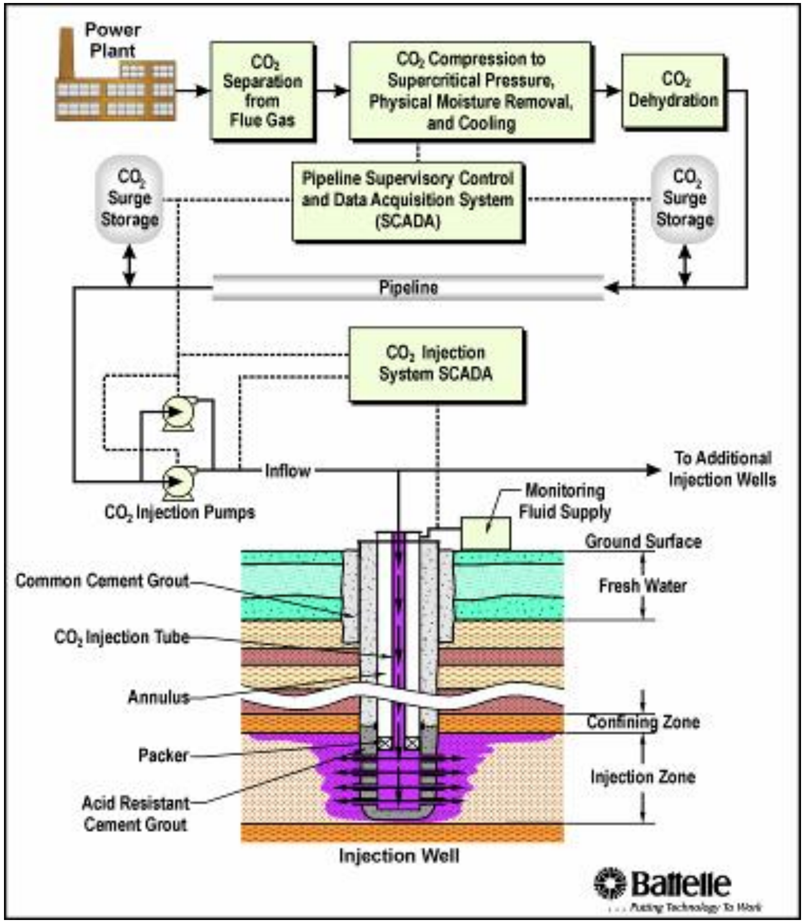
Terrestrial Sequestration

- Terrestrial sequestration options for **restored wetlands**, **reclaimed minelands**, **forested wetlands** in Maryland.



Restored tidal marshes at Blackwater National Wildlife Refuge, Maryland.

Components of CCUS Value Chain



Enterprise Strategic Planning
- Carbon foot print analysis
- Source reduction analysis
- Asset opportunity screening

Capture
- Development of new capture concepts
- Applications screening
- Process optimization and integration

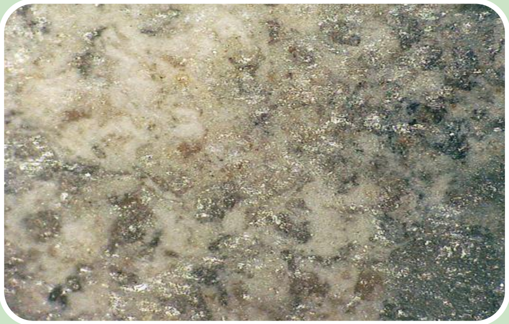
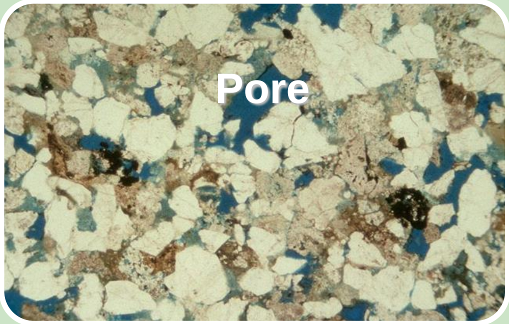
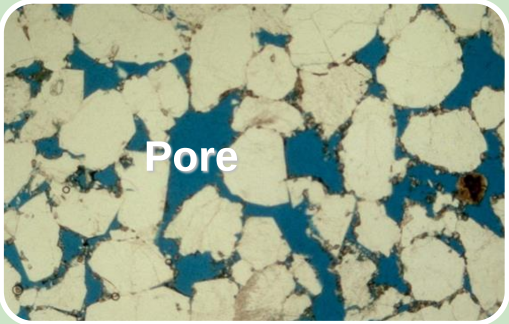
Surface Transport
- Analysis of CO_2 transport properties
- Process optimization and integration
- System design support
  - Compression and processing
  - Pipeline transport
- Monitoring (inspection, corrosion analysis etc.)

Subsurface and Injection
- Site characterization
- Permitting and Environmental
- Well field design and implementation
- Injection operations and monitoring

Measurement Mitigation and Verification
- Design, implementation and operation
- Data analysis

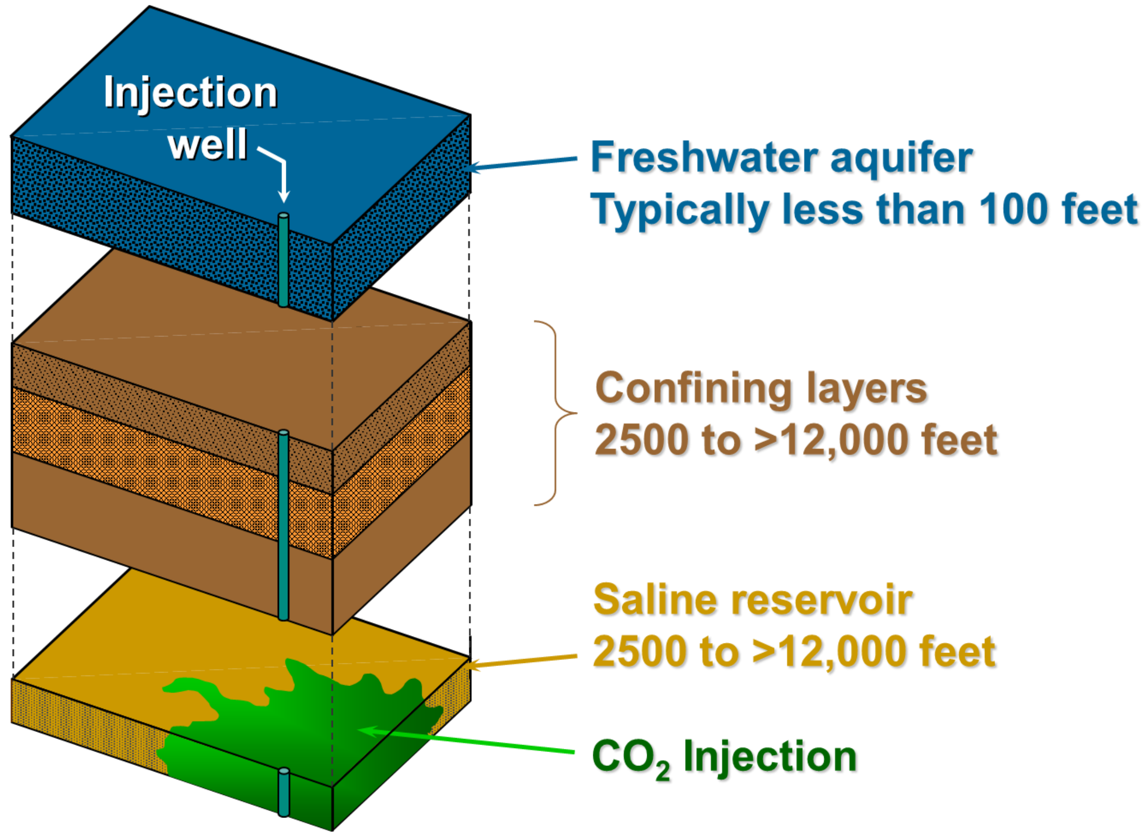
Storing CO_2

What Makes Good Reservoirs and Confining Layers?

Confining Layer	Medium Reservoir	Excellent Reservoir
	 	
• Permeability less than .01 mD • Shale, carbonate mudstone, salt	• Permeability10-100 mD • Sandstone • Dolomite with intercrystalline porosity	• Permeability >100 mD • Sandstone • Dolomite with vug development and intercrystalline porosity

Site Selection-Well Characterized Deep Reservoirs Isolated from Freshwater Sources

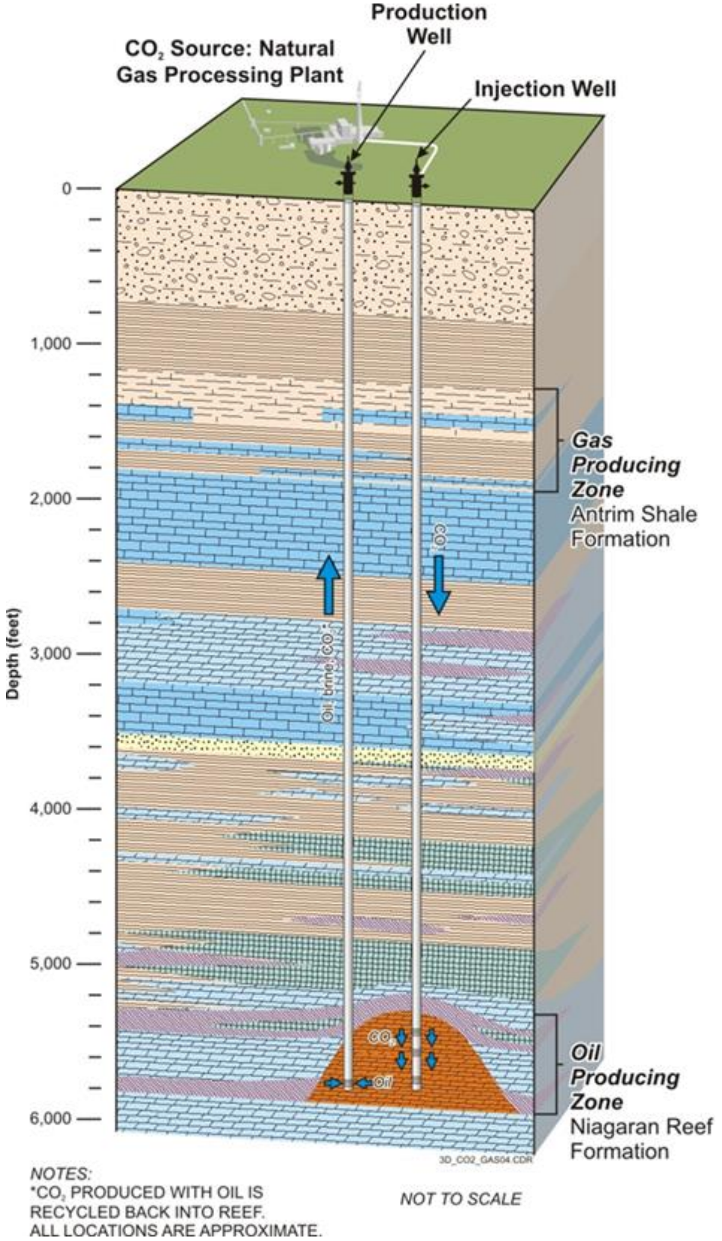
- Saline reservoirs excellent for storage
  - Not competing with O&G fields
  - Isolated from freshwater sources
  - Deep enough to keep CO_2 at supercritical



Storing/Utilizing CO_2

Depleted Oil and Gas Fields/ EOR

- Depleted oil and gas fields are ideal candidates for storage
  - Proven to hold fluids
  - Efficient seals
- Enhanced oil recovery (EOR) adds utilization option
  - Better recovery of oil
  - Recycling of CO_2
  - Once oil is recovered, reservoir can be used for storage



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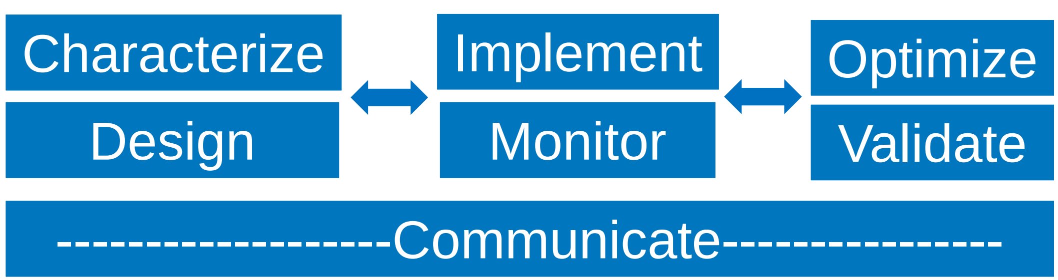
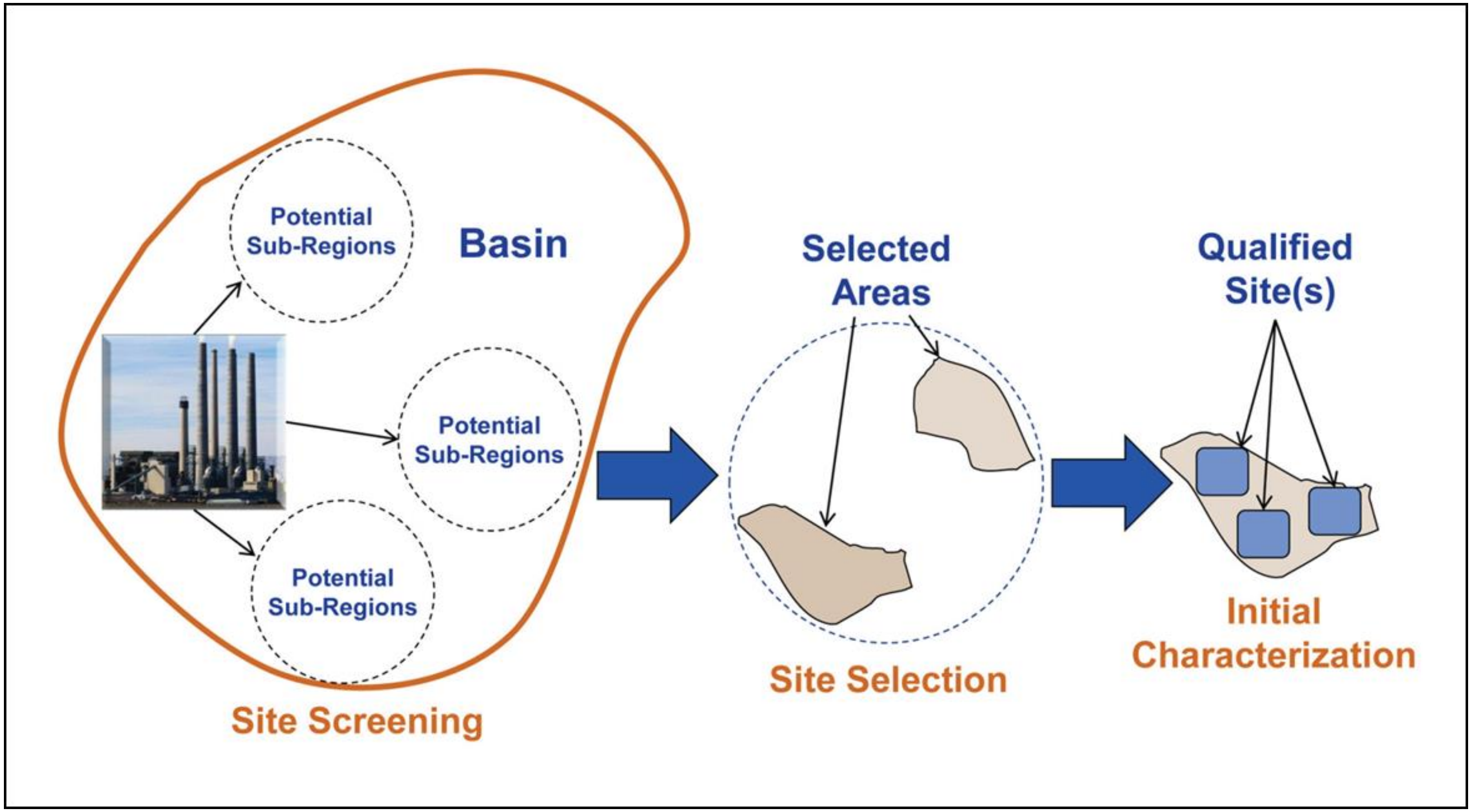
Geologic CO_2 Storage

- Candidate CO_2 storage sites are screened for suitability of long-term storage using geologic and economic criteria
- Site selection and development for geologic storage typically evolve over multiple project stage considerations
- Site characterization a key step to establish baseline conditions and develop understanding of the storage reservoir dynamics
- Monitoring of the site during injection and post-injection to track reservoir response and validate system performance and conformance criteria



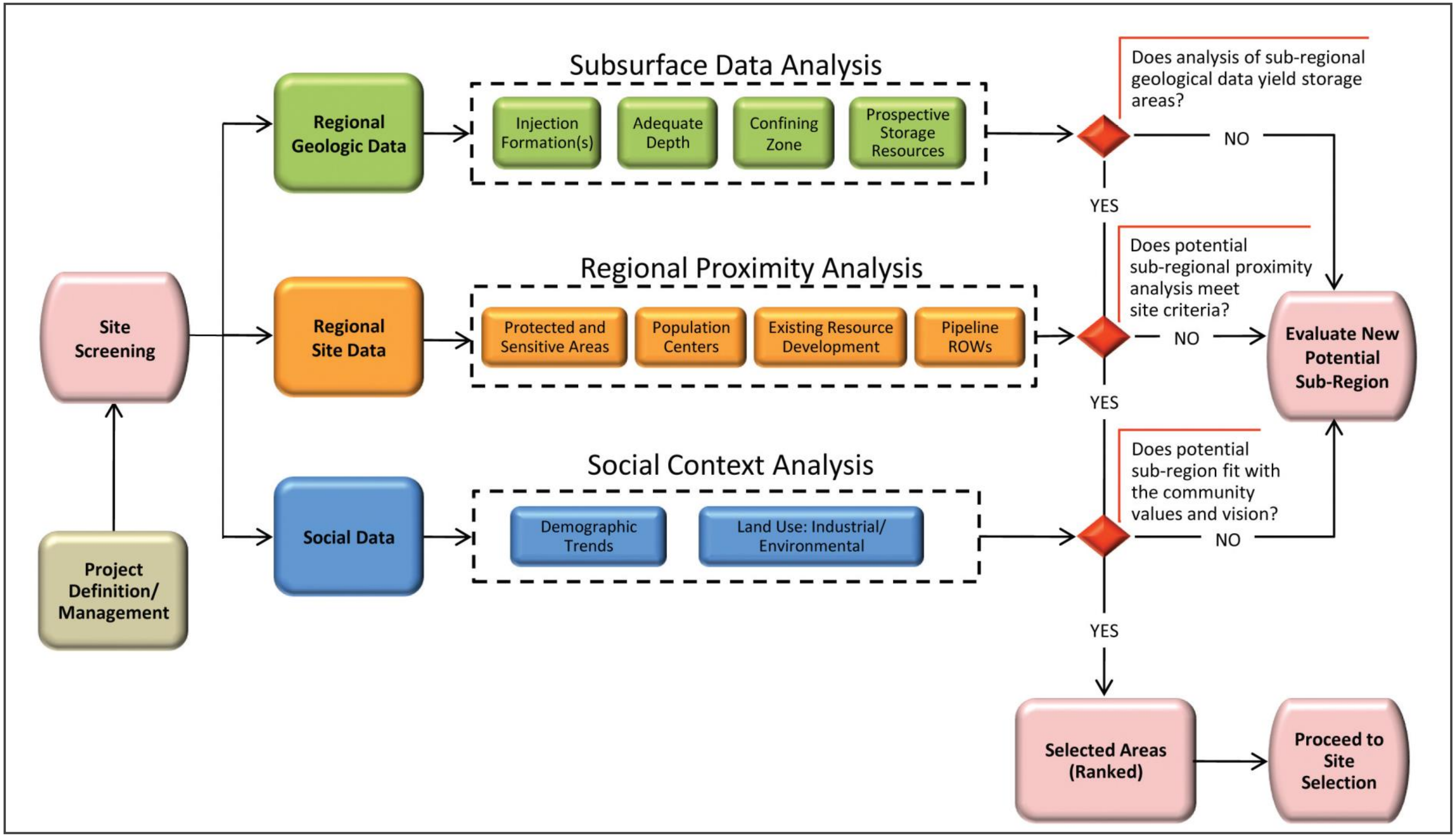
Developing CCS Projects

Site Selection Maturation over Project Stages



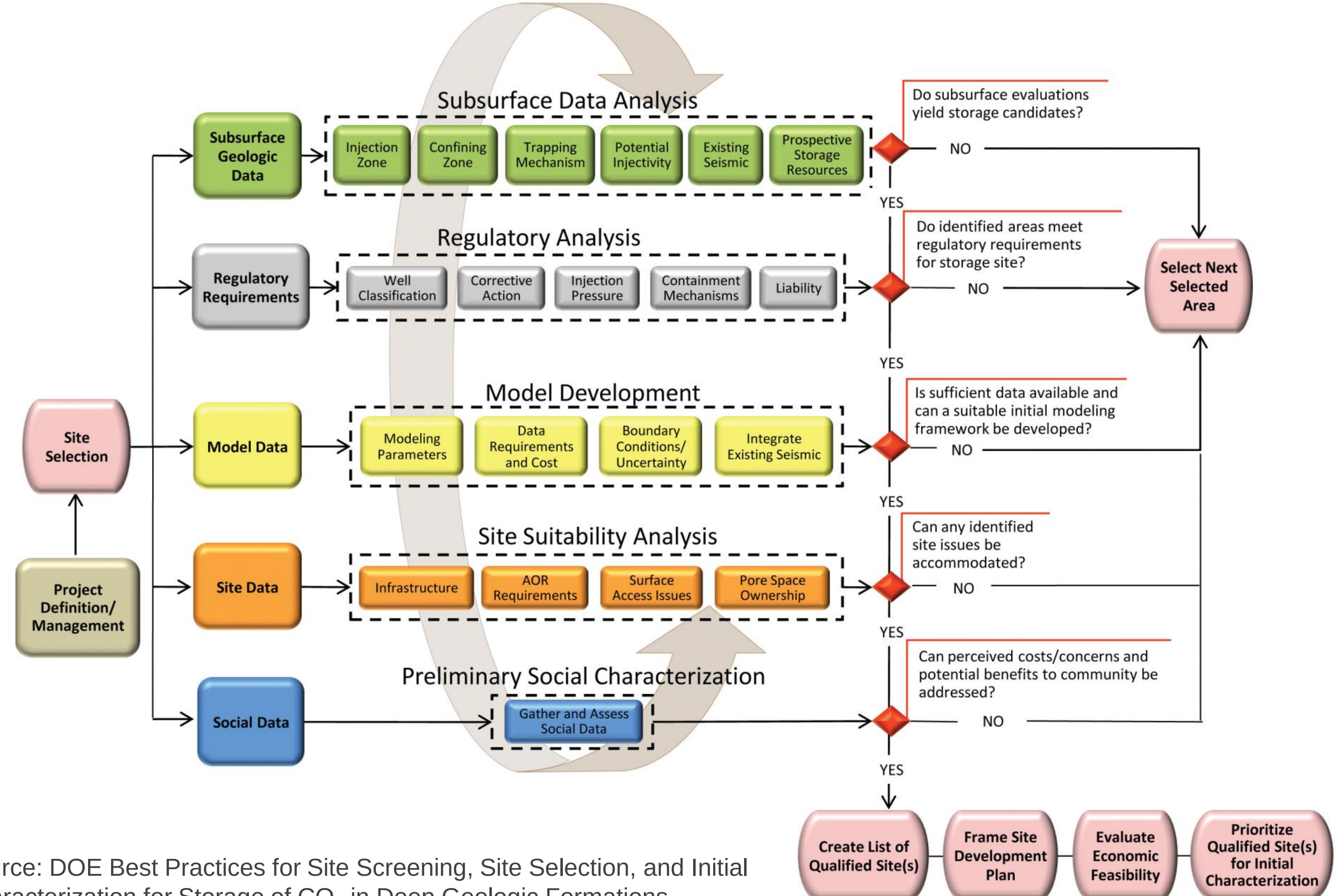
Source: DOE Best Practices for Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations

Flowchart for Site Screening



Source: DOE Best Practices for Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations

Flowchart for Site Selection



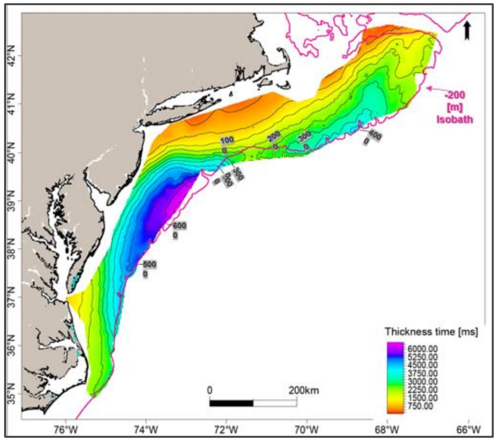
Source: DOE Best Practices for Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations

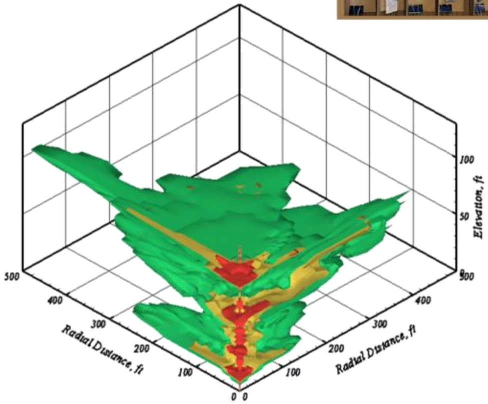
US EPA - 2 Prongs for Regulations

- Underground Injection Control (UIC) governs well permitting and injection operations
  - Class II – Oil and Gas Operations (145,707 Recovery Wells as of FY 2016)
  - Class VI – CO_2 Sequestration (7 CCS Wells as of FY 2016)
- GHG Reporting Program
  - Subpart RR for Geologic Sequestration of CO_2 (3 Approved Plans)
  - Subpart UU for Injection of CO_2 (86 Reporters)

Geologic Field Characterization Activities

- Geologic Assessment
  - Site specific assessment of target storage reservoirs and geologic setting
- Site Characterization and Design
  - Seismic surveys, test-well drilling, reservoir tests, brine sampling, other field work at the demo sites
  - Site data used to design injection and monitoring programs
- CO_2 Injection Tests and Monitoring
  - Finalize CO_2 source and delivery
  - CO_2 injection testing and monitoring
- Additional test wells may be needed in some cases

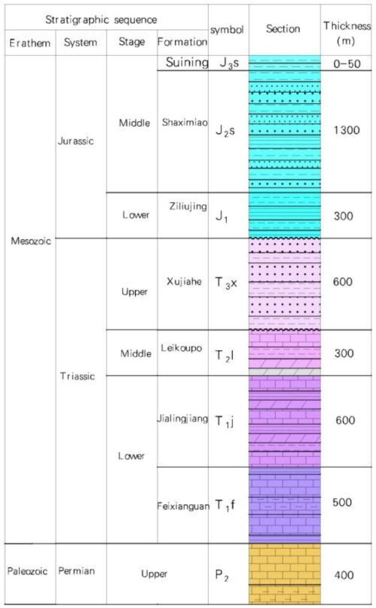




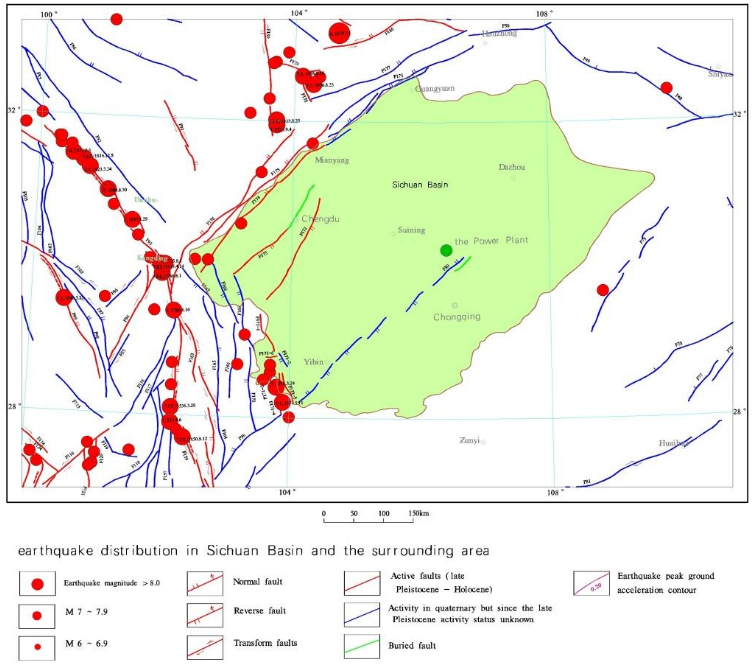
Developing CCS Projects

Site Screening Using Geological Setting-Sichuan Basin Example

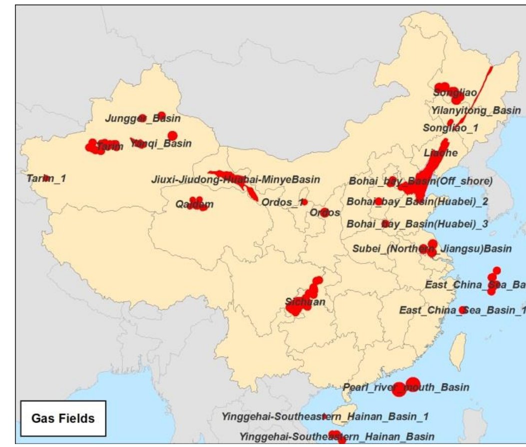
Lithology



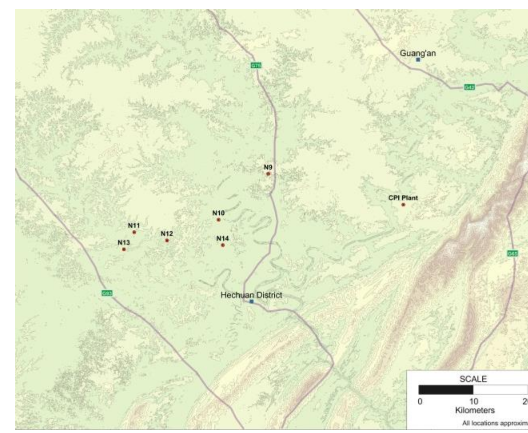
Seismic Setting



Oil and Gas Fields



Existing Deep Wells



Regional Structure and Faults

Source: China Geological Survey

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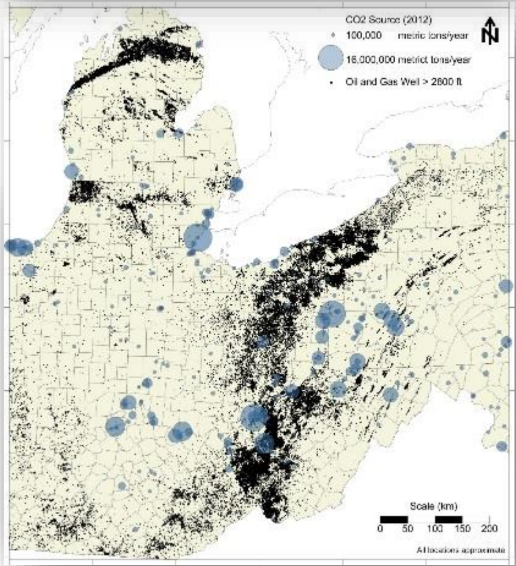
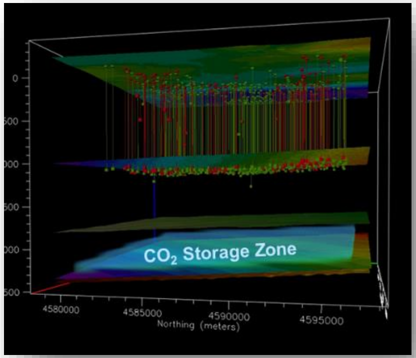
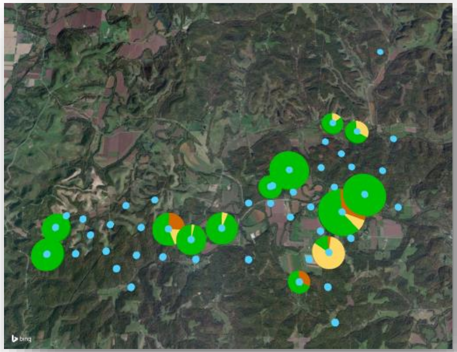
Wellbore Integrity – CCUS in Oil/Gas Rich Regions

- Old wells seen as a risk for CO_2 storage
- Regional status of oil and gas wells, cement bond logs, field monitoring of sustained casing pressure, spatial analysis of wellbore integrity indicators, 6 test study areas
- Results provide better understanding of implications of wellbore integrity issues for CO_2 storage projects in the region







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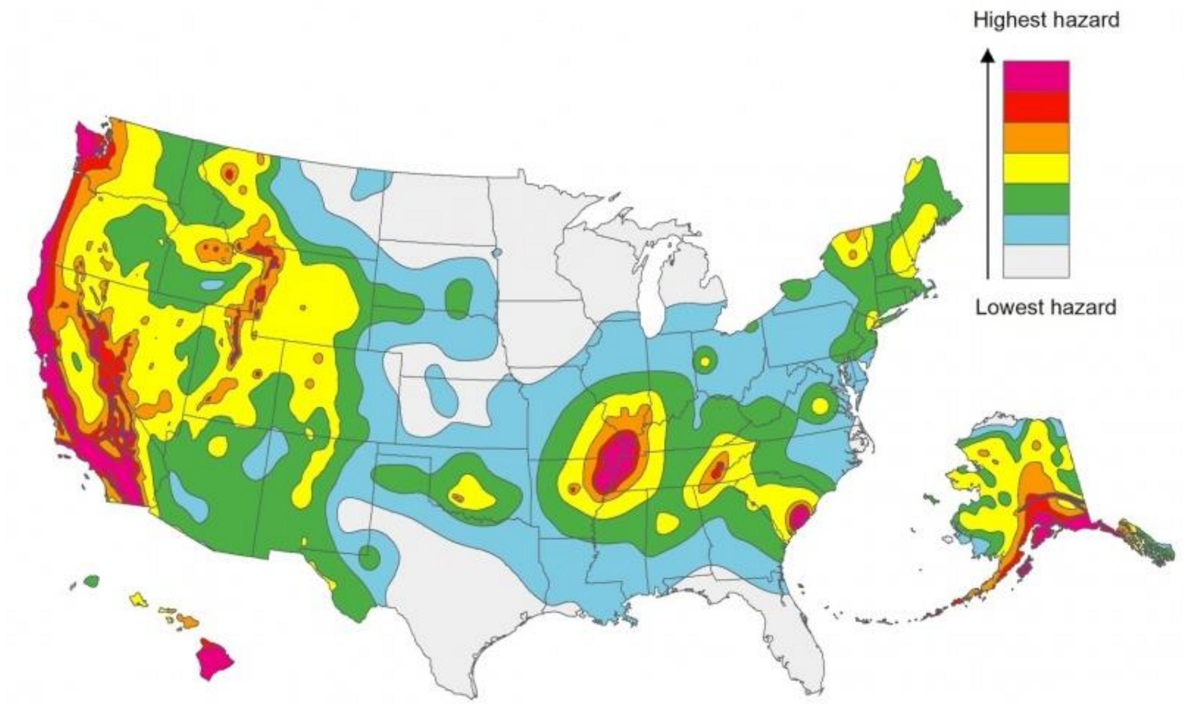
Low Seismic Hazard in Mid-Atlantic

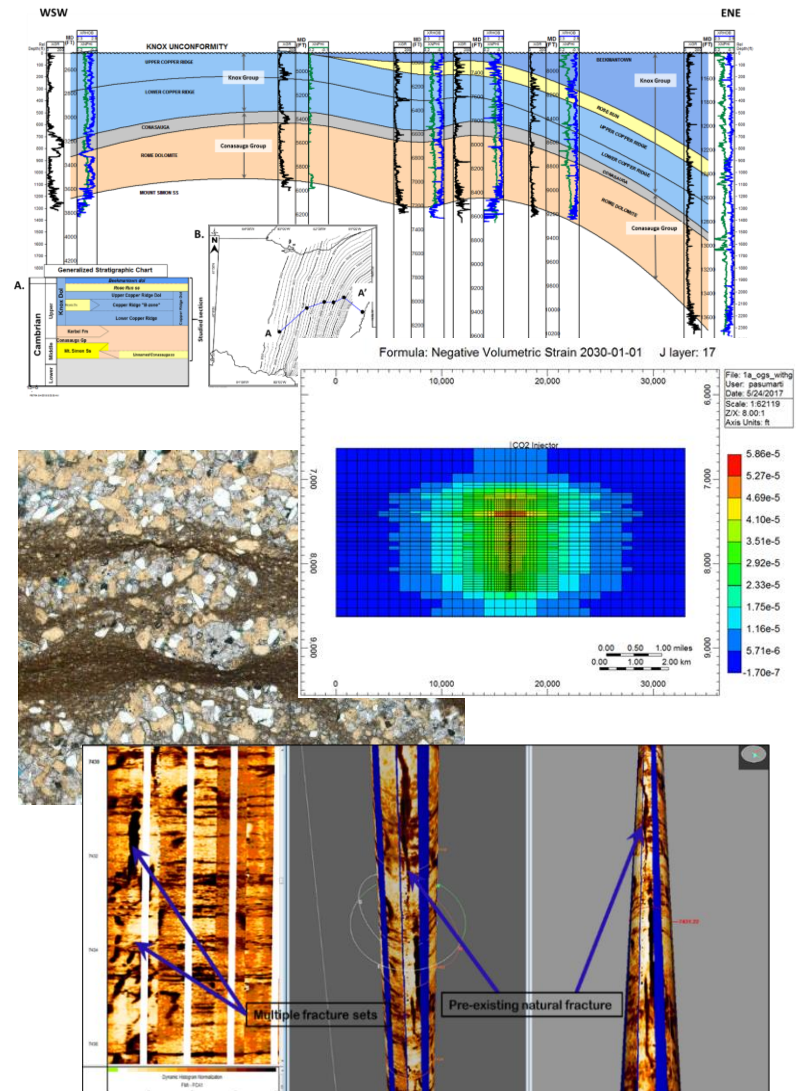
- Seismicity risk reduced through siting, characterization, and operational controls



USGS National Seismic Hazard Mapping Project

Evaluating Geomechanical Risks for CO_2 Storage

- Realistic analysis of geomechanical risk factors related to CO_2 storage:
  - Which reservoir rock formations are more fractured in the region?
  - Which caprocks have larger risk factors related to fracturing?
  - What are the key methods and tools for evaluating fractured zones in deep layers?
  - How can we better understand basin-scale stress-strain regime to more accurately define stress magnitude at depth?



Estimating Storage Resources

Defining Storage Terminology and Classification Systems

CSLF, 2007, 2008

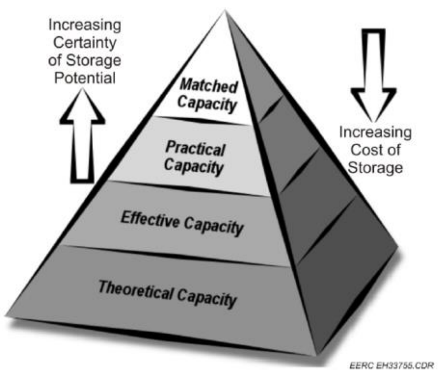


Figure 4. CSLF Techno-Economic Resource-Reserve pyramid (CSLF, 2007).

USDOE, 2008, 2010, 2011, 2012, 2015

Table 1
CO_2 geologic storage classification system.

Petroleum Industry		CO_2 Geological Storage
Reserves	Implementation	**Capacity**
On Production	Implementation	Active Injection
Approved for Development	Implementation	Approved for Development
Justified for Development	Implementation	Justified for Development
Contingent Resources	Site Characterization	**Contingent Storage Resources**
Development Pending	Site Characterization	Development Pending
Development Unclarified or On Hold	Site Characterization	Development Unclarified or On Hold
Development Not Viable	Site Characterization	Development Not Viable
Prospective Resources	Exploration	**Prospective Storage Resources**
Prospect	Exploration	Qualified Site(s)
Lead	Exploration	Selected Areas
Play	Exploration	Potential Sub-Regions

	Prospective Storage Resources	
Exploration	**Project Sub-class**	**Evaluation Process**
Exploration	Qualified Site(s)	Initial Characterization
Exploration	Selected Areas	Site Selection
Exploration	Potential Sub-Regions	Site Screening

IEA GHG, 2008

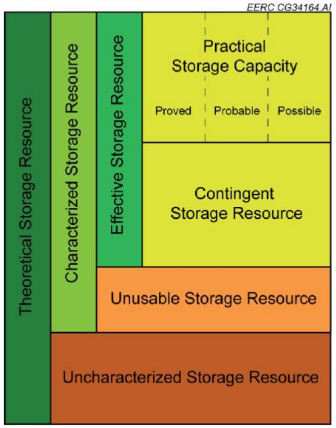
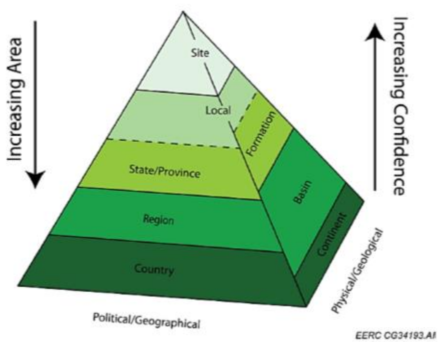


Figure 5. Proposed CO_2 storage classification framework.



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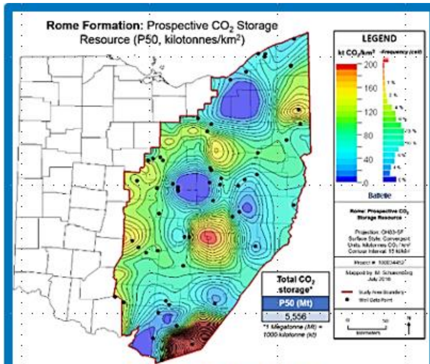
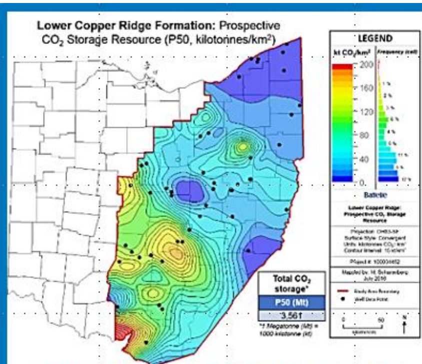
Regional Assessment In Eastern Ohio

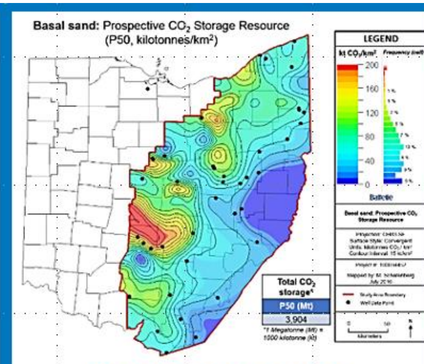
Calculation of Prospective Stacked CO_2 Storage Resource



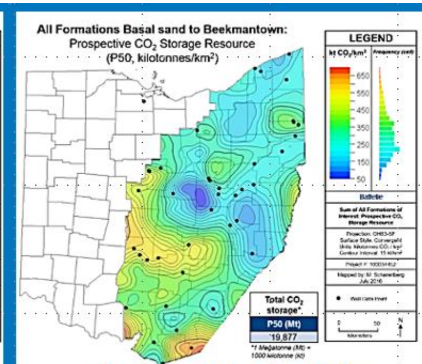
Rome Formation
P50 Prospective Resource



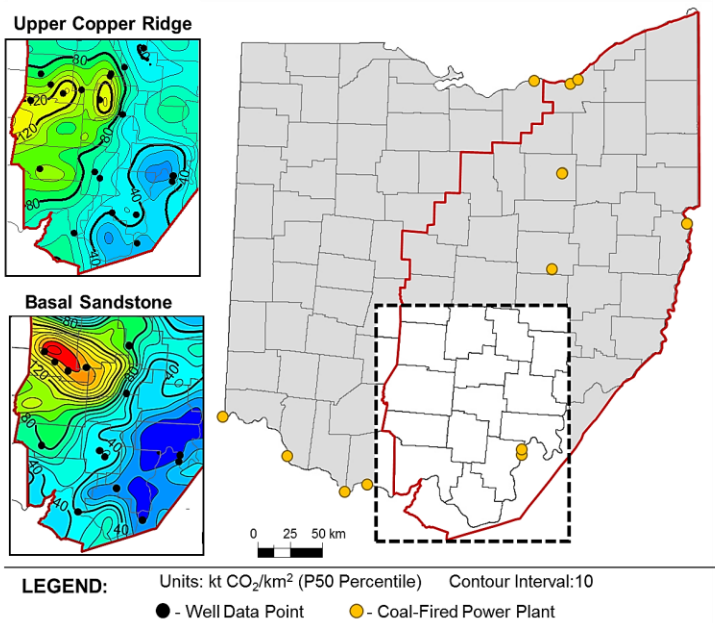
Lower Copper Ridge Formation
P50 Prospective Resource

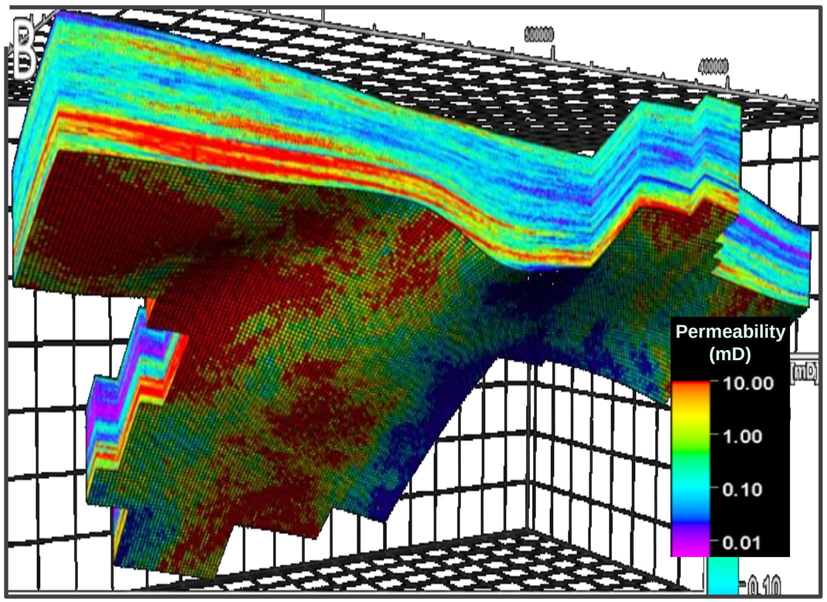


Basal sand Formation
P50 Prospective Resource



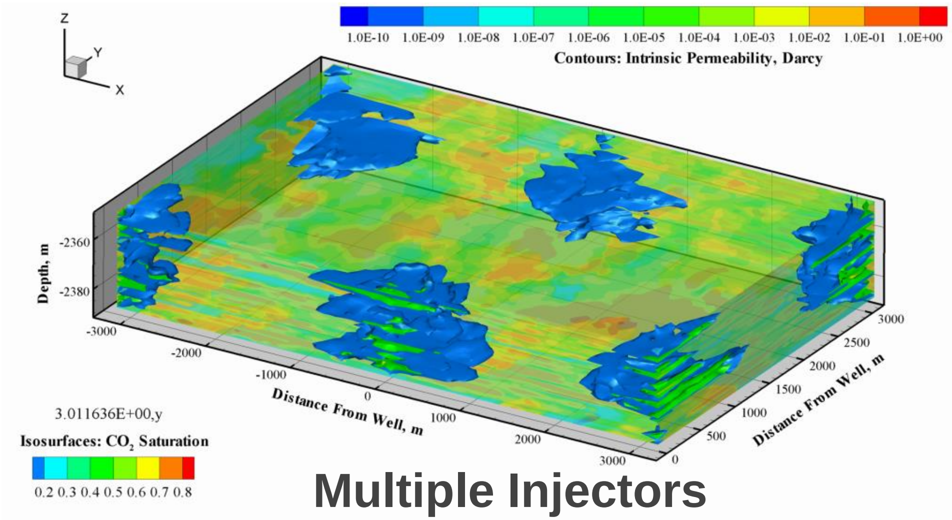
All Reservoirs in Study
P50 Prospective Resource

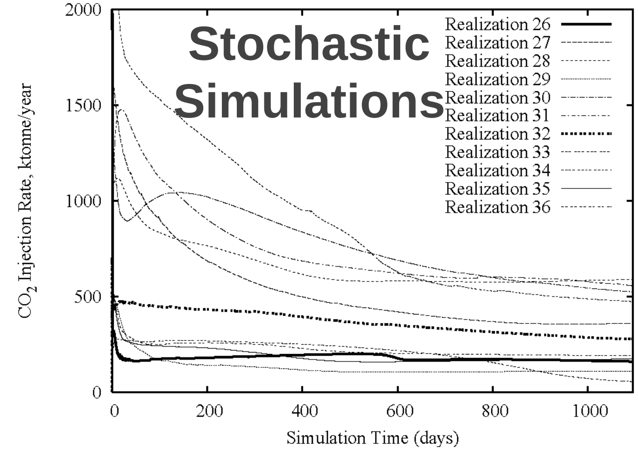


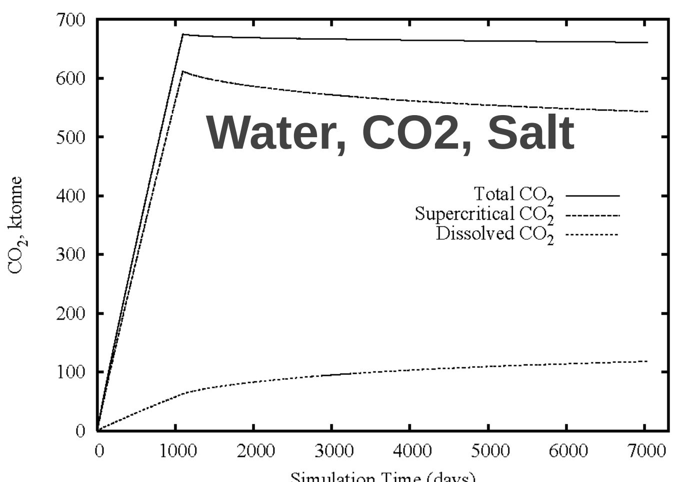


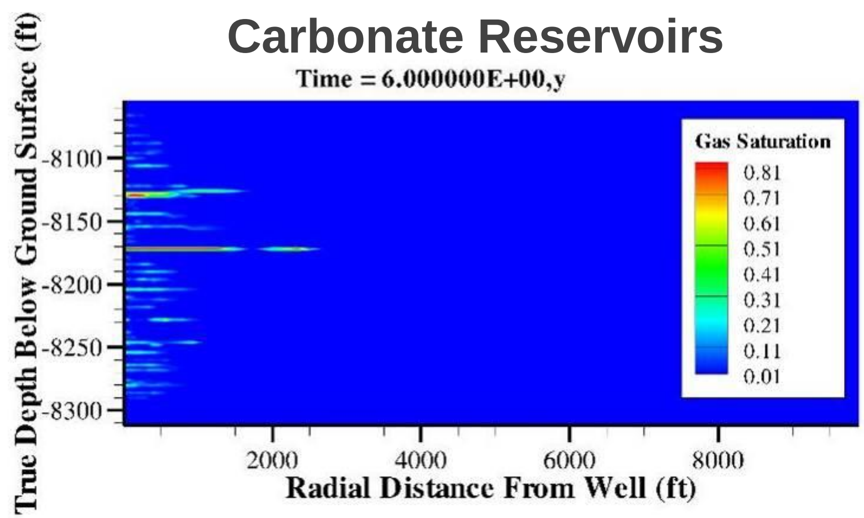
Co-Funded by ODSA/OCDO Project D-13-22

Reservoir Simulations Aspects
Example from Mountaineer Site









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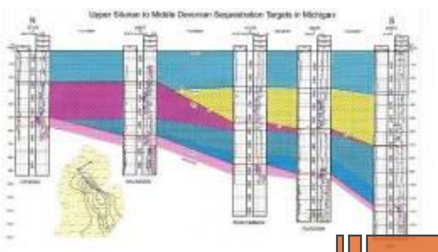
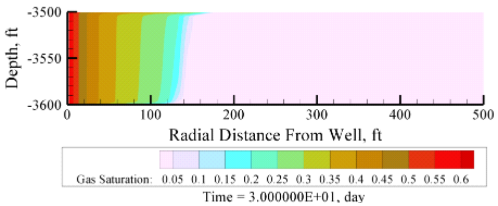
Reservoir Modeling - Model Evolution with Project Phases

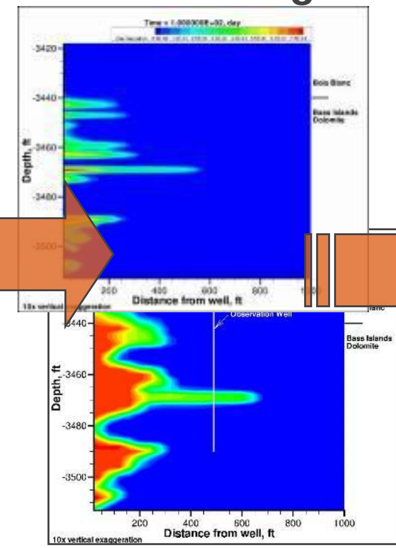
Preliminary Modeling Based on Regional Data



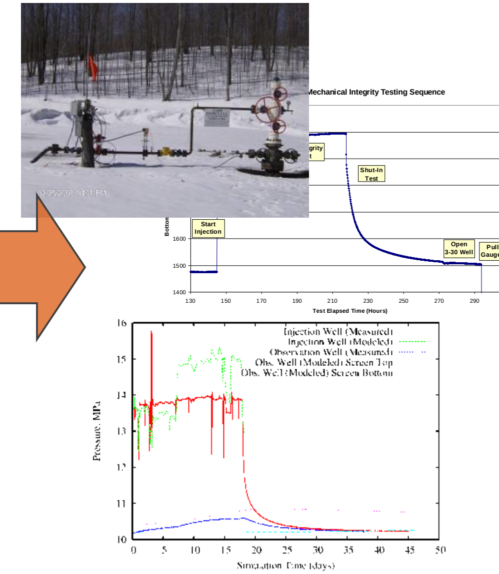


Site Drilling and Testing

Site Specific Modeling



Post-Injection Calibration/Validation



Conceptualize | Characterize | Design | Monitor | Calibrate | Validate

-------------------------------------Communicate-------------------------------------

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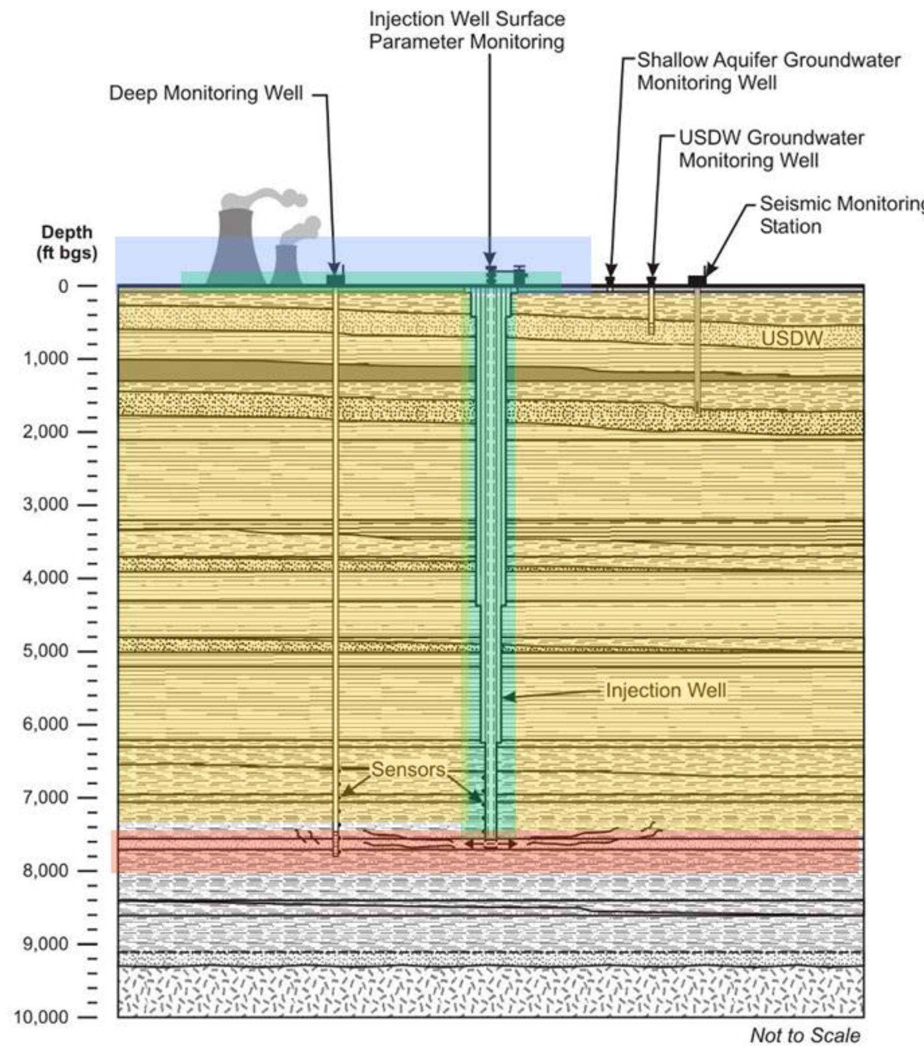
Why is Monitoring Important?

- Accounting for injection
- Regulatory requirements
- Optimization
- Operational safety
- Leakage detection
- Map injected CO_2



Monitoring Technologies

Atmospheric Monitoring

- Optical sensors
- Atmospheric tracers
- Eddy covariance

Near-Surface Monitoring

- Geochemical monitoring in soil, vadose zone, and shallow groundwater
- Surface displacement
- Ecosystem stress

Subsurface-Monitoring

- Well logging tools
- Downhole monitoring tools
- Seismic
- Subsurface fluid sampling and tracer analysis
- Gravity
- Electrical techniques

MVA Data Integration and Analysis

- Intelligent monitoring networks
- Advanced data integration and analysis

Source: Best Practices for Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations

Developing a Monitoring Plan

Pre-Injection through Post CO_2 Injection

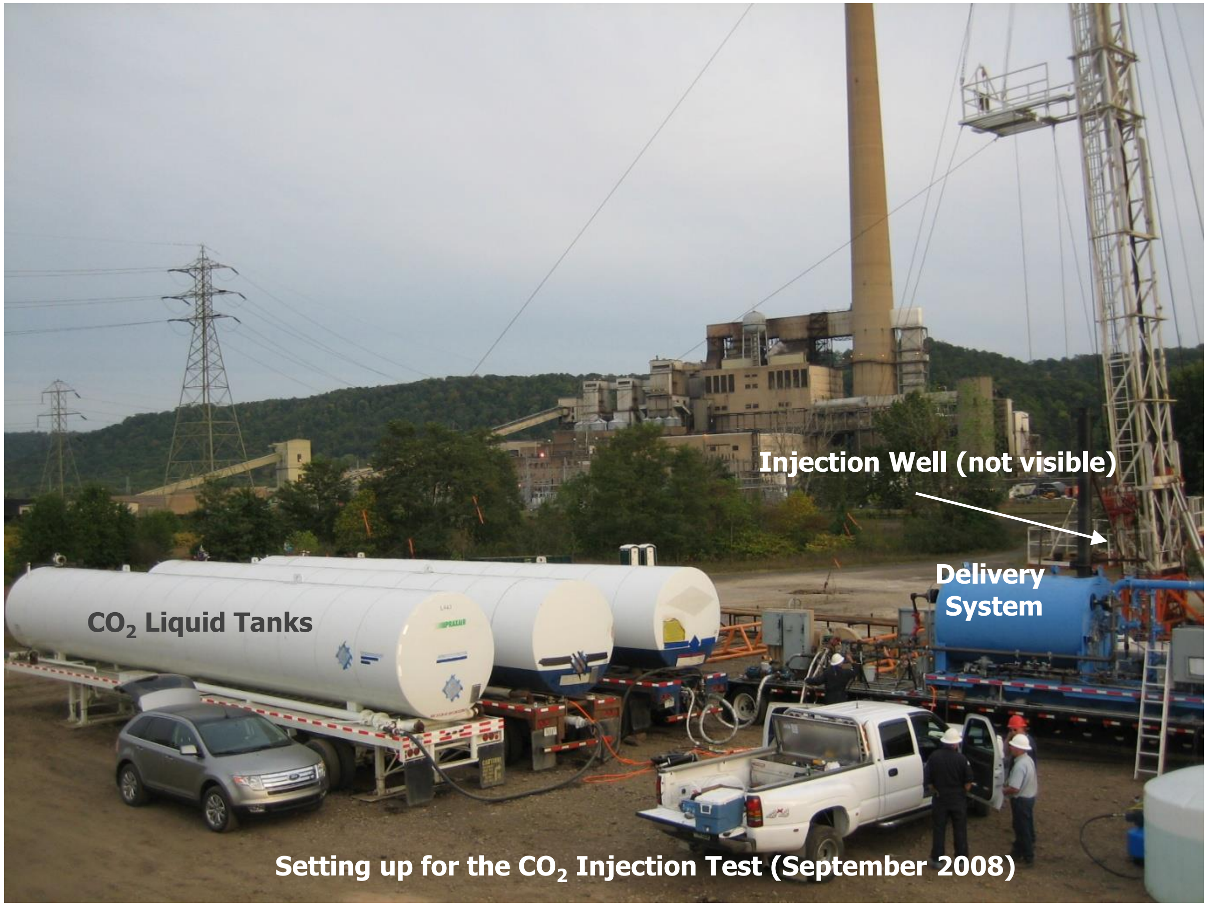
- **Baseline monitoring** to establish conditions pre-injection
- **Active injection monitoring** for operational safety, leakage detection, and plume transport
- **Post injection monitoring** to verify CO_2 plume location and leakage detection

Time (Months)	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
Phase	Preinjection Baseline Monitoring						Active Injection																Post-Injection		
Capture System																									
Compression																									
Transport																									
Injection System																									
SCADA																									
Health and Safety																									
Mechanical Integrity Test						X							X						X						X
Well Workover													X						X						X
Passive Seismic																									
Groundwater Monitoring	X			X			X			X			X			X			X			X			X
Soil-gas	X			X			X			X			X			X			X			X			X
Atmospheric Flux				X			X						X						X						X
Wireline						X				X			X			X			X			X			X
VSP/X-well Sesimic						X							X						X						X
Tracer Testing																									
Reservoir Sampling						X							X						X						X
Well Indicator sensors																									

X = sampling event

Injection Operations and Monitoring

- Injectivity testing at a power plant in a pilot test
- At this site, very limited injection was possible due to low permeability



Developing clear communications about CCS critical towards increasing public acceptance

- Addressing public concerns about safety
- CCS' role in climate change mitigation
- Addressing specific concerns such as the protection of groundwater resources
- Key conclusions resulting from research and demonstrations

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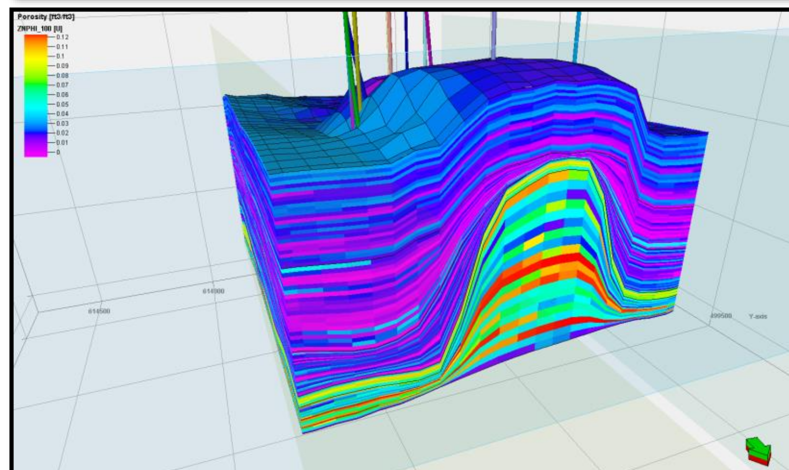
CCUS: An Important Option for Climate Change Mitigation

- Safe CO_2 storage sites can be selected using well-known techniques
- CO_2 can be injected and monitored using available techniques
- The behavior of injected CO_2 can be reliably predicted using modeling
- Risks are well understood and measures are taken to greatly reduce those risks
- <u>Without CCUS the cost of addressing climate change is much higher</u>



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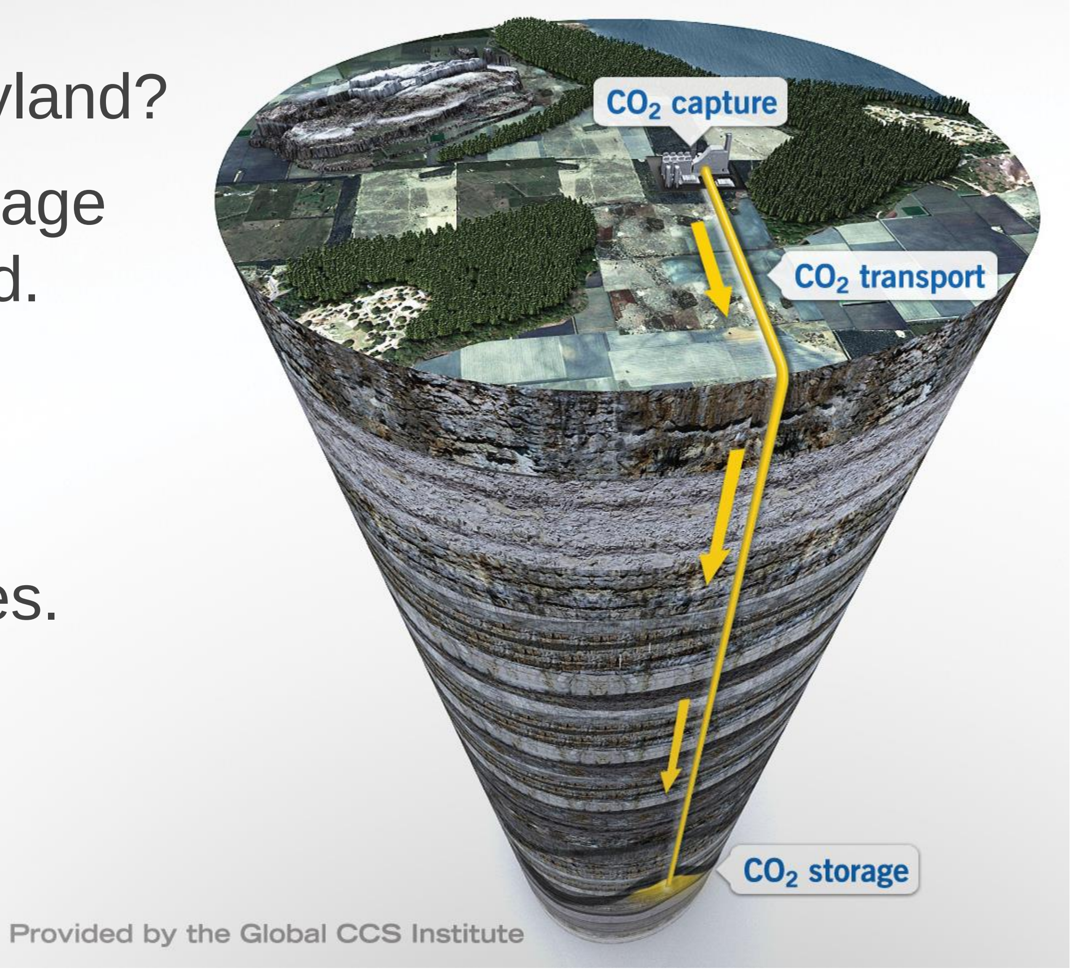
Moving Forward

- Storage options in Maryland?
- Key issues for CO_2 storage applications in Maryland.
- Pilot tests
- Source-sink matching.
- Feasibility, FEED studies.
- Policy support.



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Questions?

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