Resource Assessment Methods for CO_2 Storage in Geologic Formations

U.S. Department of Energy
National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Pittsburgh, PA

Angela Goodman
Research & Innovation Center / National Energy Technology Laboratory

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

the ENERGY lab

NETL RESEARCH CARBON STORAGE PROGRAM

NETL Research Presentations and Posters

TUESDAY, AUGUST 16, 2016

- **12:40 PM** Monitoring Groundwater Impacts - Christina Lopano
- **1:55 PM** Multi Variate Examination of the Cause of Increasing Induced Seismicity – Kelly Rose
- **4:40 PM** Exploring the Behavior of Shales as Seals and Storage Reservoirs for CO_2 – Ernest Lindner
- **5:05 PM** Risk Assessment for Offshore Systems – Kelly Rose
- **5:30 PM** Metal-based systems in Extreme Environments – Jeff Hawk
- 6:15 p.m. **Poster Session**
  - Kelly Rose - Developing a carbon storage resource assessment methodology for offshore systems
  - Doug Kauffman - Catalytic Conversion of CO2 to Ind. Chem. And eval. Of CO2 Use and Re-Use
  - Liwel Zhang - Numerical simulation of pressure and CO2 saturation above an imperfect seal as a result of CO2 injection: implications for CO2 migration detection

WEDNESDAY, AUGUST 17, 2016

- **12:30 PM** MVA Field Activities – Hank Edenborn
- **1:20 PM** Microseismicity –Erik Zorn
- **2:35 PM** Resource Assessment – Angela Goodman
- **2:35 PM** Understanding Impacts to Air Quality from Unconventional Natural Gas – Natalie Pekney
- **4:05 PM** Improving Science-Base for Wellbore Integrity, Barrier Interface Performance – Nik Huerta
- **5:20 PM** Wellbore Integrity and Mitigation – Barbara Kutchko

THURSDAY, AUGUST 18, 2016

- **1:00 PM** Advances in Data Discovery, Mining, & Integration for Energy (EDX) – Vic Baker
- **1:25 PM** Methods for Locating Legacy Wells – Garrett Veloski
- **2:40 PM** Reservoir Performance – Johnathan Moore
- **3:05 PM** Geochemical Evolution of Hydraulically-Fractured Shales – Ale Hakala

UCR Unconventional Resources

https://edx.netl.doe.gov/carbonstorage/
https://edx.netl.doe.gov/offshore/
https://edx.netl.doe.gov/ucr/

NETL RESEARCH CARBON STORAGE PROGRAM

Benefit to the Program

- **Carbon Storage Program Major Goals**
  - Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- **Project Benefits Statement:**
  - This research project aims at developing and maintaining tools/resources that facilitate assessment of prospective CO_2 storage at the national, regional, basin, and formation scale

Project Overview: Goals and Objectives

- Carbon Storage Program Major Goals:
  - Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- Project Benefits Statement:
  - This research project aims at developing and maintaining tools/resources that facilitate regional- and national-scale assessment of carbon storage
- Project Objectives:
  - Resource Assessments: **Develop a Defensible DOE Methodology for Regional Assessments**
- Develop, refine, and evaluate a suite of methodologies/methods to quantitatively assess CO_2 storage resource potential in onshore and offshore reservoirs including saline formations, oil and gas reservoirs, coal seams, and shales.

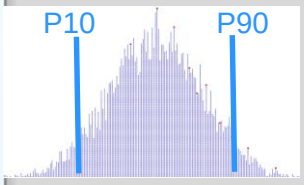
Technical Status

Resource Assessments and Geospatial Resources

Develop Defensible DOE Methodology for Regional Assessments

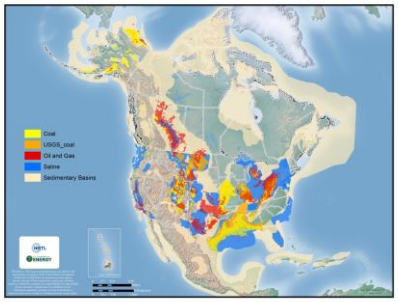
Mass Resource Estimate

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

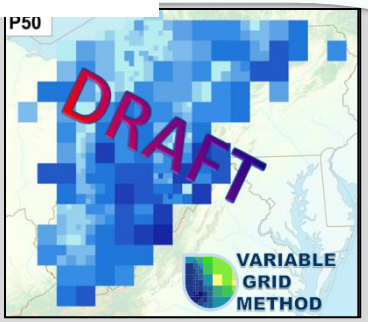


Reserves		Capacity
On Production	Implementation	Active Injection
Approved for Development		Approved for Development
Justified for Development		Justified for Development
Contingent Resources	Site Characterization	**Contingent Storage Resources**
Development Pending		Development Pending
Development Unclarified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

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



Expand Methodology to Include Geospatially Variable Key Parameters

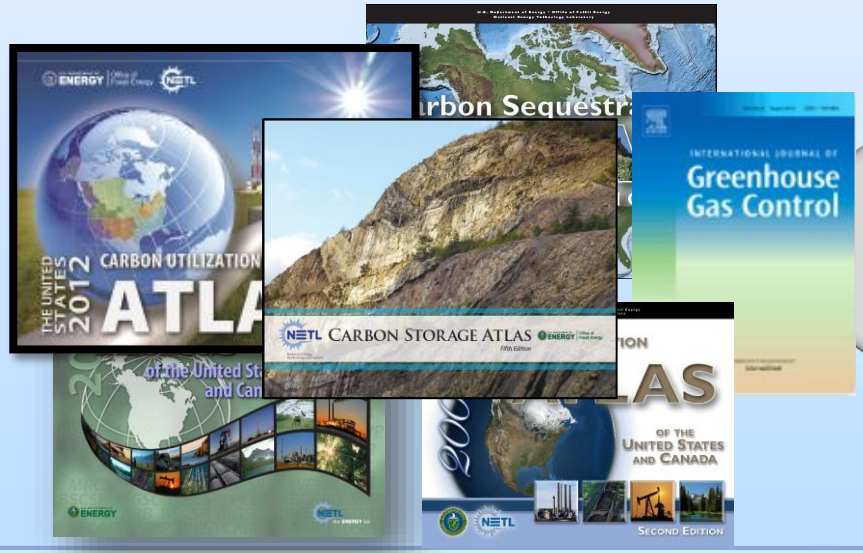


Formation													
Pair-wise Differences	A	B	C	D	E	F	G	H	I	J	K	L	M
USGS - CSLF													
USGS - AtlasI,II													
USGS - AtlasIII,IV													
USGS - Szulc.													
USGS - Zhou													
CSLF - AtlasI,II													
CSLF - AtlasIII,IV													
CSLF - Szulc.													
CSLF - Zhou													
AtlasI,II - AtlasIII,IV													
AtlasI,II - Szulc.													
AtlasI,II - Zhou													
AtlasIII,IV - Szulc.													
AtlasIII,IV - Zhou													
Szulc. - Zhou													

*white boxes represent statistical differences

Spatial Statistical Data Analysis

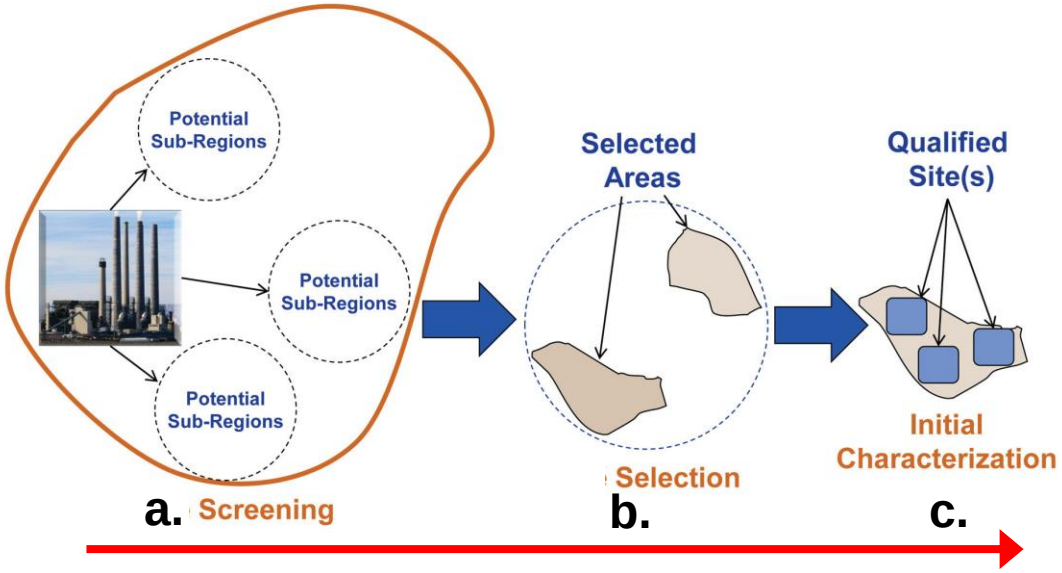
Develop methods to aid broad energy-related government policy and business decisions; Develop, refine, and evaluate a suite of methodologies/methods to quantitatively assess CO2 storage resource potential in onshore and offshore reservoirs



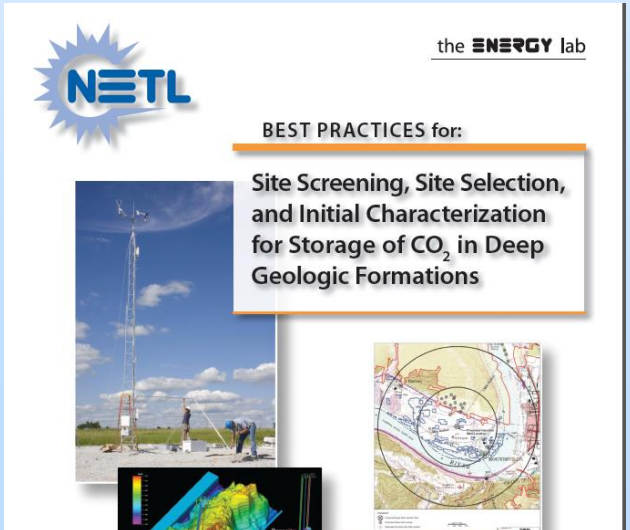
Geospatial Platforms

DEVELOP DEFENSIBLE DOE METHODOLOGY FOR REGIONAL ASSESSMENTS

Prospective Storage Resource for CO_2 storage reservoirs



"Project Site Maturation" through the Exploration Phase.



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

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

DEVELOP DEFENSIBLE DOE METHODOLOGY FOR REGIONAL ASSESSMENTS

Prospective Storage Resource for CO_2 storage reservoirs

Volumetric approach: *geologic properties & storage efficiency*

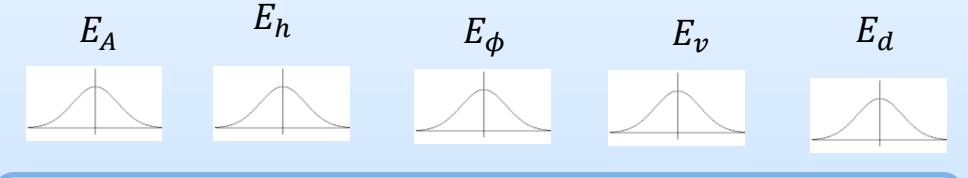
Subsurface Data Analysis

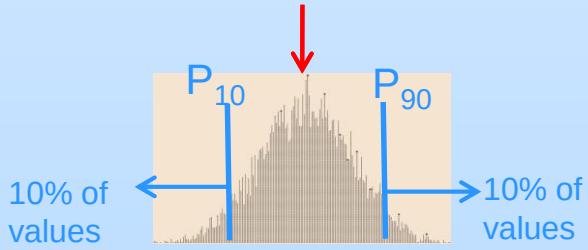
- *i. Injection Formation*
  - Oil and Natural Gas Reservoirs, Saline Formations, Unmineable Coal Seams, Shale, Basalt and Other Volcanic and Mafic Rocks
- *ii. Adequate Depth*
  - Sufficient depth to maintain injected CO_2 in the supercritical state
- *iii. Confining Zone*
  - Contain injected CO_2
- *iv. Prospective Storage Resources*
  - Sufficient pore volumes and can accept the change in pressure to accommodate planned injection volumes

Mass Resource Estimate

$$G_{Storage} = Ah\phi\,\rho\,E$$

$$E = E_A\,E_h E_\phi\,E_v\,E_d$$





Presentation Outline

Resource Assessment

Develop Defensible DOE Methodology for Regional Assessments

Unconventional Systems

- ***Team Members:*** Soeder, Bromhal, Dilmore, Sanguinito, Myshakin and Goodman

Oil and Gas Systems

- ***Team Members:*** Dilmore; Johns; Azzolina; Nakles; Goodman

Offshore

- ***Team Members:*** Rose, Disenhof, Bauer, Goodman

Expand Methodology to Include Stochastic Approach for Key Parameters

- ***Saline Systems / CO_2 SCREEN***

- ***Team Members:*** Sanguinito and Goodman

Expand Methodology to Include Geospatially Variable Key Parameters

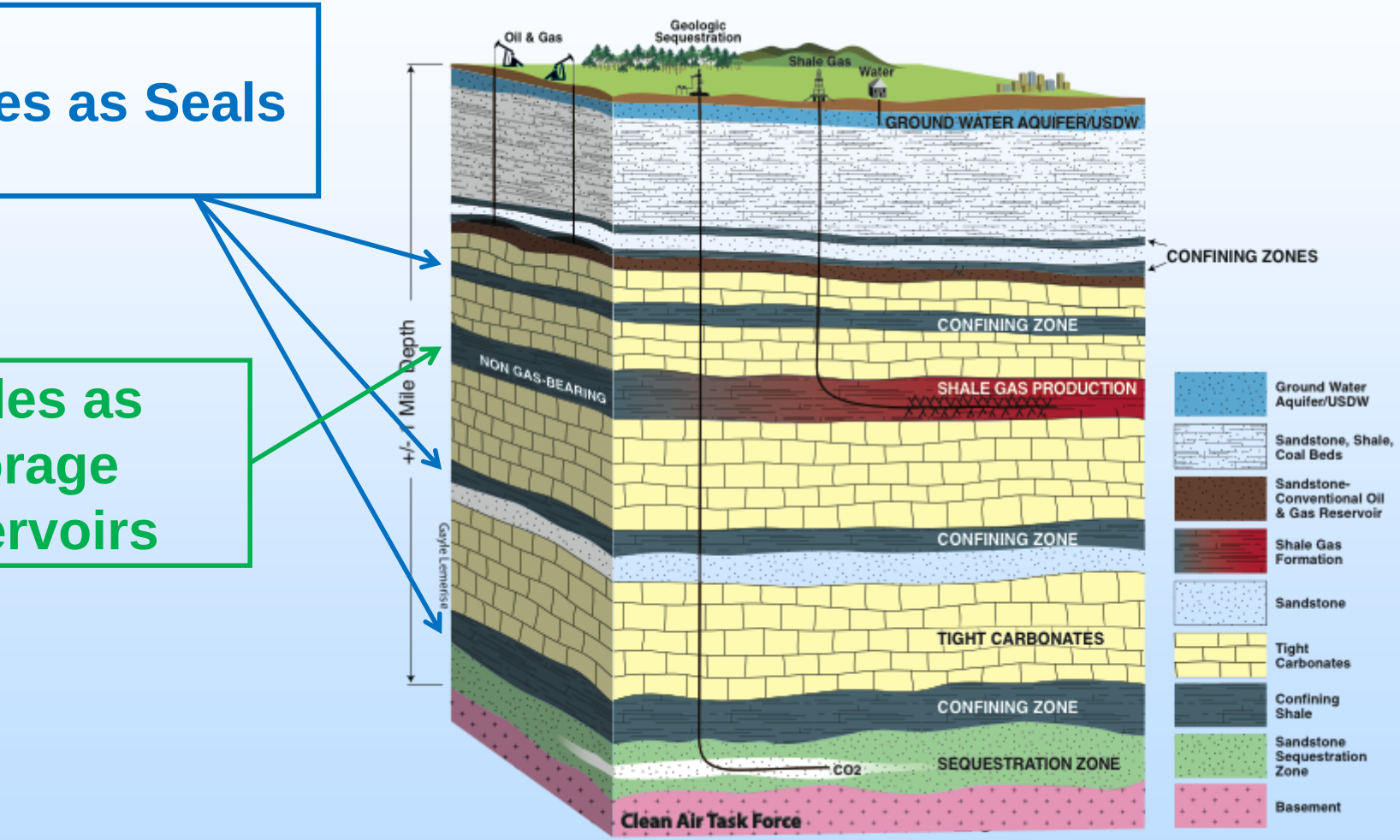
- ***Saline Systems - SIMPA***

- ***Team Members:*** Rose, Disenhof, Bauer

Unconventional Systems:
Prospective Storage for Shale Formations

Shales as Seals

Shales as Storage Reservoirs



Sources: ***HF illustration from National Energy Technology Laboratory (NETL), 2011),*** *Micro CT images by Rebecca Rodriguez, ORISE; Shale image from Reference: Lacazette , A. and Engelder, T. (1992) Fluid-driven cyclic propagation of a joint in the Ithaca Siltstone, Appalachian Basin, New York: p. 297 - 323 in B. Evans and T.-F. Wong (editors): Fault Mechanics and Transport Properties of Rocks; a festschrift in honor of W. F. Brace: Academic Press, San Diego.; NETL Carbon Storage Atlas IV (2012)*

Unconventional Systems:
Prospective Storage for Shale Formations

- Majority of shale formations will serve as reservoir seals for stored anthropogenic CO_2
- Hydrocarbon-bearing shale formations may be potential geologic sinks after depletion through primary production
- US-DOE-NETL methodology for screening-level assessment of prospective CO_2 storage resources in shale using a volumetric equation.
  - Volumetric resource estimates are produced from the bulk volume, porosity, and sorptivity of the shale and storage efficiency factors based on formation-scale properties and petrophysical limitations on fluid transport.

International Journal of Greenhouse Gas Control 51 (2016) 81–94

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

U.S. DOE NETL methodology for estimating the prospective CO_2 storage resource of shales at the national and regional scale

Jonathan S. Levine[a], Isis Fukai[a,1], Daniel J. Soeder[b], Grant Bromhal[b], Robert M. Dilmore[a], George D. Guthrie[a,2], Traci Rodosta[b], Sean Sanguinito[a], Scott Frailey[c], Charles Gorecki[d], Wesley Peck[d], Angela L. Goodman[a,*]

[a] U.S. Department of Energy, National Energy Technology Laboratory, 626 Cochrans Mill Road, Pittsburgh, PA 15236, United States
[b] U.S. Department of Energy, National Energy Technology Laboratory, 3610 Collins Ferry Road, Morgantown, WV 26507, United States
[c] Illinois State Geological Survey, 615 E. Peabody, Champaign, IL 61820, United States
[d] Energy & Environmental Research Center, University of North Dakota, 15 North 23rd Street, Stop 9018, Grand Forks, ND 58202-9018, United States

- Prospective shale formations require:
  1. Prior hydrocarbon production using horizontal drilling and stimulation via staged, high-volume hydraulic fracturing
  2. Depths sufficient to maintain CO_2 in a supercritical state, generally >800 m
  3. Over-lying seal

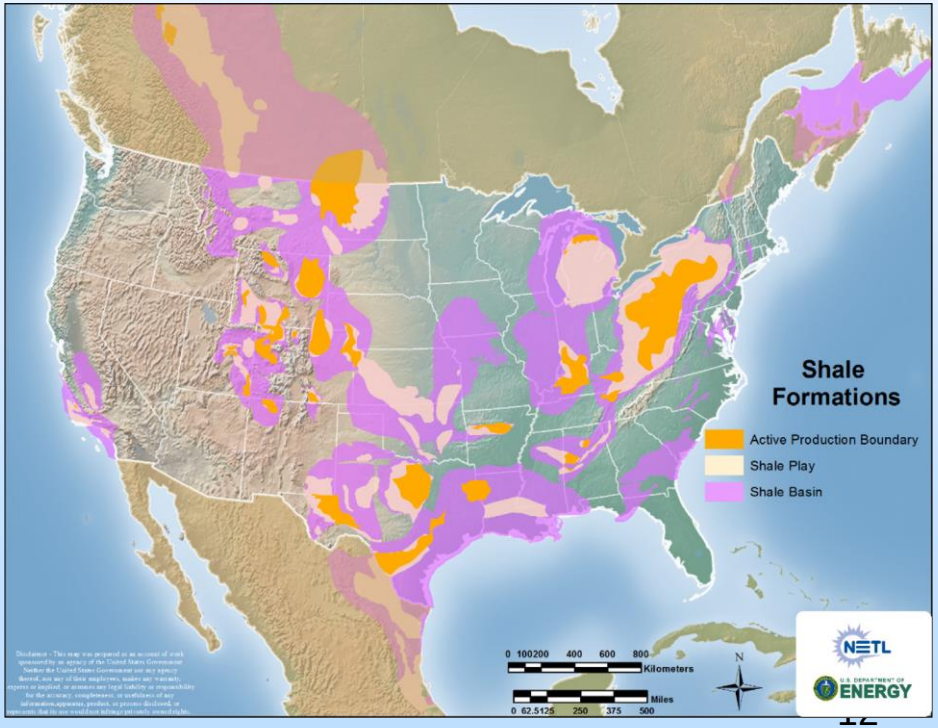
ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

EERC Energy & Environmental Research Center
EERC . . . The International Center for Applied Energy Technology

Unconventional Systems:
Prospective CO_2 Storage for Shale Formations:

- Storage of CO_2 in shale as a
  - Free fluid phase within fractures and matrix pores
  - Sorbed phase on organic and inorganic matter
- Uncertainties include but are not limited to
  - poorly-constrained geologic variability in formation thickness, porosity
  - existing fluid content
  - organic richness
  - Mineralogy
- Knowledge of how these parameters may be linked to depositional environments, facies, and diagenetic history of the shale will improve the understanding of pore-to-reservoir scale behavior, and provide improved estimates of prospective CO_2 storage.

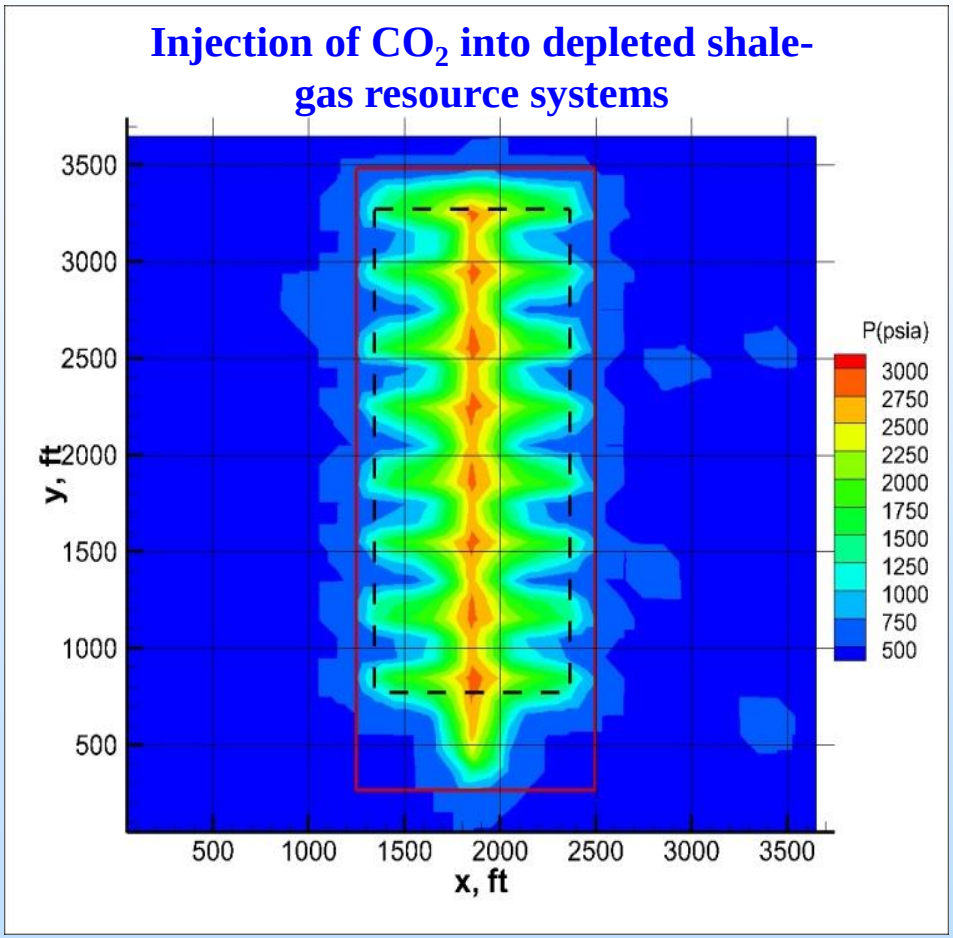
- Volumetric Equation
  - $G_{CO_2} = A_t h_g \left[\phi \rho_{CO_2} + (1-\phi)\rho_{sCO_2}\right]$
  - $G_{CO_2} = A_t E_A h_g E_h \left[\rho_{CO_2} \phi E_\phi + \rho_{sCO_2}(1-\phi)E_S)\right]$
  - $G_{CO_2} = A_t E_A h_g E_h \left[\rho_{CO_2} \phi E_\phi + \rho_{sCO_2}(1-\phi)E_m E_{sorb})\right]$



Unconventional Systems:

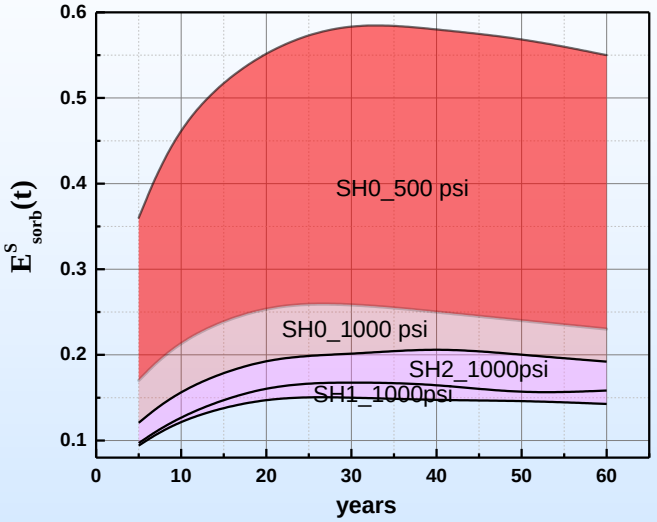
Prospective CO_2 Storage for Shale Formations:

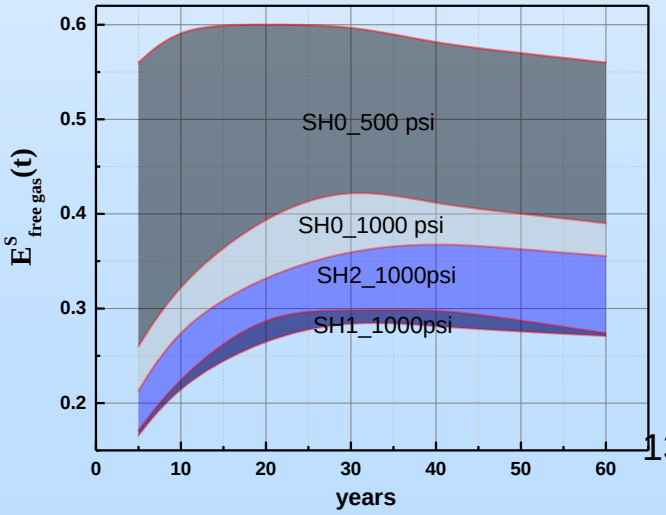
Injection of CO_2 into depleted shale-gas resource systems



Reservoir area dimensions: 4500 ft x 4500 ft; Depth: 7300 ft, T = 145 ^{0}F

Simulation free gas and sorption efficiency factors



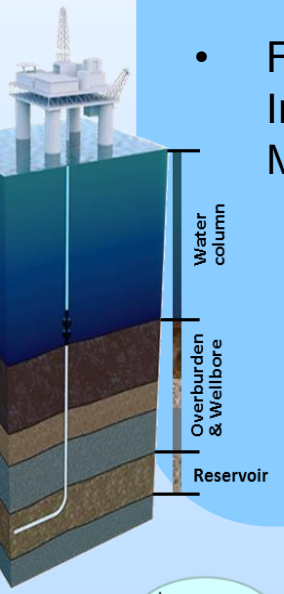


Offshore

Prospective CO_2 Storage in the Offshore

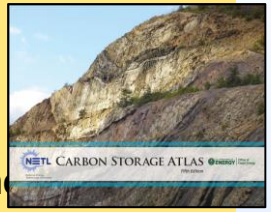
Offshore Hydrocarbon Spill Prevention 2005-present

- 7 projects (2011-2015) focused on:
  - Wellbore integrity
  - Rapid detection and in situ characterization
  - Risk reduction
- Feeding NETL's Offshore Integrated risk Assessment Model (IAM)
  - Integrated **modeling and data system**, from subsurface to the shore, developed to **identify knowledge & technology gaps** for spill prevention
  - 8 IAM component tools to date



Offshore Carbon Storage

- **Developing an offshore CO_2 storage methodology**
- **Leveraging off of NETL/DOE's onshore methodology**
- **Addressing key differen with offshore systems including:**
  - Young, immature basin conditions
  - Unconsolidated/unlithified sediments
  - Over-pressured conditions
  - Presence/behavior of natural seeps



$$G_{CO_2} = Ah\phi\rho E$$

Both efforts are based on a foundation of open data resources

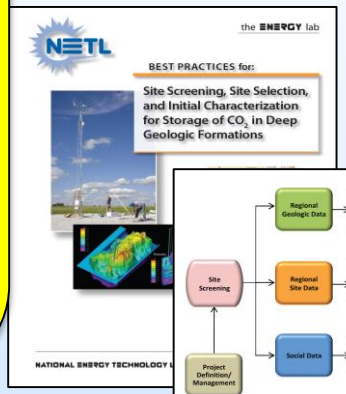
Offshore

Prospective CO_2 Storage in the Offshore

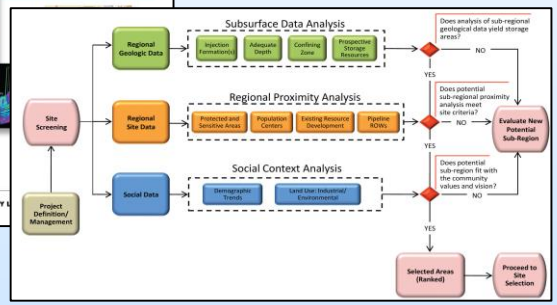
NETL's Approach (FY15-present):

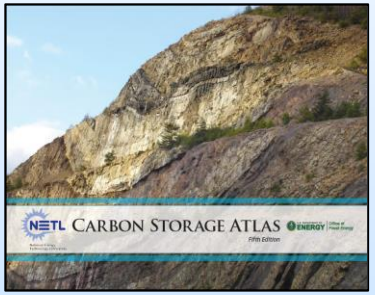
1. **Literature review and meta analysis (Complete)**
2. **Identify and report key factors for offshore carbon storage (Current efforts)**
3. **Incorporate NETL geospatial tools for robust offshore storage assessment methodology (Future)**

Current DOE Methodologies: **subsurface data analysis and volumetric estimate using regional geologic data**



$$G_{CO_2} = Ah\phi\rho E$$





Report is in prep that addresses geologic differences between onshore and offshore environments and implications for CO_2 storage assessments

- **Young, unconsolidated sediments**
- **Overpressured conditions**
- **Presence and behavior of natural seeps**

Offshore conditions suggest exploratory assessments should incorporate analysis of leakage risk, injection efficiency, infrastructure, and <u>data availability</u>

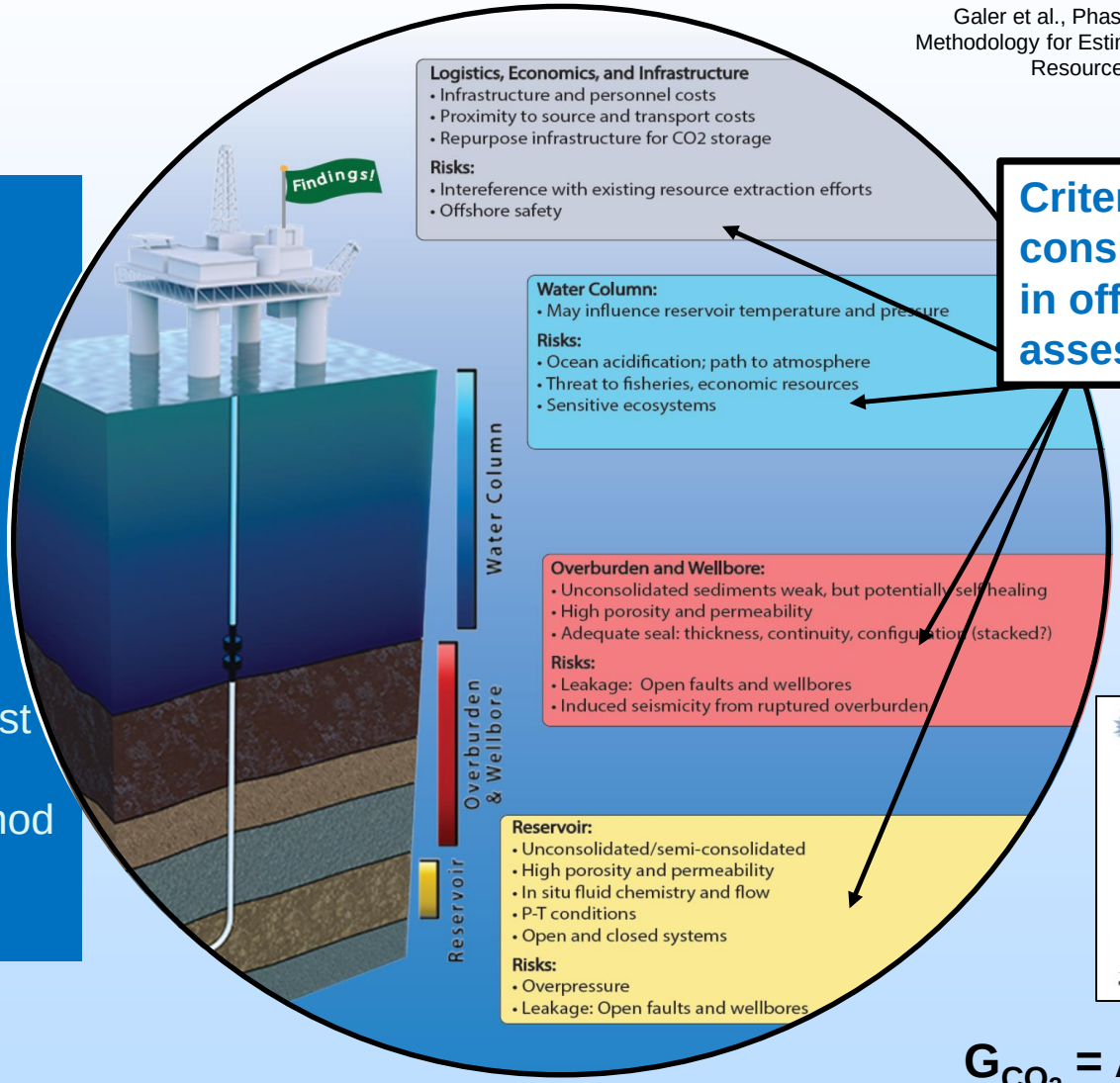
Offshore

Prospective CO_2 Storage in the Offshore

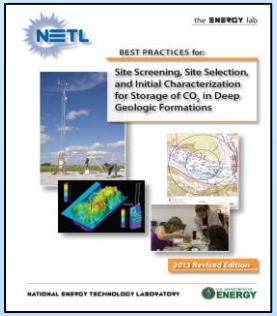
Galer et al., Phase 1 Report *In Prep*: "A Methodology for Estimating Carbon Storage Resources in Offshore Geologic Environments"

Key Findings:

- Offshore environments make up a significant portion of U.S. CO2 storage resource
- Current DOE/NETL volumetric approach is adequate for high level estimates, however, numerous offshore specific parameters must be appropriately represented in the method to ensure meaningful assessment values



Criteria for consideration in offshore assessments

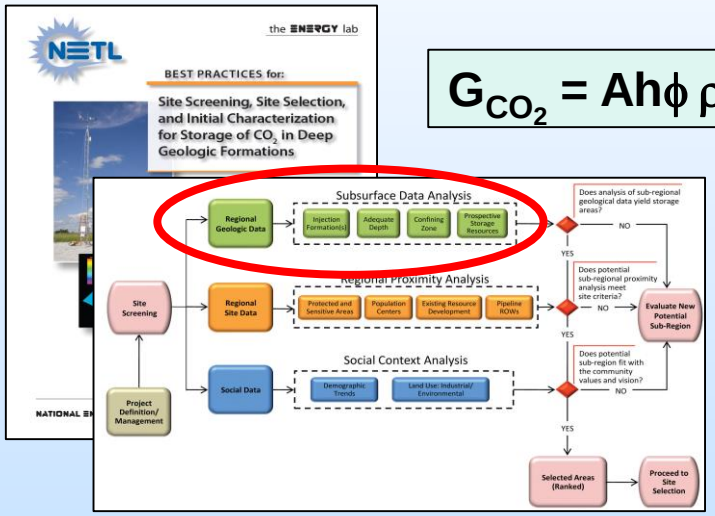


$$G_{CO_2} = Ah\phi\,\rho\,E$$

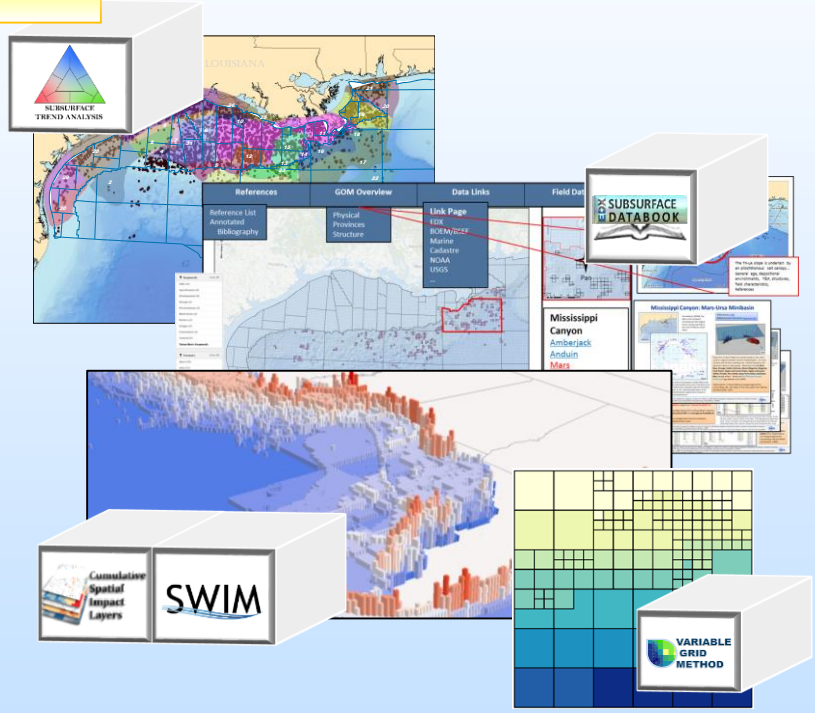
Offshore

Prospective CO_2 Storage in the Offshore

Next Steps, incorporating risk, ranking and prospectively capabilities



$$G_{CO_2} = Ah\phi\rho E$$



- **Current methodologies from DOE NETL Best Practices Manual and volumetric method**
- **Modified for offshore environments**
- **Test offshore storage methodology – this requires relevant data** BOEM
  - Leveraging BOEM sands database for test & validation
  - Development storage efficiency factors

Offshore Methodology & Analysis criteria

Potential to incorporate NETL's Geospatial Tools for

- Storage "resource evaluation", risk analysis, and uncertainty evaluation in the offshore method

Presentation Outline

Resource Assessment

Develop Defensible DOE Methodology for Regional Assessments

Unconventional Systems

- ***Team Members:*** Soeder, Bromhal, Dilmore, Sanguinito, Myshakin and Goodman

Oil and Gas Systems

- ***Team Members:*** Dilmore; Johns; Azzolina; Nakles; Goodman

Offshore

- ***Team Members:*** Rose, Disenhof, Bauer, Goodman

Expand Methodology to Include Stochastic Approach for Key Parameters

- ***Saline Systems / CO_2 SCREEN***

- ***Team Members:*** Sanguinito and Goodman

Expand Methodology to Include Geospatially Variable Key Parameters

- ***Saline Systems - SIMPA***

- ***Team Members:*** Rose, Disenhof, Bauer

EXPAND METHODOLOGY TO INCLUDE STOCHASTIC APPROACH FOR KEY PARAMETERS

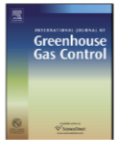
- Prospective CO_2 resource estimation
  - Large regions or sub-regions occurs at the initial screening stages of a project using only limited publicly available geophysical data
  - Selected areas and formations can be refined when site-specific geophysical data are available
- Refine US-DOE-NETL methodology
  - geologic parameters : identifies differences between data availability and data sources used for
  - efficiency factors: refined for specific sites
  - CO_2-SCREEN (Beta).

Guidelines for Site Screening (US-DOE-NETL, 2013)

Complete Site Screening	Social Data		Regional Site Data				Regional Geologic Data				COMPONENT
	Social Context Analysis		Regional Proximity Analysis				Subsurface Data Analysis				
Selected Area	Land Use: Industrial and Environmental History	Demographic Trends	Pipeline ROWs	Existing Resource Development	Population Centers	Protected and Sensitive Areas	Prospective Storage Resources	Confining Zone	Adequate Depth	Injection Formation(s)	ELEMENT
Develop a list of potential Selected Areas and rank based on criteria established in Project Definition.	Describe the trends in land use, industrial development and environmental impacts in communities above or near candidate Sub-Regions by evaluating sources such as online media sites, regulatory agencies, corporate websites, local environmental group websites, and other sources. Begin to assess community sensitivities to land use and the environment.	Describe communities above and near candidate Sub-Regions by evaluating readily available demographic data and media sources. To the extent possible, assess public perceptions of carbon storage and related issues; develop an understanding of local economic and industrial trends; and begin to identify opinion leaders.	Identify all pipelines and gathering lines/systems. Assess potential for conflicts in routing of pipelines to carbon storage projects as well as the potential for use or access to existing pipeline right-of-ways (ROWs). Identify other ROWs (e.g., power lines, RR's highways) and assess potential for synergies or conflicts in siting carbon storage projects. This data can be found through commercial and government sources.	Identify existing resource development, including wells that penetrate the confining zone, using data from state and federal oil and gas, coal, mining and UIC and natural resource management offices. Assess the potential for conflicts between siting of carbon storage projects and existing or prospective mineral leases as well the availability of complementary or competing infrastructure.	Identify population centers using state and federal census data. Assess the potential for conflicts with siting of carbon storage projects.	Identify environmentally sensitive areas using U.S. Environmental Protection Agency, U.S. Department of Interior, U.S. Forest Service and U.S. Bureau of Land Management GIS systems. Assess the potential for conflicts with siting of pipeline routes, field compressors and injection wells. In addition, evaluate potential for other surface sensitivities utilizing maps for other hazards (e.g., flood, landslide, and tsunami).	Candidate CO_2 storage formations should contain sufficient Prospective Storage Resources beneath a robust confining zone for the volume of CO_2 estimated during Project Definition and the displaced fluids while maintaining acceptable pressure limits. Prospective Storage Resources (and injectivity if permeability data are available) should be estimated at the sub-regional scale utilizing existing data (e.g., NATCARB, and state geological surveys) to populate basic numerical models.	Candidate injection zones should be overlain by a confining zone comprised of one or more thick and impermeable confining intervals of sufficient lateral extent to cover the projected aerial extent of the injected CO_2. Confining zones can be identified on a regional basis from the same types of information used to identify injection formations. Wells that penetrate potential confining zones should be identified and included in the risk assessment; this information can be obtained from state oil and gas regulatory agencies. Faulting and folding information that may impact confining zone integrity should be mapped along with potential communication pathways. Confining zone integrity may be validated by presence of nearby hydrocarbon accumulations.	Assessment of minimum depth of the injection zone to protect USDWs is required; in addition depths greater than 800 m generally indicate CO_2 will be in a supercritical state and may be more cost-effectively stored. Shallow depths (generally < 800 m) may add to the risk profile because (1) CO_2 could be in gas phase and (2) the injection zone may be closer to USDW.	Identify regional and sub-regional injection formation types. Utilize readily accessible data from public sources (e.g., state geological surveys, NATCARB, the Regional Sequestration Partnerships; published and open-file literature, academic sources) or acquired from private firms. Data gathered should include regional lithology maps, injection zone data (thickness, porosity, permeability), structural maps, information about structure closure and features that might compartmentalize the reservoir such as stratigraphic pinch outs, regional type logs, offset logs, petrophysical data, and regional seismicity maps.	GUIDELINES FOR SITE SCREENING

Table 3.1. Guidelines for Site Screening.

Accepted
Contents lists available at ScienceDirect
International Journal of Greenhouse Gas Control
journal homepage: www.elsevier.com/locate/ijggc
ELSEVIER



Prospective CO_2 Saline Resource Estimation Methodology: Refinement of Existing DOE-NETL Methods Based on Data Availability ***Goodman, Sanguinito, Levine***

Expand Methodology to Include Stochastic Approach for Key Parameters

- CO_2- SCREEN (Beta)
  - Storage prospeCtive Resource Estimation Excel aNalysis
  - https://edx.netl.doe.gov/organization/co2-screen

Excel (Data Inputs) | GoldSim (Monte Carlo) | Excel (Data Outputs)

General Information

Researcher Name	Jane Smith
Formation Name	Example Formation
Date	1/1/2016
Run ID	123-Clastics

Storage Efficiency Factors

Auto-populate: Choose lithology and depositional environment

User Specified: Directly enter P_{10} and P_{90} values

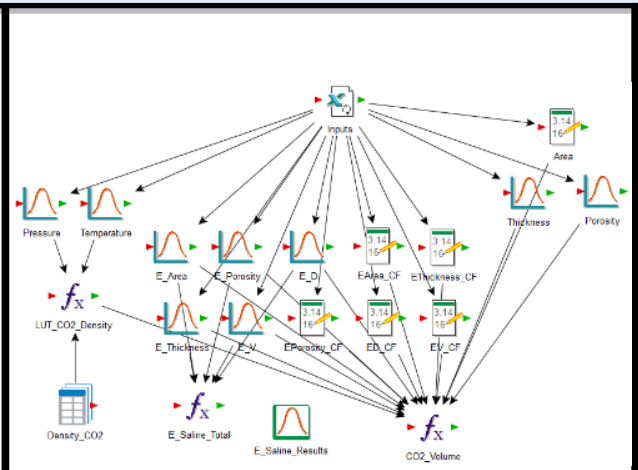
Lithology and Depositional Environment	Clastics: Unspecified

	Auto-populated		User Specified					
	P_{10}	P_{90}	P_{10}	P_{90}	X_{10}	X_{90}	μ_x	σ_x
Net-to-Total Area	0.20	0.80	0.2	0.8	-1.39	1.39	0.00	1.08
Net-to-Gross Thickness	0.21	0.76	0.13	0.62	-1.90	0.49	-0.71	0.93
Effective-to-Total Porosity	0.64	0.77	0.64	0.75	0.58	1.10	0.84	0.20
Volumetric Displacement	0.16	0.39	0.33	0.57	-0.71	0.28	-0.21	0.39
Microscopic Displacement	0.35	0.76	0.27	0.42	-0.99	-0.32	-0.66	0.26

Physical Parameters

Mean and standard deviation values for each grid

Grid #	Area* (km²)		Gross Thickness* (m)		Total Porosity* (%)		Pressure† (MPa)		Temperature† (°C)	
	Mean	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	100	50	0	5	0	25	0	100	0
2	100	50	0	5	0	25	0	100	0
3	100	50	0	5	0	25	0	100	0
4	100	50	0	5	0	25	0	100	0
5	100	50	0	5	0	25	0	100	0
6	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1



Prospective CO_2 Storage Resource

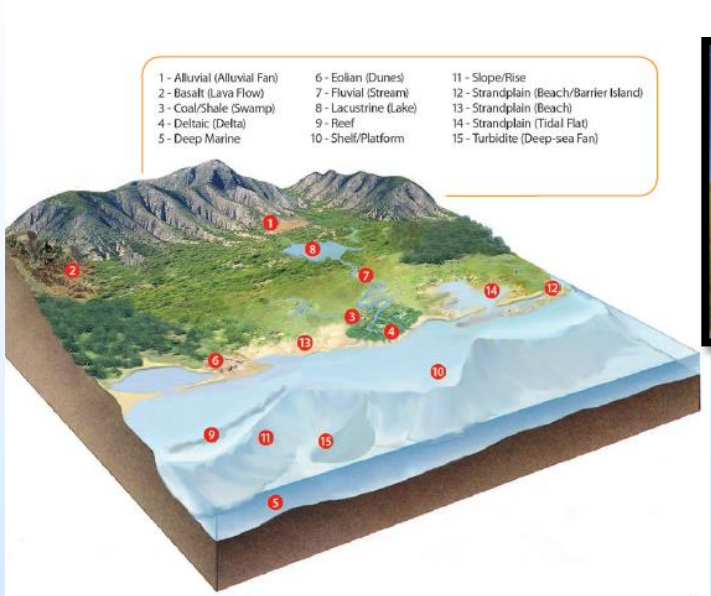
Information

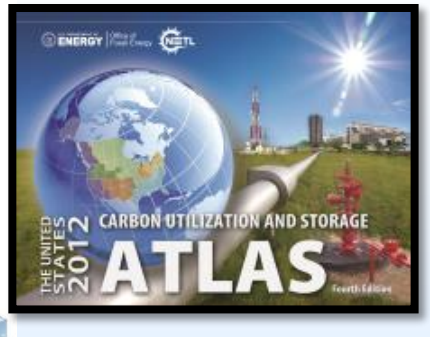
Researcher Name	Jane Smith
Formation Name	Example Formation
Date	1/1/2016
Depositional Environment	Clastics: Unspecified
Number of Grids	5
Run ID	123-Clastics

CO_2 Storage Statistics

	P_{10}	P_{50}	P_{90}	
Summed CO_2 Total	9.91	31.06	61.27	Mt
Average CO_2 per Grid	1.98	6.21	12.25	Mt
Summed CO_2 Total	0.010	0.031	0.061	Gt
Average CO_2 per Grid	0.002	0.006	0.012	Gt

Geologic Storage Formation Classes





Lithology	Depositional Environment
Clastics	Clastics
Dolomite	Dolomite
Limestone	Limestone
Clastics	Alluvial fan
Clastics	Delta
Clastics	Eolian
Clastics	Fluvial
Clastics	Peritidal
Clastics	Shallow shelf
Clastics	Shelf
Clastics	Slope basin
Clastics	Strand plain
Limestone	Peritidal
Limestone	Reef
Limestone	Shallow shelf

Matrix of Field Activities in Different Reservoir Classes (2012)

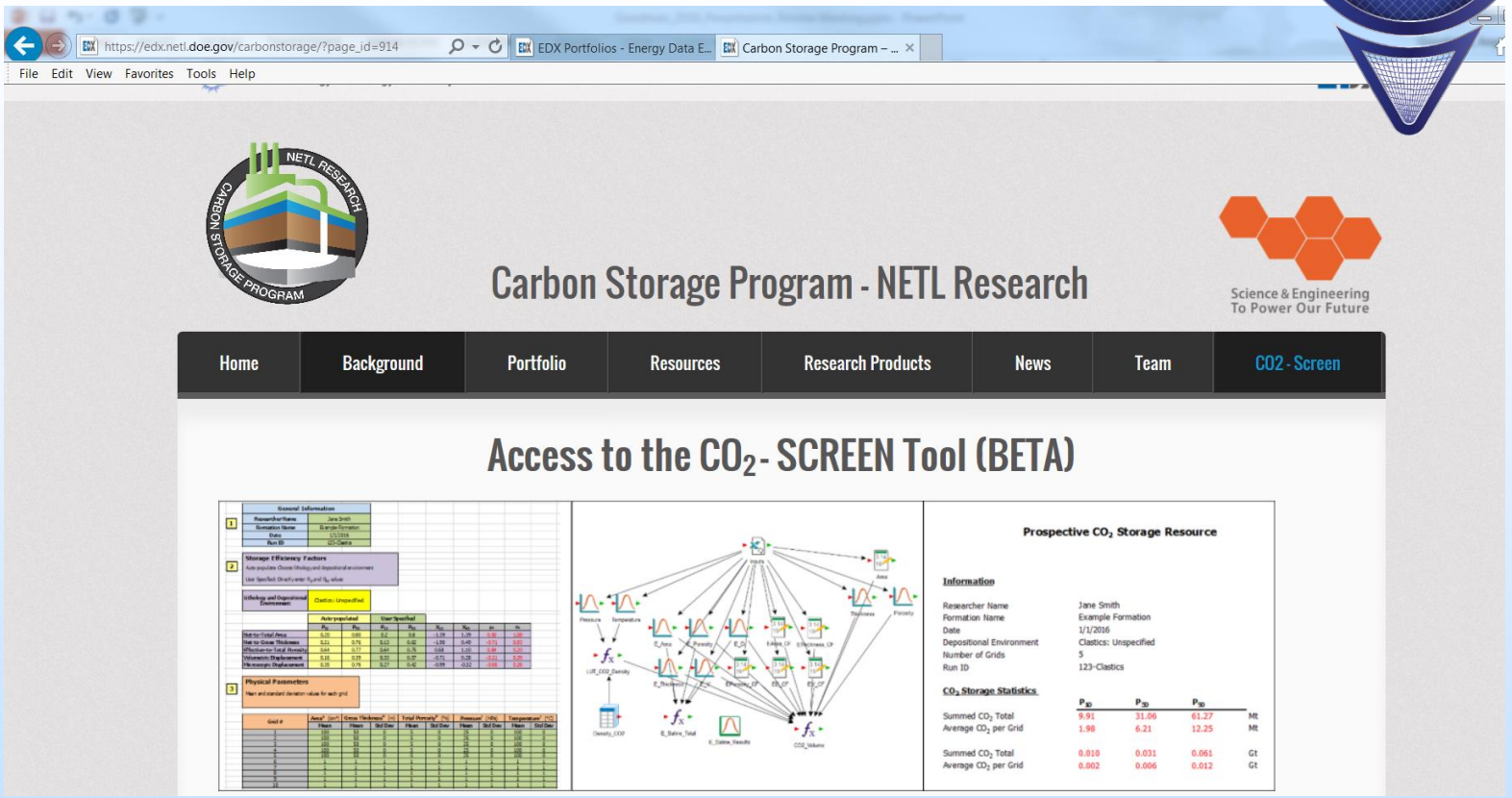
		High Potential Reservoirs					Medium Potential Reservoirs				Lower/Unknown Potential Reservoirs*	
Large-Scale Field Projects[a]	Saline	-	-	1	1	-	1	-	1	-	-	-
	EOR	1	-	-	-	1	2	-	-	-	-	-
Small-Scale Field Projects[b]	Saline	2	1	1	1	-	-	-	1	-	-	1
	EOR	1	1	3	1	2	1	-	1	-	6	0
Reservoir Class		Deltaic	Shelf Clastic	Shelf Carbonate	Strandplain	Reef	Fluvial Deltaic	Eolian	Fluvial & Alluvial	Turbidite	Coal	Basalt (LIP)

Notes:
The number in the cell is the number of investigations by NETL per geologic storage formation classification.
* Potential reservoirs were inferred from petroleum industry and field data from the Carbon Storage Program.
[a] Large-Scale Field Projects – Injection of more than 1,000,000 tons of CO_2.
[b] Small-Scale Field Projects – Injection of less than 500,000 tons of CO_2 for EOR and 100,000 tons for saline formations.

IEA, 2009/13. Development of Storage Coefficients for CO2 Storage in Deep Saline Formations, IEA Green house Gas R&D Programme (IEA GHG) October.

CO_2-SCREEN Tool

https://edx.netl.doe.gov/carbonstorage/?page_id=914



Beta Version 1

- Released March 2016
- Extensively reviewed by users at Battelle and Key Logic
- Saline Formations
- 1-300 grids

Beta Version 2

- Released July 2016
- Added features based on feedback from Battelle and Key Logic
- Grid Specific Storage Efficiency

Beta Version 3

- Expected to be released in fall 2016

Presentation Outline

Resource Assessment

Develop Defensible DOE Methodology for Regional Assessments

Unconventional Systems

- ***Team Members:*** Soeder, Bromhal, Dilmore, Sanguinito, Myshakin and Goodman

Oil and Gas Systems

- ***Team Members:*** Dilmore; Johns; Azzolina; Nakles; Goodman

Offshore

- ***Team Members:*** Rose, Disenhof, Bauer, Goodman

Expand Methodology to Include Stochastic Approach for Key Parameters

- ***Saline Systems / CO_2 SCREEN***

- ***Team Members:*** Sanguinito and Goodman

Expand Methodology to Include Geospatially Variable Key Parameters

- ***Saline Systems - SIMPA***

- ***Team Members:*** Rose, Disenhof, Bauer

Expand Methodology to Include Geospatially Variable Key Parameters

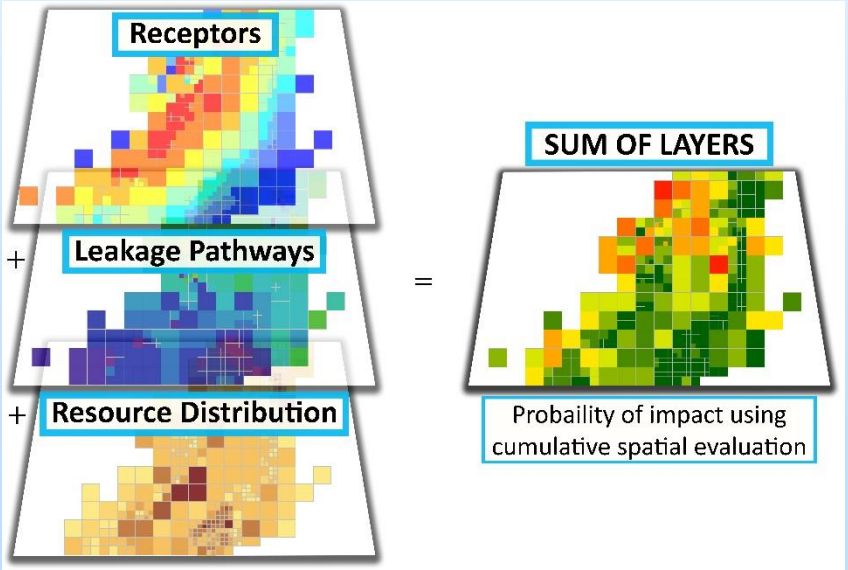
Increasing need for a method capable of:

- Integrating multiple spatial attributes and their uncertainties at various scales…

to better evaluate spatial trends and relationships amongst these attributes

- There is a need for scientists, regulators and other decision makers to efficiently assess the relationships between subsurface "reservoirs" and pathways to near surface receptors to evaluate risk and inform decision making.

- This capability can be applied to inform various use cases, such as:
  - Evaluating Resources,
  - Assessing Potential Impacts,
  - Calculating Project Feasibility,
  - Identifying Knowledge Gaps,
  - Complement NRAP and subTER



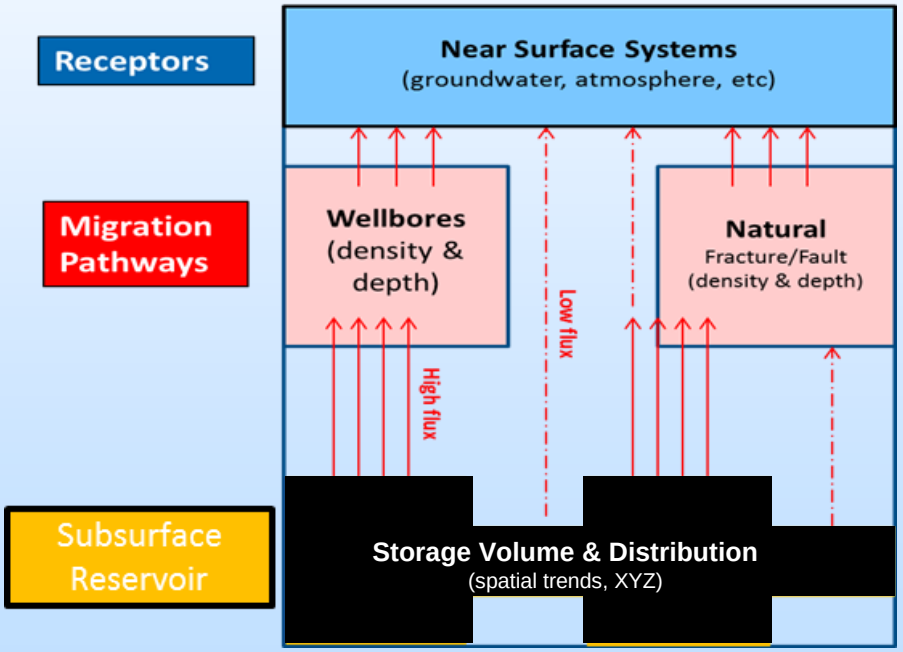
Expand Methodology to Include Geospatially Variable Key Parameters

The **spatially integrated multi-scale probabilistic assessment (SIMPA)** spatial analysis framework will support **evaluation of potential risks and impacts CO_2 storage might pose to various human health and environmental factors to help guide decision making and risk management** pertaining to the develop and use of various carbon capture and storage methods

Using in situ Knowledge and Data to Identify the Probability of Subsurface Fluid Migration

Developing a framework (data & tools) to assess multiple spatial attributes related to:

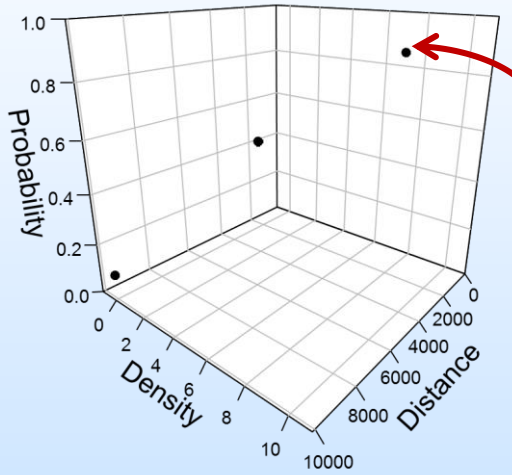
- Seek to identify areas within an user specific area that have a higher probability of **connectivity to fluid flow pathways**
- **Calculating the probability at meso- to regional scales**



Produce a product that helps decision makers **evaluate** cumulative spatial trends and **identify** knowledge gaps

Expand Methodology to Include Geospatially Variable Key Parameters

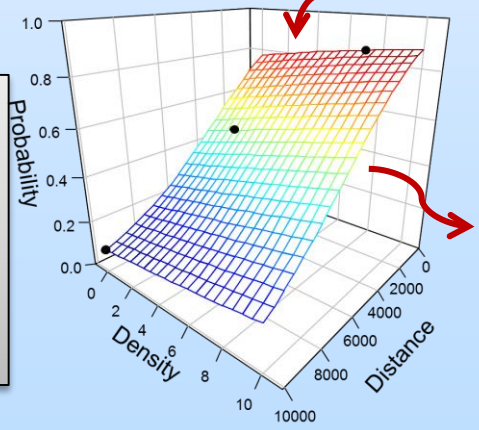
Initial development **focused on a spatial framework and model** for evaluating a combination of environmental variables and expert knowledge to determine risk related to leakage



User_input_prob.csv

	A	B	C
1	Den_Mean	Dist_Mean	Probability
2	7	0	0.85
3	2	4000	0.5
4	0	10000	0.1

Analysis relied on defined/expert knowledge probability table to create a probability surface fitted to the user- defined points



Initial use case focused on estimating wellbore leakage probabilities in relation to wellbore density and distance to the closest well

Access SIMPA Tool

Input Analysis Data and Criteria

Execute Tool

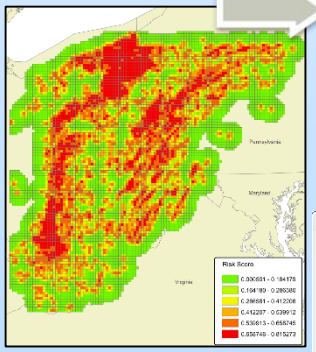
ArcGIS Python Script passes Inputs to R

R passes results back to ArcGIS

Initial tool integrated three different coding languages,

- Python,
- R, and
- Arc (esri)

to create advanced spatial analysis capabilities

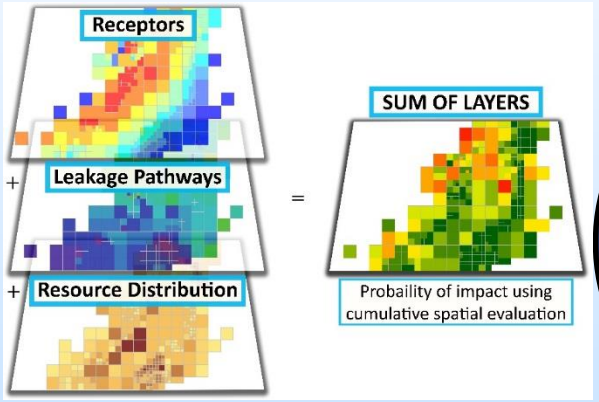


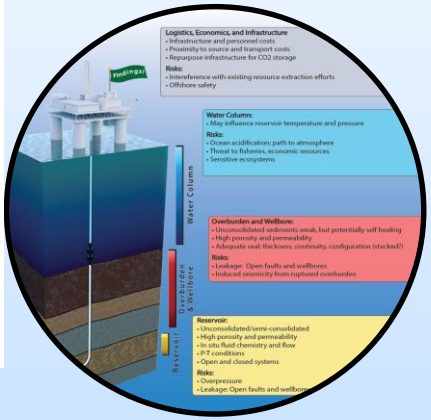
PredGrid.csv

	A	B	C	D
1	OID	FID	pred	std
2	0	0	6.50E-05	5.42E-06
3	1	1	8.76E-05	6.63E-06
4	2	2	0.000119	8.79E-06
5	3	3	0.000159	1.18E-05
6	4	4	0.000213	1.52E-05
7	5	5	0.000285	2.13E-05
8	6	6	0.000384	3.12E-05
9	7	7	0.000513	3.87E-05

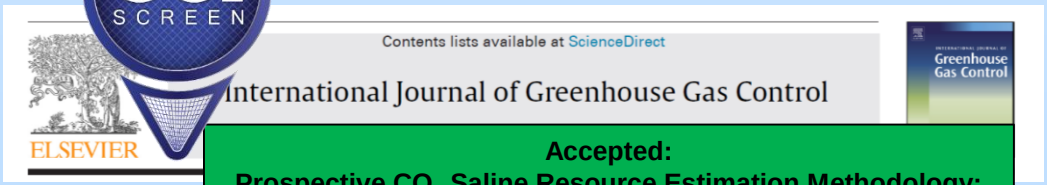
Accomplishments to Date

- *Unconventional*
  - **Methodology developed for prospective CO_2 storage resource of shales**
- *Offshore Saline*
  - Developing a methodology for CO_2 storage in the offshore: **key differences are being addressed with offshore systems**
- *Saline CO_2-SCREEN*
  - **Refined existing DOE-NETL methods based on data availability and developed (CO_2-SCREEN)**
- *SIMPA*
  - Producing a product/tool that helps decision makers **evaluate** cumulative spatial trends and **identify** knowledge gaps





CO_2 SCREEN



Accepted:
Prospective CO_2 Saline Resource Estimation Methodology: Refinement of Existing DOE-NETL Methods Based on Data Availability ***Goodman, Sanguinito, Levine***

Summary/Future Plans

Develop Defensible DOE Methodology for Regional Assessments

Unconventional Systems

- *Development of storage efficiency factors for storage in shale formations*

Oil and Gas Systems

- *Method will be ready for RCSP review in the near term followed by peer review*

Offshore

- *Continue developing a method for prospective storage in the offshore*

Expand Methodology to Include Stochastic Approach for Key Parameters

- ***Saline Systems / CO2 SCREEN***

- *Finalize CO2 SCREEN and develop SCREEN for shales*

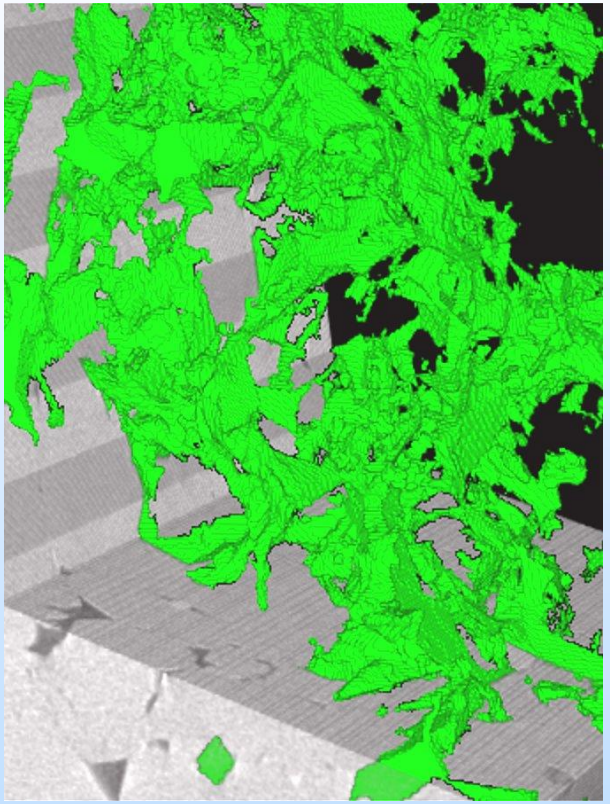
Expand Methodology to Include Geospatially Variable Key Parameters

- ***Saline Systems - SIMPA***

- *Finalize SIMPA tool for release on EDX*

Synergy Opportunities

- CO_2 storage methodology development and refinement manuscripts undergo review by the Regional Carbon Sequestration Partnerships (RCSP's), field experts, and the peer-review process prior to publication
- Incorporation of Experimental and Modeling parameters need to refine and improve storage efficiency factors – Offshore/Saline/Shale
- SIMPA:
  - Wellbore pathways: Developing & incorporating information on probability of wellbore occurrence, proximity and leakage potential Ties to NRAP
  - Structural pathways: Incorporating information related to the probability of existing structural complexity for a given domain/area (e.g., faults, folds) Ties to SubTER Induced seismicity project



Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

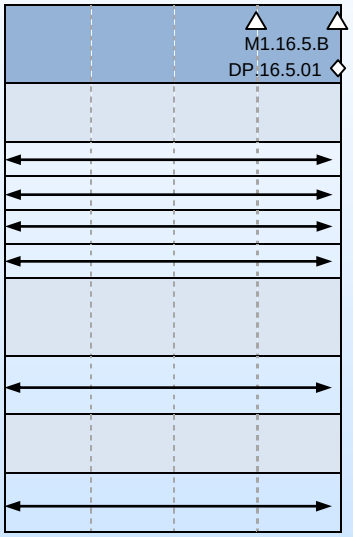
Carbon Storage Research Execution Plan (TPL: Angela Goodman)

- Task 5.0 Resource Assessment

- **Task 5.0 Resource Assessments (Goodman)**
- **Subtask 5.1 Develop Defensible DOE Methodology for National and Regional Assessment (FY16–18)**
- ***Sub-subtask 5.1.1 Methodology for Assessment of Unconventional Systems (FY16) (Goodman)***
- ***Sub-subtask 5.1.2 Methodology for Assessment of Conventional Oil and Gas Systems (FY16) (Dilmore)***
- ***Sub-subtask 5.1.3 Methodology for Assessment of Off Shore Systems (FY16) (Rose)***
- ***Sub-subtask 5.1.4 Predictive Geosciences Support for Methodology of Unconventional Systems (FY16) (Crandall)***
- The objective of this task is to obtain predictive geoscience support for aid in method development for unconventional systems in *Sub-subtask 5.1.1 Methodology for Assessment of Unconventional Systems*.
- **Subtask 5.2 Expand Methodology to Include Stochastic Approach for Key Parameters for Basin and Formation Scale Assessment (FY16–18)**
- ***Sub-subtask 5.2.1 Methodology with Stochastic Approach for Assessment of CO_2 Storage in Geologic Formations (FY16) (Goodman)***
- **Subtask 5.3 Expand Methodology to Include Geospatially Variable Key Parameters (FY16–18)**
- ***Sub-subtask 5.3.1 Development of a Spatial Integrative Multi-Scale Probabilistic Assessment Tool to Guide Decision Making and Risk Management (FY16) (Rose)***

Gantt Chart

5. Resource Assessments	10/01/2015	09/30/2018
5.1 Develop Defensible DOE Methodology for National and Regional Assessment	10/01/2015	09/30/2018
5.1.1 Methodology for Assessment of Unconventional Systems	10/01/2015	09/30/2016
5.1.2 Methodology for Assessment of Conventional Oil and Gas Systems	10/01/2015	09/30/2016
5.1.3 Methodology for Assessment of Off Shore Systems	10/01/2015	09/30/2016
5.1.4 Predictive Geosciences Support for Methodology of Unconventional Systems	10/01/2015	09/30/2016
5.2 Expand Methodology to Include Stochastic Approach for Key Parameters for Basin and Formation Scale Assessment	10/01/2015	09/30/2018
5.2.1 Methodology with Stochastic Approach for Assessment of CO2 Storage in Geologic Formations	10/01/2015	09/30/2016
5.3 Expand Methodology to Include Geospatially Variable Key Parameters	10/01/2015	09/30/2018
5.3.1 Development of a Spatial Integrative Multi-scale Probabilistic Assessment Tool to Guide Decision Making and Risk Management	10/01/2015	09/30/2016



Bibliography

Publications

1. Tudek, J., Crandall, D., Moore, J., Goodman, A., McIntyre "Direct CO_2/brine contact angle measurement in reservoir rock" **Journal of Petroleum Science and Engineering**, 2016, *under review.*
2. Goodman, A., Sanguinito, S., Levine, J. Prospective CO_2 Saline Resource Estimation Methodology: Refinement of Existing DOE-NETL Methods Based on Data Availability, **International Journal of Greenhouse Gas Control**, 2016, *under review*.
3. Sanguinito, S., Goodman, A., Levine, J.S., 2016, NETL CO_2 Storage prospective Resource Estimation Excel aNalysis (CO2-SCREEN) User's Manual; NETL-TRS-X-2016; Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA, 2016; p. 31. https://edx.netl.doe.gov/carbonstorage/?page_id=914
4. Levine, J. S., Fukai, I. Soeder, D. J., Bromhal, G., Dilmore, R.M., Guthrie, G. D., Rodosta, T., Sanguinito, S., Frailey, S., Gorecki, D., Peck, W. and Goodman, A.L. "U.S. DOE NETL Methodology for Estimating the Prospective CO_2 Storage Resource of Shales at the National and Regional Scale" **International Journal of Greenhouse Gas Control**, 2016, *51*, 81-94.
5. Glosser, D., Rose, K., and J. R. Bauer, **2016**. Spatio-Temporal Analysis to Constrain Uncertainty in Wellbore Datasets: An Adaptable Analytical Approach in Support of Science-Based Decision Making, *Journal of Sustainable Energy Engineering.*
6. Glosser, D.; Bauer, J.R.; Rose, K., 2016. Drilling Induced Fracture Networks: A Graph Theoretic Approach for Spatial Analysis of Fractures around a Wellbore, *Journal of Sustainable Energy Engineering*
7. Glosser, D; Rose, K; Huerta, N., in prep, Using Temporal Trends in Wellbore Materials, Design, and Plugging, to Estimate the Flow Barrier Lifetimes of Well Populations by Age, NETL-TRS-X-201X; Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Albany, OR
8. Phase 1 Report *In Prep*: "A Methodology for Estimating Carbon Storage Resources in Offshore Geologic Environments"

Presentations

1. Goodman, A. "NETL's Research & Innovation Center Carbon Storage Portfolio**" GSCO$_2$ Annual Meeting Champaign, IL March 30-31, 2016**
2. Rose, K., Glosser, D., Bauer, J. R., and Barkhurst, A. The Variable Grid Method, an Approach for the Simultaneous Visualization and Assessment of Spatial Trends and Uncertainty. American Geophysical Union Fall Meeting, December 14-18, 2015. http://fallmeeting.agu.org/2015/.

Accomplishments to Date

Develop Defensible DOE Methodology for Regional Assessments

- *Conventional*
  - A method is being developed for Assessment of **Conventional Oil Systems**. Three CO_2-flood enhanced oil recovery mechanisms are evaluated to characterize CO_2 storage efficiency.
- *Unconventional*
  - A methodology was developed for estimating the **prospective CO_2 storage resource of shales** at the national and regional scale. While the majority of shale formations will serve as reservoir seals for stored anthropogenic CO_2, hydrocarbon-bearing shale formations may be potential geologic sinks after depletion through primary production.
- *Offshore Saline*
  - A methodology is being developed for CO_2 storage in the offshore. While leveraging off of NETL-DOE's onshore portfolio, **key differences are being addressed with offshore systems** including: young, immature basin conditions; unconsolidated/unlithified sediments; over-pressured conditions; and the behavior of natural seeps.

Expand Methodology to Include Stochastic Approach for Key Parameters

- *Saline CO_2-SCREEN*
  - A **refinement of existing DOE-NETL methods based on data availability** is being developed for prospective CO_2 saline resource estimation methodology and as a tool (**CO_2-SCREEN**) that is available on EDX. As the scale of investigation is narrowed and selected areas and formations are identified, prospective CO_2 resource estimation can be refined when site-specific geophysical data are available.

Expand Methodology to Include Geospatially Variable Key Parameters

- *SIMPA*
  - **Tool/method enhancements**: Expand SIMPA tool to incorporate multi-variate inputs using real world datasets
  - Wellbore pathways: Developing & incorporating information on probability of wellbore occurrence, proximity and leakage potential (material status)
  - Structural pathways: Incorporating information related to the probability of existing structural complexity for a given domain/area (e.g., faults, folds)
    - Ties to SubTER Induced seismicity project