Task 5.0 - Resource Assessment

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U.S. Department of Energy

National Energy Technology Laboratory

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

August 1-3, 2017

Presentation Outline

Resource Assessment

Methods

DEVELOP DEFENSIBLE DOE METHODOLOGY FOR REGIONAL ASSESSMENTS

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- *Team Members: Sean Sanguinito, Eugene Myshakin, Harpeet Singh, Grant Bromhal, and Angela Goodman*

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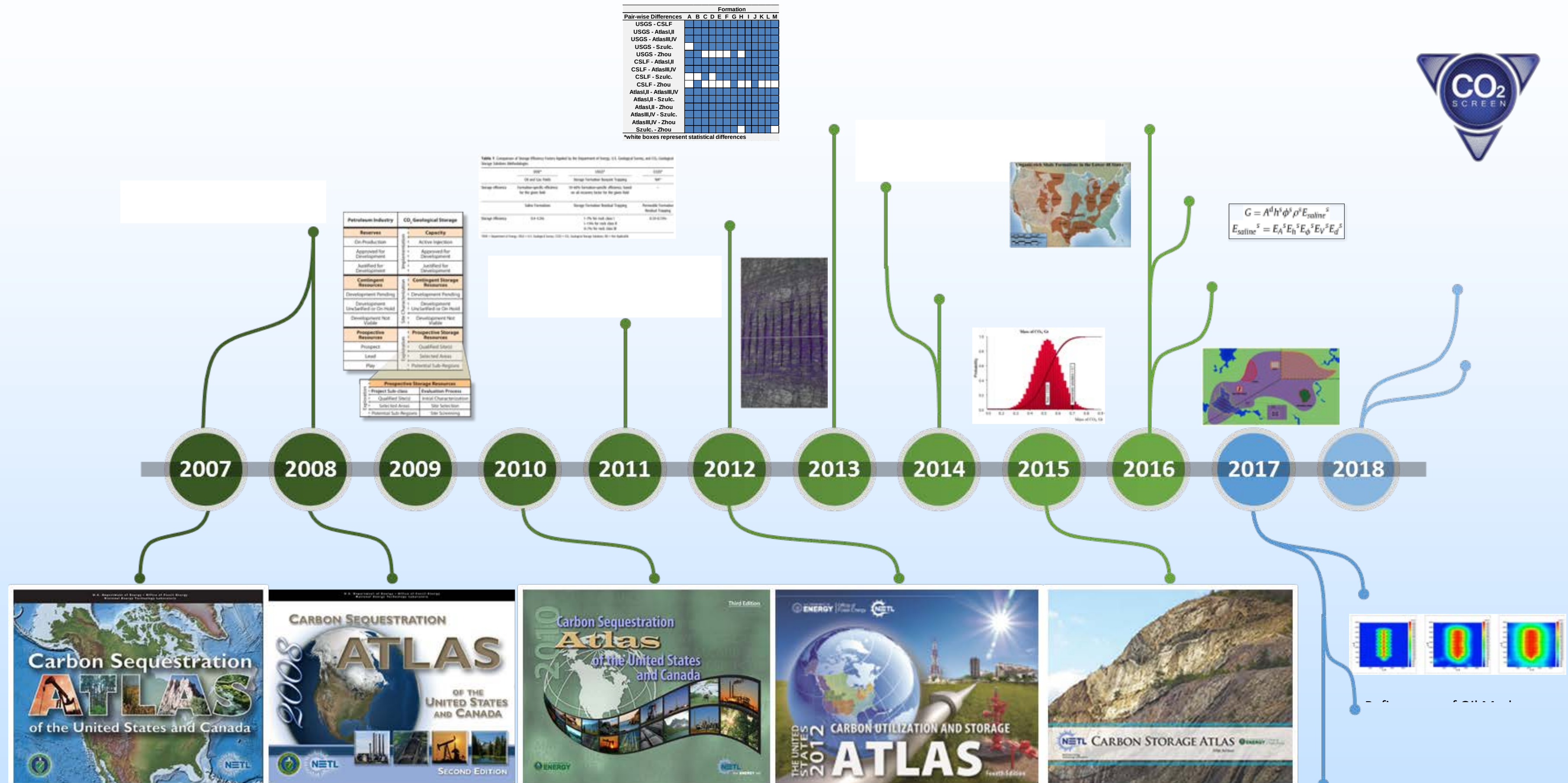
Development of DOE Defensible CO_2 Storage Methods



Carbon Sequestration Atlas of the United States and Canada

References:

[1] Goodman, A; Hakala, A; Bromhal, G; Deel, D; Rodosta, T; Frailey, S; Small, M; Allen, D; Romanov, V; Fazio, J; Huerta, N; McIntyre, D; Kutchko, B; Guthrie, G "US DOE methodology for the development of geologic storage potential for carbon dioxide at the national and regional scale" **International Journal of Greenhouse Gas Control 2011**, *5*, 4, 952-965. **cited 63 times** *(viewed >1882 times)*

[2] Olga H. Popova, Mitchell Small, Sean T. McCoy, Andrew C. Thomas, Bobak Karimi, Angela Goodman, and Kristin M. Carter "Comparative Analysis of Carbon Dioxide Storage Resource Assessments Methodologies" Environmental Geosciences **2012**, 19, 3, 105-124. **cited >5 times**

[3] Goodman, Angela; Bromhal, Grant; Strazisar, Brian; Rodosta, Traci; Guthrie, William; Allen, Doug, Guthrie, George "Comparison of methods for geologic storage of carbon dioxide in saline formations" International Journal of Greenhouse Gas Control **2013**, 18, 329–342. **cited 12 times** *(viewed >851 times)*

[4] Popova, O.; Small, M.; McCoy, S.; Thomas, A.; Rose, S.; Karimi, B.; Carter, K.; Goodman, A. "Spatial Stochastic Modeling of Sedimentary Formations to Assess CO2 Storage Potential" Environmental Science & Technology 2014, 48, 6247-6255 **cited 3 times**

[5] Goodman, Angela; Fukai, Isis; Dilmore, Robert; Frailey, Scott; Bromhal, Grant; Soeder, Dan; Gorecki, Charlie; Peck, Wesley; Rodosta, Traci; Guthrie, George "Methodology for assessing CO2 storage potential of organic-rich shale formations" Energy Procedia **2014**, 63, 5178-5184 **cited >2 times** *(viewed >422 times)*

[6] Sanguinito, S., Goodman, A., Levine, J.S., **2016**, NETL CO2 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

[7] Goodman, A., Sanguinito, S., Levine, J. Prospective CO2 Saline Resource Estimation Methodology: Refinement of Existing DOE-NETL Methods Based on Data Availability, International Journal of Greenhouse Gas Control, **2016**, 54, 242-249 *(viewed >100 times)*

[8] 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 CO2 Storage Resource of Shales at the National and Regional Scale" International Journal of Greenhouse Gas Control, 2016, 51, 81-94. **cited >1 times** *(viewed >368 times)*

[9] Evgeniy M. Myshakin, Harpreet Singh, Sean Sanguinito, Grant Bromhal, Angela L. Goodman Simulated Efficiency Factors for Estimating the Prospective CO2 Storage Resource of Shales, accepted to the International Journal of Greenhouse Gas Control, **2017**

[10] Robert Dilmore, Russel Johns, Nicholas A. Azzolina, Angela L. Goodman U.S. DOE NETL Methodology for Estimating the Assessment of CO2 Storage Potential in Oil Reservoirs, accepted to the International Journal of Greenhouse Gas Control, **2017**

Technical Status

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Unconventional Systems

Shale Method

- **Majority of shale formations will serve as reservoir seals for stored anthropogenic CO_2**

- **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

- **Storage of CO_2 in shale as a**
  - Free fluid phase within fractures and matrix pores
  - Sorbed phase on organic and inorganic matter

- **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

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

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PRAIRIE RESEARCH INSTITUTE

Unconventional Systems

Volumetric Equation

$$G_{CO_2} = A_t h_g [\phi \rho_{CO_2} + (1-\phi)\rho_{sCO_2}]$$

(1) *Free phase* storage in stimulated reservoir fractures, natural fractures and matrix pores

(2) *Solid phase* storage on kerogen & clay components

$$G_{CO_2} = A_t E_A h_g E_h [\rho_{CO_2} \phi E_\phi + \rho_{sCO_2}(1-\phi)E_S)]$$

Effective Volume

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

Efficiency: *fraction* of the total formation volume that will be accessed for CO_2 storage

G_{CO2}	CO_2 storage resource (mass) of the shale formation
A_t	Total area (map view) of the shale formation being assessed for CO_2 storage
h_g	Gross thickness of the shale formation
V_e	Net effective volume of the formation ($A_t E_A h_g E_h$)
ρ_{CO2}	Density of CO_2 at the pressure ($\bar{P}$) and temperature ($\bar{T}$) of V_e prior to production
ϕ	Percentage of bulk volume that is void volume
ρ_{sCO_2}	Maximum mass of CO_2 sorbed per unit volume solid rock, e.g. the asymptotic value of a adsorption isotherm
E_A	Fraction of shale formation total area available for CO_2 storage
E_h	Fraction of shale formation gross thickness available for CO_2 storage
E_ϕ	Fraction of shale porosity within the net effective volume of the formation, V_e, available for CO_2 storage. This is a reservoir scale efficiency factor that is meant to address the probability that CO_2 will never reach some of the pore space due to transport heterogeneities associated with fracture networks and low matrix permeability.
E_S	Fraction of the total potential sorbed volume of CO_2 within the net effective volume of the formation, V_e. This is a reservoir scale efficiency factor that is meant to address both transport and sorption inefficiencies. $E_S = E_m E_{sorb}$
E_m	Fraction of the shale matrix within the effective volume of the formation, V_e, available for CO_2 storage. This is a reservoir scale efficiency factor that is meant to address the probability that CO_2 will never reach some of the shale matrix rock due to transport heterogeneities associated with fracture networks and low matrix permeability.
E_{sorb}	Fraction of ρ_{sCO_2} due to reductions in sorptive packing at reservoir pressure and temperature conditions. This is a reservoir scale efficiency factor that is meant to address the inefficiency of sorptive packing on shale matrix rock due to competitive sorption (sorption/desorption with other species) and non-ideality of sorption surfaces (reduction of surface coverage) in the shale matrix.

ILLINOIS STATE GEOLOGICAL SURVEY
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EERC Energy & Environmental Research Center
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Unconventional Systems

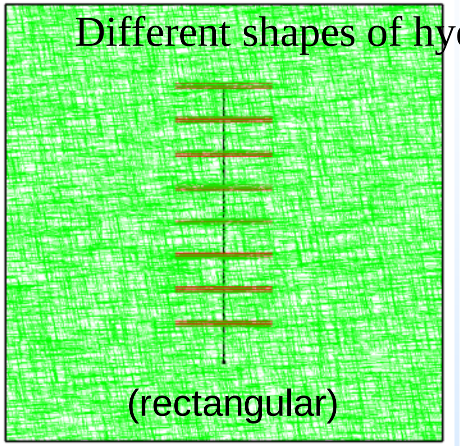
Simulated Shale Efficiency Factors

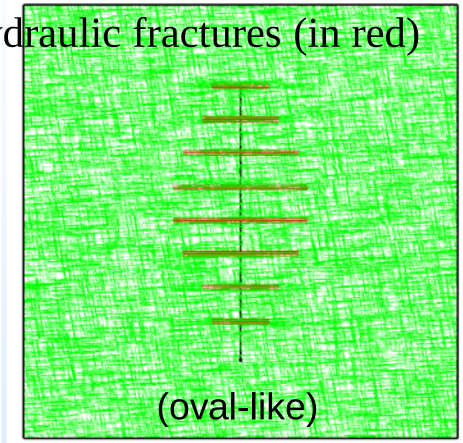
$$G_{CO_2}(t) = A_t E_A h_g E_h \left[\rho_{CO_2} \phi E_\phi(t) + \rho_{sCO_2}(1-\phi) E_S(t)\right]$$

$E_\phi(t)$ is a fraction of a maximum gas volume stored in a net effective volume of the formation at time *t*..

$E_S(t)$ is a fraction of a maximum sorptive capacity in a net effective volume of the formation at time *t*.

Different shapes of hydraulic fractures (in red)

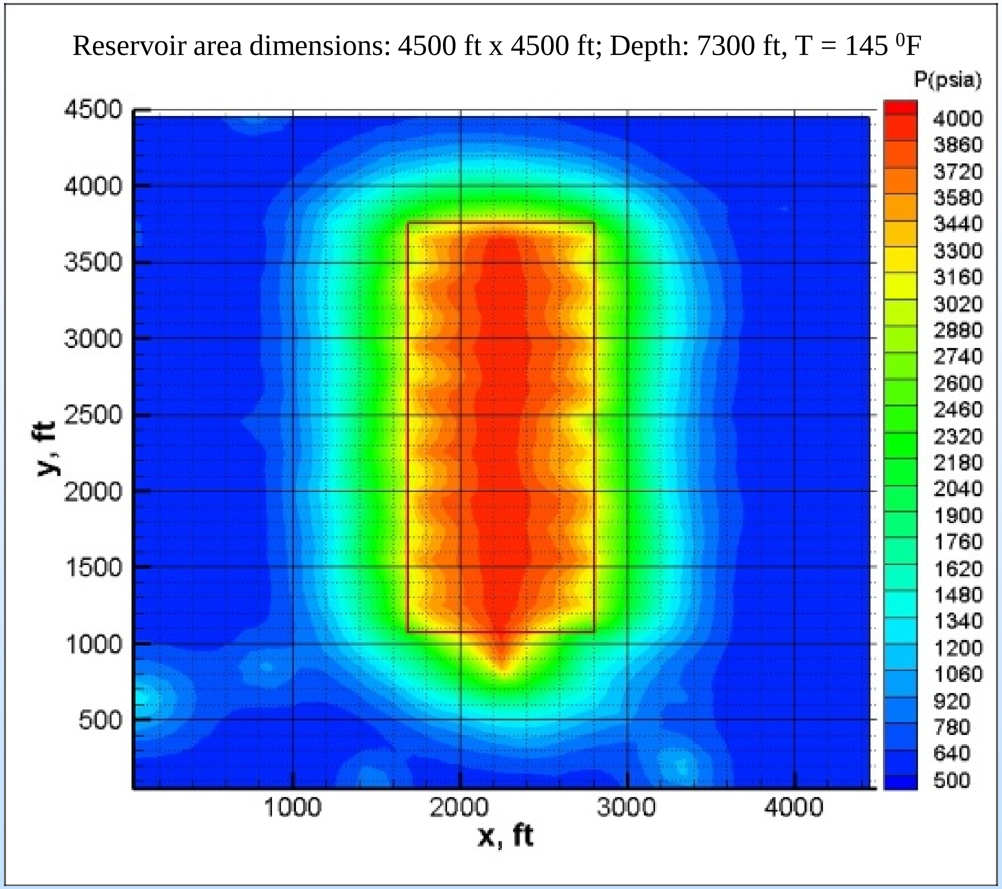

(rectangular)


(oval-like)

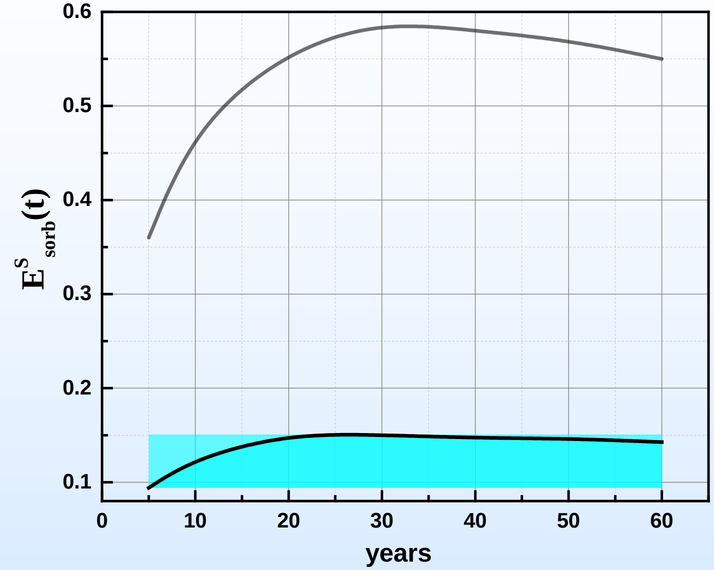
Parameter	Symbol	Settings	
		LOW (L)	HIGH (H)
Density of natural fracture center points	D	6.35 x10^{-5} / 3.81 x10^{-5} m^{-2}* (2.083x10^{-4} / 1.250x10^{-4} ft^{-2})	2.03 x10^{-4} / 1.91 x10^{-4}* (6.670x10^{-4} / 6.250x10^{-4})
Langmuir volume	V	3.40 m^3/ton (120 scf/ton)	9.35 (330)
Injection pressure	I	20.68 MPa (3000 psia)	27.58 (4000)
Initial reservoir pressure	R	3.45 MPa (500 psia)	6.90 (1000)
Thickness	T	30 m (100 ft)	152 (500)
Matrix porosity	P	0.045	0.125
Matrix permeability	M	5.92 x 10^{-21} m^2 (6 nD)	5.92 x 10^{-19} (600)
Shape of hydraulic fracture representation	SH	Thee different shapes (figures to the right)	

Unconventional Systems

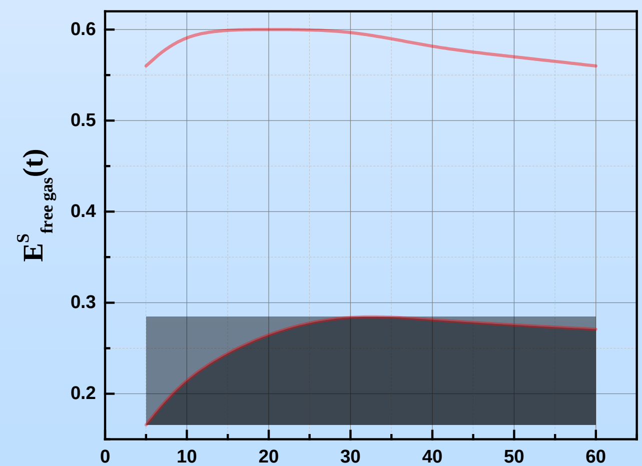
Simulated Shale Efficiency Factors



Pressure distributions in the middle horizontal plane of the shale reservoir model after 60 years of injection using the rectangular shape of hydraulic fractures



$E_S(t)$ Sorption efficiency factors



$E_\phi(t)$ Free gas efficiency factors

Unconventional Systems

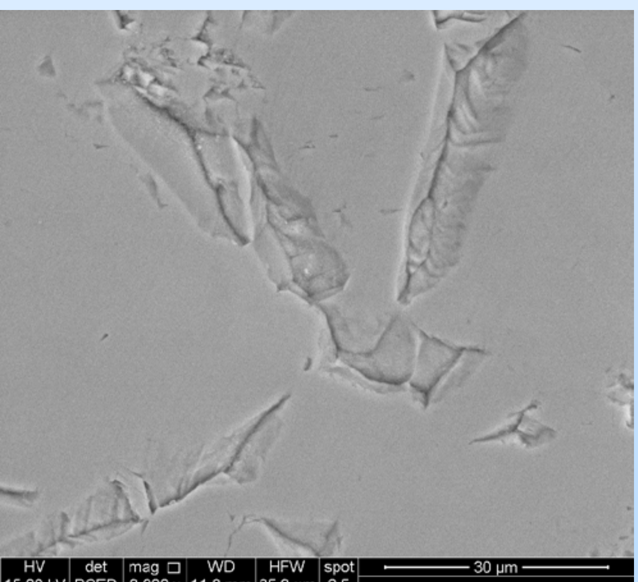
Data Gaps

- As with all resource assessments, an uncertainty in the estimate of the prospective storage resource in shale is a consequence of the lack of appropriate quantitative geologic data

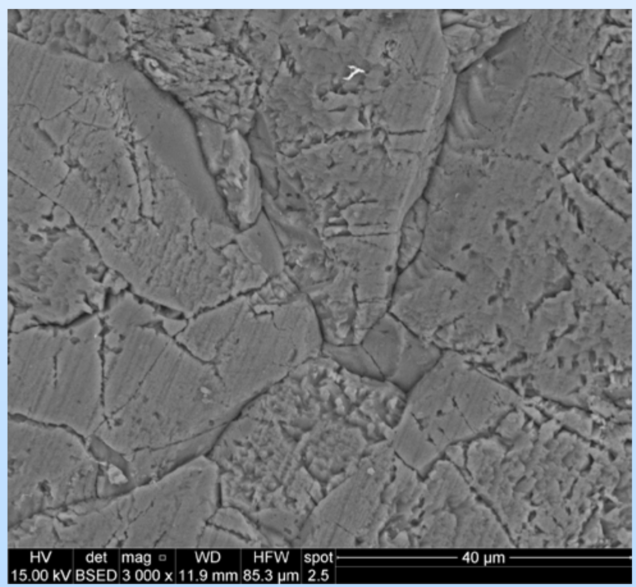
Precipitation and etching

Chemical Reactivity?

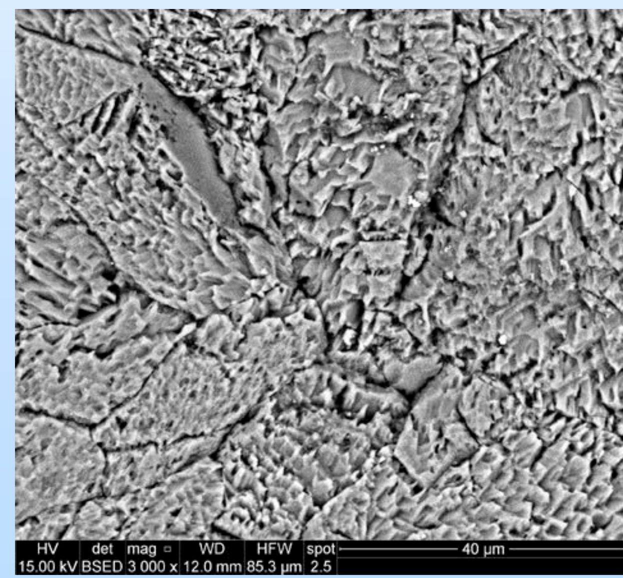
Pre-Exposure



CO_2 Exposure



Wet CO_2 Exposure



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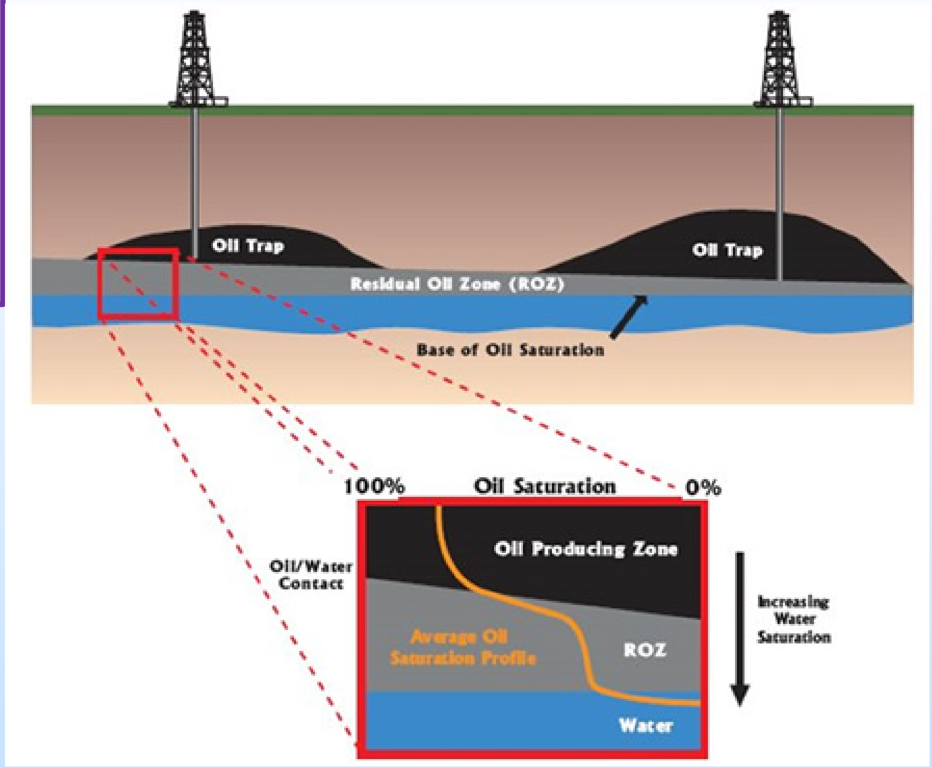
Residual Oil Zones (ROZs)

ROZ Method

- Goal:
  - Identify key aspects of CO_2 storage in a ROZ and develop a draft method for prospective storage of CO_2 in ROZs



- ROZs contain remnants of oil that were not swept away by natural waterflood.
- ROZs are proposed to be the product of three different geological processes: regional/local basin tilt, breached reservoir seals, or altered hydrodynamic flow fields.

FOCUS: New work will focus on investigating the feasibility of CO_2 storage in a ROZ and method development for prospective storage of CO_2 in ROZs.

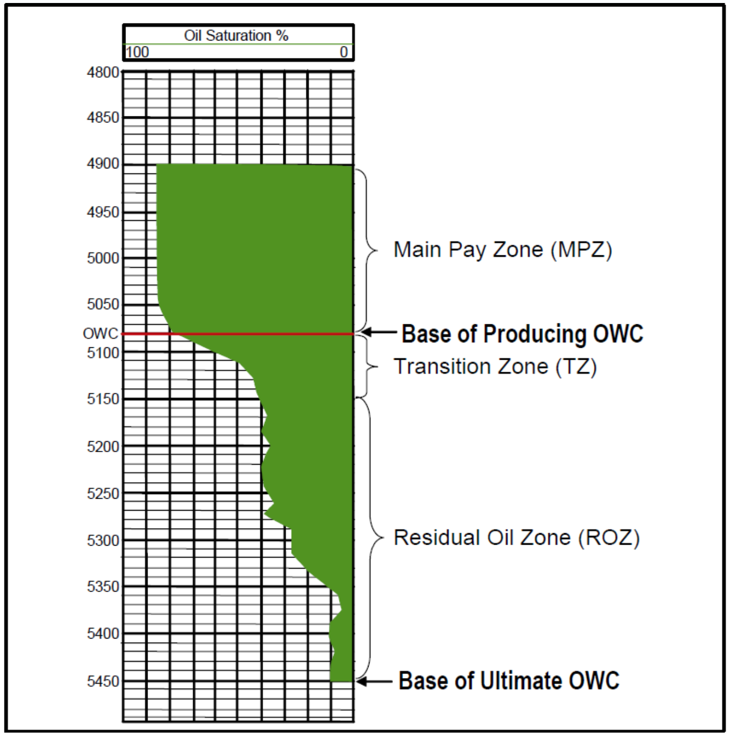
https://www.netl.doe.gov/research/oil-and-gas/project-summaries/enhanced-oil-recovery/fe0005889_utpermian; http://melzerconsulting.com/residual-oil-zones/

Residual Oil Zones (ROZs)

Volumetric Equation

$$G_{CO_2} = A h_n \phi_e (1 - S_{wi}) B \rho_{CO_2 std} E_{oil/gas}$$

A = the area of the structure
h_n = the net thickness
ϕ_e = the effective porosity of the formation
B = the fluid formation volume factor that converts standard oil and gas volume to subsurface volume
S_{wi} = the initial water saturation in the formation
$\rho_{CO_2 std}$ = the standard density of CO_2
$E_{oil/gas}$ = the efficiency coefficient



Field/Unit	MPZ (BB)	TZ/ROZ (BB)	CO_2 Storage Resource
Northern Shelf Permian Basin	2.8	5.5	?
Horseshoe Atoll (Cayon)	1.4	1.3	?
East New Mexico (San Andres)	.4	1.3	?

https://www.netl.doe.gov/research/oil-and-gas/project-summaries/enhanced-oil-recovery/fe0005889_utpermian; http://melzerconsulting.com/residual-oil-zones/

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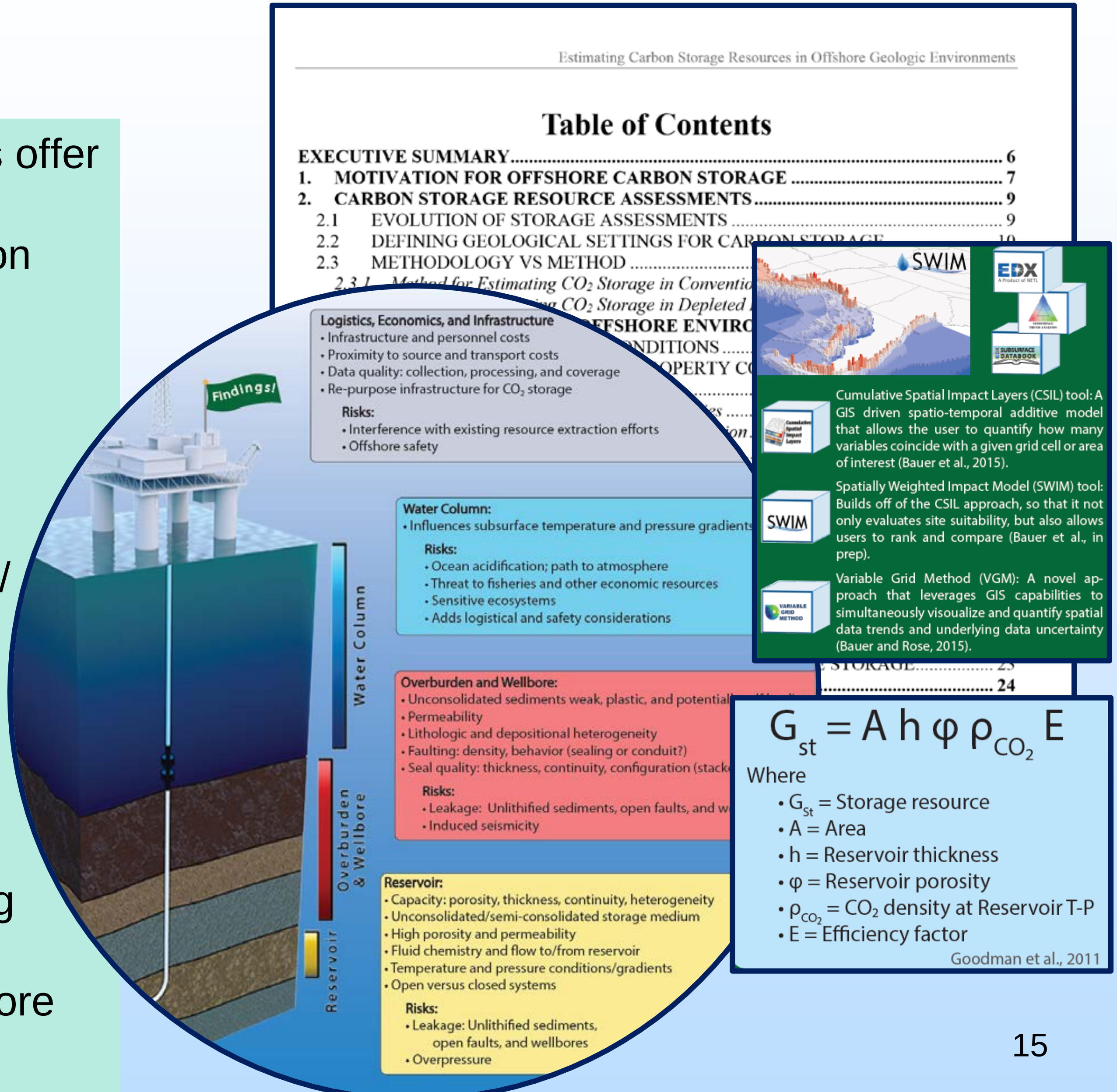
Offshore - Saline

Method

- Offshore environments offer a significant resource potential for U.S. carbon storage efforts
- Offshore-specific parameters must be considered to make application of the DOE/ NETL method meaningful
- Also an opportunity to leverage tools from Offshore Risk Modeling suite to highlight areas more suitable for offshore Carbon Storage



Offshore - Saline

Storage Efficiency

Improving efficiency variables for offshore systems

- Published efficiency factors by Gorecki apply to a range of lithologies and depositional environments in ONSHORE environments
  - *Onshore – old, hard rocks, generally consolidated, no loose sediment layers*
- Can we improve these factors for OFFSHORE systems with much different rock types?
  - *active deposition & unconsolidated sediments dominate*

Carbon storage formula:

$$G_{CO_2} = A * h * \rho * \varphi * E_{saline}$$

Breaking down the efficiency term:

$$E_{saline} = E_{A_n/A_t} * E_{H_n/H_g} * E_{\varphi_e/\varphi_t} * E_V * E_d$$

"E_{geol}" terms – the volumetric factors that we can model using BOEM data to improve on what Gorecki et al have published

Table 12. Ranges of Variables Used to Calculate Storage Coefficients for Different Lithologies and Depositional Environments

Lithology	Depositional Environment	E_{geol}			E_V	E_d	$\frac{(1-S_{wave})}{(1-S_{wirr})}$
		A_n/A_t	h_n/h_g	$\varnothing_{eff}/\varnothing_{tot}$			
Clastics	Clastics	0.2–0.8	0.21–0.76	0.64–0.77	0.16–0.39	0.35–0.76	0.44–0.95
Dolomite	Dolomite	0.2–0.8	0.17–0.68	0.53–0.71	0.26–0.43	0.57–0.64	0.71–0.79
Limestone	Limestone	0.2–0.8	0.13–0.62	0.64–0.75	0.33–0.57	0.27–0.42	0.67–0.98
Clastics	Alluvial fan	0.2–0.8	0.21–0.76	0.7–0.82	0.18–0.54	0.32–0.71	0.39–0.89
Clastics	Delta	0.2–0.8	0.21–0.76	0.61–0.71	0.19–0.59	0.39–0.81	0.48–1.00
Clastics	Eolian	0.2–0.8	0.21–0.76	0.69–0.79	0.12–0.54	0.53–0.80	0.66–1.00
Clastics	Fluvial	0.2–0.8	0.21–0.76	0.63–0.77	0.19–0.53	0.34–0.73	0.42–0.90
Clastics	Peritidal	0.2–0.8	0.21–0.76	0.60–0.78	0.14–0.58	0.42–0.80	0.52–0.99
Clastics	Shallow shelf	0.2–0.8	0.21–0.76	0.62–0.78	0.18–0.63	0.39–0.82	0.49–1.00
Clastics	Shelf	0.2–0.8	0.21–0.76	0.62–0.74	0.20–0.59	0.41–0.84	0.51–1.00
Clastics	Slope basin	0.2–0.8	0.21–0.76	0.68–0.77	0.12–0.54	0.53–0.80	0.66–1.00
Clastics	Strand plain	0.2–0.8	0.21–0.76	0.64–0.76	0.19–0.58	0.38–0.74	0.47–0.92
Limestone	Peritidal	0.2–0.8	0.13–0.62	0.61–0.75	0.30–0.67	0.37–0.42	0.87–0.97
Limestone	Reef	0.2–0.8	0.13–0.62	0.62–0.77	0.36–0.63	0.28–0.42	0.66–0.98
Limestone	Shallow shelf	0.2–0.8	0.13–0.62	0.69–0.73	0.44–0.72	0.31–0.42	0.71–0.96

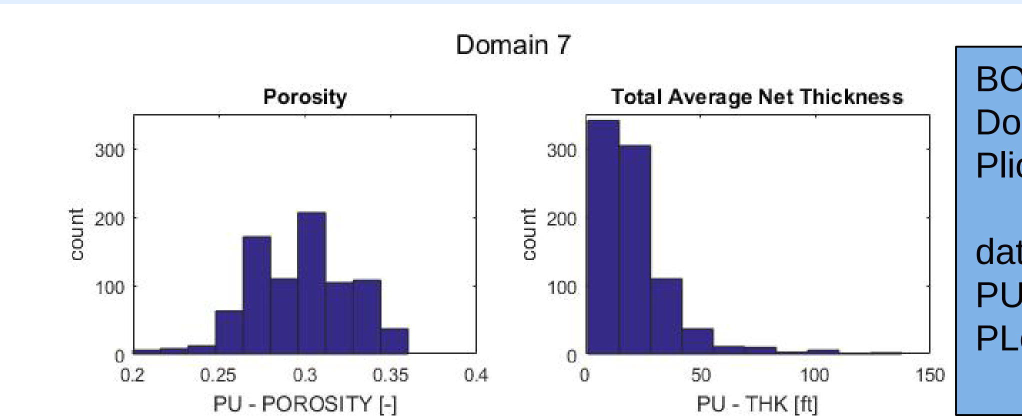
Table 11 in Gorecki, C. D., Sorensen, J. A., Bremer, J. M., Knudsen, D., Smith, S. A., Steadman, E. N., & Harju, J. A. (2009, January). Development of storage coefficients for determining the effective CO2 storage resource in deep saline formations. In *SPE International Conference on CO2 Capture, Storage, and Utilization*. Society of Petroleum Engineers.

Offshore - Saline

Storage Efficiency

BOEM data are useful to constrain spatial variability of (Oil) reservoir properties

Are they useful to constrain carbon storage sands more generally?

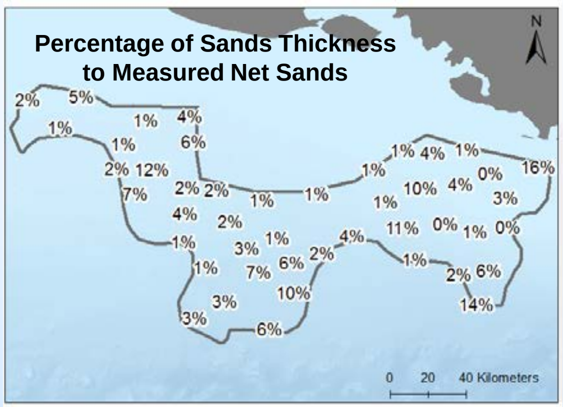


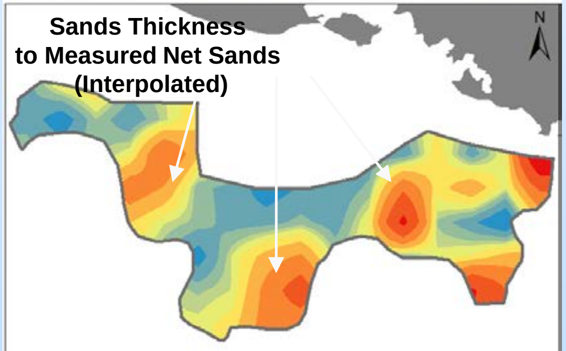
BOEM SANDS
Domain 7
Pliocene

data points:
PUpper – 825
PLower – 601

produced by code:R:\H_NETL Code Library\Matlab\Code_Working\New folder\mc_carbon_GoM_plio7_only.m

Domain 7 with selected BOEM points



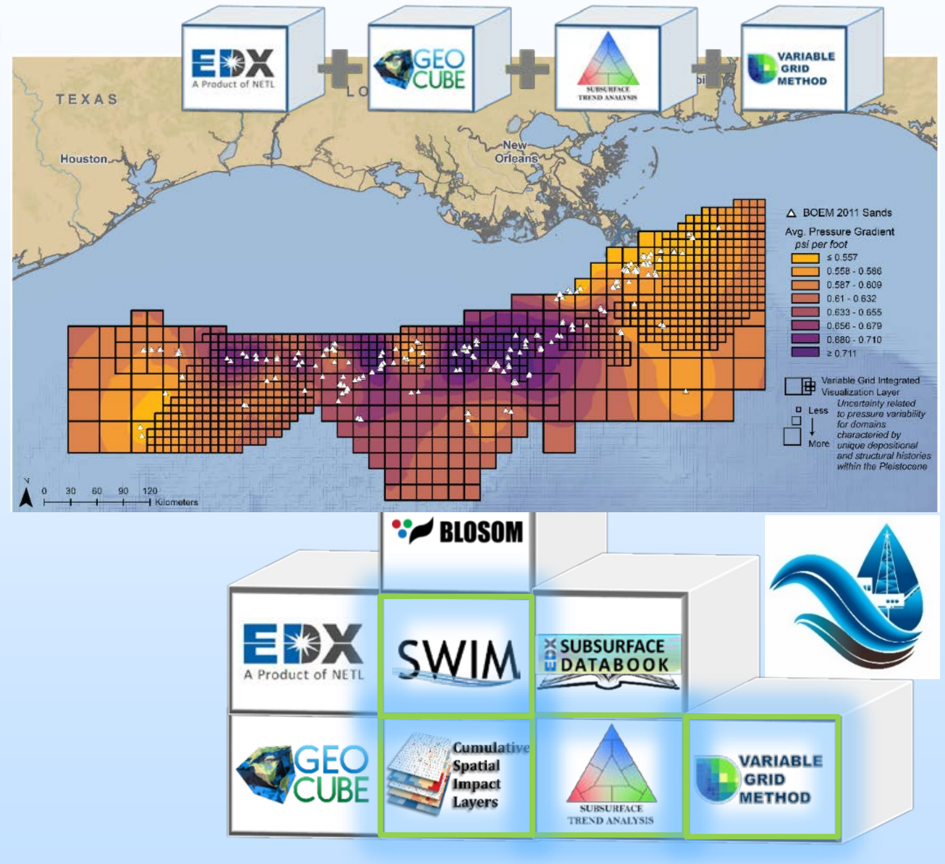


Sand fairways are red hot spots

Offshore - Saline

Incorporate Tools/Models from ORM

Focused on evaluating **tools/models from NETL's Advanced Offshore Research Portfolio's Offshore Risk Model (ORM)** for use in the Offshore carbon storage methodology:



- These tools can help assess prospectivity/storage feasibility questions related to:
  - basin conditions
  - unconsolidated/unlithified sediments
  - over-pressure conditions
  - pressure & temperature adjustments required to handle the overlying water column system
  - presence/behavior of natural seeps, quantify
  - visualize uncertainty

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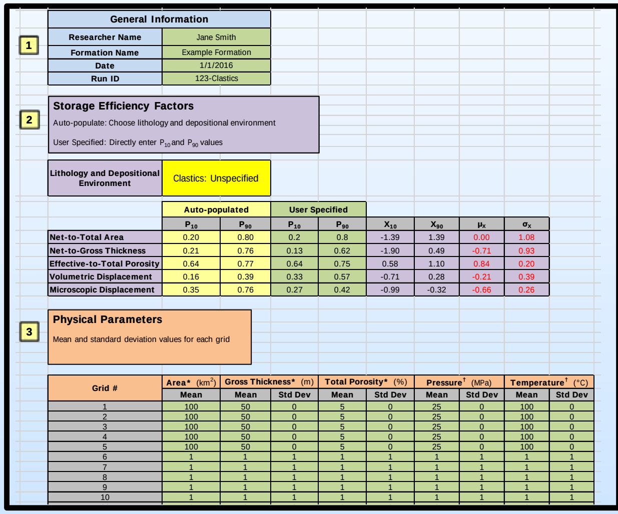
CO_2-SCREEN

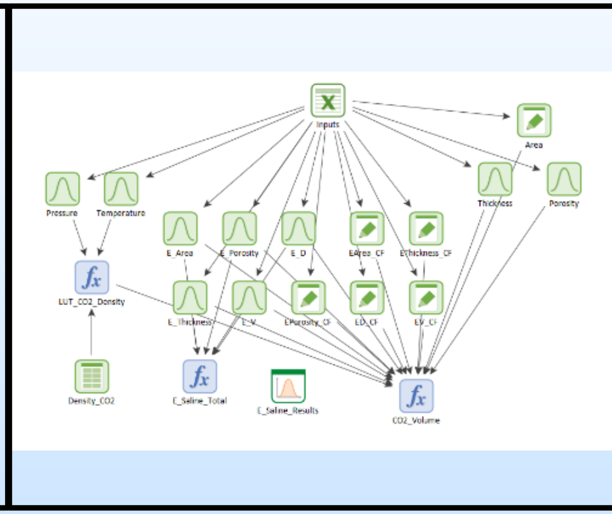
Final tool version for Saline Formations released: April 2017

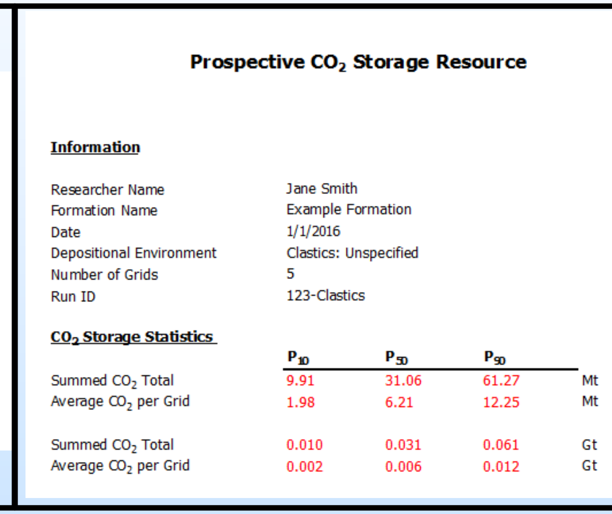
Storage prospeCtive Resource Estimation Excel aNalysis

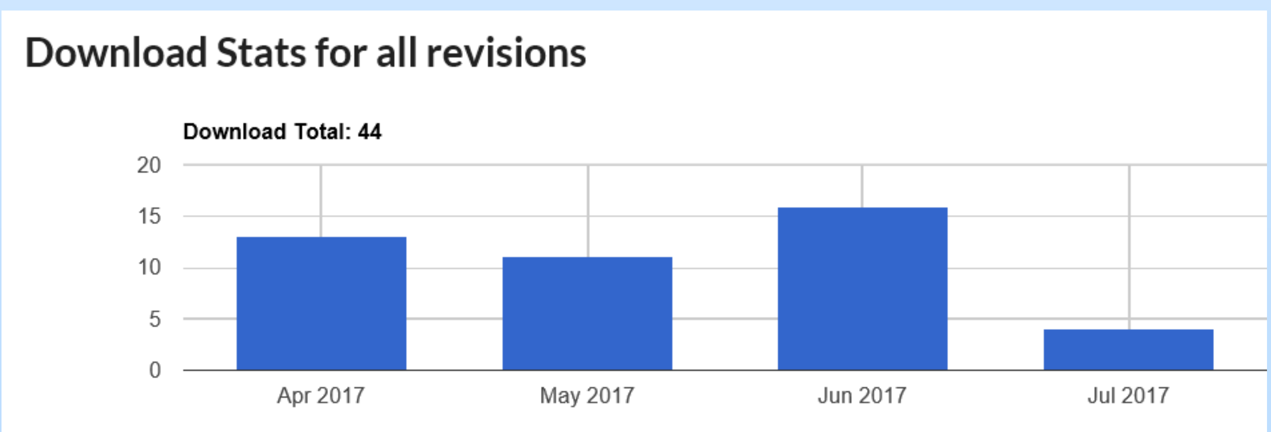
- https://edx.netl.doe.gov/dataset/netl-co2-screen

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







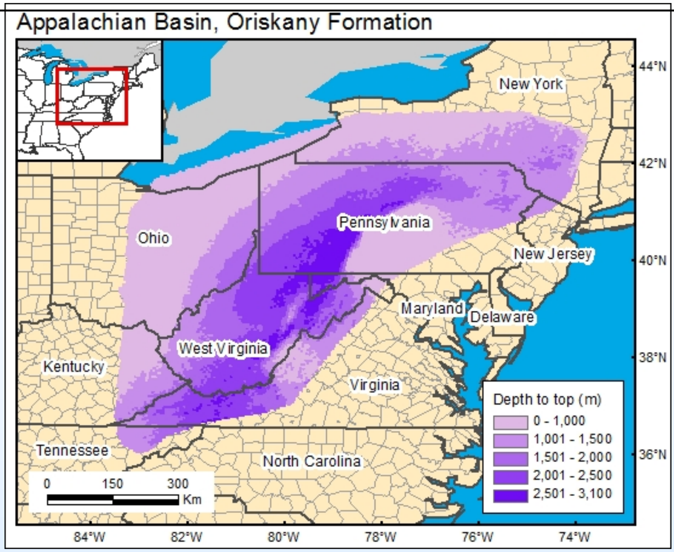


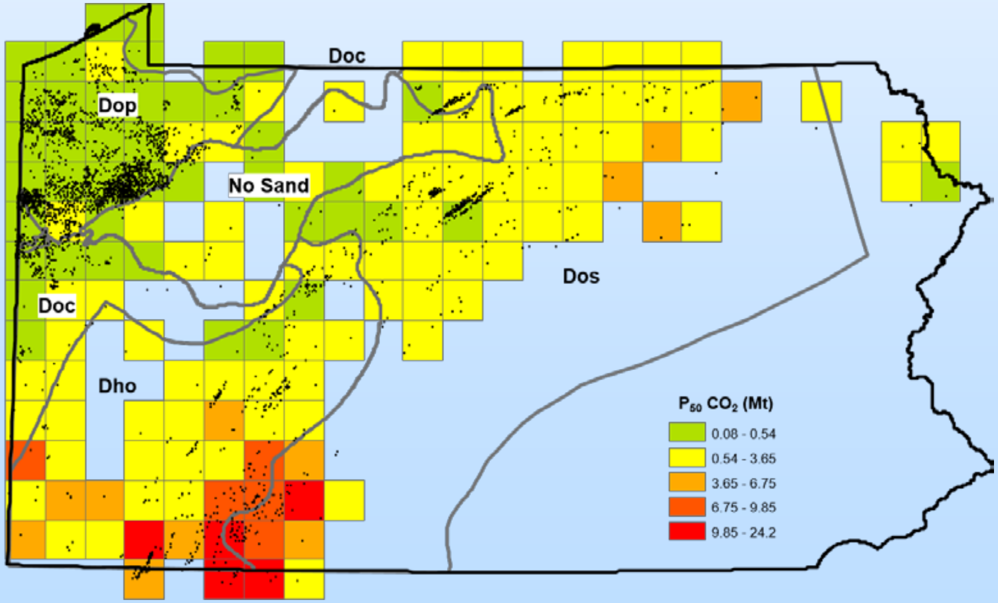
CO_2-SCREEN

Saline Formation Example

- **Oriskany Formation (PA only)**
- Well log data set (5744 wells)
  - Depth, thickness, porosity, temperature, pressure

Lithology: Clastics
Depositional Environment: Shallow Shelf





Pennsylvania Oriskany CO_2 Storage Resource

CO_2-SCREEN Results:

P_{10} = 0.07 Gt

P_{90} = 1.28 Gt

Popova et al., (2014) Results:

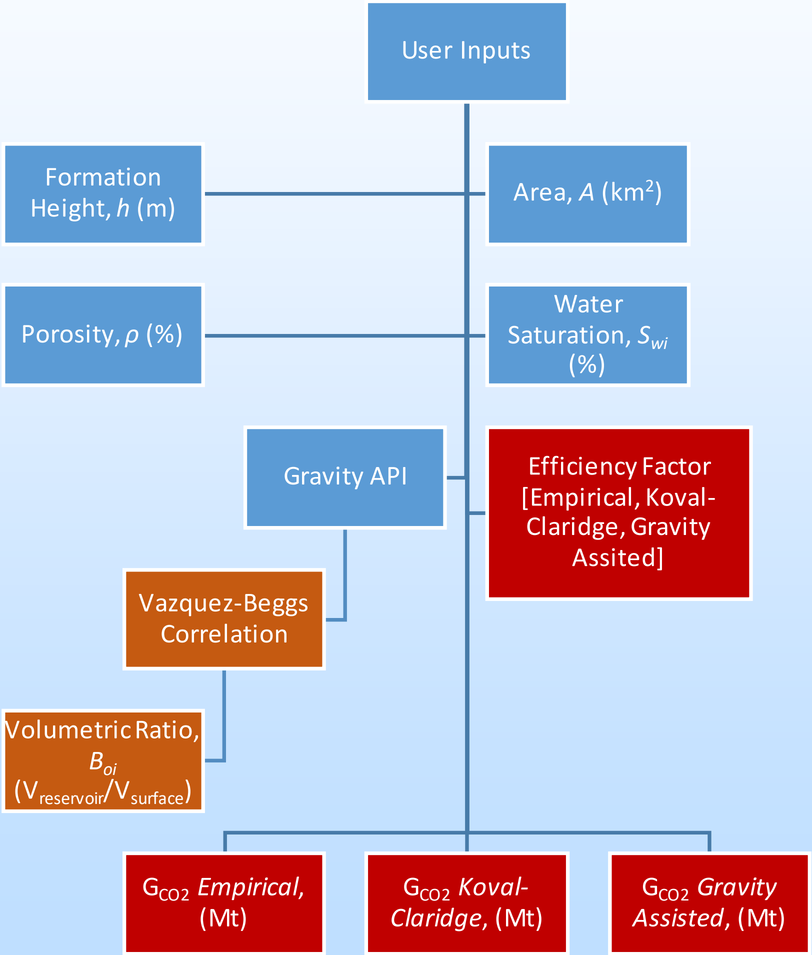
- P_{10} = 0.15 Gt
- P_{90} = 1.01 Gt

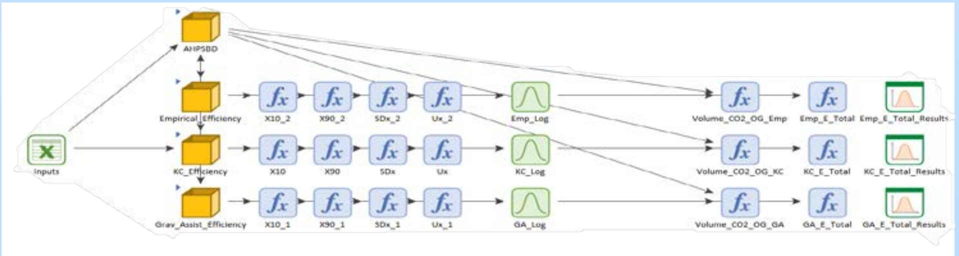
CO_2-SCREEN

Enhanced Oil Recovery

$$G_{CO_2} = Ah_n\phi_e(1 - S_{wi})B\rho_{CO_2std}E_{oil/gas}$$

A = the area of the structure
h_n = the net thickness
ϕ_e = the effective porosity of the formation
B = the fluid formation volume factor that converts standard oil and gas volume to subsurface volume
S_{wi} = the initial water saturation in the formation
ρ_{CO_2std} = the standard density of CO_2
$E_{oil/gas}$ = the efficiency coefficient

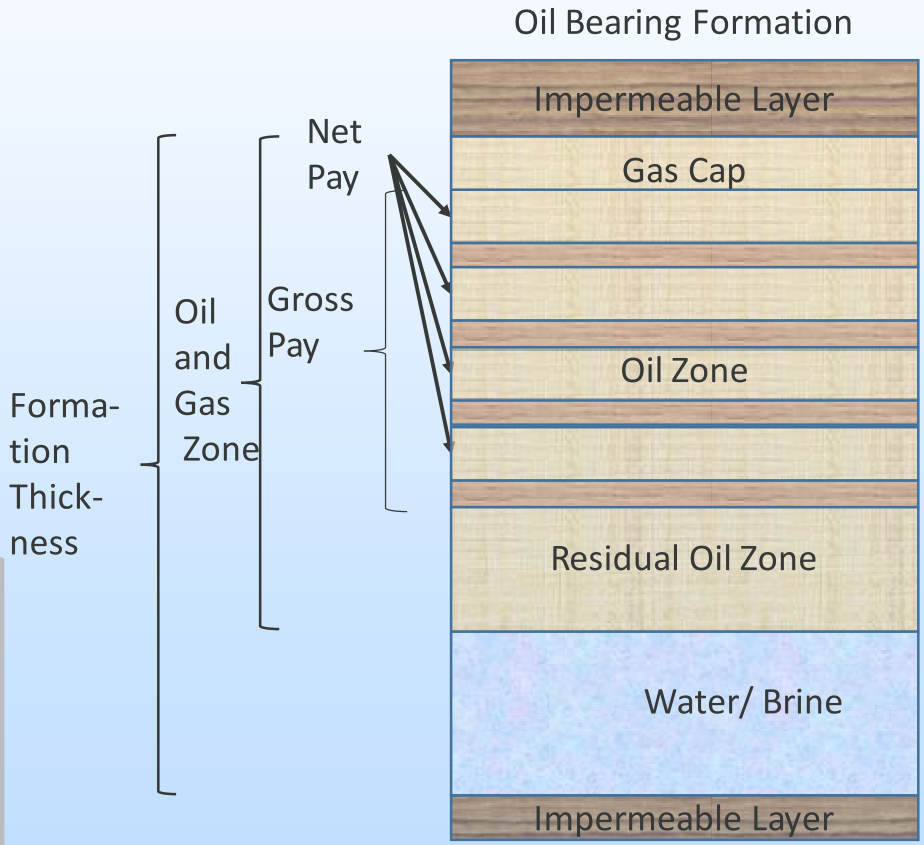




Comparison of CO_2 Storage Factors from CO_2 Enhanced Oil Recovery Using the FE/NETL CO_2 Prophet Model and from Saline Storage Using NETL's CO_2-SCREEN Model

- CO_2 stored via CO_2 EOR with water chase is comparable to CO_2 stored via saline storage with a domal structure
- CO_2 storage is lowest for saline storage with flat structure
- If CO_2 EOR with CO_2 chase or almost pure CO_2 flood is used, CO_2 storage with CO_2 EOR is greater
- If ROZ is produced as well as main pay zone, then CO_2 storage is greater with CO_2 EOR

- Conceptually, CO_2 EOR should have the highest CO_2 storage and CO_2 storage coefficients
  - CO_2 EOR removes oil and water and replaces with CO_2
  - CO_2 saline storage must displace water to store CO_2



CO_2-SCREEN

CO_2 Prophet Model and CO_2-SCREEN

Wasson Denver Unit in Permian Basin in West Texas

Results for Prophet

Category	Main Pay			Main Pay and ROZ		
	WAG wat chs	WAG CO_2 chs	"Pure" CO_2	WAG wat chs	WAG CO_2 chs	"Pure" CO_2
CO_2 in Reservoir (Mtonne)	147	206	223	190	266	289
CO_2 saturation in net pay	0.181	0.285	0.298	0.181	0.285	0.298
Percent of CO_2 in net pay	56%	63%	60%	56%	63%	60%
CO_2 storage coefficient	0.131	0.183	0.198	0.169	0.236	0.256

Results for CO_2-SCREEN

Category	Domal Structure			Flat Structure		
	P_{10}	P_{50}	P_{90}	P_{10}	P_{50}	P_{90}
CO_2 in Reservoir (Mtonne)	128	164	206	68	75	82
CO_2 storage coefficient	0.115	0.146	0.184	0.061	0.067	0.073

Presentation Outline

Resource Assessment

Methods

DEVELOP DEFENSIBLE DOE METHODOLOGY FOR REGIONAL ASSESSMENTS

Unconventional Systems

- *Team Members: Sean Sanguinito, Eugene Myshakin, Harpeet Singh, Grant Bromhal, and Angela Goodman*

Residual Oil Zones (ROZs)

- *Team Members: Tom McGuire, Tim Grant, Dave Morgan, Bob Dilmore, Angela Goodman*

Offshore

- ***Team Members:*** Kelly Rose , Emily Cameron, Burt Thomas, Jen Bauer, Andrew Bean, Jenny DeGiulio, Roy Miller, Lucy Romeo, Mike Sabbatino

Tools

EXPAND METHODOLOGY TO INCLUDE STOCHASTIC APPROACH FOR KEY PARAMETERS

- ***Saline Systems , Oil Reservoirs, Shale Formations/ CO_2 SCREEN***

- **Team Members: *Sean*** *Sanguinito, Jim Sams, Maggie Martin, and Angela Goodman*

EXPAND METHODOLOGY TO INCLUDE GEOSPATIALLY VARIABLE KEY PARAMETERS

- ***Saline Systems - SIMPA***

- ***Team Members:*** Jennifer Bauer, Devin Justman, Katherine Jones, Patrick Wingo, Kelly Rose, Gabe Creason, Veronika Vasylkivska, Jake Nelson

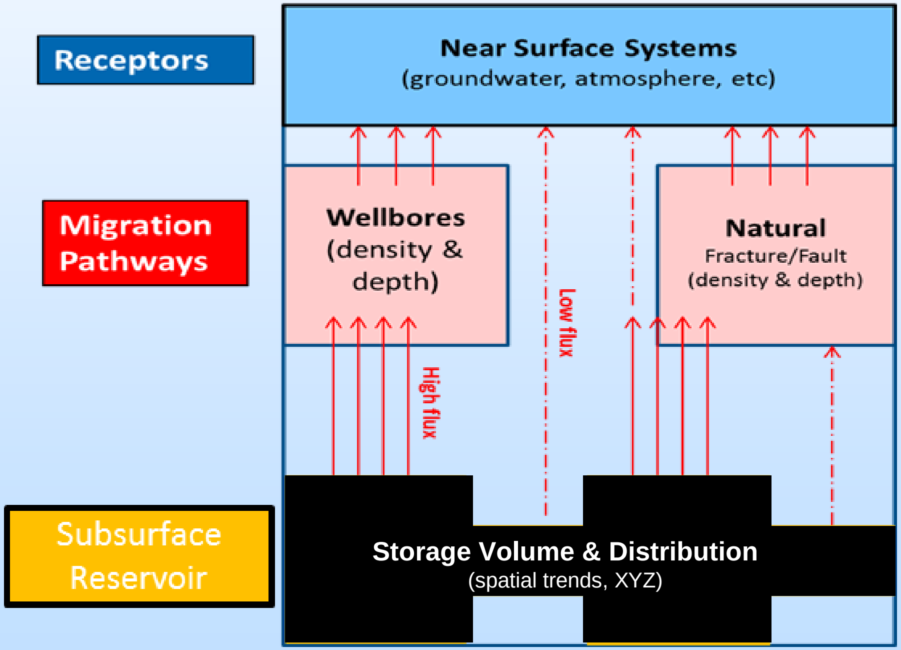
SIMPA

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

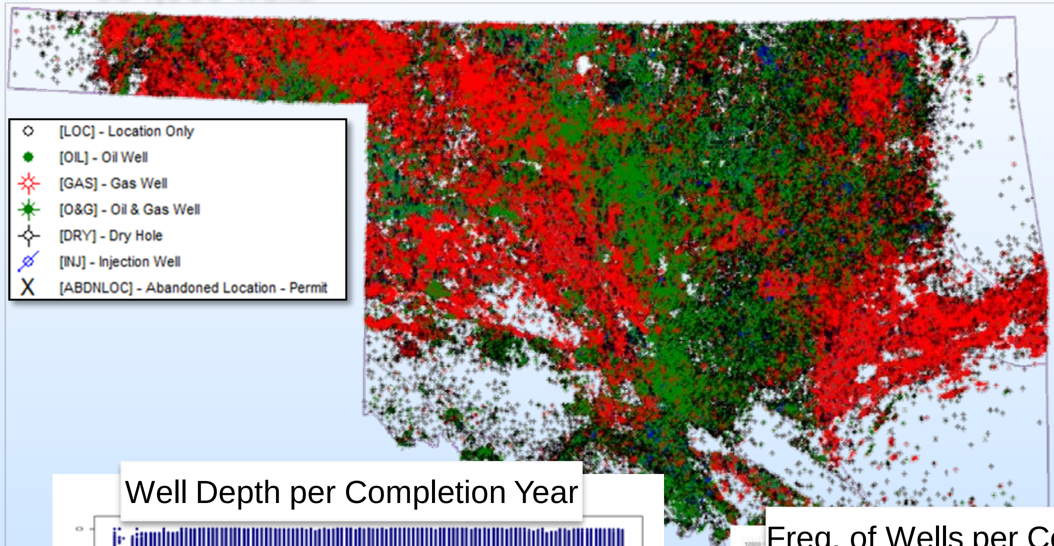
Developing Input Data for SIMPA Model

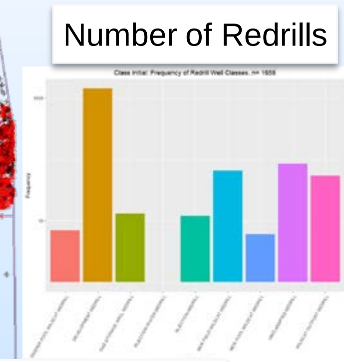
Testing and validation of **wellbore** materials and pathways data

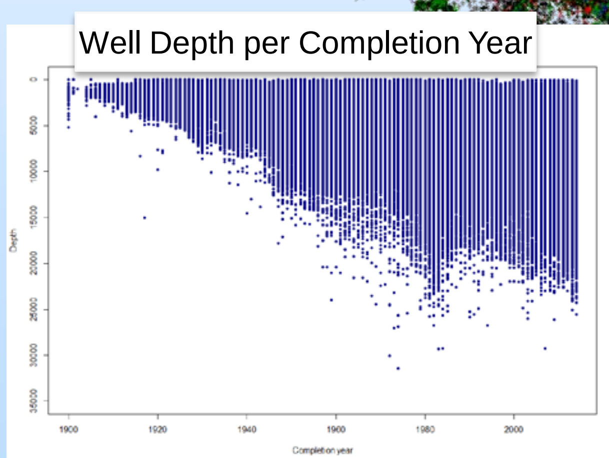
- Identify optimal data attributes and support development of membership functions

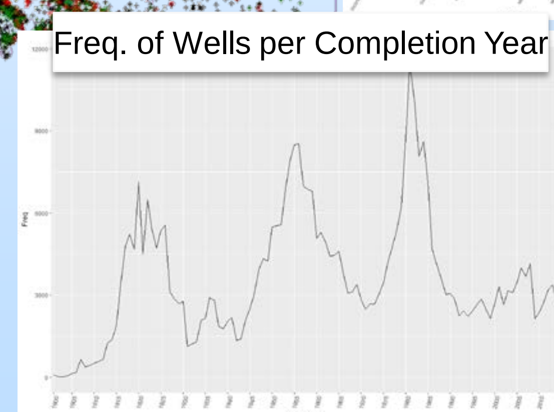
Data from IHS Enerdeq database

534,965 wells





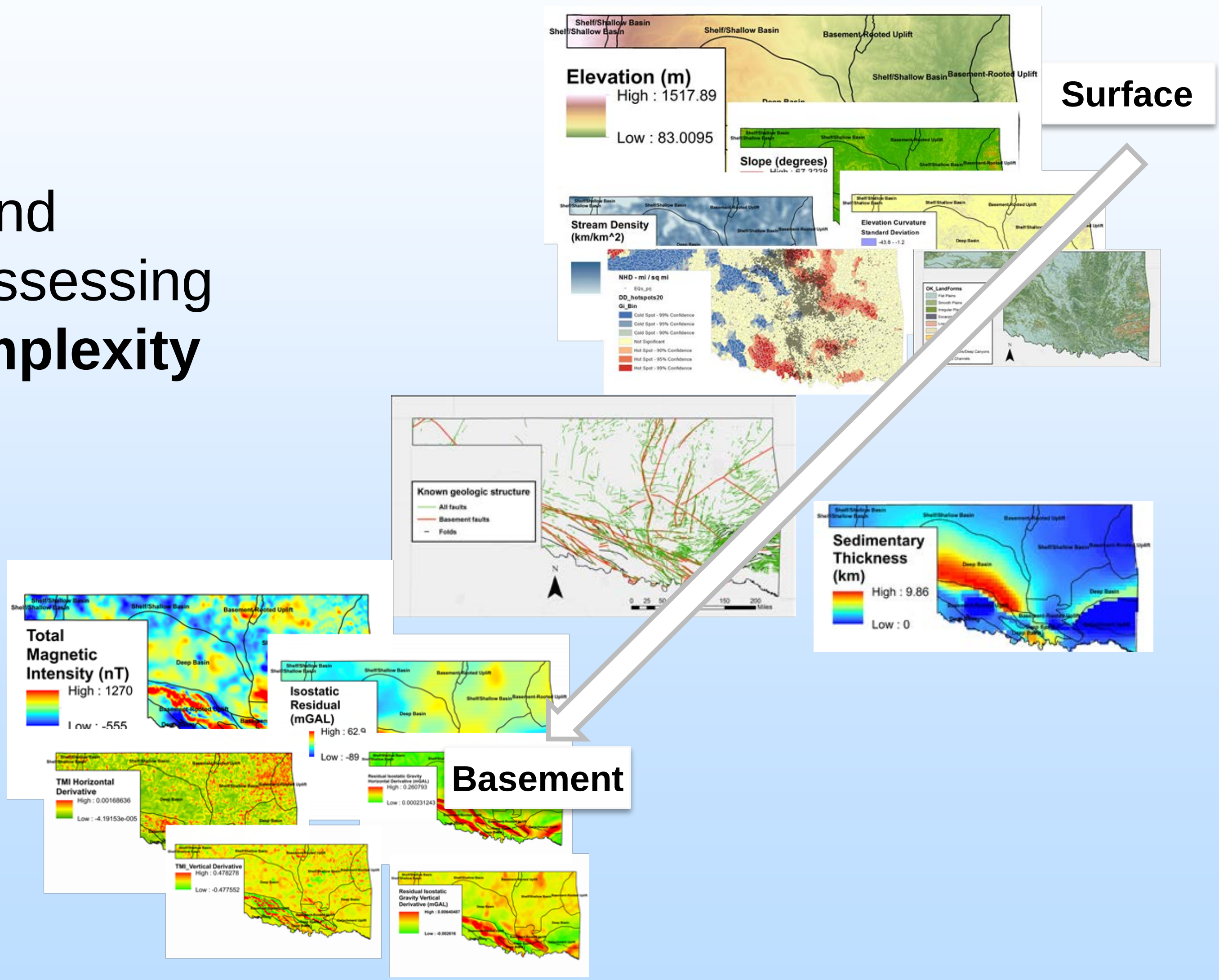




SIMPA

Developing Input Data for SIMPA Model

Finalize data and approach for assessing **structural complexity**

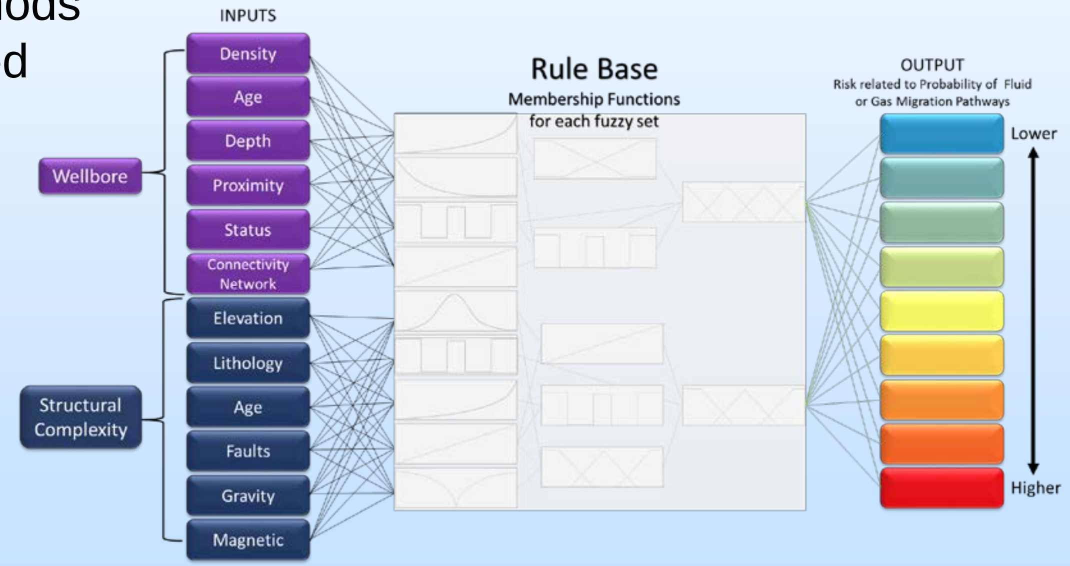


Developing SIMPA Framework

Evaluate, select, and develop data-driven, machine learning framework for SIMPA model, leveraging wellbore and structural data as inputs

Various machine learning (ML) methods were assessed; Fuzzy Logic selected because it:

- Handles highly complex, real world data and uncertainty
- Works with numerical and categorical data inputs
- Can readily couple with other ML approaches and spatial data
- Supervised, Natural language processing helps make the workflow more intuitive
    - Uses “If – Then” statements

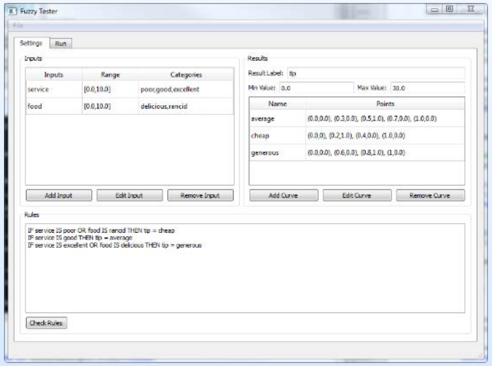


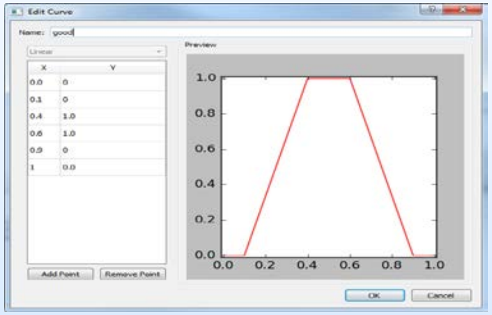
SIMPA

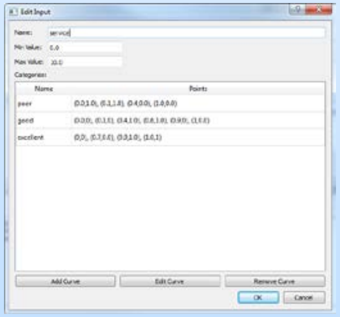
Developing SIMPA Tool

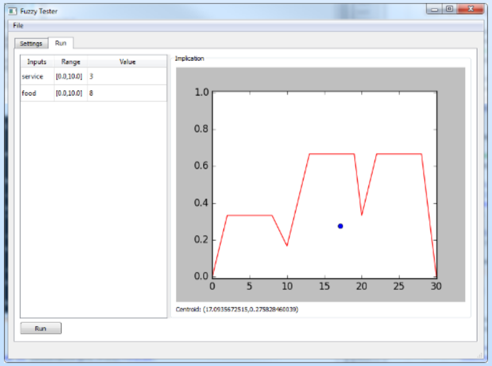
Release SIMPA Tool, *beta* version 1, for testing via EDX to internal NETL and select external parties for testing

- Team has begun developing User Interface and scripts containing logic for executing the SIMPA workflow
- Tool built in Python, an open source language to support broader applications
- Team will continue to develop the tool by integrating inputs, defining membership functions, and testing tool capabilities over the next several months









Accomplishments to Date

Project Summary

DEVELOP DEFENSIBLE DOE METHODOLOGY FOR REGIONAL ASSESSMENTS

Methods

Unconventional Systems

- **Storage efficiencies developed for prospective CO_2 storage resource of shales**
- **Development of CO_2-SCREEN for shale**

Residual Oil Zones (ROZs)

- **Identify key aspects of CO_2 storage in a ROZ and develop a draft method for prospective storage of CO_2 in ROZs**

Offshore

- **Started a database of saline reservoir properties for GOM Including porosity, net, gross and other saline reservoir properties**
- **Update storage efficiencies**

Tools

EXPAND METHODOLOGY TO INCLUDE STOCHASTIC APPROACH FOR KEY PARAMETERS - *CO_2 SCREEN*

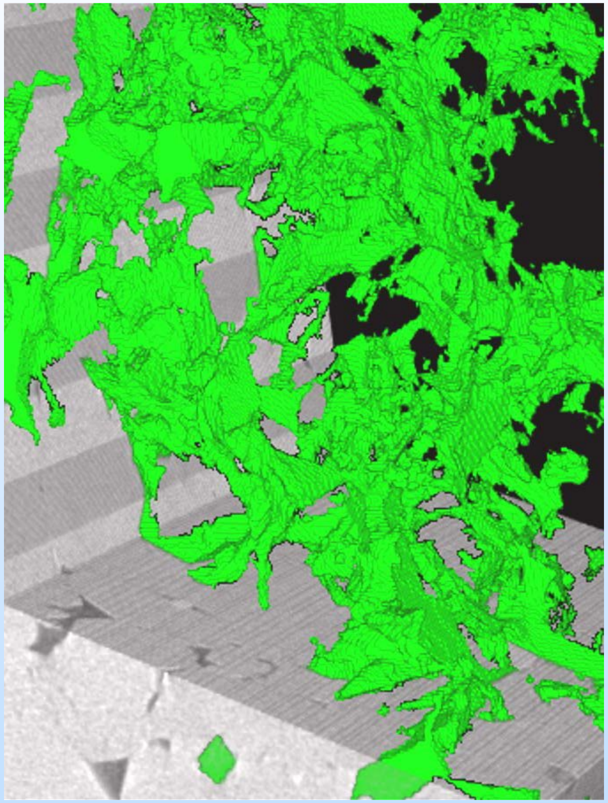
- **Released CO_2-SCREEN** to the public. Applying to saline formations and EOR
- **Develop SCREEN for shale, EOR, and ROZs**

EXPAND METHODOLOGY TO INCLUDE GEOSPATIALLY VARIABLE KEY PARAMETERS - *SIMPA*

- Testing and validation of wellbore materials/pathways data and structural complexity
- **Release SIMPA model, version 1 through 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



Lessons Learned

– Research gaps/challenges.
– Unanticipated research difficulties.
– Technical disappointments.
– Changes that should be made next time.
– Multiple slides can be used if needed.

Appendix

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

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.

Organization Chart

Task 5.0 Resource Assessment

Task 5.0 Resource Assessments (Goodman)

- **Subtask 5.1 Develop Defensible DOE Methodology for National and Regional Assessment**
- ***Sub-subtask 5.1.1 Methodology for Assessment of Unconventional Systems (Goodman)***
- ***Sub-subtask 5.1.2 Methodology for Assessment of ROZs (Goodman)***
- ***Sub-subtask 5.1.3 Methodology for Assessment of Off Shore Systems (Rose)***

Subtask 5.2 Expand Methodology to Include Stochastic Approach for Key Parameters for Basin and Formation Scale Assessment

- ***Sub-subtask 5.2.1 Methodology with Stochastic Approach for Assessment of CO2 Storage in Geologic Formations (Goodman)***

Subtask 5.3 Expand Methodology to Include Geospatially Variable Key Parameters

- ***Sub-subtask 5.3.1 Development of a Spatial Integrative Multi-Scale Probabilistic Assessment Tool to Guide Decision Making and Risk (Bauer)***

Gantt Chart

Task 5.0 Resource Assessments	1/10/2017 – 12/31/2017			
Develop Defensible DOE Methodology for National and Regional Assessment	Q1	Q2	Q3	Q4
Milestone – Complete modeling and simulation efforts to estimate storage efficiency factors needed to estimate prospective CO_2 storage in shale.				
Milestone – Develop beta CO_2-SCREEN Tool for shale for public assess on EDX.				
Milestone – Conduct a joint meeting with the SE&A Team to coordinate and communicate work and progress on ROZ research.				
Milestone – Identify key aspects of CO_2 storage in a ROZ and develop a draft method for prospective storage of CO_2 in ROZs while including input and collaboration from additional stakeholder discussions with ROZ experts, including RCSP.				
Milestone – Develop framework and approach for incorporating tools/models from the Offshore Risk Model into the Offshore carbon storage methodology to address prospectivity/storage feasibility steps for the storage assessment.				
Milestone – Develop approach for developing GoM specific efficiency factors custom using BOEM open source reservoir data.				
Milestone – Complete draft development/calculation of GoM efficiency factors.				
Milestone – Complete evaluation of options for developing an unconventional, offshore assessment approach.				

Gantt Chart

	Milestone – Demonstrate in GoM integrated DOE storage assessment approach with GoM tailored efficiency factors and Offshore risk tools for enhanced offshore carbon storage and feasibility assessment.				
5.2	Expand Methodology to Include Stochastic Approach for Key Parameters for Basin and Formation Scale Assessment				
	Milestone – Expand methodology to include stochastic approach for key parameters for basin and formation scale assessment for saline formations. This includes having the method ready for inclusion of the future Carbon Storage Atlas and as a peer-reviewed journal article.				
	M1 Milestone (M1.17.5.A) – Complete development and review of a screening tool for CO_2 storage in saline formation. This will incorporate comments and suggestions of CO_2-SCREEN by users such as KeyLogic, Battelle, and the SW Partnership.				
	Milestone – Develop new beta CO_2-SCREEN Tools for conventional (oil reservoirs) and unconventional (depleted shale) systems.				
5.3	Expand Methodology to Include Geospatially Variable Key Parameters				
	Milestone – Summarize key results of testing and validation of wellbore materials/pathways input data for use in the SIMPA framework in quarterly report.				
	M1 Milestone (M1.17.5.B) – SIMPA Tool (version 1) available for internal and selected external testing on an EDX collaborative workspace.				
	Milestone – Develop draft report or manuscript detailing spatial approach for assessing structural complexity.				
	Milestone – Develop a draft user manual (in a presentation or report) for the SIMPA tool that provides information on the tool and a couple example products.				

Bibliography

Publications

1. Sanguinito, S.; Goodman, A. L.; Levine, J. S. NETL CO2 Storage prospeCtive Resource Estimation Excel aNalysis (CO2-SCREEN) User's Manual; NETL-TRS-6-2017; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA, 2017; p 28.
2. Tudek, J.; Crandall, D.; Fuchs, S.; Werth, C. J.; Valocchi, A. J.; Chen, Y.; Goodman, A. In situ contact angle measurements of liquid CO2, brine, and Mount Simon sandstone core using micro X-ray CT imaging, sessile drop, and Lattice Boltzmann modeling. Journal of Petroleum Science and Engineering in press 2017.
3. Glosser, D.; Bauer, J. R. A Graph Theoretic Approach for Spatial Analysis of Induced Fracture Networks. Journal of Sustainable Energy Engineering 2016, 4, 232–249.
4. Glosser, D.; Rose, K.; Bauer, J. R. 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 2016, 3, 299–317.
5. Goodman, A.; Sanguinito, S.; Levine, J. Prospective CO2 Saline Resource Estimation Methodology: Refinement of Existing DOE-NETL Methods Based on Data Availability. International Journal of Greenhouse Gas Control 2016, 54, 242–249.

Presentations

1. "DOE Screening Methodology for Estimating the Prospective CO2 Storage Resource of Shales and Identifying Data Gaps" Joint 52nd Northeastern Annual Section / 51st North-Central Annual Section Meeting - Pittsburgh, Pennsylvania March 18-22, 2017
2. "Resource Assessment Methods for CO2 Storage in Geologic Formations" Mastering the Subsurface Through Technology, Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, Pennsylvania August 16-18, 2016
3. "NETL's Research & Innovation Center Carbon Storage Portfolio" GSCO2 Annual Meeting Champaign, IL March 30-31, 2016