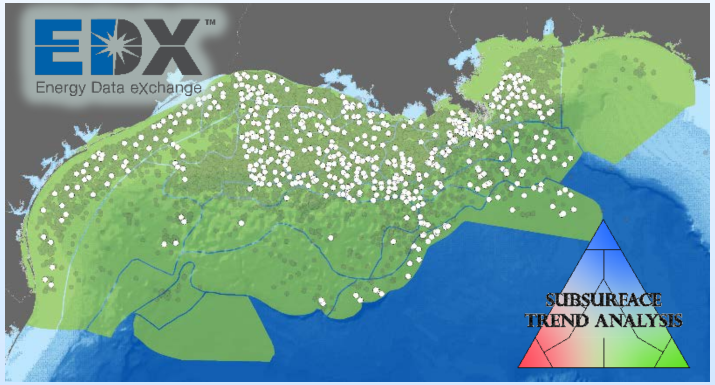
Development of Defensible CO_2 Storage Methods and Tools to Quantify Prospective Storage in the Subsurface

Carbon Storage DE-FE1022403



Angela Goodman and Kelly Rose
National Energy Technology Laboratory

U.S. Department of Energy
National Energy Technology Laboratory
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting
August 26-30, 2019

Presentation Outline

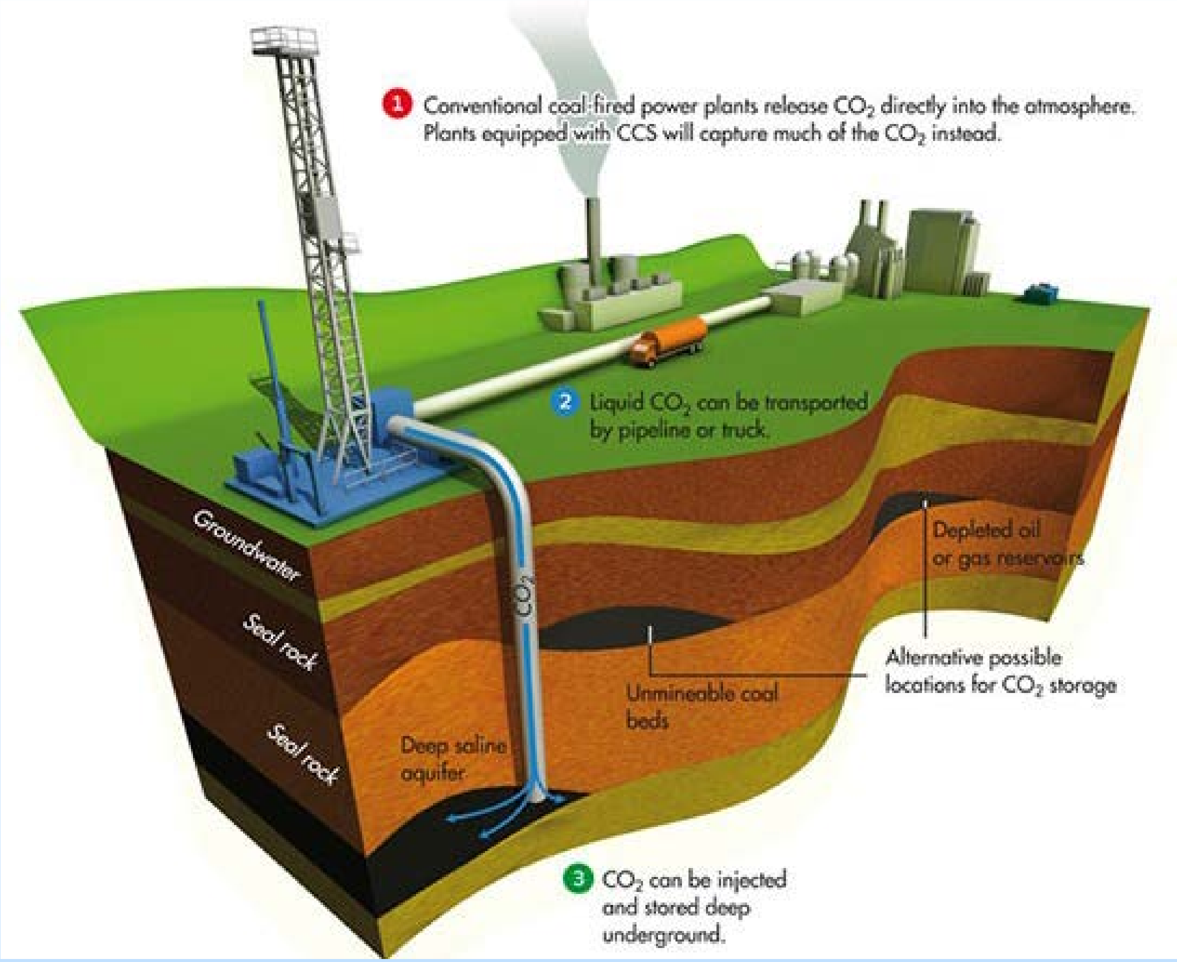
Resource Assessments: Provides the Department of Energy (DOE) defensible carbon dioxide (CO_2) storage methods and tools to quantify prospective storage for the Carbon Storage Atlas, National Energy Technology Laboratory's (NETL's) Regional Carbon Sequestration Partnership (RCSP), and CARBONSAFE projects.

Task 2: Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Shale Systems – *presented by Angela Goodman*

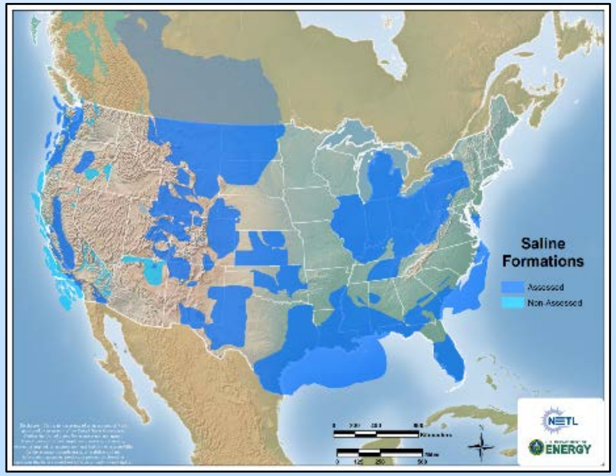
Task 3: Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in ROZs – *presented by Angela Goodman*

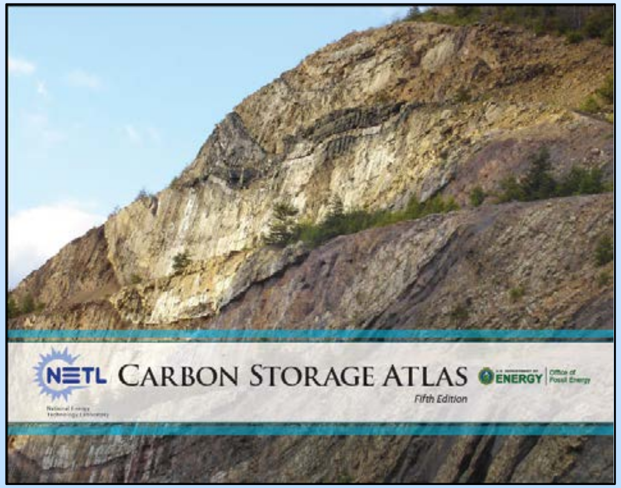
Task 4: Developing Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Offshore Reservoirs – *presented by Kelly Rose*

Prospective CO_2 Storage in the Subsurface



Prospective CO_2 Storage Resource for U.S. and parts of Canada		
Regonal Carbon Storage Partnerships	Billion Metric Tons	
	Low	High
Oil and Natural Gas Reservoirs	**186**	**232**
Unmineable Coal	**54**	**113**
Saline Onshore	**2,379**	**21,633**
Shale Formations	Task 2	
Saline Offshore	Task 4	
Residual Oil Zones	Task 3	





Task 2: Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Shale Systems

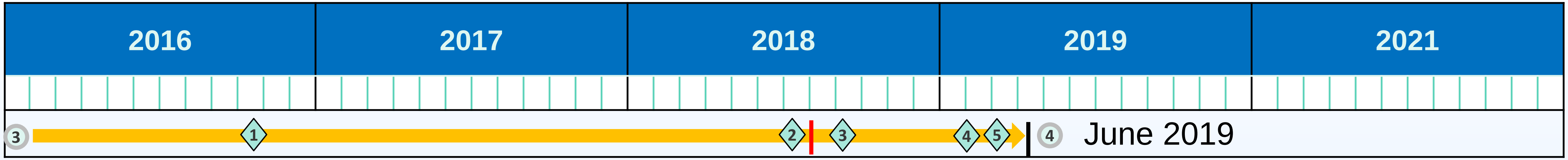
Task Technical Approach and Project Relevancy

- **Objective:**
  - Deliver a **quantitative method and CO2-SCREENv2.0 Tool** that estimates carbon dioxide (CO_2) storage resource in shale formations.
- **Benefit:**
  - Results to **inform high-level decision making** related to carbon storage initiatives at the national and regional scale.
- **Challenges:**
  - **Lack of detailed** geologic and petrophysical data
  - Need to understand the **void space within fractures and pores for CO_2 storage** and how **kerogen and minerals** are affected by CO_2 contact.
- **Approach:**
  - Develop method and tool that are **accepted by the peer review community** for public dissemination.

Team: *Angela Goodman, Sean Sanguinito, Eugene Myshakin, Bob Dilmore, Grant Bromhal, Harpreet Singh, Scott Frailey, Alex Azenkeng, Beth Kurz, Wes Peck, Charlie Gorecki*

Task 2: Project Timeline Overview

Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Shale Systems



Key Accomplishments

- ✓ Developed U.S. DOE NETL **Methodology** for Estimating the Prospective CO_2 Storage Resource of Shales at the National and Regional Scale (2016)
- ✓ Developed **storage efficiency factors** for shale storage (2018)
- ✓ Deployed **beta CO2-SCREENv2.0 Tool** for shale for community validation on EDX (2018)
- ✓ Modeled **flow regimes and storage efficiency** of CO_2 injected into depleted shale reservoirs (2019)
- ✓ Incorporating **image-based techniques** to estimate the CO_2 storage resource in shale organic and inorganic components stemming from the efforts at **EERC** into the SCREEN Tool (2019)
- ✓ Developed **final CO2-SCREENv2.0 Tool** for shale for public access on EDX (2019)

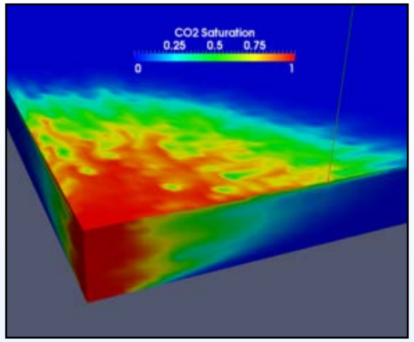
Shale Methodology Equation

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

Net effective formation volume

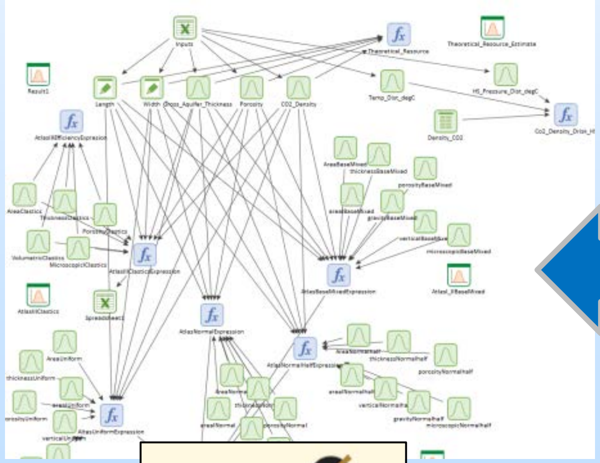
Efficiency of storage as free gas

Efficiency of storage in sorbed phase



E_ϕ: P_{10} to P_{90} range of 0.15 to 0.36
E_S: P_{10} to P_{90} range of 0.11 to 0.24

CO_2-SCREEN

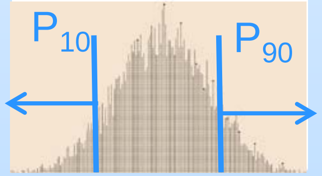


Log-odds stochastic approach

E_A E_h E_ϕ E_S

$$\frac{1}{(1+e^{(-E_A)})} * \frac{1}{(1+e^{(-E_h)})} * \frac{1}{(1+e^{(-E_\phi)})} * \frac{1}{(1+e^{(-E_S)})}$$

10% of values



10% of values


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, Isis Fukai, Daniel J. Soeder, Grant Bromhal, Robert M. Dilmore, George D. Guthrie, Traci Rodosta, Sean Sanguinito, Scott Frailey, Charles Gorecki, Wesley Peck, Angela L. Goodman


International Journal of Greenhouse Gas Control 76 (2018) 24–31

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

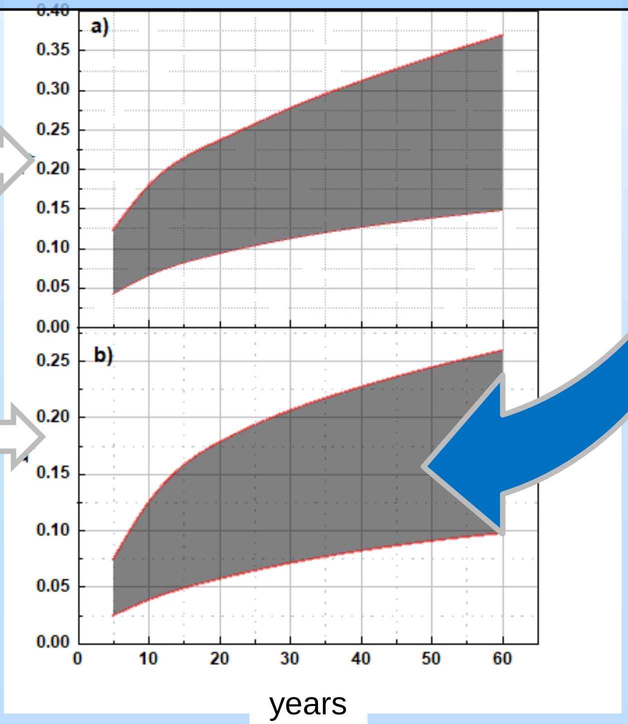
journal homepage: www.elsevier.com/locate/ijggc

Numerical estimations of storage efficiency for the prospective CO_2 storage resource of shales

Evgeniy M. Myshakin, Harpreet Singh, Sean Sanguinito, Grant Bromhal, Angela L. Goodman

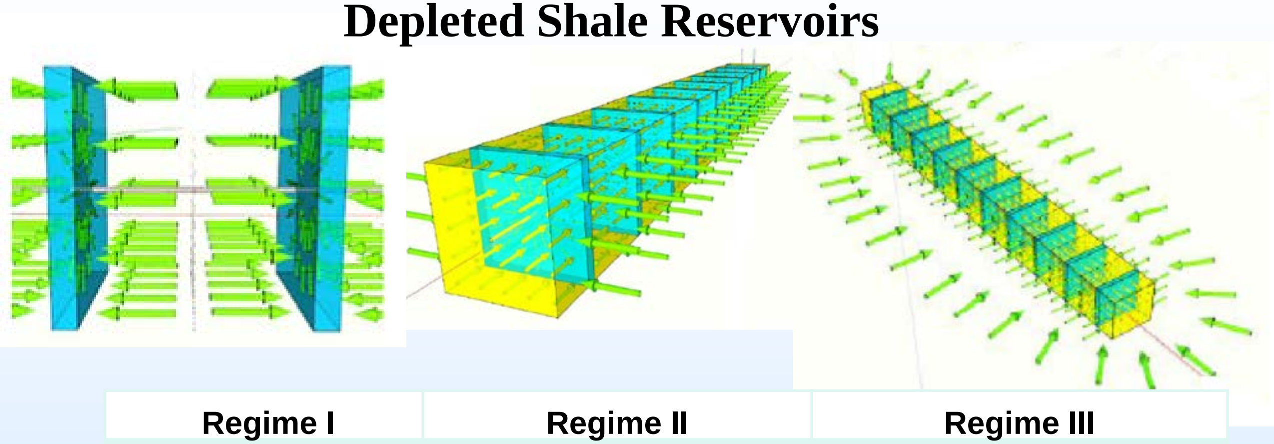
E_ϕ

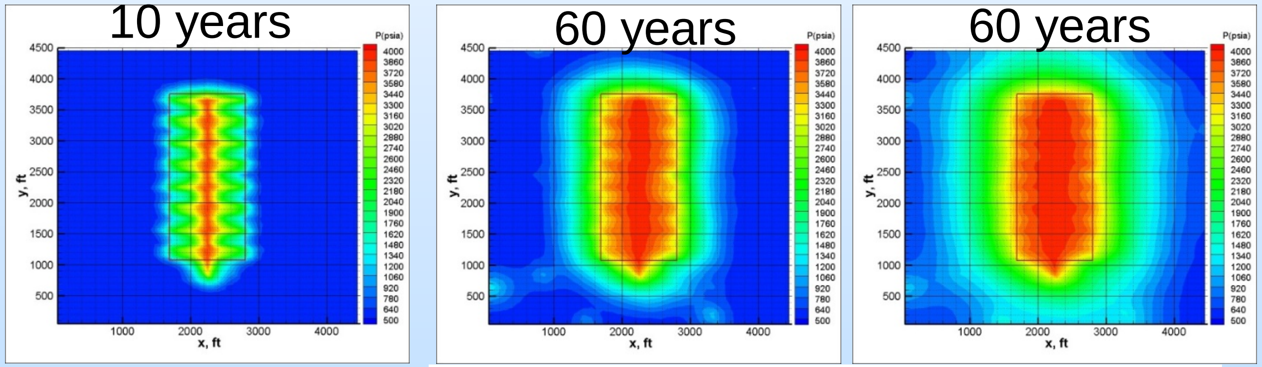
E_S

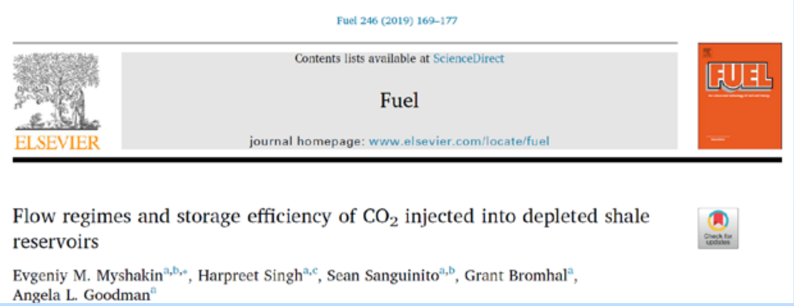


Refinements of Storage Efficiency Factors

Flow Regimes and Storage Efficiency of CO_2 Injected into Depleted Shale Reservoirs



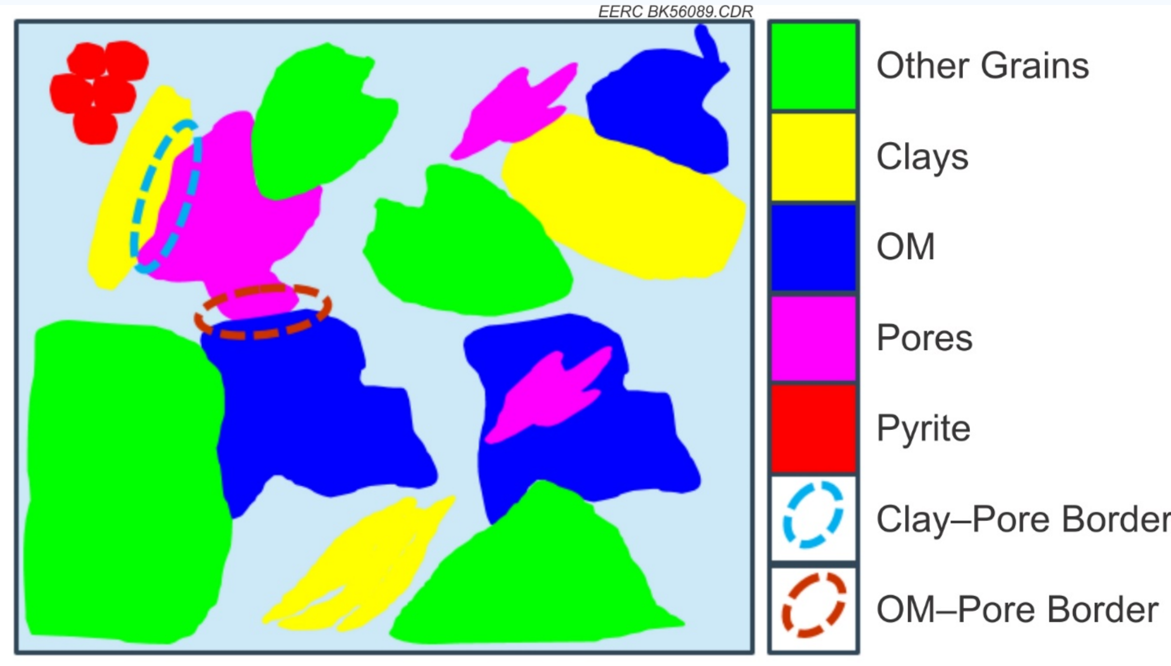



Fuel 246 (2019) 169–177
Contents lists available at ScienceDirect
Fuel
journal homepage: www.elsevier.com/locate/fuel

Flow regimes and storage efficiency of CO_2 injected into depleted shale reservoirs

Evgeniy M. Myshakin[a,b,*], Harpreet Singh[a,c], Sean Sanguinito[a,b], Grant Bromhal[a], Angela L. Goodman[a]

Image-Based Approach for Estimating Prospective CO_2 Storage



Task 3: Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in ROZs

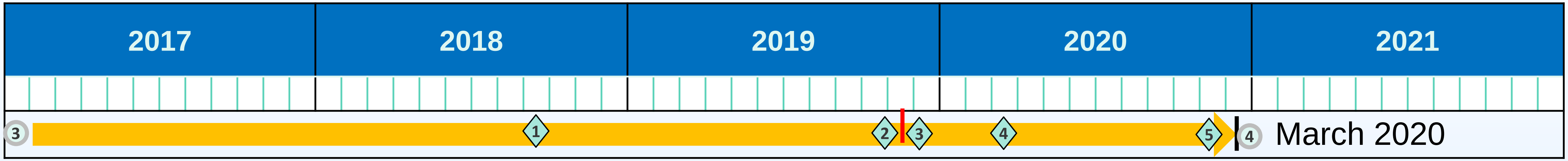
Task Technical Approach and Project Relevancy

- **Objective:**
  - Deliver a quantitative method and CO_2-SCREENv3.0 Tool that estimates carbon dioxide (CO_2) storage resource in residual oil zone (ROZ) formations.
- **Benefit:**
  - Estimate the CO_2 storage potential in ROZs. Results to **inform high-level decision making** related to carbon storage initiatives at the national and regional scale.
- **Challenges:**
  - Limits on the library of data which characterizes ROZ systems.
  - Industry has not fully recognized ROZ oil resources worthy of exploitation.
  - False indicators of mobile oil in cores may give the impression of a ROZ.
  - CO_2 floods for ROZ fairways may take a considerable amount of time to produce a sustainable rate of oil production.
- **Approach:**
  - Develop method and tool that are **accepted by the peer review community** for public dissemination.

Team: *Angela Goodman, Sean Sanguinito, Eugene Myshakin, Bob Dilmore, Harpreet Singh, Tim Grant, Dave Morgan, Grant Bromhal, Peter Warwick, Sean T. Brennan, Charles Gorecki, Wesley Peck, Matthew, Scott Frailey, Rajesh Pawar*

Task 3: Project Timeline Overview

- Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in ROZs



Key Accomplishments

- ✓ Developed **Methodology and Efficiency Factors** for Estimating the Prospective CO_2 Storage Resource of ROZs at the National and Regional Scale (2019)
- ✓ Deployed **beta CO2-SCREENv3.0 Tool** for ROZ for community validation on EDX (2019)
- Develop **final CO2-SCREENv3.0 Tool** for shale for public access on EDX (2020)
- Deploy **CO2-SCREENv1, 2, and 3.0 Tool** without license restrictions (2020)

ROZ Methodology Equation

$$G_{CO_2} = A_t E_A h_g E_h \phi_{tot} E_\phi \left[(1 - S_{wirr} - S_{or}) \rho_{CO_2} E_v + S_{or} R_{c/o} E_{Ds} \right]$$

Net effective formation volume

Sweep Efficiency

CO_2 dissolution in oil

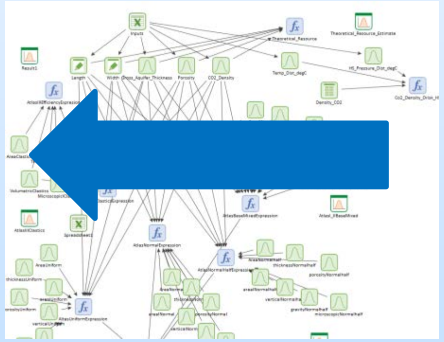
S_{wirr}	0.1
$S_{or\ (Low)}$	0.2
$S_{or\ (High)}$	0.38
$R_{c/o(Low)}$	680 kg/m^3
$R_{c/o(High)}$	740 kg/m^3

$$G_{CO2} = A_t E_A h_g E_h \phi_{tot} E_\phi \left[(1 - S_{wirr} - S_{or}) \rho_{CO2} E_v + S_{or} R_{c/o} E_{Ds} \right]$$

Total CO_2 Storage (Equation 4)		
P_{10} (Mt)	P_{50} (Mt)	P_{90} (Mt)
1.75	5.89	14.47

	Mass (Mt)	Percent of Total
Total CO_2 (P_{50})	5.89	100
Free phase (P_{50})	5.30	90
Oil Diss. (P_{50})	0.44	10

GoldSim



Log-odds stochastic approach

Efficiency Factors

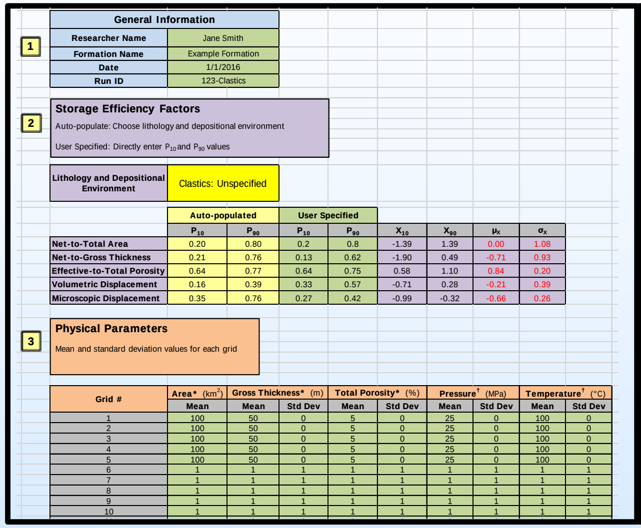
Parameter	P_{10}	P_{90}	Source
E_A	0.20	0.80	IEA-GHG, 2009
E_h	0.21	0.76	IEA-GHG, 2009
E_ϕ	0.64	0.77	IEA-GHG, 2009
E_V	0.16	0.39	IEA-GHG, 2009
E_D	0.35	0.76	IEA-GHG, 2009
E_{Ds}	0.009	0.011	MRST

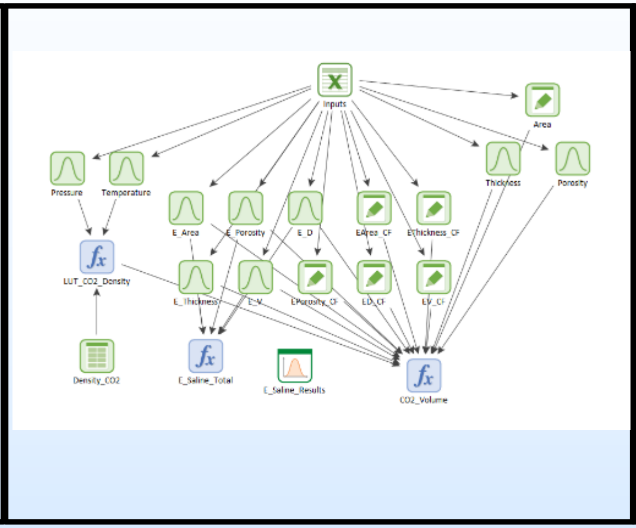
$$E_D = 1 - S_{wirr} - S_{or}$$

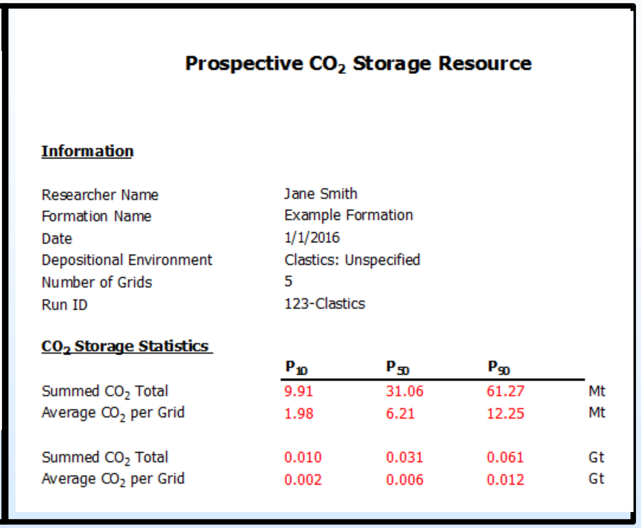
CO_2-SCREEN

NATIONAL ENERGY TECHNOLOGY LABORATORY

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







CO_2- SCREEN (Version 1.0, 2.0, 3.0, 4.0)

Storage prospeCtive Resource Estimation Excel aNalysis

464 downloads since April 2017

- Version 1.0 = Saline Formations
- Version 2.0 = Shale Formations
- Version 3.0 = Residual Oil Zones
- Version 4.0 = Converted to Python


International Journal of Greenhouse Gas Control 75 (2018) 180–188

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

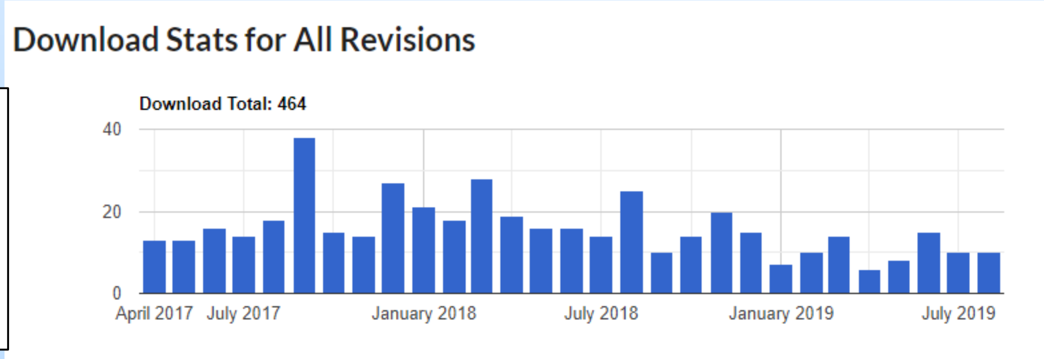
journal homepage: www.elsevier.com/locate/ijggc

CO_2-SCREEN tool: Application to the oriskany sandstone to estimate prospective CO_2 storage resource

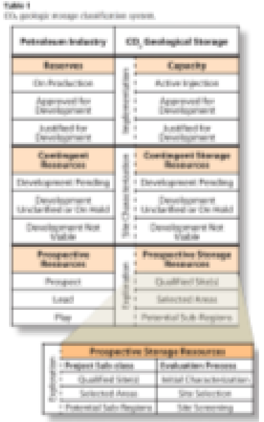
Sean Sanguinito[a,b,*], Angela L. Goodman[a], James I. Sams III[a]

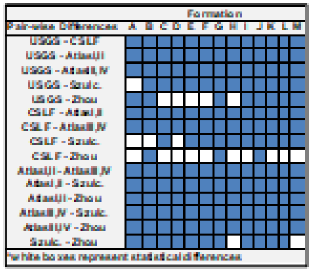
[a] U.S. Department of Energy, National Energy Technology Laboratory, 626 Cochrans Mill Road, Pittsburgh, PA 15236, United States

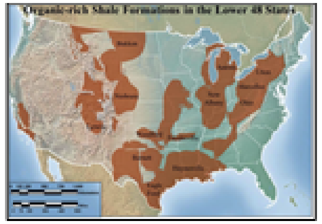
[b] AECOM Corporation, 626 Cochrans Mill Road, Pittsburgh, PA 15236, United States

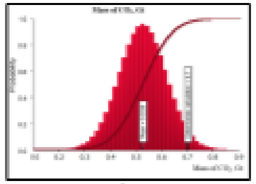


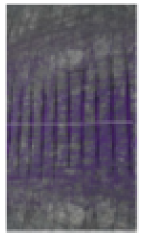
https://edx.netl.doe.gov/dataset/co2-screen-version-2-0

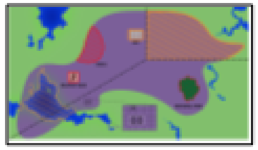








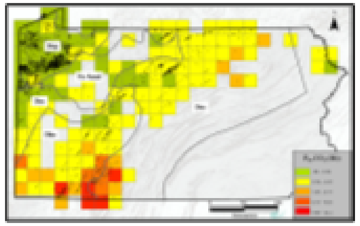


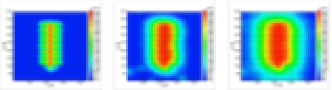


$$G = A^d h^s \phi^s \rho^s E_{saline}^s$$

$$E_{saline}^s = E_A^s E_h^s E_\phi^s E_V^s E_d^s$$

CO_2 SCREEN





2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

Method Development through RCSP's Working Groups

Initial Methodology for Saline, Coal, and Oil and Gas Reservoirs

Saline Method Comparative Analysis

Saline Method Statistical Comparison

Initial Methodology for Shale

Stochastic Modeling of Sedimentary Formations

Shale Method

Saline Method Refinement[7]

Development of CO_2-SCREEN Tool

Offshore Storage Method

Shale Efficiency Factors

ROZ Storage Method

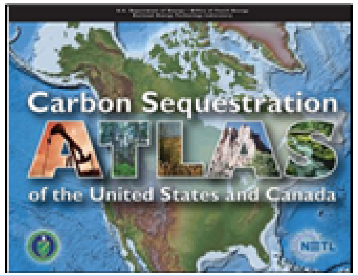
CO_2-SCREEN Oriskany Example

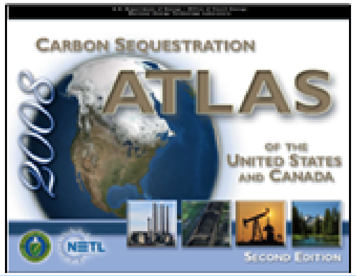
ROZ Efficiency Factors

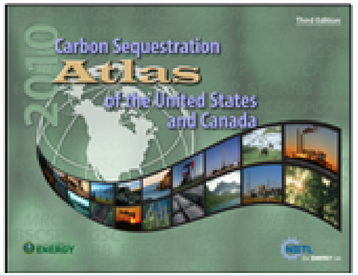
Offshore Efficiency Factors

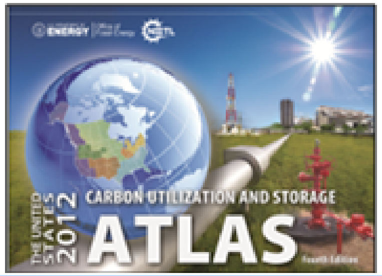
Shale flow regimes

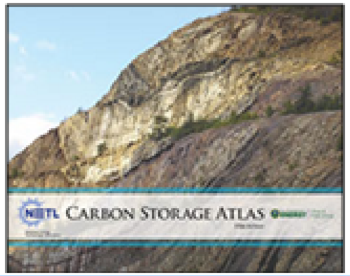
Carbon Sequestration Atlas of the United States and Canada











Tasks 2 & 3 Synergy Opportunities

- Developed quantitative statistical methods to estimate the prospective CO_2 storage resource of sub-surface geologic formations across the United States [> *2,400 billion metric tons of storage = 400 yrs. of storage space*]
  - Significantly **advances accuracy and science** behind storage estimates
  - **First of its kind storage** methods meets DOE program goals by directly **impacting global energy policy for CCS**
  - Provides guidance for other **strategic planning by nations worldwide (*United States, Canada, Mexico, China, Sweden, Norway, Israel, and South Africa*)**
  - **Publicly accessible** via peer-reviewed journals, Carbon Storage Atlas, **CO_2-SCREEN (EDX and GoldSim)**
  - This estimation tool (CO_2-SCREEN), has been **downloaded by external peers over 400 times** since it became available on EDX as a public tool in 2017
  - **Highly collaborative** effort: **USGS, EERC, ISGS, CMU, NIST, LANL**
- Policy makers and potential investors need reliable estimates of storage estimates for indication of long term sustainability for use in public **policy and business investment decisions**
  - Reduce CO_2 emissions / Store CO_2 securely
  - Unknown effect causing CO_2 to escape
  - Public health
  - Successfully deploy CCUS technology
- **Valuable resources** and time could be wasted if sorption estimates are made based on unreliable data
  - MVA, drilling patterns, CO_2 pipelines, etc

Task 4: Developing Defensible DOE Methods, Tools, & Storage Efficiency for CO_2 Storage in Offshore Reservoirs

Offshore Carbon Storage, Task 4, Kelly Rose (PI) Lucy Romeo (co-PI)
POP: 2017-present

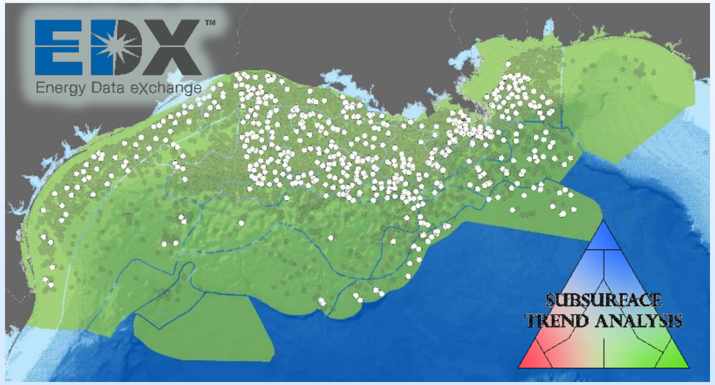
Values Delivered

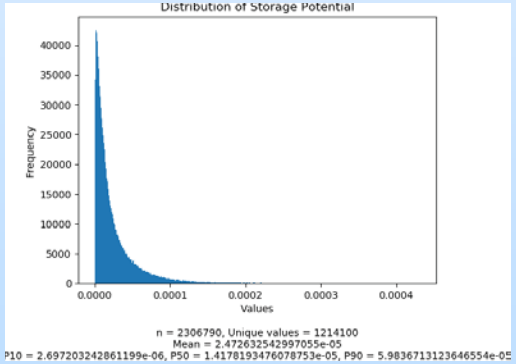
- Improved the ***accuracy*** of ***offshore saline resource estimations*** at multiple spatial scales
- ***Offshore tailored efficiency terms*** from DOE carbon storage method
- Methodology & tool to execute ***data-driven technical assessment*** of offshore storage resources
- Extended and integrated ***offshore oil/gas spatial, analytical tools*** for offshore CS stakeholder needs
- This methodology ***complements NETL's CO_2 Storage prospeCtive Resource Estimation Excel aNalysis (CO_2 Screen) Tool***

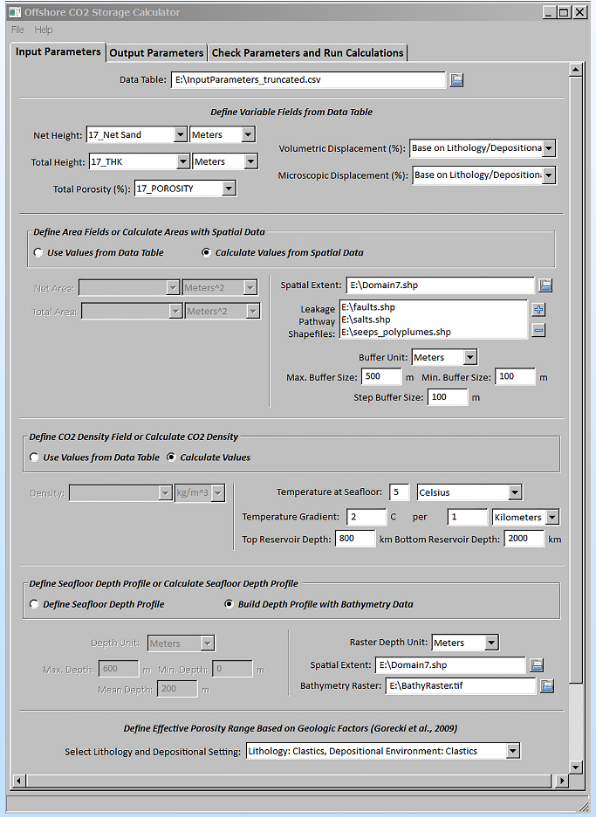
Goodman et al., 2016

$$G_{CO_2} = A_t h_g \phi_t \rho E_{saline}$$

$$E_{saline} = E_A \times E_H \times E_\phi \times E_v \times E_d$$





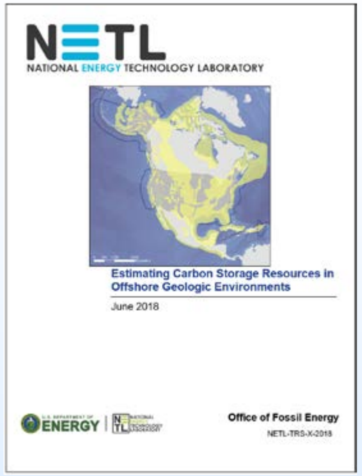


Team: *Kelly Rose, Lucy Romeo, Jennifer Bauer, Kate Jones, R. Burt Thomas, & Patrick Wingo*

Task 4 Accomplishments

Technical report describing tailoring DOE methodology to the offshore

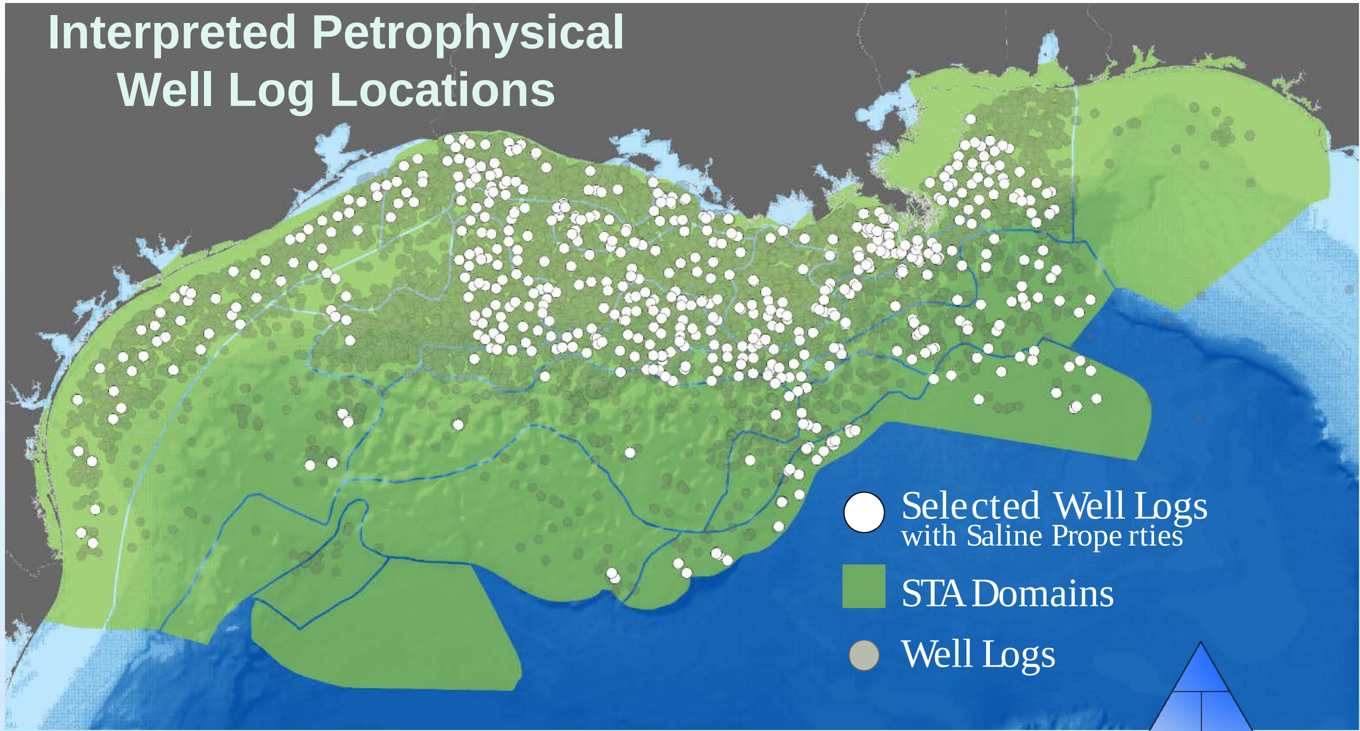
Cameron, E. et al., Estimating Carbon Storage Resources in Offshore Geologic Environments; NETL-TRS-14-2018; NETL Technical Report Series p 32. DOI: 10.18141/1464460



Interpreted >650 petrophysical well logs for storage resource parameters

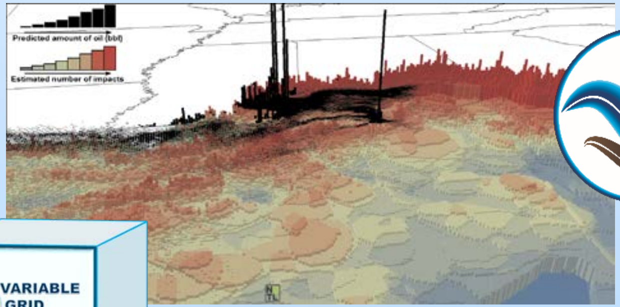
- Spans 21 geologic domains, as defined by Subsurface Trend Analysis™ (Mark-Moser et al., 2018; Rose et al., in press)
- Available via Energy Data eXchange (EDX)

EDX™ Energy Data eXchange



DiGiulio, J., Miller, R., Bean, A., Cameron, E., Romeo, L., and Rose, K. Petrophysical Well Log Interpretation Dataset, 2019-04-10, Energy Data Exchange, https://edx.netl.doe.gov

Documented integration of NETL's Offshore Risk Modeling (ORM) suite tools work with CS Offshore Methodology



SUBSURFACE TREND ANALYSIS

Mark-Moser, M.; et al. Detailed Analysis of Geospatial Trends of Hydrocarbon Accumulations, Offshore Gulf of Mexico; NETL-TRS-13-2018; NETL p 108. DOI: 10.18141/1461471.

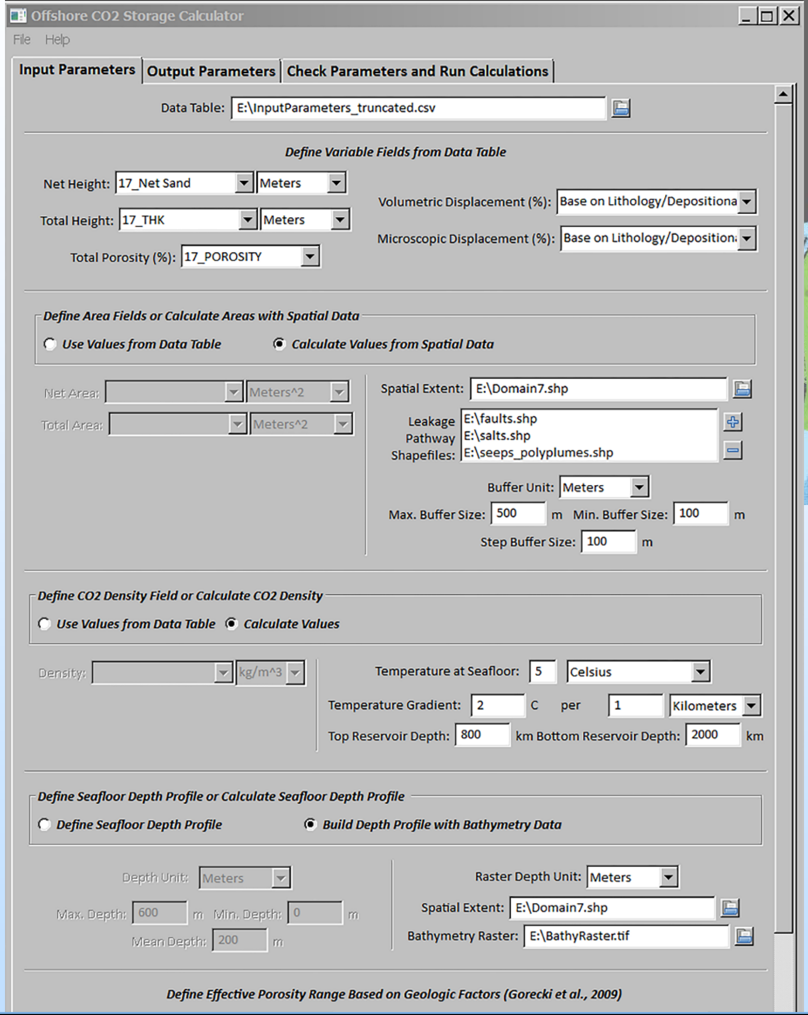
Rose, K., et al, in press, A Systematic Science-Driven Approach for Predicting Subsurface Properties, **Interpretation**

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

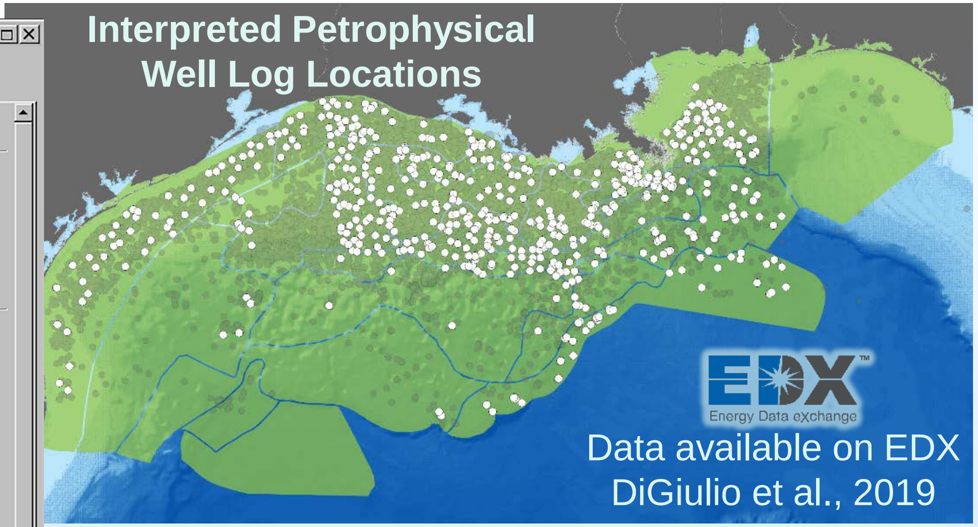
Task 4 Accomplishments (cont.)

- **Offshore CO_2 Storage Calculator tool** developed with tailored geologic efficiency terms from DOE storage methodology
  - Data-driven, with spatial data application for area and density
  - Calculates distributions of estimated efficiency and storage resource potential for sand packages
- Initial tool testing uses NETL's Petrophysical Well Log Interpretation Dataset
- **Manuscript in prep. on methodology** and tool to be submitted to International Journal of Greenhouse Gas Control

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



Tool **builds distributions for saline efficiency & amount of storage resource** by calculating all possible variable combinations



$$E_{saline} = E_A \times E_H \times E_{\Phi} \times E_v \times E_d$$

$$G_{CO_2} = A_T \times H_T \times \Phi_T \times \rho \times E_{saline}$$

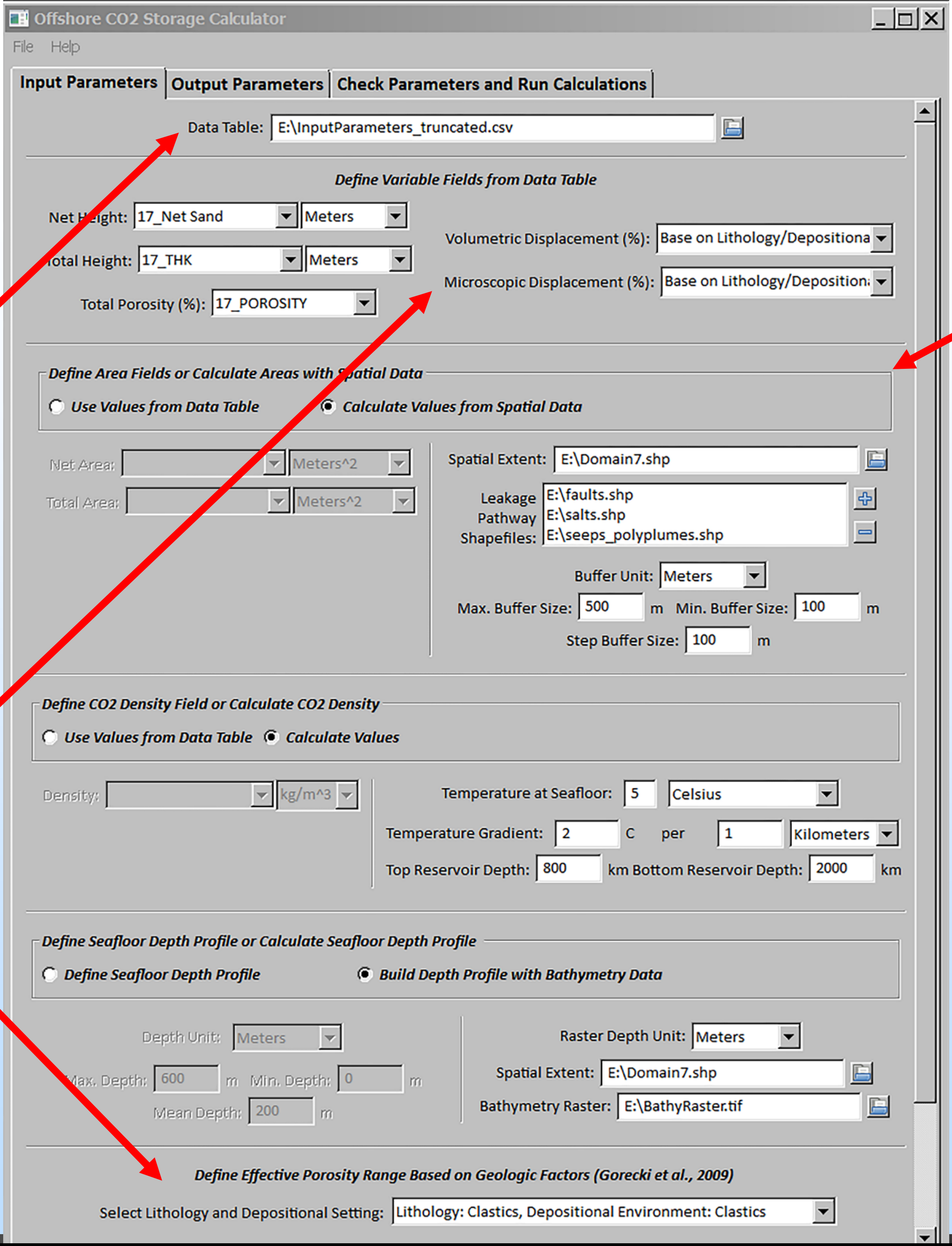
E_A: Ratio of net to total area suitable for storage resource
E_H: Ratio of net to total thickness of formations suitable for storage
E_{Φ}: Ratio of effective porosity to total porosity
E_V & E_d : Volumetric and microscopic displacement factors
E_{saline}: Storage efficiency
A_T: Total area suitable for storage
H_T: Gross thickness of suitable formations
Φ_T: Total porosity
ρ: Density of CO_2 at pressure and temperature
G_{CO_2}: Amount of storable CO_2

Offshore CO_2 Storage Calculator

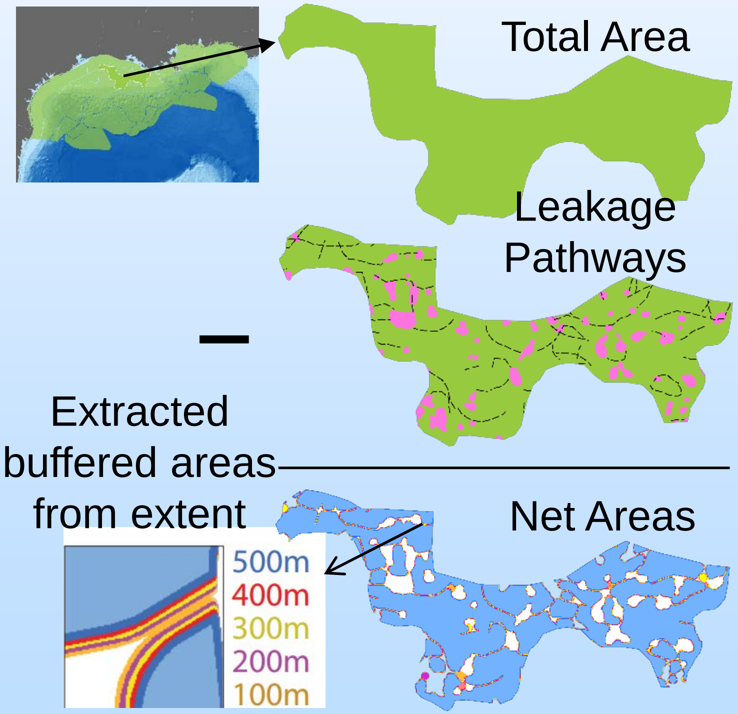
- Python (version 3.7)
- ***Data Table*** contains fields for Net and Total Height, and Total Porosity. Other variables (Volumetric and microscopic displacement, net and total area, density) might also be included
- ***Volumetric and Microscopic Displacement*** can be based on the lithology & depositional setting (Gorecki et al., 2009)
- **Effective ϕ** based on Gorecki et al. 2009

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

Lithology	Depositional Environment	E_{geol} A_n/A_t	E_{geol} h_g/h_g	E_{geol} ϕ_{eff}/ϕ_{tot}	E_V	E_d	$\frac{(1-S_{wirr})}{(1-S_{wirr})}$
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



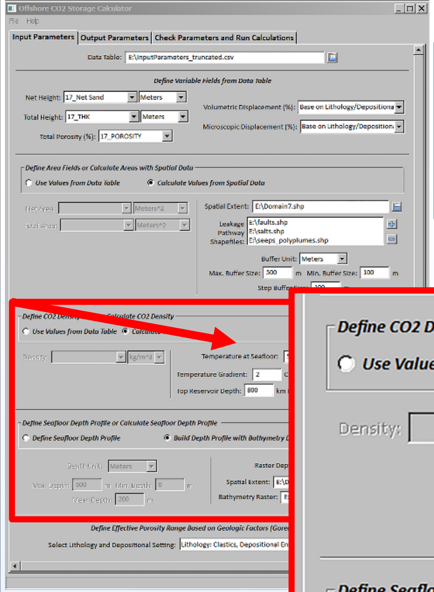
Net and Total Area values can be calculated using spatial data, where net area is the spatial difference between the extent (total area) and buffered leakage pathways



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.

Calculating CO2 Density

Alterations made for the offshore environment, where density (ρ) is derived as a function of subsea pressure and temperature at a given depth (Cameron et al., 2018)



CO_2 density values can be calculated using **depth & temperature**

(assumes hydrostatic pressure)

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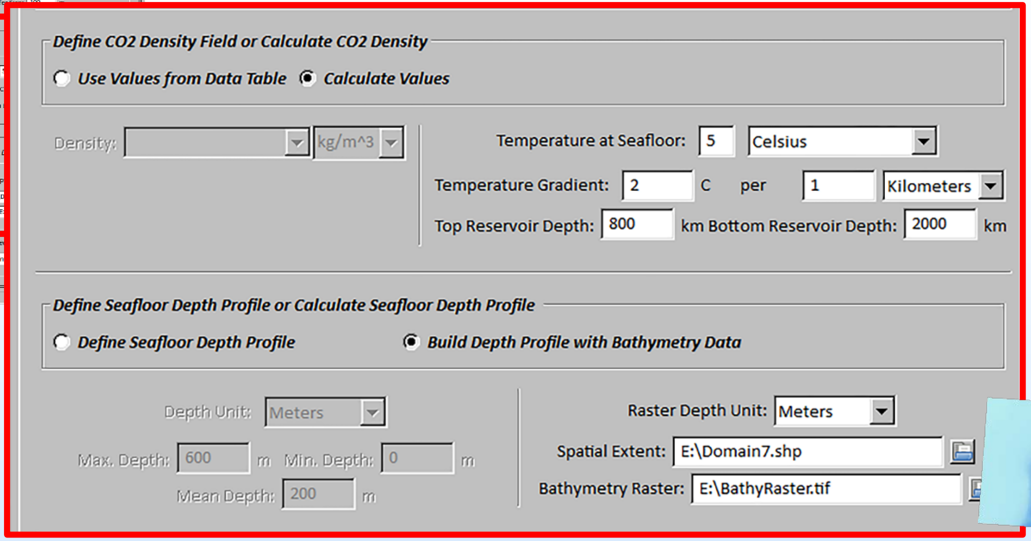
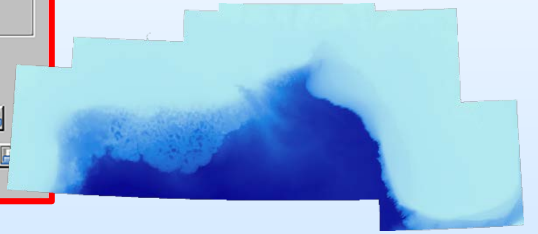
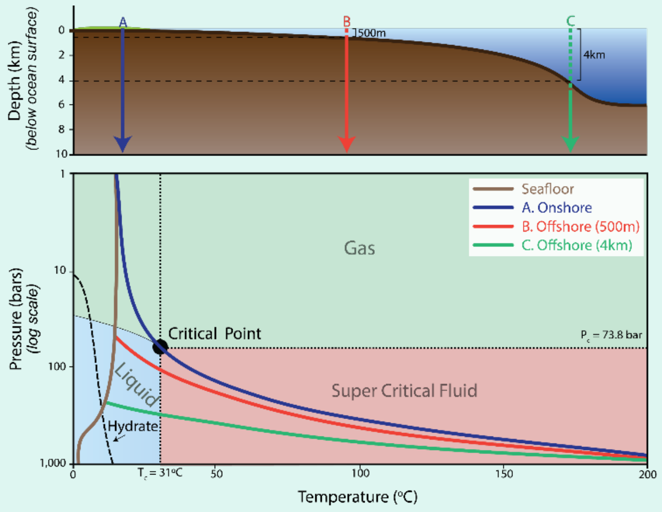


Water depth is used to define the PT regime. Depth can be extract from a **bathymetry dataset**, if available





Density and **phase** values are calculated and checked using the Thermophysical Properties of Fluid Systems Model from the National Institute of Standard's and Technology (Lemmon et al., 2019)

Depth	Temperature (C)	Pressure (bar)	Density (kg/m3)	Volume (m3/kg)	Internal Energy (kJ/mol)	Enthalpy (kJ/mol)	Entropy (J/mol*K)	Cv (J/mol*K)	Cp (J/mol*K)	Sound Spd. (m/s)	Joule-Thomson (K/bar)	Viscosity (uPa*s)	Therm. Cond. (W/m*K)	Phase
10533	5	1053.3	1182.4	0.00084576	6.0895	10.01	33.432	42.388	71.747	1147.2	-0.026536	225.25	0.18644	liquid
10667							3.345	42.415	71.682	1151.8	-0.026681	226.64	0.18711	liquid
10800							3.259	42.442	71.618	1156.3	-0.026823	228.02	0.18777	liquid
10933							3.173	42.47	71.555	1160.7	-0.026962	229.4	0.18843	liquid
11067							3.088	42.497	71.494	1165.1	-0.027097	230.78	0.18908	liquid
11200							3.004	42.525	71.434	1169.5	-0.02723	232.15	0.18973	liquid
11333							32.92	42.552	71.376	1173.9	-0.02736	233.52	0.19038	liquid
11467							2.837	42.579	71.319	1178.2	-0.027487	234.89	0.19102	liquid
11600							2.755	42.607	71.263	1182.5	-0.027611	236.26	0.19166	liquid
11733							2.673	42.634	71.209	1186.7	-0.027733	237.62	0.1923	liquid
11867							2.592	42.662	71.156	1191	-0.027852	238.98	0.19293	liquid
12000							2.511	42.689	71.104	1195.1	-0.027968	240.34	0.19356	liquid
12133							2.431	42.717	71.053	1199.3	-0.028083	241.7	0.19419	liquid
12267							2.351	42.744	71.003	1203.4	-0.028194	243.05	0.19482	liquid
12400							2.272	42.772	70.954	1207.5	-0.028304	244.41	0.19544	liquid
12533	5	1253.3	1206.4	0.00082889	5.8306	10.403	32							
12667	5	1266.7	1207.9	0.00082786	5.8146	10.43	32							
12800	5	1280	1209.4	0.00082684	5.7987	10.457	32							
12933	5	1293.3	1210.9	0.00082583	5.783	10.484	31							
13067	5	1306.7	1212.4	0.00082484	5.7674	10.511	31							
13200	5	1320	1213.8	0.00082385	5.752	10.538	31.809	42.937	70.683	1231.5	-0.028916	252.48	0.1991	liquid
13333	5	1333.3	1215.3	0.00082287	5.7366	10.565	31.733	42.964	70.641	1235.4	-0.029012	253.82	0.1997	liquid
13467	5	1346.7	1216.7	0.0008219	5.7215	10.593	31.658	42.992	70.6	1239.3	-0.029105	255.16	0.20029	liquid
13600	5	1360	1218.1	0.00082095	5.7064	10.62	31.583	43.019	70.56	1243.2	-0.029196	256.49	0.20089	liquid

Lemmon, E.W., McLinden, M.O., and Friend, D.G., "Thermophysical Properties of Fluid Systems" in NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, https://doi.org/10.18434/T4D303, (retrieved August 21, 2019)

Tool Outputs

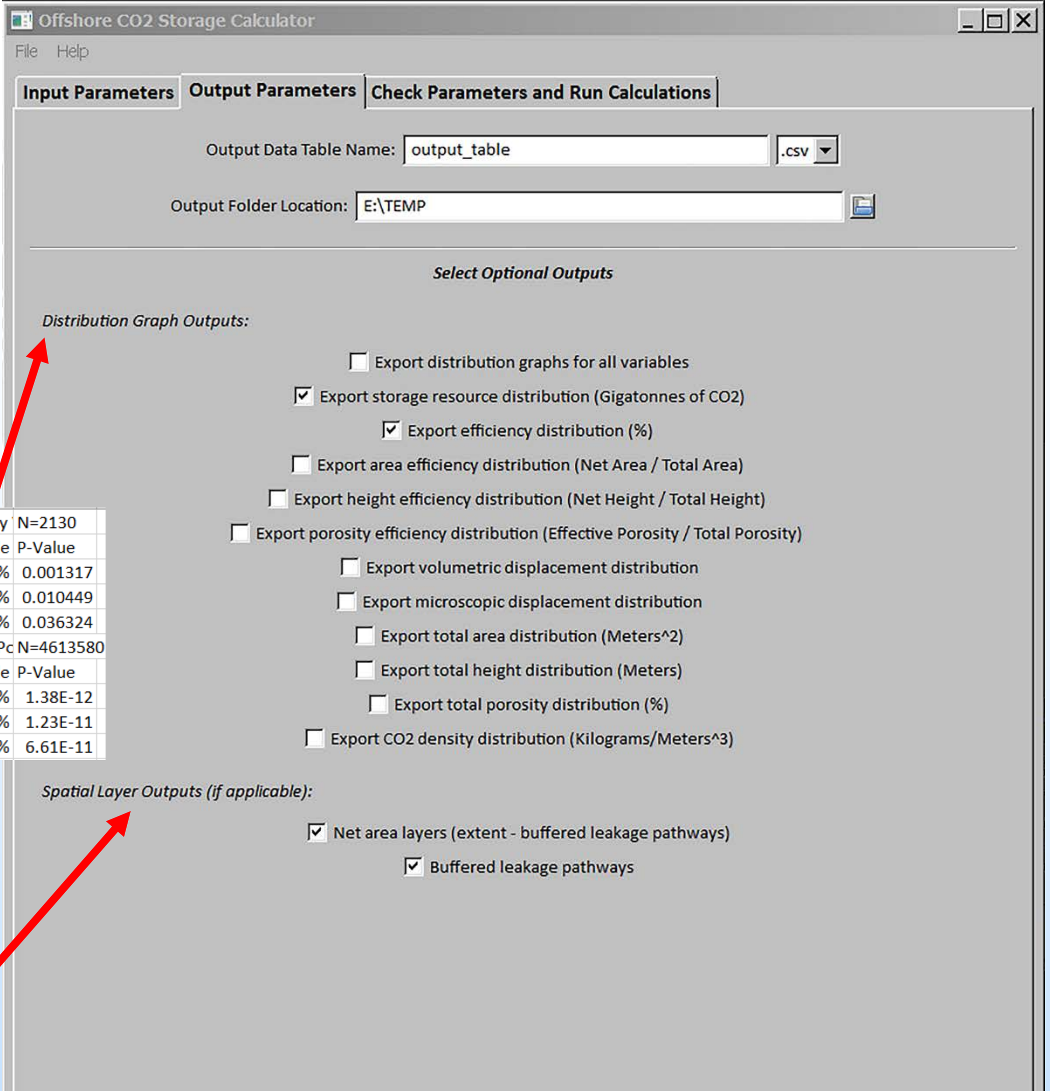
Outputs:

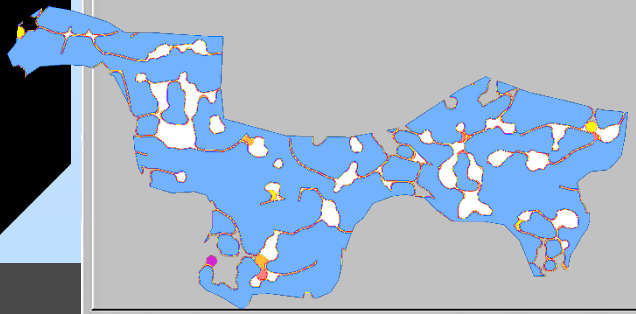
- ***Output Data Table*** containing all variable combinations, where each field represents a variable
- ***Statistical Report*** with P10, P50, and P90 values for saline efficiency and resource storage potential

Efficiency	N=2130
Percentile	P-Value
10%	0.001317
50%	0.010449
90%	0.036324
Storage Pc	N=4613580
Percentile	P-Value
10%	1.38E-12
50%	1.23E-11
90%	6.61E-11

Optional outputs:

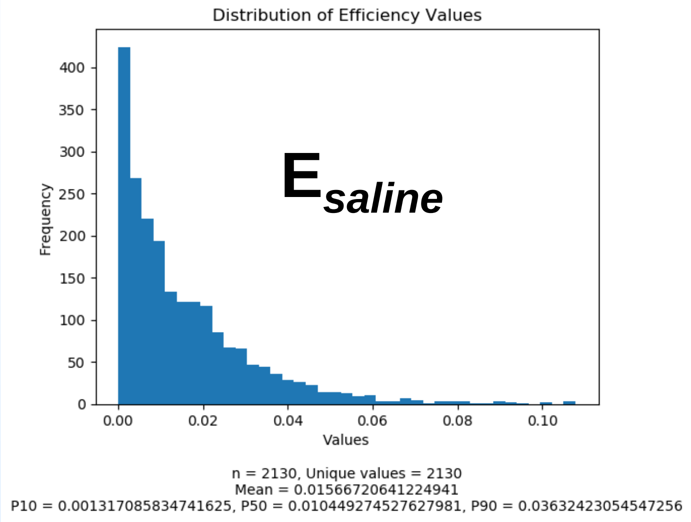
- ***Distribution graphs*** for ***any of the variables*** used calculate saline efficiency and resource storage potential
- Net area and buffered leakage pathway ***shapefiles***

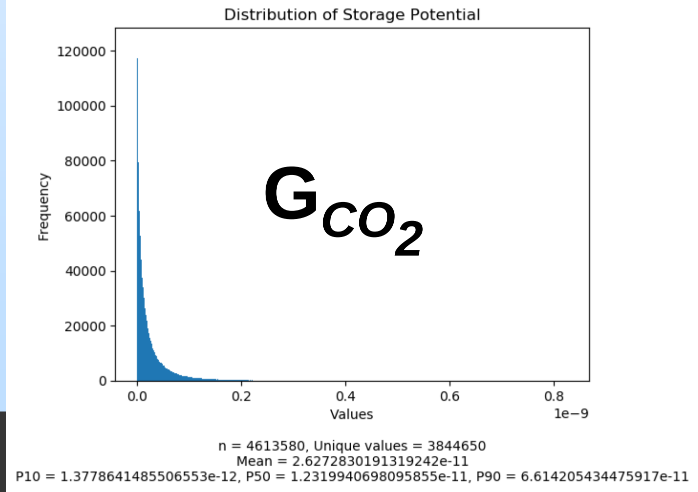




$$E_{saline} = E_A \times E_H \times E_\Phi \times E_v \times E_d$$

$$G_{CO_2} = A_T \times H_T \times \Phi_T \times \rho \times E_{saline}$$



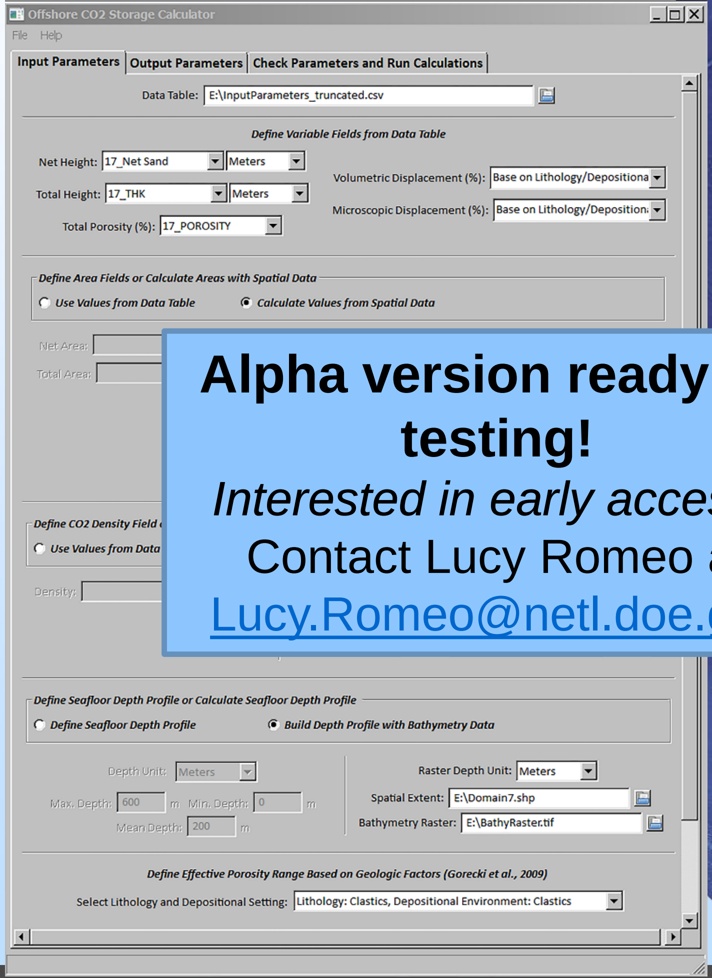


Fall 2019 Milestones & Deliverables

- In parallel with testing the tool, evaluate robustness of offshore efficiency factors for saline reservoir assessment for offshore regions in additional offshore regions
- Submit manuscript on methodology and tool to International Journal of Greenhouse Gas Control (Romeo et al., in preparation)

Romeo, L., Thomas, R., Rose, K., Bauer, J. Data-driven and spatially informed offshore carbon storage efficiency and storage resource methodology. International Journal of Greenhouse Gas Control. In preparation

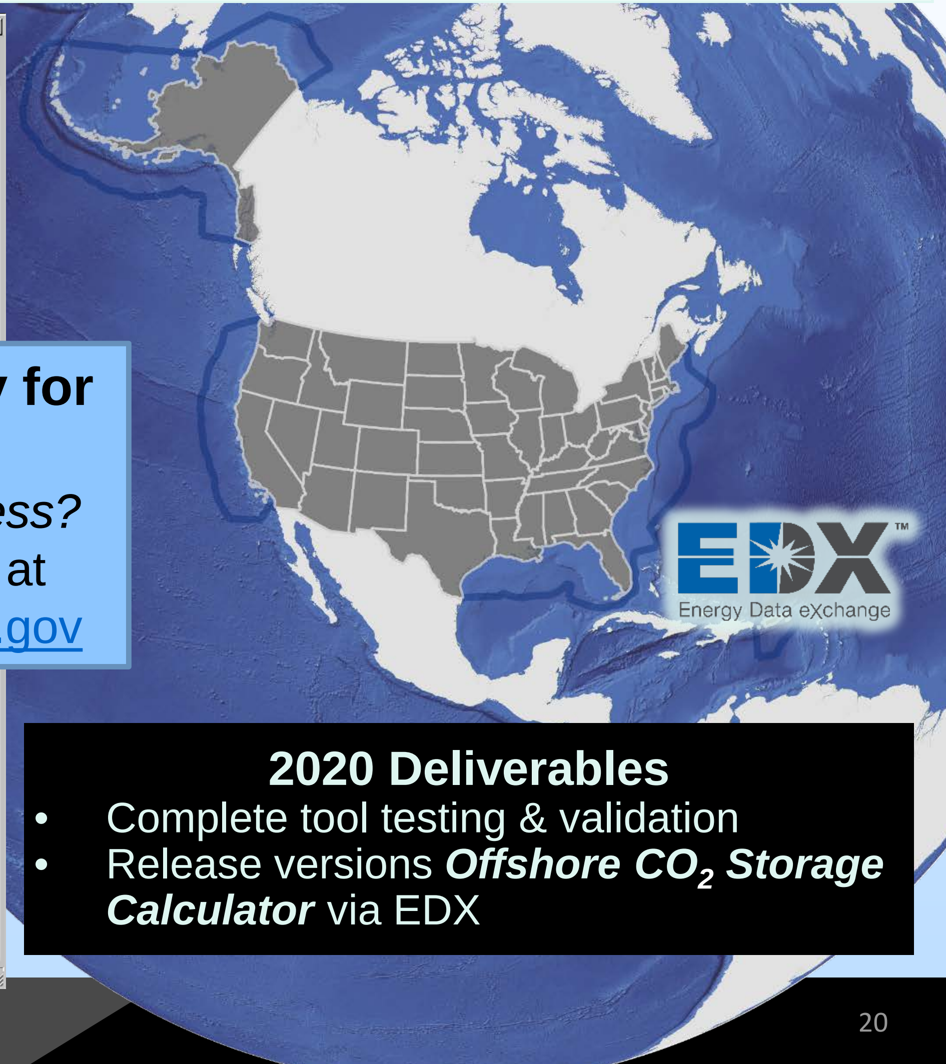
Number	Expected Completion Date	Description
1	06/29/2018	M.4.1 – Submit the final TRS report describing the Offshore Carbon Storage Methodology for Saline Reservoirs to the Carbon Storage Portfolio page on EDX for release.
2	08/31/2018	Develop carbon storage prediction surfaces based on well log attributes for multiple domains in the GOM.
3	11/30/2018	Begin peer-reviewed journal manuscript of the NETL offshore carbon storage methodology.
4	03/29/2019	Document how integration of NETL's Cumulative Spatial Impact Layer tool can work with CS Offshore Methodology and Screen Tool to improve CS assessment outcomes
5	09/30/2019	Evaluate robustness of offshore efficiency factors for saline reservoir assessment of offshore reservoirs in non-GOM, offshore regions.
6	3/31/2020	Release updated versions of advanced spatial data computing tool, offshore CS efficiency factors, via EDX



Alpha version ready for testing!

Interested in early access?

Contact Lucy Romeo at Lucy.Romeo@netl.doe.gov



2020 Deliverables

- Complete tool testing & validation
- Release versions ***Offshore CO_2 Storage Calculator*** via EDX

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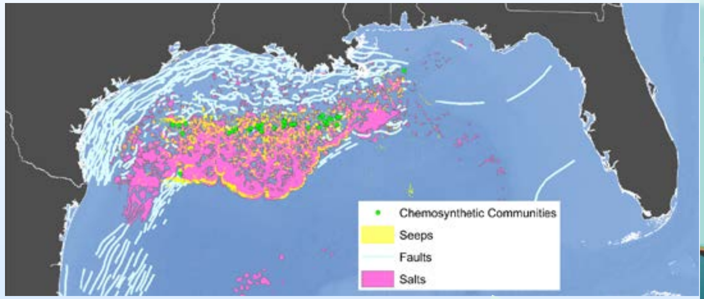
Task 4 Synergy Opportunities

- Provides the DOE with justifiable carbon storage estimates for use in public **policy and business investment decisions**
- Builds off of carbon storage assessment knowledge & capabilities from domestic & international efforts e.g.
  - United States Geological Survey (USGS)
  - Energy & Environmental Research Center (EERC)
  - NETL
  - Norway, Australia, Japan, Brazil, others
- Leverages big-data, spatio-temporal analytical models and tools from DOE FE's Oil/Gas Program's Offshore Risk Modeling program
  - https://edx.netl.doe.gov/offshore
- Provides offshore storage methodology & data-driven tool for **strategic planning by entities and nations worldwide**
  - United States, NETL CarbonSafe projects, etc

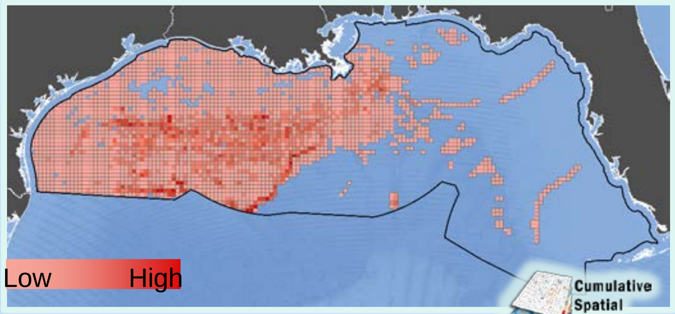
SUBSURFACE TREND ANALYSIS

Mitigate injection risk by leveraging **data-driven analyses** to constrain **favorable vs. unfavorable** storage areas

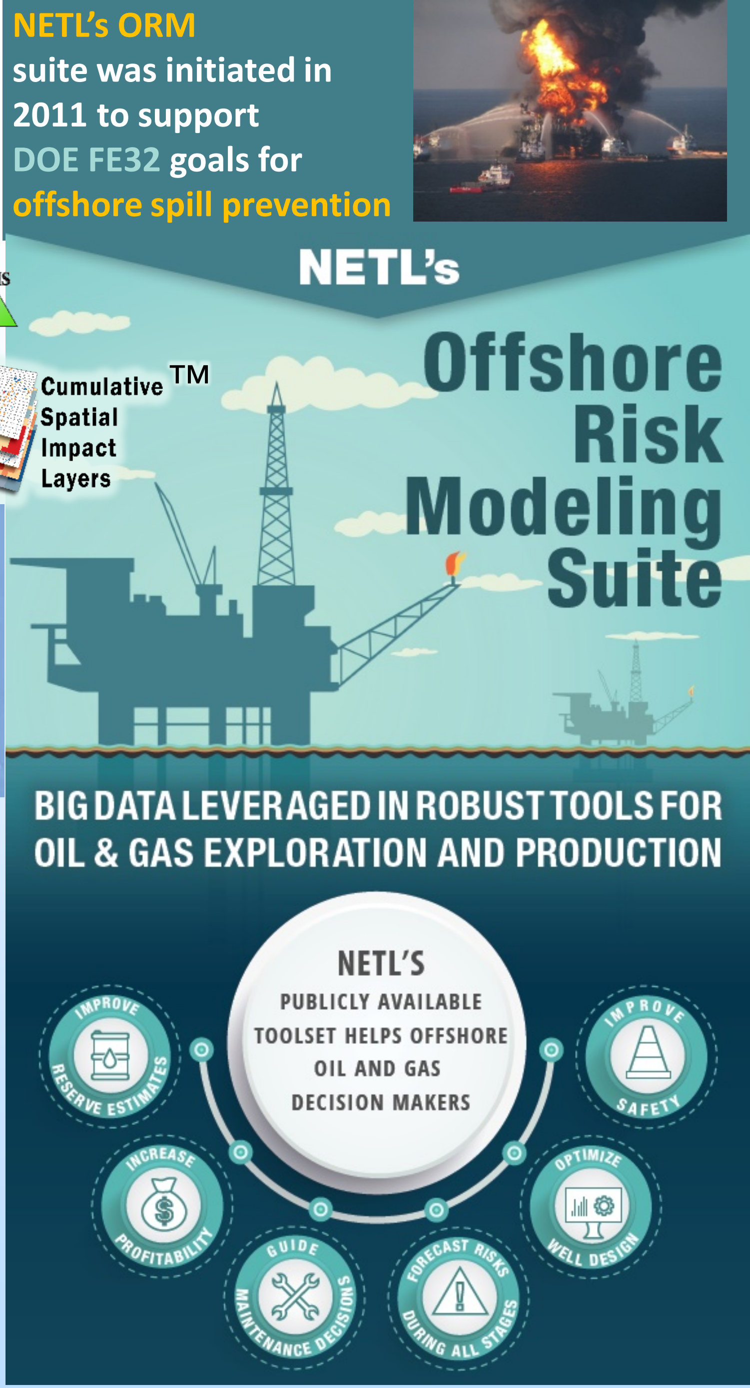
Cumulative Spatial Impact Layers ™



Potential leakage pathways



Leakage Pathway Density



Romeo, L., Wingo, P., Nelson, J., Bauer, J., and Rose, K., Cumulative Spatial Impact Layers, 2019-01-24, DOI: 10.18141/1491843
Romeo, L., Nelson, J., Wingo, P., Bauer, J., Justman, D., and Rose, K. accepted. Cumulative Spatial Impact Layers: a novel multivariate spatio-temporal analytical summarization tool. Transactions in GIS.

Development of Defensible CO_2 Storage Methods & Tools to Quantify Prospective Storage in the Subsurface

Tasks 2 & 3 PI

Angela Goodman

Angela.goodman@netl.doe.gov

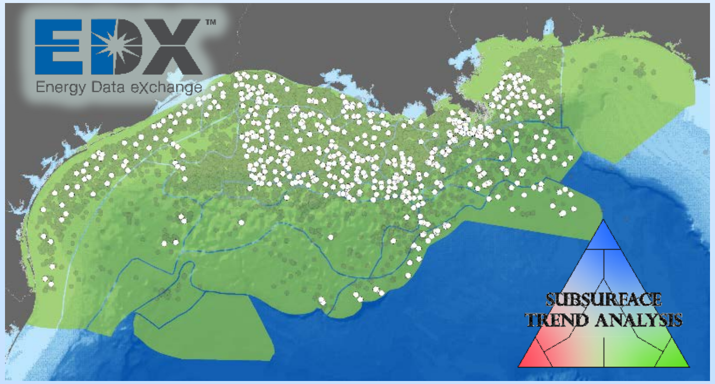
Task 4 co-PI's

Kelly Rose & Lucy Romeo

Kelly.rose@netl.doe.gov

Lucy.Romeo@netl.doe.gov

For the publications, tools & datasets from these studies please visit: https://edx.netl.doe.gov/carbonstorage



Acknowledgement: Parts of this technical effort were performed in support of the National Energy Technology Laboratory's ongoing research under the Carbon Storage Field Work Proposal DE-FE-1022403 by NETL's Research and Innovation Center, including work performed by Leidos Research Support Team staff under the RSS contract 89243318CFE000003.

Appendix

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

Lessons Learned

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

See project slides above

Project Summary

– Key Findings.
– Next Steps.

See project slides above

Benefit to the Program

- **Specific Goals & Benefits**
- 1. Develop and validate technologies to ensure for 99 percent storage permanence.
- 2. Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- 3. Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- 4. Develop Best Practice Manuals (BPMs) for monitoring, verification, accounting (MVA), and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation.

Project Overview

Goals and Objectives

- ***Resource Assessments:*** Provides the Department of Energy (DOE) defensible carbon dioxide (CO2) storage methods and tools to quantify prospective storage for the Carbon Storage Atlas, National Energy Technology Laboratory's (NETL's) Regional Carbon Sequestration Partnership (RCSP), and CARBONSAFE projects.

Organization Chart

- *Resource Assessments* theme will provide DOE defensible CO_2 storage methods and tools to quantify prospective storage for the Carbon Storage Atlas, the NETL's Regional Carbon Sequestration Partnership (RCSP), and CARBONSAFE projects.

Task 2. Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Shale Systems

Task 3. Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in ROZs

Task 4. Developing Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Offshore Reservoirs

Gantt Chart

- Provide a simple Gantt chart showing project lifetime in years on the horizontal axis and major tasks along the vertical axis. Use symbols to indicate major and minor milestones. Use shaded lines or the like to indicate duration of each task and the amount of work completed to date.

Task 2: Project Timeline Overview

Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Shale Systems (PI: Angela Goodman)

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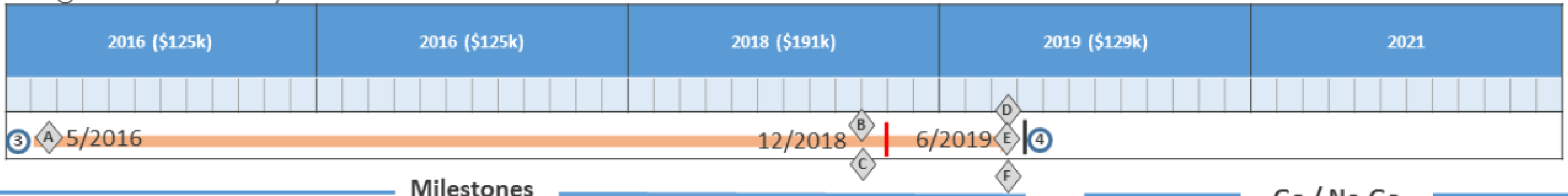

Milestones

A. M.2.1 – Publish "U.S. DOE NETL Methodology for Estimating the Prospective CO_2 Storage Resource of Shales at the National and Regional Scale" in the International Journal of Greenhouse Gas Control, 2016, 51, 81-94.
B. Acceptance of storage efficiency factors by the peer review community.
C. Deploy beta CO2-SCREEN Tool for shale for community validation on EDX.
D. Incorporation of improved techniques to estimate the CO_2 storage resource potential of unconventional formations stemming from the efforts at EERC into the SCREEN Tool.
E. Publish effect of flow regimes on storage efficiency during injection of CO_2 in depleted shale reservoirs.
F. Develop final CO2-SCREEN Tool for shale for public access on EDX.

Go / No-Go

2. To move past this milestone, method and storage efficiency factors must be fully developed and accepted in a peer review journal.

Impact

Key Accomplishments/Deliverables	Value Delivered
2016: Methodology for Assessment of Shale Systems. (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.)	• Quantitative method and CO2-SCREENv2.0 Tool to estimate how much CO_2 can be stored in depleted shale formations. • Method and tool ready for inclusion in the next DOE's Carbon Storage Atlas in 2020.

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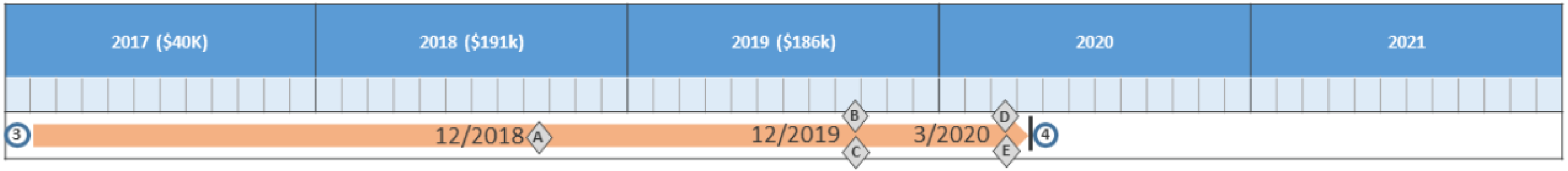
Chart Key: # TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

Task 3: Project Timeline Overview

Develop Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in ROZs
(PI: Angela Goodman)



Milestones

Go / No-Go

A. Develop working draft of ROZ method that has been reviewed by external stakeholders.
B. ROZ method accepted by the peer review community and ready for the next Carbon Storage Atlas.
C. Deploy beta CO2-SCREENv3.0 Tool for ROZs for community validation on EDX.
D. Develop final CO2-SCREEN Tool for ROZs for public access on EDX.
E. Deploy CO2-SCREEN v1.0, v2.0, and v3.0 Tools into a format that does not depend on license restrictions.

Impact

Key Accomplishments/Deliverables	Value Delivered
<u>2017:</u> • Conducted an extensive literature review. • Assembled a group of collaborators and experts with USGS, LANL, ISGS, EERC to provide key input for developing method.	• Quantitative method and CO2-SCREENv3.0 Tool to estimate how much CO_2 can be stored in ROZs. • Method and tool ready for inclusion in the next DOE's Carbon Storage Atlas in 2020.

Task 4: Project Timeline Overview

Developing Defensible DOE Methods, Tools, and Storage Efficiency for CO_2 Storage in Offshore Reservoirs (PI: Kelly Rose)

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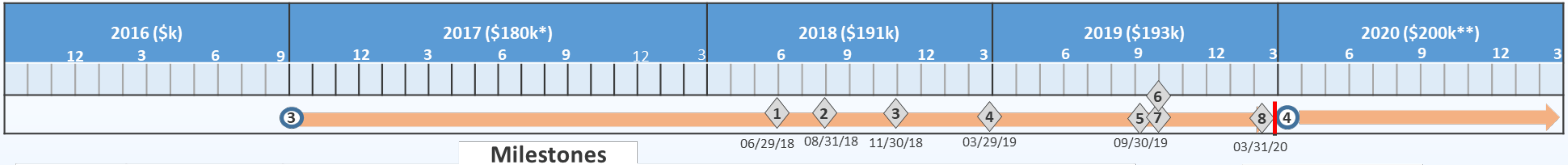

Milestones

Number	Expected Completion Date	Description
1	06/29/2018	M.4.1 – Submit the final TRS report describing the Offshore Carbon Storage Methodology for Saline Reservoirs to the Carbon Storage Portfolio page on EDX for release.
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5	09/30/2019	Evaluate robustness of offshore efficiency factors for saline reservoir assessment of offshore reservoirs in non-GOM, offshore regions.
6	10/31/2019	Finalize development of and submit a manuscript to a journal for peer-review for saline offshore CO2 methodology
7	10/31/2019	Evaluate potential of adapting saline offshore methodology for use with Offshore CO_2 EOR storage approach
8	03/31/2020	If appropriate release advanced data computing tool for offshore CS efficiency factors, spatial analysis & SCREEN via EDX app store.

Go / No-Go

Past milestones 4 & 6, scope proposed is dependent on Program input and alignment to needs.

- *2017 funds spanned 18 months of work, 10/01/2016 through 03/31/2018
- **Pending outcome of go/no-go milestone 7

Impact

Key Accomplishments/Deliverables

- 2018, TRS report describing CS methodology for saline reservoirs & database of offshore efficiency factors for geol terms
    - Cameron, E., Thomas, R., Rose, K., Galer, S., Disenhof, C., Mark-Moser, M., Bauer, J., in review, Estimating Carbon Storage Resources in Offshore Saline Geologic Environments, NETL-TRS-X-2018, 34 pgs.
- 2018, a beta Python scripted tool was developed to automate the methodology for calculating offshore storage resource efficiency and potential
- 2019, Journal manuscript submitted for peer review describing Offshore CS in saline reservoir methodology
- 2020, Release versions 1 of advanced spatial data computing tool offshore CS efficiency factors outside GOM, via EDX

Value Delivered

- Improving accuracy of offshore saline **resource estimations**
- Tailored geologic efficiency terms from DOE carbon storage method that **improve characterization of offshore carbon storage reservoirs**
- Adaptation of data computing tools and algorithms to support efficient and data-driven **technical assessment** of offshore carbon storage resources through integration of NETL's spatial, analytical tools (**first developed under FE32 projects**)
- Integration of carbon storage tools, data and models for resource assessment via EDX to improve external stakeholder **access and utility**

Chart Key

\# TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

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