NETL RIC's Carbon Storage Research TECHNOLOGY Supporting Field Efforts

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CEMEN Mature ENERGY



Alternate title

• Research & Innovation Center, not **Technology Development Center**

• Just to make sure we're clear that this is inhouse research efforts



- The NETL Research and Innovation Center (RIC) work in carbon storage has deep roots. I'll do my best to represent.
 - First real talk speaking at the technology portfolio lead across the range of research that is

underway in the Carbon Storage Adv R&D

NETL *In-House* Research Supporting Field Efforts



Movement Toward Adoption by Industry

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Image from Darin Damiani's talk yesterday

• Large scale field projects to develop best practices and facilitate widespread commercialization



20-plus Years of Storage Research

Most of the work here is highly collaborative by nature

- Individual research thrusts within the RIC portfolio with principal investigators who have worked in this space for years.
- Since NETL RIC cannot be directly part of DOE FECM funded external work, we have developed mechanisms to assist in addition to initially scoped and planned work.

- Broad Categories
 - Resource Assessment
 - Core Characterization
 - Basic
 - Unique
 - Advanced
 - Risk Assessment
 - NRAP
 - Wellbores
 - Monitoring
 - Seismic
 - Geochemical





History of DOE CO₂ Storage Methods



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Los Alamos

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GEOLOGICAL SURVEY

PRAIRIE RESEARCH INSTITUTE

Carbon Sequestration Atlas of the United States and Canada



Putting Research into Practice





CO2-SCREEN - ON-LINE SCREENING TOOL

Storage prospeCtive Resource Estimation in Excel aNalysis

CO₂- SCREEN

- Saline, shale, and ROZ formation storage estimation in a convenient and open tool
- Built on methods
- Examples of use published:

Gupta et al (2019) Assessment of options for the development of a stacked storage complex in the Northern Michigan Basin, USA, Int J Greenhouse Gas Control https://doi.org/10.1016/j.ijggc.2019.06.008

Sanguinito et al (2020) CO₂-SCREEN tool: Application to the Oriskany sandstone to estimate prospective CO₂ storage resource, Int J Greenhouse Gas Control <u>https://doi.org/10.1016/j.ijggc.2018.05.022</u>





CO2-Screen

Department of Energy



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



CO₂-SCREEN: Saline Equation Background





Required Inputs:

- Physical Parameters
 - Area (km²)
 - Gross Thickness (m)
 - Porosity (%)
 - Pressure (MPa)
 - Temperature (°C)
- Efficiency Factors
 - Net-to-Total Area
 - Net-to-Gross Thickness
 - Effective-to-Total Porosity
 - Volumetric Displacement
 - Microscopic Displacement



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

San Juan Basin CarbonSAFE Estimates



Point of Contact: <u>Angela.Goodman@netl.doe.gov</u>



Formation	Area (km2)		Gross Thickness (m)		Total Porosity (%)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Entrada	841.75	42.09	148.47	18.26	23.00	1.15
Bluff	841.75	42.09	63.94	4.94	14.89	0.85
Salt Wash	841.75	42.09	69.52	7.21	14.89	0.85

CO₂-SCREEN Results

Formation	Storage Resource (Mt)			Storage Efficiency (%)		
	P ₁₀	P50	P ₉₀	P ₁₀	P ₅₀	P ₉₀
Entrada	140.37	560.77	1718.31	0.68	2.72	8.30
Bluff	39.14	154.66	479.04	0.67	2.68	8.17
Salt Wash	41.54	168.93	519.43	0.67	2.68	8.14

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

Core Characterization



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'Basic' Core Characterization

And reporting out via EDX

- CT scanning & high-resolution core logging (XRF, gamma density, magnetic susceptibility)
 - <u>https://edx.netl.doe.gov/group/core-</u> characterization

62.40

6252

6284

6288 6292

- FutureGEN 2.0 and several **CarbonSAFE** sites already characterized/available
 - Three CarbonSAFE cores data collected on and to be published this year



Open Core Data Access on EDX



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



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Raw & Processed Data



Summary Report



'Unique' Core Characterization

Article



Point of Contact: <u>Angela.Goodman@netl.doe.gov</u>

• scCO₂/brine contact angles

• Unique measurements of small bubble contact angles of supercritical CO₂ and brine on rock surfaces.







energysfuels

pubs.acs.org/EF

CO₂-Brine Contact Angle Measurements on Navajo, Nugget, Bentheimer, Bandera Brown, Berea, and Mt. Simon Sandstones

Foad Haeri,* Deepak Tapriyal, Sean Sanguinito, Fan Shi, Samantha J. Fuchs, Laura E. Dalton, John Baltrus, Bret Howard, Dustin Crandall, Christopher Matranga, and Angela Goodman Contact angle versus CO₂ bubble diameter (< 500 μm) for some samples at supercritical conditions (1800 psig and 45°C).



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Haeri et al (2020) CO₂-Brine Contact Angle Measurement on Navajo, Nugget, Bentheimer, Bandera Brown, Berea, and Mt. Simon Sandstones, *Energy & Fuels*, https://doi.org/10.1021/acs.energyfuels.0c00436

'Unique' Core Characterization



Points of Contact: <u>Barbara.Kutchko@netl.doe.gov</u> & <u>Angela.Goodman@netl.doe.gov</u>

- SEM Imaging + Exposure
 - Feature relocation
- Fourier transform infrared spectroscopy
 - Dynamic alteration at T & P
- AutoLAB 1500 Measurements
 - Permeability, sonic velocities and material properties (E, μ , λ , etc)

Contents list	s available at ScienceDirect
International Journa	al of Greenhouse Gas Control
ELSEVIER journal homepage	: www.elsevier.com/locate/ijggc

 CO_2 induced changes in Mount Simon sandstone: Understanding links to post CO_2 injection monitoring, seismicity, and reservoir integrity



William Harbert^{a,b,*}, Angela Goodman^c, Richard Spaulding^c, Igor Haljasmaa^{c,d}, Dustin Crandall^c, Sean Sanguinito^{c,d}, Barbara Kutchko^c, Mary Tkach^{a,c}, Samantha Fuchs^e, Charles J. Werth^e, Theodore Tsotsis^f, Laura Dalton^d, Kristian Jessen^f, Zhuofan Shi^f, Scott Frailey⁸







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Harbert et al (2020) CO₂ induced geochemical and petrophysical changes in Mount Simon sandstone: Understanding links to seismic monitoring, post CO₂ injection seismicity, and reservoir integrity, Int J Greenhouse Gas Control https://doi.org/10.1016/j.ijggc.2020.101105

'Advanced' Core Characterization



Unsteady State scCO₂ Relative Permeability Measurements



ENERGY https://edx.netl.doe.gov/hosting/co2bra/

Moore et al (2021) Adv Water Resources 153 103953 14

CO₂/Brine k_r Database

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https://edx.netl.doe.gov/hosting/co2bra/

As with core characterization, all data available online through EDX



Reactive scCO₂/brine relative permeability $\mathbf{N}_{\mathbf{I}}$

Point of Contact: Johnathan.Moore@netl.doe.gov

- Unsteady k_r measurements with CT imaging
 - quantify changes to porosity dynamically and flow
 - Not applicable in all situations, but informative in reactive zones.





ENERGY https://edx.netl.doe.gov/hosting/co2bra/

Moore et al (2021) Adv Water Resources 153 103953 16

San Juan Basin Core Characterization

Arrived this week, initial scans and characterization ongoing

- Outcrop cores from the San Juan Basin CarbonSAFE project arrived Tuesday
 - Initial scans and porosity measurements completed
 - Discussions with team on upcoming $scCO_2 k_r$ tests
- Planned/ongoing work with Kemper site and ISGS









Medical CT Scanner, Toshiba Acquilon RXL. Resolution (67 µm by 67 µm by 0.5 mm) 135 kV & 200 mA

U.S. DOE's National Risk Assessment Partnership

Please see session tomorrow morning, 10AM ET

NRAP leverages DOE's capabilities to quantitatively assess and manage long-term environmental risks amidst significant geologic uncertainty and variability.





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NRAP's General Approach (ROMs + IAM)





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component models that



- C. Develop reduced-order models (ROMs) that
- D. Link ROMs via integrated assessment models (IAMs) to predict system performance



E. Exercise whole system model to explore risk performance

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



Wellbore Interactions

Point of Contact: <u>Barbara.Kutchko@netl.doe.gov</u>

- Batch and Flow Reactions to Examine Pathway Alteration due to CO₂ Interactions
 - In process of reporting out on reactions observed in CO₂ resistive and standard cements, and looking to understand coupled systems.





48 Hours of Reactions



168 Hours of Reactions



312 Hours of Reactions





Wellbore Data Analysis

Point of Contact: <u>Gregory.Lackey@netl.doe.gov</u>

- "Public data from three US states provides new insights into well leakage" in PNAS
 - Used data mining and ML techniques to compile largest O&G well integrity dataset in the US (105,031 wells).
 - Estimated leakage frequencies and identified major trends among well types in CO, NM, and PA





Lackey et al (2021) "Public data from three US states provide new insights into well

integrity"PNAS April 6, 2021 118 (14) e2013894118; https://doi.org/10.1073/pnas





Seismic Monitoring

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Baseline seismic measurements at ISGS CarbonSAFE

- Will deploy eight seismometers during August 16-20 at the Prairie State ISGS CarbonSAFE site, prior to CO_2 injection.
 - Baseline seismicity record
- May move more to the south after a few months to monitor CO_2 injection.



Seismic Monitoring



Point of Contact: <u>Richard.Hammack@netl.doe.gov</u>

• This initial deployment coincides with ongoing blasting of a coal mine shaft, so we'll attempt to utilize this unique opportunity to seismically probe the subsurface.



Novel Geochemical Signal Methodologies



- Bayesian network statistical modeling of expected geochemical reactions to monitor groundwater
- San Juan Basin CarbonSAFE baseline samples are being collected







Gardiner et al. (2020) "Utilization of Produced Water Baseline as a Groundwater Monitoring Tool at a CO₂-EOR 25 Site in the Permian Basin, Texas, USA," Applied Geochemistry https://doi.org/10.1016/j.apgeochem.2020.104688



Summary

THANK YOU!! Dustin.Crandall@netl.doe.gov

• Much of the work Carbon Storage Advanced Research that is ongoing in NETL RIC has can be linked to field activities



- Broad Categories
 - Resource Assessment
 - Core Characterization
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 - Electromagnetic
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