Fundamental Reservoir Properties for High Priority Depositional Environments Targeted for CO_2 Storage

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US DOE NETL, Research and Innovation Center

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 13-16, 2018

Tuesday, August 14th 1:50 PM

Presentation Outline

- Title is representative of the entire task, but we're going to focus on a single subtask here.
  - For detail in subtasks, please see Gannt charts or ask about it later (there is good stuff there!)
- Relative permeability measurements of $scCO_2$ in depositional environments identified as primary targets for carbon storage
  - Motivation
  - Methodology
  - Results to date

Motivation

- CO_2 storage resource estimates for saline formations can be calculated with G_{CO_2} (Goodman et al 2016).
- The CO_2 storage efficiency factor (E_{saline}) incorporates geologic and displacement terms to characterize the ability of CO_2 to utilize the formation.
- The volumetric (E_V) and microscopic (E_d) displacement terms are impacted by the relative permeability of the injection site.

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

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


International Journal of Greenhouse Gas Control 54 (2016) 242–249

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

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

Prospective CO_2 saline resource estimation methodology: Refinement of existing US-DOE-NETL methods based on data availability

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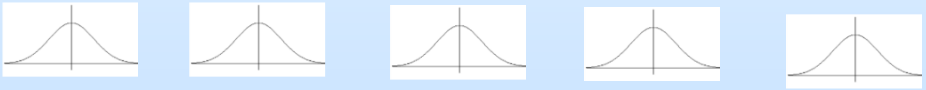
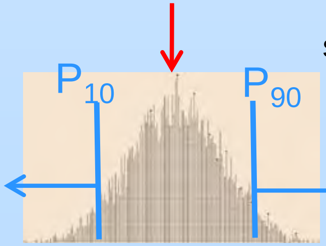
E_A E_h E_ϕ E_v E_d



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

Log-odds stochastic approach



Motivation – Depositional Environments

- Gorecki et al (2009) calculated P_{10}/P_{90} efficiency ranges for various depositional environments.
  - But limited information on the $scCO_2$/brine k_r curves were available to perform this analysis.
- Experiments are being performed to expand this data set.

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

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

Motivation – Depositional Environments

Matrix of Field Activities in Different Reservoir Classes (2012)

		High Potential Reservoirs					Medium Potential Reservoirs				Lower/Unknown Potential Reservoirs*	
Reservoir Class		Deltaic	Shelf Clastic	Shelf Carbonate	Strandplain	Reef	Fluvial Deltaic	Eolian	Fluvial & Alluvial	Turbidite	Coal	Basalt (LIP)
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

Notes:

The number in the cell is the number of investigations by NETL per geologic storage formation classification.

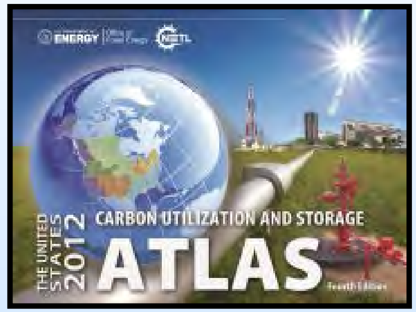
* Potential reservoirs were inferred from petroleum industry and field data from the Carbon Storage Program.

[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.

27 $scCO_2$/brine k_r tests completed

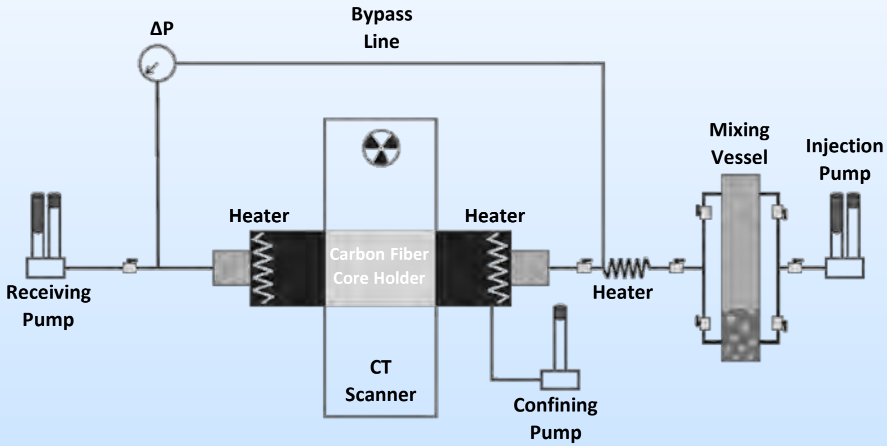
– 10 with multiple flow rates

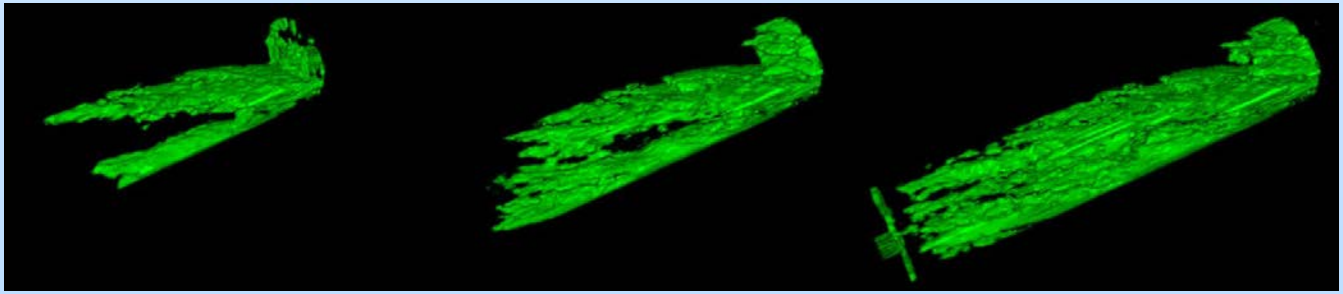


Methodology

- Unsteady state $scCO_2$ injections into brine saturated cores

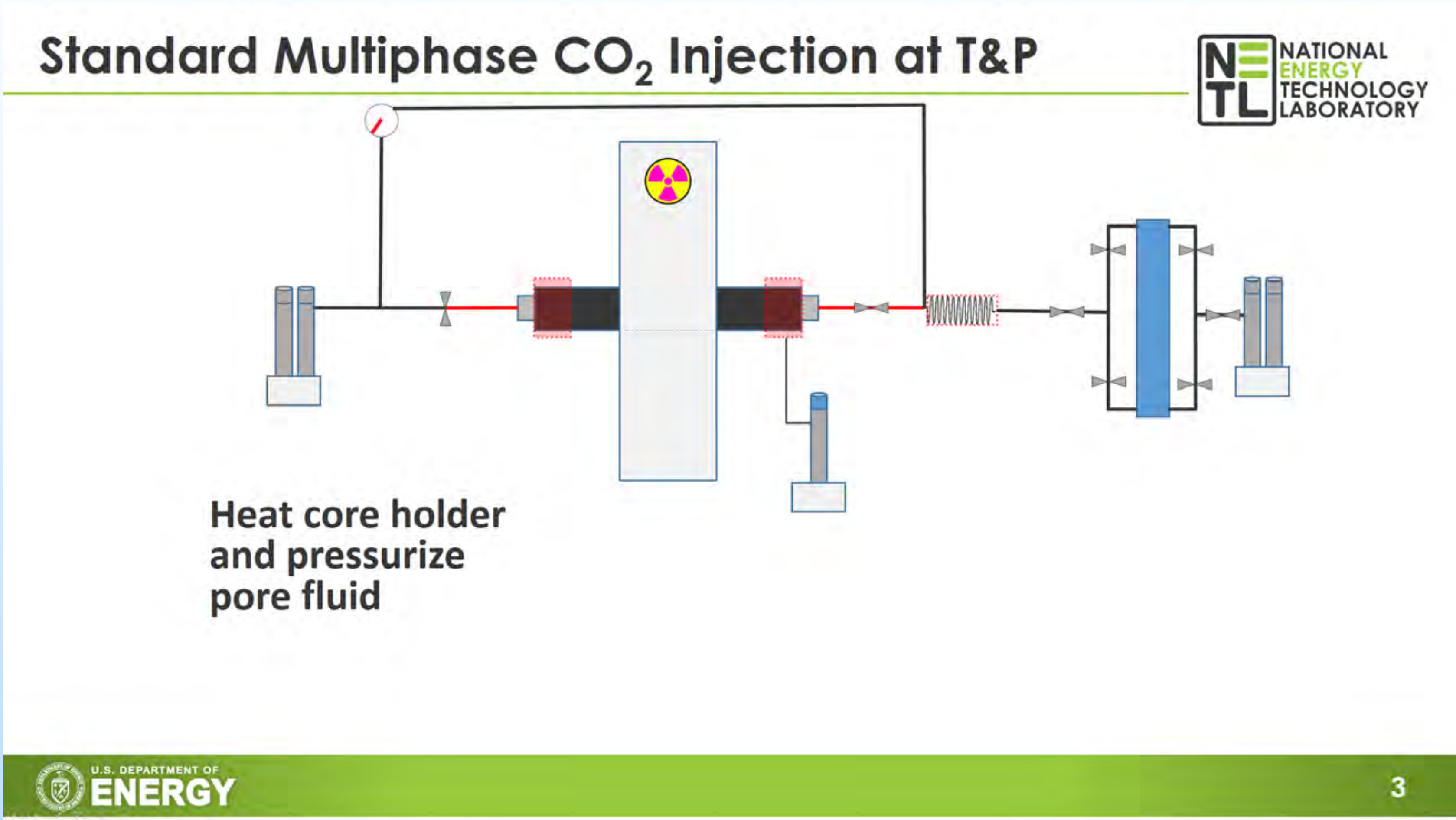
- 6” L, 2” D cores
- P_p = 1400 psi (9.6 MPa)
- P_{conf} = 2000 psi (13.8 MPa)
- T = 140°F (60°C)
- $0.2 < Q < 6\ ^{ml}/_{min}$





Recent CO_2 flood in Navajo sandstone

Experimental Methodology



Experimental Methodology

Standard Multiphase CO_2 Injection at T&P

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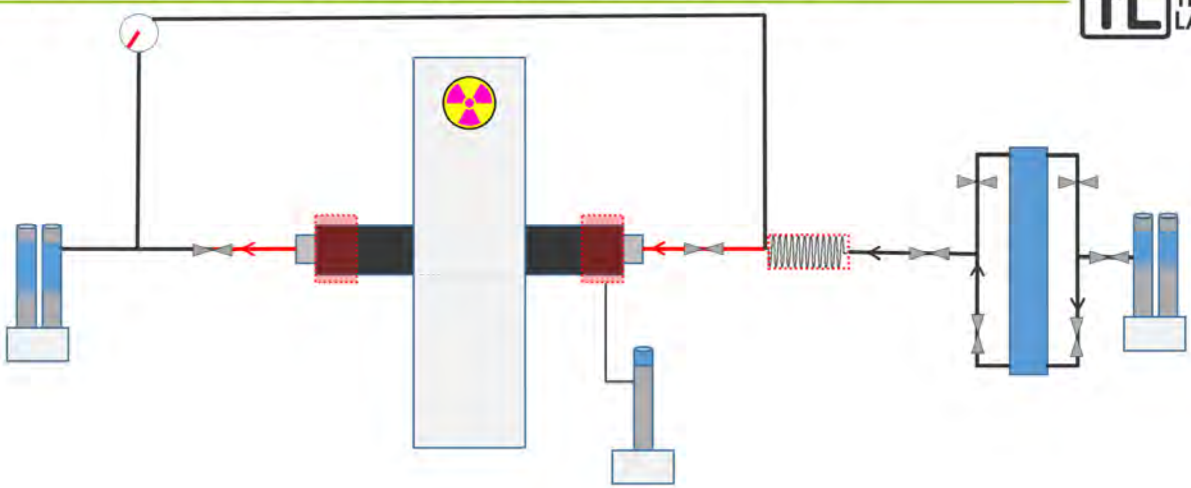

Saturate core at T&P

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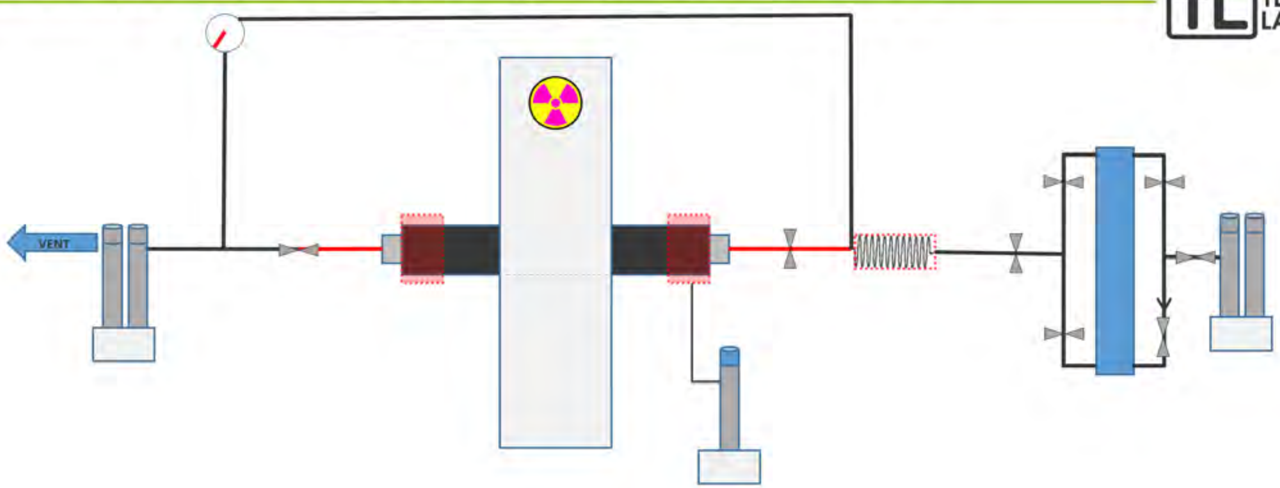
Experimental Methodology

Standard Multiphase CO_2 Injection at T&P

NATIONAL ENERGY TECHNOLOGY LABORATORY



Drain effluent pumps while leaving core at condition

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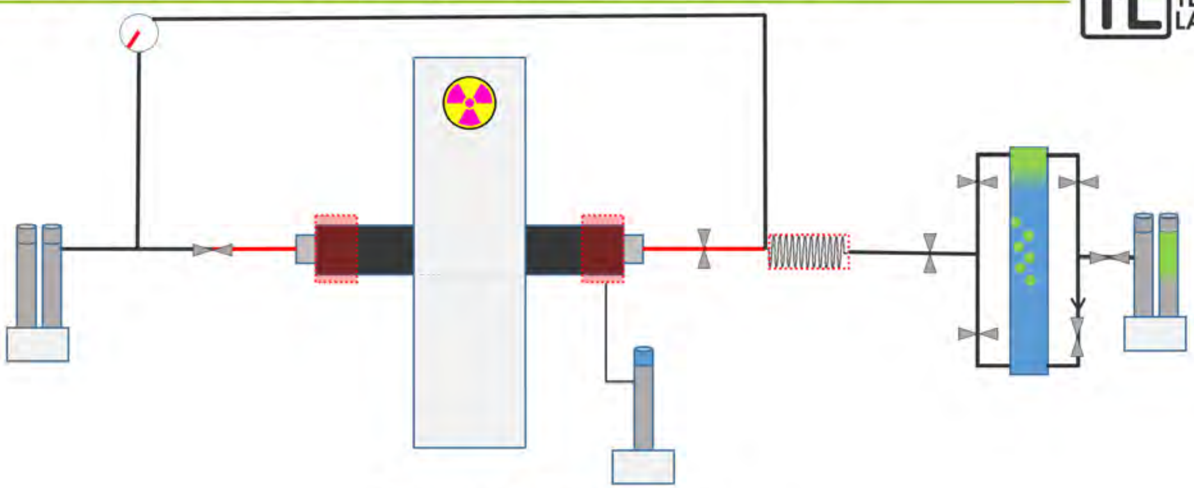
Experimental Methodology

Standard Multiphase CO_2 Injection at T&P

NATIONAL ENERGY TECHNOLOGY LABORATORY



Saturate injection fluid with CO_2 and equilibrate

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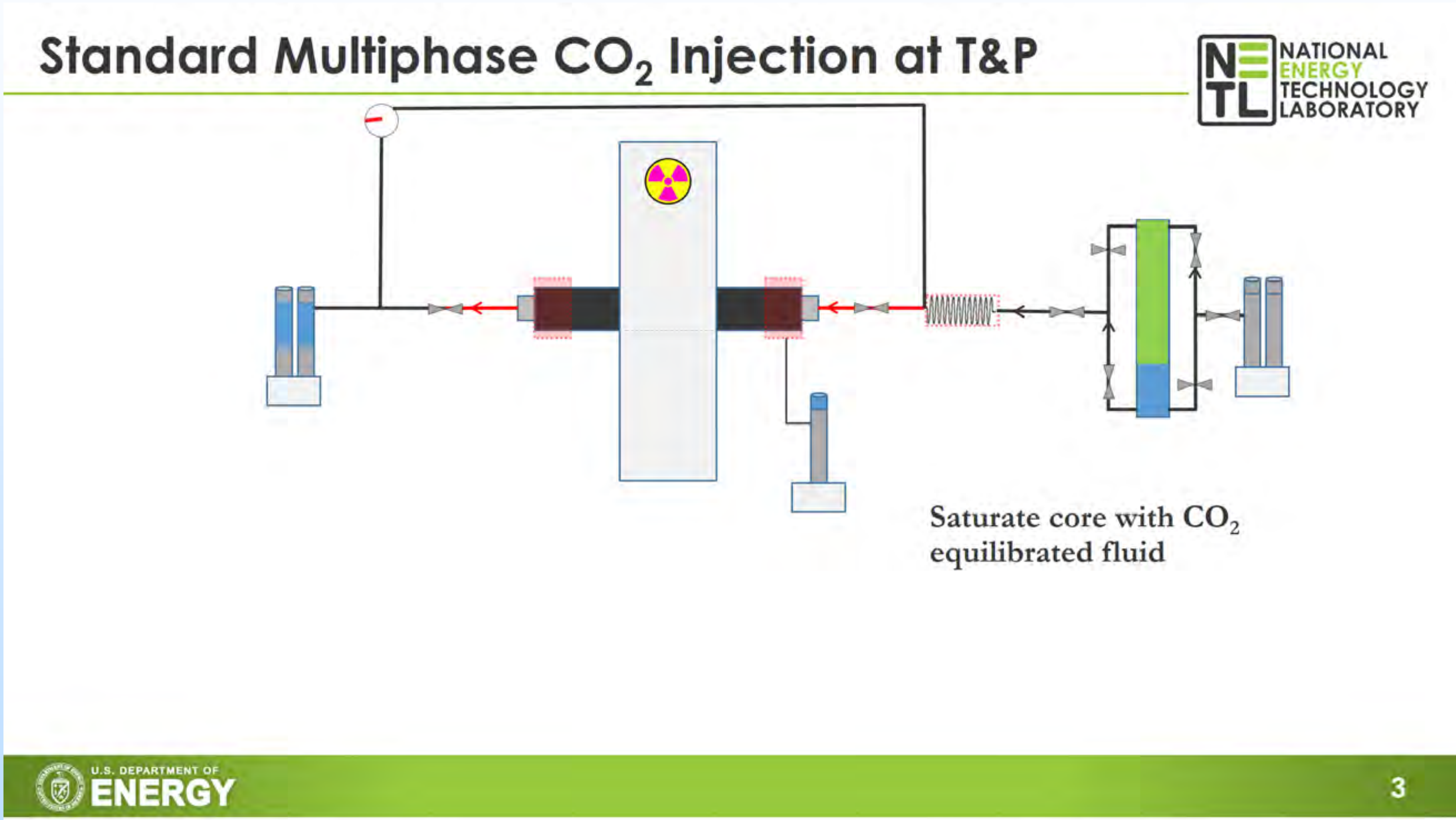
Experimental Methodology



Experimental Methodology

Standard Multiphase CO_2 Injection at T&P

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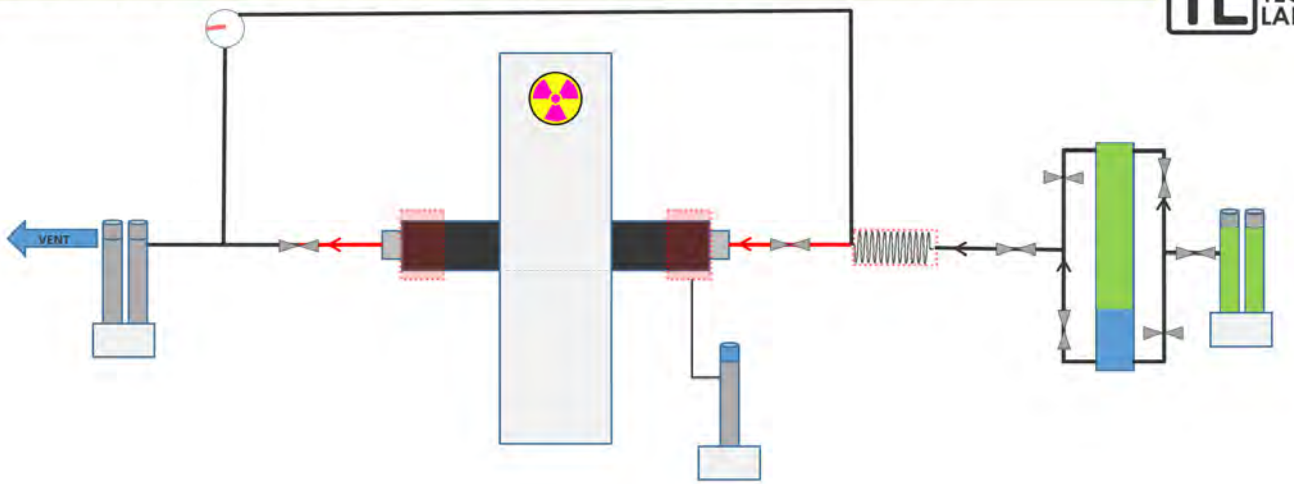

Vent effluent pumps and fill injection pumps with CO_2

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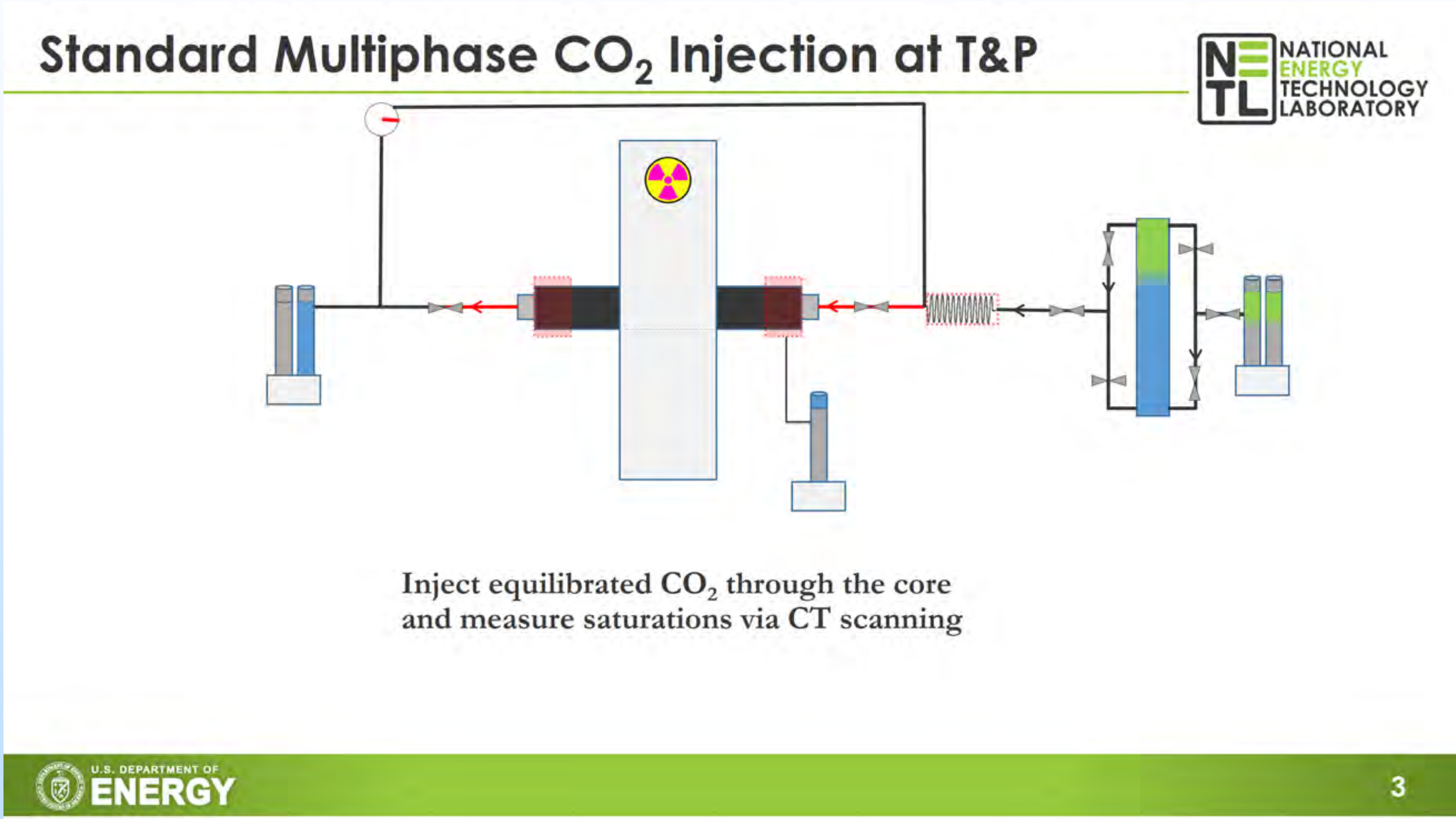
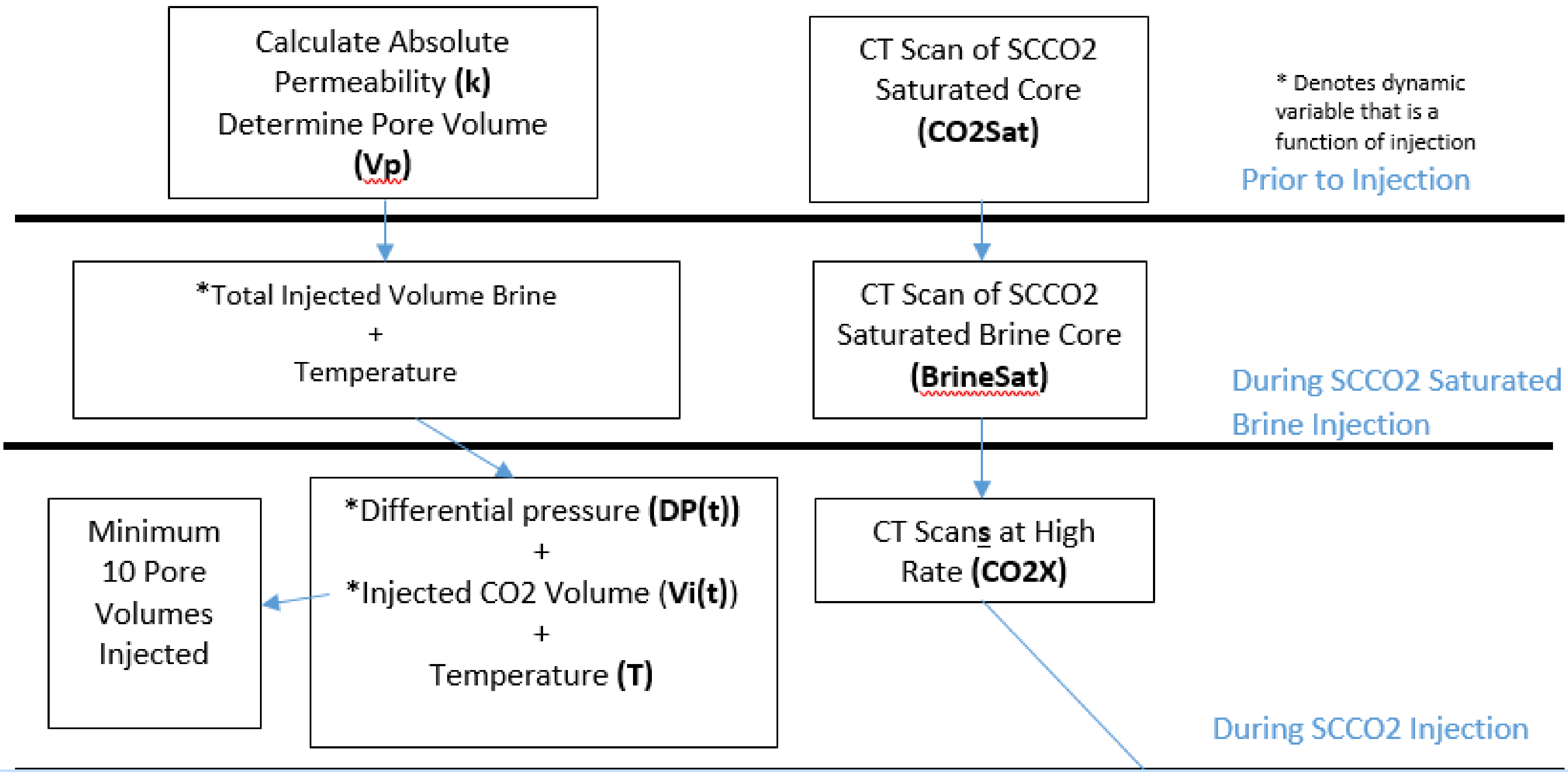
Experimental Methodology



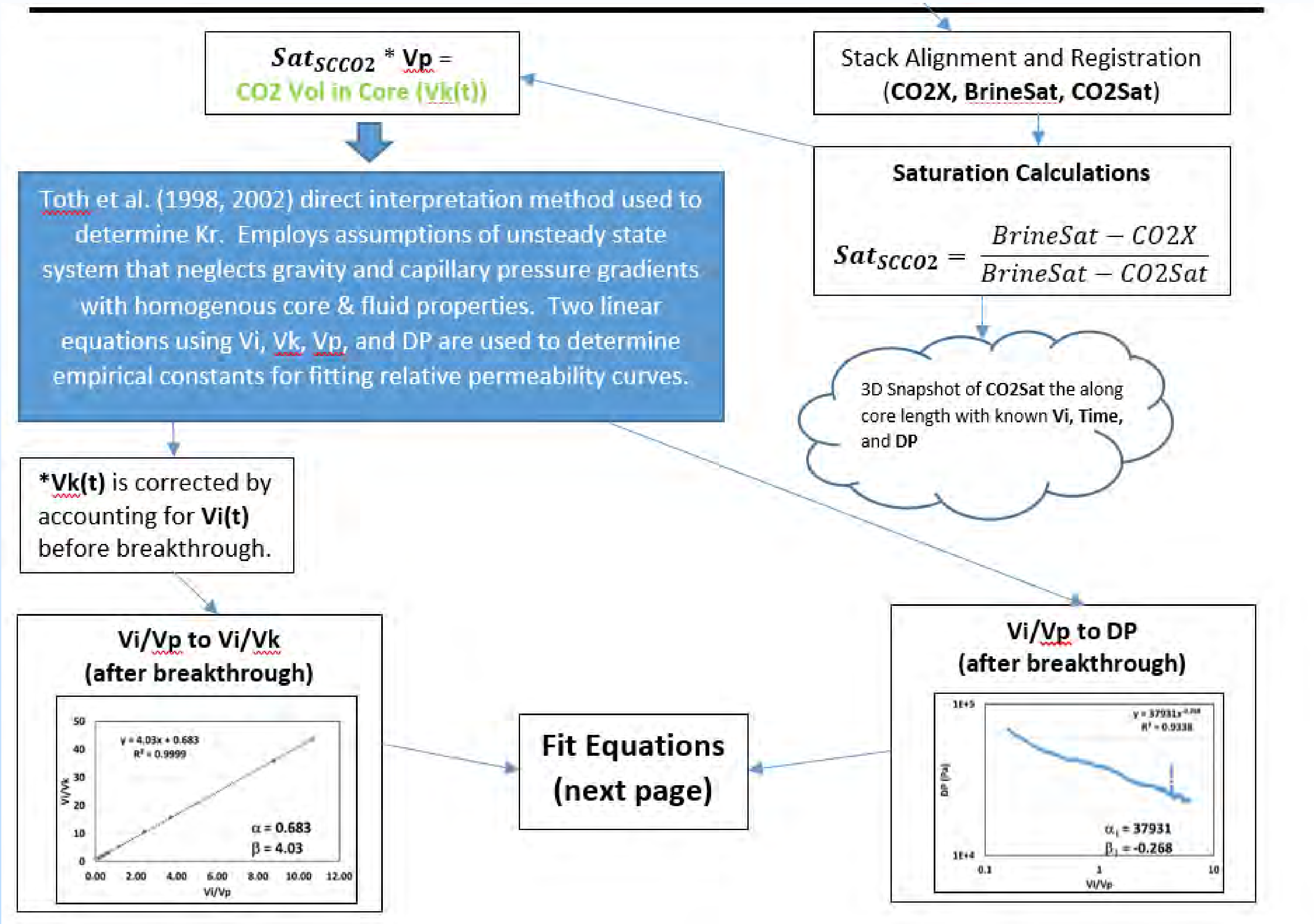
Analysis Methodology

- Data collection
  - Baseline core properties (ϕ, k, pore volume)
  - Baseline CO_2 and brine saturated CT scans
  - Dynamic measurements
    - Differential pressure, injected CO_2 volume, saturation (via CT scans)
- Used methods set forth by Krevor et al (2012) for saturation and Toth et al (2002) for mobility functions & k_r calculations

Analysis Methodology



Analysis Methodology



Analysis Methodology

Mobility Ratio of Fluids (Md_2)

$$Md_2 = \left[\alpha + \beta \frac{V_i}{V_p}\right]^2 + i$$

Fractional Flow of Displacing Fluid (SCCO2)

$$f_d = \frac{Md_2}{Md_2 + 1}$$

Fractional Flow of Displaced Fluid (Brine)

$$f_k = \frac{1}{Md_2 + 1}$$

Total Mobility Function

$$Y(S_{d,2}) = \frac{q_i L}{KA\alpha_1 + (1-\beta_1)\left(\frac{V_i}{Vp}\right)^{\beta_1}}$$

Relative Permeability of SCCO2

$$k_d = \mu_d f_d Y(S_{d,2})$$

Relative Permeability of Brine

$$k_k = \mu_k f_k Y(S_{d,2})$$

Terminology:

K	permeability (cm^2)
A	core cross-sectional area (cm^2)
L	core length (cm)
T	temperature (°C)
DP	differential pressure across rock core (Pa)
q_i	flow rate (cm^3/min)
α	empirical constant, dimensionless
β	empirical constant, dimensionless
α_1	empirical constant (Pa)
β_1	empirical constant, dimensionless
f_d	fractional fluid flow of SCCO2, dimensionless
f_k	fractional fluid flow of brine, dimensionless
Vp	pore volume (ml)
Vi	SCCO2 volume injected (ml)
Vk	volume of SCCO2 in the rock core (ml)
CO2Sat	Computed tomography scan of SCCO2 saturated core
BrineSat	Computed tomography scan of brine saturated core
CO2X	Computed tomography scans of SCCO2 injection into brine saturated core
M_{d2}	mobility ratio of fluids, dimensionless

Technical Status

- 27 tests completed, 10 with multiple flow rates
  - Detailed sample information collected and to be reported with saturation and relative permeability results.
  - All samples curated with International Geo Sample Number (ISGN) with the System for Earth Sample Registration (SESAR) – www.geosamples.org

Go Back

IGSN: IENTL0100

IGSN:	IENTL0100
Sample Name:	White Rim Sandstone
Other Name(s):	
Sample Type:	Core Whole Round
Parent IGSN:	Not Provided

Description	
Material:	Rock
Classification:	Sedimentary
Field Name:	White Rim Sandstone Member of the Permian Cutler Formation
Description:	Sandstone, three types of eolian deposits: dune, interdune, and sabkha; surface outcrop
Age (min):	Not Provided
Age (max):	Not Provided
Collection Method:	Drilling
Collection Method Description:	Not Provided
Size:	2 inch
Geological Age:	Not Provided
Geological Unit:	Not Provided
Comment:	Not Provided
Purpose:	ongoing test for the relative permeability atlas

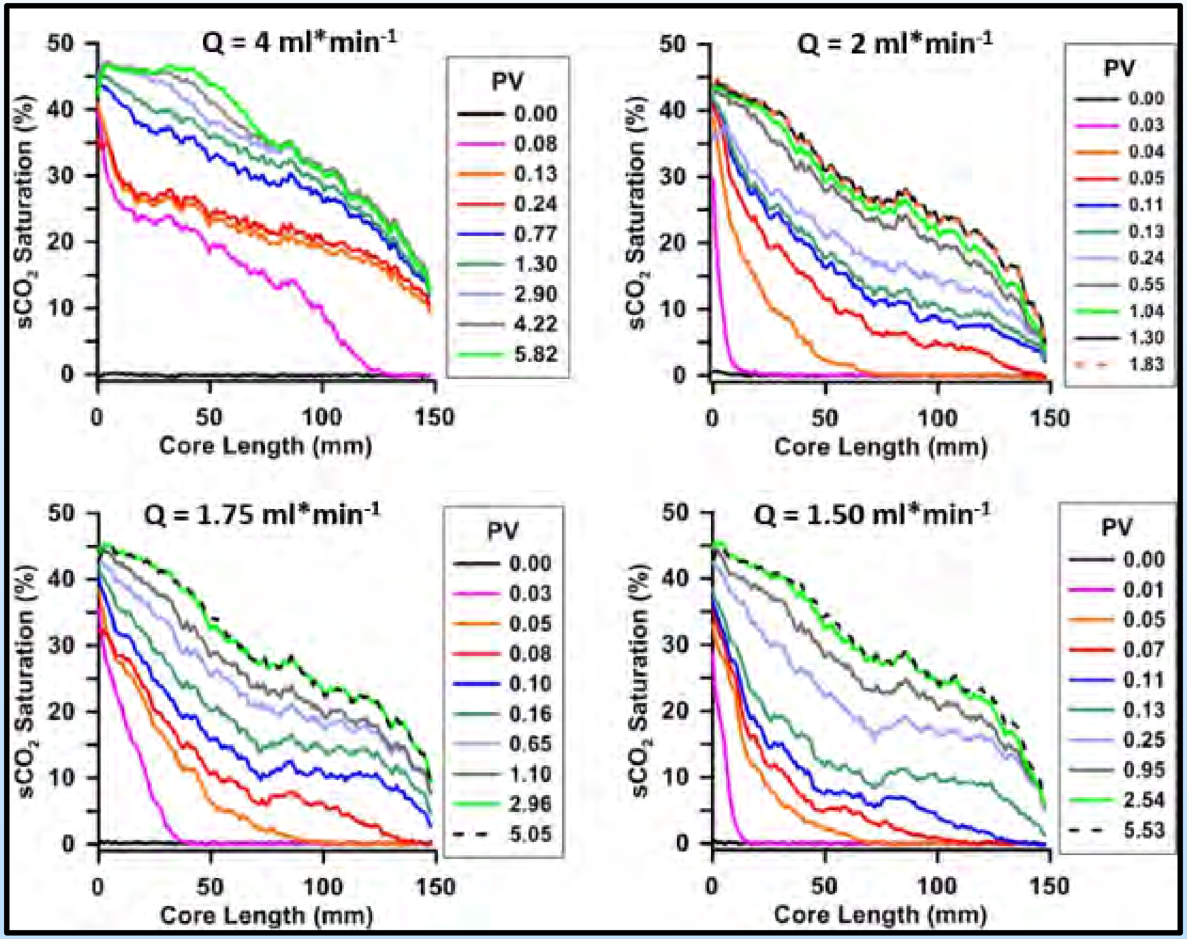
Geolocation	
Latitude (WGS84):	Not Provided
Longitude (WGS84):	Not Provided
Northing (m) (UTM NAD83):	Not Provided
Easting (m) (UTM NAD83):	Not Provided
Zone:	Not Provided
Vertical Datum:	Not Provided
Elevation:	Not Provided
Nav Type:	Not Provided
Physiographic Feature:	Not Provided
Name Of Physiographic Feature:	Not Provided
Location Description:	Not Provided
Locality:	Utah
Locality Description:	Not Provided
Country:	United States
State/Province:	Utah
County:	Not Provided
City:	Not Provided

Collection	
Field Program/Cruise:	Not Provided
Platform Type:	Not Provided

Formation or Age	Location	Lithology and Properties	Depositional Environment	Depth/Outcrop	Permeability - lab determined	Porosity- lab determined	UCS (PSI)- lab determined	Homogeneous	Success	Subsampled for Contact Angles	Acquired	Current Location	ISGN Number	ISGN Link
Upper Devonian, Kipton	Clevand Quarries, Ohio	sandstone	strand plain, barrier bar		85.2 +/- 19.2*			Yes	1 failed		Clevand Quarries	NETL MGN	IENTL00ZQ	https://app.geosamples.org/sample/igsn/IENTL00ZQ
Lower Cretaceous, Edwards Plateau	Big Spring Texas Quarry	Carbonate	reef	100 feet	150-350 mD	33-35%	3000-35000	No	1 success	No	Kocurek Industries	NETL MGN	IENTL00ZR	https://app.geosamples.org/sample/igsn/IENTL00ZR
Upper Devonian, Kipton	Clevand Quarries, Ohio	sandstone	strand plain, barrier bar		85.2 +/- 19.2*			Yes	1 success	Yes	Clevand Quarries	NETL MGN	IENTL00ZS	https://app.geosamples.org/sample/igsn/IENTL00ZS
Late Cretaceous, Mesaverde	Rangely Colorado Quarry	sandstone	Deltaic complex fluvial	surface outcrop	800-1200 mD	27-29%	2000-2500	Yes	1 success	attemped but fell apart	Kocurek Industries	Debris at NETL MGN, new piece sent to FIRE	IENTL00ZT	https://app.geosamples.org/sample/igsn/IENTL00ZT
Triassic, Glen Canyon Group	an Rafael area of central Utah, 3	sandstone	Aeolian	surface outcrop	41.2 +/- 2.4 mD*				1 success	Yes	Eric Edelman, U of U	Used up	IENTL00ZU	https://app.geosamples.org/sample/igsn/IENTL00ZU
Desmoinesian, Kansas	Readfield Kansas Quarry	sandstone	Marginal Marine	20-50 feet	30-45 mD	21-23%	4000-5000	No	1 success	Yes	Kocurek Industries	NETL MGN, subsampled and sent to FIRE	IENTL00ZV	https://app.geosamples.org/sample/igsn/IENTL00ZV
Upper Cretaceous, Edwards Plateau	Georgetown Texas Quarry	Limestone	shallow marine	30-60 feet	8-15 mD	22-27%	2000-3600	No	1 success	No	Kocurek Industries	NETL MGN	IENTL00ZW	https://app.geosamples.org/sample/igsn/IENTL00ZW
Paleozoic, Edwards Plateau	Big Spring Texas Quarry	Carbonate		30-60 feet	1-3 mD	16-18%	5000-7000	Yes	1 success	No	Kocurek Industries	NETL MGN	IENTL00ZX	https://app.geosamples.org/sample/igsn/IENTL00ZX
Silurian	Thornton Quarry Indiana	Dolomite	reef	200 feet	35-100mD	16-17%	10,000-12,000	No	1 success	No	Kocurek Industries	NETL MGN	IENTL00ZY	https://app.geosamples.org/sample/igsn/IENTL00ZY
Silurian	New York	Dolomite	reef	surface outcrop	2-10mD	9-10%	9000-12000	No	1 failed	No	Kocurek Industries	NETL MGN	IENTL00ZZ	https://app.geosamples.org/sample/igsn/IENTL00ZZ
White Rim Sandstone Member of the Permian Cutler Formatio	38°58'06.3"N, 110°39'43.3"W	sandstone	three types of eolian deposits: dune, interdune,	surface outcrop	less than 10mD				1 success	No	Eric Edelman, U of U	NETL MGN	IENTL0100	https://app.geosamples.org/sample/igsn/IENTL0100
Pleistocene-Holocene Big Pine volcanic field	Big Pine, CA from the northe	Igneous - volcanic	volcanic	surface outcrop					1 success	No				
	Salt Lake City Utah	Shale		surface outcrop					1 failed		Kocurek Industries	NETL MGN		
	Langtry Texas	Shale		surface outcrop					1 failed		Kocurek Industries	NETL MGN		
	San Saba Texas	Shale		surface outcrop					1 failed		Kocurek Industries	NETL MGN		

Technical Status

- Example results from Castlegate sandstone tests: deltaic to fluvial



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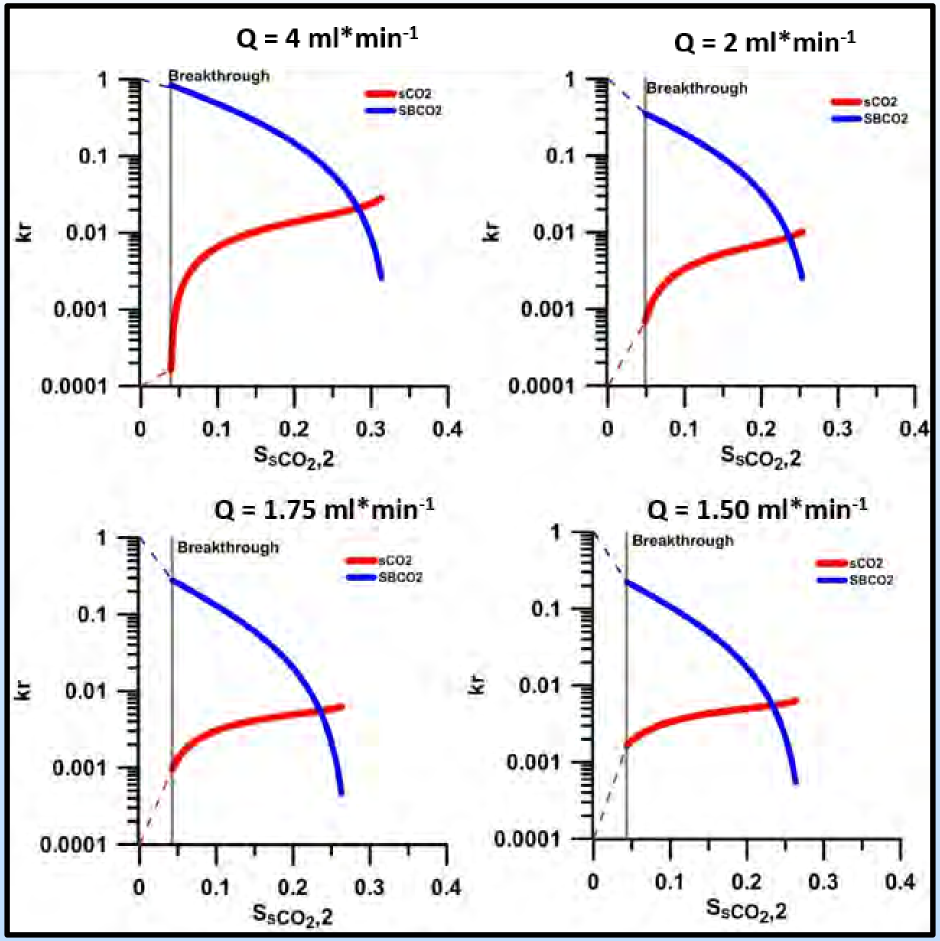
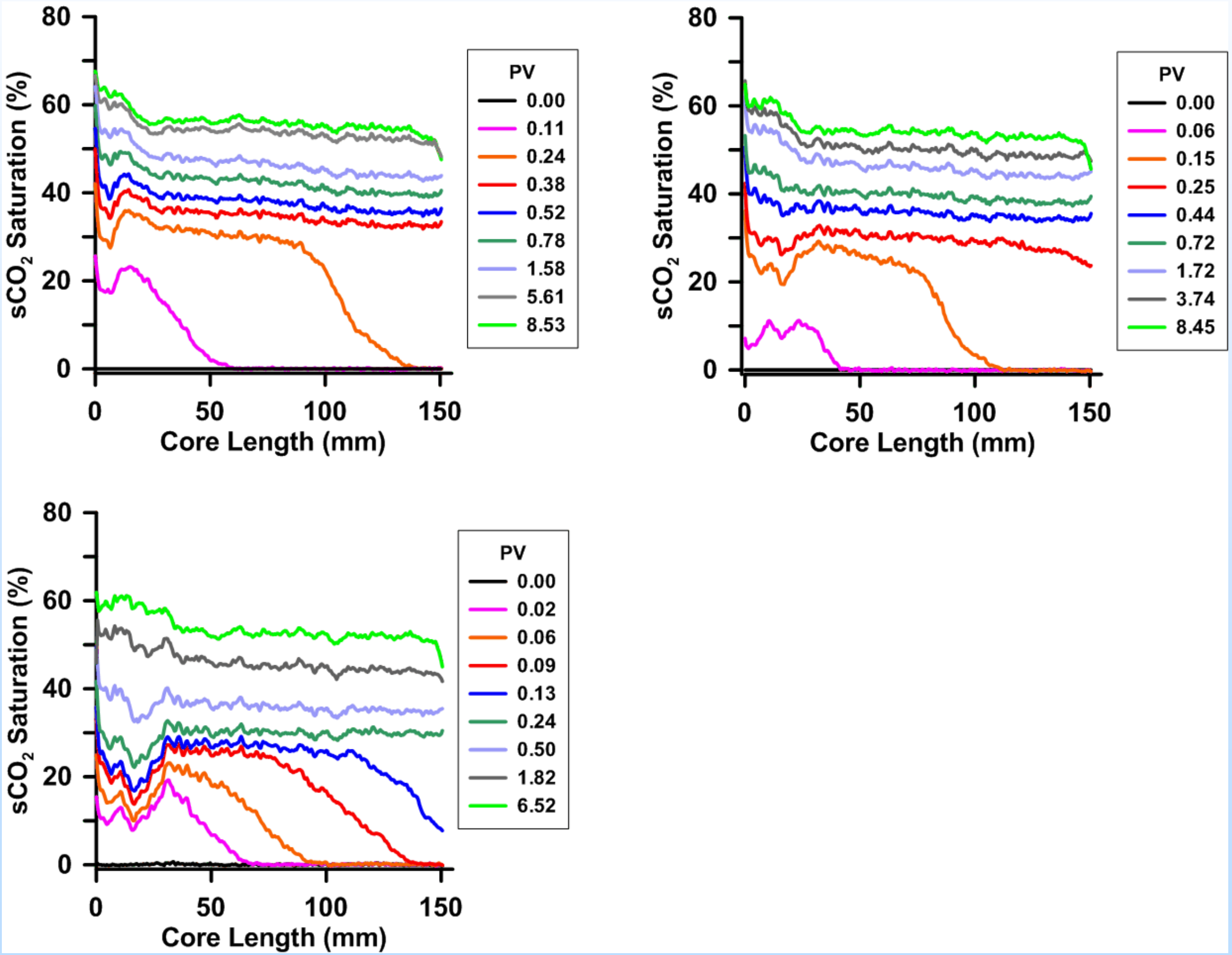


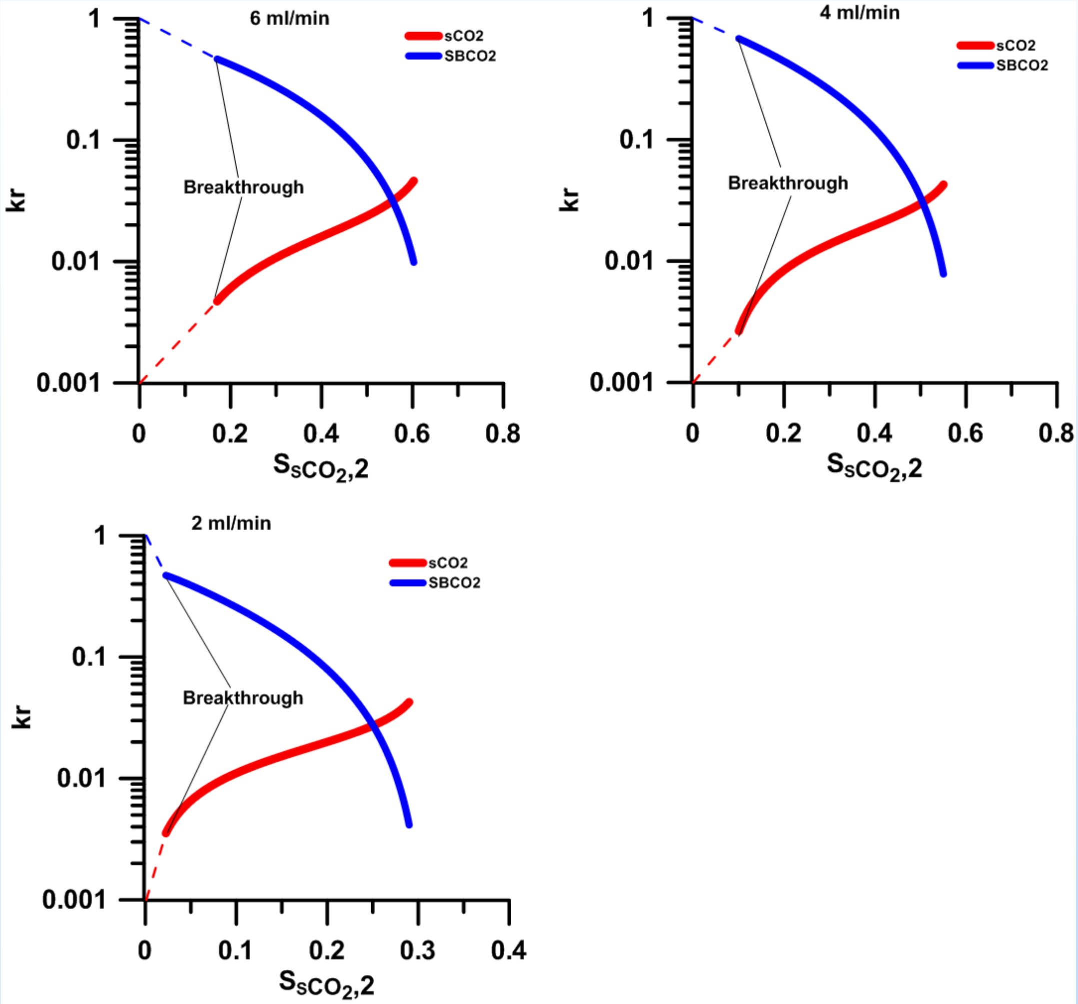
Technical Status

- Example results from Edwards Yellow tests: Carbonate



Technical Status

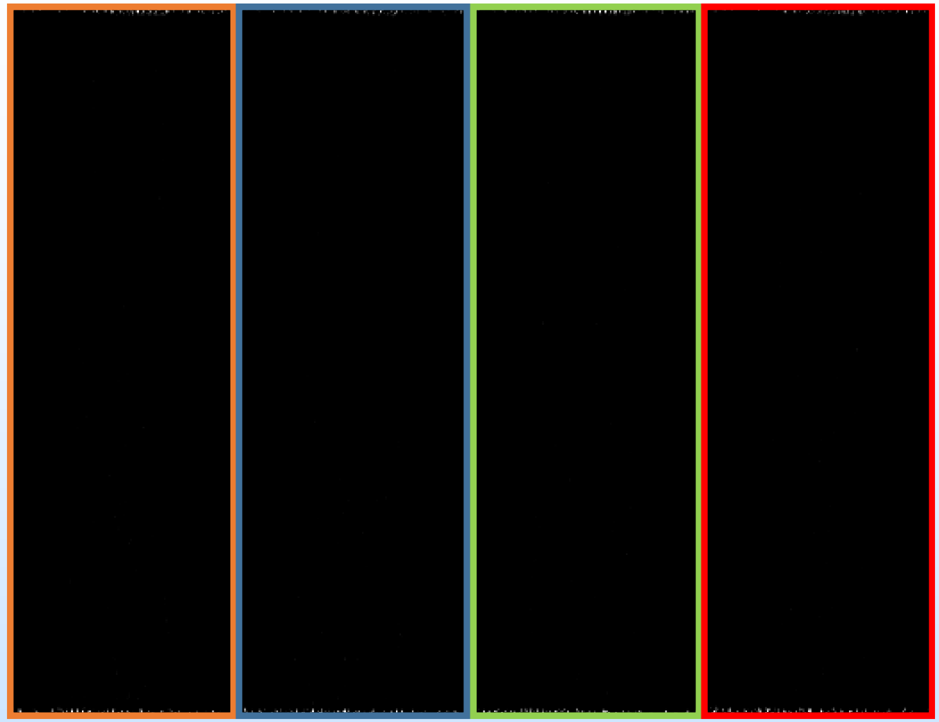
- Example results from Edwards Yellow tests: Carbonate



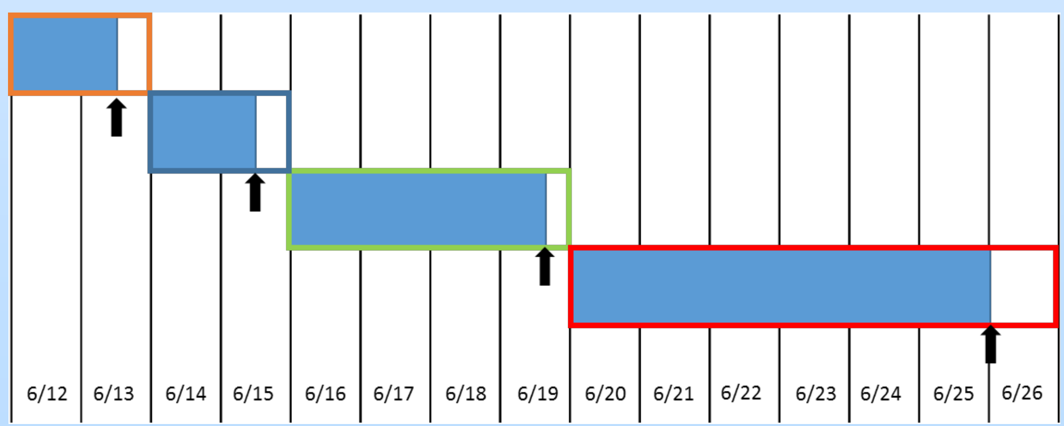
Wormhole Generation

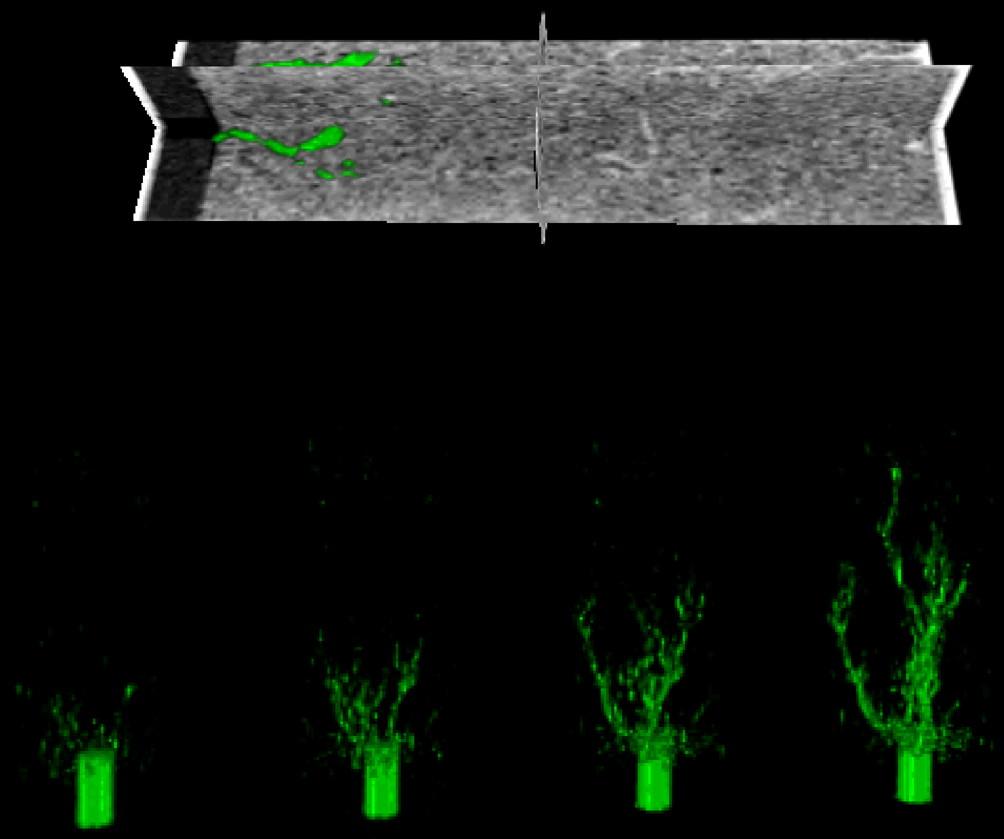
- Edwards Yellow (Carbonate)
- $Q = 6, 4, 2, 1\ ^{ml}/_{min}$
- Wormhole generation near to the inlet evolved over sequential CO_2 injections.

Injection



Exit



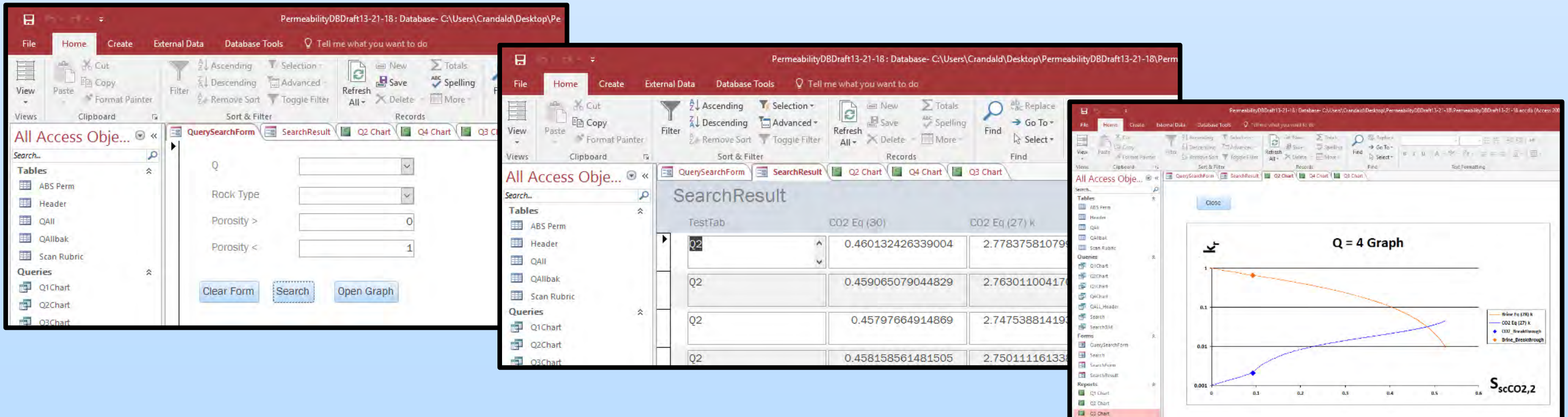


Compare/Contrast Results across Cores

- Sandstones are relatively uniform in the relationship between k_r and k
- Carbonates are dependent on the material sensitivity and initial permeability
  - Dolostones tend to be less prone to secondary macro-porosity development and short-circuiting of fluid. They tend to behave more predictably like sandstone.
  - Limestones (pure $CaCO_3$) tend to wormhole significantly, which causes dynamic changes in the relationship between k and k_r during the flow test

Accomplishments to Date

- 27 experiments completed.
  - Most depositional environments run with multiple cores.
- Only three depositional environments remain to be tested.
  - Lacustrine, alluvial and turbidite.
- Draft manuscript on methodology almost complete.
  - Introduction needs refining.
- Draft database for EDX created and populated.

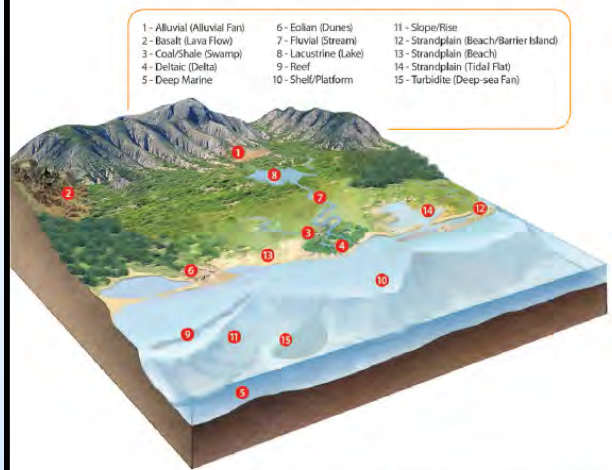


Lessons Learned

– Core scale heterogeneity obviously an issue.

– Low potential/uncertain reservoir systems difficult to determine k_r
  - Low permeability: not surprising

– Dynamic carbonate evolution is able to be captured with unsteady k_r measurements
  - Quantification of k_r difficult (Vp is changing …)
  - We have been able to characterize this impact on k_r, and observed interesting behavior with respect to k and dissolution behavior. Early results, but planning to submit manuscript late '18 or early '19.



Matrix of Field Activities in Different Reservoir Classes (2012)

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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

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.

Synergy Opportunities

We are very happy to utilize the skills and resources at NETL RIC to further the mission(s) of FE across portfolios. The number of ongoing collaborative studies is numerous, and if you identify places where we can help with your studies, please let me know.

Figure 1. Toshiba Aquilion™ PXL medical CT

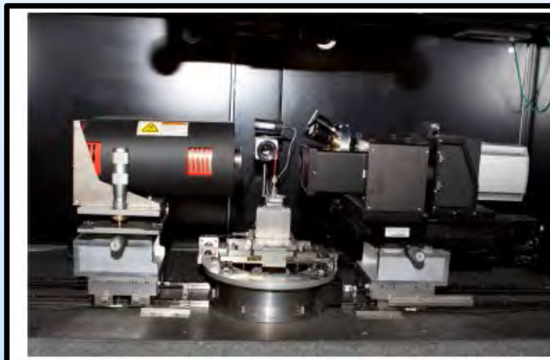


Figure 7. ZEISS Xradia Micro-CT scanner.

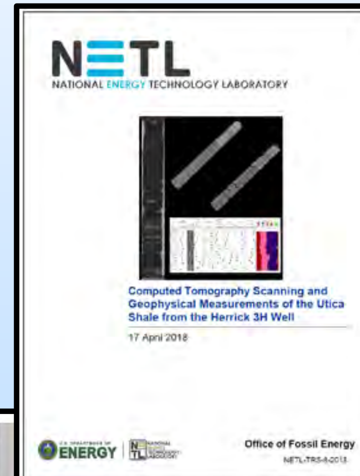


Figure 4. North Star Imaging M-5000 industrial CT scanner.

Figure 9. Multi-sensor core logging unit.

Project Summary

– Key Findings
  - Dynamic carbonate evolution captured with unsteady k_r measurements
    – We have developed a methodology for correcting for these changes.
  - We have been able to do a depositional environment, to completion, at a rate of 1 per 1-2 weeks.

– Next Steps
  - Submission of methods manuscript.
  - Completion of depositional environment experiments.
  - Finalization of database and publication to EDX.
  - Manuscript generation for dataset highlighting variation.

Appendix

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

Benefit to the Program

- To improve assessments of CO_2 storage for key reservoir classes, basic research of critical properties at in situ conditions and linked to potential reservoir classes needs to be conducted. Work will focus on measuring relative permeability, residual saturation, and wettability for high priority depositional environments targeted for CO_2 storage and developing accessible tools for reservoir modelers to access this data and utilize to reduce uncertainty in their estimates.

Project Overview

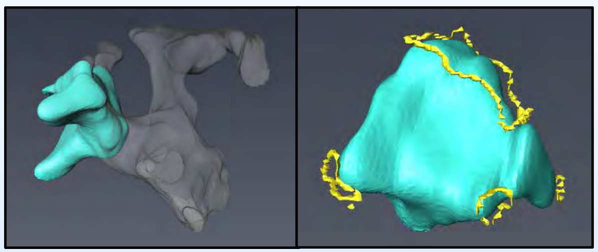
Goals and Objectives

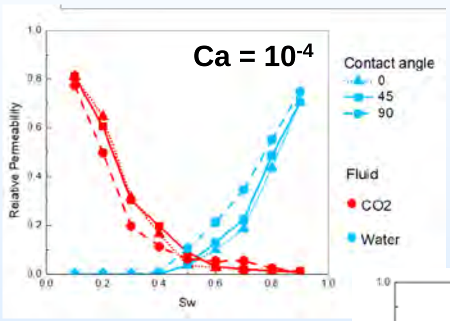
- Determination of non-rock specific relative permeability curves to reservoir scale assessments of CO_2 migration results in higher levels of uncertainty than could be attained with more targeted models. By developing a set of relative permeability curves, and understanding how they vary with different depositional environments, the benefit of this task will be reduced uncertainty in CO_2 migration in real world reservoirs.
  - Success is development and publication of an accessible database of experimentally determined relative permeability curves of $scCO_2$/brine through various high priority depositional environments.

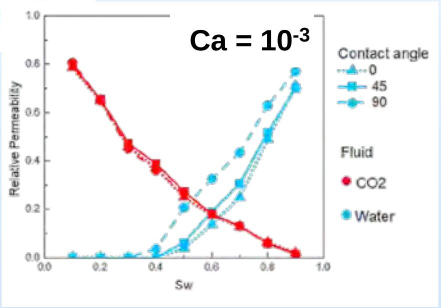
Project Overview

Brief highlights of additional subtask 13.1.2

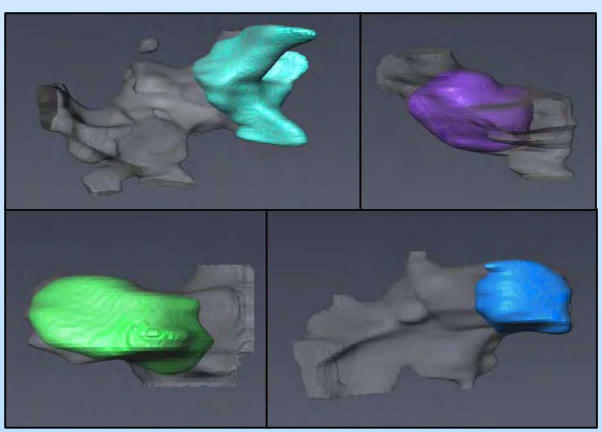
- Improved brine-CO_2 understanding in reservoirs, from pores to flow properties.



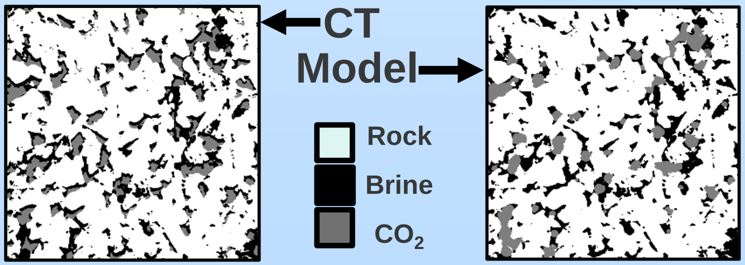




Measurement of $scCO_2$/brine contact angles in pore space



Simulated relative permeability in micro-CT derived geometries



Organization Chart

- NETL Researchers: Johnathan Moore, Sarah Brown, Laura Dalton, Karl Jarvis, Bryan Tennant, Scott Workman, Aaron Boylan, Magdalena Gill, Jeong Choi, Michael Sabbatino, Leebyn Chong, Eugene Myshakin, Angela Goodman, Sean Sanguinito, Deepak Tapriyal, Foad Haeri, Fan Shi, Christopher Matranga, Greggory Breault, Samantha Fuchs, Paige Mackey, Thomas Paronish,

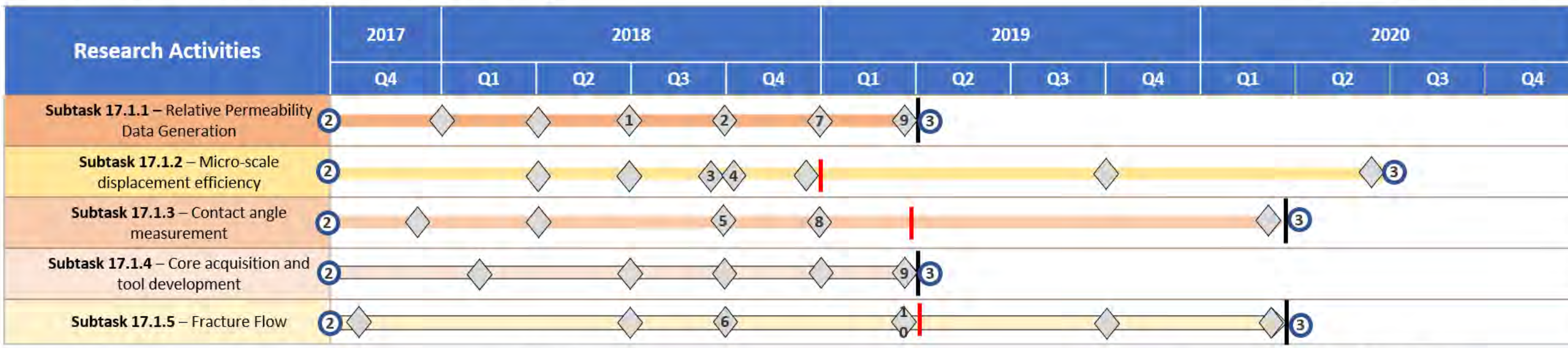
- ORISE Faculty: Cheng Chen (Virginia Tech), Goodarz Ahmadi (Clarkson University), Kevin Shanley (SUNY New Paltz), Brian Ellis (U of Michigan)

Gantt Chart – Task Overview

Timeline Overview – Task 13

NATIONAL ENERGY TECHNOLOGY LABORATORY

Relative Perm, Residual Sat, and Porosity



Milestones

Numbered milestones are listed in the following slides for each subtask.

Go / No-Go

Go/no-go gates are listed in subtask details.

Impact

Key Accomplishments/Deliverables	Value Delivered
• Over the past year five different depositional environments have been successfully tested using the techniques developed at NETL. • Fundamental measurements of scCO2 contact angles were obtained inside pores and with traditional methods: • 3D printed model of a CT scanned rock fracture was developed and used to test flow properties.	• The product of this work is to deliver a database with measurements of relative permeability, residual saturation, and wettability for high priority depositional environments targeted for CO_2 storage and accessible tools for reservoir modelers to access this data and reduce uncertainty in their estimates.

U.S. DEPARTMENT OF ENERGY

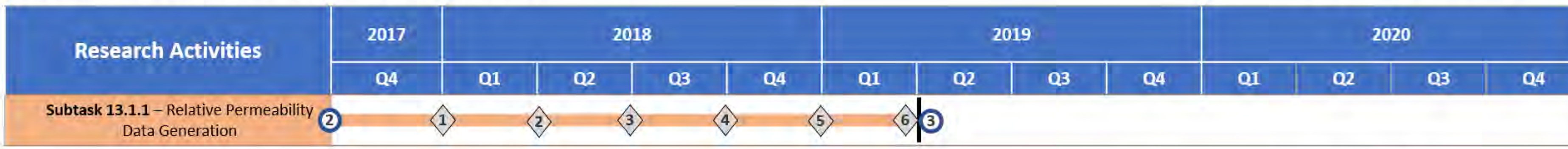
Chart Key: # TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

Gantt Chart – Subtask 1

Timeline Overview – Sub-Task 13.1.1

NATIONAL ENERGY TECHNOLOGY LABORATORY

Relative Permeability Data Generation



Milestones

1. Completion of six successful relative permeability experiments in different depositional environments. (Completed - December 2017)
2. Perform full relative permeability tests of two new depositional environments at $scCO_2$ conditions. (April 2018)
3. Perform full relative permeability tests of two new depositional environments at $scCO_2$ conditions. (June 2018)
4. Perform full relative permeability tests of two new depositional environments at $scCO_2$ conditions. (September 2018)
5. Perform relative permeability tests to identify uncertainty in measurements through duplicative runs. (December 2018)
6. Perform final full relative permeability tests of depositional environments at $scCO_2$ conditions. (April 2019)

Go / No-Go

None listed as project is only planned to continue for another 18 months.

Impact

Key Accomplishments/Deliverables	Value Delivered
2016-2017: Relative permeability data acquired from core flow testing has been incorporated into a database that can be queried by an online based tool. • Five successful tests in different depositional environments complete • Draft tool has been developed	• Various depositional environments can be utilized for geologic carbon storage, but how the migration of $scCO_2$ through these formations varies is relatively unknown. By focusing efforts on development of relative permeability curves of $scCO_2$/brine through various key depositional environments, and providing this data to modelers, this effort will reduce uncertainty in subsurface CO_2 migration for risk analysis.

Chart Key

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

U.S. DEPARTMENT OF ENERGY

Gantt Chart – Subtask 2

Timeline Overview – Sub-Task 13.1.2

NATIONAL ENERGY TECHNOLOGY LABORATORY

Micro-scale Displacement Efficiency

Milestones

1. With EFRC GSCO2 collaborators, present results of micro-CT measurement of trapped $scCO_2$ at conference. (April 2018)
2. Working with the EFRC GSCO2 scan cores and provide pore characterization for detailed simulations. (June 2018)
3. Perform minimum one CO_2/brine flood in the umCT at elevated P&T. (September 2018)
4. Submit manuscript of observed variation in contact angle measurements from umCT. (September 2018)
5. Complete lattice Boltzmann simulations of $scCO_2$/brine flow through umCT geometry at conditions of experiment. (December 2018)
6. Development of relative permeability curves from lattice Boltzmann simulations that illustrate the influence of contact angle variation. (September 2019)
7. Submission of peer reviewed manuscript that describes the influence of contact angle variation on trapping efficiencies in reservoir formations. (June 2020)

Go / No-Go

December 2018 – Do the contact angles from experimental measurements result in numerical simulation results that match trapped $scCO_2$ locations? If not, continued work upscaling results via LBM may be inappropriate.

Impact

Key Accomplishments/Deliverables	Value Delivered
• **<u>2016-2017</u>:** Through collaboration with the EFRC GSCO2, VT, and Sandia, including hosting two students at NETL to perform tests in the um and medical CT scanners. • One publication on measurements accepted and another nearing completion on measurements taken, and an analysis of methods. • Preliminary LBM models of pore space and contact angles conducted to digitally obtain relative permeabilities.	• Non-destructive contact angle (θ) measurement with CT is becoming more common, but there is no agreed upon measurement technique. A best practices peer-reviewed publication is needed to guide development. • θ is different in pores as opposed to surfaces. Understanding why will inform CO_2 trapping mechanism and flow relationships at the reservoir/formation scale. • An ability to scale individual surface measurements to flow relationships.

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

Gantt Chart – Subtask 3

Timeline Overview – Sub-Task 13.1.3

NATIONAL ENERGY TECHNOLOGY LABORATORY

Contact Angle Measurements

Milestones

1. Bring reactor cell online to measure contact angle of $scCO_2$/brine on various substrates at reservoir conditions. (Completed - 2017)
2. Minimalization of contaminant sources in sessile drop chamber to reduce surface chemistry disruptions in measurements. (April 2018)
3. Report on results from CO_2 flooding tests along with comparison and contrasting results to contact angle measurements performed in the umCT scanner. (September 2018)
4. Complete shakedown of reactor cell and perform 6 in situ contact angle measurements on a synthetic mineral substrate (e.g., SiO2) to illustrate the performance of this new capability. (December 2018)
5. A written report and slide deck summarizing the design shakedown and operation of the cell with analysis of how this approach can be used to correlate surface chemistry, surface composition, and surface roughness with wettability and relative permeability. (December 2019)

Go / No-Go

3/29/19 - Assess the utility of in situ contact angle measurements to provide quantitative insight into wettability and relative permeability changes during $scCO_2$/brine exposures. If these measurements are able to quantify and correlate surface chemistry changes, surface composition, and surface roughness with wettability and relative permeability continue the contact angle measurements at conditions that mimic those in the CT laboratory (Go Decision). If these measurements are unable to provide this insight, closeout the contact angle measurements (No-Go Decision)

Impact

Key Accomplishments/Deliverables	Value Delivered
<u>2016-2017:</u> Sessile drop measurement device, capable of operating at reservoir temperature and pressure, made operational. Upon examination, several potential containments in the system have been identified. These are likely ubiquitous in all published literature on this topic, and their impact on contact angle is being assessed.	• An improved understanding of the influence of surface chemistry changes, surface composition, and surface roughness on the contact angle between $scCO_2$ and brine on natural rock surfaces will improve estimates of transport and trapping of CO_2 in geologic repositories.

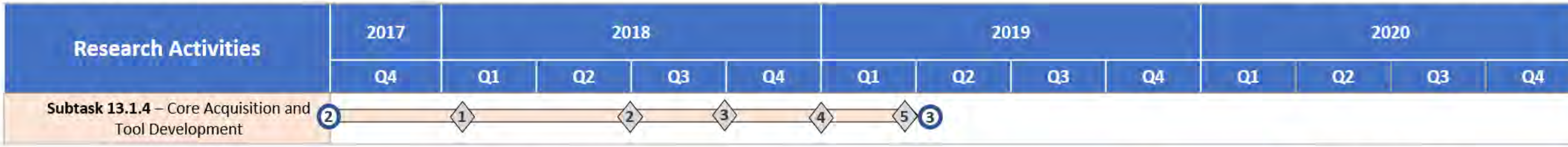
Chart Key: # TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

Gantt Chart – Subtask 4

Timeline Overview – Task 13.1.4

NATIONAL ENERGY TECHNOLOGY LABORATORY

Core Acquisition and Tool Development



Milestones

1. Draft tool to distribute relative permeability curves developed for internal RIC testing. (January 2018)
2. Acquisition of all cores required for relative permeability tests in task 13.1.1. Tool updated with new results. (June 2018)
3. Report on core characterization of reservoir core submitted. Tool updated with new results. (September 2018)
4. Tool updated with new results and beta tested by external interested parties. (December 2018)
5. Final relative permeability values incorporated into tool. (April 2019)

Go / No-Go

None listed as project is only planned to continue for another 18 months.

Impact

Key Accomplishments/Deliverables	Value Delivered
<u>2017:</u> Relative permeability data acquired from core flow testing has been incorporated into a database that can be queried by an online based tool. • Five successful tests in different depositional environments complete • Draft tool has been developed	• Various depositional environments can be utilized for geologic carbon storage, but how the migration of $scCO_2$ through these formations varies is relatively unknown. By focusing efforts on development of relative permeability curves of $scCO_2$/brine through various key depositional environments, and providing this data to modelers, this effort will reduce uncertainty in subsurface CO_2 migration for risk analysis.

Gantt Chart – Subtask 5

Timeline Overview – Task 13.1.5

Fracture Flow

NATIONAL ENERGY TECHNOLOGY LABORATORY

Milestones

1. 3D printed model of fracture created from CT scans capable of visualizing fluid flow. (Completed – November 2017)
2. Development of process workflow to convert 3D scanned fracture geometries to 3D printable structure. (June 2018)
3. Successful experiment of multiple fluids moving through a 3D printed model of a rough walled fracture. (September 2018)
4. Calculation of relative permeability curve from experimental data. (April 2019)
5. Experiments completed with 3 different pairs of immiscible fluid. (September 2019)
6. Submission of manuscript describing the influence of fracture properties on multiphase flow transport. (April 2020)

Go / No-Go

April 2019 – Successful calculation of relative permeability curve from 3D printed fracture model. Does calculated relative permeability curve align with small amount of published data?

Impact

Key Accomplishments/Deliverables	Value Delivered
<u>2015-2017:</u> An early 3D printed model of a CT scanned fracture was created by the PI in 2007 and used for basic comparisons of fluid flow properties to computational fluid dynamic simulations. At that time 3D printing and CT scanning resolution were both quite coarse. Working with Mickey Leland Energy Fellows and reprocessing of old CT scanned images of fractures a new model was created last year that enables basic tests to be run, with much lower cost and higher resolution than previous efforts.	• The goal of the proposed research is to utilize CT scanned fracture data to create benchscale models to visualize multiphase fluid transport in rough walled fractures. • If these can be readily produced and used to measure saturations, then relative permeability curves of fluids through fractures can be developed that will improve large scale simulations of flow through fractured reservoirs and seals.

Bibliography

- List peer reviewed publications generated from the project per the format of the examples below.
- Publications for subtask 13.1.1 (focus of this talk) are in the draft preparation stage.

- Journal, one author:
  - Gaus, I., 2010, Role and impact of CO_2-rock interactions during CO_2 storage in sedimentary rocks: International Journal of Greenhouse Gas Control, v. 4, p. 73-89, available at: XXXXXXX.com.
- Journal, multiple authors:
  - MacQuarrie, K., and Mayer, K.U., 2005, Reactive transport modeling in fractured rock: A state-of-the-science review. Earth Science Reviews, v. 72, p. 189-227, available at: XXXXXXX.com.
- Publication:
  - Bethke, C.M., 1996, Geochemical reaction modeling, concepts and applications: New York, Oxford University Press, 397 p.