CCUS Potential for the Niobrara A and B Intervals at Redtail Field, Weld County, Colorado

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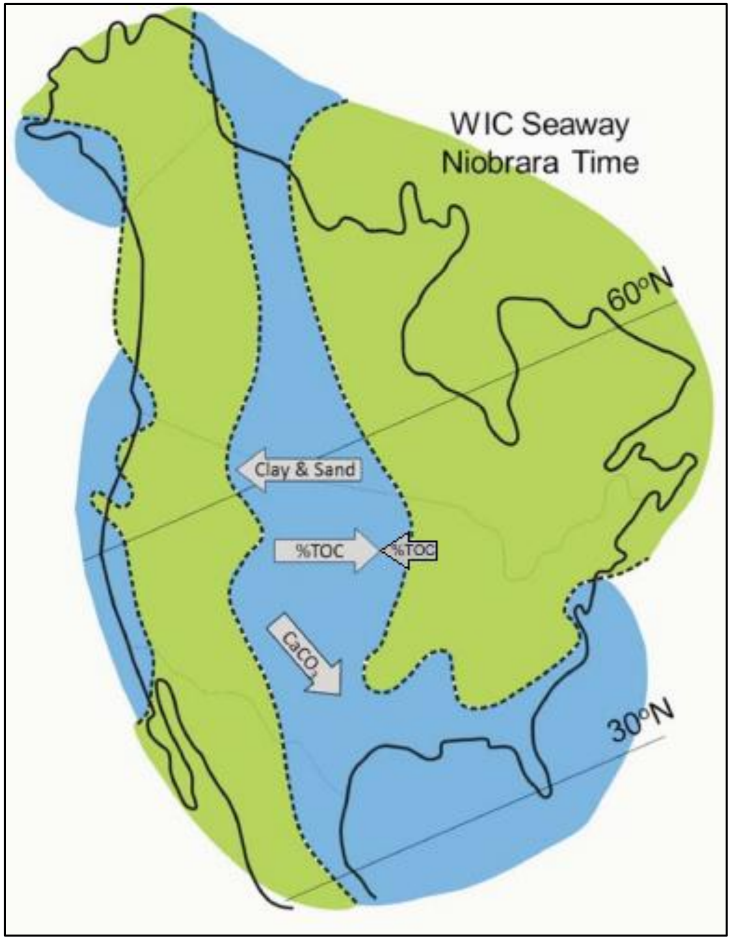
Outline

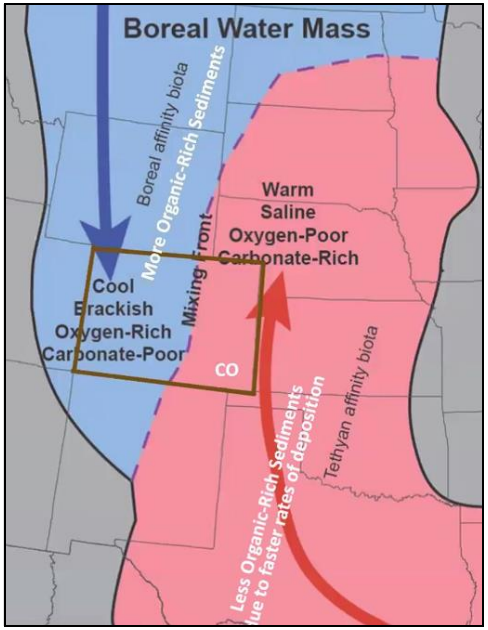
- Brief Geologic History of the Niobrara
- Study Area and Overview of Redtail Field Production by Bench
- CCUS Overview and Current Projects
- Progress on Lab Work and Preliminary Work
- Different Lab Techniques Going Forward to Examine Feasibility of CCUS

Brief Niobrara Background



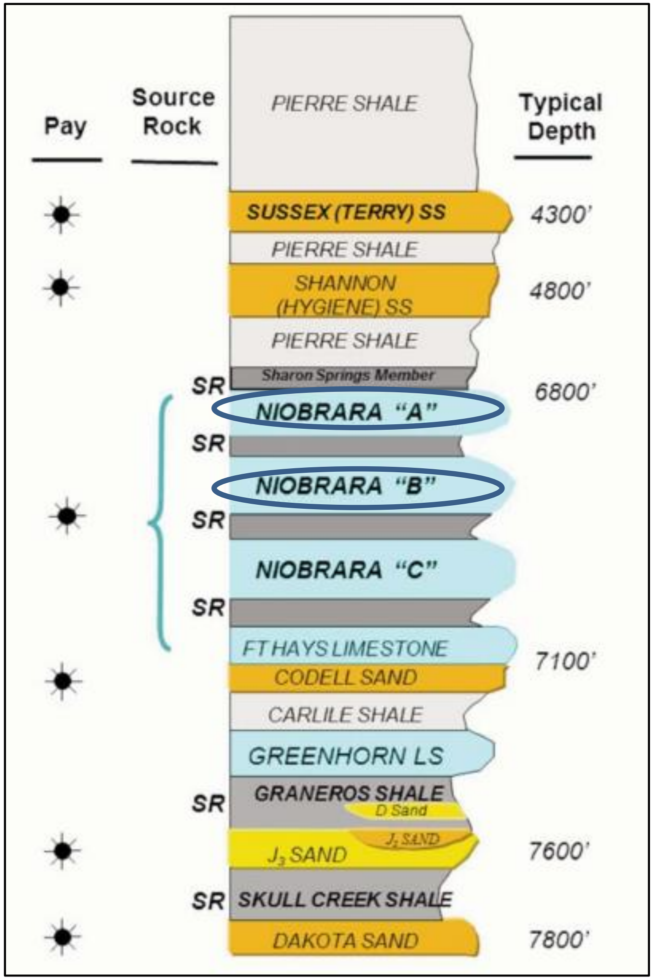
Schematic of the Western Interior Cretaceous Basin during the Niobrara time modified from (Longman, Luneau, & Landon, 1998)

- Increasing TOC% to the east to a certain extent though we now know TOC% extending into Kansas and Nebraska is not as high as once thought
- Deepest part of WIC along the Western Margin
- Cooler, nutrient rich, carbonate poor arctic water from the north mixed with warmer, oxygen poor, carbonate rich chalk-rich water from the Gulf of Mexico

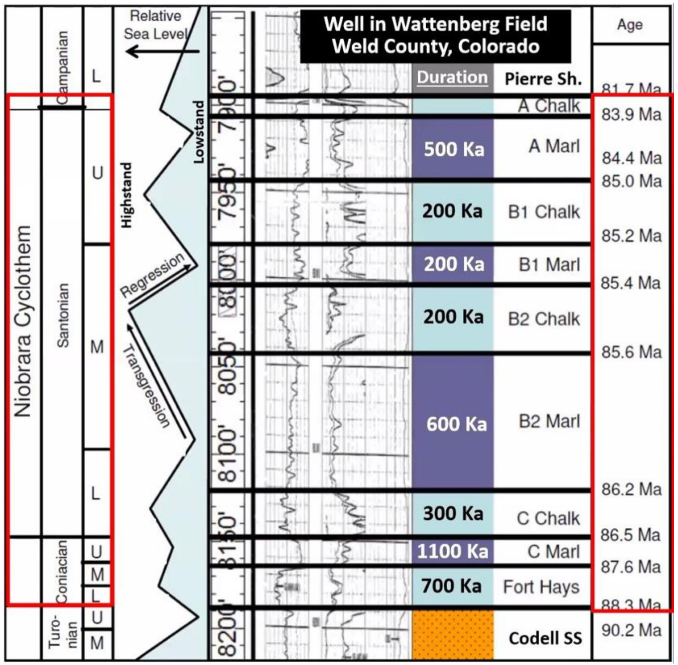


Schematic of the Western Interior Cretaceous Basin water mixture during the Niobrara time (Lowery, et al. 2017)

Brief Niobrara Background



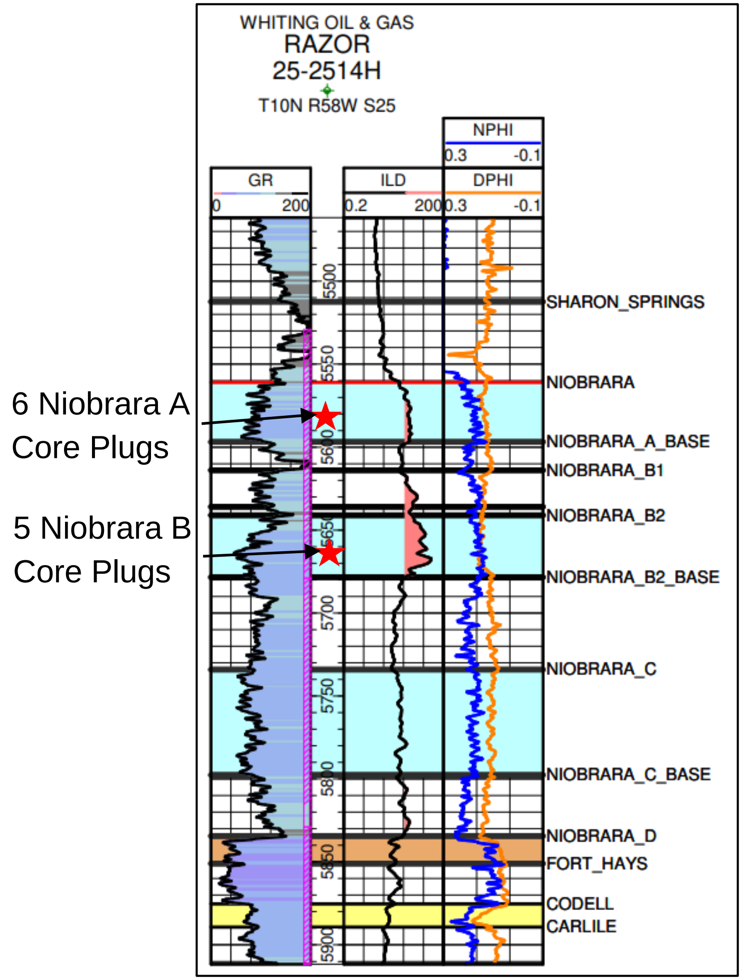
Stratigraphic column for the Niobrara specifically for the Wattenberg Area (Sonnenberg, 2011)



Stratigraphic column for the Niobrara showing relative sea level, duration of deposit, and age of deposit. (Longman & Luneau, 2020)

- Warmer gulfian currents dominated the B Chalk through a strong transgression as shown
- In the B2 Marl, we see a large amount of deposition in a relatively short period of time

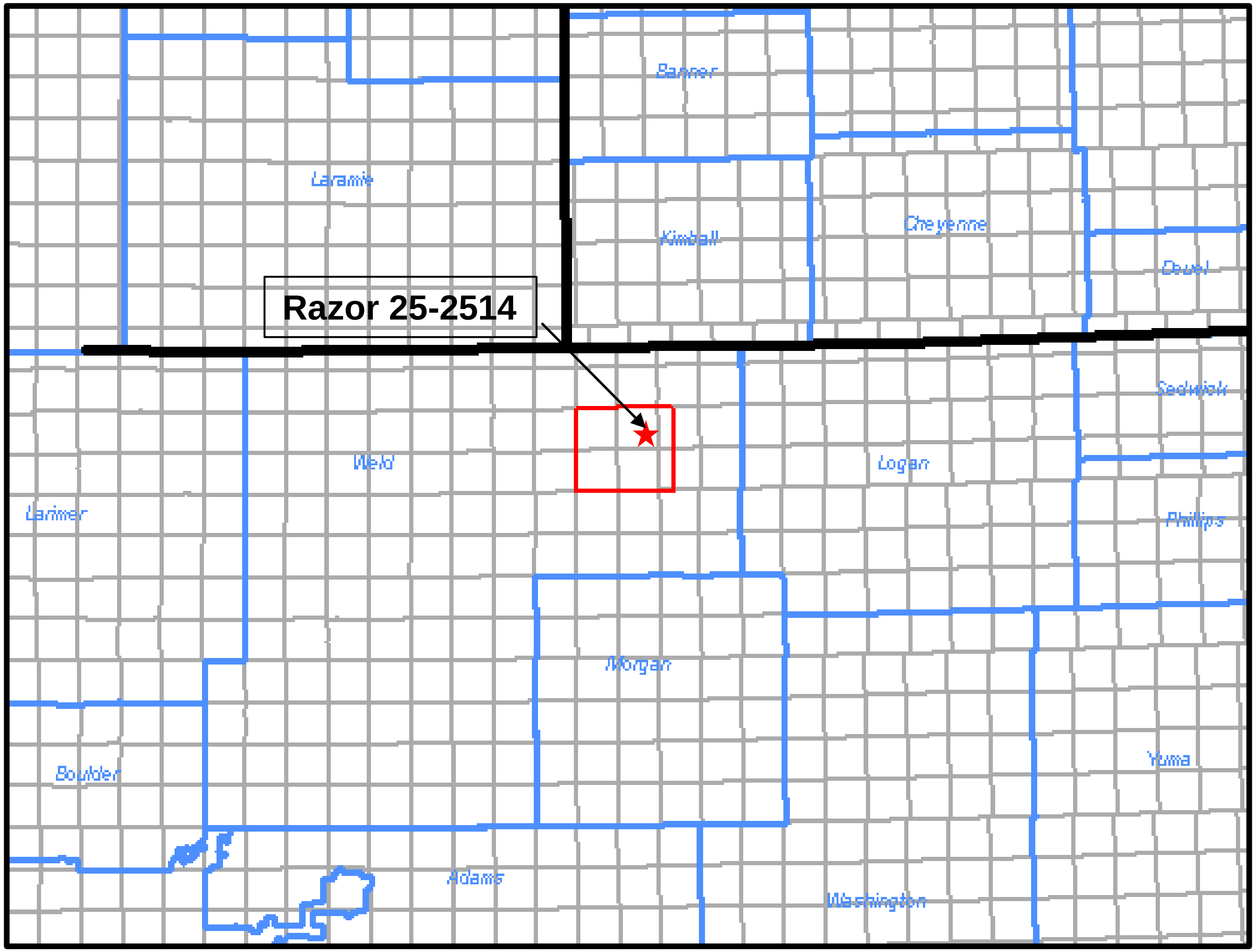
Petrophysical Properties Overview



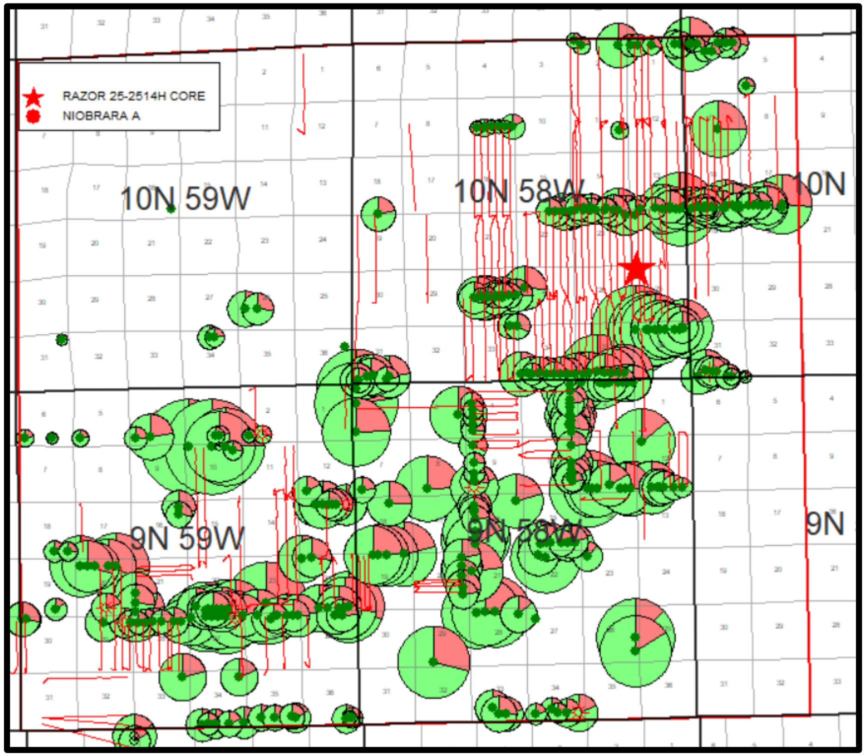
Petrophysical Overview for the Razor 25-2514H

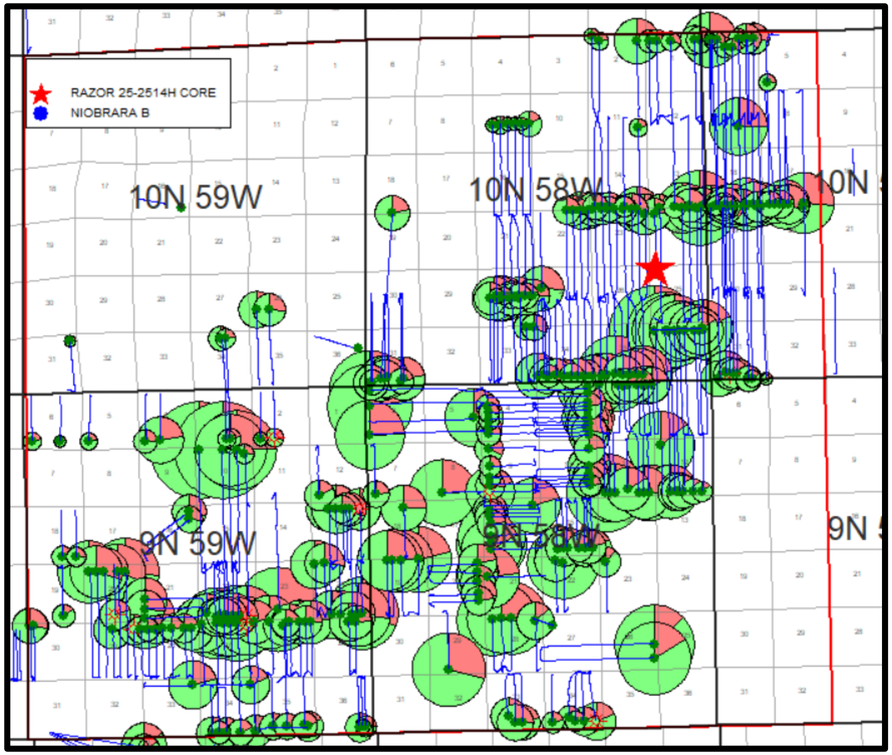
- Most favorable petrophysical properties are over the Niobrara A and B (particularly the B2) with increased resistivity and porosity
- 11 core plugs to run experiments on

Redtail Field Study Area



Redtail/East Pony Field Production

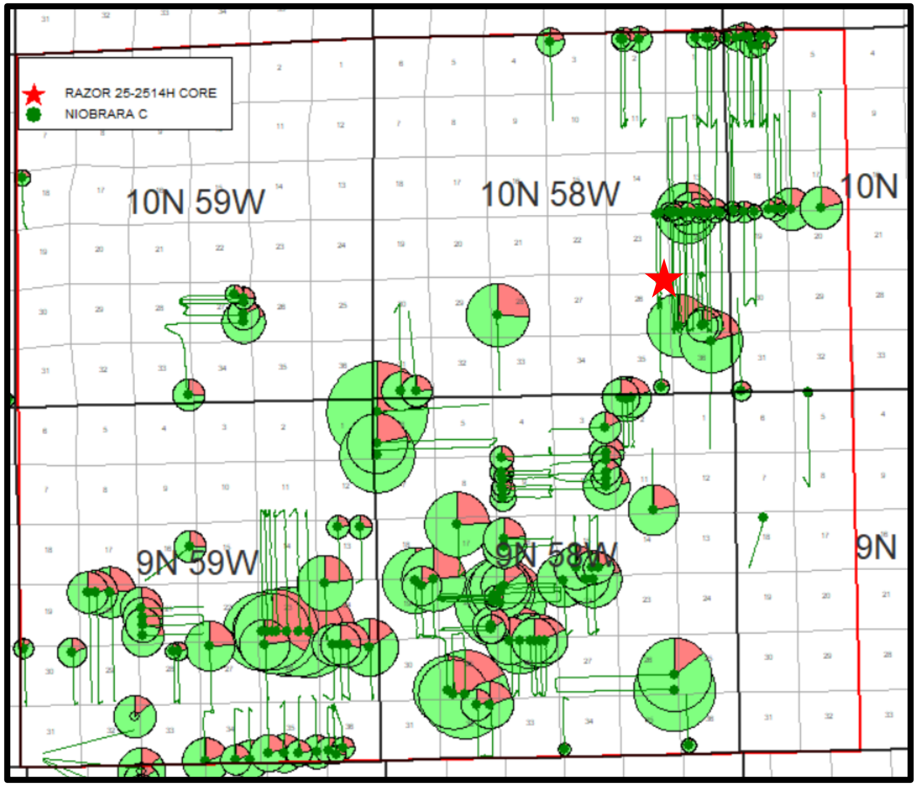


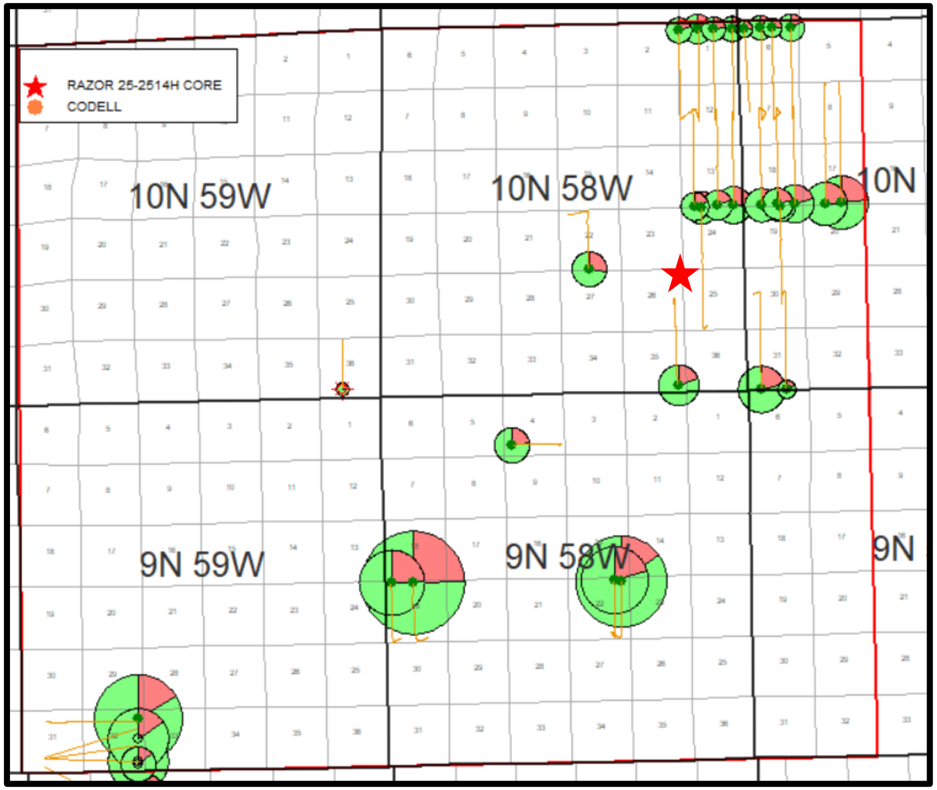


- 158 Horizontal Wells
- ~6-8 Wells per Developed Section
- 18,688,688 Cum Bbls Oil Produced
- 40,830,731 Cum MCF Gas Produced
- 21,020 Bbls/Oil/1,000' of Lateral
- 45,249 MCF/Gas/1,000' of Lateral
- **2,296 GOR** (~25% higher than B, C, Codell)
- Wells completed between ~2012-2016

- 336 Horizontal Wells
- ~6-8 Wells per Developed Section
- **43,741,284 Cum Bbls Oil Produced** (~2x A, C, Codell)
- **78,296,643 Cum MCF Gas Produced** (~2x A, C, Codell)
- **25,999 Bbls/Oil/1,000' of Lateral** (Best Among Benches)
- **46,331 MCF/Gas/1,000' of Lateral** (Best Among Benches)
- 1,856 GOR
- Wells completed between ~2011-2016

Redtail/East Pony Field Production





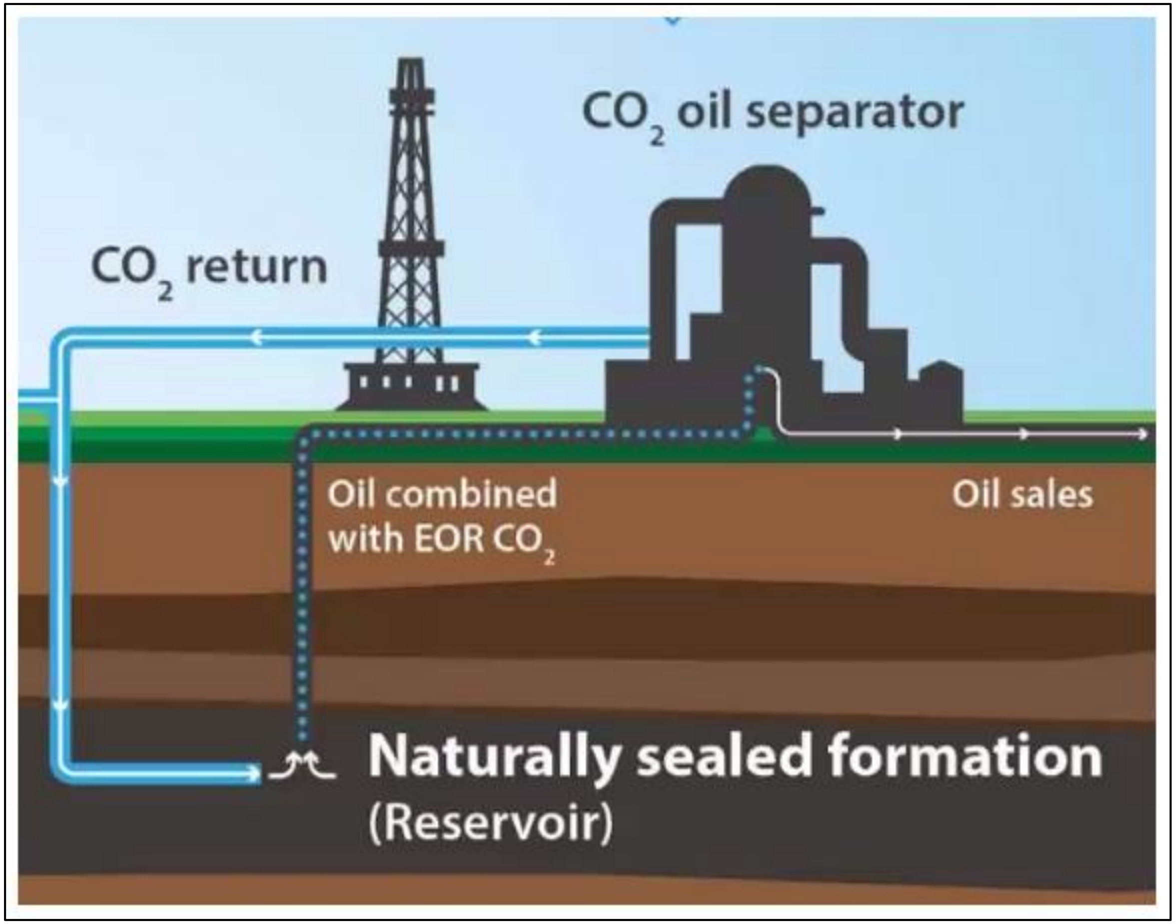
- 160 Horizontal Wells
- ~6-8 Wells per Developed Section
  -Increased Around Razor 25-2514H Core
- 19,571,371 Cum Bbls Oil Produced
- 32,838,208 Cum MCF Gas Produced
- 25,020 Bbls/Oil/1,000’ of Lateral
- 41,386 MCF/Gas/1,000’ of Lateral
- 1,766 GOR
- Wells completed between ~2012-2016

- 32 Horizontal Wells
- ~2-4 Wells per Developed Section
- 2,629,164 Cum Bbls Oil Produced
- 3,985,642 Cum MCF Gas Produced
- 16,006 Bbls/Oil/1,000’ of Lateral
- 25,116 MCF/Gas/1,000’ of Lateral
- **1,570 GOR**
- **Lowest Overall/Average Production and GOR**
- Wells completed between ~2012-2016

CCUS Overview

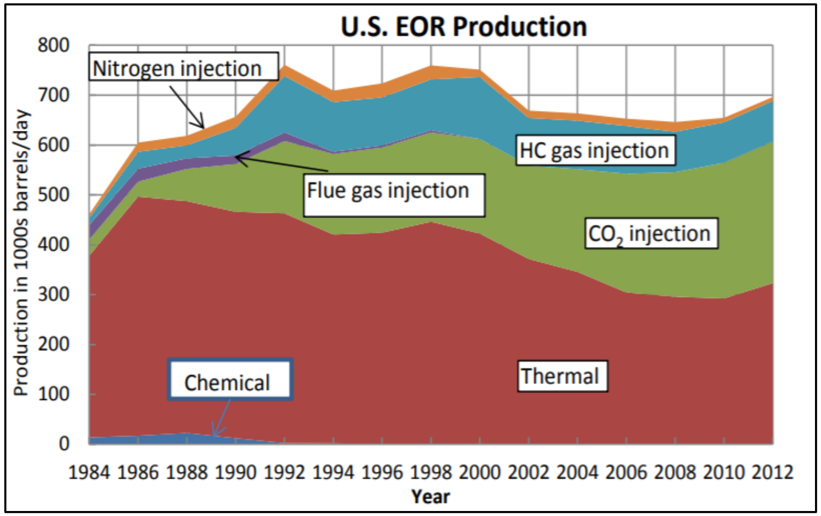
- CCUS is the is the process to capture CO_2 from gas, utilize that carbon in some way, and find a safe, permanent storage option
- CO_2 can and has been used successfully by the oil and gas industry for enhanced recovery techniques, most notably, Enhanced Oil Recovery (EOR)
  - Up to 80% of oil can be left in place after primary and secondary recovery methods
- Four major types of enhanced recovery are:
  - **Enhanced Oil Recovery (EOR)**
  - Enhanced Coalbed Methane Recovery (ECBM)
  - Enhanced Gas Recovery (EGR)
  - Enhanced Shale Gas Recovery (ESGR)
- 45Q tax credit introduced in 2008 originally provided $10/t$CO_2$ stored via CCUS and $20/t$CO_2$ stored via CCS
  - Since increased to $35/t$CO_2$ stored via CCUS and $50/t$CO_2$ stored via CCS
- Hydrocarbon gas injection also increasingly being used

CCUS Process

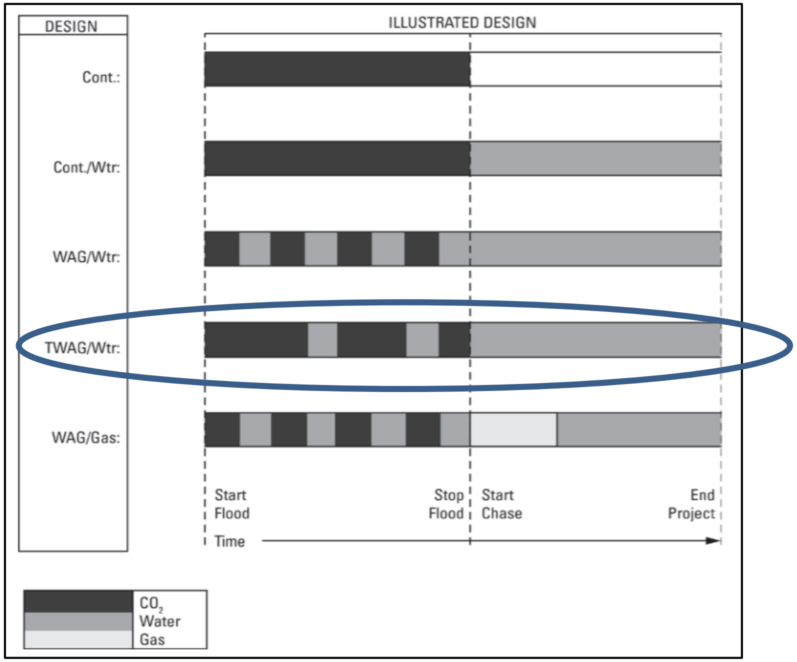


CCUS Process *Schematic (University of North Dakota EERC, 2021)*

CCUS Practicality and Design



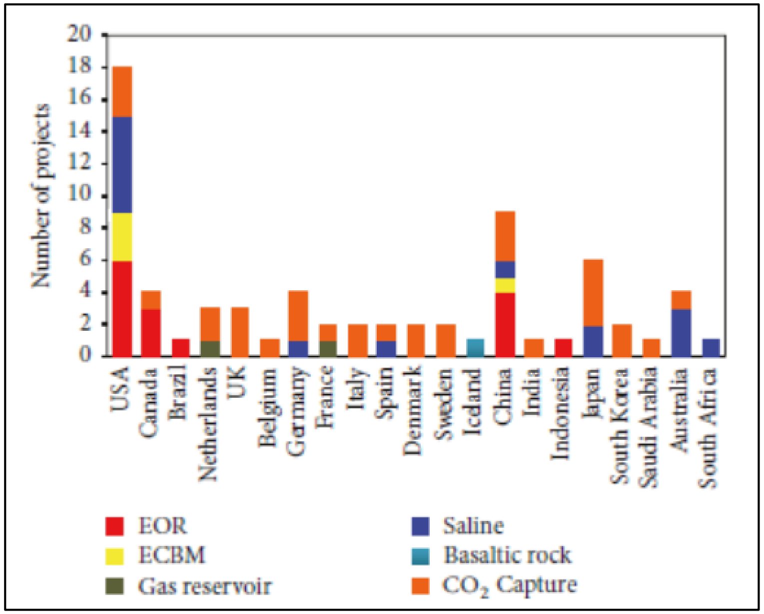
U.S. EOR Production by year Showing an Increase in CO_2 *Injection* (Koottungal, 2012)



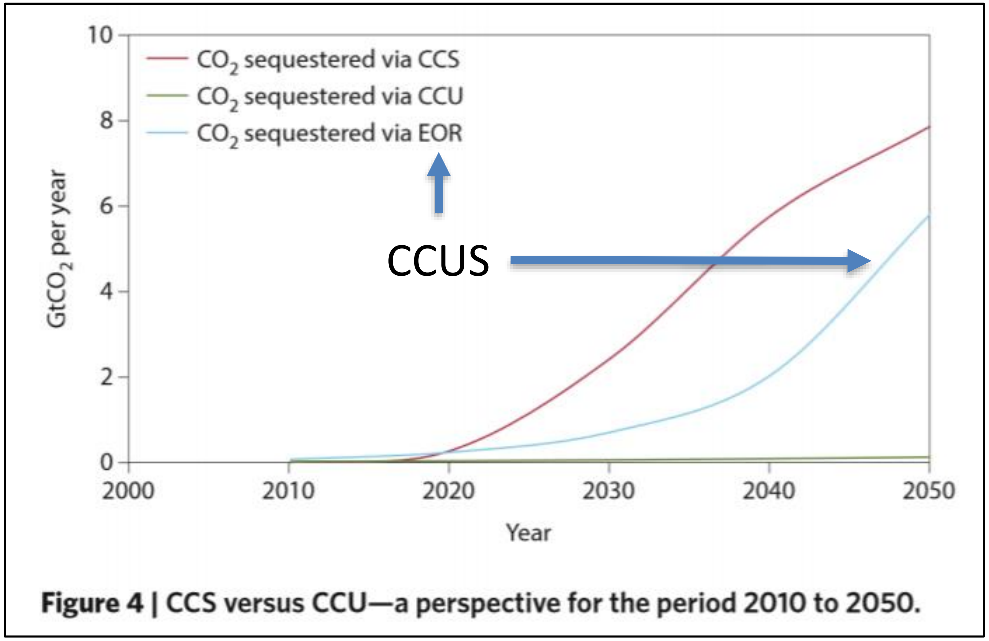
CO_2 *Flood and Injection Designs Schematic (Jarrell et al., 2002)*

- Tapered Water Alternating Gas or TWAG is the most common technique where the water acts as a “slug” pushing the hydrocarbons through the reservoir to production
- CO_2 has ~60% success factor in remaining stored

CCUS- Where Are We Today?



Graph from (Liu, et al., 2017) *Showing CC(U)S Projects by Country*



Projections of CO_2 *Sequestration by Method Modified* (Serdoner, 2019)

- Most of the CCUS projects are in the United States and most of those are EOR
- To put the graph on the right in perspective, the world released ~33 gigatons of CO_2 in 2019

CCUS Projects and Operators

Region	Projects	Operators
Permian (TX, NM)	80	Apache, Chevron, ConocoPhillips, Fasken, Four Corners Petroleum, George R. Brown, Great Western Drilling, KinderMorgan, Oxy, OrlaPetco, Remnant, Sabinal, Tabula Rasa, XTO
Gulf Coast (MS, LA, TX)	25	Denbury, Hillcorp, Tellus, TMR Exploration
Rockies (WY, UT, MT, CO)	17	Amplify Energy, Chevron, Denbury, Devon, Elk Petroleum, Fleur De Lis
Mid Continent (OK, KS)	10	Daylight Petroleum, Maverick Energy, Perdure Petroleum, PetroSantander
Mid West (MI)	10	Core Energy
Total	142	

Table of CCUS Projects by Region and Operator (CCUS)

Region	Updated U.S. CO_2 EOR Survey (EOY 2019)		
	No. Projects	Enhanced Recovery* (MB/D)	CO_2 Supply (MMcf/D)
Permian Basin (W TX, NM)	80	204.4	1,830
Gulf Coast (MS, LA, E TX)	25	43.3	600
Rockies (CO, WY, MT, UT)	17	38.8	445
Mid Continent (OK)	10	11.3	135
Mid West (MI)	10	1.4	20
Total	142	299.3	3,030

Table of CCUS Projects by Enhanced Recovery and CO_2 Supply (CCUS)

The Status of U.S. CO_2 EOR (EOY 2019)

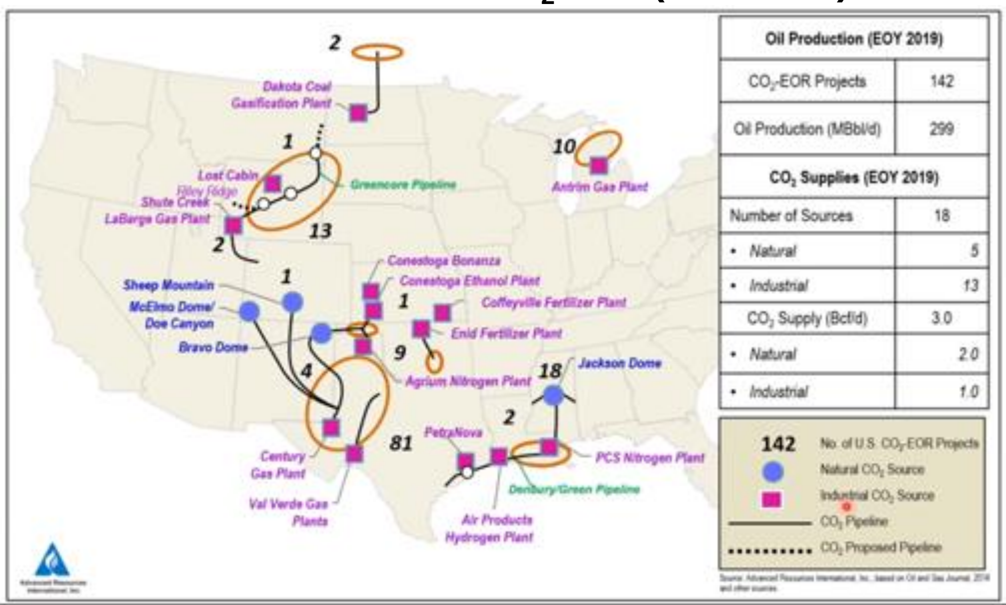
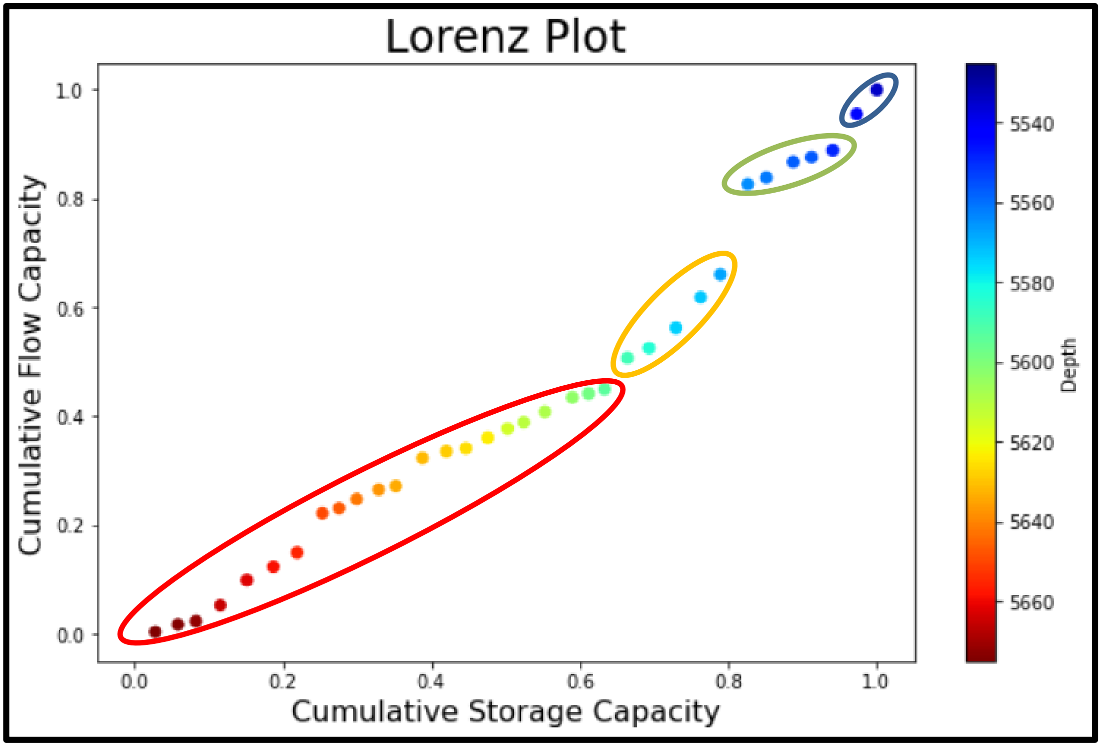
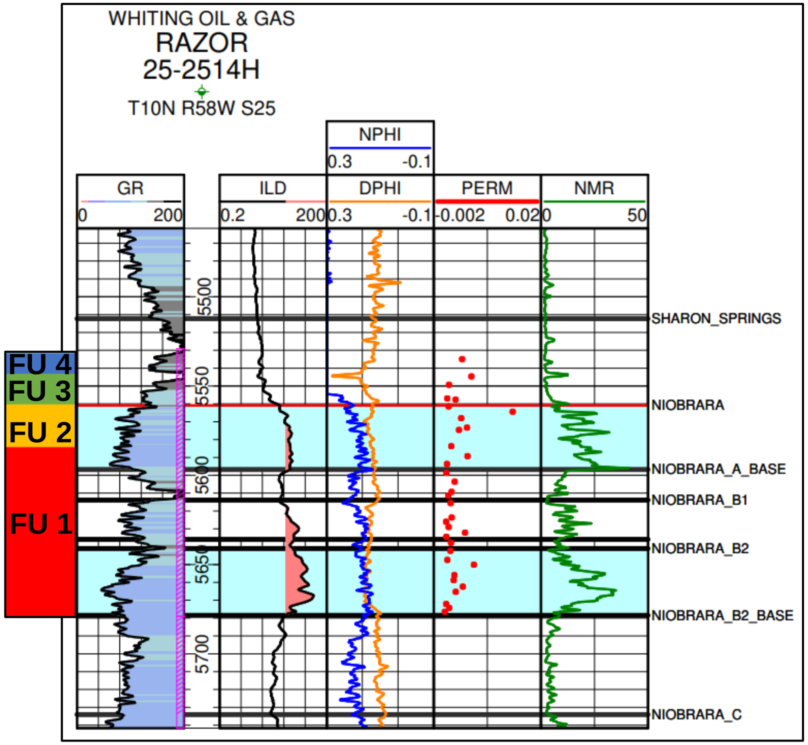


Table of CCUS Projects by Region (CCUS)

- As of 2019, 27 operators engaging in CCUS in the United States
- CCUS producing ~300k BOEPD
- Chevron operates in the Redtail/East Pony Field, and is engaged in CCUS projects in other areas

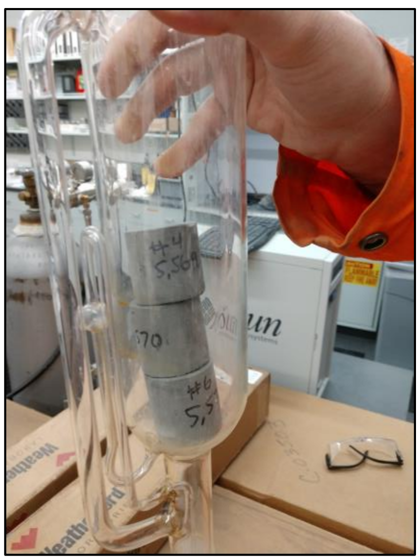
Flow Units of Razor Core Over Niobrara A & B





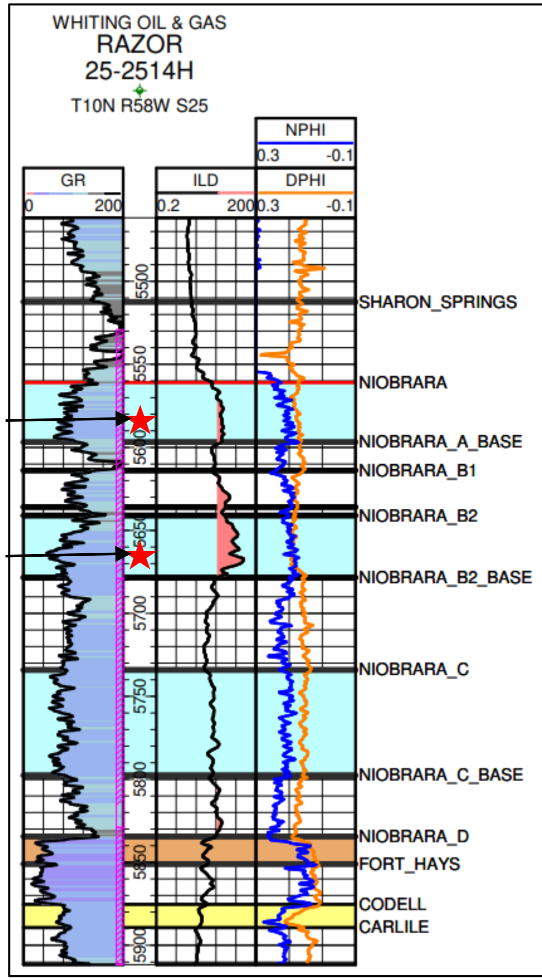
- Flow Unit 1 generally defines the payzone of the Niobrara B and A
- Flow Unit 2 defines the more limited hydrocarbon zone of the upper Niobrara A
- Flow Unit 3 defines just above the Niobrara A low permeability to porosity interval
  - -Could be promising for CO_2 storage by providing a barrier helping prevent escape
- Flow Unit 4, just 2 data points, is the Sharon Springs above the hot shale marker
- As expected, the NMR curve is highly correlated with permeability lab measurements and also offers a comparison between the overlying Sharon Springs formation and marls in between the Niobrara Intervals

Core Plugs for Experiment



6 Niobrara A Core Plugs

5 Niobrara B Core Plugs

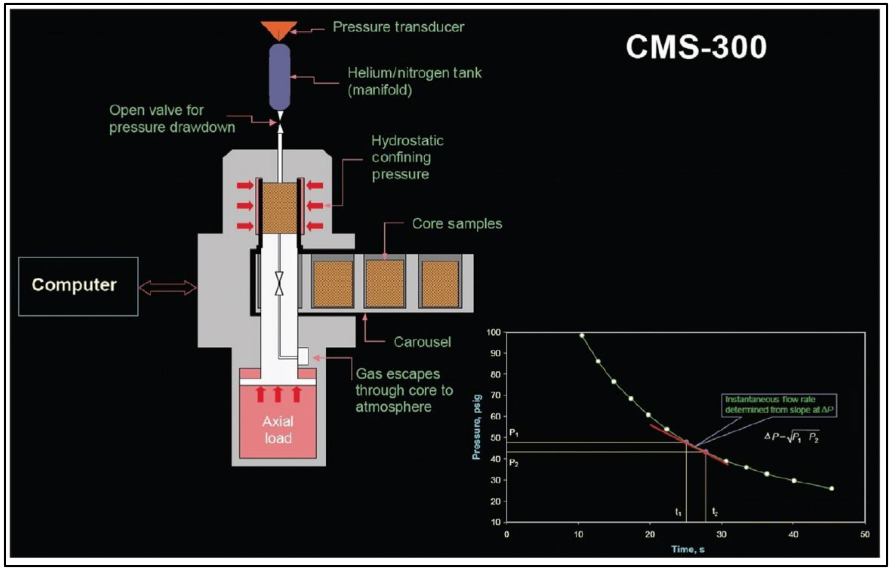


Sample #	Depth	Formation
1	5,563.25	Niobrara A
2	5,569.25	Niobrara A
3	5,569.50	Niobrara A
4	5,569.75	Niobrara A
5	5,570.00	Niobrara A
6	5,570.50	Niobrara A
7	5,664.75	Niobrara B
8	5,665.75	Niobrara B
9	5,670.00	Niobrara B
10	5,670.50	Niobrara B
11	5,672.50	Niobrara B

- 11 1.5” diameter, 2” tall core plugs being chemically cleaned with chloroform, toluene, and methanol for experimentation
- Niobrara C core proved too unstable to effectively run lab tests on; focus on the Niobrara A & B with samples spanning ~8’ over the payzone

Methodology of Lab Work

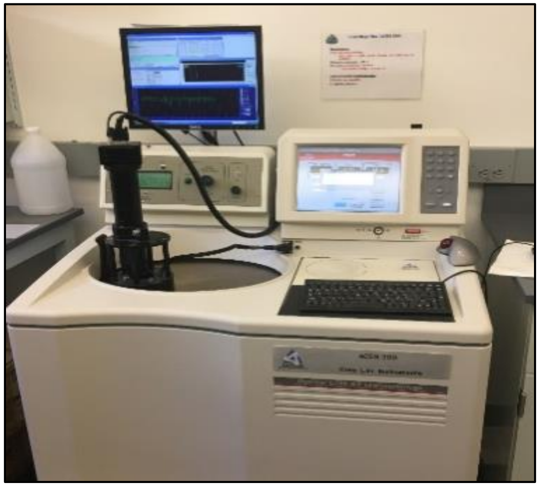
- Core Measurement System (CMS 300) to measure porosity, permeability, and pore volume at different confining stresses



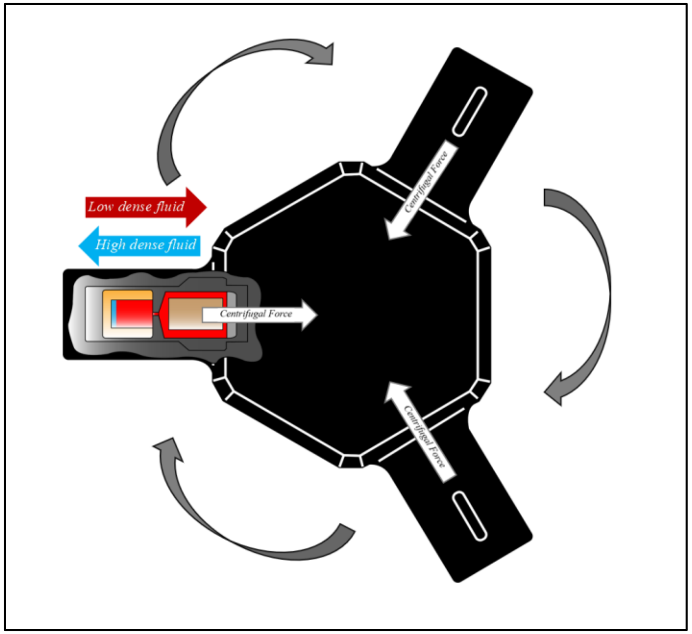
Core Laboratories CMS-300 unsteady-state permeameter/porosimeter (McPhee et al. 2015)

Methodology of Lab Work

- Use the Beckman ultra-fast centrifuge (ACES-200) to surround and oil saturated core plug with another type of fluid (such as CO_2 or methane) to displace the fluid inside the core observing changes quantitatively and qualitatively
- A high resolution camera and captures the fluid interaction and data is collected looking at changes in oil saturation



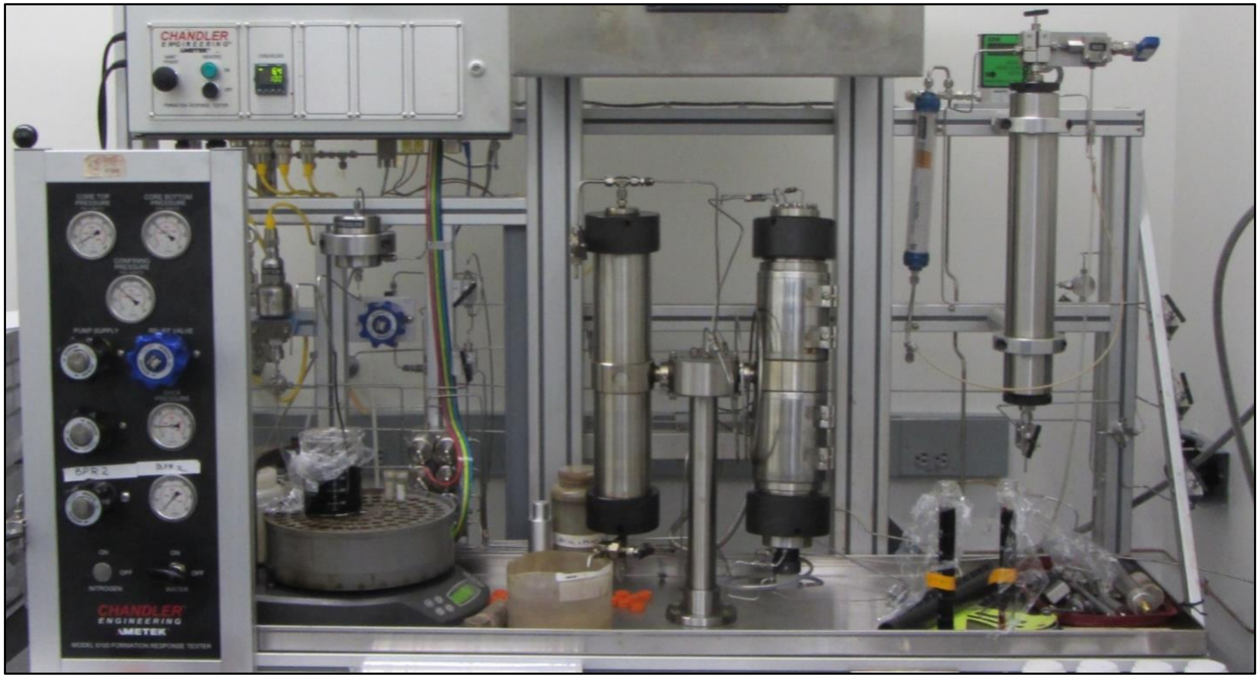
Core Laboratories ACES-200 ultra-high-speed centrifuge (Uzun 2018)



Schematic of Centrifuge (Uzun 2018)

Methodology of Lab Work

- Chandler's Formation Response Tester (FRT) Model 6100 allows CO_2 to be flowed across the core to observe permeability changes
  - Can look at both potential production flow or injection treatments



Chandler's FRT Model 6100 (Chandler Engineering, 2020)

Research Moving Forward

- Run the aforementioned lab tests over the Summer and Fall
- Tie in lab results to log data to make this process repeatable in lieu of core
- Detailed mapping work in the Redtail field, particularly for gross/net thickness and porosity to understand the Niobrara A and B
- Understand the porosity and permeability of the Sharon Springs as it’s important to mitigate CO_2 leakage

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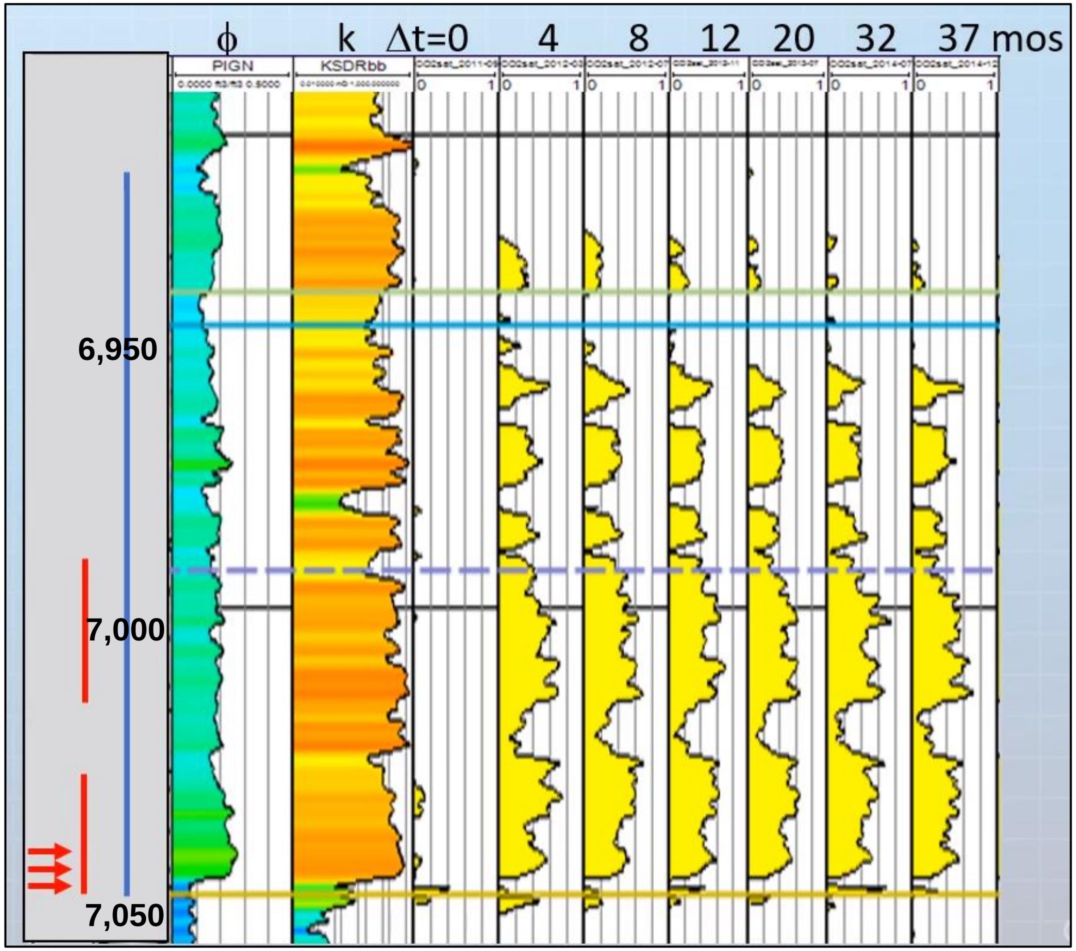
Case Study: Cased Hole Log Monitoring



Cased Hole Logging Response by Month After CO_2 Injection (Frailey, 2021)

- CCS project by the Illinois Geological Survey as part of the Illinois Basin Decatur project
- Pumped ~1,000 tons/day of CO_2 over ~3 years for a total of ~1M tons of CO_2
- Above the perforated interval, some leakage, but not much
- Increased leakage first ~4 months, but steady after
- Shale break above image where there was no CO_2 observed from this experiment

CCUS Geologic Parameters

Number of projects	Lithology	Porosity (percent)	Perm. (md)	Depth (feet)	Gravity (°API)	Viscosity (cp)	Temp. (°F)
Miscible							
42	ss.	7–26	16–280	1,600–11,950	30–45	0.6–3.0	82–257
2	ss./ls.-dol.	10	4–5	5,400–6,400	35	1	170–181
41	dol.	7–5	2–28	4,000–11,100	28–42	0.6–6.0	86–232
12	dol./ls.	3–12	2–5	4,900–6,700	31–44	0.4–1.8	100–139
6	ls.	4–20	5–70	5,600–6,800	39–43	0.4–1.5	125–135
1	dol./trip. chert	13.5	9	8,000	40	NA	122
7	tripolite	18–24	2–5	5,200–7,500	40–44	0.4–1.0	101–123
1	inadequate data						
Immiscible							
8	ss.	17–30	30–1,000	1,500–8,500	11–35	0.6–45	99–198
1	dol.	17	175	1,400	30	6	82

Table Showing EOR Projects Broken into Lithology, Porosity, Permeability, etc. (Koottungal, 2012)

Optimum reservoir parameters and weighting factors for ranking oil reservoirs suitable for CO_2 EOR

Reservoir parameters	Optimum values	Parametric weight
API Gravity (°API)	37	0.24
Remaining oil saturation	60%	0.20
Pressure over MMP (MPa)	1.4	0.19
Temperature (°C)	71	0.14
Net oil thickness (m)	15	0.11
Permeability (mD)	300	0.07
Reservoir dip	20	0.03
Porosity	20%	0.02

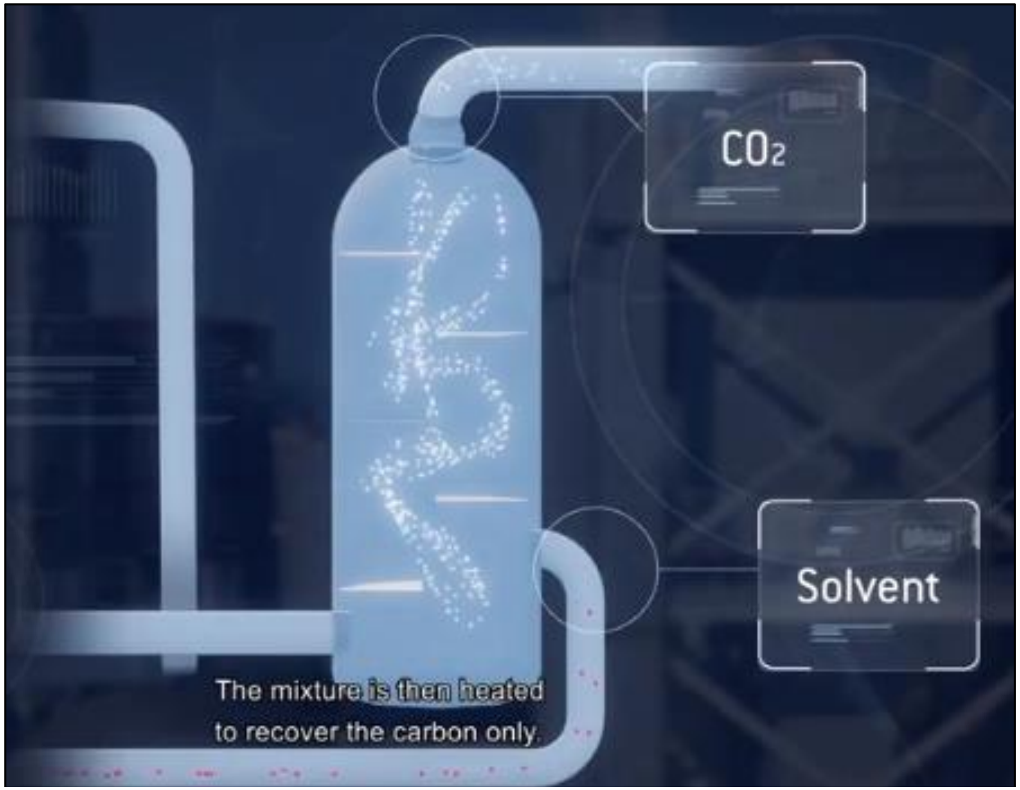
Chart Weighing the Various Parameters for EOR (Gozalpour, Ren, & Tohidi, 2005)

- All types of reservoirs (siliclastic, carbonate, etc.) are suitable for EOR
- Most of the applications of EOR have been with medium to light gravity oils
- As shown, the API of oil, OIP, pressure and temperature matter more than other geologic parameters though permeability is important and imperative
- Miscible (where CO_2 mixes with oil) is preferred as that better facilitates production

CCUS Process

Images from a Video Explaining Part of the CCUS Process (Total, 2018)

CO_2	○
Flue Gas	(blue circle)
Solvent	(red circle)



Finally, the mixture is heated to recover just the carbon where it is cooled and used for various purposes including to produce more hydrocarbons

Maybe?

Monitoring Technology