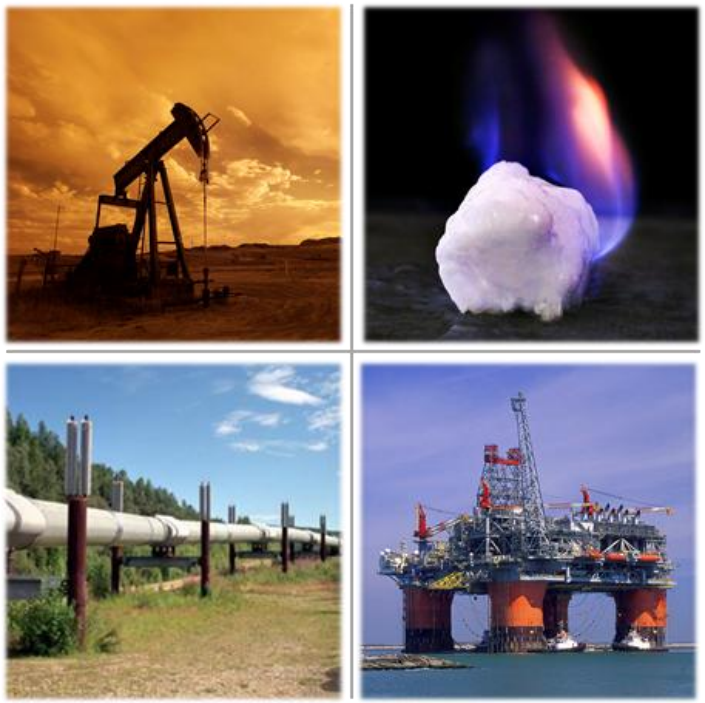


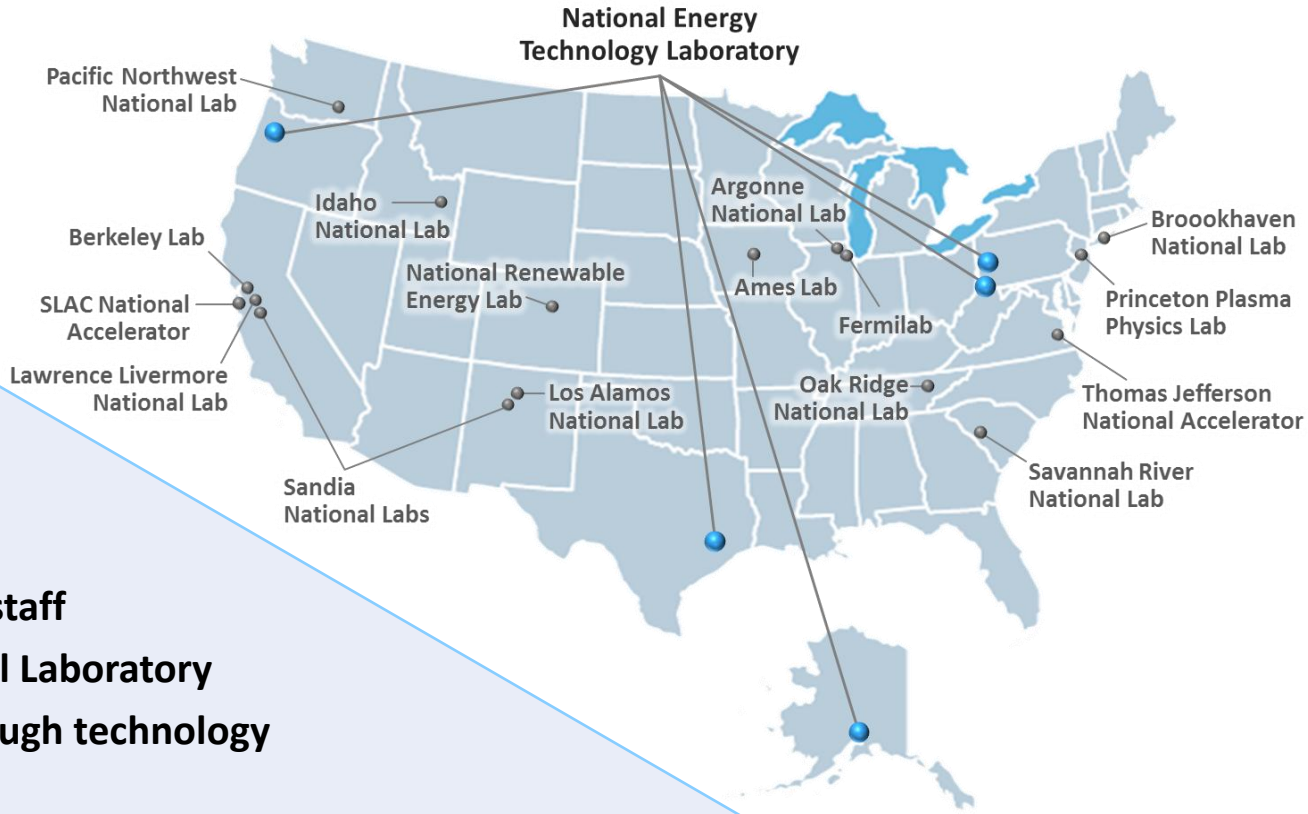
DOE CO_2 EOR Research: Summary of Recent Projects

NorTex CO_2 EOR Symposium
Rice University

Eric Smistad
Oil and Gas Technology Manager

October 5, 2015

National Energy Technology Laboratory



- Partner in DOE's national laboratory system
- Five locations with 1,200 staff
- 'Full-service' DOE National Laboratory
- Fundamental science through technology demonstration
- Unique industry, academia and government collaborations
- The Nation's only laboratory focused on fossil energy
- The only government-owned, government-operated DOE national lab

NETL's Unique Business Model

National Lab like no other

NETL's Role:

1. **Provide Financial Assistance through "Co-operative Agreements"**
   - "Substantial" DOE involvement to ensure "Best Effort"
   - Require Cost Share → 4 R's (Risk Reduction, Relevant Research)
2. **On-Site Research to fill R&D gaps**
3. **Systems Analysis to guide R&D programs**
4. **Collaboration at multiple scales – Partnerships Critical to Mission**

NETL Core Competencies:

1. **Leveraging science and engineering to accelerate scale-up and technology commercialization**
2. **Coordinating large complex projects and demonstrations**
   - NEPA Regulations, Outreach
3. **Managing projects and R&D collaborations with international scope**

Partnerships Critical to Oil & Gas Mission

Government

Los Alamos National Laboratory
Pacific Northwest National Laboratory
BSEE Bureau of Safety and Environmental Enforcement
Department of the Army
Lawrence Livermore National Laboratory
United States Environmental Protection Agency
USGS science for a changing world
Berkeley Lab
Sandia National Laboratories
Argonne National Laboratory
Oak Ridge National Laboratory

Academia

West Virginia University
University of California
Carnegie Mellon
Princeton University
University of Pittsburgh
Penn State
MIT
OSU Oregon State University
Virginia Tech
UK University of Kentucky

Industry

Anadarko
Marathon Oil Corporation
Statoil
Landmark A Halliburton Company
bhpbilliton resourcing the future
Petrobras
Total
WesternGeco
Sigma³
RPSEA Research Partnership to Secure Energy for America
SEG
RSI
Repsol
CGG Passion for Geoscience
devon
nexen
PGS
Maersk Oil
Chevron Human Energy
Geotrace
emgs
ion GX Technology
ConocoPhillips
ExxonMobil Upstream Research
Eni
Hess

Social Responsibilities

Take Our Daughters and Sons to Work
Celebrate Earth Day! April 22
WV Regional Science Bowl
Society for Analytical Chemists of Pittsburgh
southwestern pa ScienceBowl
2015 NSB National Science Bowl a competition like no other
Society of Pittsburgh Spectroscopy 1946
Pittsburgh Regional Center for Science Teachers University of Pittsburgh
Mickey Leland Energy Fellowship

CO_2 EOR Portfolio Structure

- Research focus "Next Generation" CO_2 EOR R&D
- Four general technology development areas:
  - Mobility Control Enhancement
  - Improved Flood Conformance
  - Monitoring Technology Enhancement
  - Planning and Evaluation Enhancement
- Eleven on-going/recently completed projects

CO_2 EOR Project Portfolio

- **Engineered Nanoparticle-Stabilized CO2 Foams to Improve Volumetric Sweep of CO2 EOR Processes (U. Texas - Austin)**
- **Novel CO2 Foam Concepts and Injection Schemes for Improving CO2 Sweep Efficiency in Sandstone and Carbonate Hydrocarbon Formations (U. Texas - Austin)**
- **Nanoparticle-Stabilized CO2 Foam for CO2-EOR Application (New Mexico Institute of Mining and Technology)**
- **Improved Mobility Control in CO2 Enhanced Recovery Using SPI Gels (Impact Technologies LLC)**
- **Development of an Advanced Simulator to Model Mobility Control and Geomechanics During CO2 Floods (U. Texas - Austin)**
- **CO2-EOR and Sequestration Planning Software (NITEC LLC)**
- **Carbon-Dioxide-Enhanced Oil Production from the Citronelle Oil Field in the Rodessa Formation, South Alabama (University of Alabama at Birmingham)**
- Novel Surfactant-Based Concepts for Improved Mobility Control of CO_2 Floods (NETL-RUA)
- Case Studies of the ROZ CO2 Flood and the Combined ROZ/MPZ CO2 Flood at The Goldsmith Landreth Unit, Ector County, Texas (U. Texas – Permian Basin)
- Small Molecule Associative Carbon Dioxide (CO2) Thickeners for Improved Mobility Control (University of Pittsburgh)
- Development of Nanoparticle-Stabilized Foams To Improve Performance of Water-less Hydraulic Fracturing (U. Texas - Austin)

CO_2 EOR/Sequestration Project Portfolio

- **A Nonconventional CO2-Enhanced Oil Recovery Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone (University of Illinois)**
- **Carbon Life Cycle Analysis of CO2-EOR For Net Carbon Negative Oil (NCNO) Classification (University of Texas Austin)**
- **Identification of Residual Oil Zones in the Williston and Powder River Basins (University of North Dakota)**
- **Improved Characterization and Modeling of Tight Oil Formations for CO2 Enhanced Oil Recovery Potential and Storage Capacity Estimation (University of North Dakota)**
- **Optimizing CO2 Sweep Based on Geochemical and Reservoir Characterization of the Residual Oil Zone of Hess Seminole Unit (University of Texas Austin)**

Portfolio Technology Development Areas

- **Mobility Control Enhancement:** Improve the mobility ratio between the injected CO2/water and the residual oil in the reservoir
- **Improved Flood Conformance:** Reduce the unproductive channeling of CO2 (and water) through high permeability reservoir flow paths
- **Monitoring Technology Enhancement:** Develop and enhance data acquisition and processing systems to improve monitoring of CO2 flood performance
- **Reservoir Modeling Tool Improvement:** Develop improved planning and monitoring tools to optimize the technical and economical performance of CO2 floods

Current Projects Focus Matrix

Project	Performer	Improved Mobility Control	Improved Flood Conformance	Enhanced Monitoring	Enhanced Modeling, Planning	Demo to Accelerate Application
SPI Gels	Impact Tech.	X	X			X
Nanoparticle Foams 1	U. Texas (Austin)	X	X			X*
Nanoparticle Foams 2	New Mexico Tech	X	X			X*
Surfactant Foam	U. Texas (Austin)	X	X			X*
Surfactant Concepts	NETL	X	X		X	X
CO_2 Thickners	U. Pittsburgh	X	X		X	X*
Nanoparticle Foams 1A – Waterless HF	U. Texas (Austin)	X	X			
Optimize ROZ	U. Texas (PB)			X	X	X
Advanced Simulator	U. Texas (Austin)				X	
Planning Software	NITEC				X	
Citronelle Demo	U. Alabama Birmingham					X

* Industry field test planned, not part of project

CO_2-EOR Selected Projects Status

- **Improved Mobility Control in CO2 Enhanced Recovery Using SPI Gels (Impact Technologies LLC)**
- **CO2-EOR and Sequestration Planning Software (NITEC LLC)**
- **Engineered Nanoparticle-Stabilized CO2 Foams to Improve Volumetric Sweep of CO2 EOR Processes (U. Texas - Austin)**
- Small Molecular Associative Carbon Dioxide (CO2) Thickeners for Improved Mobility Control (University of Pittsburgh)
- Case Studies of the ROZ CO2 Flood and the Combined ROZ/MPZ CO2 Flood at The Goldsmith Landreth Unit, Ector County, Texas (U. Texas – Permian Basin)

Improved Mobility Control in CO2 Enhanced Recovery Using SPI Gels

Impact Technologies Inc.

Goal: Demonstrate the potential of Silica Polymer Initiator-Carbon Dioxide (SPI-CO_2) gel systems for profile modifications in CO_2 injection/production wells.

SPI Gel Characteristics

- SPI gels are multi-component silicate based gels for improving (areal and vertical) conformance in oilfield enhanced recovery operations
- SPI chemical components are environmentally friendly, with most of the base materials suitable for food grade
- SPI mixtures are like-water when pumped, but form light up to very thick, paste-like gels in contact with CO_2
- SPI mixtures can also use internal initiators for a time/temperature based gelation. Ranging from minutes up to 36 hours based on temperature and concentrations of the mixture
- SPI gels are 3 to 10 times stronger than gelled polyacrylamide gels now available, however, they are not as strong as cement or epoxy, allowing them to be jetted out of the wellbore without drilling

Field Injection Study Setup

- A total of 8 SPI field treatments were performed in 6 wells (injection and production) with 2 operators. The injection study was completed in 2 different basins (Gulf Coast and Permian) and 2 different rock types (sandstone and dolomite)
- Field A was in a central Mississippi sandstone that injected CO_2 as an immiscible process
- Field B was in the west Texas San Andres dolomite formation with a mature water-alternating-gas miscible CO_2 flood
- Field A treatments are now over 1 year old while Field B treatments have 3 months of data under variable WAG conditions

Full SPI Slip-Stream equipment Setup

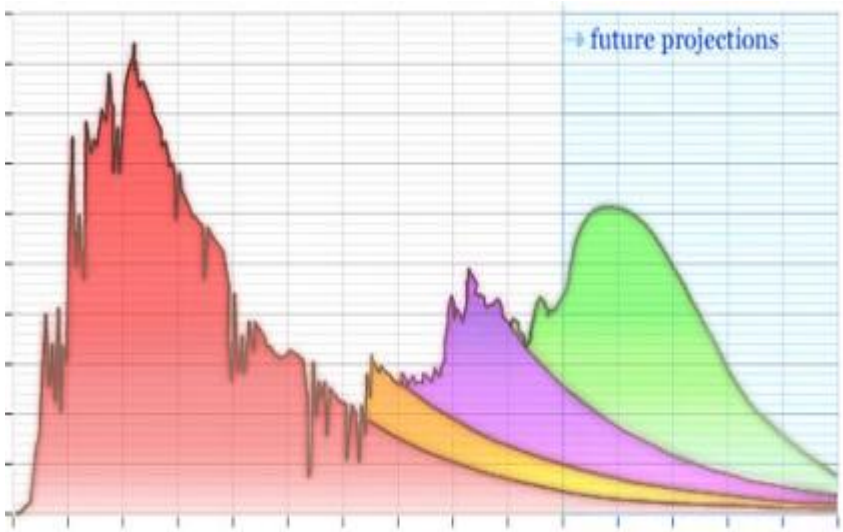
Field Injection Findings

- SPI gels were successfully injected into fractured sandstone and dolomite fields and in Gulf Coast and Permian Basins
- Gel injection was successful in moving CO_2 out into previously unswept zones of the reservoir (areal and/or vertical)
  - CO_2 injectivity in both fields were reduced by 23% to 70%
- Gels were effective in the field in both injection and production wells; lowering GOR, produced gas rate, and increasing oil recovery
  - Sandstone - Initial 81% GOR reduction in one production well; tapered to pre-production level after one year; incremental production 14,250 bbl
  - Dolomite - Increase of 66% incremental recovery (28.5 bbl/d to 47.3 bbl/d) in one production well over 90 day monitoring period
- Treatments were shown to last over one year (and running) in a difficult fractured sandstone system. Laboratory gel samples showed a similar life span
- Operational costs during the project were estimated at a high $50-70/bbl of SPI mix pumped

CO_2-EOR and Sequestration Planning Software

NITEC LLC

Goal: To develop a full-featured, user friendly Carbon Dioxide Enhanced Oil Recovery (CO_2-EOR) and sequestration planning software system to allow small- to mid-sized field operators to design and optimize CO_2-EOR and sequestration operations over a short period of time.



Planning Software Options

Expensive, top line, compositional, commercial simulation packages

ECLIPSE-300® (Schlumberger), VIP-Comp® (Halliburton), GEM® (CMG), Sensor® (Coats Engineering), and MORE® (Roxar)

NITEC Project

User Friendly, Full Featured, CO_2 EOR and Sequestration Planning Software

Simplistic solutions

Published charts, Volumetric methods, and PVT relationships

Directed towards development of a software tool that will accelerate CO_2 injection technical studies (for EOR and sequestration purposes) for small operators

Software Features

- The tool, called "COZ," addresses the significant physical and chemical factors that impact the flow and recovery, such as solubility of CO_2 in water/oil and swelling of oil in presence of CO_2
- Integrates a friendly, interactive user interface which handles pre- and post-processing of simulation results with a comprehensive 3D, 3-phase, 4-component reservoir simulator
- Studies on candidate reservoirs can be completed within one month, compared to the six-plus months required for other approaches
- Small- and mid-sized operators could save $250,000 per study

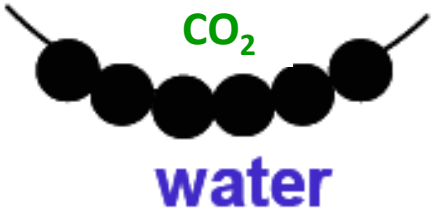
Current Status

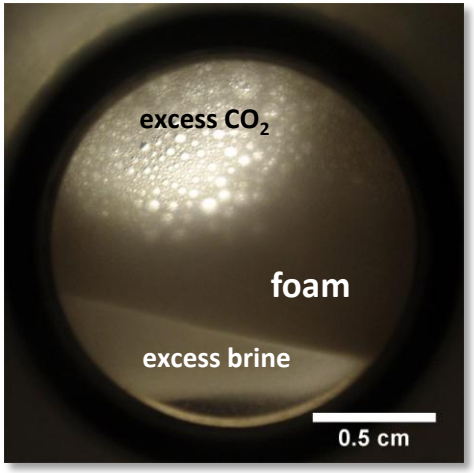
- The complete Software package can be downloaded for use at NITEC LLCs webpage. http://www.nitecllc.com/COZ_Download.html
- NITEC plans to support and enhance the software based on user funding to make it increasingly more beneficial for smaller oil field operators

Use of Engineered Nanoparticle-Stabilized CO_2 Foams to Improve Volumetric Sweep of CO_2 EOR Processes

University of Texas at Austin

- **Goal:** Develop engineered nanoparticles to create more stable (and thus more effective) foams designed to improve volumetric sweep efficiency and extend the range of the conventional CO_2 process
  - Synthesize silica nanoparticles with low-MW polymeric surface coatings to create CO_2-in-water foams with long-term stability over range of temperatures and salinities
  - Characterize these nanoparticles and foams
  - Develop a foam transport simulator to study the feasibility of field application





CO_2/brine foam generated by flow through fracture, stabilized with coated silica nanoparticles

Key Findings

- Surface coating of nanoparticle is key - appropriate balance of hydrophilicity and CO_2-philicity enables stable foams
- Foam generation requires critical shear rate; value depends on permeability of matrix
- Commercially available nanoparticles stabilize CO_2-in-water foams at range of reservoir conditions
- Foam viscosity large enough to improve sweep
- Evidence of diversion of flow from fracture into matrix at coreplug scale

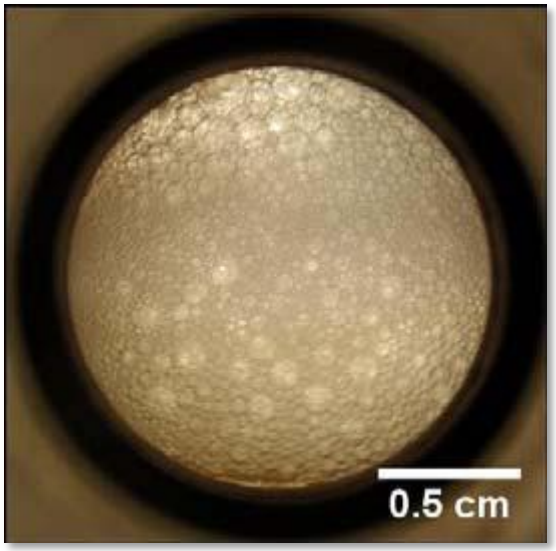


Image from view cell showing quality of foam generated with Nexsil 6-nm nanoparticle dispersion

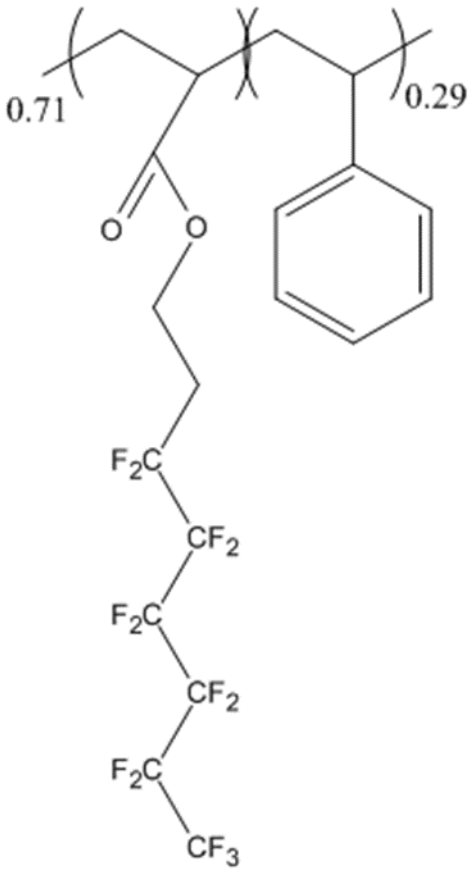
Current Pursuit

- Support design of nanoparticle-stabilized foam trial in existing CO_2 flood
  - Experimental evaluation of nanoparticles for reservoir fluids and field conditions
  - Evaluate foam transport and rheology in rock matrix
  - Simple modeling of single well response during field test
  - Production well response simulation

Small Molecule Associative Carbon Dioxide (CO2) Thickeners for Improved Mobility Control

University of Pittsburgh

Goal: Test the effectiveness of various CO_2 thickener compounds that can induce very large changes in CO_2 viscosity at typical injection and reservoir conditions associated CO_2-EOR.



Research Objectives

- Design or identify an effective, affordable (several dollars per pound), small molecule thickener
- Dissolve in CO_2 at typical reservoir conditions in dilute concentrations (< 1 w%)
- Increase the CO_2 viscosity by ~20-30

Alternative to WAG…….

- WAG requires massive amounts of water (brine)
- WAG delays the injection of the solvent (CO_2)
- WAG results in water production, water separation, water treatment, and water-reinjection facilities (a significant capital and operating expense)

Research Progress

- Letters of commitment have been obtained from Denbury Resources, Kinder Morgan, Tabula Rasa, and Conoco Phillips.
- Discussions are ongoing with Denbury Resources concerning the equipment requirements for a field trial
- Candidate compounds tested in sandstone core floods at NETL showed a modest increase CO_2 viscosity
- ARPA-e funded synthesis of new, small molecule thickener candidate capable of thickening CO_2 100-fold at a concentration of 1wt%.
  - Requires extremely large concentrations of a co-solvent.
  - Structure is currently being modified to reduce or eliminate the need for the co-solvent.

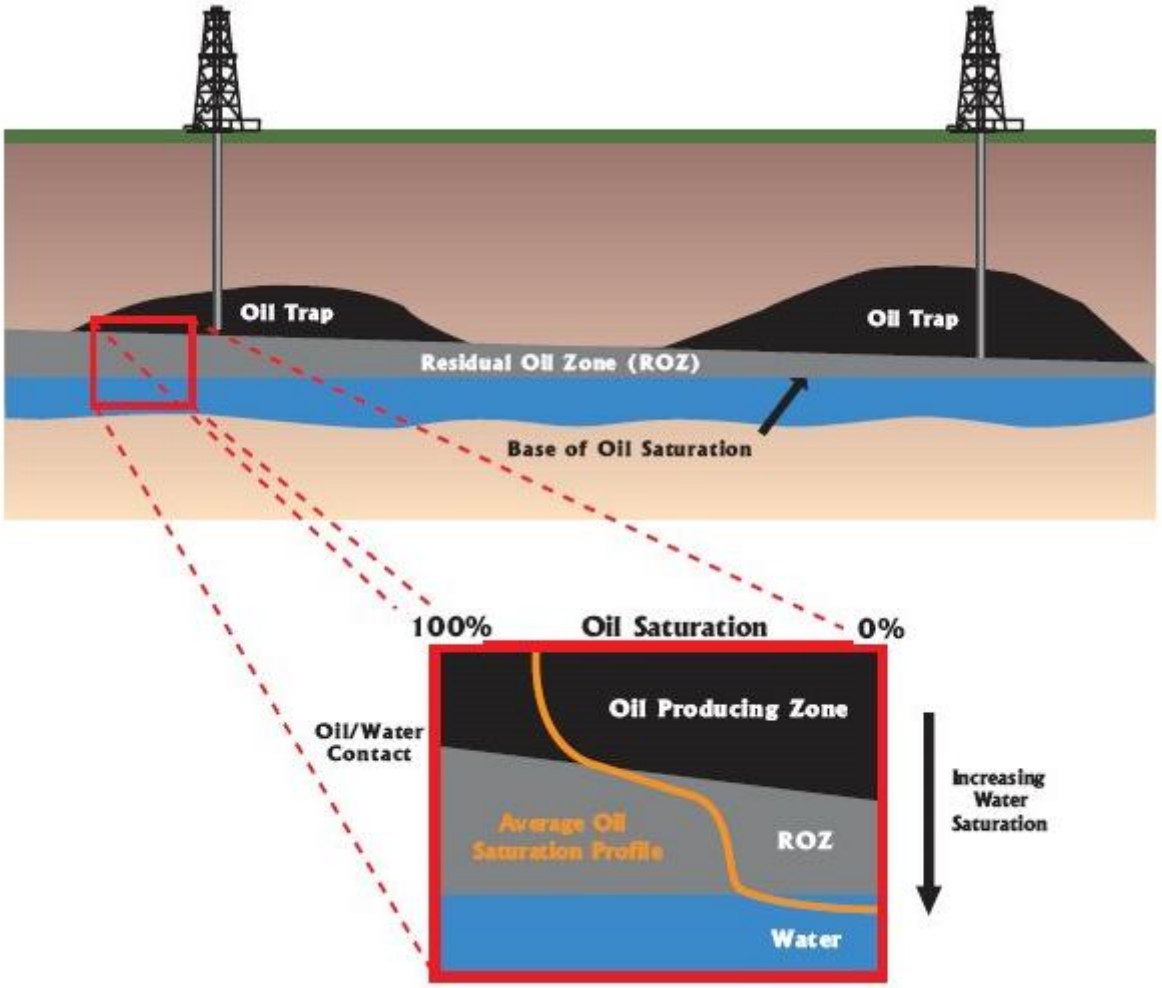
Case Studies of the ROZ CO_2 Flood and the Combined ROZ/MPZ CO_2 Flood at the Goldsmith Landreth Unit, Ector County, Texas

The University of Texas of the Permian Basin

Goal: Optimize the technical and economic performance of an ROZ CO_2 flood and transfer the knowledge to other operators.

Permian Basin CO2 injector

Residual Oil Zone



Research Questions and Objectives

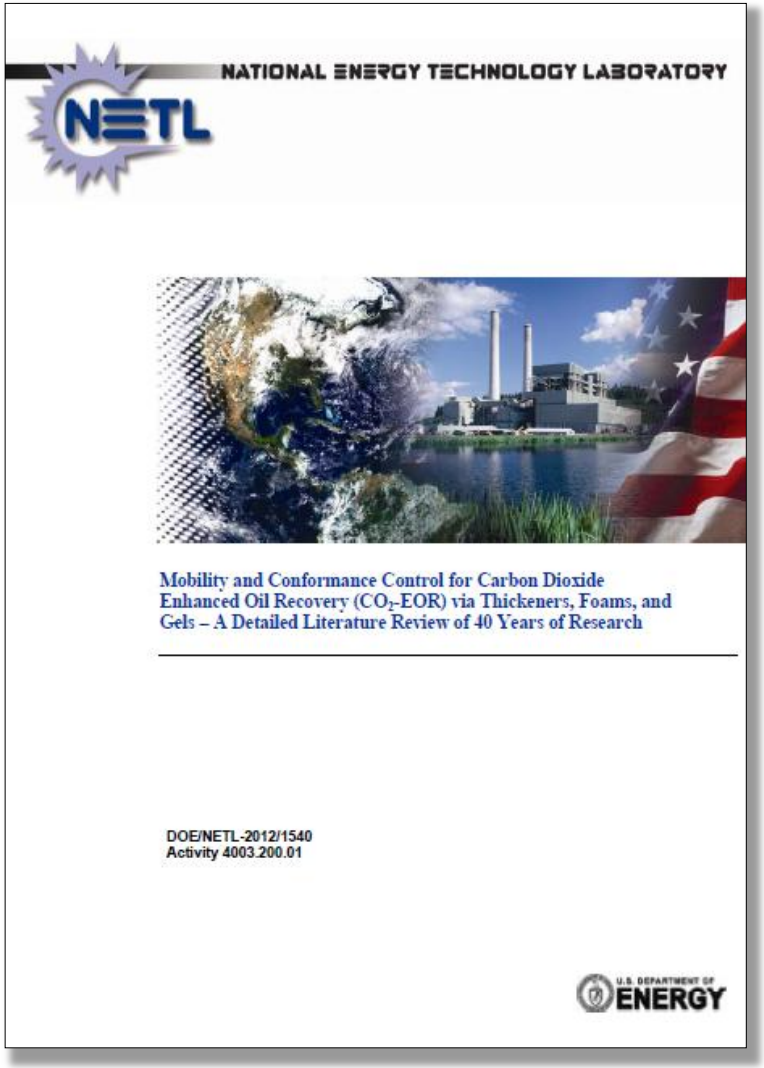
- Are there significant differences present in the reservoir between the (waterflooded) MPZ and ROZ?
  - Reservoir properties
  - Response to flooding
- Are there some promising next generation technologies or methods that can improve response to CO2 and project economics?
- Characterize the geology of MPZ and underlying ROZ
- Document and extrapolate performance of a ROZ flood and compare to a MPZ flood

Key Findings

- ROZ sections generally have slightly better porosity and permeability than the overlying MPZs
- Utilization factors for ROZ oil recovery are higher than the post waterflood CO_2 EOR MPZ
- ROZ sections have more complex water chemistries resulting in scaling tendencies
- Original depositional environment is more important than observed reservoir changes due to natural ROZ flooding
- When comingling the ROZ and MPZ intervals, a profile of uniform vertical injection is challenged and takes constant attention to more adequately distribute the injectant throughout the vertical section
- Novel CO_2 gas lift has been proven to work well in 4500’ depth environments and has reduced operating (lifting) and increased production
- Combined CO_2 gas lift and chemical treatment can further improve recovery and/or economics

NETL CO_2 Mobility Control Publication

- Review of 40 years of RD&D related to lab- and field-scale efforts to reduce CO_2 mobility using CO_2 thickeners, foams, and gels.
- Purpose: Show that mobility and conformance control for CO_2 EOR is technically and economically attainable, and catalyze continued effort to develop and apply technology.
- Report highlighted in a four-part series of articles in *World Oil*, beginning in April 2012

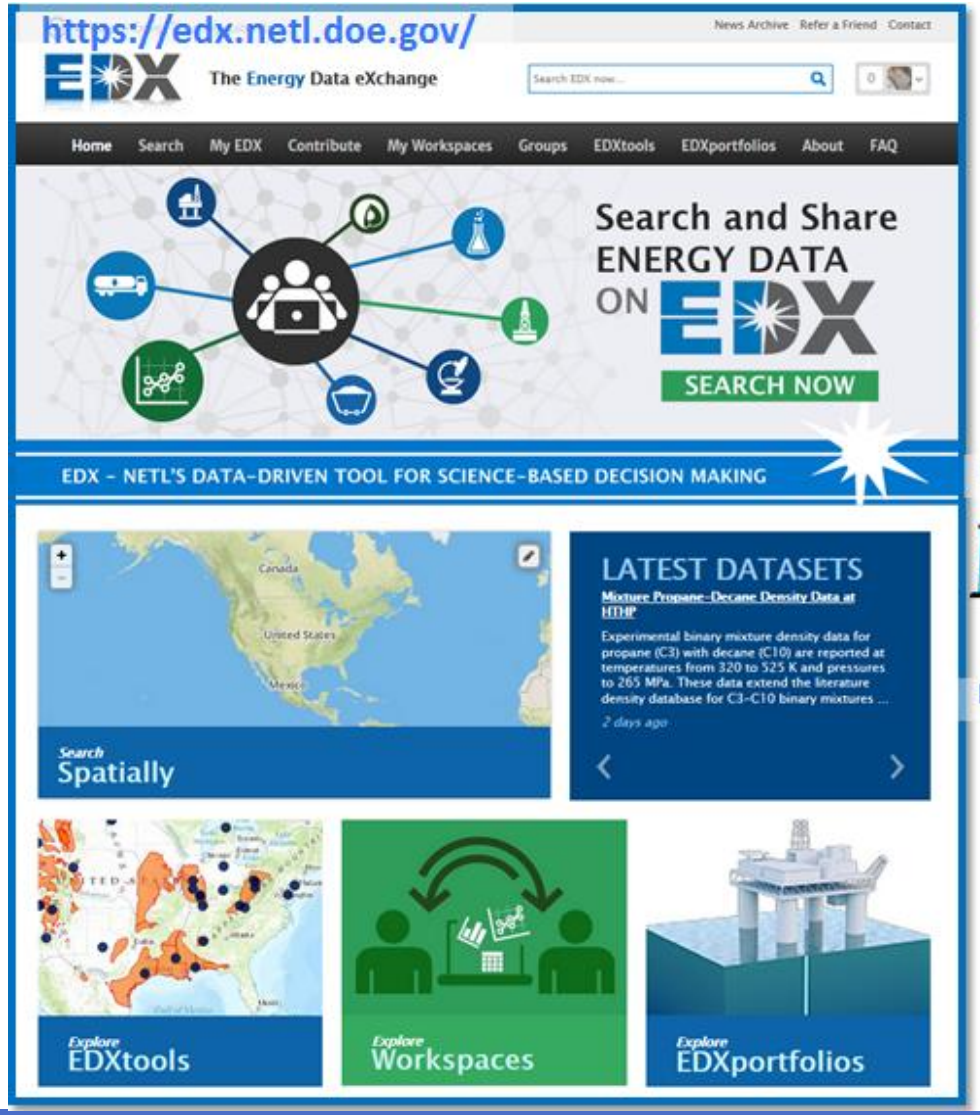

NATIONAL ENERGY TECHNOLOGY LABORATORY

Mobility and Conformance Control for Carbon Dioxide Enhanced Oil Recovery (CO_2-EOR) via Thickeners, Foams, and Gels – A Detailed Literature Review of 40 Years of Research

DOE/NETL-2012/1540
Activity 4003.200.01

U.S. DEPARTMENT OF ENERGY

EDX: NETL's Big Data Portal



Motivation for EDX was in part a result of the BP Deepwater Horizon

EDX is ready to serve if there are needs requiring multi-organizational energy R&D to support the government efforts.

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

What is EDX...

UCR Unconventional Resources

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

- An online platform for **rapid and efficient access** to priority datasets
- Provides an opportunity for researchers to **share** and "publish" online **datasets & data-driven products**
- A **secure** environment for **multi-organizational** research **teams** to share, build, and **collaborate** in a common workspace
- **Online** tool to **disseminate** data, information, and results from **DOE's Fossil Energy** intramural **research** portfolios

It’s All About a Clean, Affordable Energy Future




For More Information, Contact NETL

the ENERGY lab

Delivering Yesterday and Preparing for Tomorrow




Thank You!

eric.smistad@netl.doe.gov