“Residual Oil Zones: The Long Term Future of Enhanced Oil Recovery in the Permian Basin and Elsewhere”.

5th Annual EORI CO2 Workshop, Casper Wyoming

Dr. Bob Trentham, University of Texas of the Permian Basin.
The 100 Billion Barrel Question

• For decades, when asked, geologists would say there were +/-100 BB OOIP in the Permian Basin and that we have produced roughly ~1/3 of that total.

• 75 MYA the answer to that question may have been 300 BB OOIP.

• Today, with our new understanding of the potential extent of, and oil saturation within, Residual Oil Zones (ROZ’s) the answer lies somewhere between those numbers.

• How did we get here from there?

• Through Mother Nature’s Waterflood.
**Size of the Prize**

56 fields in five major Permian Basin oil plays that have potential for significant TZ/ROZ resources were identified by Advanced Resources Intl. TZ/ROZ OOIP in these 56 fields is estimated to be 30.7 Billion Barrels.

<table>
<thead>
<tr>
<th>Field/Unit</th>
<th>MPZ OOIP (BB)</th>
<th>TZ/ROZ OOIP (BB)</th>
<th>No. of Fields</th>
<th>No. of MPZ Fields with CO2-EOR Projects</th>
<th>No. of Fields with TZ/ROZ CO₂-EOR Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Northern Shelf Permian Basin</td>
<td>13.0</td>
<td>13.2</td>
<td>13</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>(San Andres)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. North Central Basin Platform</td>
<td>2.9</td>
<td>2.6</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>(San Andres/Grayburg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. South Central Basin Platform</td>
<td>9.9</td>
<td>7.9</td>
<td>16</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>(San Andres/Grayburg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Horseshoe Atoll (Canyon)</td>
<td>5.4</td>
<td>2.9</td>
<td>10</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5. East New Mexico (San Andres)</td>
<td>2.3</td>
<td>4.1</td>
<td>11</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33.5</strong></td>
<td><strong>30.7</strong></td>
<td><strong>56</strong></td>
<td><strong>18</strong></td>
<td><strong>4</strong></td>
</tr>
</tbody>
</table>

Koperna, et, al., 2006
**Technically Recoverable Resources from the MPZ and ROZ**

Based on reservoir modeling of applying CO\textsubscript{2}-EOR to the TZ/ROZ resources, ARI estimates that there are **11.9 Billion BO** is technically recoverable from the 30.7 Billion BO of TZ/ROZ oil in-place in these five Permian Basin oil plays.

<table>
<thead>
<tr>
<th>Field/Unit</th>
<th>Total CO\textsubscript{2}-EOR (BB)</th>
<th>MPZ CO\textsubscript{2}-EOR (BB)</th>
<th>TZ/ROZ CO\textsubscript{2}-EOR (BB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Northern Shelf Permian Basin (San Andres)</td>
<td>8.3</td>
<td>2.8</td>
<td>5.5</td>
</tr>
<tr>
<td>2. North Central Basin Platform (San Andres/Grayburg)</td>
<td>1.5</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>3. South Central Basin Platform (San Andres/Grayburg)</td>
<td>4.6</td>
<td>1.7</td>
<td>2.9</td>
</tr>
<tr>
<td>4. Horseshoe Atoll (Canyon)</td>
<td>2.7</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>5. East New Mexico (San Andres)</td>
<td>1.7</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18.8</strong></td>
<td><strong>6.9</strong></td>
<td><strong>11.9</strong></td>
</tr>
</tbody>
</table>

Koperna, et al., 2006
Mother Nature’s Waterflood
Changes in Hydrodynamic Conditions, Sweep of the lower part of the Oil Column, and Development of a Residual Oil Zone.

Dynamic System

Areas with ROZ without associated field

Uplift to the west of Permian Basin

Meteoric drive
<table>
<thead>
<tr>
<th>Epoch</th>
<th>Time Range</th>
<th>Event Description</th>
</tr>
</thead>
</table>
| Quat                | Pliocene - Pleistocene - Holocene | -5 Ma to Present  
Base level downcutting of ancestral Pecos River. At ~600 Ka Capitan Aquifer hydrologically connects with Pecos River at Carlsbad. Possible draining of lower Carlsbad and Lechuguilla Caverns. |
| Cenozoic            | Late Miocene | -12 to -5 Ma  
H2S ascends into Guadalupe Mtns from basin. Sulfuric acid caves develop from Se to NE, enlarge and cut across older thermal caves. |
|                     | Early Miocene| -25 to -12 Ma  
|                     | Oligocene    | -40 to -25 Ma  
|                     | Paleocene    | -65 to -58 Ma  
Laramide uplift continues into Early Tertiary. Older caves get enlarged and connected. |
|                     | Cretaceous-Gulfian | -95 to -65 Ma  
Late Cretaceous Laramide Orogeny begins. Guadalupe and Apache Mtns. Lifted 1000’s of feet above sea level. |
|                     | Guadalupian  | -255 to -251 Ma  
Seven Rives Yates and Tansill Backreef, Capitan Reef, Delaware Mountain Group Deposition. Early dolomitization in Apache and Glass Mountains. |

The top of the San Andres was uplifted over 7000’ by the tectonism. A gradient of ~80’ mile exists today between the Guadalupe Mountains (+6000’) and the Central Basin Platform (~1000’).
Bob Lindsay, correlated outcrops to Guadalupian fields, identifying the flushing pathway of “Mother Nature’s Waterflood” and framed it’s history.

Modified from Matchus & Jones, 1984
Alton Brown documented the distribution of Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin.*

The direction of OWC tilt may be influenced by the age of the producing interval and its relationship to the shelf margin.

* Brown, 1999, ** Ward et al, 1986
Proximity to the recharge. Relationship of San Andres outcrops and San Andres Fairways in New Mexico.
There are a number of probable pathways that will eventually documented
The Gold Standard
Seminole Water Saturation Profile.

**Reservoir Description:** Limestone and dolomite deposited in a shallow carbonate ramp environment.

**Fluid Type:** Saturated black oil

**Drive Mechanism:** Gas in solution and gas cap during primary. External energy from water and CO2 injection during secondary and tertiary recovery.

**Develop. History:**
- 1936: Discovery
- 1936: First Production
- 1969: Unitized/Waterflood
- 1983: MPZ CO2 Flood Begins
- 1996: ROZ Phase 1 Pilot
- 2004: ROZ Phase 2 Pilot
- 2007: ROZ Stage 1

**Cumulative Production:** 675 MMBO, 40 MMBOE NGL, 702 BCF HC Gas

**Current Rate:** 19.6 MBOPD, 200 MMCFD CO2+HC 25,500 MBOE PD (Oil+NGL+Gas)
Anecdotal Evidence

- Info from a growing number of exploration wells documents what can be interpreted as ROZ’s where the tests were unsuccessful as there was no associated primary production. Data from a number of explorationists and review and reinterpretation of research articles on Permian Basin fields, suggest a set of common ROZ characteristics:
  - Sample shows of oil and/or gas throughout the ROZ interval,
  - Sulfur water or salty sulfur produced on DST’s or attempted production tests, not salt water,
  - Cores with 20-40% oil saturation,
  - Log calculations that suggest producible hydrocarbons,
  - IP’s similar to mature waterflood.
  - Evaporites may be dissolved or altered in the lower part of the main pay.
  - The presence of sulfur crystals associated with gypsum/anhydrite/calcite in the ROZ,
  - Solution enhanced fractures in lower portion of the ROZ
  - Enhanced porosity and permeability in the ROZ relative to in the main pay zone as the result of meteoric dissolution of sulfates.
  - Pervasive “late” dolomitization indicating meteoric sweep.
  - “Tight” high So intervals near the BOSO transition.
  - Sequence stratigraphic boundaries to top and bottom of ROZ.
  - Possible oil and water chemistry differences between main pay and ROZ.
The new Residual Oil Zone Paradigms

• Large intervals and areas have been swept by the tectonically driven “Mother Natures Waterflood” which occurred post basin subsidence and oil emplacement.
• Thick intervals within the ROZ’s intervals have the same saturation characteristics as mature waterfloods (30-40% Sorw).
• Tests of ROZ’s produce high percentage of water on DST’s or completions, but not a “deal killer”.
• ROZ’s often are interpreted/calculated as producible in Exploration Wells, and Primary and Secondary Production Environments:
  – Good Odor, Cut, Fluorescence, and Gas in samples
  – 20 -40 % oil saturations in core
  – Calculate as oil productive on logs
• The “faux-productive” appearance of ROZ’s with significant thicknesses (50 to 300’) of CO2 EOR producible hydrocarbons and 20-50% So exist beneath both producing fields (Brown Fields) and in areas where there is no, or a minimum, producible oil column (Green Fields).
Pre Laramide
Original Oil Water contact at base of present ROZ
Post Basin and Range - Flow units, deeper in the reservoir and with higher permeability are swept

Field Wide - Tidal Flat/Sabkha provide updip permeability trap.
MP - Flow units within Main Pay unaffected by Meteoric derived sweep.
ROZ - Updip shallow subtidal and intertidal will produce low volumes/ low water cut
Downdip higher energy shelf produces “Mature Waterflood” oil cuts and volumes
Post Basin and Range
Most higher permeability Flow Units are Swept

Field Wide - Tidal Flat/Sabkha provide updip permeability trap.
Main Pay - Either thin producing interval or no associated producing interval
ROZ - Updip shallow subtidal and intertidal will produce low volumes/low water cut
Downdip higher energy shelf with “Mature Waterflood” oil cuts & large volumes
Post Basin and Range
Updip shallow subtidal and Intertidal are productive, downdip swept with mature waterflood IP’s

Well 5. Wet Attempted completion in ROZ deeper than Well 3
Well 4. Wet Attempted completion in Well 2 zone
Well 3. Wet Attempted completion in ROZ only
Well 2. Producer Lower Volumes from tite facies
Well 1. DH All intervals tite

Wells drilled in different portions of the interval will have different recoveries.
W. A. Estes “Holt” Field
(actually Glorieta)

Discovered in 1991, produced over 1MMBO from a small closure with “tight” tidal flat and shallow subtidal carbonates. Why did it take so long to discover it?

It’s a cap for a thick porous dolomite considered to be the “pay” in the area. The interval had shows & calculated as productive, DST’s a skim of oil and lots of sulfur water, tested a few times and left alone.

What is going on? It’s postulated that the lower, porous portion was swept and only the tight, up-dip facies were left with >70% $S_o$.

Thick, porous ROZ with CO2 potential?

The pay is the upper Glorieta/San Angelo. The more porous lower section calculates as productive on logs and is oil stained BUT 100% sulfur water productive.
Outer Shelf to Tidal Flat
The updip section thinned by pre San Andres tilt and Erosion

- Texaco 1-17 Univ
- W. A. Estes Field
- #144 W. A. Estes

- Fluor, Cut, Minor Gas
- Sulfur Water
- No Shows
- Tight
Texaco #1-17 Univ

W. A. Estes Field

W. A. Estes #144

Fluor, Cut, Minor Gas

Sulfur Water

ROZ Maximum 550’!

Tight

Base ROZ?

No Shows

Subtidal/Tidal Flat

Tidal Flat

Outer Shelf
What is the impact of the prograding Capitan Reef?
Eunice Monument/South Monument

- Grayburg productive with NaCl rich connate water
- San Andres mostly wet with sulfate rich connate water
- Two different sources for the connate waters
- Thickness of San Andres swept reservoir?
- **Eunice Monument South Unit** Productive from the Grayburg with minor production from the underlying San Andres Formation—
  - Discovery Oil/Water contact - 350’
  - Unitization Oil/Water contact - 540’
  - Deepest Grayburg Oil in core - 664’
  - Deepest San Andres Oil in core - 719’
- >300’ thick SADR w/oil saturation below O/W in Eunice Monument
North Monument Grayburg, Eunice Monument, Eunice Monument South “B”, Eunice Monument South, and Arrowhead Grayburg Unit.

- area combined total of 57 square miles.
- Lindsay suggests the sulfate poor edge water is recharged from the Guadalupe Mountains thru the Goat Seep Reef. The Sulfate-rich bottom water drive in the San Andres is recharged from the Sacramento Mountain thru the evaporite rich San Andres. **Eunice Monument South Unit.** The edge water was pulled into the oil leg since production was established in 1929 (from Lindsey, Chevron in-house pubs).
- Structural closures formed by re-activation of existing deep seated faults which folded and fractured the Permian. The structural event increased closure on the reservoir and trapped a larger oil column.

- Eunice Monument
  - -150 G/O, -400’ O/W (150’ below top SADR).
  - Na 2000ppm, Cl 2950ppm, TDS 7800PPM (similar to Capitan Reef in Winkler Co.)
SE NM Grayburg & Upper San Andres Dolomitization Trend

Carlsbad Caverns and Lechiguilla Cave Area

The two meteoric sourced waters take different pathways.

What happens when the entire oil column is swept by Mother Nature?
Your left with a tertiary recovery target.

“Green Field” an ROZ without an associated field
Gaines, Future Targets or goat pasture?

- A Clearfork test, the **IP #1 Campbell Heirs “158”** pipe on “WET” San Andres test just south of Seminole.
- All wireline logs, drill time, gas curves and sample shows said “slam dunk” oil production. Atlas log analyst said it should be a producer.
- 100% water test with barely a sniff of live oil. ROZ?
- **Anschutz #1 Patrick Keating “447”,** drilled for San Andres west of Seminole, had good shows but made only water for a few months before P & A (3600 BW, 3 BO). Water analyses show progressive drop in TDS over the two months of production.
- The 2 CORED intervals, from 5464 – 5602, had oil saturations ranging from 15 to 35%, 3 - 12% porosity, & 50-100% fluorescence.
- These are what we term “GREENFIELDS”
- TZ/ROZ’s are “BROWNFIELDSD”. 
ROZ Regional Context

• Establish regional flow paths through and between reservoirs along the “reservoir trend”.
• Modeling to establish inflow and outflow pathways.
• Determine timing of oil emplacement(s) relative to potential regional sweep events.
• Develop a regional understanding and time line for the relationships among major post depositional/oil emplacement tectonic events and the meteoric associated flushing that create the ROZ’s.
• Understand the impact of tectonic events on the fluid/rock properties along the reservoir trend.
• Characterize the difference and similarities between “classic” reservoir and Residual Oil Zone (ROZ) Reservoir.
“Early” Reservoir Parameters

Main Pay
- >80% So
- Salt Water – higher TDS
- Will respond to Waterflood
- CO2 EOR Potential
- Dolomite Reservoir
- Infill potential
- More Karst
- No Sulfur in cuttings and core
- Lower Porosity and Permeability
- Mixed wet
- No Greenfield Potential
- Oil Gravity
- Man made flowpaths /fractures

Residual Oil Zone
- 20 to 40% So
- Sulfur Water – lower TDS
- NO waterflood potential
- CO2 EOR Potential
- Dolomite Reservoir
- Deepening potential
- Less Karst
- Sulfur in cuttings and core
- Higher Porosity and Permeability
- Wettability issues
- Greenfield Potential
- Oil Gravity
- “Virgin” Reservoir Conditions
“Late” Reservoir Parameters

Waterflooded Main Pay
- 20 to 40% So
- Salt Water – ???? TDS
- No remaining Waterflood Potential
- CO2 EOR Potential
- Well known reservoir parameters
- Enhanced high perm streaks
- Mixed wetability
- Man made flowpaths /fractures

Residual Oil Zone
- 20 to 40% So
- Sulfur Water – lower TDS
- NO waterflood potential
- CO2 EOR Potential
- Estimated reservoir parameters
- Potentially more homogeneous
- Wettability questions
- Untouched
The first modeled Fairway is the “Artesia” Fairway and the west side of the Central Basin Platform.
Some other questions to consider:

• The total thickness of the San Andres at major producing field ranges from 650-750’ [Yates and Goldsmith] to 1400 to 1600’ [Seminole to Vacuum], yet,
  – The ratio of ROZ to main pay thickness in many of those large field may remain close to 1:1.
  – In other fields the thickness of the ROZ can equal or exceed the thickness of the main pay AND the ROZ elsewhere, and
  – Where there is no main pay, “Greenfields”, the ROZ can be 50 – 300’ thick or more. WHY?

• Why is there no major San Andres, Grayburg or Clearfork production south of the Texas/New Mexico border on the west side of the Central Basin Platform?
• How many pore volumes of water passed through the ROZR during Mother Nature’s Waterflood (MNW)?
• How does that relate to the volumes of water that passed through our Main Pays during modern Waterfloods.
• Consider the time frame in which these two “sweeps” occur, would you expect to see the same results?
• Significant ROZ’s appear to be present in the Leonard (Glorieta and upper and lower Clearfork) which are below the San Andres (Guadalupian) path across the San Simon channel.
Camels passing through the eye of a needle

• Dolomitizing pathways.
• Basin dewatering is often invoked for late dolomitization of reservoirs
• How many pore volumes can you pass through a reservoir when the updip traps are sabkha’s?
• What is the pathway down dip to up dip then parallel to the margin?
Working backward from what we see.
Characteristics of the ROZ vs. the Main Pay.

• Sulfur crystals associated with anhydrite and calcite in vuggy porosity at the Base of ROZR.
• Patchy high oil saturation above/at/below the Base of Saturation of Oil (BOSO) in low permeability intervals.
• Late stage solution enhanced fractures
• Solid Hydrocarbon Residue
• Oil Chemistry differences
• Oil Gravity differences
• Transition from limestone below the ROZ reservoir, to dolomite within the ROZ reservoir.
• Relationship of Limestone to dolomite transition to Sequence Stratigraphic Boundaries
• Enhanced Porosity due to the limestone-to-dolomite conversion
• Enhanced Porosity due to the dissolution of evaporites
• Enhanced Permeability due to limestone to dolomite conversion and secondary dolomitization
• Changes in wettability
• Vertical ROZ salinity variations
• Lateral/Trend salinity variations
• Chloride to sulfate water transition
• Bow Shaped, Pervasively Dolomitized Intervals (PDI)
• Relationship between ROZ and MP thickness.
• 90 degree turn for fluids
• Relationship of MP/ROZ/100% water transitions to Sequence Stratigraphic boundaries.
RESIDUAL OIL ZONE HISTORICAL FRAMEWORK

THE EVOLUTION OF ROZ PROGRESS TO TODAY

• Private Characterization Studies, ROZ Pilot and Field Demos (and now… Full Scale) Projects

• Reframing the ROZ Origins
  — Permian Basin Observations,
  — Chipping Away at Some Myths (e.g., Transition Zones, Weathered Oil, etc.)

• Defining the Areal Distributions and The Properties
THE RESEARCH FRAMEWORK: 
ROZ HISTORY / INITIATIVES

1) EARLY PRIVATE TZ/ROZ* INVESTIGATIONS
   - Private Industry Research
   - UTPB, Melzer Consulting, and ARI Syntheses

2) 2006 DOE REPORT AND SUBSEQUENT SPE PAPERS

3) RPSEA** ROZ ORIGINS AND HYROLOGICAL MODELING

4) DOE: ROZ & MPZ CO$_2$ FLOODING OIL RESPONSE

5) REGIONAL ROZ ORIGINS AND DISTRIBUTIONS

* Transition Zone/Residual Oil Zone
**Research Partnership to Secure Energy for America
**INITIATIVE 1)**

THE EARLY WORK (TZ/ROZ)

- Hess’ Seminole Field ‘Thinking’
- Shell’s Wasson Field Approach
- TZ Sweet Spot Pilot at Denver Unit, Wasson Field
- Hess’ Phase I and Phase II Pilots at Seminole
- Chevron’s Vacuum Field Investigations
INITIATIVE 2
GOING PUBLIC

The CO2 Flooding Conference in Midland and It’s Role

References


INITIATIVE 3
THE RPSEA PROJECT (all about the Science)

• Building a ROZ Team
• ROZ Symposium
• Defining and Gathering the Anecdotal Evidence of ROZ Presence
• Assimilating Hydrodynamic Fairway Data (Fluid, Rock Property Data)
• Developing Some Related Hypotheses
  – Pervasive (Laterally) Dolomitized Intervals
  – Oil Wetting
THE GOLDSMITH FIELD STUDY - (INITIATIVE 4)
The DOE/NETL Project (Almost All about Oil Response…’the Engineering’)

- Selecting a Field Partner (Legado Resources)
- ‘Perfect’ Timing (Jump Start on Field Work)
- Six Cored Wells
- Opportunity for Modeling Permutations
- Venues for Vetting ROZ Response/Commerciality
- Opening the Door for Larger Scale Implementation
  - Industry Acknowledgment/Acceptance
INITIATIVE 5
RPSEA II

• Permian Basin-Wide ROZ Distributions

• Relationships
  – Sorw = F (water salinity)
  – Lineament Exit Pathways
  – Other?

• Extrapolations to Other Basins
  – Bighorn
  – Southern Williston
DOE ROZ Project Description/Plans

“Next Generation” CO2 EOR Technologies To Optimize The Residual Oil Zone CO2 Flood At The Goldsmith Landreth San Andres (GLSAU) Unit, Ector County, Texas
Project Overview

• **The Project:** Characterizing and Defining the Response of the GLSAU San Andres Formation to CO2 in both the Main Pay Zone and the Residual Oil Zone

• **Project Goals:** Develop a Case History of ROZ Response to CO2 which will Allow Demonstration and Comparison of the Commerciality of CO2 EOR in both the MPZ and ROZ

• **Project Scope:** Perform a Detailed Characterization of the MPZ & ROZ Reservoirs; Illustrate, Individually and Collectively, the Response of MPZ & ROZ to CO2 EOR; Model Response; Examine Next-Generation Diagnostics and Sweep Improvement Methods
THE PROJECT TASKS

I. PROJECT MANAGEMENT & PLANNING
II. IDENTIFY, MAP AND CHARACTERIZE THE GLSAU
III. RESERVOIR SIMULATION
IV. NEXT GENERATION FEEDBACK AND CONTROL TECHNOLOGY TO OPTIMIZE THE CO2 FLOOD
V. CONDUCT DETAILED ANALYSIS OF THE ROZ AND MPZ CO2 EOR PROJECTS AT THE GLSA UNIT, ECTOR COUNTY, TX
VI. TECHNOLOGY TRANSFER
Task 1: Project Management and Planning

- Legado Resources
- Remote Teams
- Advanced Resources International
- Engineering
- UTPB / APTA support

Project
Task 2: Identify, Map and Characterize a Major Permian Basin ROZ Field Area (GLSAU)

- Assemble Data on the Outline, Geologic Setting and Reservoir Properties of the ROZ
- Conduct Laboratory Work to More Accurately Establish the Level and Distribution of the Residual Oil in the ROZ and Compare to the Flushed Zone in the Waterflooded Area
- Integrate the Data and laboratory Work to Develop a Geologic Model for the ROZ
Task 3: Undertake Reservoir Simulation to Assist with CO2 Flood Design – Track Project Performance

• Conduct Reservoir Modeling of the CO2 Flood Using a Full-Scale, compositional Simulator (GEM)

• Examine the Performance of the CO2 Flood Under Alternative Designs

• Establish Alternative Designs for the CO2 Flood
Task 4: Apply Next Generation Feedback and Control Technology to Optimize the CO2 Flood

• Evaluate Alternative Techniques for Obtaining Real Time Feedback Data on Flood Performance

• Implement New Diagnostic/Feedback Data and Control System
Task 5: Conduct Detailed Analysis of the ROZ CO2 EOR Pilot at the GLSA Unit, Ector Co, TX

- Document the Implementation of the ROZ CO2 EOR Pilot
- Gather All Flood Diagnostics Feedback Data on Performance
- Conduct Detailed Performance Analysis
- Use Diagnostics Data to Manage and Optimize a Dedicated CO2 ROZ Flood
- Use Diagnostic Data to Manage and Optimize a Commingled MPZ and ROZ Flood
Task 6: Conduct Technology Transfer of Findings and Document These in a Draft and Final Report

• Conduct Engineering and Geologic Presentations at Local, State and National Workshops and Conferences*

• Prepare Final Report
How does this apply to Wyoming?

• CO2 has been increasingly important in EOR in Wyoming.
• With the continued development of a pipeline network, additional sources of Anthropogenic CO2 are being rapidly developed.
• Evidence suggests that long term, ROZ’s are going to be a source of new EOR projects.
• Anthropogenic CO2 will be required for these ROZ projects.
Regional Structure of the Mission Canyon Fm. and Location of Important Oil Fields and Greater Billings Nose Study Area, Williston Basin *

* Adapted from Berg, R.R., DeMis, W.D., Mitsdarffer, A.R. (1994),
Early work suggesting the presence of ROZ’s was seen in the sequence of Oil Migration and Accumulation in the Billing Nose Fields, Williston Basin.

* Adapted from Berg, R.R., DeMis, W.D., Mitsdarffer, A.R. (1994),
Examples of Hydrodynamic Traps seen in the Williston Basin

* Adapted from Berg, R.R., DeMis, W.D., Mitsdarffer, A.R. (1994),
Frannie Oil Field, Big Horn Basin Illustrating the SW OWC Tilt of ~600 ft/mi

Adapted from Hubbert, M.K. (1953)
Anthropogenic CO$_2$ in Wyoming and points north

- The largest single source of anthropogenic CO2 used for EOR is the capture of 230 MMcfd (4+ MMmt/yr) of CO2 from the gas processing plant at La Barge in western Wyoming.
- This is followed by the “poster child” for integrating large-scale CO2-EOR with CCS -- the capture of 150 MMcfd (~3MMmt/yr) of CO2 from the Northern Great Plains Gasification plant in Beulah, North Dakota and its transport, via a 200 mile cross-border CO2 pipeline, to the two EOR projects at the Weyburn oil field in Saskatchewan, Canada.
- Other sources will be coming to a neighborhood new you in the future.
## Rockies New Anthropogenic CO2 Sources

<table>
<thead>
<tr>
<th>Location</th>
<th>MMcfd</th>
<th>Million mt/yr</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural Gas Treating Plants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Exxon La Barge, SW Wyoming</td>
<td>230</td>
<td>4.1</td>
<td>Plant Expansion</td>
</tr>
<tr>
<td>2. COP Lost Cabin, Central Wyoming</td>
<td>50</td>
<td>1.0</td>
<td>Under contract</td>
</tr>
<tr>
<td>3. Riley Ridge, SW Wyoming</td>
<td></td>
<td></td>
<td>Under Discussion</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>150</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td><strong>Proposed Coal to Gas/Liquids Plants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. KRW/Medicine Bow, SE Wyoming</td>
<td>150</td>
<td>2.9</td>
<td>DOE Loan Guarantee</td>
</tr>
<tr>
<td>2. Refined Energy, SE Idaho</td>
<td>80-175</td>
<td>2.3</td>
<td>Diesel/Fertilizer</td>
</tr>
<tr>
<td>3. Gas Tech, NE Wyoming</td>
<td>115</td>
<td>2.2</td>
<td>UCG</td>
</tr>
<tr>
<td>4. Many Stars, C. Montana</td>
<td>250</td>
<td>4.8</td>
<td>Start in 2012</td>
</tr>
<tr>
<td>5. South Heart, SW N. Dakota</td>
<td>100</td>
<td>1.9</td>
<td>Coal to H2</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>595-690</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>745-840</td>
<td>17.0</td>
<td></td>
</tr>
</tbody>
</table>

From Kuuskraa (2010)
Summary

• We’ve only just begun.
• ROZ’s are real and a major tertiary recovery target for today and long into the future.
• Modeling using regional scale groundwater modeling package is underway.
• Documentation of areas/fields with potential is underway.
• Phase 2 – testing models in the field has begun.
• A number of presentations have been/or will be made and can be found on our RPSEA supported website: Residualoilzones.com.

Special Thanks to:
RPSEA
Steve Melzer
Arcadis - David Vance, Steve Tischer
Phil Eager, Edith Stanton, Saswati Chakraborty
Chevron & Legado our industry partners
George Koperna, Advanced Resources International
All those who have battled with ROZ’s in the past.