Permian CCS Center

Carbon Capture & Storage Technology
UTILIZING CO_2 EOR INDUSTRY KNOWLEDGE

TEXAS ALLIANCE MEETING

CORPUS CHRISTI

JULY 14,2011

Robert D. Kiker

President

Applied Petroleum Technology Academy

(APTA)

Presentation Overview

- The Permian Basin Carbon Capture & Storage Training Center
- The Changing Face of CO_2 EOR
  - Introducing Residual Oil Zones (ROZs)
- CO_2 EOR & CCS Operations
  - Surface
  - Downhole
- CCS and CO_2 EOR Industry Overview
- The History and Current Status of CO_2 Flooding
- Existing CO_2 Markets
- An Exciting New Reservoir Development: ROZs

PBCCS OUTLINE

- What is the Permian Basin Carbon Capture and Storage Training Center?
- Training Media
- Other CCS Training Centers
- Changing Focus
- Operations Workshop Highlights

About the Permian CCS Center

- World class training in carbon capture and storage (and EOR) for and by industry professionals, focusing on individuals in the Permian Basin but through online presence available to individuals throughout the U.S. and the world
- Stimulated by a grant for the National Energy Technology Laboratory of the DOE and the American Recovery and Reinvestment Act of 2009
- Efforts guided by an Industry Advisory Board

Permian Basin CCS Approach

- By and For Industry – Industry organizations instructing industry professionals
- Targeted audience of wide range of energy professionals potentially involved in CCS: engineers, geoscientists, regulators, academia
- Its also about the money: for the individuals to advance, for PBCCS to become self-sustaining

PERMIAN CCS CENTER

Three World Class Organizations

Petroleum Technology Transfer Council

Tech Transfer, Workshops, Newsletter, Tech Alerts

American Association of Petroleum Geologists

37,000 Members, Publications and Conferences

Distance Learning

Applied Petroleum Technology Academy

CO_2 Course, CO_2 Conference

Applied Petroleum Technology Academy

- The Applied Petroleum Technology Academy ("APTA") is a non-profit organization created to teach energy companies how to apply cost-effective technology in order to extend the lives of aging oil and gas fields around the world. APTA's mission statement is simple:

  "To provide practical training of oilfield practices in a mature oilfield environment emphasizing cost savings with ample opportunity for field visitation."

- Headquartered in Midland, Texas - in the heart of the Permian Basin
  - APTA can provide access to hands-on practical training based on decades of CO_2 experience. Curricula can be customized to meet the specific needs of clients with respect to both their levels of experience and to the types of fields they are dealing with. APTA's curricula are designed to cover all aspects of petroleum production.

Petroleum Technology Transfer Council

- PTTC provides a forum for technology transfer and learning
- The Petroleum Technology Transfer Council (PTTC) is a national not-for-profit organization led by an independent Board of Directors and managed by the American Association of Petroleum Geologists. PTTC was established to provide a forum for transfer of technology and best-practices within the producer community. Local Producer Advisory Groups ensure that PTTC activities in a particular region address the technology needs of producers in that area.
- PTTC is a partnership to connect independents with the technology and knowledge to safely and responsibly develop the nation's CCS and oil and gas resources. As such, it is an important part of America's energy solution

American Association of Petroleum Geologists

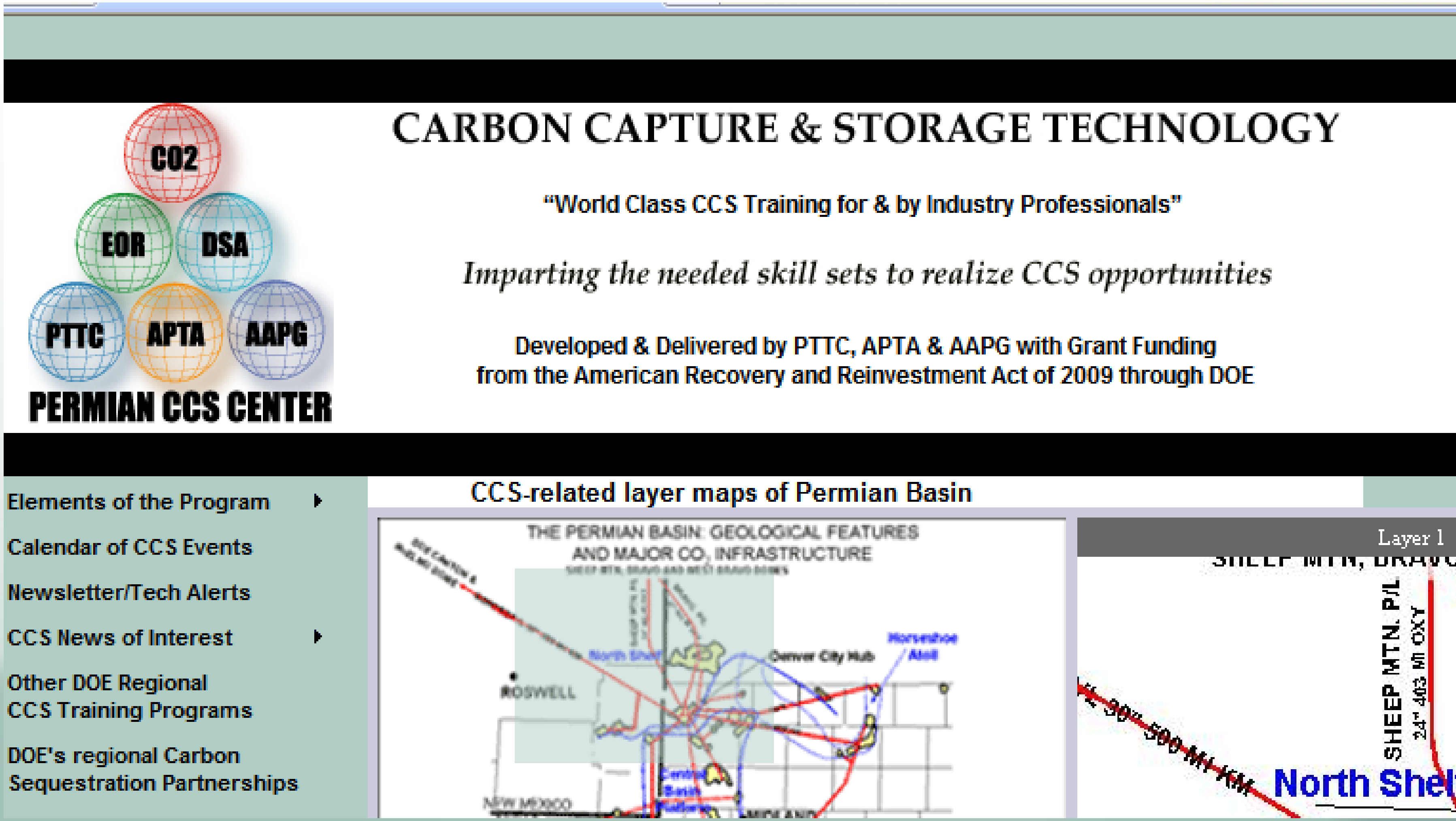
- Founded in 1917, the American Association of Petroleum Geologists is currently the world's largest professional geological society.
- The membership of AAPG includes geologists, geophysicists, CEOs, managers, consultants, students and academicians. The purpose of the organization is to foster scientific research, advance the science of geology, promote technology and inspire high professional conduct.

PERMIAN CCS CENTER

Major Elements of Permian Basin CCS

- Week-Long Short Course (APTA) – Industry Professionals instructing Industry Professionals
- Series of One-Day Workshops and Webinars (PTTC)
- E-Certificate (AAPG) and free Open Courseware
- Augmented by website - www.permianbasinccs.org, Newsletter, e-alert

www.permianbasinccs.org



CO2 EOR DSA PTTC APTA AAPG

Carbon Capture and Storage Technology

Catch & STORE

World Class CCS Training for and by Industry Professionals

pttc.org aptapb.org aapg.org permianbasinccs.org VOLUME 1, NUMBER 2 AUGUST 2010

Residual Oil Zones

BY STEVE MELZER

Our first issue described pervasively dolomitized intervals (PDI) in the Permian Basin (PB). PDIs stem from a slow lateral invasion of water from outcrops on the western side of the PB that pervasively altered the limestone to dolomite resulting in a laterally continuous, moderately porous and permeable zone that provides a large potential

What does a Residual Oil Zone (ROZ) look like?

BY BOB TRENTHAM, UTPB/CEED

Research is documenting the evidence for and characteristics of ROZs below the major San Andres reservoirs in the Permian Basin (PB). There is significant anecdotal evidence for the presence of ROZs from exploration wells in "goat pasture" both adjacent to, and at distance

Characteristics. Rock properties include: the presence of sulfur crystals associated with gypsum in the swept interval (ROZ) of carbonate reservoirs; evaporites that are dissolved in the ROZ or altered in the lower part of the main pay; sample shows of oil and/or gas (odor, cut, fluorescence in

Permian CCS Workshops

Extended Length Workshop (4 ½ days) contains most of the aggregate material found in the 1 day workshop listed below

- Overview of the Elements of CCS – CCS (and CO_2 Flooding in the Permian Basin)
- Site Selection and Operations – The Reservoir – Characterization, Modeling and Monitoring
- CO_2 Flood Operations & Surface Facilities – CO_2 Sources and Capture Technology
- Business of CO_2 Flooding and Moving Forward with CCS

Webinars – Slides and Voice

- The Promise and Performance of Next Generation CO_2-EOR by Advanced Resources International with VelloKuuskraa and Michael Godec
- CCS (and CO_2 Flooding) in the Permian Basin – An Overview of the Science and the Training Program with Steve Melzer and Dwight Rychel
- CCS in the Permian Basin, The Reservoir – Characterization, Modeling and Monitoring with Steve Melzer and Bob Trentham

Free Open Courseware - AAPG

- Carbon Capture and Sequestration: An Introduction
- Geological Models in CO_2 Separation
- CO_2 Supply, Demand: Legal and Regulatory Issues
- CO_2 Separation, Compression, Transportation and Marketing

Permian CCS e-Cert Program

- Online program
- Proceed at your own pace
- Certification after demonstrated learning
- Similar topics as short courses
- Structure the same as recent AAPG Solar Energy Program

Other CCS Training Organizations

Midwest Geological Sequestration Consortium – Sequestration Training and Education Center – MGSC-STTC (http://sequestration.org/step/index.html) by Illinois State Geological Survey.

Carbon Capture and Storage Training (CCST) Northwest – Carbon Tech Alliance (www.carbontechalliance.org) by Environmental Outreach and Stewardship Alliance.

Southwestern United States CO_2 Sequestration Training Center – CO2TC (New Mexico Institute of Mining and Technology) www.southwestcarbonpartnership.org/default.aspx.

Southeast Regional CO_2 Sequestration Technology Training Program – SECARB-Ed (www.sseb.org/secarb-ed.php) by Southern States Energy Board (www.sseb.org).

Sequestration Training, Outreach, Research & Education – STORE (www.storeco2now.com) by University of Texas at Austin..

Wyoming CCS Technology Institute – WCTI (http://wcti.uwyo.edu) by University of Wyoming.

What Has Worked

- Highly Qualified and Responsive Advisory Board
- Newsletter and e-Alert Informative, hundreds of readers
- Broad Encompassing Curriculum
- Structure in place for first two short Courses and Webinars

Permian Basin CCS Training Center

Challenges

- Cost of Capture Projects, State of Capture Technology, and Slow-to-Move Incentives have Combined to "Sideline" Interested Parties Resulting in few Large Scale Field Trials
- Targeted Oil and Gas Professionals in Permian Basin have excellent skill sets in place for storage/sequestration via CO_2 EOR but little interest in geological storage in saline formations
- Industry interest in first group of workshops and webinars was minimal

Where We Are Today

- Have broadened targeted audience to include regulators, environmentalists, scientists, electric generating industry and other CCS stakeholders
- Slowed the pace of delivery somewhat until the audience is motivated and some incentive legislation emerges
- Currently focussing more on electronic delivery, versus the local workshops

PERMIAN CCS CENTER

Operations Workshop Topics

- CO_2 Flood Operations
- Wellsite Surface Equipment
- Downhole Design and Considerations
- Operational Features Peculiar to CO_2 Injection Projects
- Examples of Operator Differences
- Review of Anthropogenic Sources and Existing and Future Capture Technologies
- Dehydration Processes
- Compression Facilities
- Sulfur Removal
- Recycle Plants

The Changing Face of CO_2 EOR

Environmental Concerns are Increasingly Demanding Capture of Greenhouse Gases (Now…what to do with them, especially CO_2?)

- Disposing of CO_2 Pretty Much ‘Dead-on-Arrival’
- New Age Oil Pricing is Changing Economics of CO_2 EOR
- Awareness of New EOR Targets* is Changing the View of EOR as a small Niche Industry

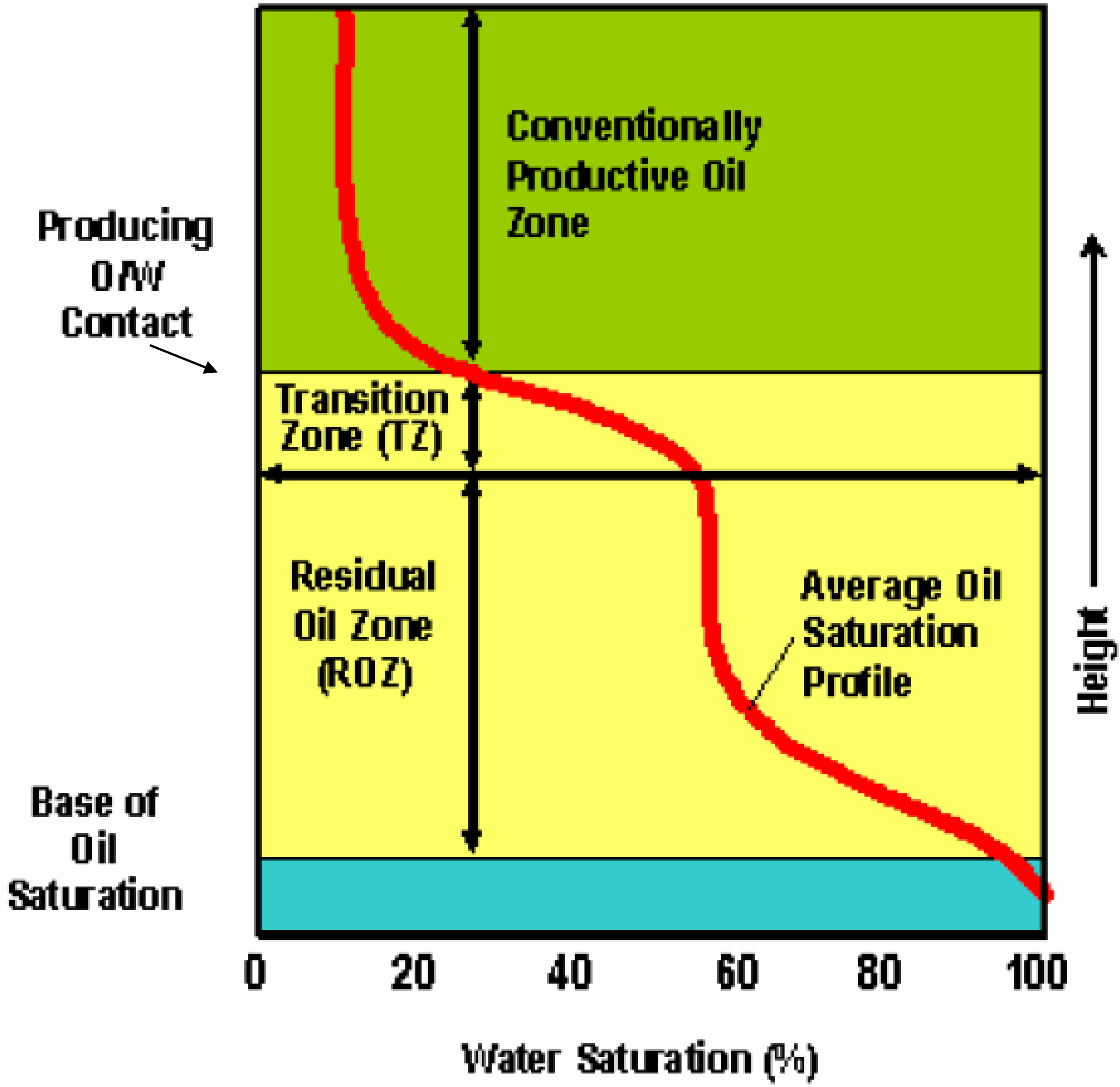
* Residual Oil Zones as Nature’s Waterfloods

ROZ (Residual Oil Zone) Developments

There will be some slides to report a new development that the Permian Basin CO_2 APTA group, which is active in the CCS/CO_2, has been actively involved in. This economic exploitation of the ROZ zones is dramatically amplifying the need for more anthropogenic CO_2 sources.

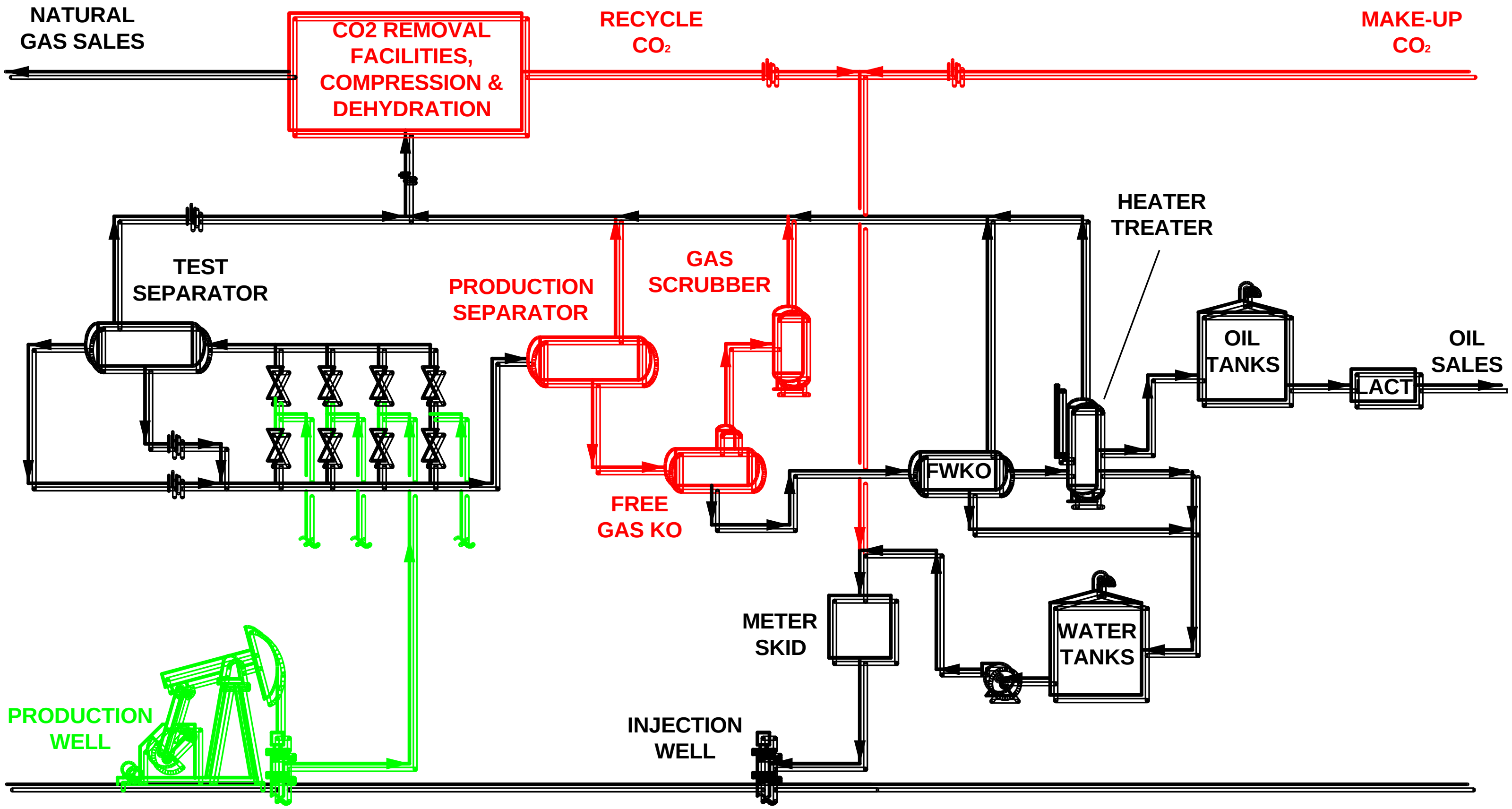
This will be covered later, but further information on the research and actual demonstration work that is going on in the ROZ zones is available at the website http://www.residualoilzones.com

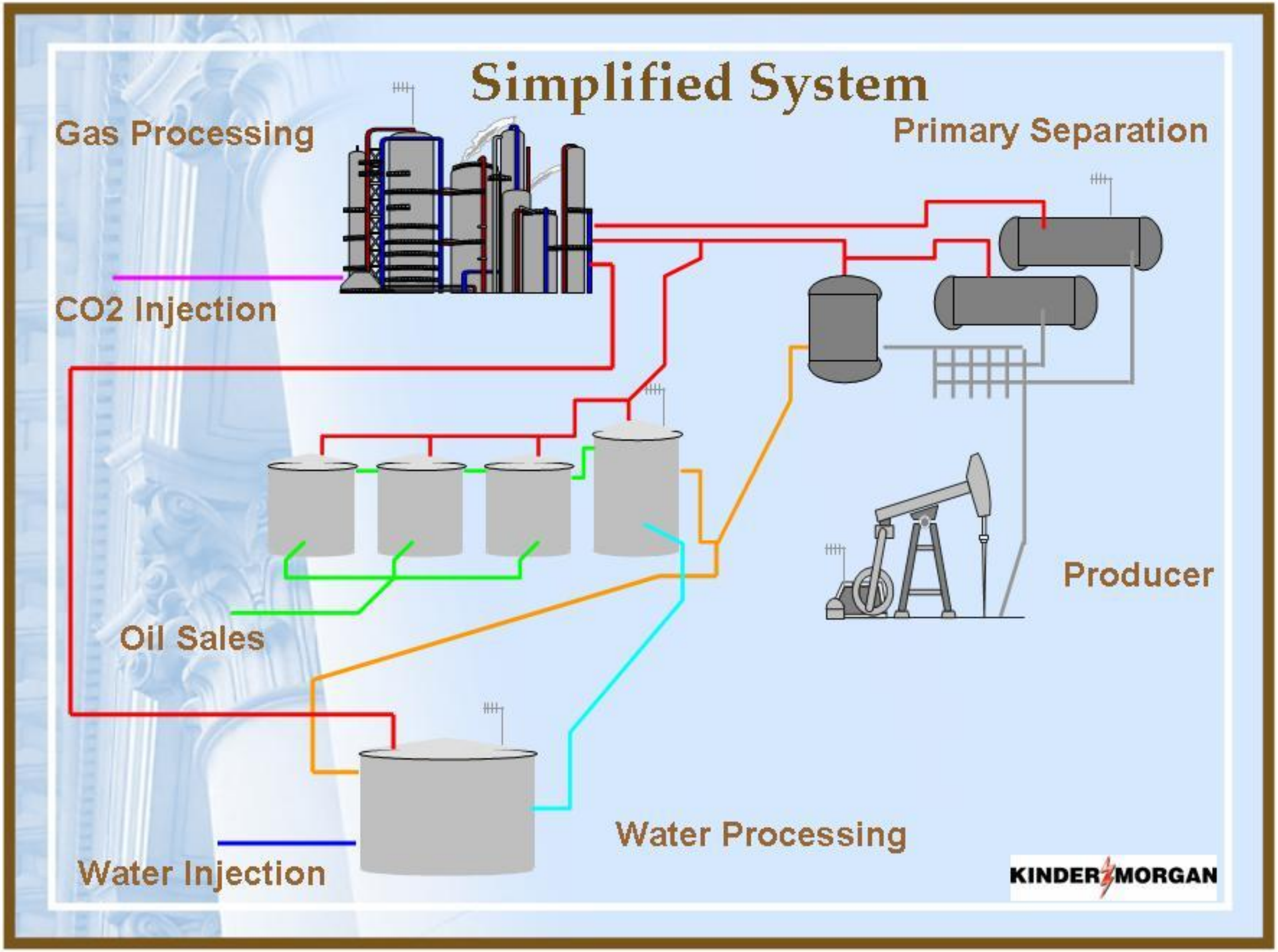
Published Seminole Field Wate Saturation Profile.



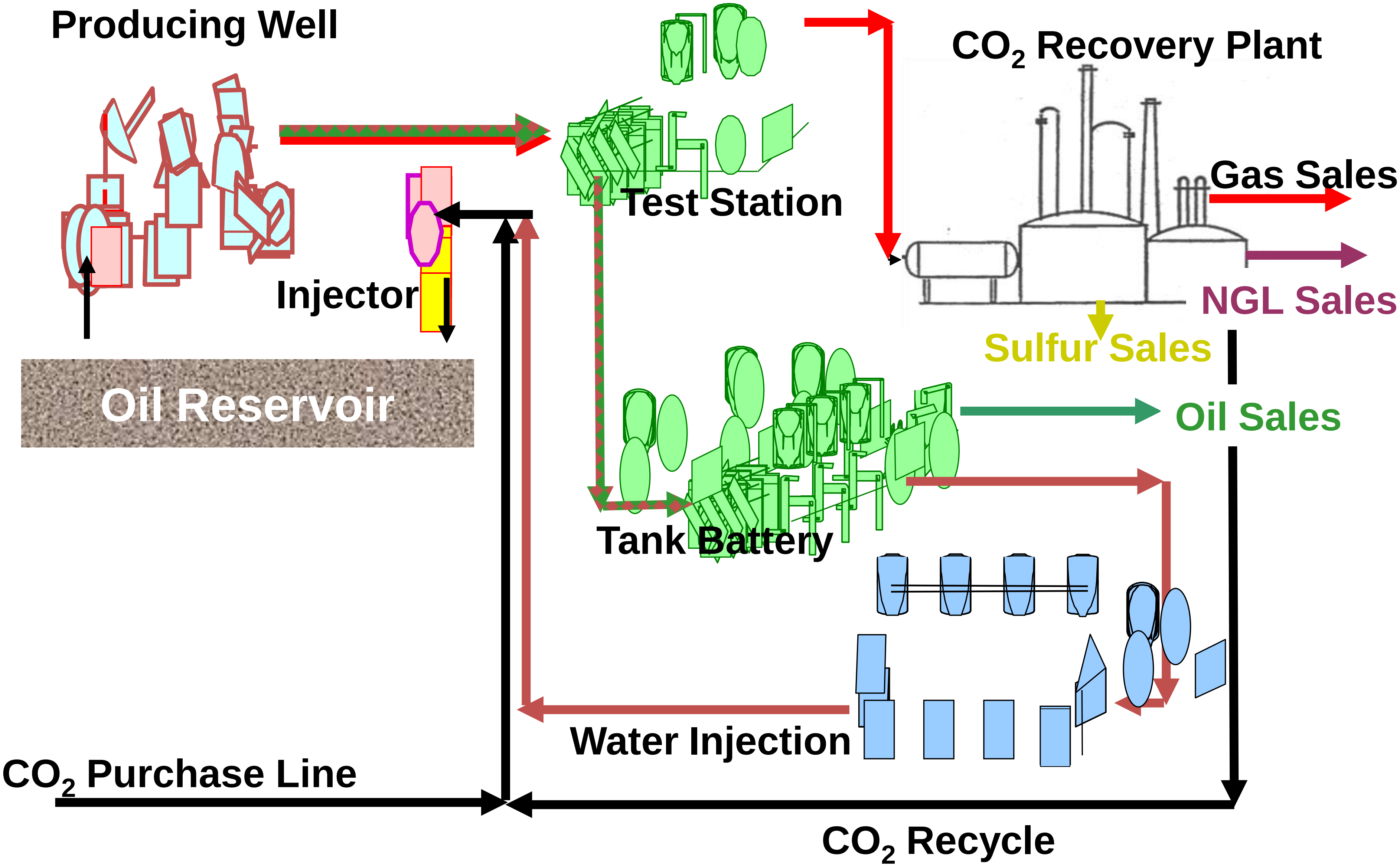
CO_2 EOR & CCS OPERATIONS

Typical CO_2 / Waterflood Operation

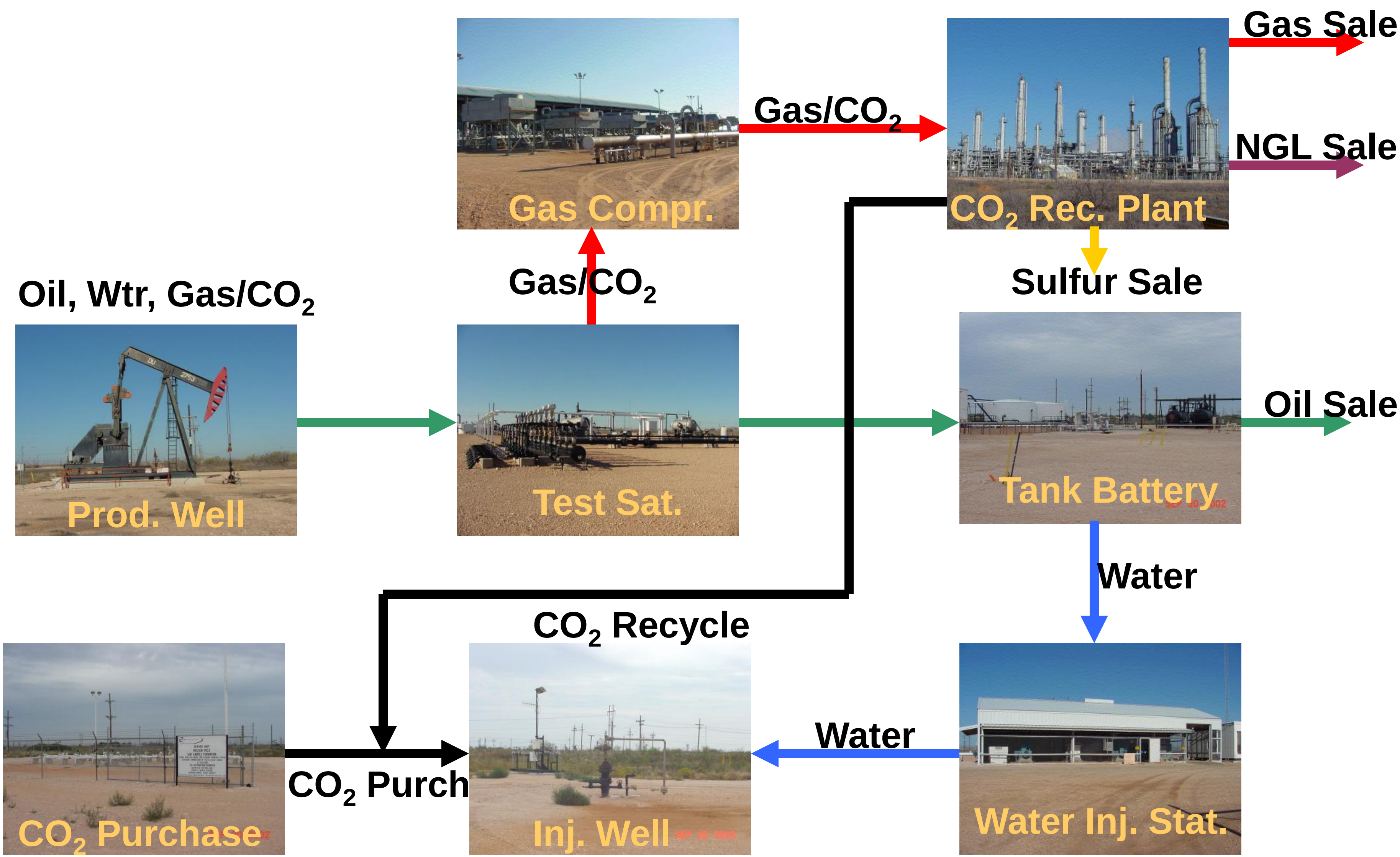



Simplified System
Gas Processing
Primary Separation
CO2 Injection
Producer
Oil Sales
Water Processing
Water Injection
KINDER MORGAN

Field Flow Diagram



Field Flow Diagram



Surface Equipment

Design Considerations

Production Equipment/Vessels
- Headers
- Separators-2 & 3 phase
- FWKO
- FGKO
- Tanks
- Oil & Water
- Vapor Recovery

Water Injection Equipment

Production Equipment - Vessels

- Production Separator
  - 2-phase
  - Eliminates large gas volumes at test site
  - Disperses slugs and surges
- Free Gas Knock Out
  - 2-phase
  - Eliminates large gas volumes
  - Regulates fluid delivery to FWKO

Production Equipment - Vessels

- Free Water Knock Out
  - 2-phase (fluid packed), or
  - 3-phase
- Heater-Treater
  - 3-phase
  - Vertical or horizontal
  - Oil/water separation
- Gas Scrubber
  - 2-phase
  - Separates carry over fluids

Production Equipment - Vessels

- Design Considerations
  - Operating pressure
  - Operating temperature
  - Production flow rates throughout life of project
- Materials
  - Internally coated carbon steel

Production Equipment - Tanks

- Working Tank
- LACT Tanks
  - Circulation system
  - Agitators (mixers)
- Design Considerations
  - Daily production rates
  - Operator response time
- Materials
  - Carbon steel
  - Partial internal coating

Production Equipment - Vapor Recovery

- Vapor Recovery System
  - Capture near atmospheric vapor from tanks
  - Often required by regulation
- LP Compression System
  - Capture low pressure and flash gas from process streams
  - Recycles gas to re-injection compressors

Production Equipment - Vapor Recovery (2)

- Design Considerations
  - Gas volumes
  - Oxygen
  - Regulatory compliance
- Materials
  - Vessels: CS hot side / SS cold side
  - Piping & Valves: CS hot side / SS cold side

Production Equipment - Flare

- Flare System
  - Emergency use only
  - Residue/supply gas assisted
  - Auto ignite
- Design Considerations
  - Supply gas availability
  - Regulatory compliance

Downhole Design Considerations

Tubulars- Both Production and Injection Wellbores

Metallurgy for Pumps and Packers

Artificial Lift

CO_2 Operations Features/ Operator Differences

Review operational feature differences and similarities in regard to production practices including artificial lift.

Review operational differences in the handling of the produced gas stream for the flood injection.

Surface Facilities Options

- Reinjection of associated gas produced (Often Referred to as Blood, Guts, and Feathers {BGF})
  - Compression and usually dehydration
- Reinjection of associated gas stream coupled with C_4+ extraction for sales
  - Compression, dehydration, rough hydrocarbon cut, CO_2 removal
- Processing of the associated gas stream into C_2+ for sales and CO_2 for reinjection
  - Compression, dehydration, hydrocarbon recovery (distillation, CO_2 membranes, etc.)

Gas Plant Processing

Dehydration/Compression

Sulfur Removal/Recycle Plants

Gas Handling - Dehydration

- Purpose of dehydration is to eliminate potential corrosion caused by the presence of free water and CO_2
- Use TEG to decrease water content in gas stream to 25 lb/MMscf or less

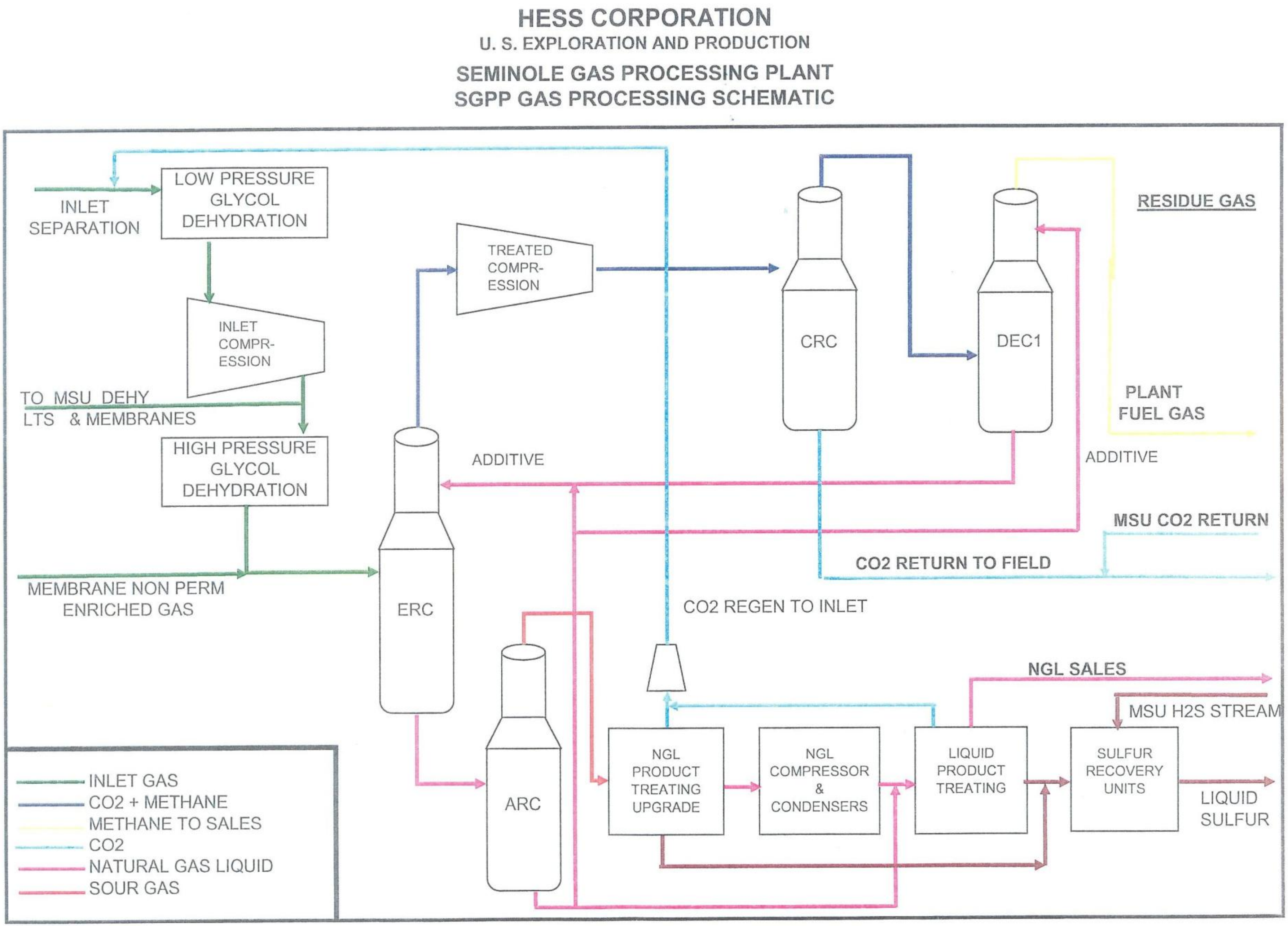
Gas Handling - Dehydration

- Design Considerations
  - Is dehydration necessary?
  - Wet CO_2 flow rates
  - Operating pressure
  - Operating temperature
- Materials
  - Contactor: Stainless steel
  - Regeneration Skid: Carbon steel and stainless steel

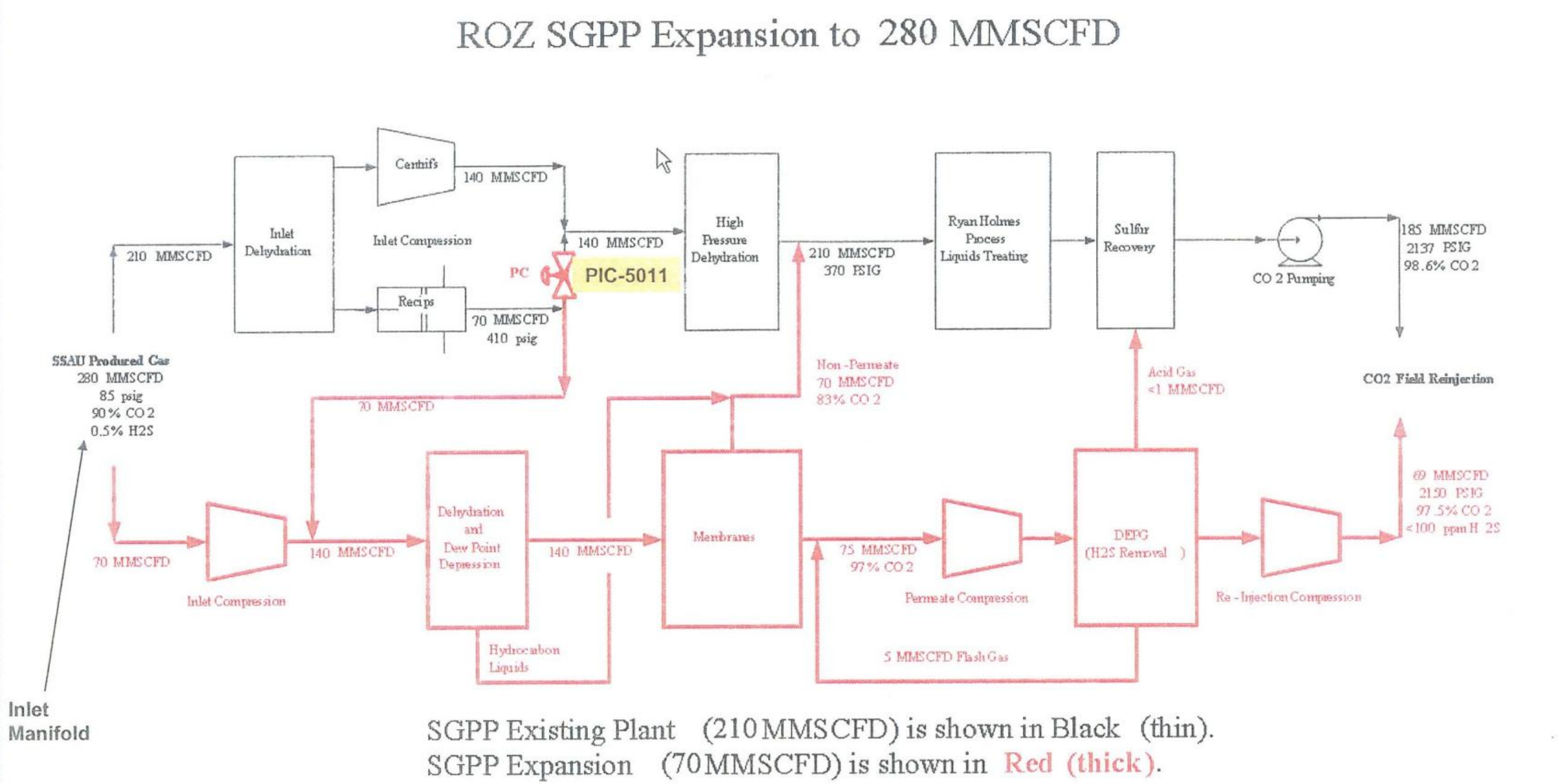
Gas Handling - Compression

- CO_2 compression differs significantly from natural gas compression
  - Materials
  - Compressor Speed
  - Drivers
  - Cooler Design

Hess Seminole Plant Schematic



Hess Seminole Plant Expansion Schematic



The nominal capacity of the ROZ expansion is 70 MMSCFD inlet gas, though design allowances and equipment margins should result in a throughput capacity of 75 to 80 MMSCFD (Dehydration through Membrane Separation is ~2 times to incorporate the SGPP gas). ROZ is designed to run on the common SGPP inlet system, analogous to trains 1-3. A new 30" inlet header around the NW corner of SGPP connects the new ROZ inlet to the existing inlet laterals and manifold. The three fixed-speed ROZ centrifugal compressors work in series, and are designed to run in complement with each other. Inlet Gas fluctuations will be absorbed by the existing SGPP I/T compressors and pressure control valves (PV-9301 and PV-5547).

The throughput of ROZ is controlled primarily by the flow-control valves on the inlets to the membrane skids (FV-03141A/B). During normal operation, it is expected that these valves will have local set-points higher than attainable, in order to maximize throughput. Variations between the ROZ Inlet and Permeate Compressors are controlled by the pressure control valves on the SGPP inlet compression discharge header (PV-5011-1/2), allowing excess inlet gas from the Reciprocating compressors to revert to the High Pressure TEG Dehydration.

CCS *and CO_2 EOR* Industry Overview

Steve Melzer

Melzer CO_2nsulting

CO_2 EOR and Carbon Capture & Storage

The Common, Simplified Components

- Capture, Process and Transport the CO_2
- Inject the CO_2
- Monitor the Movement (and Fate*)
- Produce a Portion of it Back at the Surface
  (and sell the "products and by-products")

* EOR has generally not been worried with the permanence or "fate" of the CO_2

PERMIAN CCS CENTER

CO_2 Capture Technologies

Pre-Combustion

IGCC – FutureGen

Membranes

Oxy-Combustion and Chemical Looping

Pure Oxygen vs. Air in Boiler

Post Combustion

Adsorption

Solvent

Integrated Environmental Control Model – WWW.iecm-online.com

Discuss and Evaluate all CO_2 Capture Processes

PERMIAN CCS CENTER

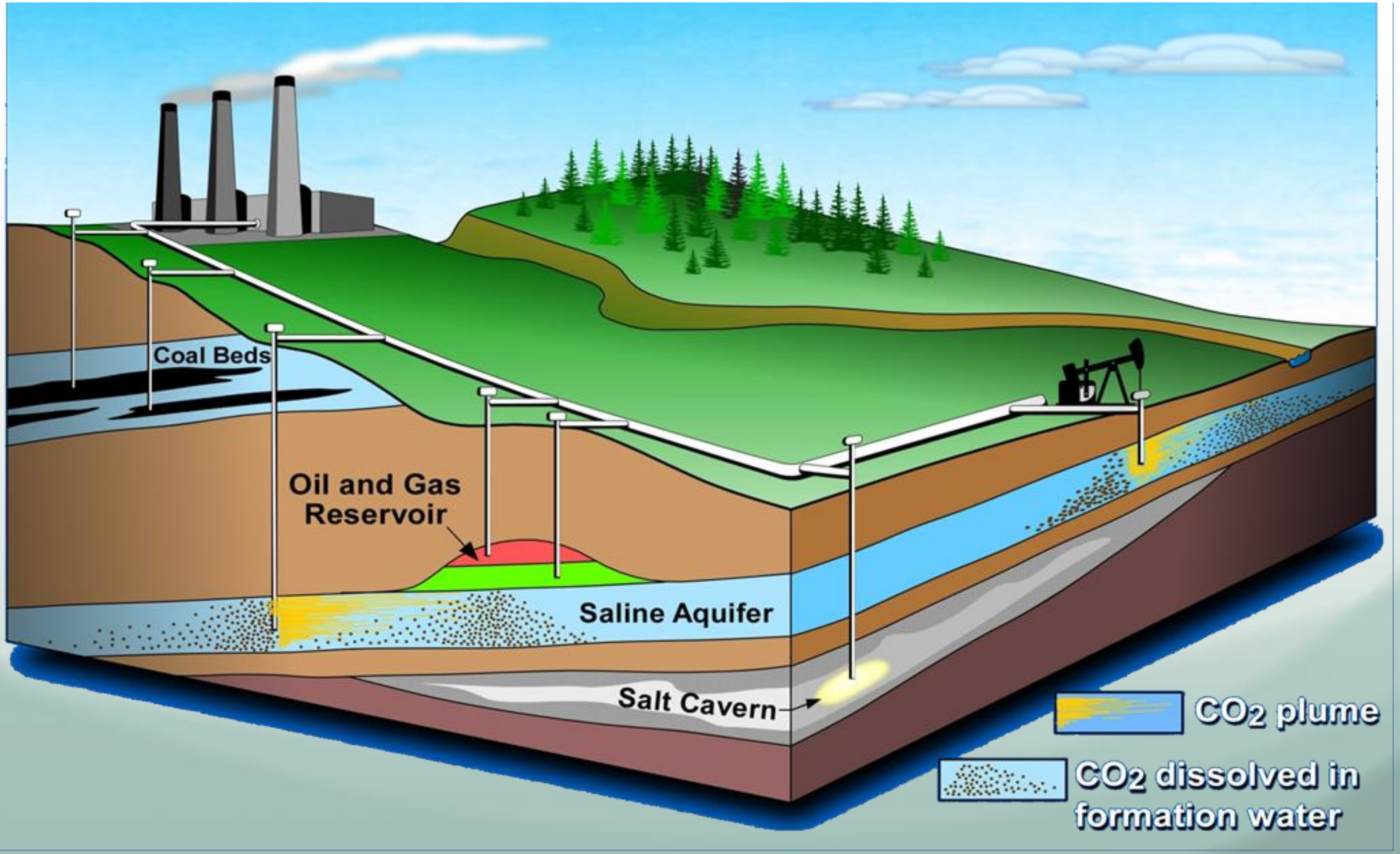
CO_2 Capture Technologies

Post Combustion Capture

- Adsorption
  - Physical – Zeolites, Carbon
  - Chemical
- Solvents
  - Chilled – ammonia, many others
  - Not Chilled – amine based
- Enzyme based capture – CO_2 Solutions claims enzyme based technology reduces size of CO_2 adsorber columns by 90% vs MDEA (low energy solvent)
- Other – Membranes, Ionic Liquids, Oligomers
- Very energy intensive, up to 35% parasitic load – large footprint

PERMIAN CCS CENTER

The Various Means of CCS



PERMIAN CCS CENTER

So We Begin with **CO_2 EOR** and What that Technology and Experience Brings to the Table

CO_2 EOR IS ONE OF SEVERAL COMMERCIALLY PROVEN EOR METHODS

Four Methods Provided Field Demonstrated Economic Viability in $20/bbl Price Range

1) Miscible Natural Gas Flooding (Canada)

   No Market for NG – Where Market Exists, it is Sold

2) Steam Flooding (e.g., San Joaquin Valley, Venezuela, Indonesia)

   High Cost of NG for Generating Steam

3) Nitrogen (Scattered Application)

4) CO_2 Flooding (e.g., Permian Basin)

   Availability of Nearby CO_2

PERMIAN CCS CENTER

A QUICK COMMENT ABOUT CO_2 EOR AND ITS DUAL ROLE

"WITH THE COMING PROLIFERATION OF INDUSTRIAL (ANTHROPOGENIC) CO_2 SOURCES – CO_2 EOR CAN PLAY ITS HISTORICAL ROLE OF INCREMENTAL PRODUCTION BUT ALSO PROVIDING VALUE BY SEQUESTERING CO_2 FROM INDUSTRIAL SOURCES"

This is becoming more widely recognized today for a variety of reasons, we will come back to this point again

The History and Current Status of CO_2 Flooding

PERMIAN CCS CENTER

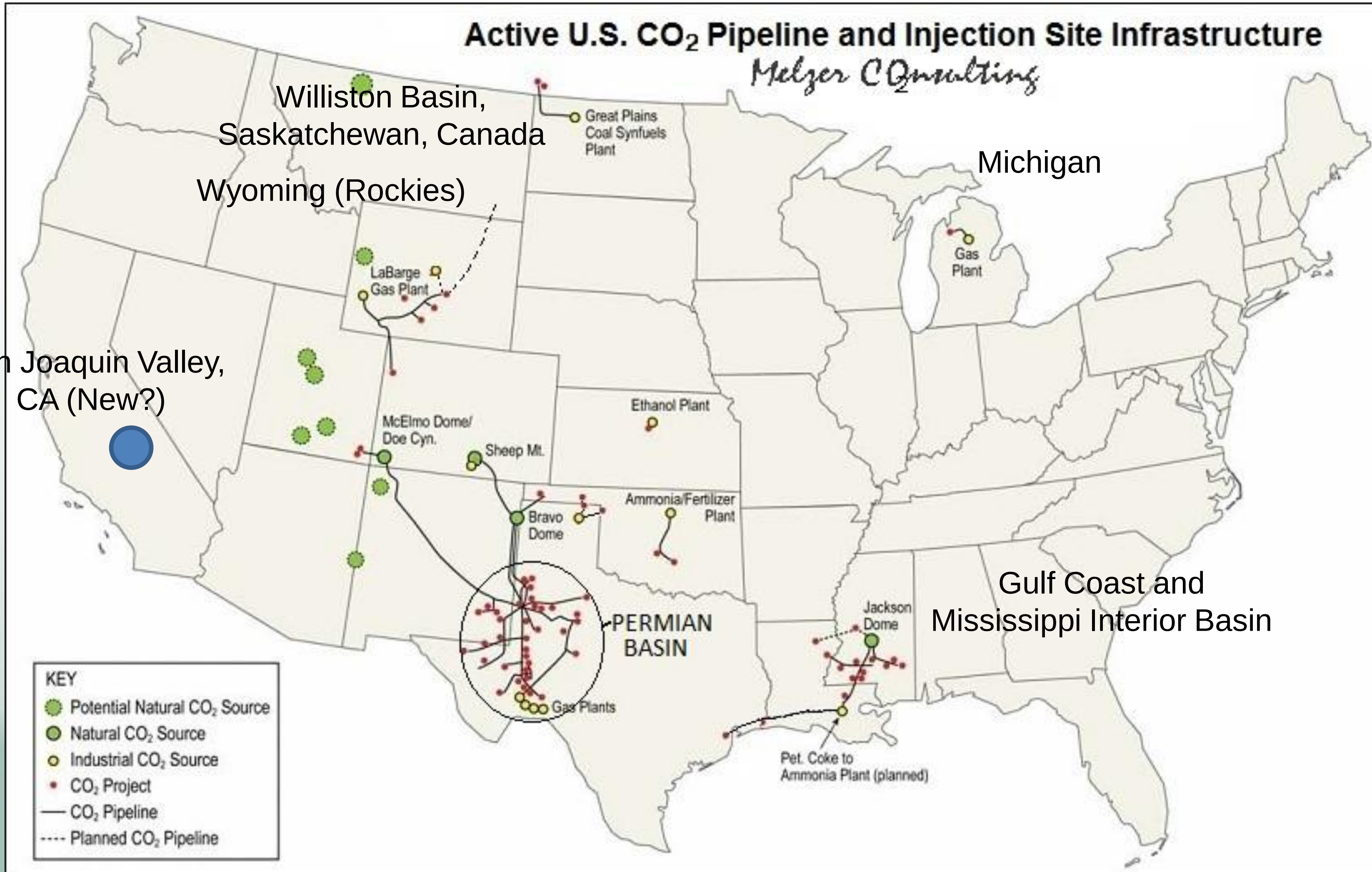
WORLDWIDE (WW) CO_2 FLOODING

- First Large-scale Demonstrations in Early 70's
- Since Then, Projects Implemented in a Number of Countries
  - Hungary, Turkey, Trinidad, France, Russia as well as in Canada and the U.S.
  - U.S. has dominated last decade of growth but with Canada now entering a new expansion phase
  - New Floods in Croatia
  - Other Countries are under study now (e.g., Denmark, UK, Norway, UAE, Indonesia, Thailand, Abu Dhabi, Saudi Arabia)
- Through all, CO_2 Flooding has had Steady Growth Through the Present Day

Some Handy Conversions

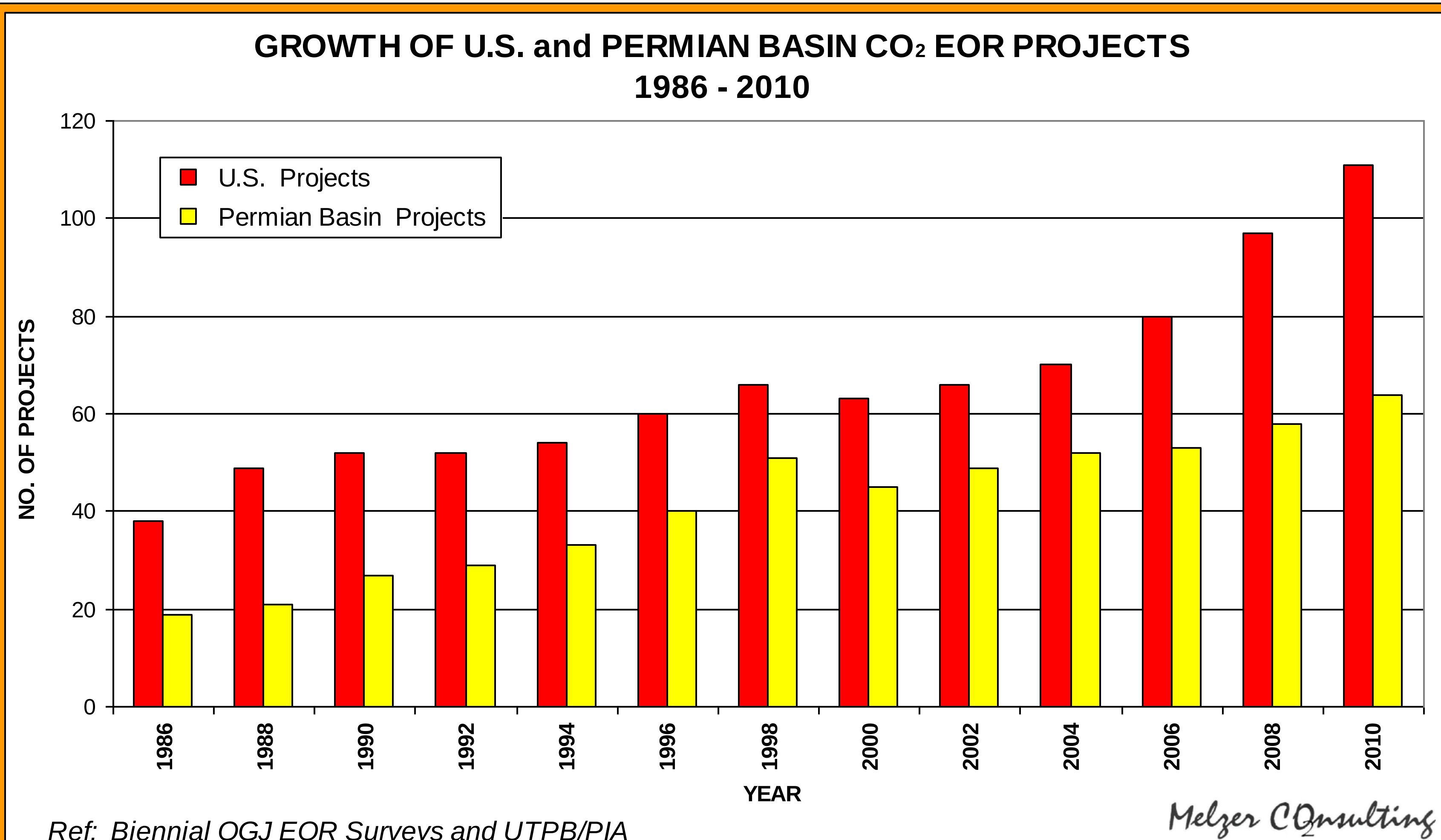
- 50 million cubic feet per day (mmcfpd) is roughly equal to 1 million tons per year (slightly less than 1 for metric tons {mt} and slightly more for english tons {ton}
- 17.5 mcf ~ 1 ton
- 19.25 mcf ~ 1 mt (tonne)
- For quick calculations (i.e., rule of thumb) we often use 3 oil bbls per mt

North American CO_2 Sources and EOR Areas



PERMIAN CCS CENTER

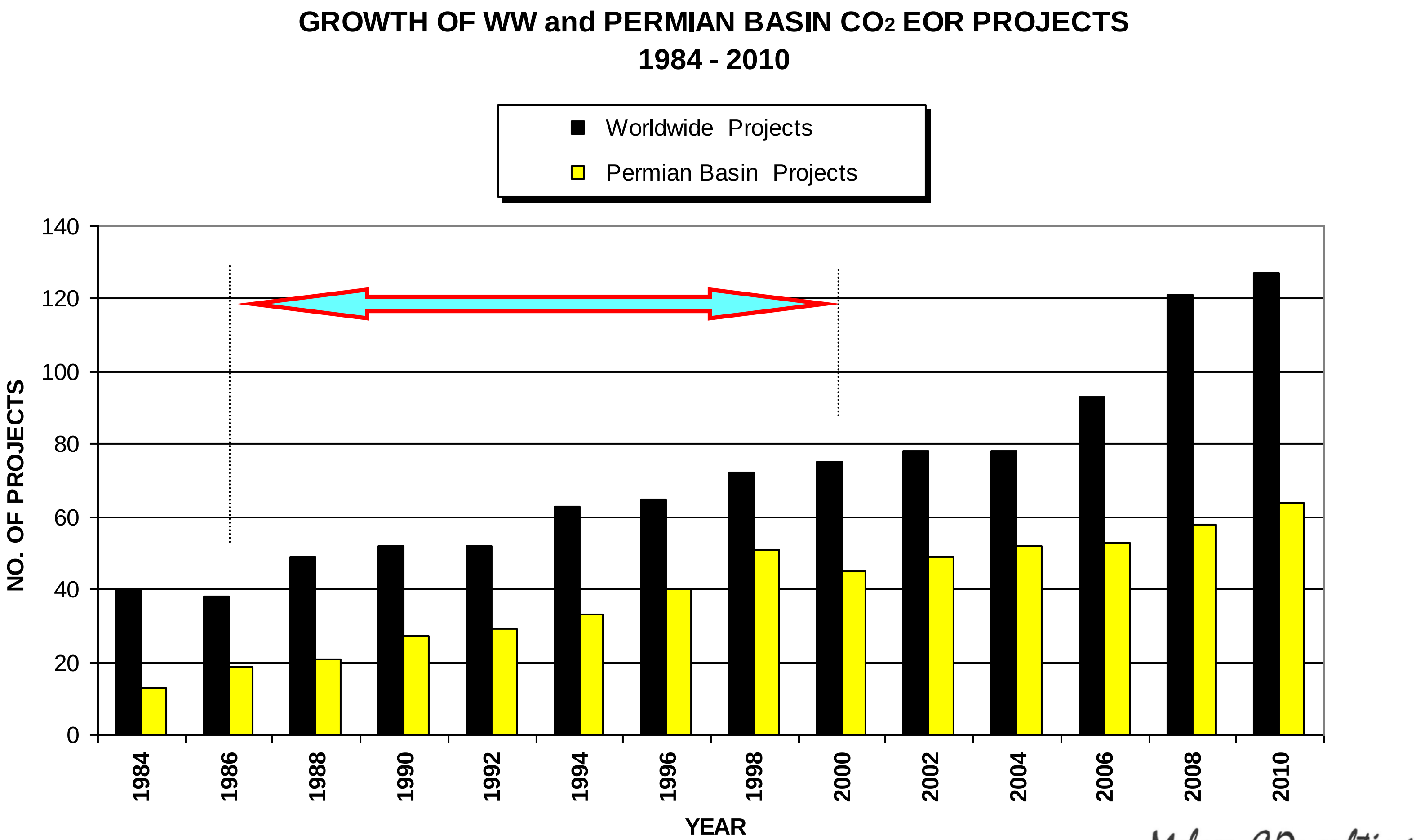
BACKGROUND
(OF CO_2 EOR PROJECT GROWTH*)



Ref: Biennial OGJ EOR Surveys and UTPB/PIA

BACKGROUND

(OF CO_2 EOR PROJECT GROWTH*)



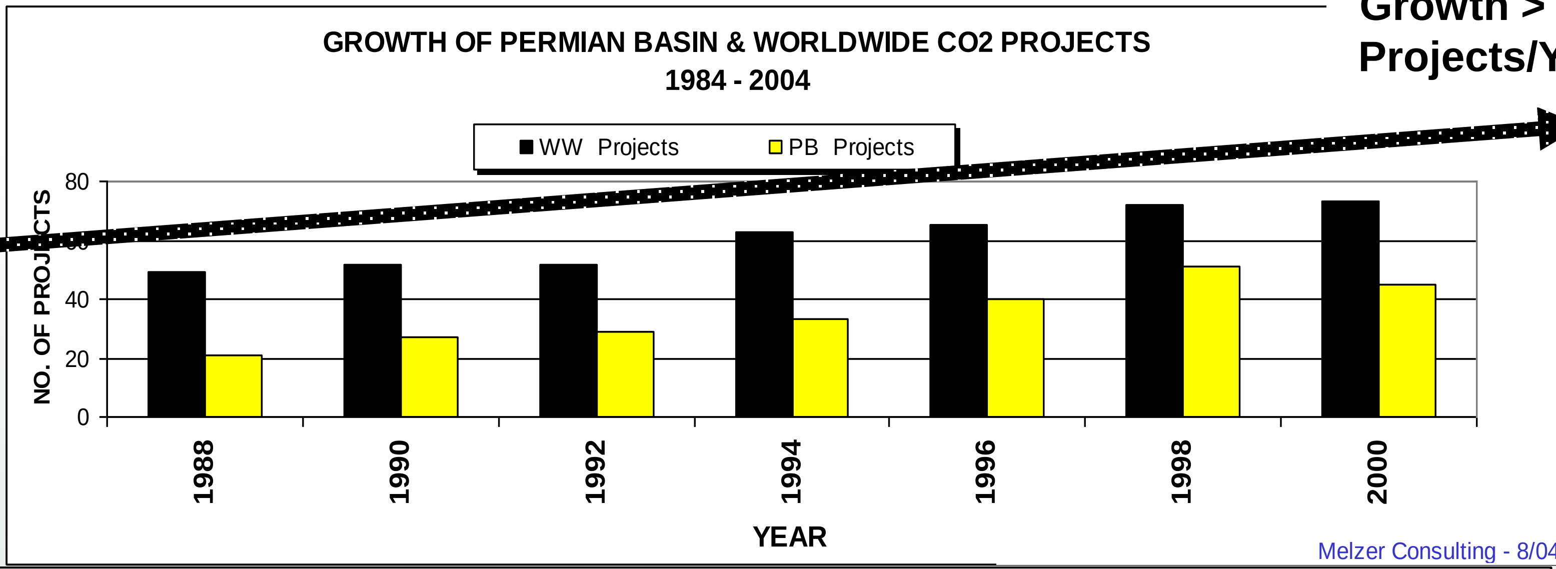
Ref: Biennial OGJ EOR Surveys and UTPB/PIA

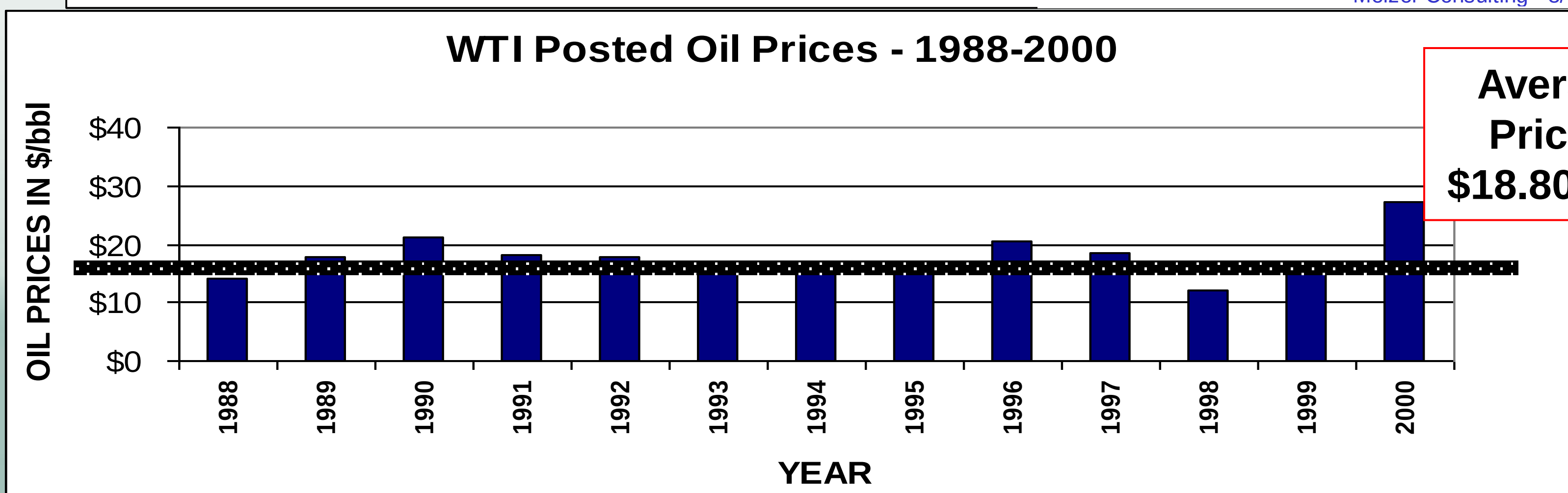
Melzer COnsulting

PERMIAN CCS CENTER

…..and Growth Even with Languishing Oil Pricing

Average Growth > 2 Projects/Yr

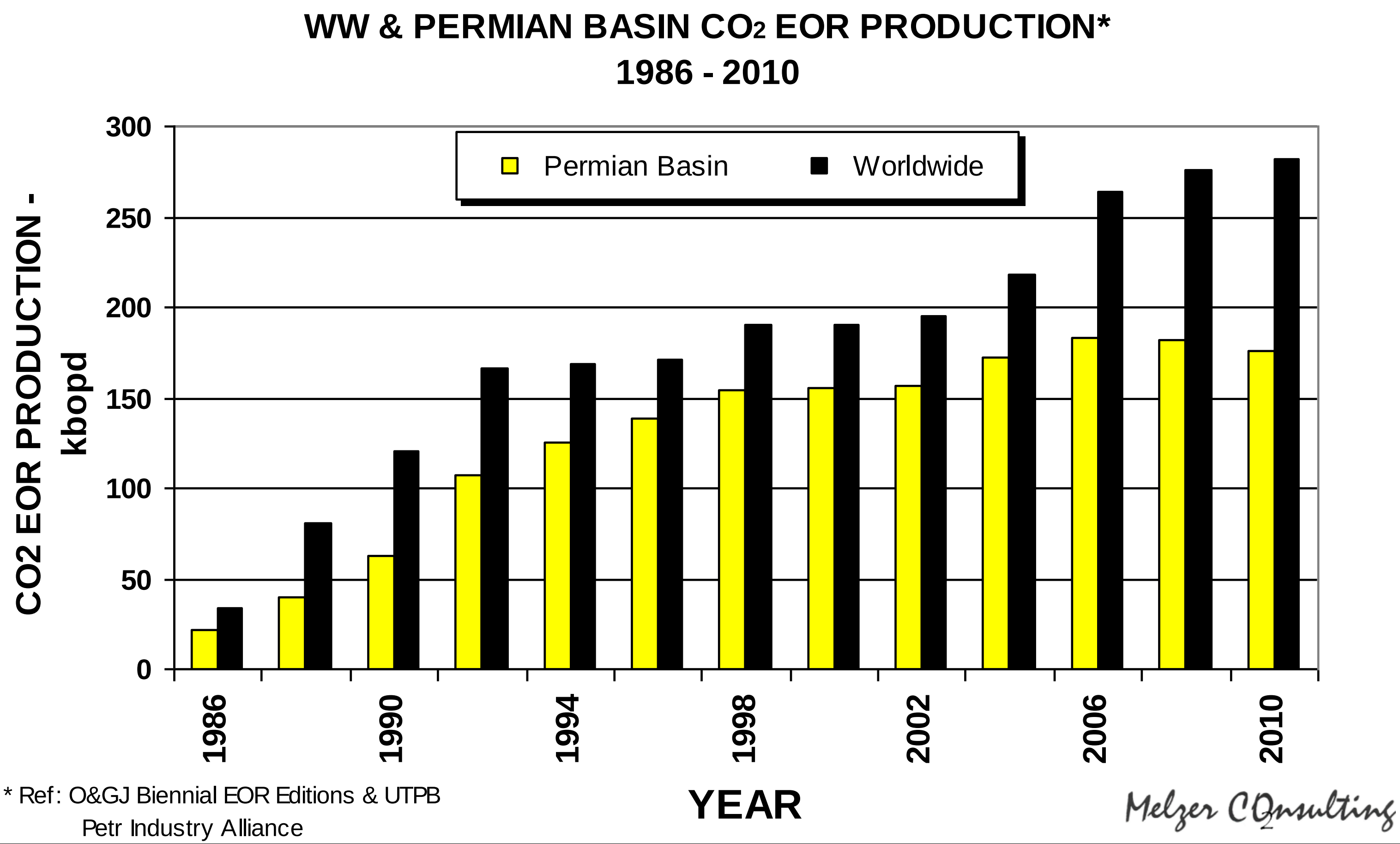




Average Price = $18.80 (U.S.)

BACKGROUND

(OF CO_2 EOR PRODUCTION GROWTH*)



* Ref: O&GJ Biennial EOR Editions & UTPB Petr Industry Alliance

PERMIAN CCS CENTER

COMPONENTS: SURFACE INFRASTRUCTURE

Common to all CO_2 Projects

- CO_2 Sources
- CO_2 Capture
- CO_2 Pipelines
- Custody and Allocation Meters
- CO_2 Distribution Lines

CO_2 EOR And CCS Projects with Produced Fluids

- Produced Fluids Gathering Lines
- Produced Gas Processing (Dehy, HC Gas and/or Liquids Removal?)
- CO_2 Compression
- Wellheads and Skids (Continuous, WAG, Co-injection?)
- Manifolds for Well Testing
- Water Handling (Disposal, Make-up)

Existing CO_2 Markets

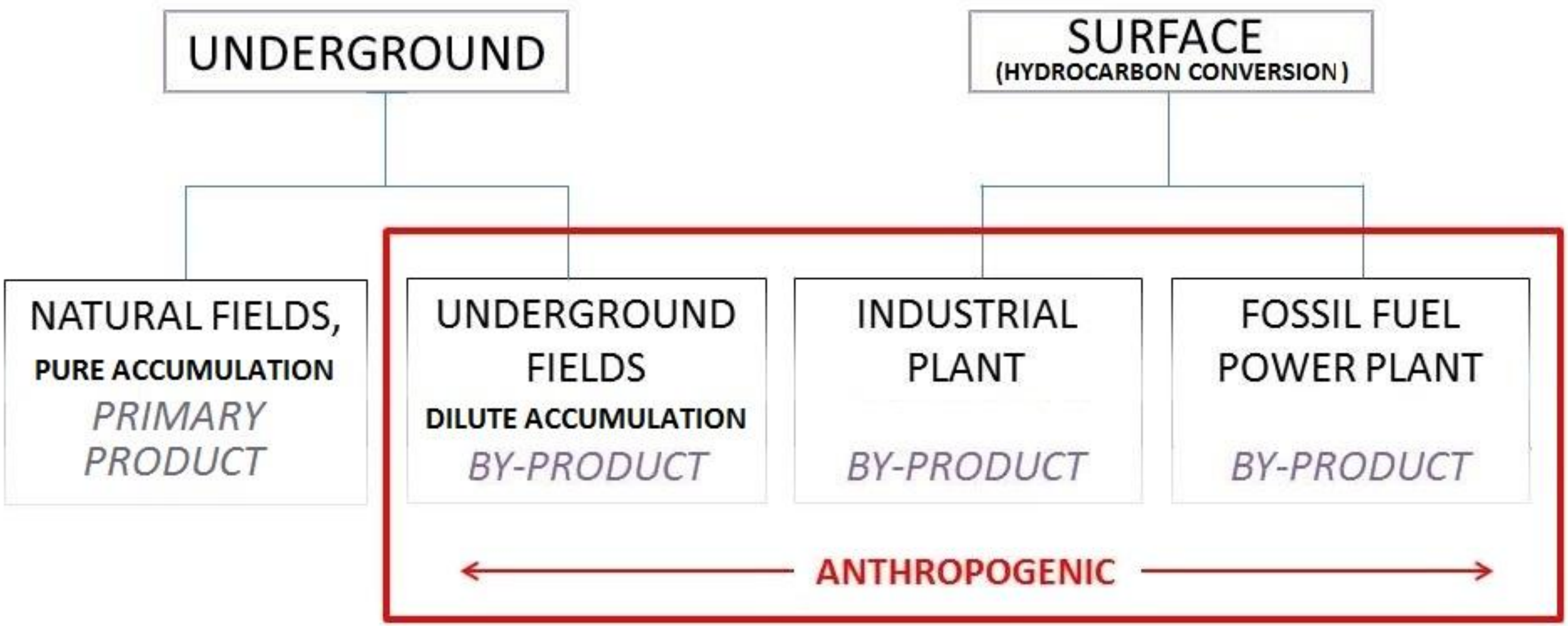
Steve Melzer

PERMIAN CCS CENTER

CO_2 SUPPLY

PERMIAN CCS CENTER

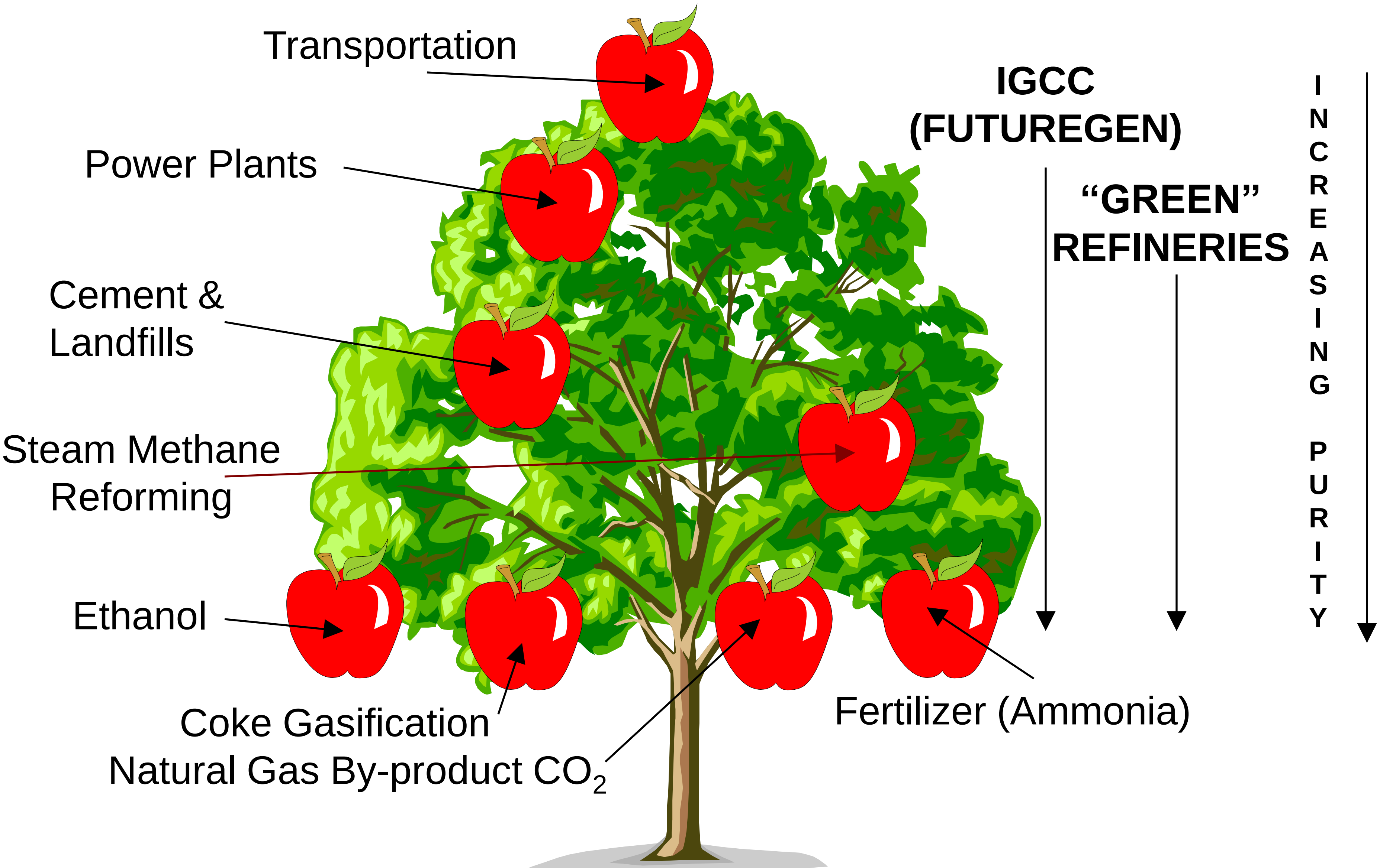
SOURCES OF CO_2 SUPPLY



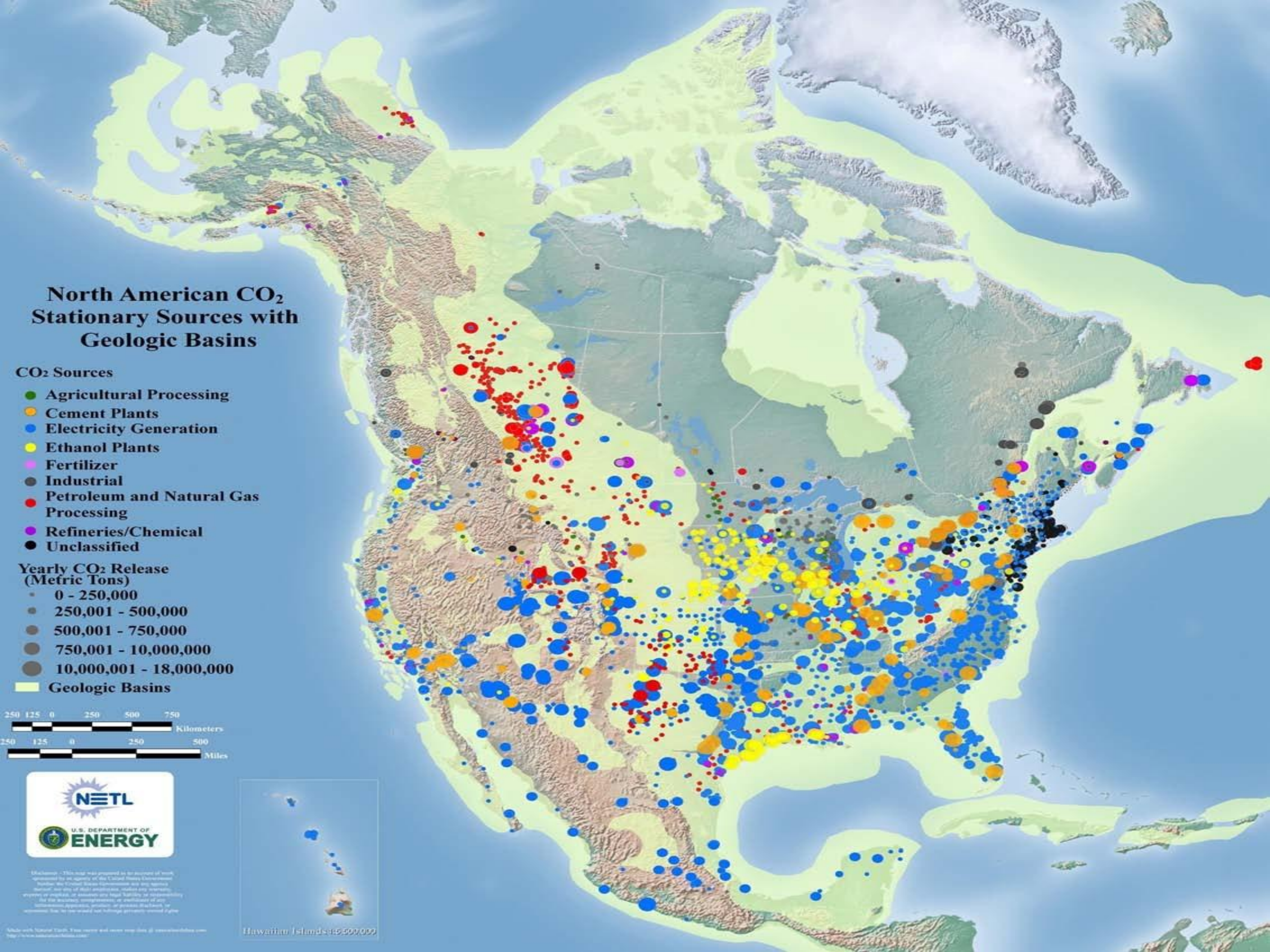
NATURAL vs. ANTHROPOGENIC CO_2

- NATURAL, PURE
  - Jackson Dome
  - Bravo Dome
  - 4 Corners Area (McElmo + Doe Canyon)
- INDUSTRIAL + NATURAL, DILUTE
  - SandRidge/Oxy Century Plant Project (PB)
  - Next Phase @ Shute Creek
  - Others in Wyoming (Lost Cabin, Riley Ridge, etc.)
  - Denbury Activity in Gulf Coast Region
  - St. Johns He Project
- Fossil Fuel Power
  - Pet Coke and Coal Gasification
  - Post Combustion Power Generation Emissions

Industrial CO_2 Sources



"THE CO_2 SOURCE FRUIT TREE"


North American CO_2 Stationary Sources with Geologic Basins
CO_2 Sources
Agricultural Processing
Cement Plants
Electricity Generation
Ethanol Plants
Fertilizer
Industrial
Petroleum and Natural Gas Processing
Refineries/Chemical
Unclassified
Yearly CO_2 Release (Metric Tons)
0 - 250,000
250,001 - 500,000
500,001 - 750,000
750,001 - 10,000,000
10,000,001 - 18,000,000
Geologic Basins
250 125 0 250 500 750
Kilometers
250 125 0 250 500
Miles
NETL
U.S. DEPARTMENT OF ENERGY
Hawaiian Islands

PERMIAN CCS CENTER

Industrial Sources of CO_2

Source	Flue Gas % CO2	CO2 Capture/yr (MM tons)	CO2 MMSCF/D
• Coal Power Plant[1]	13.3	4.6	222
• Natural Gas Turbine[2]	4.0	1.5	72
• Cement Plant[3]	14-33	1.2	56
• Steel Mill[4]	15-20	3.85	184
• Ammonia Plant[5]	98^+	0.62	30
• Hydrogen Plant[6]	95^+	0.50	24
• Ethylene Oxide[7]	98^+	0.18	9
• Ethanol Plant[8]	98^+	0.14	7

1- 546 MW(net) Supercritical Plant @ 85% Capacity Factor, 90% Capture
2 - 482 MW (net) Nat Gas Combined Cycle Plant @ 85% Capacity Factor, 90% Capture
3 - 1.1 MM ton/yr cement plant @ 92% Capacity Factor and 80% Capture
4 - Oil & Gas Journal, 10-4-2010, p.108: Original Source (IFP)
5 - 1500 ton/day NH3 plant base on steam reforming of methane, 95% Capacity Factor
6 - Based on 100 MMSCF/D hydrogen production from SMR @ 95% Capacity Factor
7 - 350,000 ton/ye Ethylene Oxide plant
8 - 50 MM gallon/year ethanol plant

Blue Strategies, 2010

PERMIAN CCS CENTER

CO_2 Capture Demonstration Projects

Coal Fired Power Plants

Performer	Location	Capture Technology	Capture Rate (tonnes/year)	Start Date
Pre-Combustion Capture				
Summit Texas Clean Energy	Odessa, TX	Selexol	3,000,000	2014
Southern Company	Kemper County, MS	Selexol	2,000,000	2014
Hydrogen Energy	California Kern County, CA	Rectisol	2,000,000	2016
Post-Combustion Capture				
Basin Electric	Beulah, ND	Amine	5,00,000 - 1,000,000	2014
NRG Energy	Thompson, TX	Amine	~500,000	2015
Amer Elec Power	New Haven, WV	Chilled Ammonia	1,500,000	2015
Oxy-Combustion Capture				
FutureGen 2.0	Meredosia, IL	Oxy-Combustion	1,000,000	2015

U.S. CO_2 SALES (AS OF 12/10)

• McElmo Dome/Doe Canyon Source Fields	1200 mmcfpd
• Sheep Mountain	30 mmcfpd
• Bravo Dome	250 mmcfpd
• LaVeta and West Bravo	60 mmcfpd
• Century Plant	180 mmcfpd
Total Permian	**1.72 bcfpd**
• Shute Creek Wyoming	320 mmcfpd
• Denbury Resources Mississippi	900 mmcfpd
• Dakota Gasification	150 mmcfpd
Total non-Permian	**1.37 bcfpd**

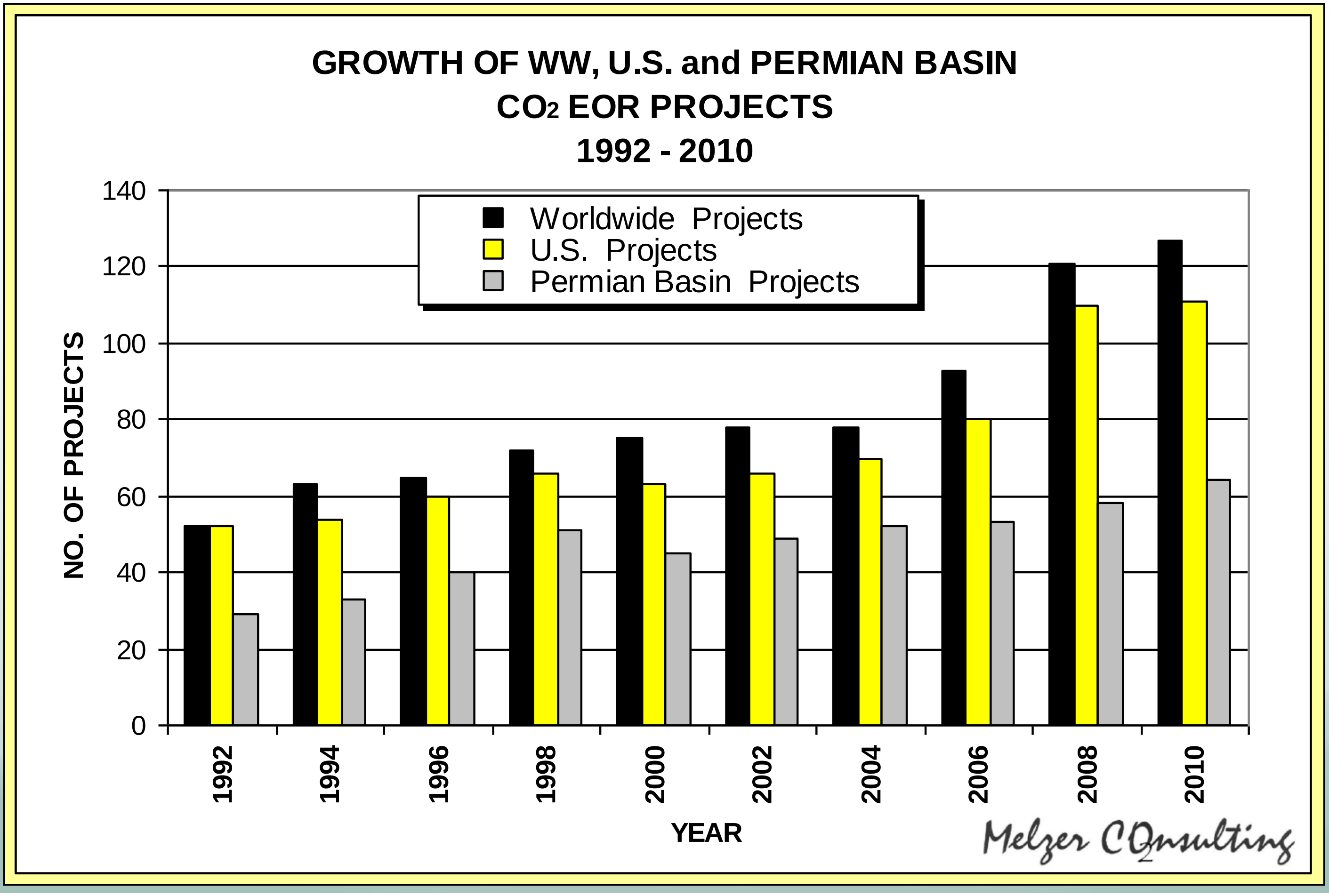
2010 CO_2 Sales: 3.09 bcfpd

CO_2 DEMAND

U.S. CO_2 EOR OIL PRODUCTION AND PROJECTS

PERMIAN CCS CENTER

Worldwide, U.S. and Permian Basin CO_2 EOR Projects*



* Includes CO_2 only Miscible Floods (Source: Data source: Oil & Gas Journal Annual Production Report, Apr 19, 2010, and APTA CO_2 School (5/2010)

PERMIAN CCS CENTER

U.S. Miscible CO_2 Projects (Part 1)*

	Type and operator	Field/Unit	State	County	Start date	Area, acres	No. wells prod.	No. wells inj.	Pay zone
	U.S. CO_2 miscible projects								
1	Anadarko	Patrick Draw Monell	Wyo.	Sweetwater	9/03	3,500	56	47	Mesaverde Almond
2	Anadarko	Salt Creek	Wyo.	Natrona	1/04	3,500	174	153	Wall Creek 2 (Frontier)
3	Anadarko	Salt Creek	Wyo.	Natrona	5/07	5	1	1	Wall Creek 1 (Frontier)
4	Anadarko	Sussex	Wyo.	Johnson	12/04	25	4	1	Tensleep
5	Apache	Slaughter - Coons, W.A.	Tex.	Hockley & Terry	5/85	569	24	11	San Andres
6	Apache	Slaughter	Tex.	Hockley & Cochran	6/89	8,559	228	154	San Andres
7	Chaparral Energy	Sho-Vel-Tum	Okla.	Stephens	9/82	1,100	60	40	Sims
8	Chaparral Energy	Camrick	Okla.	Beaver	4/01	2,320	32	19	Morrow
9	Chaparral Energy	North Perryton	Tex.	Ochiltree	12/07	2,500	6	3	Upper Morrow
10	Chevron	Rangely Weber Sand	Colo.	Rio Blanco	10/86	18,000	378	262	Weber SS
11	Chevron	Mabee	Tex.	Andrews-Martin	1/92	3,600	220	85	San Andres
12	Chevron	Slaughter Sundown	Tex.	Hockley Co	1/94	5,500	155	144	San Andres
13	Chevron	Vacuum	NM	Lea Co.	7/97	1,084	48	24	San Andres
14	ConocoPhillips	South Cowden	Tex.	Lea	2/81	4,900	43	22	San Andres
15	ConocoPhillips	Vacuum	NM	Lea	2/81	4,900	192	103	San Andres
16	Core Energy	Charlton 6	Mich.	Otsego	2006	60	1	1	Silurian - A1/Niagaran
17	Core Energy	Charlton 30-31	Mich.	Otsego	2005	285	2	1	Silurian - A1/Niagaran
18	Core Energy	Dover 33	Mich.	Otsego	1996	85	2	1	Silurian - A1/Niagaran
19	Core Energy	Dover 35	Mich.	Otsego	2004	70	3	2	Silurian - A1/Niagaran
20	Core Energy	Dover 36	Mich.	Otsego	1997	190	1	2	Silurian - A1/Niagaran
21	Denbury Resources	Lazy Creek	Miss.	Pike	12/01	840	5	6	Lower Tuscaloosa
22	Denbury Resources	Little Creek	Miss.	Lincoln & Pike	1985	6,200	30	34	Lower Tuscaloosa
23	Denbury Resources	Lockhart Crossing	La.	Livingston	12/07	3,398	11	3	First Wilcox
24	Denbury Resources	West Mallalieu	Miss.	Lincoln	1986	8,240	42	31	Lower Tuscaloosa
25	Denbury Resources	Martinville	Miss.	Simpson	3/06	280	5	1	Mooringsport
26	Denbury Resources	Martinville	Miss.	Simpson	3/06	212	2	2	Rodessa
27	Denbury Resources	McComb	Miss.	Pike	11/03	12,600	37	21	Lower Tuscaloosa
28	Denbury Resources	Smithdale	Miss.	Amite	3/05	4,100	5	3	Lower Tuscaloosa
29	Denbury Resources	Soso	Miss.	Jones/Jasper/Smith	4/06	2,600	37	17	Bailey 11701
30	Denbury Resources	Soso	Miss.	Jones/Jasper/Smith	4/06	1,800	16	8	Rodessa 11180
31	Denbury Resources	Brookhaven	Miss.	Lincoln	1/05	10,800	31	23	Lower Tuscaloosa
32	Denbury Resources	East Mallalieu	Miss.	Lincoln	12/03	880	11	8	Lower Tuscaloosa
33	Denbury Resources	Tinsley	Miss.	Yazoo	9/07	10,104		6	Woodruff
34	Energen Resources	East Penwell (SA) Unit	Tex.	Ector	5/96	1,020	47	22	San Andres
35	ExxonMobil	Greater Aneth Area	Utah	San Juan	2/85	13,440	143	120	Ismay Desert Creek
36	ExxonMobil	Means (San Andres)	Tex.	Andrews	11/83	8,500	484	284	San Andres
37	Fasken	Hanford	Tex.	Gaines	7/86	1,120	23	26	San Andres
38	Fasken	Hanford East	Tex.	Gaines	3/97	340	7	4	San Andres
39	Great Western Drilling	Twofreds	Tex.	Loving,Ward,Reeves	1/74	4,392	32	9	Delawar, Ramsey
40	George R. Brown	Garza	Tex.	Garza	5/06	650			San Andres
41	Apache	Adair San Andres Unit	Tex.	Gaines	11/97	1,100	19	18	San Andres
42	Hess	Seminole Unit-Main Pay Zo	Tex.	Gaines	7/83	15,699	408	160	San Andres
43	Hess	Seminole Unit-ROZ Phase	Tex.	Gaines	7/96	500	15	10	San Andres
44	Hess	Seminole Unit-ROZ Phase	Tex.	Gaines	4/04	480	16	9	San Andres
45	Kinder Morgan	SACROC	TX	Scurry	1/72	49,900	391	444	Canyon
46	erit Energy	Lost Soldier (1)	Wyo.	Sweetwater	5/89	1,345	33	39	Tensleep
47	Merit Energy	Lost Soldier (2)	Wyo.	Sweetwater	5/89	790	16	17	Darwin-Madison
48	Merit Energy	Lost Soldier (3)	Wyo.	Sweetwater	6/96	120	11	7	Cambrian
49	Merit Energy	Wertz (1)	Wyo.	Carbon, Sweetwater	10/86	1,400	12	22	Tensleep
50	Merit Energy	Wertz (2)	Wyo.	Carbon, Sweetwater	9/00	810	12	18	Darwin-Madison
51	Merit Energy	Northeast Purdy	Okla.	Garvin	9/82	3,400	85	49	Springer
52	Merit Energy	Bradley Unit	Okla.	Garvin/Gardy	2/97	700	29	12	Springer
53	urfin Drilling	Hall-Gurney	Kan.	Russell	12/03	10	2	3	LKC C
54	rla Petco	East Ford	Tex.	Reeves	7/95	1,953	8	4	Delaware, Ramsey
55	Occidental	Alex Slaughter Estate	Tex.	Hockley	8/00	246	21	14	San Andres

* SOURCE: OGJ (MAR '08 & UPTB/PIA '08)

PERMIAN CCS CENTER

U.S. Miscible CO_2 Projects (Part 1a)*

* SOURCE: OGJ (MAR '08 & UPTB/PIA '08)

	Type and operator	Field/Unit	Porosity, %	Perm-eability, md	Depth, ft	Oil Gravity, °API	Oil Viscosity, cp	Formation °F	Prev. prod.	Satur. start, %	Satur. end, %
	U.S. CO_2 miscible projects										
1	Anadarko	Patrick Draw Monell	20	30	5,000	43	0.6	120	Prim, WF	39	24
2	Anadarko	Salt Creek	18	75	1,900	37	0.6		Prim, GI,	39	24
3	Anadarko	Salt Creek	17	30	1,500	35	0.6	99	Prim, WF	39	24
4	Anadarko	Sussex	10	16	9,000	30	2.0	200	WF		
5	Apache	Slaughter - Coons, W.A.	12.5	6	4,900	32	1	110	WF		
6	Apache	Slaughter	10	3	5,000	32	2	107	WF	45	8
7	Chaparral Energy	Sho-Vel-Tum	16	70	6,200	30	3	115	WF	59	42
8	Chaparral Energy	Camrick	15	63	7,260	38.5	2	152	WF	52	
9	Chaparral Energy	North Perryton	15.2	63	7,300	38	2	152	WF	52	
10	Chevron	Rangely Weber Sand	12	10	6,000	35	2	160	WF	38	29
11	Chevron	Mabee	9	4	4,700	32	2	104	WF	36	10
12	Chevron	Slaughter Sundown	11	6	4,950	33	1	105	WF	41	25
13	Chevron	Vacuum	12	22	4,550	38	1	101	WF	36	15
14	ConocoPhillips	South Cowden	11.7	11	4,500	38	1	101	Prim.	70	50
15	ConocoPhillips	Vacuum	11.7	11	4,500	38	1	101	Prim.	70	50
16	Core Energy	Charlton 6		0.1 - 100	5,450	43	0.8	103	Prim.	54	44
17	Core Energy	Charlton 30-31		0.1 - 100	5,450	42	0.8	103	Prim.	47	40
18	Core Energy	Dover 33	5	0.1 - 100	5,500	43	0.8	100	Prim	51	40
19	Core Energy	Dover 35	5	0.1 - 100	5,500	41	0.8	101	Prim.	51	35
20	Core Energy	Dover 36	3	0.1 - 100	5,600	42	0.8	102	Prim	52	42
21	Denbury Resources	Lazy Creek	23.4	65	10,400	39		242	Prim	27.4	
22	Denbury Resources	Little Creek	23	90	10,750	40		250	WF	44	21
23	Denbury Resources	Lockhart Crossing	21	50-4,000	10,100	38.9	0.35	212	WF	60.4	
24	Denbury Resources	West Mallalieu	26	75	10,550	40		248	Prim	44	21
25	Denbury Resources	Martinville	18	40	11,000	38		244	WF	54.7	
26	Denbury Resources	Martinville	12	200	11,600	42		250	WF	63.5	
27	Denbury Resources	McComb	26	90	10,900	40		250	Prim/WF	52	
28	Denbury Resources	Smithdale	23	90	11,000	41		250	Prim	50	
29	Denbury Resources	Soso	17.4	273	11,950	43		234	Prim	50.4	
30	Denbury Resources	Soso	16.8	171	11,500	45		228	WF	54.7	
31	Denbury Resources	Brookhaven	25.5	60	10,300	40		250	Prim./GI/	47	
32	Denbury Resources	East Mallalieu	26	75	10,550	40		248	Prim./WF	44	
33	Denbury Resources	Tinsley	21	289	4,800	33		164	Prim./ WI	24	
34	Energen Resources	East Penwell (SA) Unit	10	4	4,000	34	2	86	WF	55	40
35	ExxonMobil	Greater Aneth Area	14	5	5,600	41	1	125	Prim.	50	
36	ExxonMobil	Means (San Andres)	9	20	4,300	29	6	97	WF		
37	Fasken	Hanford	10.5	4	5,500	32	1	104	Prim.	60.7	18.7
38	Fasken	Hanford East	10	4	5,500	32	1	104	WF	45	18.7
39	Great Western Drilling	Twofreds	19.5	32	4,900	36	2	105	WF	50	
40	George R. Brown	Garza			3,000	36					
41	Apache	Adair San Andres Unit	15	8	4,852	35	1	98	WF		
42	Hess	Seminole Unit-Main Pay Zo	12	1.3-123	5,300	35	1	104	WF		
43	Hess	Seminole Unit-ROZ Phase 1	12	1.3-123	5,500	35	1	104	none		
44	Hess	Seminole Unit-ROZ Phase 2	12	1.3-123	5,500	35	1	104	none		
45	Kinder Morgan	SACROC	4	19	6,700	39	1	135	Prim / WI	63	39
46	Merit Energy	Lost Soldier (1)	9.9	31	5,000	35	1	178	WF		
47	Merit Energy	Lost Soldier (2)	10.3	4	5,400	35	1	181	WF		
48	Merit Energy	Lost Soldier (3)	7	10	7,000	35			WF		
49	Merit Energy	Wertz (1)	10	20	6,000	35	1	163	WF		
50	Merit Energy	Wertz (2)	10	5	6,400	35	1	170	WF		
51	Merit Energy	Northeast Purdy	13	44	9,400	38	1	148	WF		
52	Merit Energy	Bradley Unit	14	50	9,400	38	1	150	WF		
53	urfin Drilling	Hall-Gurney	25	85	2,900	39.6	3	99	WF	35	
54	rla Petco	East Ford	23	30	2,680	40	1	82	Prim.	49	36
55	Occidental	Alex Slaughter Estate	10	5	4,950	31	1.8	105	WF	40	25

U.S. Miscible & Immiscible CO_2 Projects * (Part 2)*

	Type and operator	Field/Unit	State	County	Start date	Area, acres	No. wells prod.	No. wells inj.	Pay zone	Formation
	U.S. CO_2 miscible projects									
62	Occidental	GMK South	Tex.	Gaines	1982	1,143	16	7	San Andres	Dolo.
63	Occidental	Igoe Smith	Tex.	Cochran	9/05	1,235	61	27	San Andres	Dolo.
64	Occidental	Levelland	Tex.	Hockley	9/04	1,179	84	51	San Andres	Dolo.
65	Occidental	Mid Cross - Devonian Unit	Tex.	Crane, Upton & Crocke	7/97	1,326	13	5	Devonian	Tripol.
66	Occidental	N. Cross - Devonian Unit	Tex.	Crane & Upton	4/72	1,155	26	13	Devonian	Tripol.
67	Occidental	North Cowden Demo.	Tex.	Ector	2/95	200	10	3	Grayburg	Dolo.
68	Occidental	North Dollarhide	Tex.	Andrews	11/97	1,280	28	20	Devonian	Tripol.
69	Occidental	North Hobbs	NM	Lea	3/03	3,100	125	75	San Andres	Dolo.
70	Occidental	S. Cross - Devonian Unit	Tex.	Crockett	6/88	2,090	73	30	Devonian	Tripol.
71	Occidental	Salt Creek	Tex.	Kent	10/93	12,000	174	135	Canyon	LS
72	Occidental	Sharon Ridge	Tex.	Scrurry	2/99	1,400	31	18	Canyon Reef	LS
73	Occidental	Slaughter (H T Boyd Lease	Tex.	Cochran	8/01	1,240	37	24	San Andres	Dolo.
74	Occidental	Slaughter Estate Unit	Tex.	Hockley	12/84	5,700	194	150	San Andres	Dolo./LS
75	Occidental	Slaughter North West Malle	Tex.	Cochran & Hockley	2008	1,048	39	24	San Andres	Dolo.
76	Occidental	Slaughter West RKM Unit	Tex.	Hockley	2006	1,204	51	33	San Andres	Dolo.
77	Occidental	South Welch	Tex.	Dawson	9/93	1,160	89	70	San Andres	Dolo.
78	Occidental	T-Star (Slaughter Consolid	Tex.	Hockley	7/99	1,700	51	35	Abo	Dolo.
79	Occidental	Wasson Bennett Ranch Un	Tex.	Yoakum	6/95	1,780	115	89	San Andres	Dolo.
80	Occidental	Wasson Denver Unit	Tex.	Yoakum & Gaines	4/83	27,848	1,010	575	San Andres	Dolo.
81	Occidental	Wasson ODC Unit	Tex.	Yoakum	11/84	7,800	325	270	San Andres	Dolo./LS
82	Occidental	Wasson Willard Unit	Tex.	Yoakum	1/86	8,500	275	228	San Andres	Dolo.
83	Occidental	West Welch	Tex.	Gaines	10/97	240	0	0	San Andres	Dolo.
84	Pure Resources	Dollarhide (Devonian) Unit	Tex.	Andrews	5/85	6,183	83	66	Devonian	Dolo./Tripolitic
85	Pure Resources	Dollarhide (Clearfork "AB")	Tex.	Andrews	11/95	160	21	4	Clearfork	Dolo.
86	Pure Resources	Reinecke	Tex.	Borden	1/98	700	32	8	Cisco Canyon Reef	LS/Dolo.
87	Resolute Natural Reso	Greater Aneth	Utah	San Juan	10/98	1,200	12	10	Desert Creek	LS
88	Stanberry Oil	Hansford Marmaton	Tex.	Hansford	6/80	2,010	5	6	Marmaton	S
89	Whiting Petroleum	North Ward Estes	Tex.	Ward/Winkler	5/07	16,300	816	816	Yates	SS
90	Whiting Petroleum	Postle	Okla.	Texas	11/95	11,000	92	82	Morrow	SS
91	Whiting Petroleum	Postle Expansion	Okla.	Texas	/07-1/09	7,000	72	62	Morrow	SS
92	XTO Energy, Inc.	Goldsmith	Tex.	Ector	12/96	330	16	9	San Andres	Dolo.
93	XTO Energy, Inc.	Cordona Lake	Tex.	Crane	12/85	2,084	64	26	Devonian	Tripol.
94	XTO Energy, Inc.	Wasson (Cornell Unit)	Tex.	Yoakum	7/85	1,923	90	62	San Andres	Dolo.
95	XTO Energy, Inc.	Wasson (Mahoney)	Tex.	Yoakum	10/85	640	45	30	San Andres	Dolo.
				Miscible Totals =		**388,582**	**8,528**	**5,952**		
	U.S. CO_2 immiscible projects									
96	Anadarko	Salt Creek	Wyo.	Natrona	10/05	5	4	1	Wall Creek 1 (Frontier)	S
97	Chaparral Energy	Sho-Vel-Tum	Okla.	Stephens	11/98	98	6	1	Aldridge	S
98	Denbury	Eucutta	Miss.	Wayne	4/06	2,100	25	29	Eutaw	S
99	Denbury	Martinville	Miss.	Simpson	3/06	180	3	1	Wash-Fred 8500	S
100	Kinder Morgan	Yates	TX	Pecos	3/04	26,000	551	121	San Andres	Dolo.
						416,965	9,117	6,105		

* SOURCE: OGJ (MAR '08 & UPTB/PIA '08)

U.S. Miscible & Immiscible CO_2 Projects* (Part 2a)

* SOURCE: OGJ (MAR '08 & UPTB/PIA '08)

	Type and operator	Field/Unit	Porosity, %	Perm-eability, md	Depth, ft	Oil Gravity, °API	Oil Viscosity, cp	Formation °F	Prev. prod.	Satur. start, %	Satur. end, %	Proj. matur.	Tot. prod., b/d	Enh. prod., b/d
	U.S. CO_2 miscible projects													
62	Occidental	GMK South	10	3	5,400	30	3.0	101	WF	55	28	HF	610	375
63	Occidental	Igoe Smith	11	4	5,040	34	1.5	105	WF	47	36	HF	700	440
64	Occidental	Levelland	12	2	4,900	34	1.4	108	WF	45	30	JS	1,800	950
65	Occidental	Mid Cross - Devonian Unit	18	2	5,400	42	0.4	104	Prim., GI	60	20	HF	320	296
66	Occidental	N. Cross - Devonian Unit	22	5	5,300	44	0.4	104	Prim., GI	49	21	NC	1,045	835
67	Occidental	North Cowden Demo.	10	2-5	4,200	34	1.5	91	WF	40	25	NC	230	80
68	Occidental	North Dollarhide	22	5	7,500	40	0.5	123	WF	38	23	HF	1,950	1,000
69	Occidental	North Hobbs	15	15	4,200	35	0.9	102	WF	35	24	HF	8,560	6,300
70	Occidental	S. Cross - Devonian Unit	21	4	5,200	43	0.6	104	Prim., GI	43	24	HF	5,875	5,790
71	Occidental	Salt Creek	20	12	6,300	39	1.0	125	WF	89	15	HF	7,700	6,600
72	Occidental	Sharon Ridge	10	70	6,600	43	0.4	125	WF	39	26	HF	900	400
73	Occidental	Slaughter (H T Boyd Lease	10	4	5,000	31	1.6	108	WF	47	36	NC	1,080	1,040
74	Occidental	Slaughter Estate Unit	12	5	4,950	31	1.8	105	WF	40	23	HF	4,100	2,430
75	Occidental	Slaughter North West Malle	10	4	4,950	32	2.0	105	WF	47	31	PP	950	0
76	Occidental	Slaughter West RKM Unit	9	4	4,900	32	2.0	105	WF	42	29	JS	1,560	30
77	Occidental	South Welch	11	4	4,900	34	2.3	98	WF	50	15	HF	1,180	865
78	Occidental	T-Star (Slaughter Consolid	7	2	7,850	28	1.9	134	Prim./WF	75	45	HF	2,100	2,100
79	Occidental	Wasson Bennett Ranch Un	11	8	5,250	34	1.2	105	WF	55	37	HF	4,320	3,510
80	Occidental	Wasson Denver Unit	12	8	5,200	33	1.2	105	WF	51	31	HF	31,500	26,850
81	Occidental	Wasson ODC Unit	10	5	5,100	34	1.3	110	WF	49	34	HF	9,900	9,200
82	Occidental	Wasson Willard Unit	10	1.5	5,100	32	2.0	105	WF	56	41	HF	4,965	4,765
83	Occidental	West Welch	10	3	4,900	34	2.3	98	WF	50	15	C	1,790	0
84	Pure Resources	Dollarhide (Devonian) Unit	13.5	9	8,000	40	0	122	Prim./WF	35	22	HF	2,420	1,970
85	Pure Resources	Dollarhide (Clearfork "AB")	11.5	4	6,500	40	1	113	Prim./WF	30	10	JS	230	124
86	Pure Resources	Reinecke	10.4	170	6,700	43.5	0.4	139	WF	35	10	JS	977	830
87	Resolute Natural Reso	Greater Aneth	12	18.3	5,700	42	1.5	129	WF	40	28	JS	1,200	400
88	Stanberry Oil	Hansford Marmaton	18.1	48	6,500	44	2	142	Prim.	43		NC	102	102
89	Whiting Petroleum	North Ward Estes	16	37	2,600	36	1.6	83	Prim, WF	26.5	21	JS	4,225	700
90	Whiting Petroleum	Postle	16	50	6,200	40	1	145	WF	37	25	HF	4,500	4,500
91	Whiting Petroleum	Postle Expansion	16	35	6,200	40	1	145	WF	37	25		1,700	1,700
92	XTO Energy, Inc.	Goldsmith	11.6	32	4,200	34	0.98	104	WF			JS	120	20
93	XTO Energy, Inc.	Cordona Lake	22	4	5,500	40	0.50	101	WF			HF	1,350	400
94	XTO Energy, Inc.	Wasson (Cornell Unit)	8.6	2	4,500	33	1.00	106	WF			HF	1,675	800
95	XTO Energy, Inc.	Wasson (Mahoney)	13	6	5,100	33	0.97	110	WF	54.4	39.2	HF	1,875	1,450
												miscible =	289,932	238,187
	U.S. CO_2 immiscible projects													
96	Anadarko	Salt Creek	17	30	1,150	35	0.6	99	Prim, WF	32	24	C		
97	Chaparral Energy	Sho-Vel-Tum	20	270	5,400	19	45	105	Prim	62	47	JS	72	70
98	Denbury	Eucutta	27	250	5,050	22		152	WF	42		JS	3,000	3,000
99	Denbury	Martinville	26	1,000	8,500	11		198	Prim	44.3		JS	270	0
100	Kinder Morgan	Yates	17	175	1,400	30	6	82	GI	75	54	JS	27,940	6,280
												immiscible + miscible =	321,214	247,537

International Projects

4/19/2010 Data source: Oil & Gas Journal Annual Production Report, Apr 19, 2010, andMelzer Consulting (5/2010)

Producing CO_2 EOR projects outside U.S. and CANADA Table E1

Operator	Field	Country and state/area	Type Flood	Start date	Area, acres	No. wells prod.	No. wells inj.	Pay zone	Form-ation
		Brazil							
Petrobras	Buracica	Bahia	CO_2 immiscible	1991	1,670		7	Sergi	S
Petrobras	Rio Pojuca	Bahia	CO_2 miscible	1999			1	Agua Grande	S
Petrobras	Miranga	Bahia	CO_2 miscible	D-10		27	10	Catu-1	S
		Trinidad							
Petrotrin	Area 2102	Forest Reserve	CO_2 immiscible	6/76	58	6	2	Forest Sands	S
Petrotrin	Area 2121	Forest Reserve	CO_2 immiscible	1/74	29	2	2	Forest Sands	S
Petrotrin	Area 2124	Forest Reserve	CO_2 immiscible	1/86	184	3	1	Forest Sands	S
Petrotrin	EOR 34 - Cyclic	Forest Reserve	CO_2 immiscible	84	NA	11	0	Forest/MLE	S
Petrotrin	Oropouche	Oropouche	CO_2 immiscible	6/90	175	4	3	Retrench	S
		Turkey							
TPAO	Bati Raman	Batman	CO_2 immiscible	3/86	12,890	212	69	Garzan	LS
				M+I =	15,006	265	95		
				M =	0	0	1		

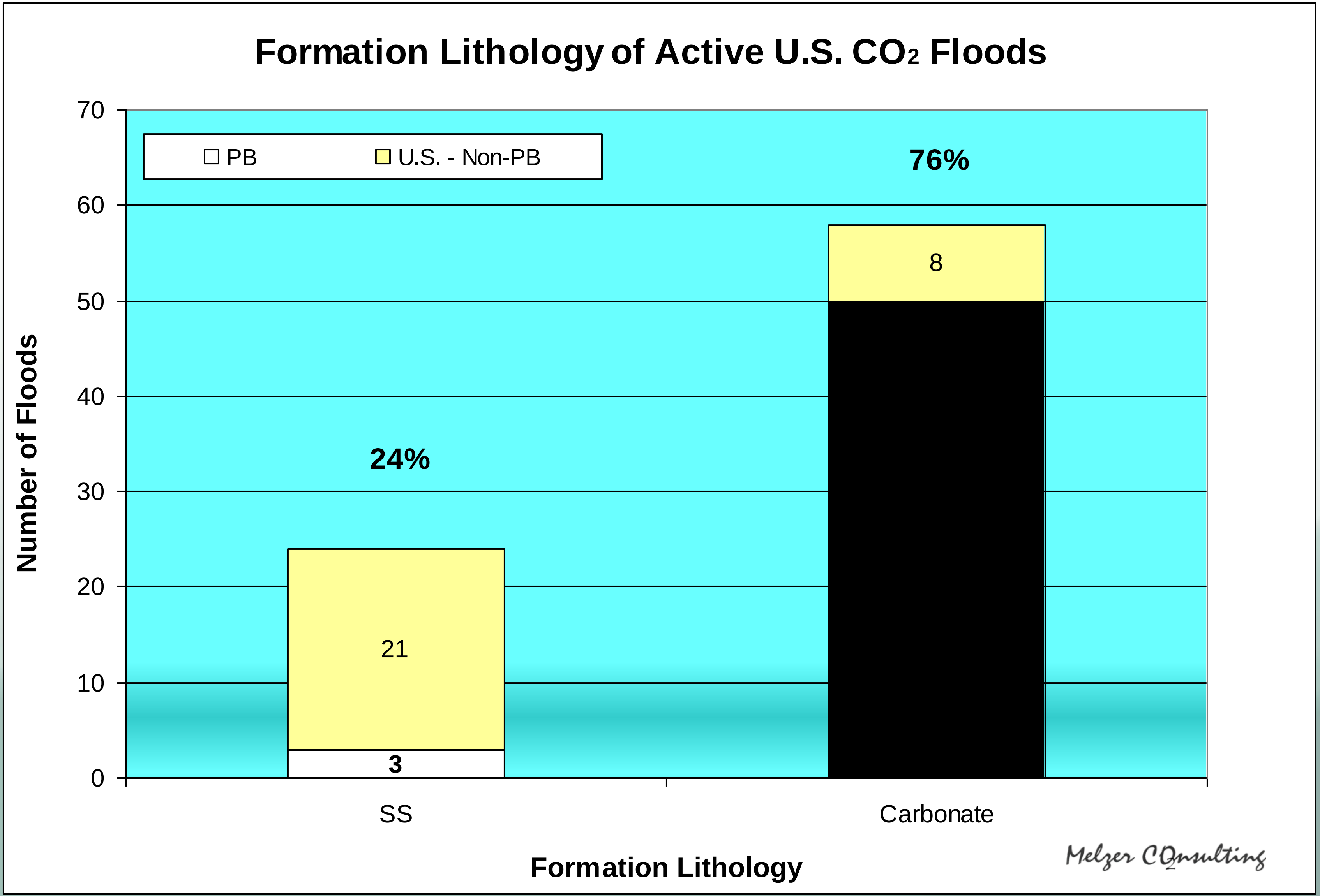
Table E2

Operator	Field	Porosity, %	Permea-bility, md	Depth, ft.	Gravity °API	Oil, cp	Oil, °F	Prev. prod.	Satur. % start	Satur. % end	Proj. matur.	Total prod. b/d	Enh. prod. b/d
Petrobras	Buracica	22		1,970	35	10.5	120	Prim, WF			NC		
Petrobras	Rio Pojuca			5,900	36	2	183	Prim			HF		
Petrobras	Miranga	20	112	4,000	39.4	1.15	156	WF			JS		
Petrotrin	Area 2102	32	175	3,000	19	16	120	Prim.	56		HF	43	43
Petrotrin	Area 2121	30	150	2,600	17	32	120	Prim.	60		HF		
Petrotrin	Area 2124	31	300	4,200	25	6	130	WF	44		TS	78	78
Petrotrin	EOR 34 - Cyclic	29	150	2,025	17	11-145	120	Prim.	-		HF	160	160
Petrotrin	Oropouche	30	36	2,400	29	5	120	Prim.	53	48	HF	32	32
TPAO	Bati Raman	18	58	4,265	13	592	129		78		NC	7,000	7,000
											immiscible +miscible =	7,313	7,313
											miscible =	0	0

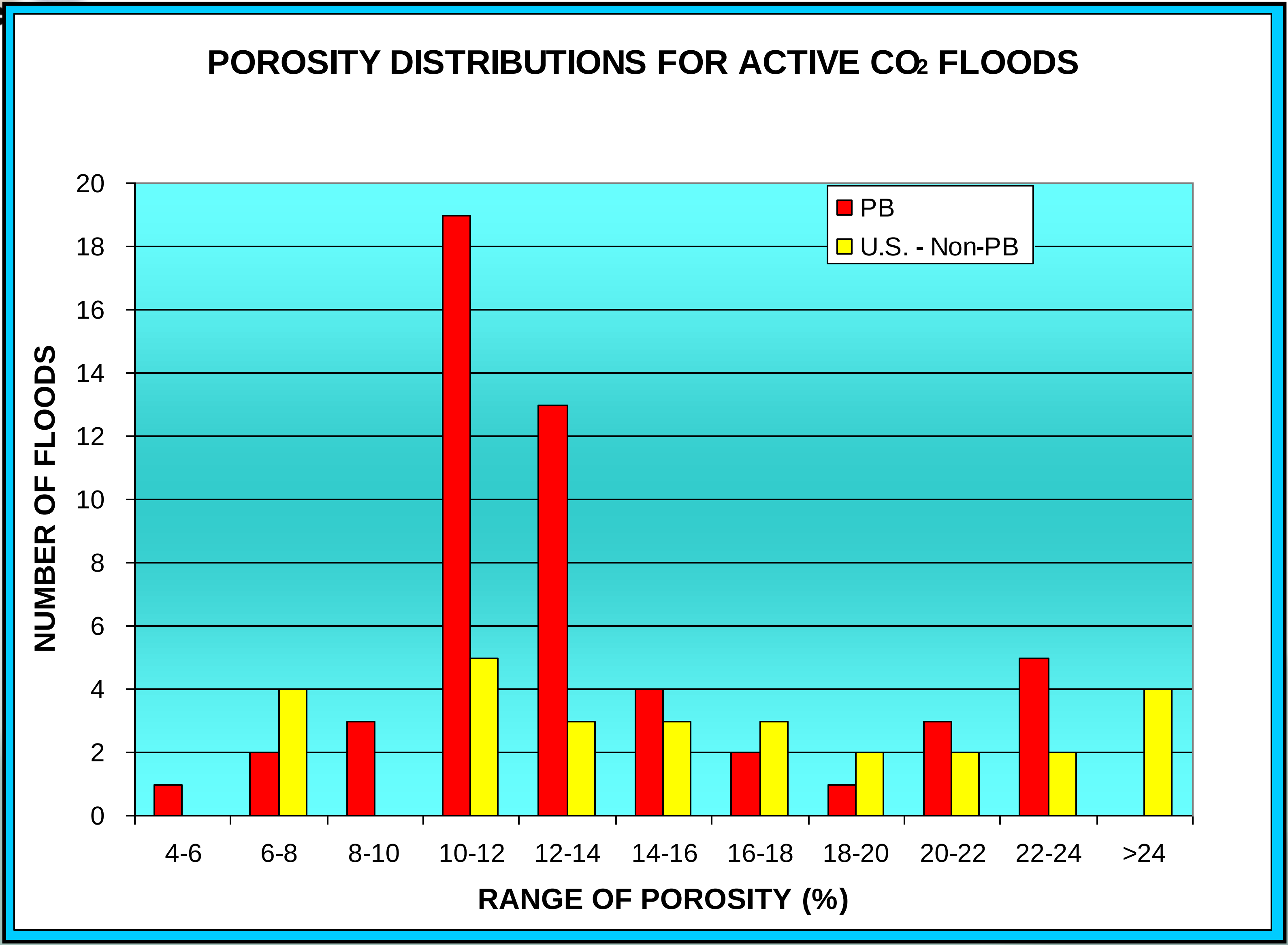
PERMIAN CCS CENTER

PROPERTIES OF CO_2 FLOODS
(main payzones)

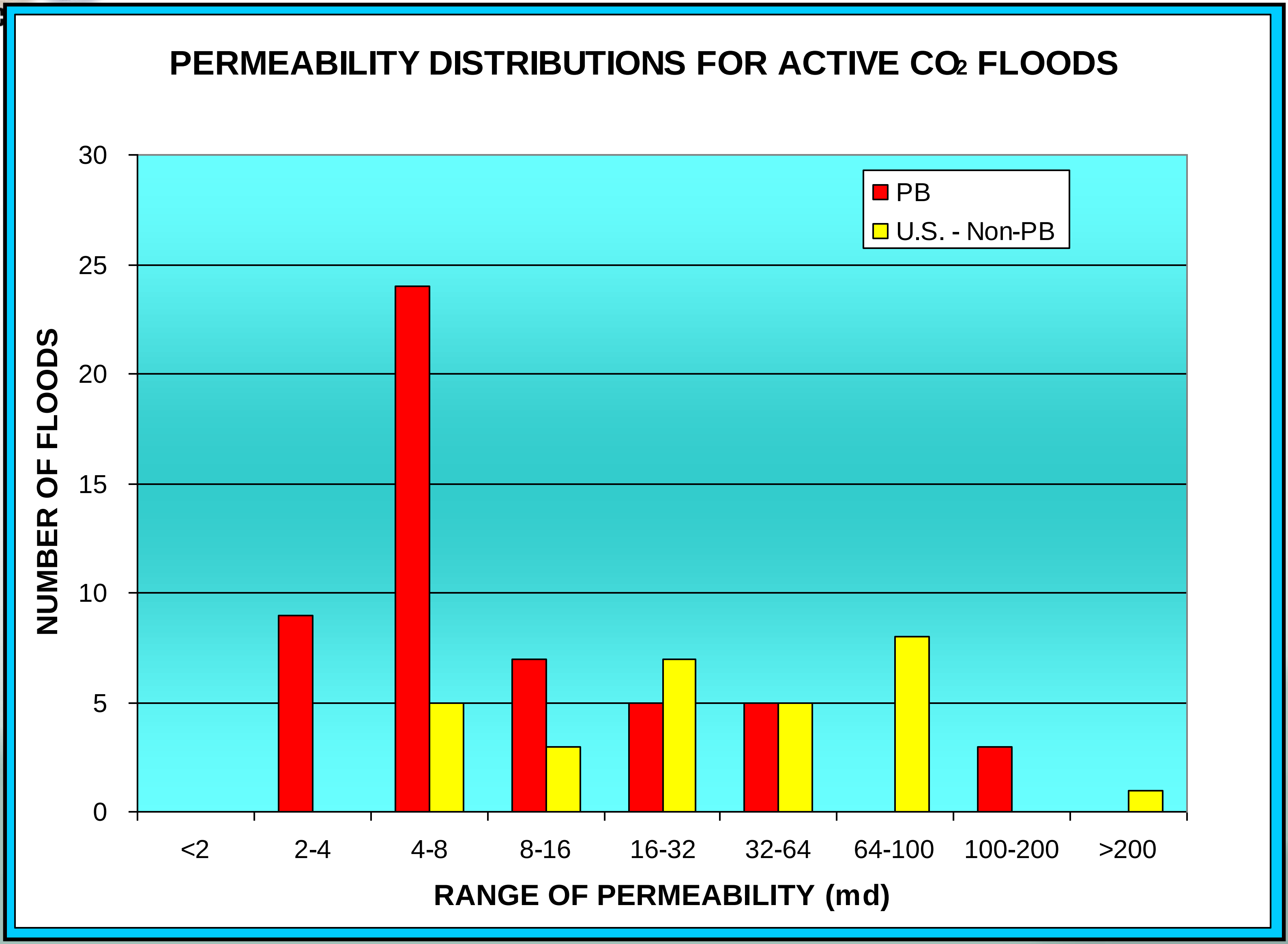
Formation Type



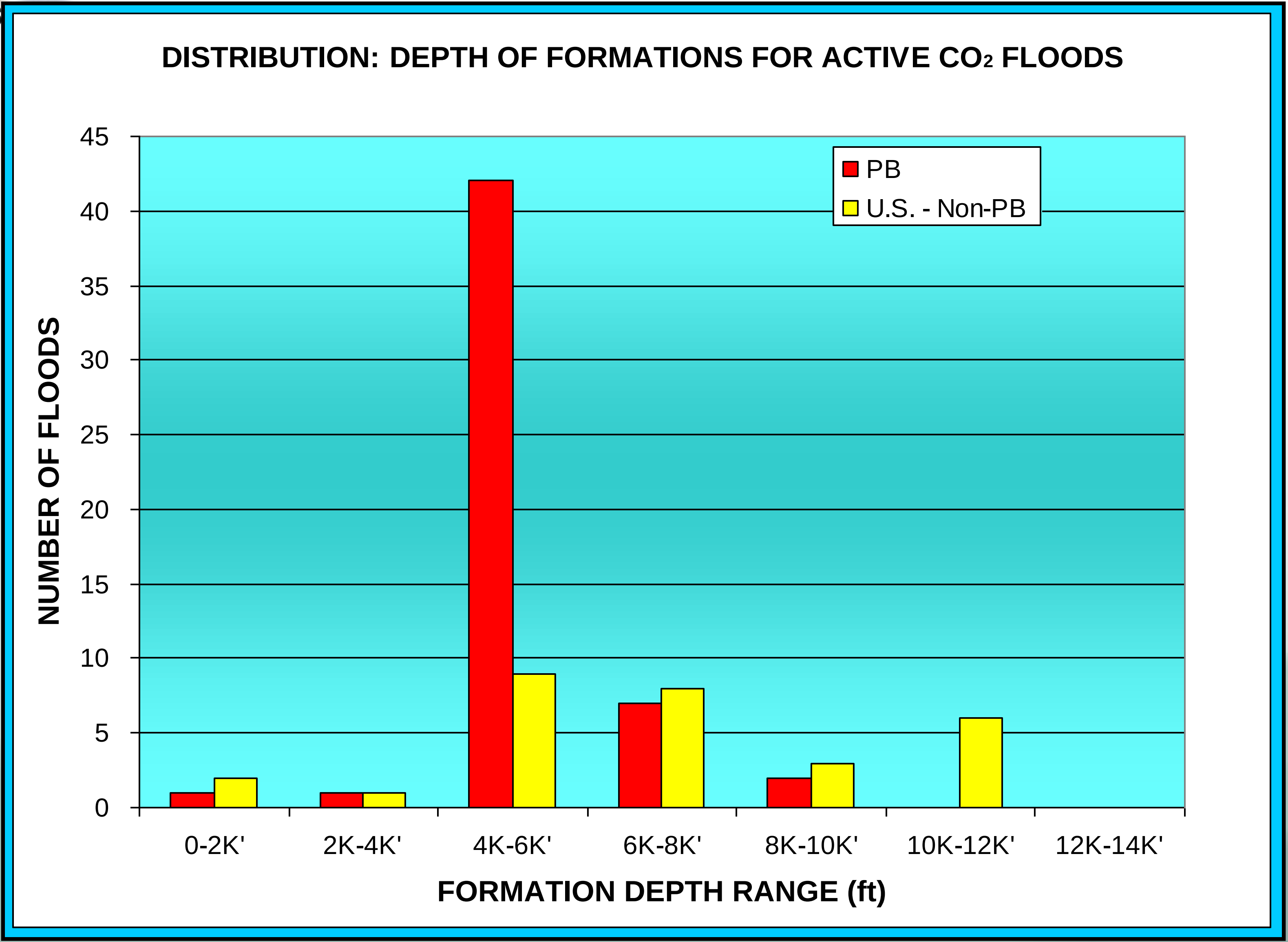
Formation Porosity



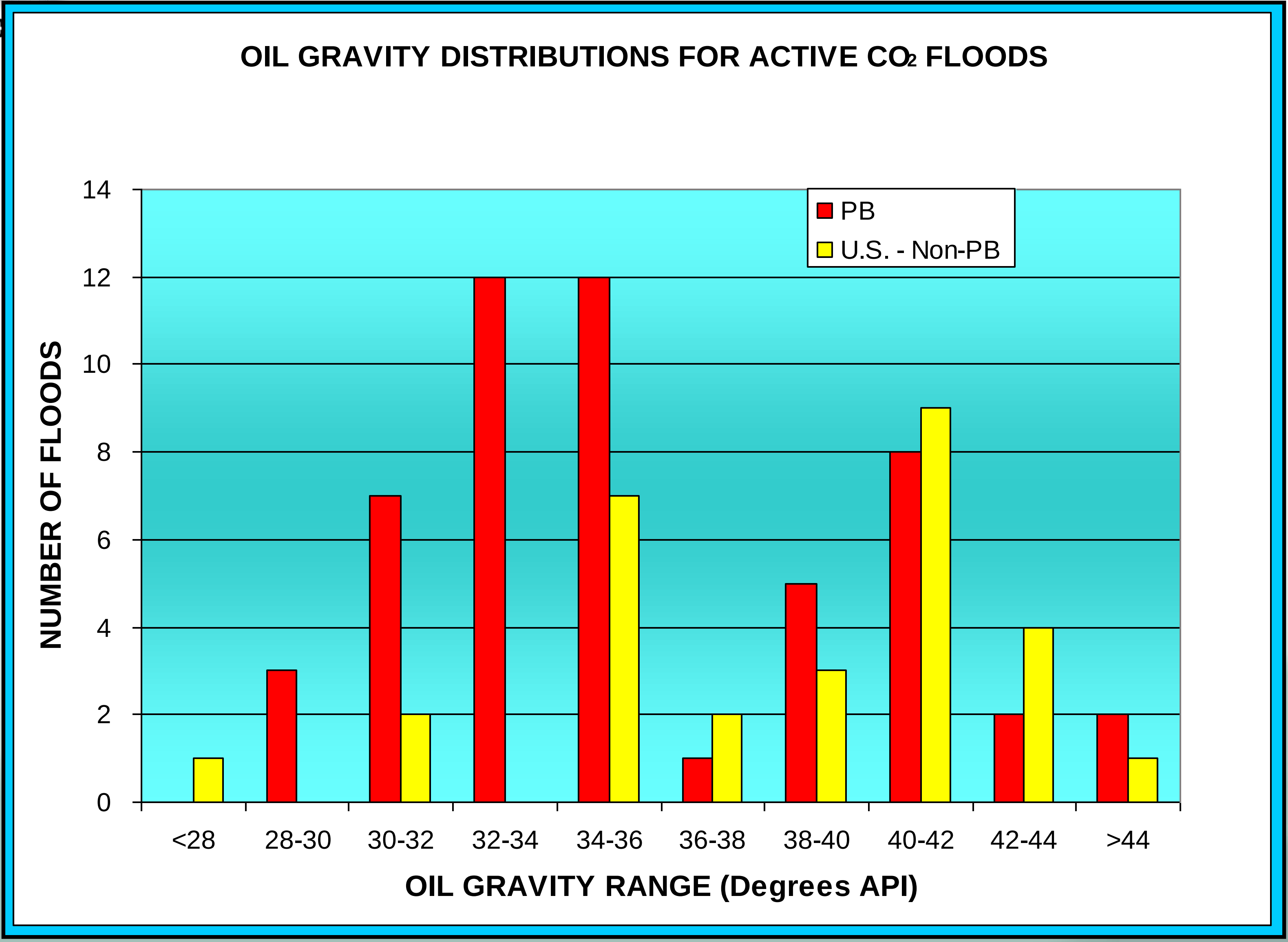
Formation Permeability



Formation Depth



Oil Gravity


OIL GRAVITY DISTRIBUTIONS FOR ACTIVE CO2 FLOODS
PB
U.S. - Non-PB
NUMBER OF FLOODS
0
2
4
6
8
10
12
14
<28
28-30
30-32
32-34
34-36
36-38
38-40
40-42
42-44
>44
OIL GRAVITY RANGE (Degrees API)

An Exciting New Reservoir Development

Steve Melzer

Two New Terms to Know

- Residual Oil Zone (ROZ): An Interval in a Reservoir Below the Oil Water Contract (OWC) or Free Oil Zone Wherein the Mobil Phase of Liquid in the Reservoir is Water

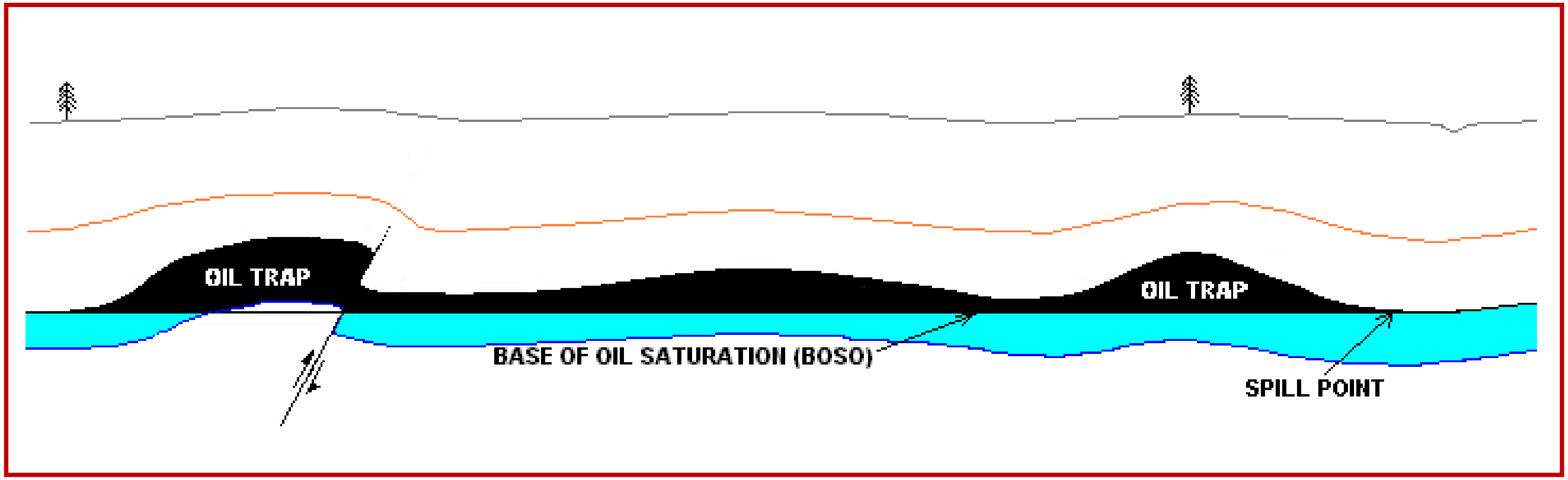
- Transition Zone (TZ): That Interval just Above and Below the Oil Water Contact Wherein the Mobil Phase is Oil at the Top and Formation Water at the Base

We have been trying to get industry out of the "Box" of explaining all ROZs as TZs (a subject for another day)

Origins of Residual Oil Zones and Mother Nature's Waterflood

Background and Understanding

Original Oil Accumulation Under Static Aquifer Conditions (A Hypothetical Example)

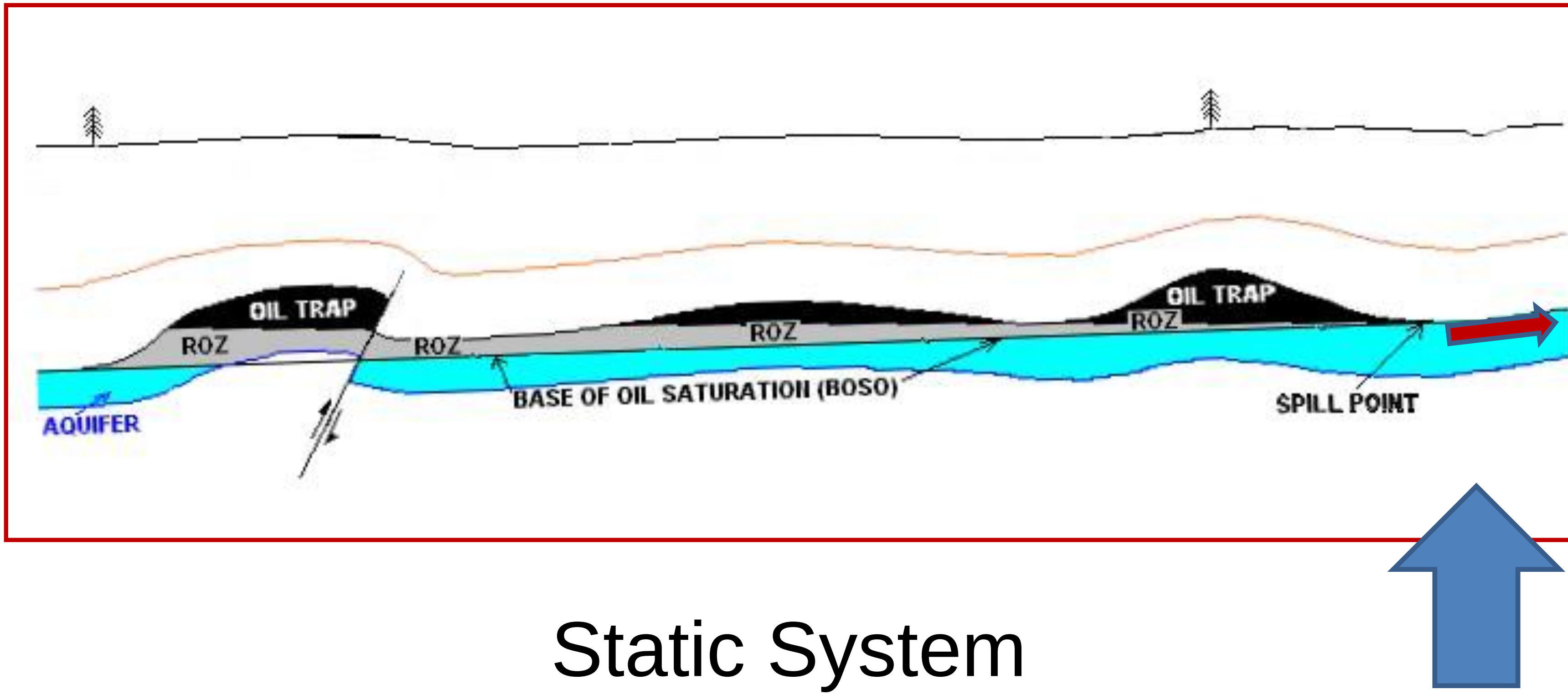


TYPE 1. Original Accumulation Subject to a Eastward Regional Tilt & Forming a ROZ.

The new O/W contact is horizontal

The base of the ROZ is tilted

Oil would have migrated out of the basin.



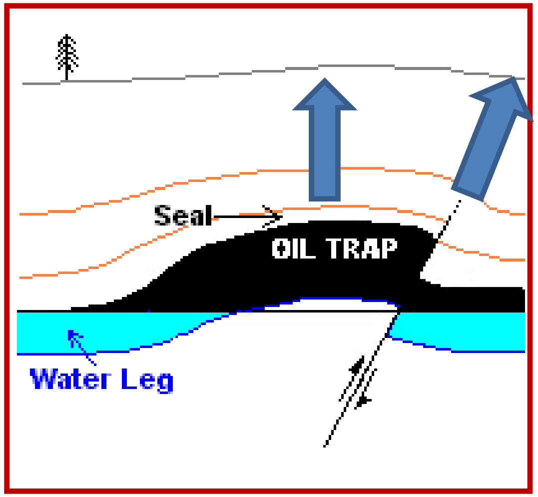
Static System

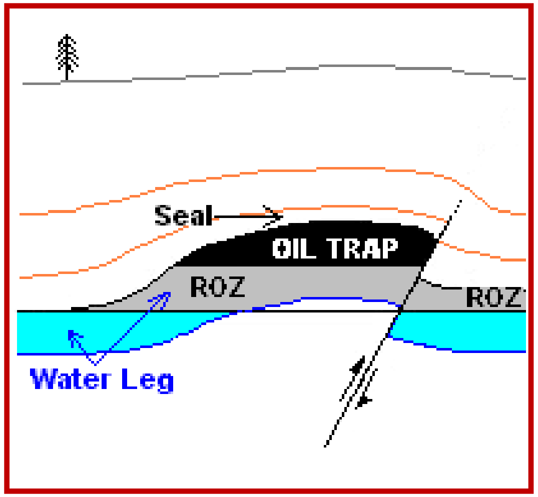
TYPE 2. Original Accumulation with a Breached, then Repaired, Seal, forming a ROZ/TZ.

A horizontal O/W contact on the main pay and the ROZ.

May also "de-gas" the reservoir.

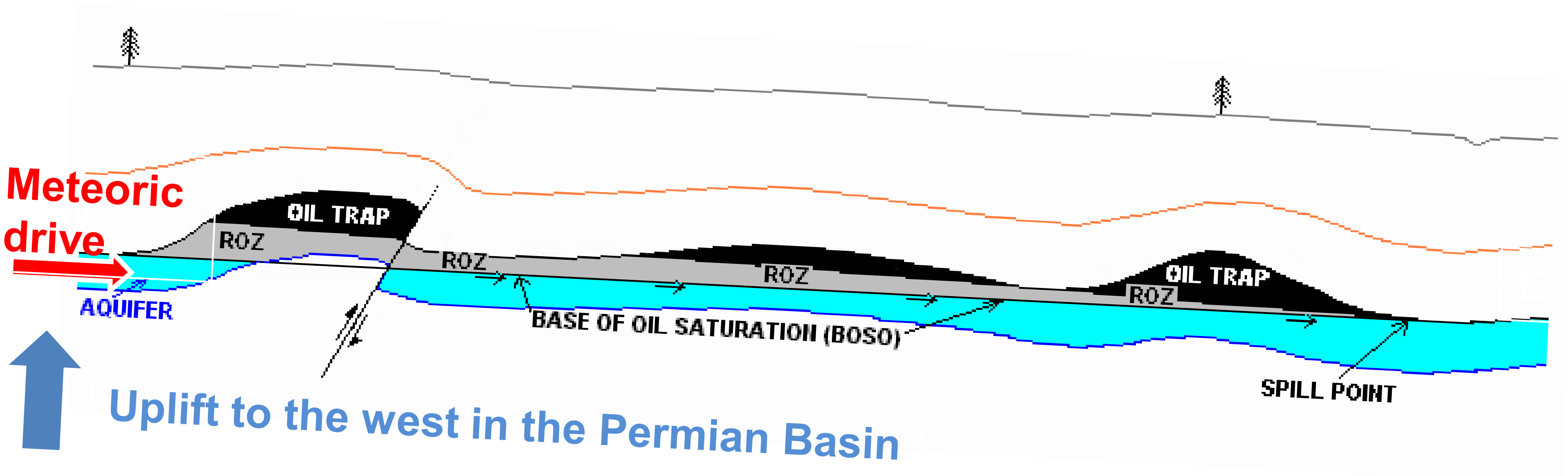
Present in the Permian Basin.



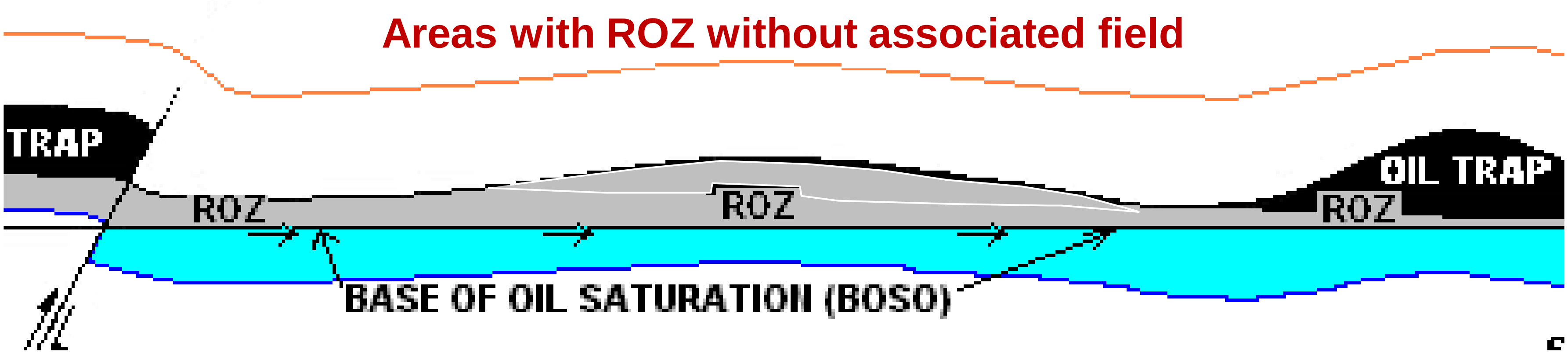


Static System

TYPE 3. Change in Hydrodynamic Conditions, Sweep of the lower part of the Oil Column and Development of a Residual Oil Zone. Oil/Water Contact is Tilted Base of the ROZ locally almost flat, regionally tilted.



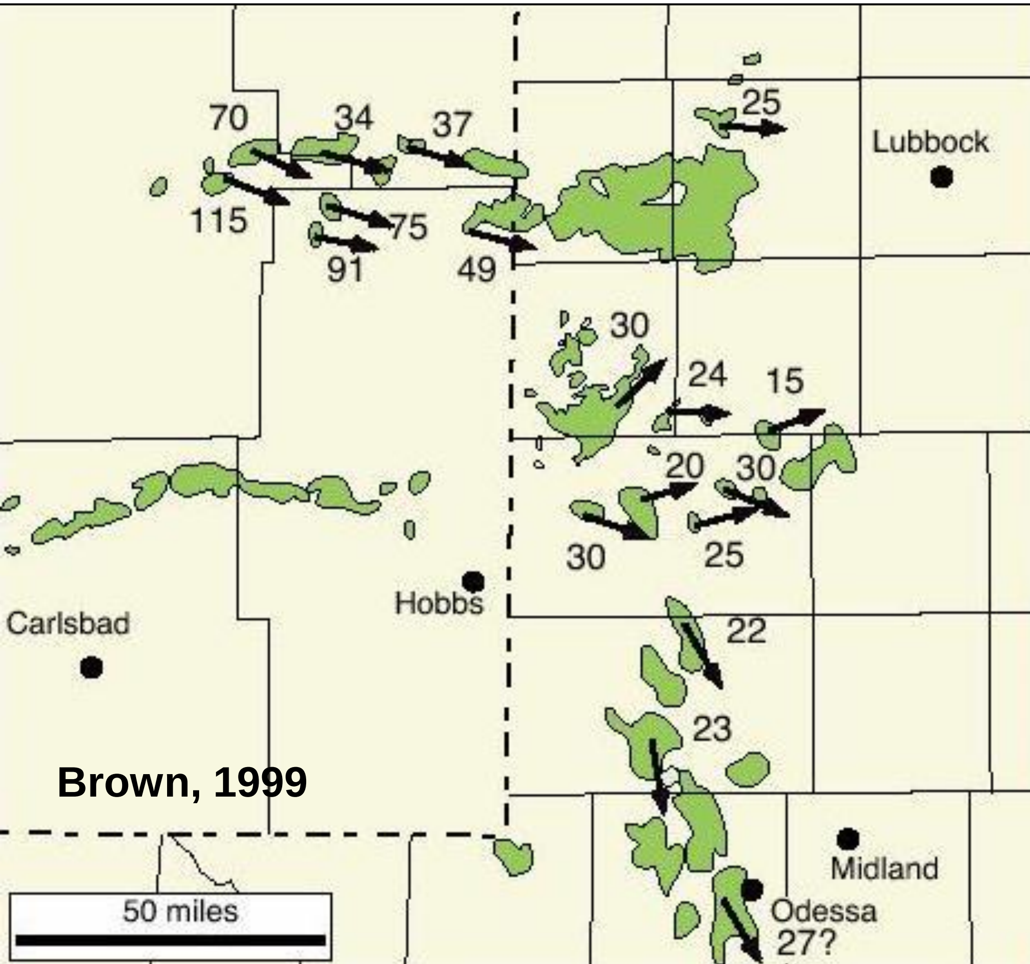
Dynamic System



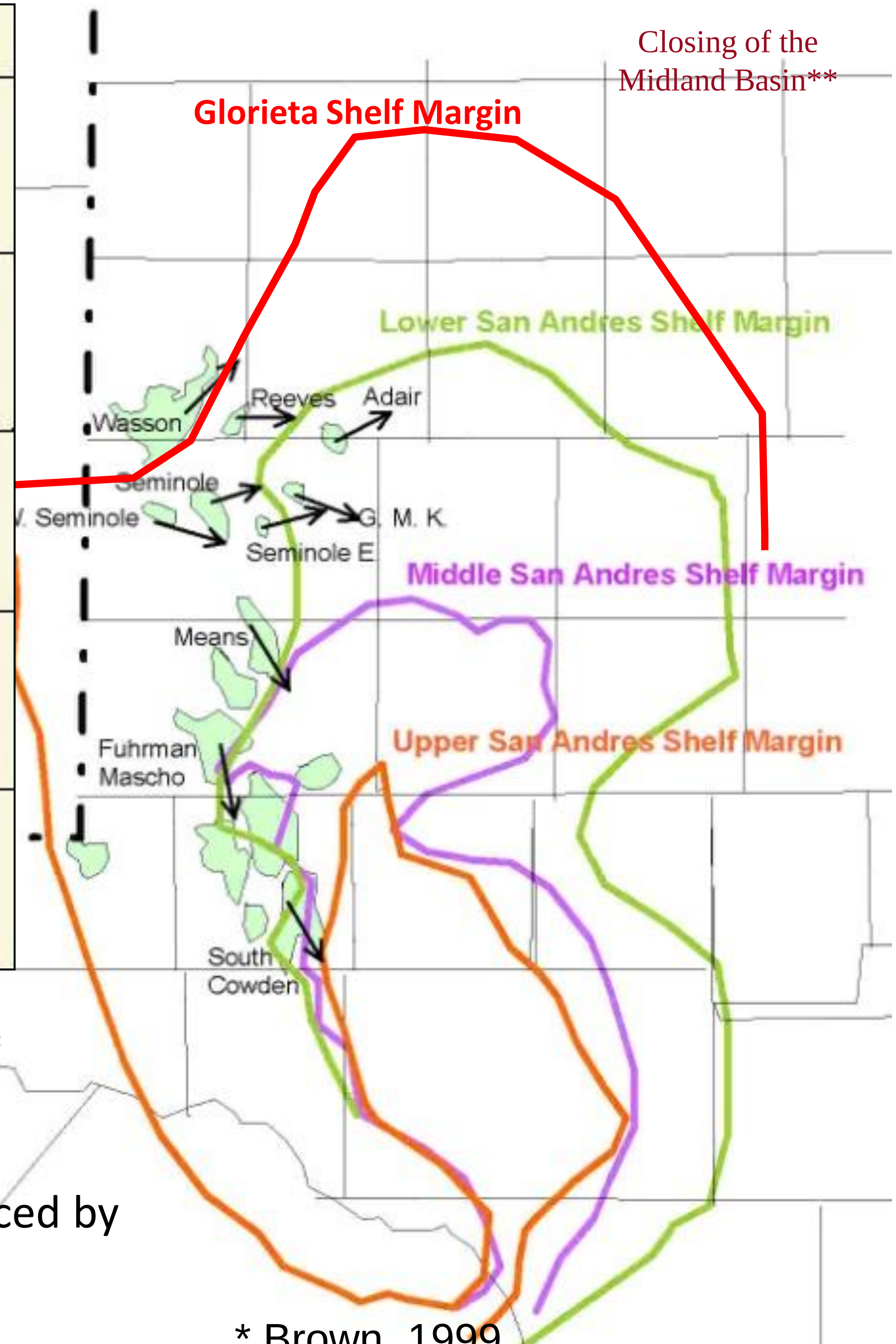
Attributes of the ROZ Types

ROZ TYPE	Oil-Water Contact	Base of Oil Saturation	Other Characteristics
Regional Tilt (1)	Horizontal	Tilted	Wedge with thin side Downdip
Breached Seal and Reaccumulation (2)	Horizontal	Horizontal	Stratified Tar Mats, Anomolously Low GOR
Hydrodynamic Tilt (3)	Tilted	Horizontal	Wedge with thin side in Direction of Flow (to Spill Point)

First, Let's Look evidence for OWC Tilt



Distribution of Tilted Oil-Water Contacts in the Northern Shelf and Central Basin Platform Areas of the Permian Basin*



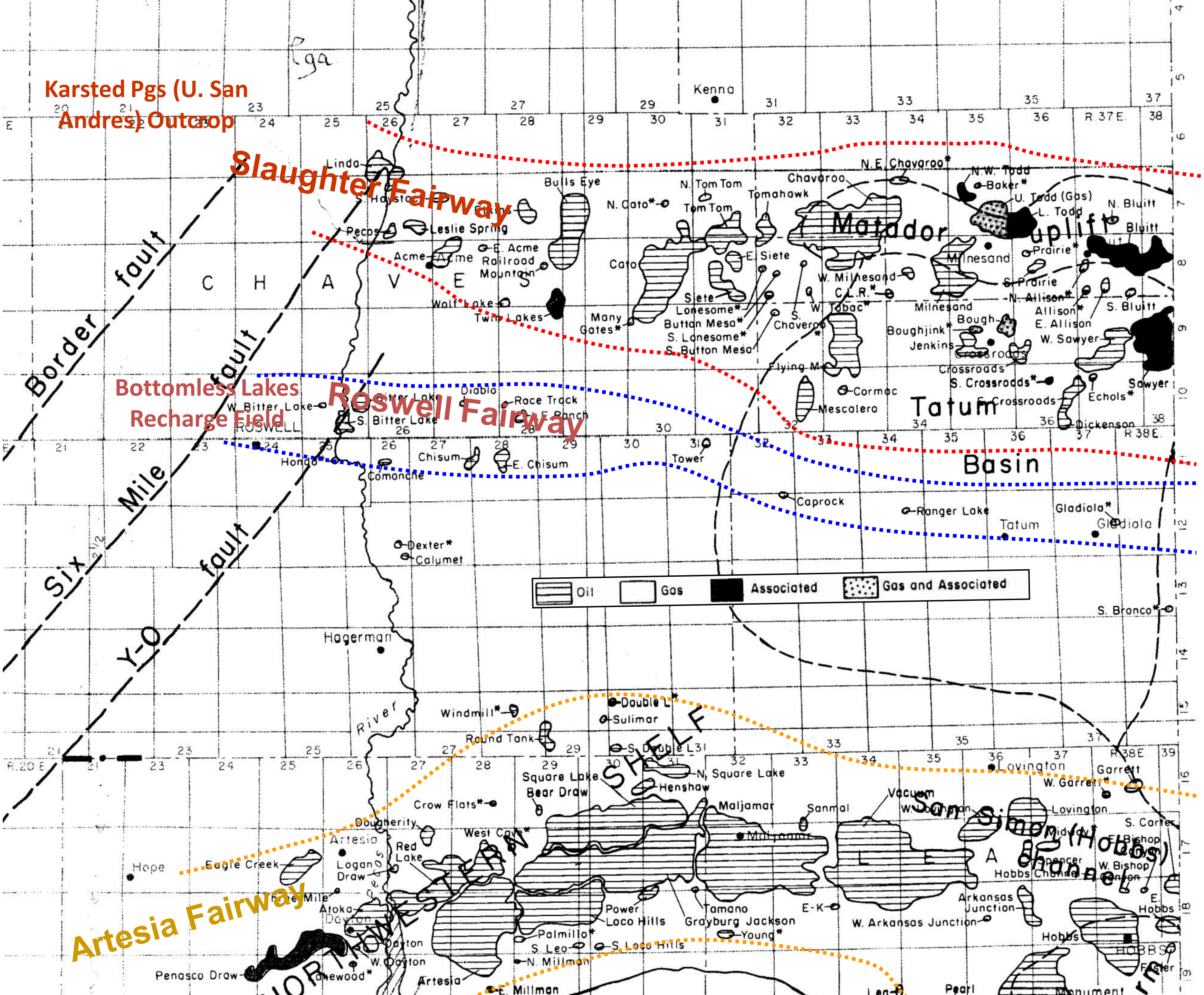
The direction of OWC tilt may be influenced by the age of the producing interval and it's relationship to the shelf margin

* Brown, 1999,
** Ward et al, 1986

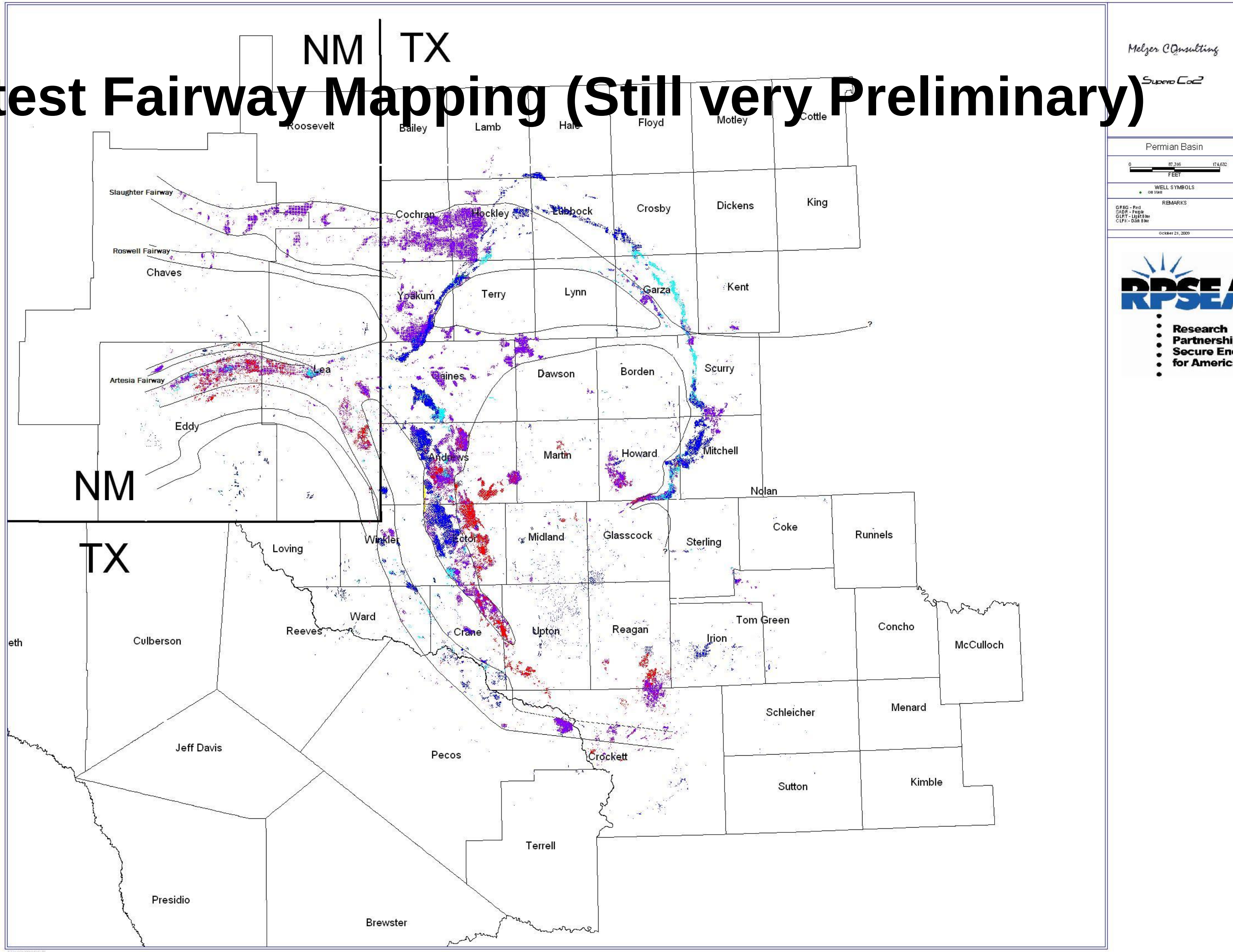
Tilted Oil Water Contacts

- New Axiom – " If you have a tilted oil/water contact in your Reservoir, you likely have a ROZ
- If you have an ROZ…….find a contract for CO_2
- Be prepared for big hug from royalty owner (just kidding)

Type 3 ROZ (Laterally Swept) and the Concept of “Fairways”


Karsted Pgs (U. San Andres) Outcrop
Slaughter Fairway
Bottomless Lakes Recharge Field
Roswell Fairway
Artesia Fairway
Border fault
Six Mile fault
Y-O fault
C H A V E S
Matador uplift
Tatum Basin
NORTHWESTERN SHELF
San Simon (Hobbs) Channel
L E A
Oil
Gas
Associated
Gas and Associated
Kenna
Linda
Pecos
Leslie Spring
Bulls Eye
N. Cato
N. Tom Tom
Tom Tom
Tomahawk
Chaveroo
N.E. Chaveroo
N.W. Todd
Baker
U. Todd (Gas)
L. Todd
N. Bluitt
Bluitt
Acme
E. Acme
Railroad Mountain
Cato
E. Siete
Siete
Lonesome
Button Mesa
S. Lonesome
S. Button Mesa
S. Chaveroo
W. Tobac
C.L.R.
W. Milnesand
Milnesand
Prairie
S. Prairie
N. Allison
Allison
E. Allison
S. Bluitt
W. Sawyer
Sawyer
Wolf Lake
Twin Lakes
Many Gates
Boughjink
Bough
Jenkins
Crossroads
S. Crossroads
E. Crossroads
Echols
Dickenson
Flying M
Cormac
Mescalero
Tatum
Diablo
Race Track
W. Bitter Lake
S. Bitter Lake
ROSWELL
Hondo
Comanche
Chisum
E. Chisum
Tower
Caprock
Ranger Lake
Gladiola
Dexter
Calumet
S. Bronco
Hagerman
Windmill
Double L
Sulimar
Round Tank
S. Double L
N. Square Lake
Square Lake
Bear Draw
Henshaw
Crow Flats
Maljamar
Sanmal
Vacuum
W. Lovington
Lovington
Garrett
W. Garrett
S. Carter
Dougherity
West Cave
Artesia
Red Lake
Logan Draw
Hope
Eagle Creek
Atoka
Dayton
W. Dayton
Lakewood
Penasco Draw
Power
Loco Hills
Palmillo
S. Loco Hills
S. Leo
N. Millman
E. Millman
Tamano
Grayburg Jackson
Young
E-K
W. Arkansas Junction
Arkansas Junction
Hobbs
Hobbs Channel
W. Bishop Canyon
E. Bishop Canyon
Spencer
E. Hobbs
HOBBS
Foster
Monument
Pearl
Lea
River
Pecos
R.37E.
R.38E
R.20E
Pga

Latest Fairway Mapping (Still very Preliminary)



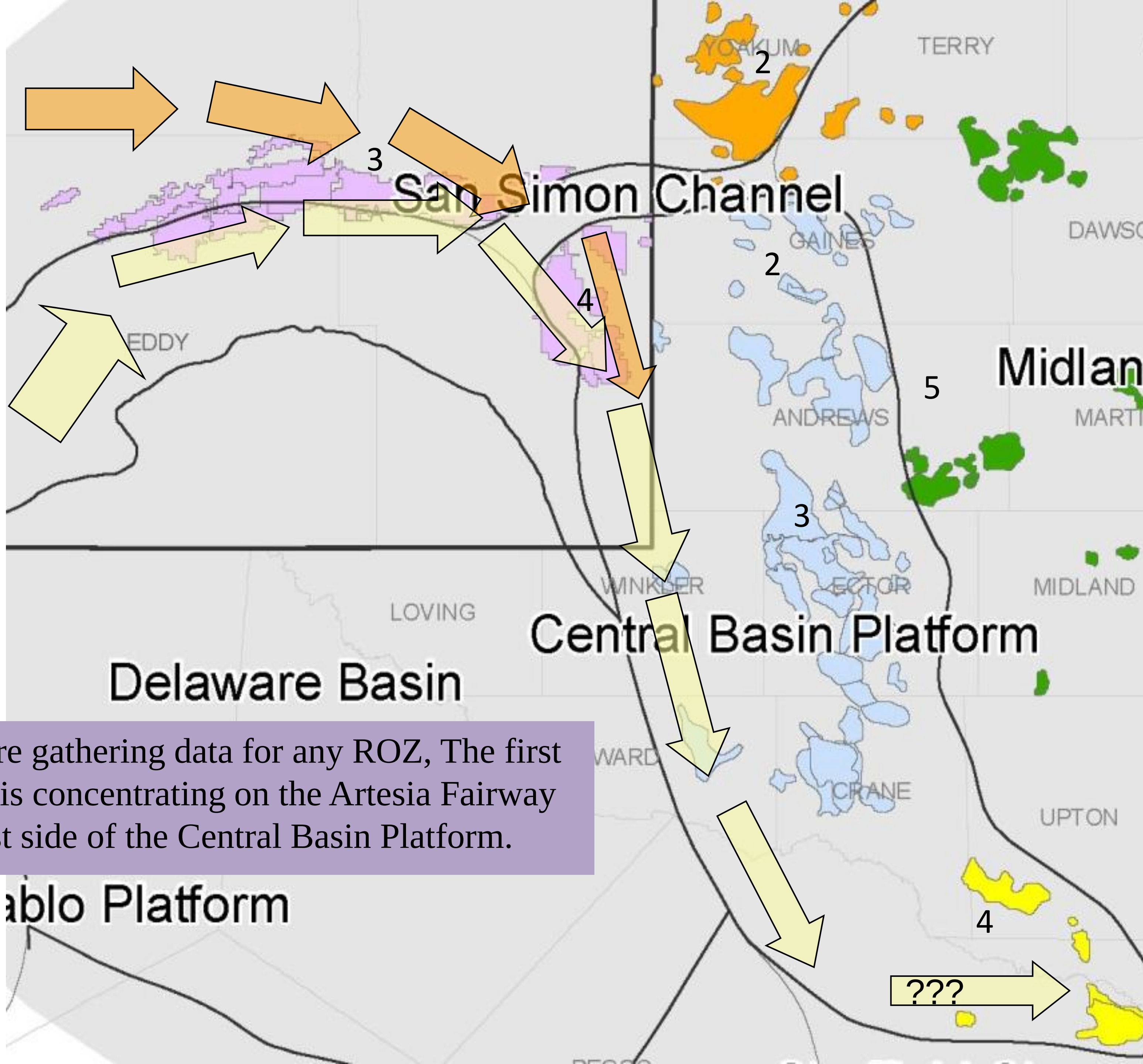
Research Partnership to Secure Energy for America

First Regional Study of Residual Oil Zones (ROZ's)

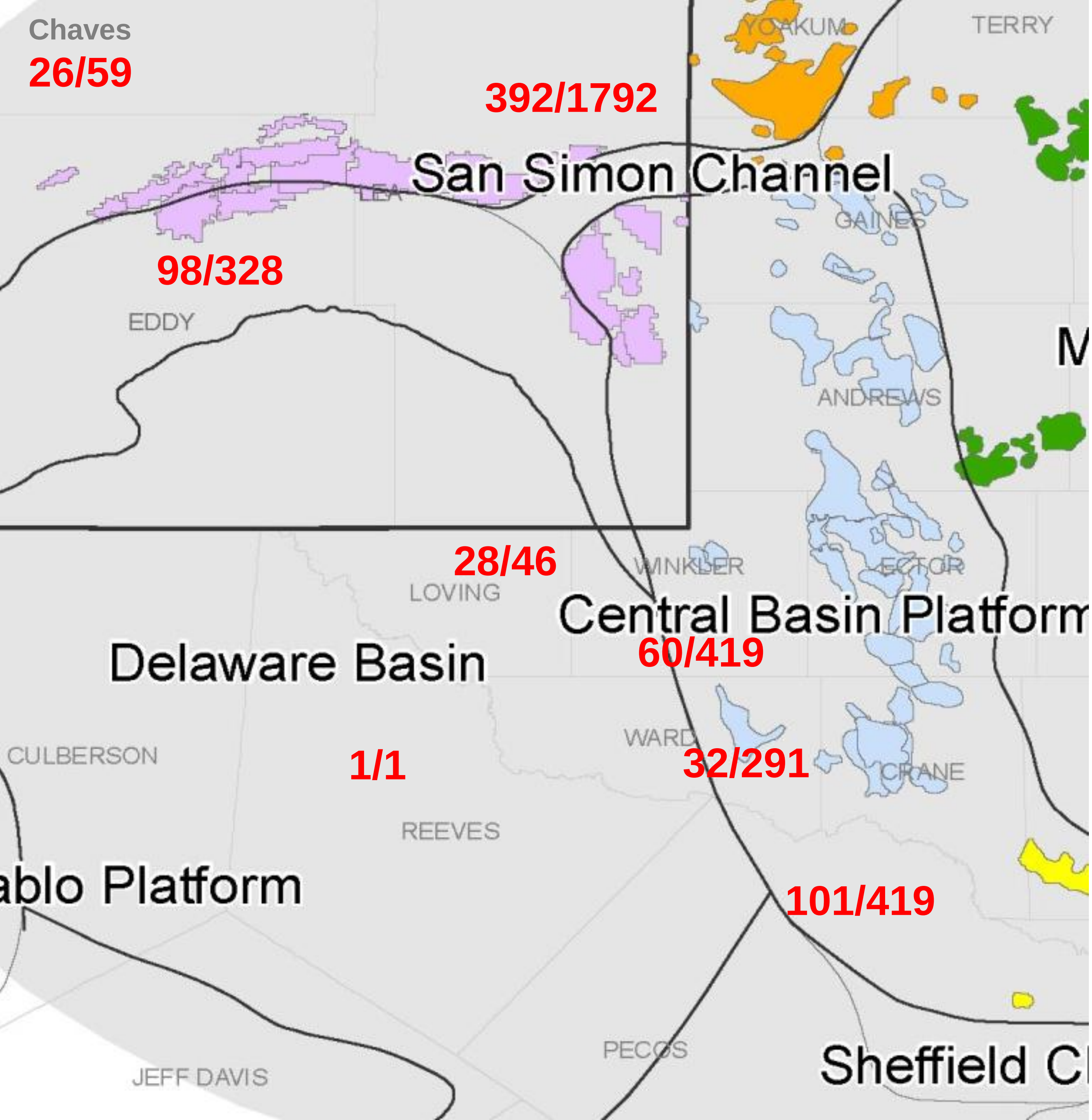
Focused on the Upper Permian Carbonates in the Basin

- It is supported by the Research Partnership to Secure Energy for America (RPSEA) and industry partners.
- ROZ's have historically been interpreted as being long Transition Zones. Although the upper portions of TZ's/ROZ's have long been assumed to contribute to production in some fields, until recently their potential as a CO2 recovery target has not been exploited.
- Development wells, scheduled to test deeper horizons, have often been drilled through zones with good shows in samples, porosity and oil saturation in core, and where the zones are calculated to be oil productive. These wells, however, have a poor record of successful completions.

RPSEA
Research Partnership to Secure Energy for America



Although we are gathering data for any ROZ, The first studied model is concentrating on the Artesia Fairway and the west side of the Central Basin Platform.



DST and Water Chemistry Data collected from various sources, by county

Wells by County

346/1563

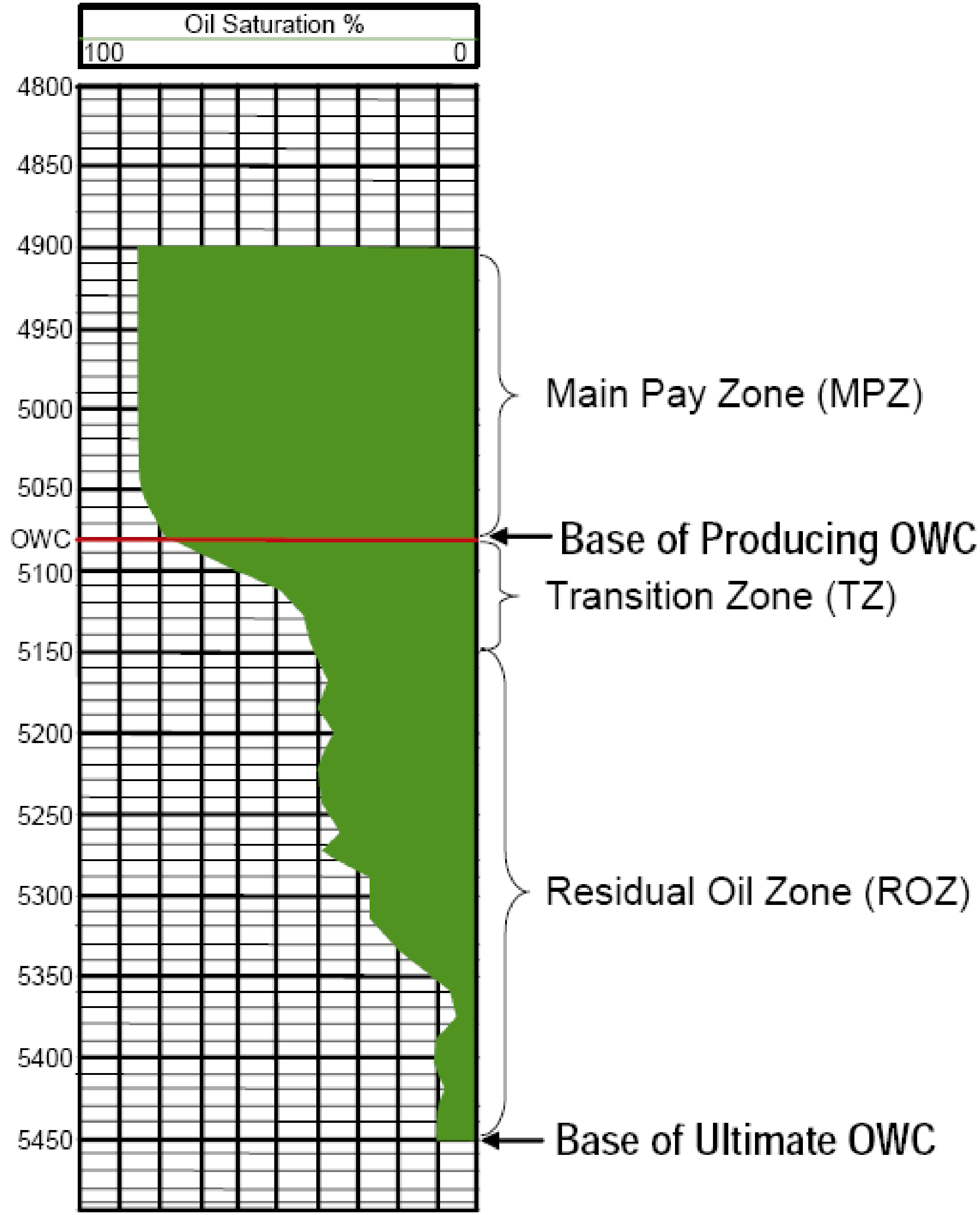
DST **/** Water Chem

Permian Basin Plays, Dutton et al (2005)

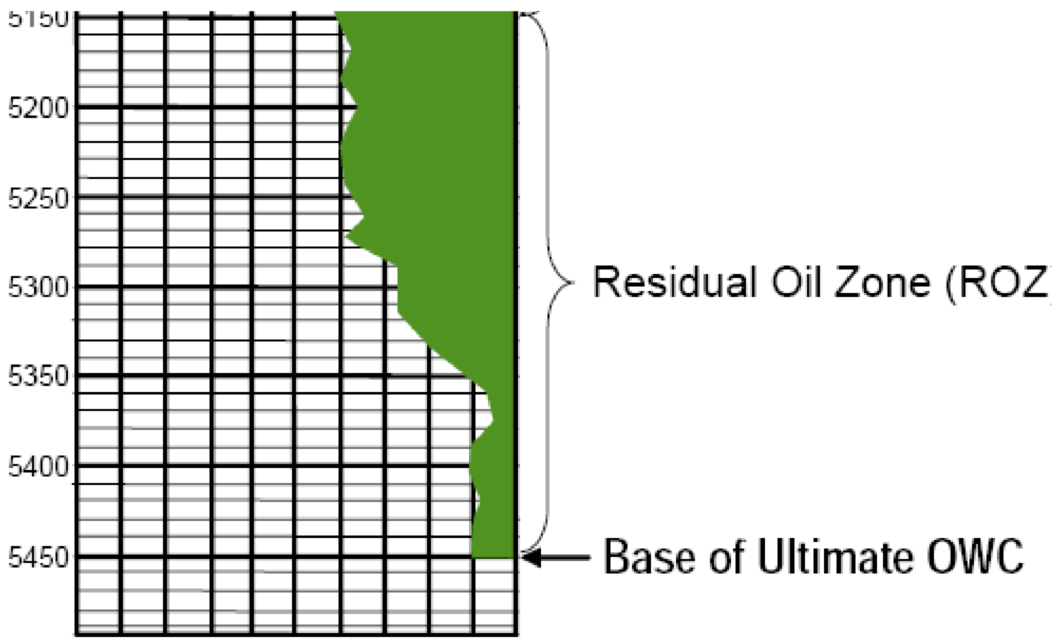
The New Residual Oil Zone Paradigms

- Large intervals and areas have been swept by "Mother Natures Waterflood" which occurred post/syn oil emplacement.
- ROZ's have the same saturation characteristics as mature waterfloods in the swept intervals.
- 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
- ROZ's produce high percentage of water on DST's or completions, but not a "deal killer".
- ROZ's originally there intervals were there were significant thicknesses (50 to 300') of producible hydrocarbons in producing fields AND outside the present limits of producing fields.
- This "faux-productive" appearance of ROZ's is presently found both beneath producing fields and in areas where there is no, or a minimum, producible oil column.

What happens when the entire oil column is swept by Mother Nature?



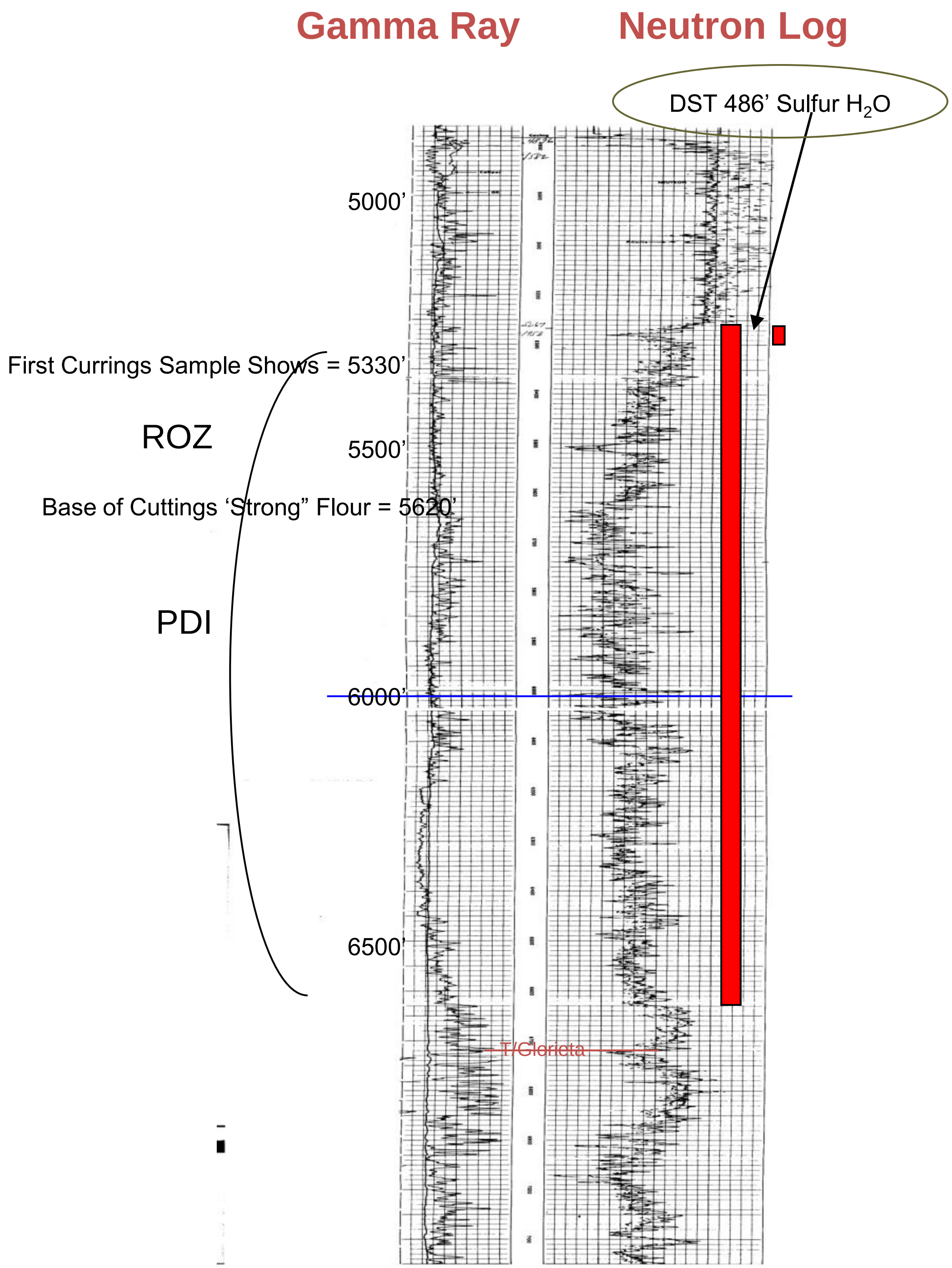
Your left with a tertiary recovery target.



What We Are Learning About the Characteristics of ROZs

Mud log and Cutting Shows,Sulfur and Sulfur Water, Leached Fractures, Pervasive Dolomitization, Bow Shape Logs, Comparisons to MPZs, Nature of Reservoir Fluids, etc.

Northern Central Basin Platform Area



PERMIAN CCS CENTE

Active ROZ Floods in the Permian Basin

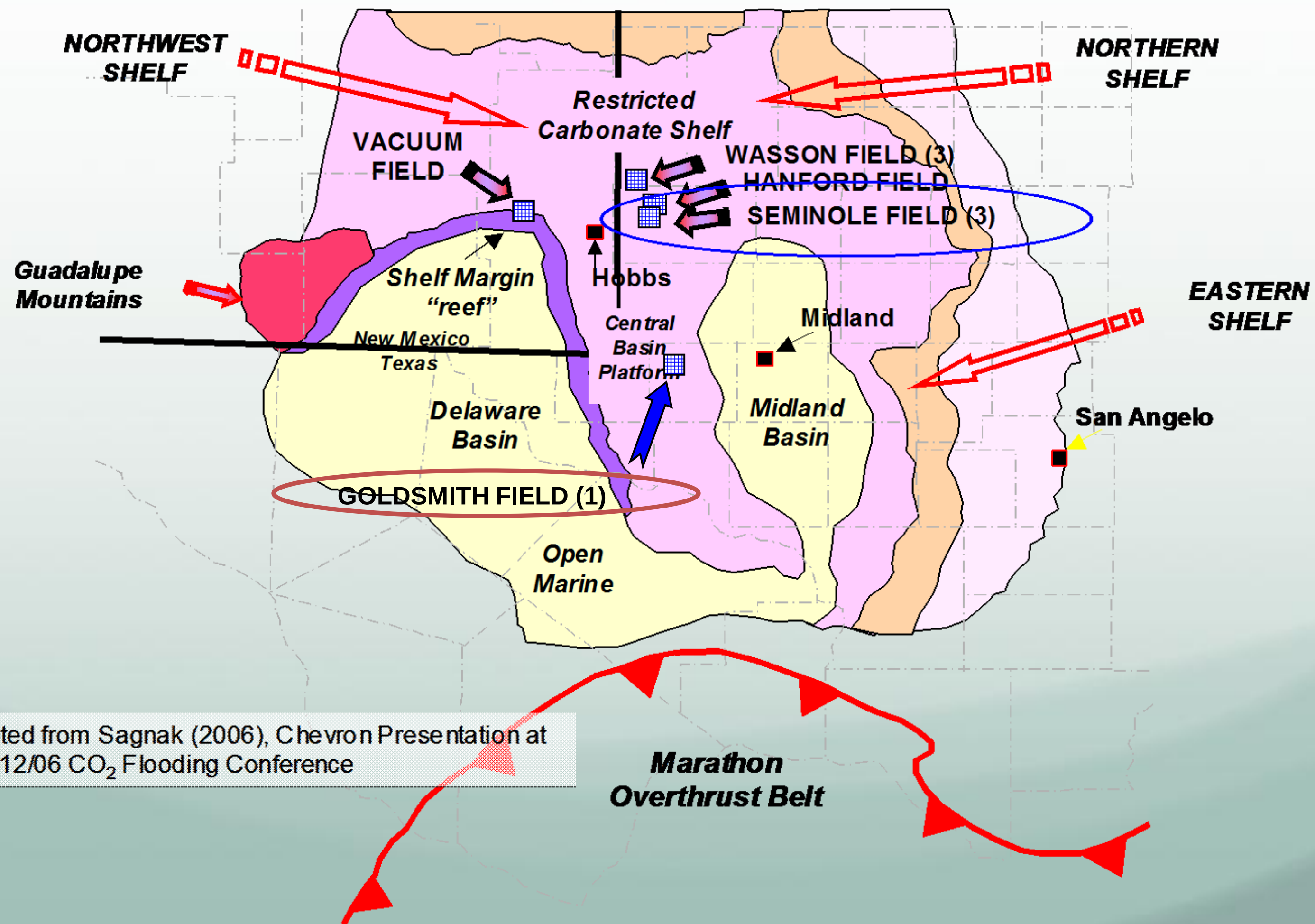
Type and operator	Field	State	County	Top MPZ Depth, ft	Pay zone
Active CO_2 miscible					
Chevron	Vacuum San Andres Grayburg Unit	NM	Lea Co.	4,550	San Andres/Grayburg
Fasken	Hanford	Tex.	Gaines	5,500	San Andres
Hess	Seminole Unit-ROZ Phase 1	Tex.	Gaines	5,500	San Andres
Hess	Seminole Unit-ROZ Phase 2	Tex.	Gaines	5,500	San Andres
Hess	Seminole Unit-ROZ Stage 1 Full Field Dev	Tex.	Gaines	5,500	San Andres
Legado	Goldsmith-Landreth Unit	Tex.	Ector	4,200	San Andres
Occidental	Wasson Bennett Ranch Unit	Tex.	Yoakum	5,250	San Andres
Occidental	Wasson Denver Unit	Tex.	Yoakum	5,200	San Andres
Occidental	Wasson ODC	Tex.	& Gaines	5,200	San Andres

COMMERCIALIZING CO_2 EOR in THE ROZ

ACTIVE RESIDUAL OIL ZONE CO_2 EOR PROJECTS IN THE PERMIAN BASIN

MIDDLE SAN ANDRES PALEOGEOGRAPHY

with Location of Industry Documented ROZ Zones/Fields*



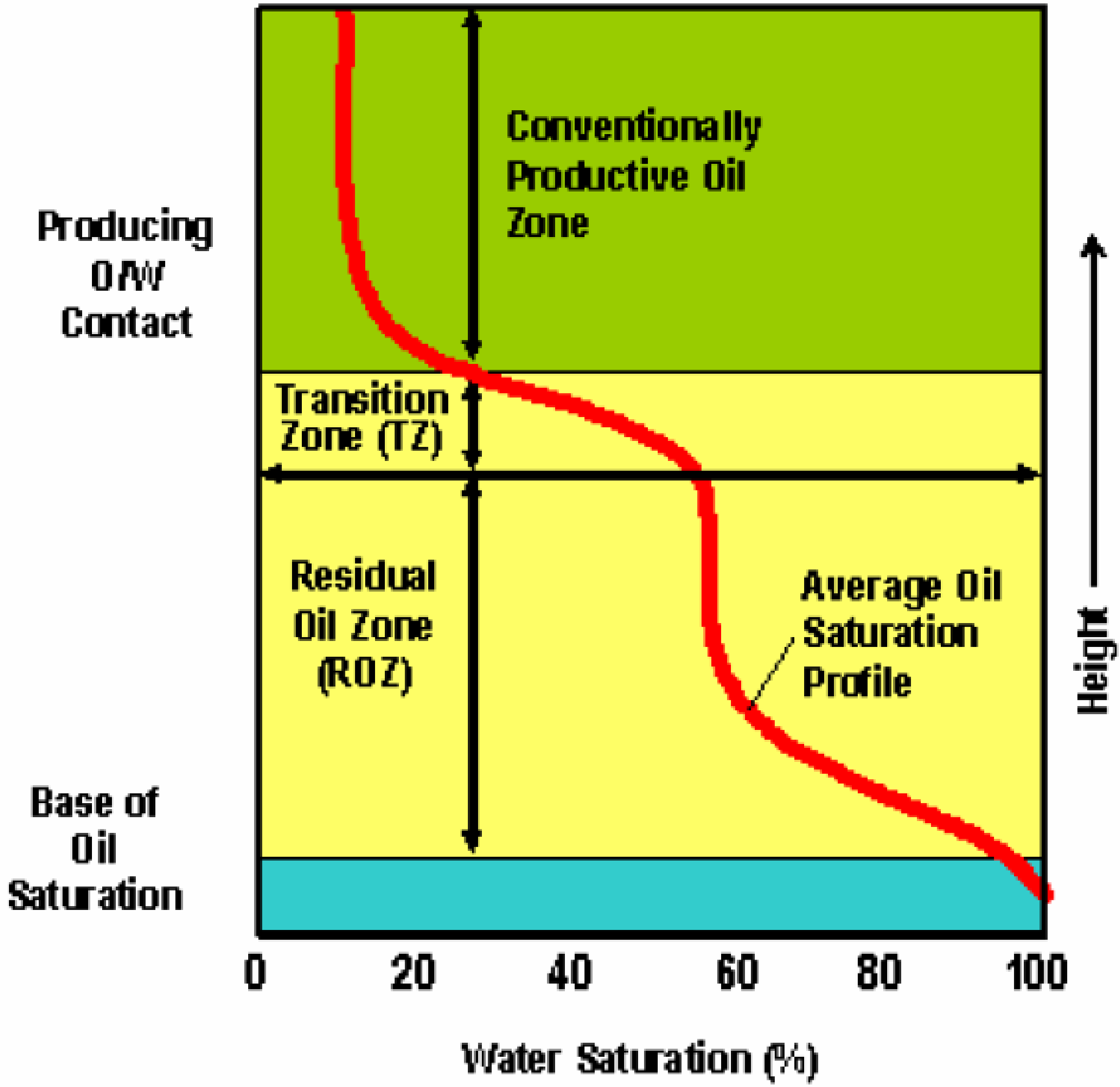
* Adapted from Sagnak (2006), Chevron Presentation at the 12/06 CO_2 Flooding Conference

Seminole Field History of Development

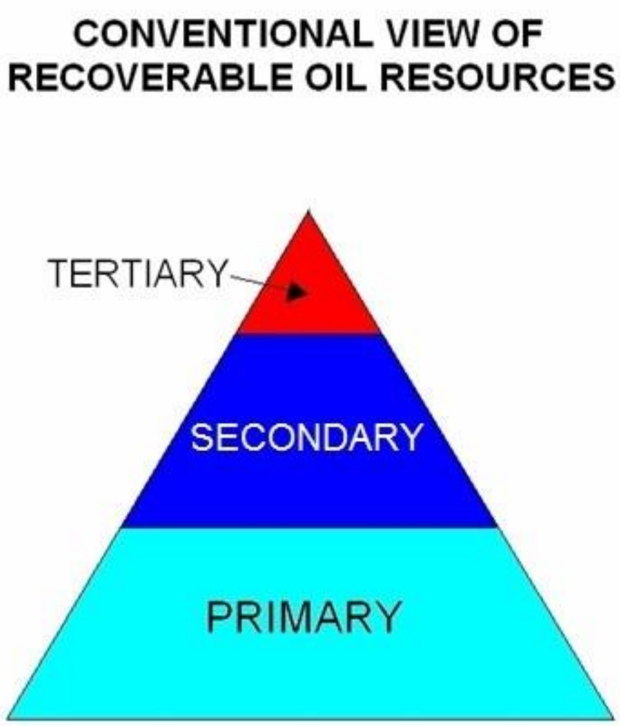
HESS

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 MBOEPD (Oil+NGL+Gas)

Seminole Field Water Saturation Profile

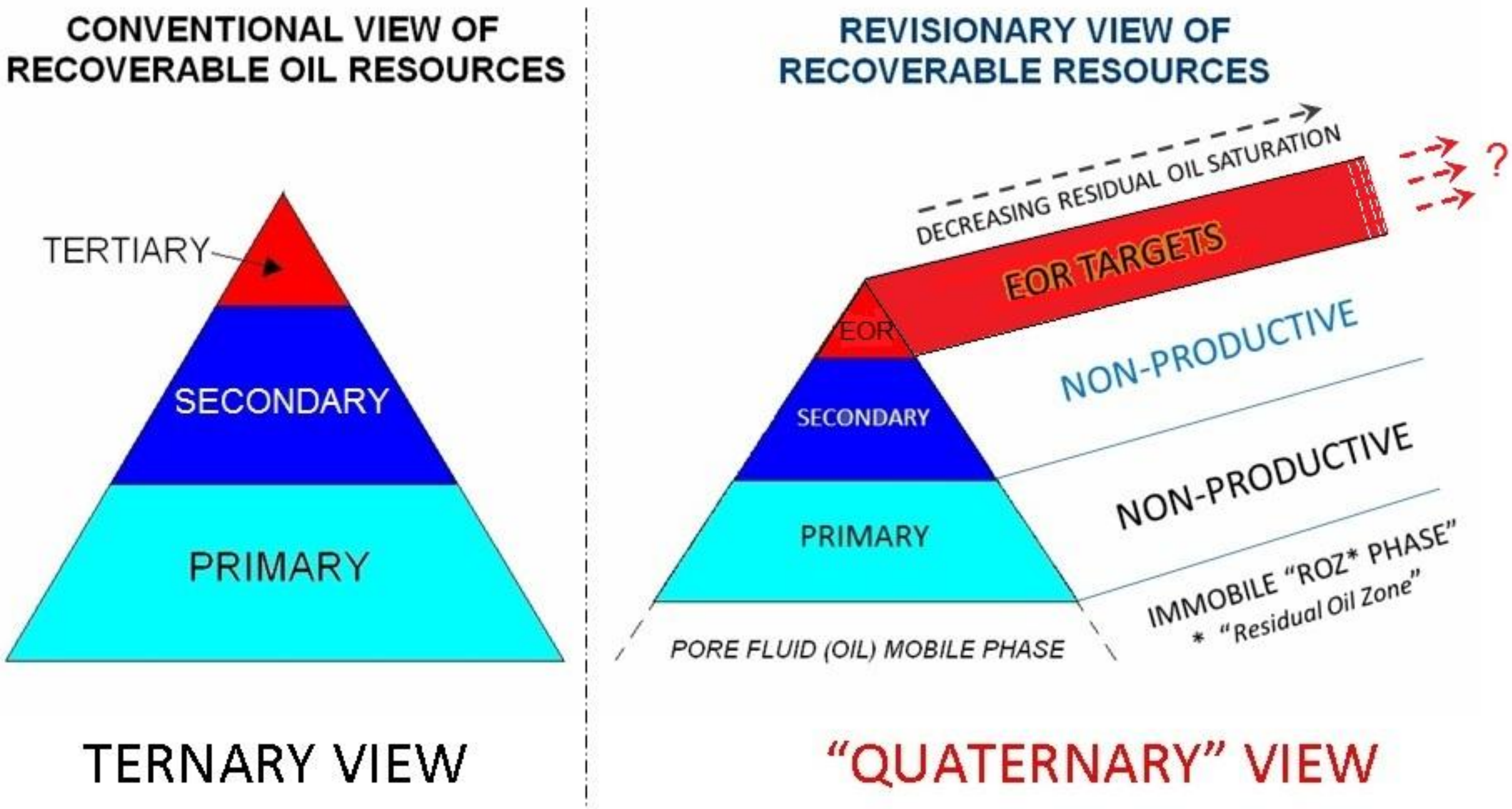


AN EMERGING NEW APPROACH FOR OIL RESOURCE DEVELOPMENT WITH CARBON CAPTURE & STORAGE



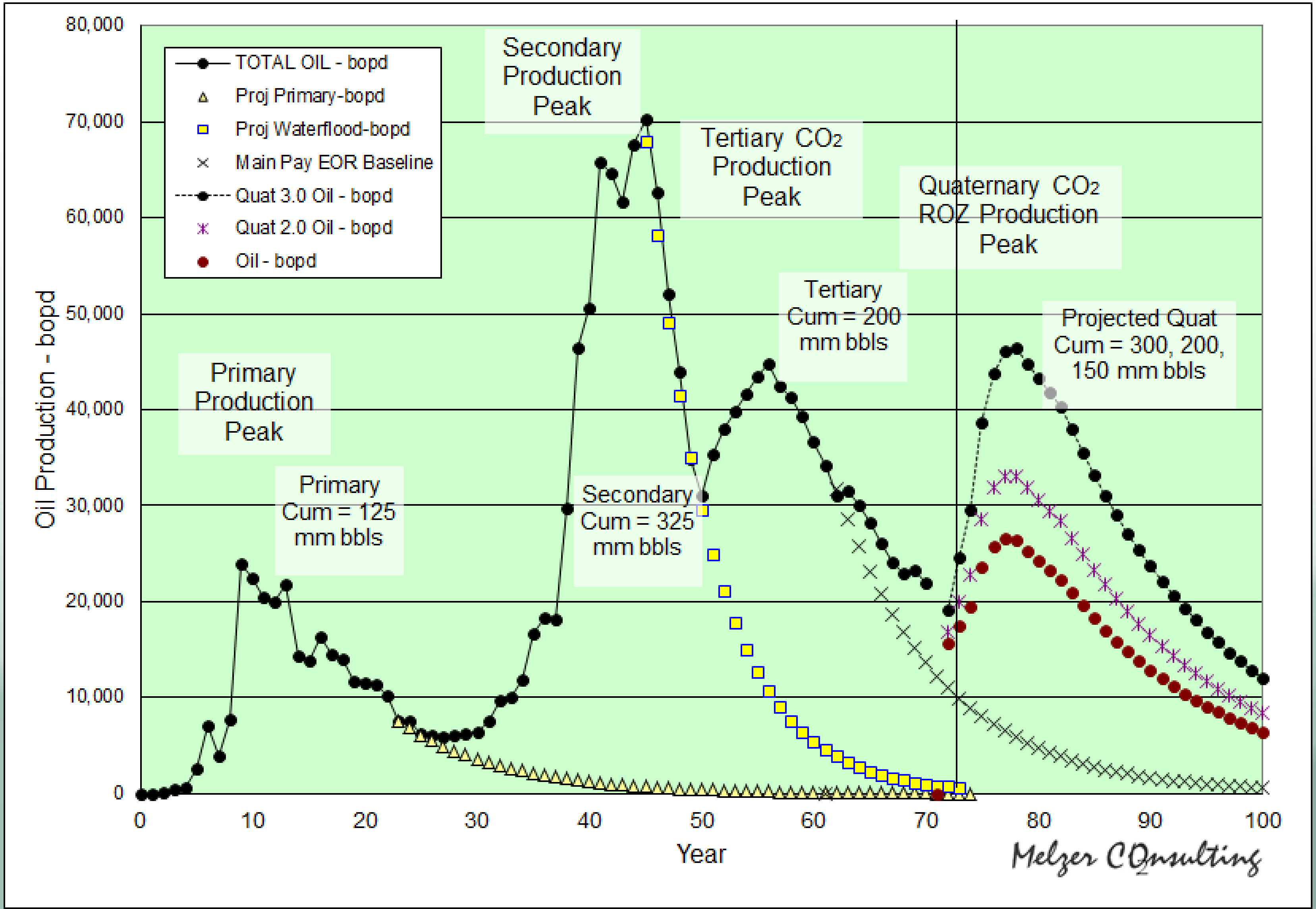
TERNARY VIEW

AN EMERGING NEW APPROACH FOR OIL RESOURCE DEVELOPMENT WITH CARBON CAPTURE & STORAGE



Melzer COnsulting

Seminole San Andres Unit Production History



Where We Are Today

- ROZ's appear to be common in Leonardian and Guadalupian carbonates on the Central Basin Platform and Northwest Shelf.
- Exploitation of thick ROZ's associated with many of the major San Andres fields has begun with CO_2 projects underway at Wasson, Seminole, Vacuum, Means, Goldsmith, and Hanford Fields, with others planned.
- Production from ROZ's and anecdotal evidence from exploration wells, coupled with the theory/model of the development of Residual Oil Zones (ROZ's), has led to the belief that there are potentially billions of barrels of additional producible tertiary reserves in the Permian Basin and elsewhere.
- Early Evidence Suggests ROZ are widely Distributed in Many Basins of the U.S. and World

Our ROZ Conclusions to Date

- Intervals Below the OWC with Shows Are More Appropriately Viewed as Residual Oil Zones and Owe Their Origins to a Variety of Causes Beyond Transition Zones
- PB ROZ Prevalent Type is Type 3: Laterally Flushed
- ROZs Can be Very Thick and Contain Huge Amounts of Oil
- New Paradigm: "Look at Intervals with 'Shows' Below the OWC as Targets for EOR" and, also, Look Between Fields
- Considerably More Research is Needed; We Aren't Starting Over but Because These Targets are Present, Very Large and Commercial, There Are a Lot of New Concepts to Grasp

Preliminary Scoping Work has been Done by Advanced Resources International, inc.

Calibrating the Oil Recovery Models and EstimatingTechnically Recoverable ROZ Oil – MPZ and TZ/ROZ Oil in Place

56 fields in five major Permian Basin oil plays that have potential for significant TZ/ROZ resources were identified by ARI.

TZ/ROZ OOIP in these 56 fields is estimated to be 30.7 Billion Barrels.

Field/Unit	MPZ OOIP (BB)	TZ/ROZ OOIP (BB)	No. of Fields	No. of MPZ Fields with CO2-EOR Projects	No. of Fields with TZ/ROZ CO_2-EOR Projects
1. Northern Shelf Permian Basin (San Andres)	13.0	13.2	13	5	1
2. North Central Basin Platform (San Andres/Grayburg)	2.9	2.6	6	2	1
3. South Central Basin Platform (San Andres/Grayburg)	9.9	7.9	16	5	0
4. Horseshoe Atoll (Canyon)	5.4	2.9	10	4	2
5. East New Mexico (San Andres)	2.3	4.1	11	2	0
Total	**33.5**	**30.7**	**56**	**18**	**4**

Thank you

Questions?