A Brief History of CO_2 EOR, New Developments and Reservoir Technologies for CO_2 EOR in Conjunction with Carbon Capture, Utilization and Storage (CCUS)

Presented at the 26th Annual CO_2 Conference

Tuesday - Thursday Dec 8th-10th, 2020

Bush Convention Center

Midland, Texas

Melzer CO_2nsulting

2020 CO_2 Conference
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A Brief History of CO_2 EOR, New Developments, and Reservoir Technologies for CO_2 EOR in Conjunction with Carbon Capture, Utilization and Storage (CCUS)

Carbon dioxide flooding (CO_2 Enhanced Oil Recovery or CO_2 EOR) was developed 40 years ago as a method to produce higher percentages of the oil that resides in a reservoir. It has grown into a sub-industry producing almost 300,000 barrels a day from over 180 enhanced oil recovery (EOR) projects around the world. During the life of a project, almost the entire amount of CO_2 purchased for the project remains stored in the reservoir while an amount roughly equal to that purchased volume of CO_2 project remains stored in the reservoir while an amount roughly equal to that purchased volume of CO_2 is recycled and reinjected in what is commonly called a "closed loop syetem." Given some form of incentives for CO_2 storage like the 45Q tax credit in the U.S., the economics of CO_2 EOR change and can greatly expand CO_2 capture projects and CO_2 EOR deployment. With the concurrent CO_2 storage (often referred to as Carbon Capture Utilization and Storage or CCUS), the EOR projects produce a lower carbon oil than other oil utilized today and will open up new targets called residual oil zones (ROZs) which can be thought of as hybrid deep saline reservoirs with the capability to produce some lower carbon oil to offset costs of industrial CO_2 capture projects.

Research related to the ROZs along with the explosive growth of horizontal drilling are beginning to be seen as adding greatly to reservoir understanding. All horizontal drilling requires depressuring of the producing formations while producing small amounts of the oil in place. The depressured pore space can be followed by CO_2 injection to further enable CO_2 EOR and CCUS while producing a greater portion of the stranded oil resource. It also can offset the expense and accelerate the capture of surface-sourced carbon dioxide and permanently storing the CO_2 in large volumes in reservoirs and out of the atmosphere.

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II. The Mounting Competition to Advanced Recovery

III. New Developments

   A. Well Drilling and Completion

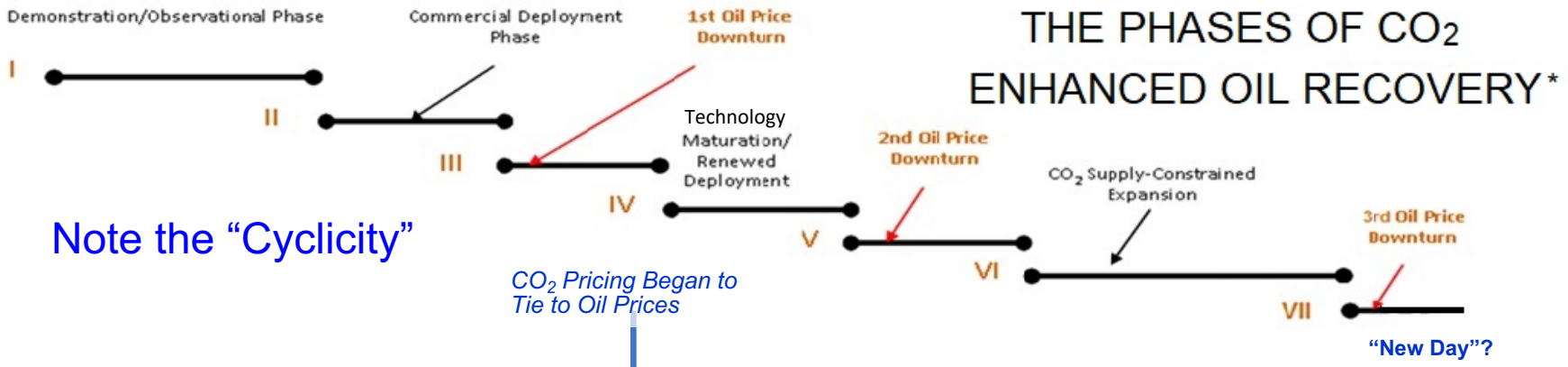
   B. Reservoir Understandings

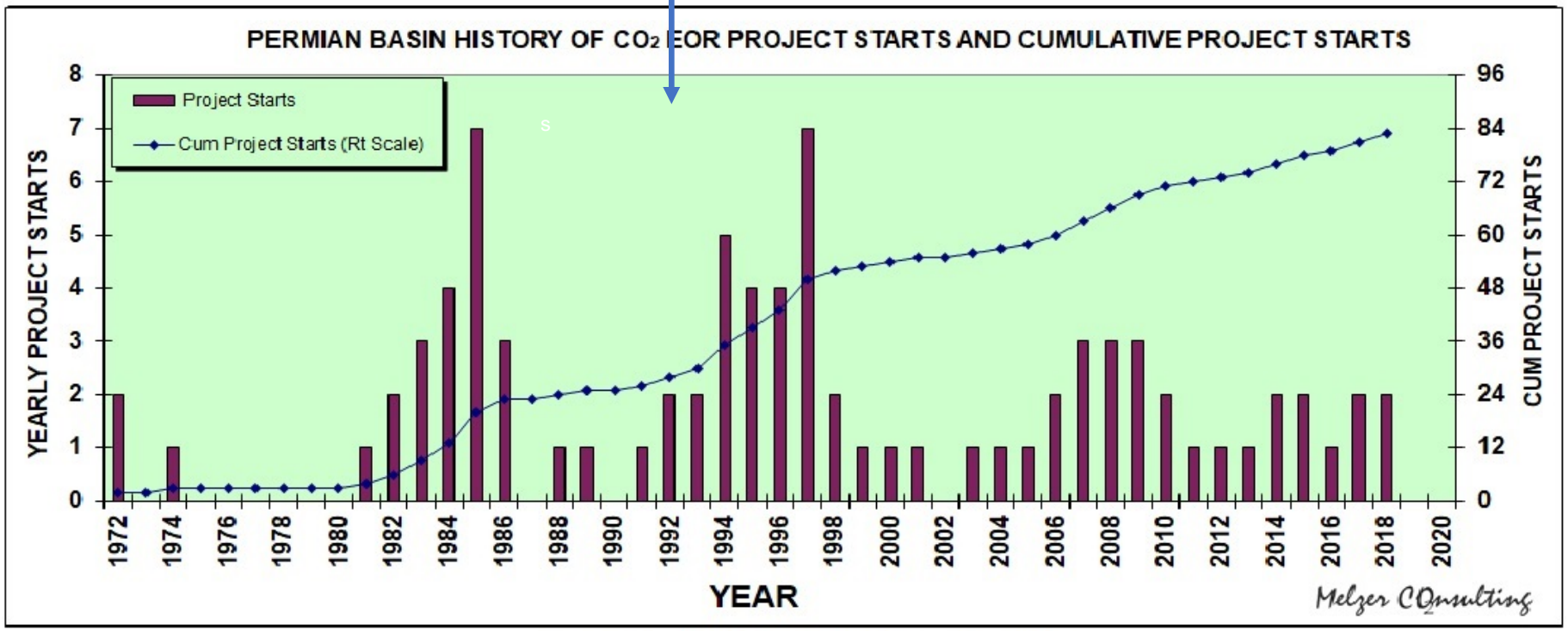
IV. CO_2 Emissions Capture and Storage

The History of CO_2 EOR

1960's	A Couple of Small Scale Pilot CO_2 Injection Projects Were Implemented
1972	CO_2 Capture & Compression was Installed in the Southern Permian Basin at Val Verde Nat'l Gas Plants, PLs Built to McCamey and Snyder for the SACROC and North Cross Fields, First Large Scale CO_2 EOR Projects Begun
1978-79	Cortez, Bravo Dome and Sheep Mtn PLs Planned and ROW Acquired
1982	Pipelines Completed and Large San Andres Oilfields Began Injecting
1980s	CO_2 PLs and EOR Projects Started in Rockies, Gulf Coast, Michigan, Canada, Hungary, Turkey, Romania and Trinidad
Late 70s to 2014	Continued Growth in the Permian Basin, Mississippi, and Rockies
2000's	CO_2 Supply Limitations in the U.S. – Slowing of New Projects & Project Expansions
2018	New Projects on Hold Due to Low Oil Prices

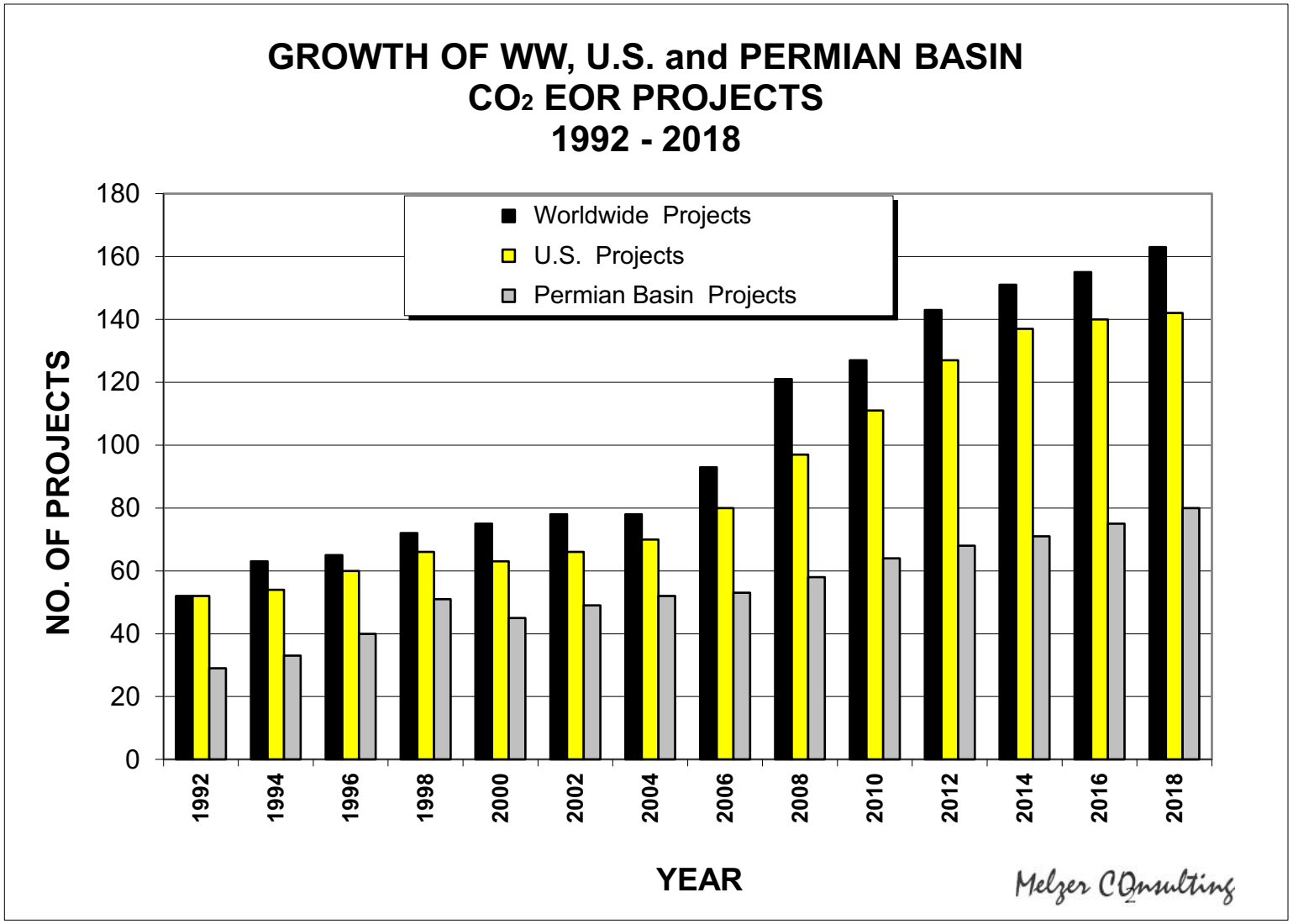
Graphical History of CO_2 EOR*



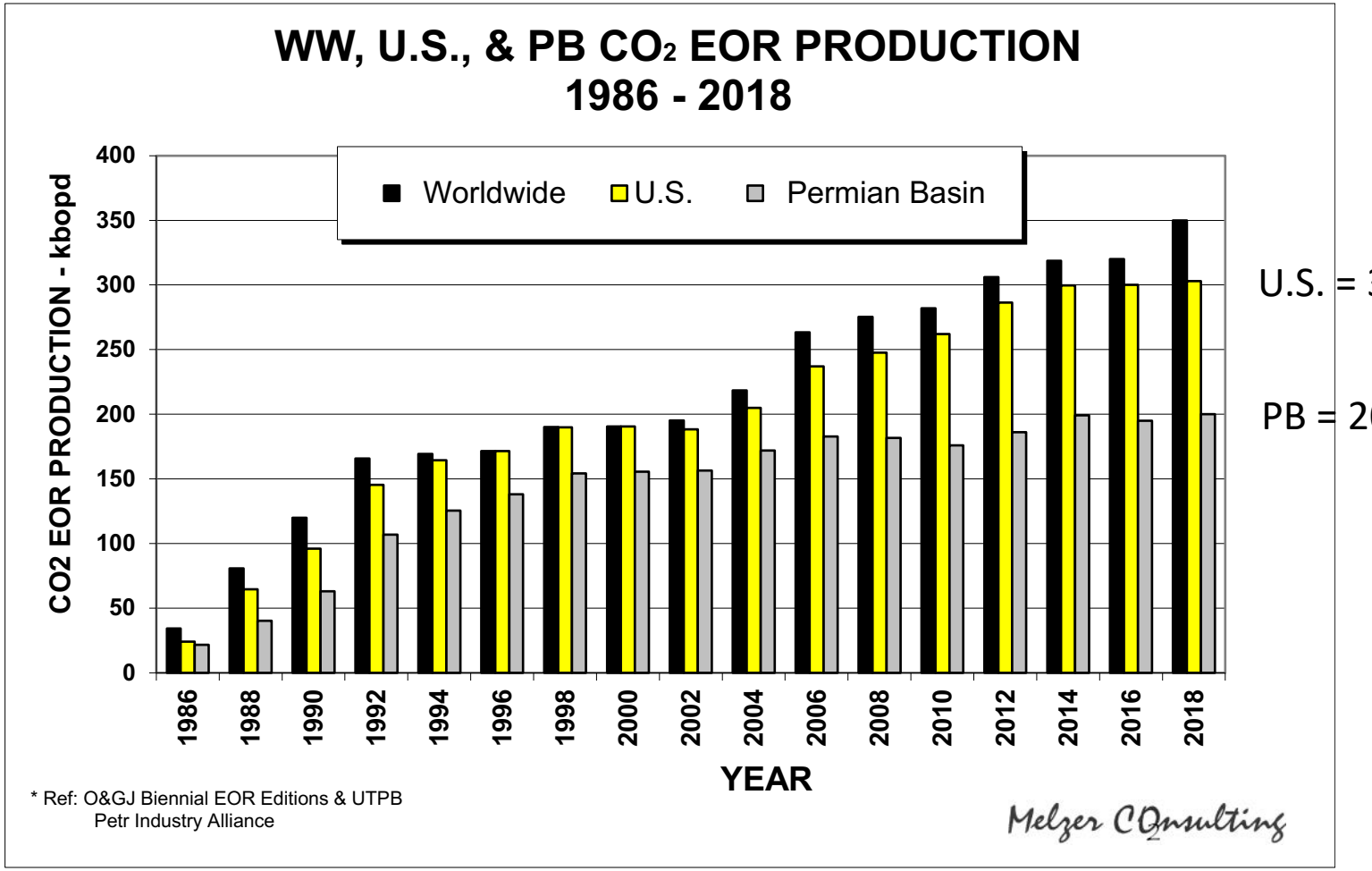


* as Benchmarked to the Permian Basin Region of the SW U.S.

The Permian Basin and Worldwide Project History



The Permian Basin and Worldwide Production History



U.S. = 300,000 bopd

PB = 200,000 bopd

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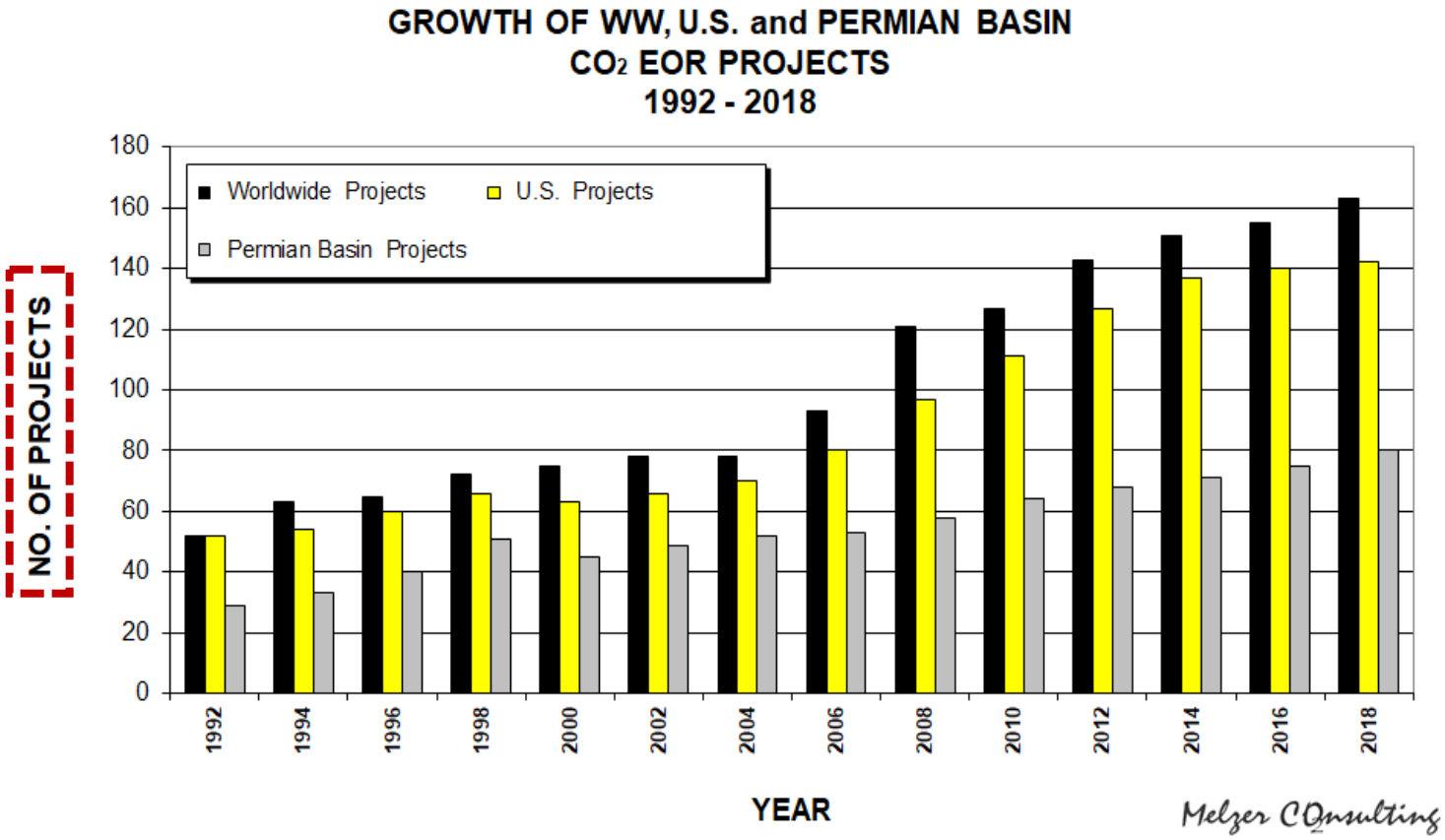
Despite the "2020 Double Whammy", Much of Our Oil & Gas Industry is Still Feeling the Excitement*

- Producing Unconventional Reservoirs
- Producing Unconventional Oil (More on this Later)
- The Explosion of Innovative Tools for Horizontal Completions
- Better Drilling Rigs and Bits for Faster Drilling

* The Saudi 'Flotilla' of Tankers (Feb 2020) and Covid-19 Oil Demand Destruction

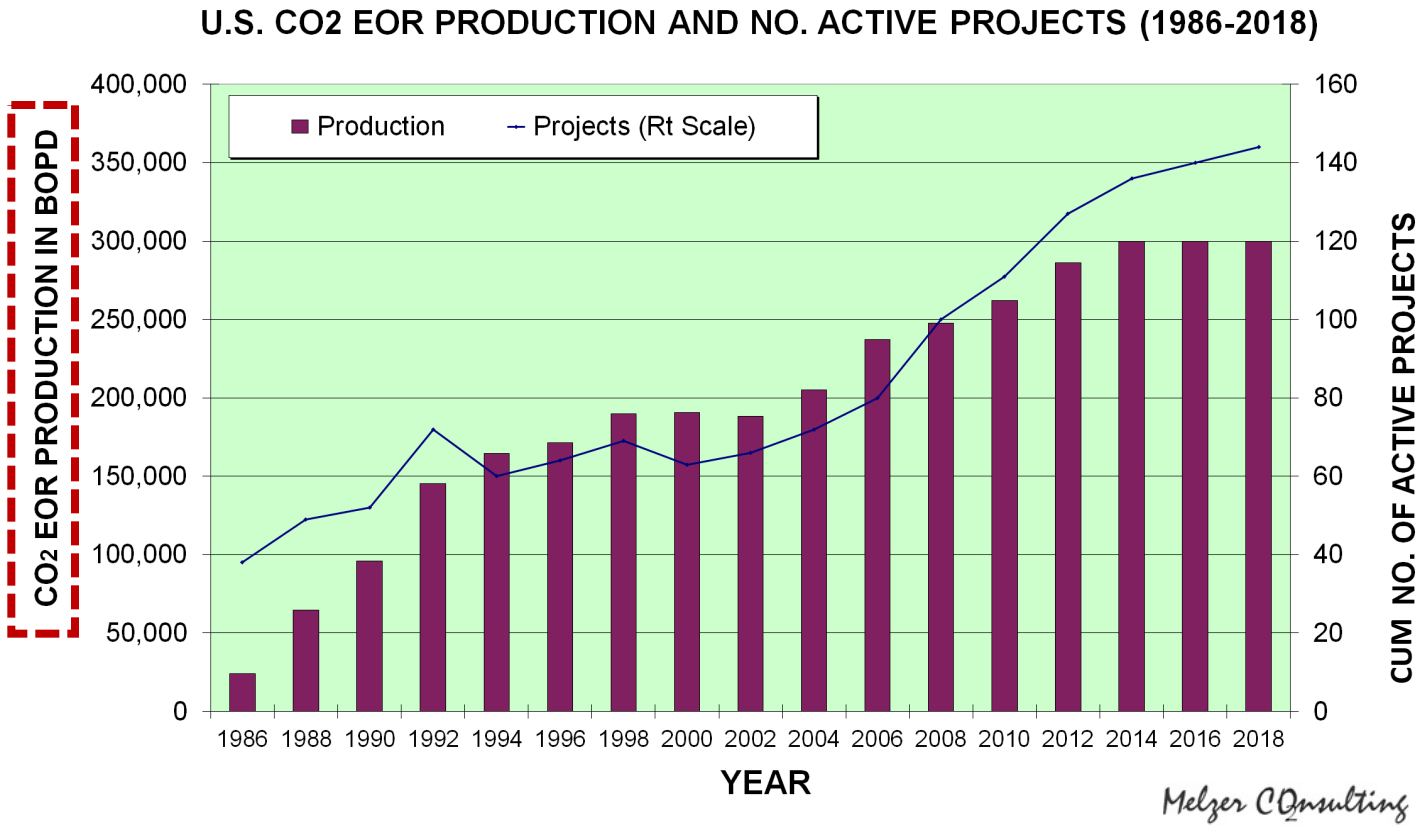
Where is CO_2 EOR in all this New Excitement? (1)

- The 'Turtle and the Hare'
  - CO_2 EOR is the Turtle
    - Steady but Slow Growth



Where is CO_2 EOR in all this New Excitement? (2)

- The 'Turtle and the Hare'
  - CO_2 EOR is the Turtle
    - Steady but Slow Growth



Where is CO_2 EOR in all this New Excitement? (3)

- The 'Turtle and the Hare'
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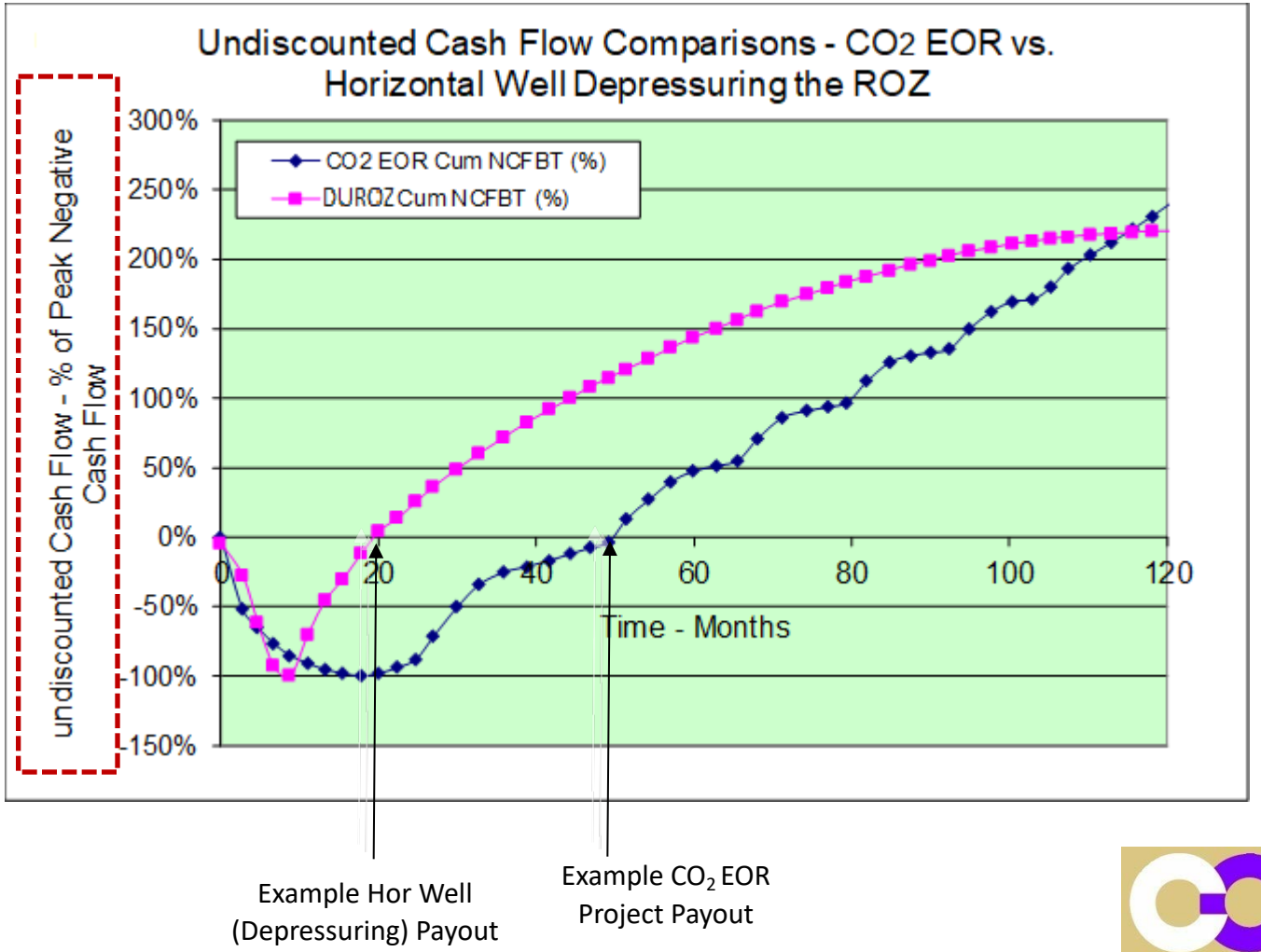
- IRR vs. Booking Reserves
  - Short Term Payouts vs.
  - Long Term Perspective?



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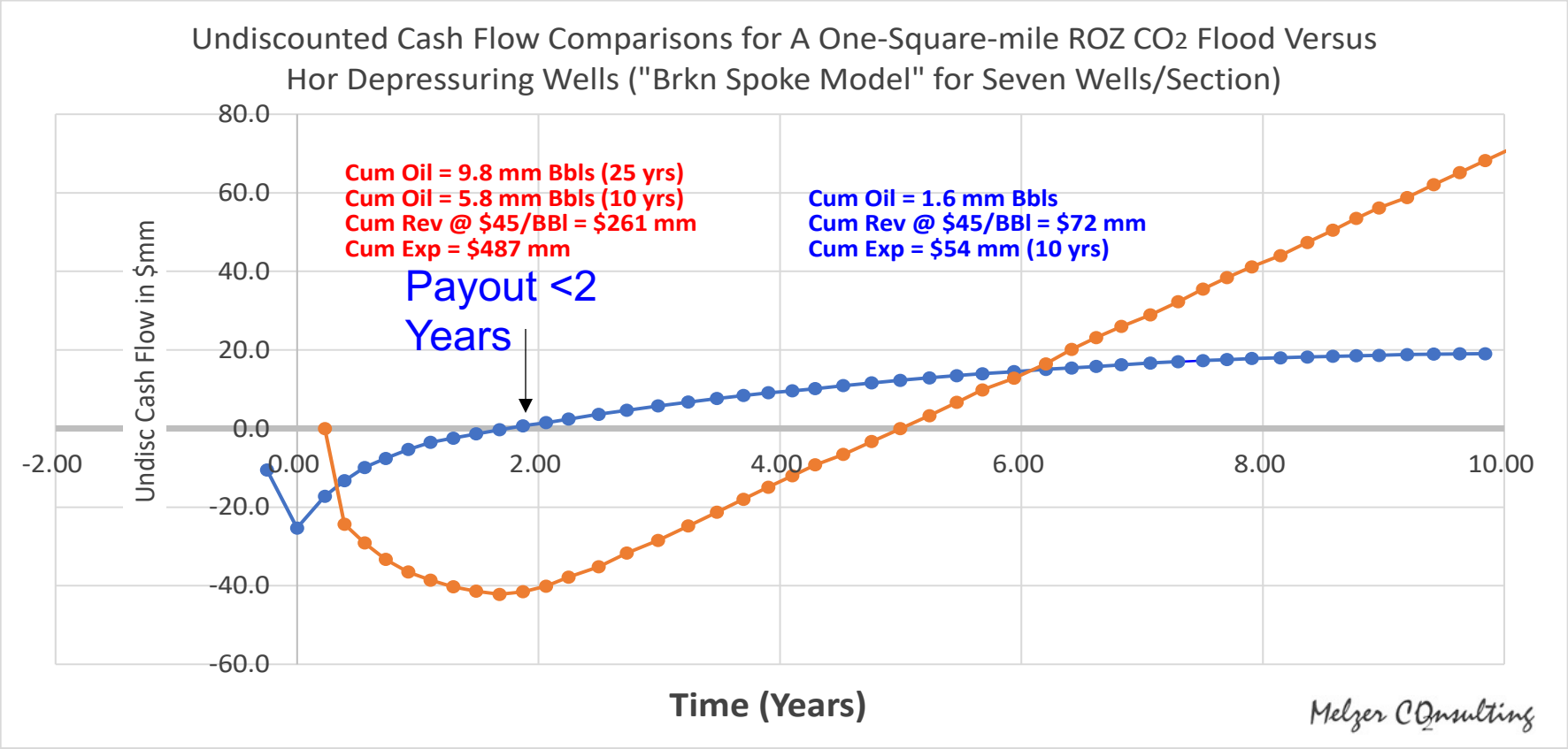
Then Compare Undisc Cash Flow of the Reservoir Depressuring Wells to the CO_2 EOR Project

- Horizontal Drilling Project Setup is Easier, Can Start Earlier



Conclusion: Less 'Out-of-Pocket' Cash and Faster Payout but Makes Less Oil, Lasts only 10 Yrs

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So Where is CO_2 EOR in all this New Excitement? (4)

- The 'Turtle and the Hare'
  - CO_2 EOR is the Turtle
    - Steady but Slow Growth
- IRR vs. Booking Reserves
  - Short Term Payouts vs.
  - Long Term Perspective?
- Looking at a "Second Life?"
  - CCUS (Concurrent Oil Production and CO_2 Storage

45Q – Value of Credit

Two different values are available:

1. EOR TYPE
   - Must be used as a tertiary injectant in enhanced oil recovery (EOR) or natural gas recovery project (or "utilized")
   - Must be disposed of in "secure geological storage" (or "utilized")
   - Old value per metric ton: $10 (2009), adjusted for inflation annually
   - New value per metric ton: $12.83 (2017) up to $35 (2026)

   = $2.00/Mcf

2. NON-EOR TYPE
   - Cannot be used as a tertiary injectant or "utilized"
   - Must be disposed of in "secure geological storage"
   - Old value per metric ton: $20 (2009), adjusted for inflation annually
   - New value per metric ton: $22.66 (2017) up to $50 (2026)

   = $2.60/Mcf

CornerPost

§ 45Q(a), (b)(1); Notice 2009-83 §§ 2.05, 4.02

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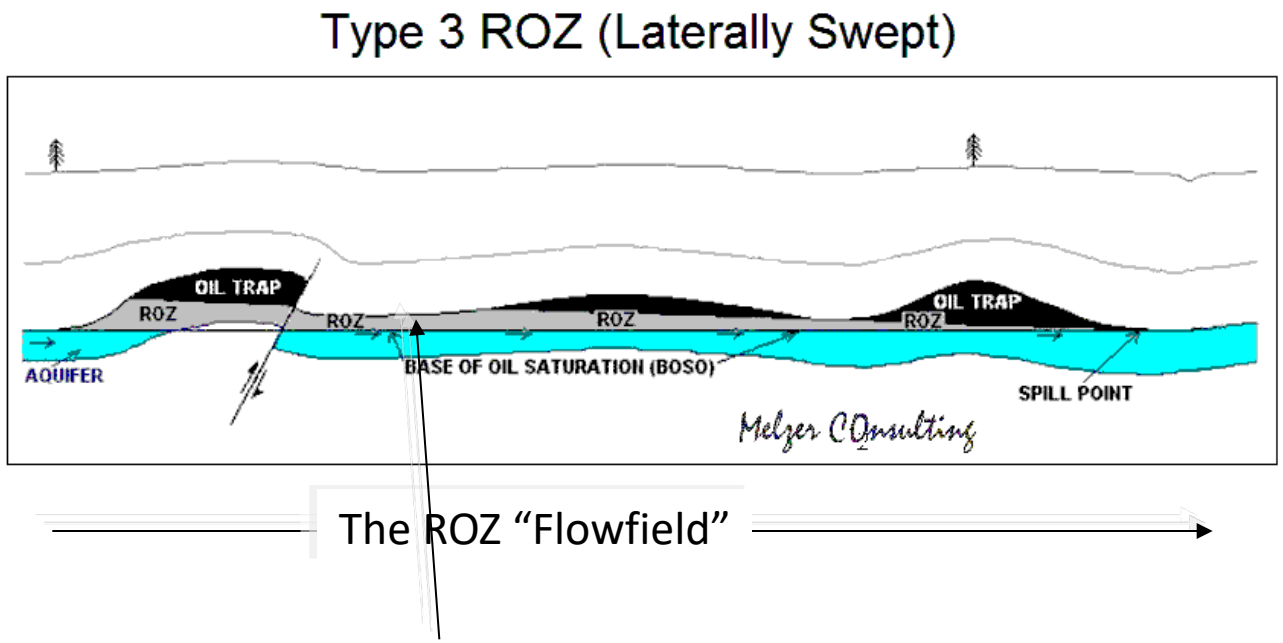
Let's Look Closer at the New Learnings that have Come from the Horizontal Revolution and CO_2 EOR

Several, Incidentally, come from the San Andres ROZ Studies (Originally Motivated by our CO_2 EOR Interests)

Very Quickly: What is a Residual Oil Zone?

- It is an Interval in a Formation with Immobile Oil but the Moveable Fluid is Water
- It can be Formed by Man's Waterfloods or by Nature
- In the Geological Past it was a Paleo Oil Entrapment and Subsequently Invaded by Water
- There are Three General Types of Natural ROZs based upon how the Water Invaded the Paleo Trap
- The One Most Common and Extensive is a Laterally Swept ROZ



ROZs can underlie an oil field and can also be present with no main payzone above ("Greenfield")

Summary of Recent (Key) New Learnings (1)

1. We already Mentioned the Faster Drilling and Completion Tool Innovations (….and there are many!)
2. Horizontal Wells are Demonstrating Vertical Transmissive Fractures are More Common than Believed in the Age of Vertical Wells
3. Flowfields in Transmissive Fractures are Often Present and Generally Analogous to ROZ Flowfields Causing Sour Oil and Gases Even in Normally Sweet Oil Environments
4. Intrinsic Microbes Alter the Oils, Gasses, and Even the Rocks But Their Effects are Relatively Minor without Flowfields to Disseminate the Normally Inhibiting H_2S (More on this later)

Summary of Recent (Key) New Learnings (2)

5. Residual Oil Zones (ROZs) are Common in Many Basins and Should be Recognized as Different from Transition Zones
6. ROZs can be Found Beneath the OWCs and in 'Greenfields'
7. ROZs can be Commercially Exploited with (CO_2) EOR
8. Gassy ROZs can be Commercially Exploited with Horizontal Well Primary Recovery (Reservoir Depressuring)
9. Limited Natural Waterflood Sweep Leaves Gassy ROZs
10. Unlimited Natural Waterflood Sweep Leaves a 'Heavy' Oil

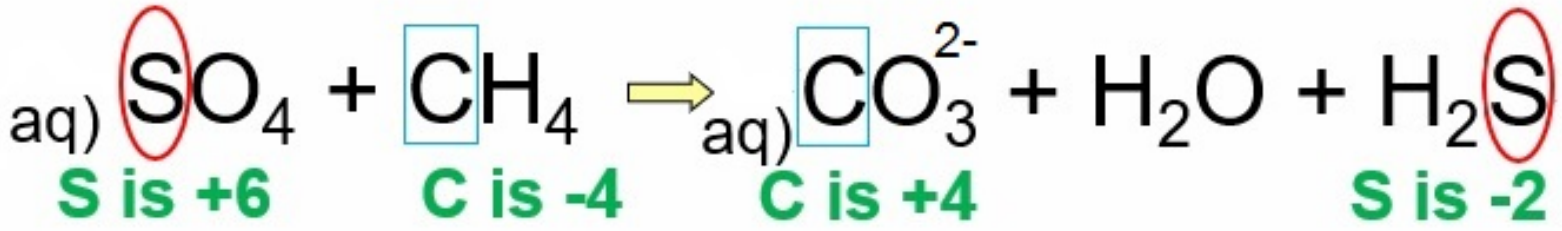
Summary of Recent (Key) New Learnings (3)

11. New Studies are Suggesting Oil- and Mixed-Wettability in a Formation are Often Functions of the Oil & Water ‘Swap’ Process and Related Microbial Activity in a Reservoir

All But that Last New Learning Have Been Addressed in Past Annual CO_2 Conferences *(see CO2Conference.net)*

- Most of those Learnings had Their Origins from Enhanced Recovery Studies and Observations Related to ROZs
- Many Apply to the Horizontal Revolution
- Many Relate Directly to CO_2 Geological Storage and Relate to GhG Emission Reductions (Segues to the Last Section)

Let's Examine that Aforementioned H_2S Generation



Microbes remove 8 Electrons from the Carbon and transfer them to the Sulfur

the Source Sulfate is Reduced and is Released as H_2S to Sour the Oil and Gas

Re: Vance, David (2012), RPSEA II Project Chapter 4 (adapted)

Note: This Process is Active When H_2S Concentrations Remain Low, i.e., < 200 ppm)

Now Taking the ROZ Biogeochemistry Insights One Level Further

- First, Why Hasn't the Industry Noted this Before?
  - Accumulations of H_2S from the Aforementioned Process Inhibits Continued Microbial Activity: Minimizing the Microbial Effects
  - The Lateral Sweep ROZ and its Flow Field Disseminates the H_2S: Amplifies the Process and Effects Such that Observational Enigmas* Emerge

* In the San Andres Fm of the PB, we see 300' Thick Oil Shows Below the Oil/Water Contacts, 300' Thick Oil Shows without an Overlying Main Payzone, Nearly Uniform 30-40% Residual Oil Saturations for 300' Distances Below the OWC, etc. In most other formations and in other basin, those shows are thinner and we dismissed as transition zones

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  - The Lateral Sweep ROZ and its Flow Field Disseminates the H_2S: Amplifies the Process and Effects Such that Observational Enigmas* Emerge
- What About the Shorter-lived Flow Field In the Original Oil Entrapment?

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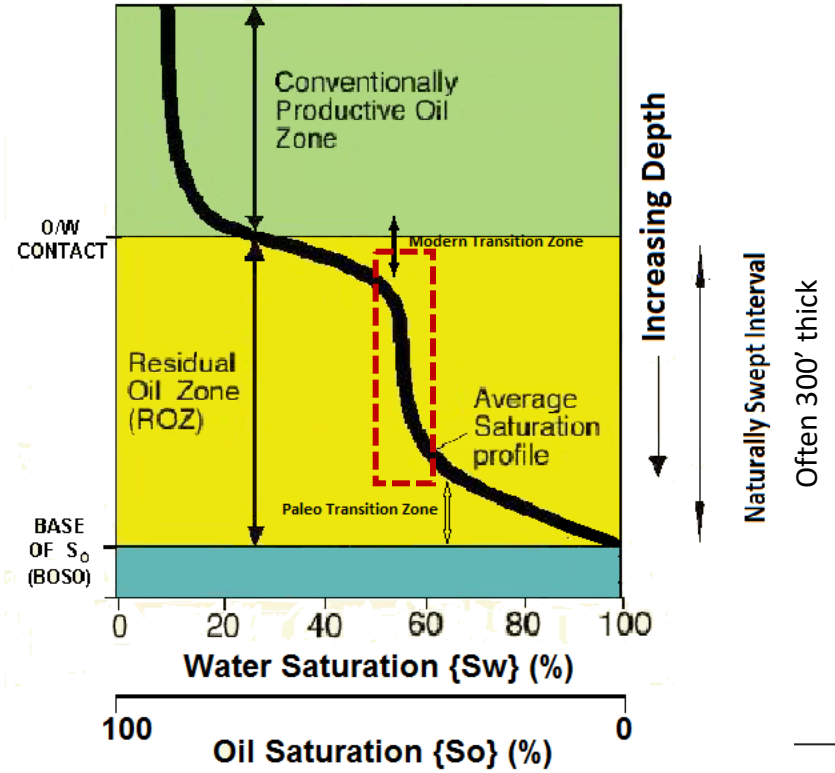
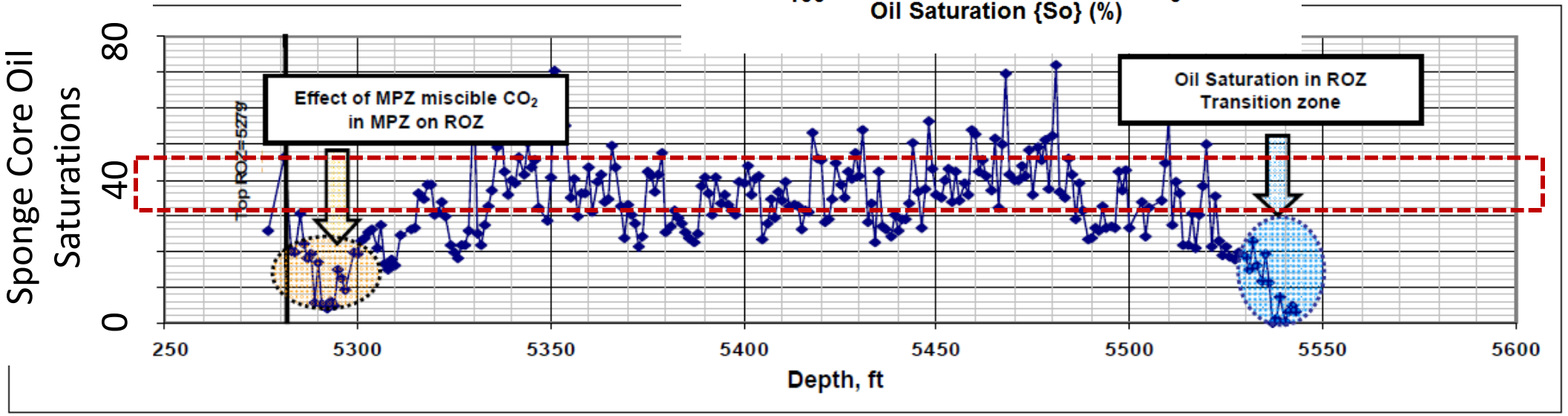
This also leads Us to Talk About Wettability





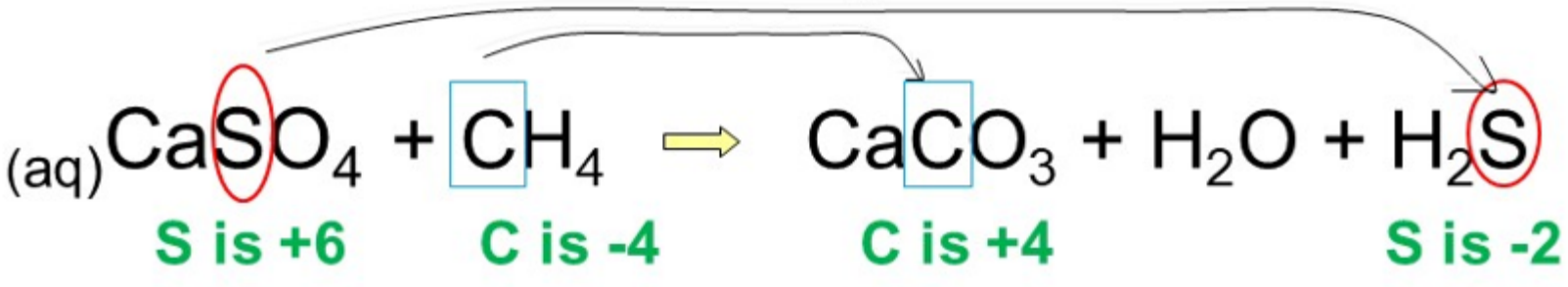
Honapour, M et al (2012), SPE 133089 – Fig 14

The Dominant Dolomization Process

(At Least for the San Andres Formation)

Key Biogenic (Redox) Reaction

Will also Create Saturated SO_4 Conditions in the Water



We are showing Methane here as the source of carbon but…..it may be other hydrocarbons molecules also

- **Microbes remove 8 Electrons from the Carbon and transfer them to the Sulfur**

- **H_2S is Created and Can Inhibit Future Activity (But…A Flowfield Can Disperse)**

Souring the Oil and Gas

- **Dolomitization Typically Follows as Well**

$$CaCO_3 + Mg \longrightarrow MgCa(CO_3)_2$$

New Dolomite Surfaces Attract Oil over Water, Re: Oil Wettability

Re: Vance, David (2012), RPSEA II Project Chapter 4

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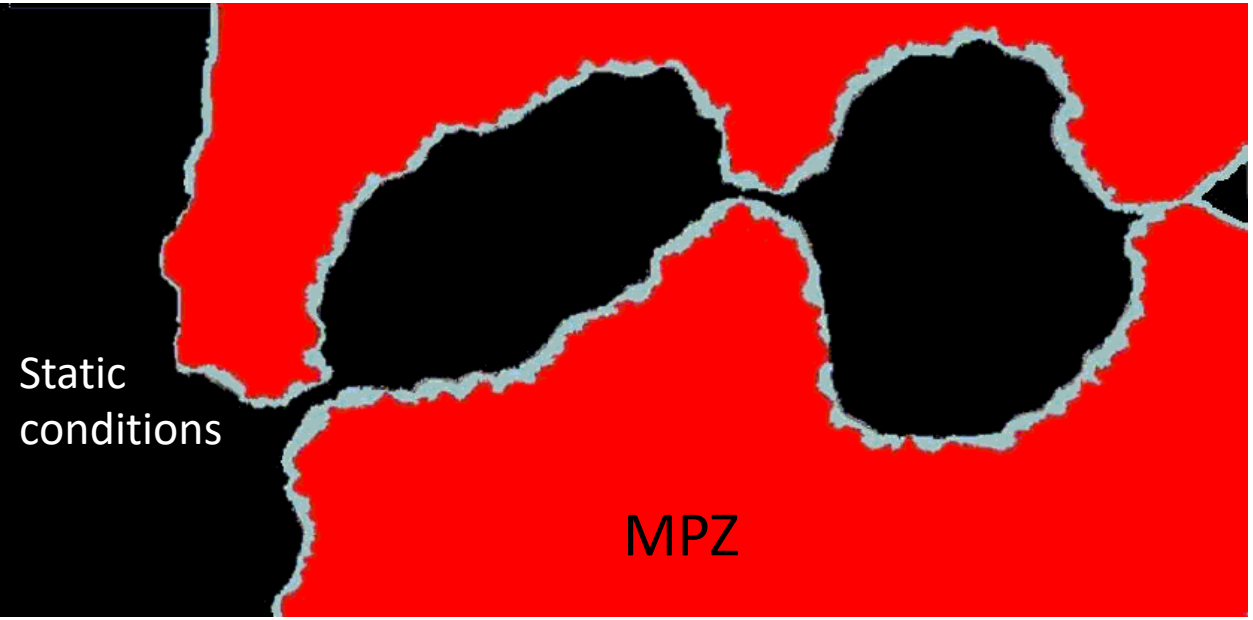
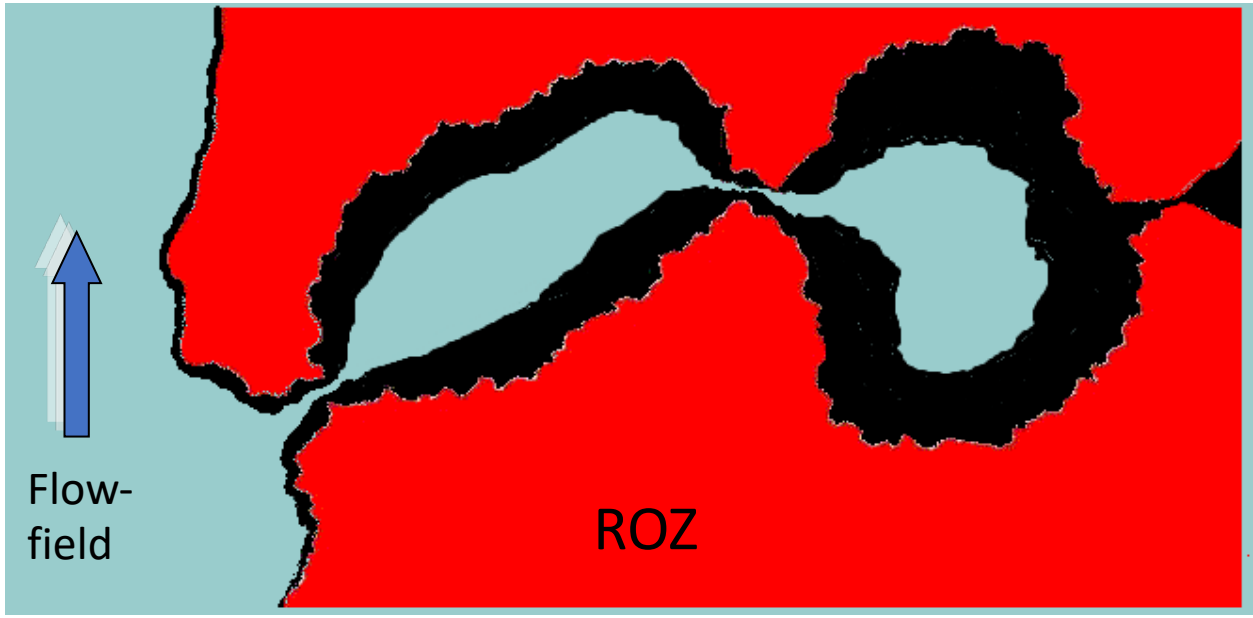
Water- and Oil-Wet





If the matrix, clastic particles, or cement is carbonate or arkosic, the rock will have a preference to oil over water and, (our theory) when during the original oil entrapment and water/oil exchange occurs, some mixed wettability will result

I Need to Stop Here for a Minute and Give Due Credit to Two Persons on our ROZ Team

- Dr. Robert Trentham at UTPB (Trentham_r@utpb.edu); For his insights on the Permian Basin tectonic history and his wealth of general geological expertise

- David Vance at Arcadis (David.Vance@arcadis.com): for his invaluable scientific understanding of biogeochemistry, intrinsic microbes present in the earth, and the biological processes often at work in anaerobic environments

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Greenhouse Gas (GhG) Emissions Capture

- The Clean Air Act (CAA) of 1970 gave EPA the Authority to Establish National Ambient Air Quality Standards (NAAQS) to Control Emissions – Particulates, S_{ox}, NO_x, and others
- In 2007 the US Supreme Court Classified Heat Trapping Emissions (including Both Methane and CO_2) as "Air Pollutants" and (under the CAA) the U.S. EPA was Given Authority to Pass Regulations to Curb GhG Emissions
  - They became Included in New Source Performance Standards (NSPS) and Required Emissions to be Reportable at Plants/Projects Exceeding Certain Threshold Emissions
  - The New Classification also placed GhGs into Regulatory Control under EPA's Federal Safe Drinking Water Act (SDWA {1974})

* The "**U**" Representing Utilization Like in CO_2 EOR where the CO_2 is Injected for Producing Oil but also Storing CO_2 in the Reservoir

No Other Utilization Scheme has Yet to Show it can Abate CO_2 Emission Streams to the Levels that CO_2 EOR can Handle

- The Permian Basin Alone has Already Securely Stored over 20 Trillion Cubic feet (1 billion metric tons)
- There is Pore Space in Many Basins Around the World also that are Available if Given Capacity to Deliver the CO_2 There can be Implemented
- The Formation Depressuring Occurring with the Shale Plays is Greatly Adding to the Pore Space that is Available
- The CCUS Technology is Proven and Ready to Go to Work on CO_2 Emission Reductions

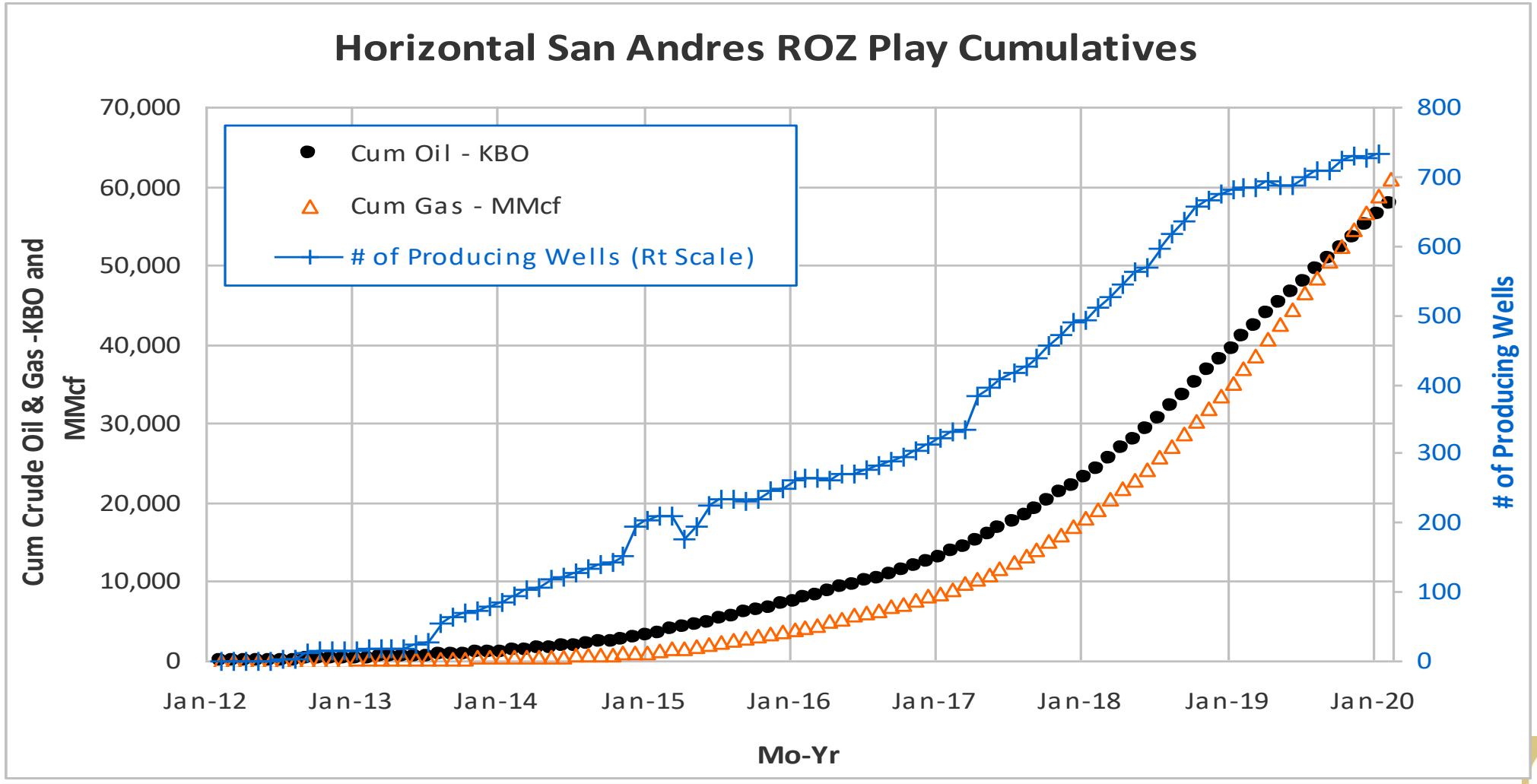
Thank you

Time for Questions?

Backup Slides

San Andres ROZ Horizontals

Cumulative Oil & Gas



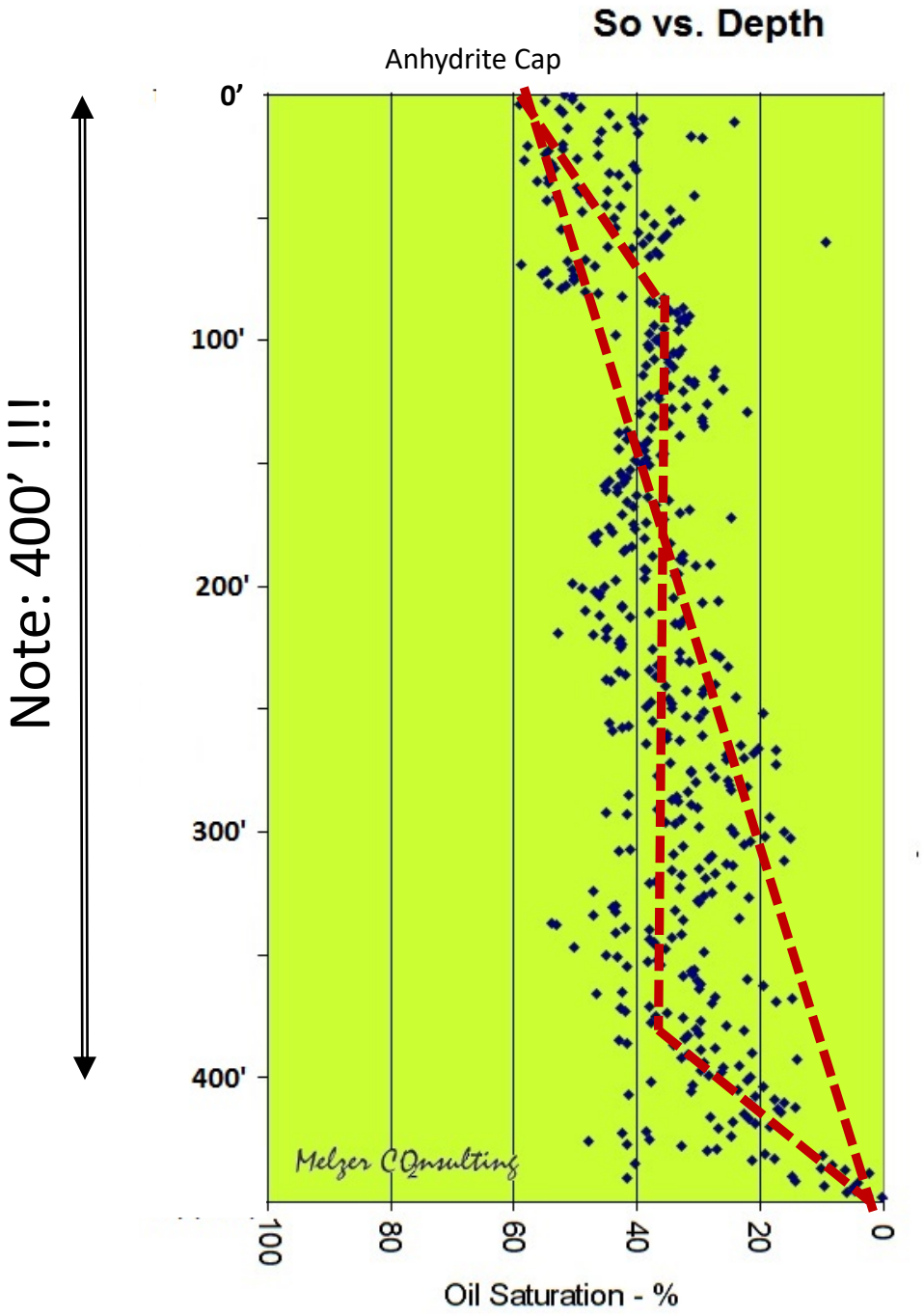
Modelling Results of a One-square Mile San Andres Fm Residual Oil Zone Area

- CO_2 EOR
  - 16 Producers, 9 CO_2 Injectors
- Horizontal Depressuring
  - 7 Total One-mile Long Laterals

- CO_2 EOR
  - Produces 5.8 million Bbls in 10 Years and 9.8 Million in 25 Years
  - Stores Over 70 Bcf (>4 mm tons) of CO_2
  - Payout of 5 Yrs Reduced to 3.5 Yrs w/ ½ Price CO_2, >300% ROI in 9 Yrs
- Horizontal Depressuring
  - Produces 1.6 million Bbls until Uneconomic (~10 years)
  - Payout in 2 years, 100% ROI 10 Yrs

We Had a New Discovery Here in the PB

What would you call this zone?



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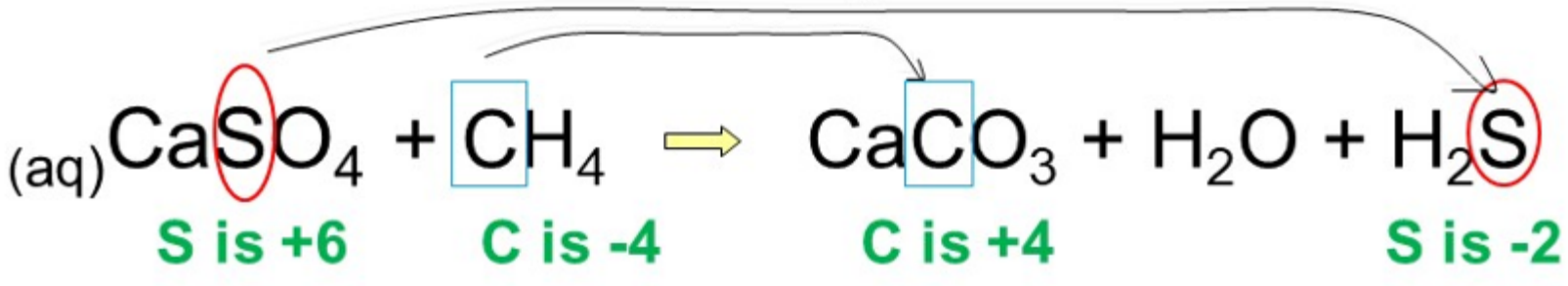

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One Might Call this Learning #12

Sulfate, Unlike Carbonate, is

- Less Soluble When the Water is Cooled
- Production Data Shows JT Effect has Created some Flow Constrictions
- Sulfate Inhibition Chemical (applied at the Flush Stage) of Fracture Treatments is Used Successfully
- Can Require Treatments of Laterals to Convert Sulfate to Carbonate and Acidizing