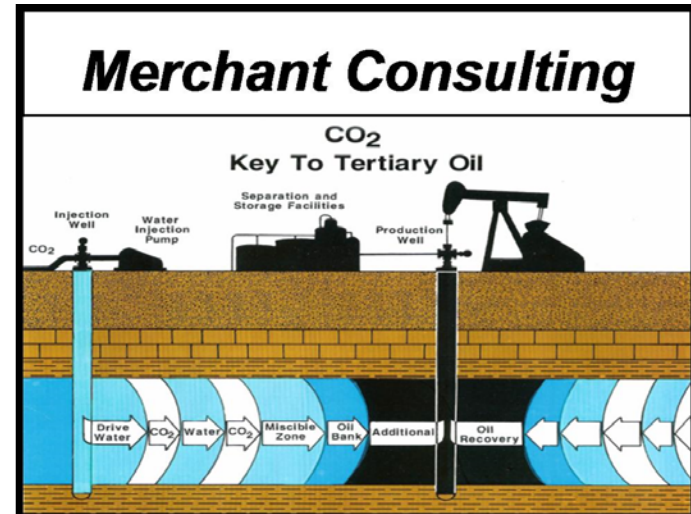


CMTC-554157-MS Enhanced Oil Recovery (CO₂/EOR "Huff-n-Puff") in the 21st Century

David H. Merchant



CO₂ Storage Solutions



Merchant Consulting

WEB Site: www.CO2StorageSolutions.com

Email: merchantconsulting@comcast.net

Presented to Houston CMTC Conference

**July 16, 2019
Houston, Texas**

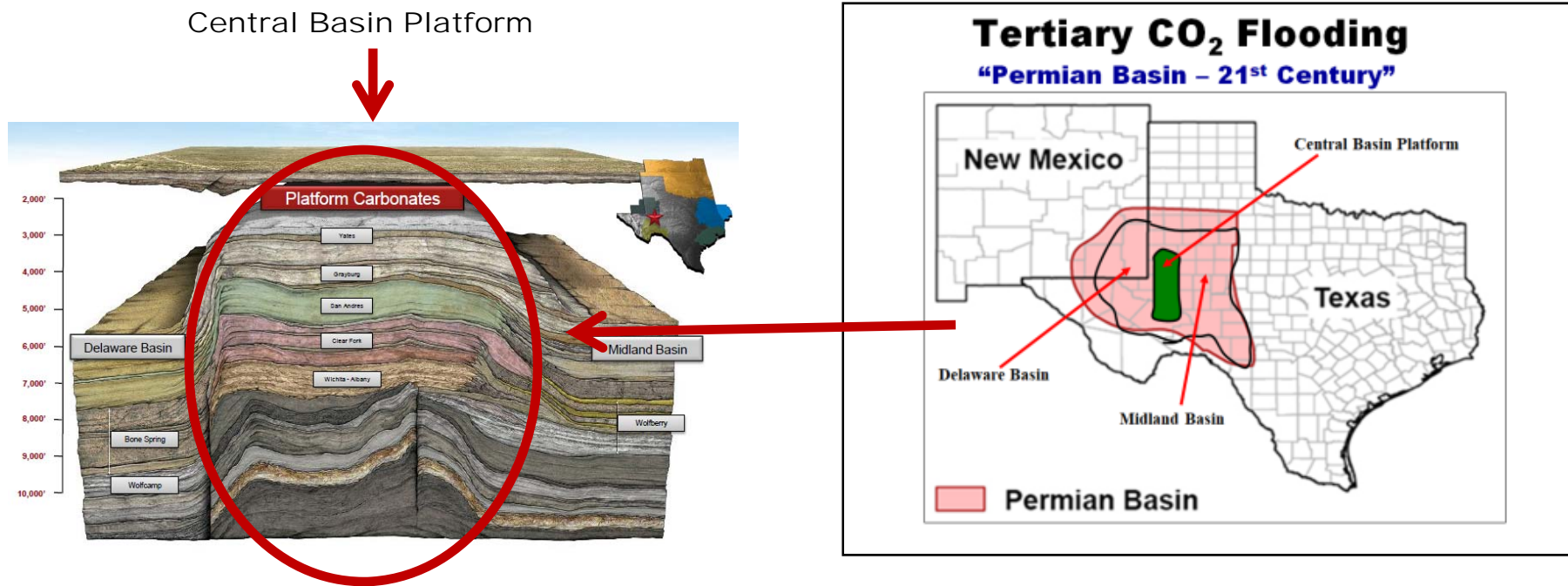
Permian Basin

Welcome to the Permian Basin?



A Truly Great Water Wonderland.....

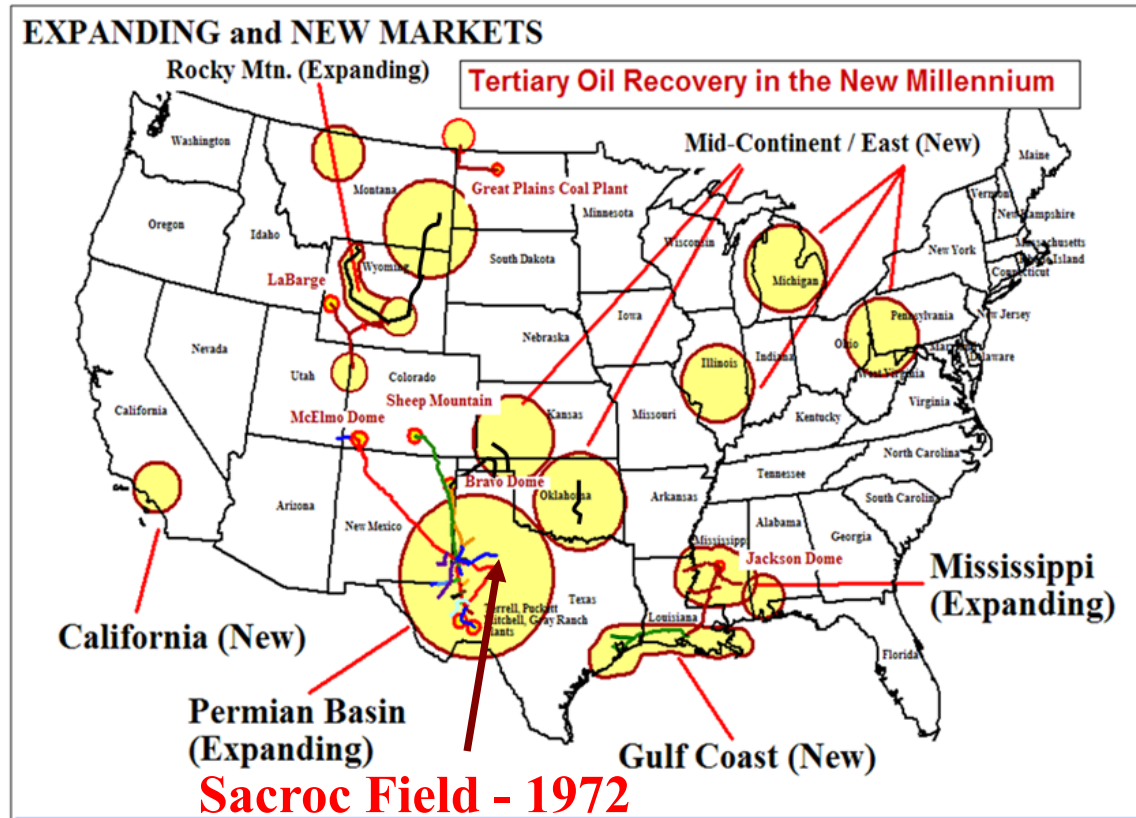
Permian Basin Conventional Oil/EOR Recovery



Central Basin Platform:

Billions of Barrels of Oil exist within the Central Basin Platform Carbonates

Conventional Tertiary CO₂ Flooding "CO₂ Flood History since 1972"

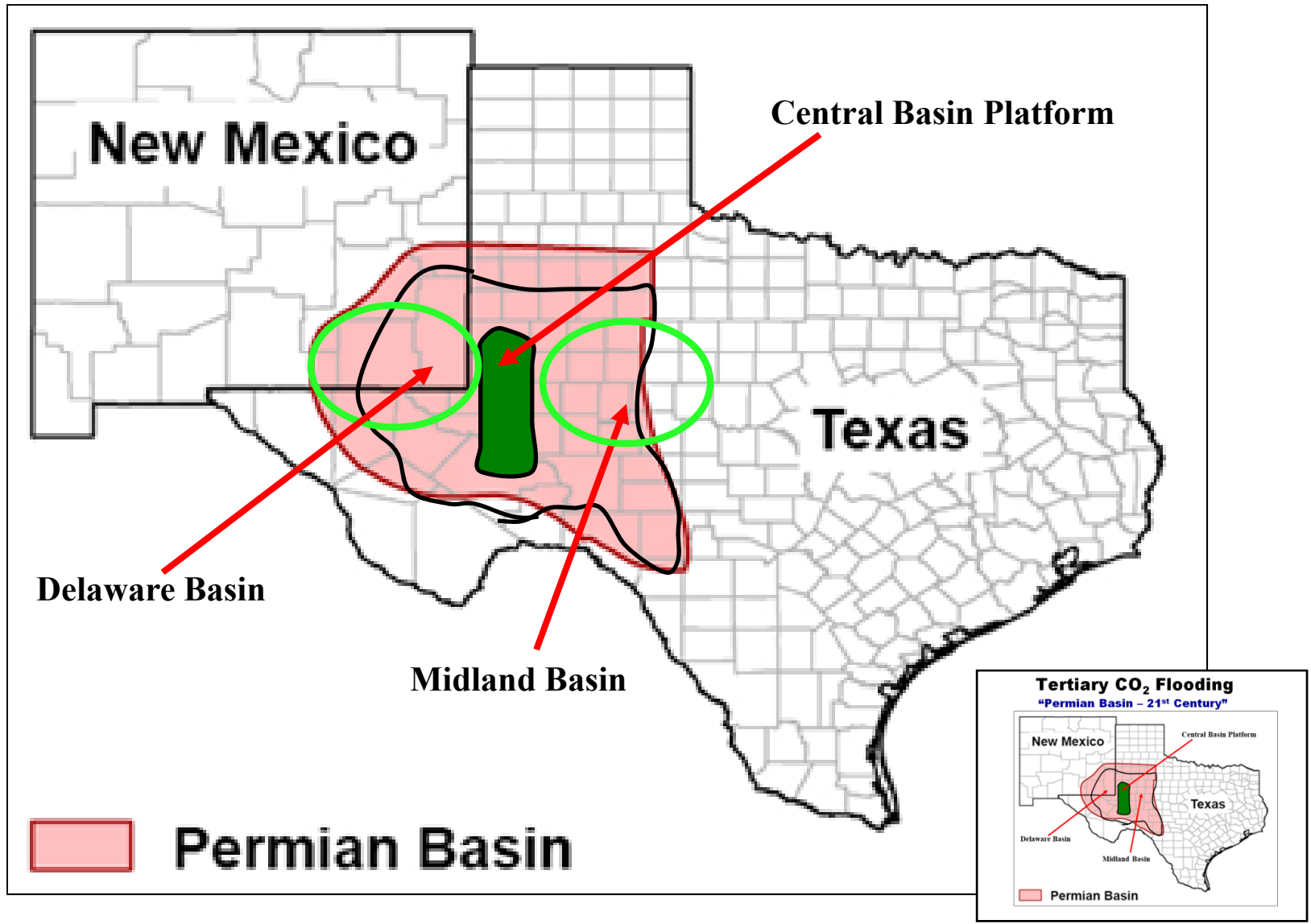


Since 1972 over 130+ CO₂ Tertiary Projects have been implemented in the United States.

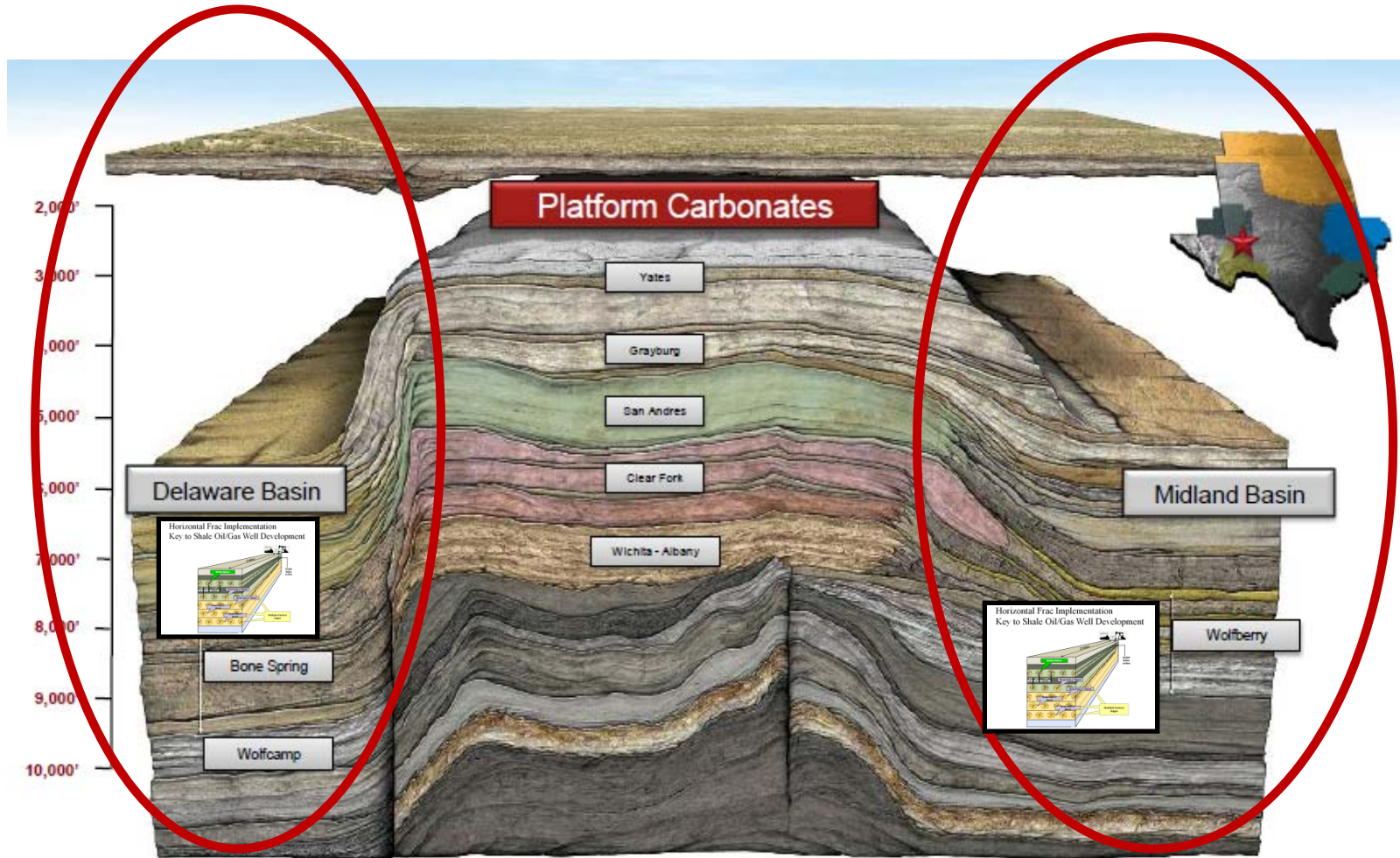
Today, CO₂ projects in the United States produce over 350,000 BOPD with CO₂ transported over 4,500 miles of CO₂ pipeline.

UnConventional Shale Oil Recovery

"Permian Basin - 21st Century"



Delaware Basin – Central Basin Platform - Midland Basin



Today, the introduction of Horizontal Frac Drilling in the Permian Basin Shale Oil Basins has provided a resurgence not seen since the expansion of major CO₂ projects in the mid-1980's

Tertiary CO₂ Flooding

"CO₂ Flood History since 1972"

CMTC 2015 Carbon Management Conference - **THANKS**

CMTC-440075-MS "Life beyond 80 – A Look at Conventional WAG Recovery beyond 80% HCPV Injection in CO₂ Tertiary Floods"
D.H. Merchant, Nov 2015

Objective: Present all **Ten CO₂ Tertiary Recovery Methods**

Tertiary CO₂ Flooding

Ten CO₂ Recovery Methods used for Tertiary Oil Recovery in the United States

1. Conventional WAG Recovery (90%+)
2. Residual Oil Zone (ROZ) (Seminole)
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9. Horizontal Well Pattern Development
10. CO₂ Gas Drive w/ Nitro Boost

CMTC 2017 Carbon Management Conference - **THANKS**

CMTC-502866-MS "Enhanced Oil Recovery - The History of CO₂ Conventional WAG Injection Techniques developed from Lab in the 1950's to 2017", D.H. Merchant, July 2017

Objective: Present **Conventional WAG and ROZ Recovery Methods**

Conventional WAG w/ ROZ

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CMTC-502866-MS "The Look at Conventional WAG Injection Techniques developed from Lab in the 1950's to 2017" deals strictly with Conventional Main Pay and ROZ Reservoirs Only

I would like to thank the George Koperna and Jose Figueroa for allowing me to publish and present my papers at both the 2015 CMTC and 2017 CMTC Conferences

CMTC 2015 Carbon Management Conference

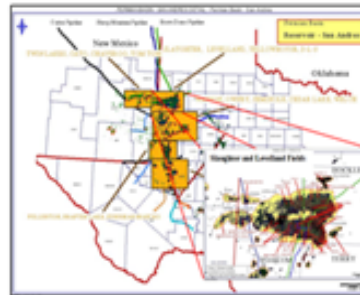
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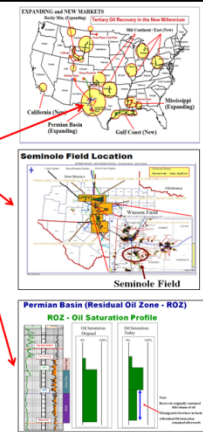
Tertiary CO₂ Flooding

Conventional CO₂EOR - (Year 2015)

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SPE Paper 139516—"Life Beyond 80—A Look at Conventional WAG Recovery beyond 80% HCPV Injection in CO₂ Tertiary Floods"

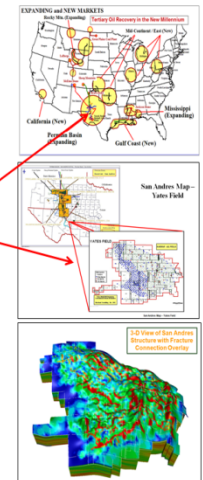


Tertiary CO₂ Flooding

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CMTC 2015 Carbon Management Conference

2015's – CMTC 440075 – “Life Beyond 80 - A Look at Conventional WAG Recovery beyond 80% HCPV Injection in CO₂ Tertiary Floods”

Ten CO₂ Tertiary Recovery Methods

Tertiary CO₂ Flooding

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Gravity Drainage / Double Displacement

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Gas Cycling – Denbury Resources

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Huff-n-Puff (Single Well Injection)

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Heavy Oil (14+ API Gravity)

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Shale Oil – Bakken, Wolfcamp

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Horizontal Well Development

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Objective: Present Ten CO₂ Tertiary Recovery Methods

CO₂ Flooding in the United States

40+ Years of CO₂ Flood History

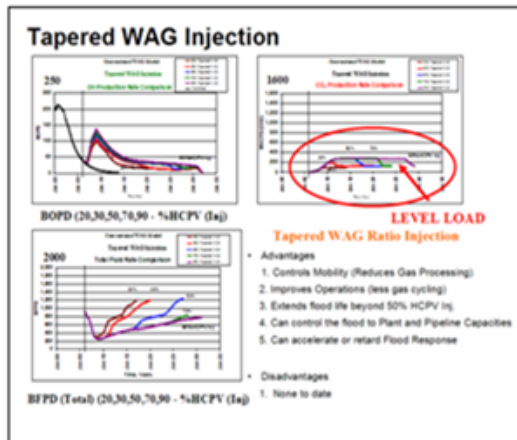
1980's – 1990's

SPE 18977 (1989), Table 1

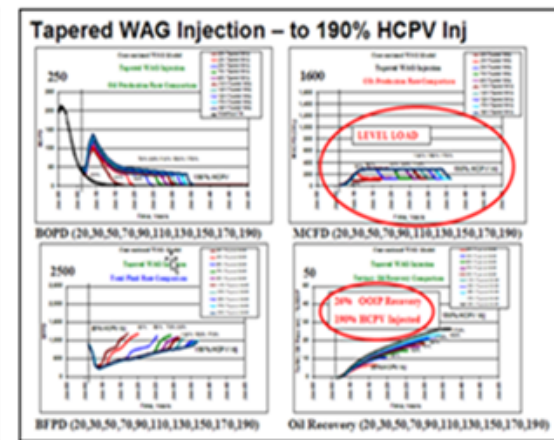
Field	State	Reservoir	Lithology	%HCPV Injected	Rec Eff, % OOP	Gross Utilization, Mcf/Bbl	Net Utilization, Mcf/Bbl
Field Scale							
Dollarhide	Texas	Devonian	Trip Chert	30	14		2.4
East Vacuum	Texas	San Andres	Oolitic Dolomite	30	8	11.1	6.3
Ford Geraldine	Texas	Delaware	Sandstone	30	17	9	5
Means	Texas	San Andres	Dolomite	55	7.1	15.2	11
North Cross	Texas	Devonian	Trip Chert	40	22	18	7.8
Northeast Purdy	Oklahoma	Springer	Sandstone	30	7.5	6.5	4.6
Rangely	Colorado	Weber	Sandstone	30	7.5	9.2	5
Sacroc (17 Pattern)	Texas	Canyon Reef	Carbonate	30	7.5	9.7	6.5
Sacroc (4 Pattern)	Texas	Canyon Reef	Carbonate	30	9.8	9.5	3.2
South Welch	Texas	San Andres	Dolomite	25	7.6		
Two Freds	Texas	Delaware	Sandstone	40	15.6	15.6	8
Wertz	Wyoming	Tensleep	Sandstone	60	10	13	10

SPE 18977 Brock and Bryon 1989

2000's



2010's



7% to 12% OOIP Rec
30% to 40% HCPV Inj

18% OOIP Rec
80% HCPV Inj

20% to 26% OOIP Rec
140% to 190% HCPV Inj

Note: Not all fields will achieve this

Look at how far we have come?

CMTC 2017 Carbon Management Conference

CMTC-502866-MS "Enhanced Oil Recovery - The History of CO₂ Conventional WAG Injection Techniques developed from Lab in the 1950's to 2017", D.H. Merchant, July 2017

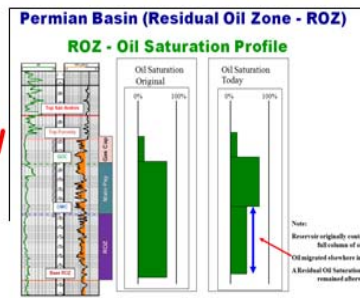
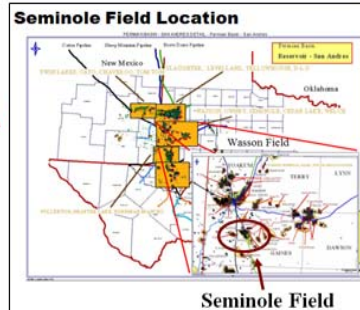
Objective: Present Conventional WAG and ROZ Recovery Methods

Conventional WAG w/ ROZ

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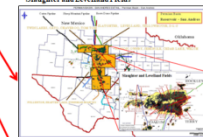


Tertiary CO₂ Flooding

Conventional CO₂EOR - (Year 2015)

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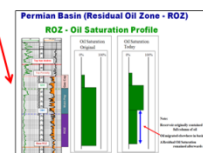
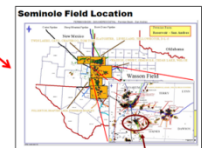


Tertiary CO₂ Flooding

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SPE Paper 139516 - "Life Beyond 80 - A Look at Conventional WAG Recovery beyond 80% BCPV Injection in CO₂ Tertiary Floods"

CMTC 2019 Carbon Management Conference

CMTC-5554157-MS "CO₂ Sequestration – Enhanced Oil Recovery (CO₂/EOR) in the 21st Century", D.H. Merchant, July 2019

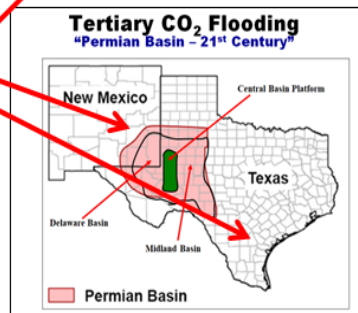
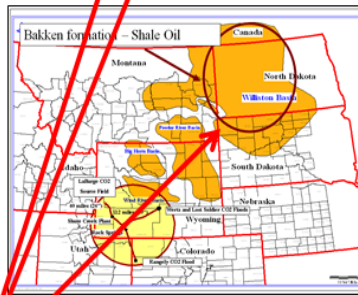
Objective: Present Shale Oil CO₂/EOR “Huff-n-Puff” Recovery Methods

Tertiary CO₂ Flooding

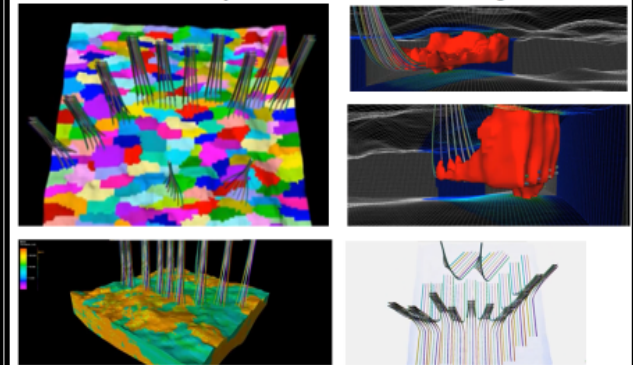
(Unconventional CO₂/EOR in the 21st Century)

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6. **Huff-and-Puff (100+ Projects)**
7. **Heavy Oil - Calif. (14+ API Gravity)**
8. **Shale Oil (Permian Basin, Eagleford, Bakken)**
9. Horizontal Well Pattern Development
10. CO₂ Gas Drive w/ Nitro Boost

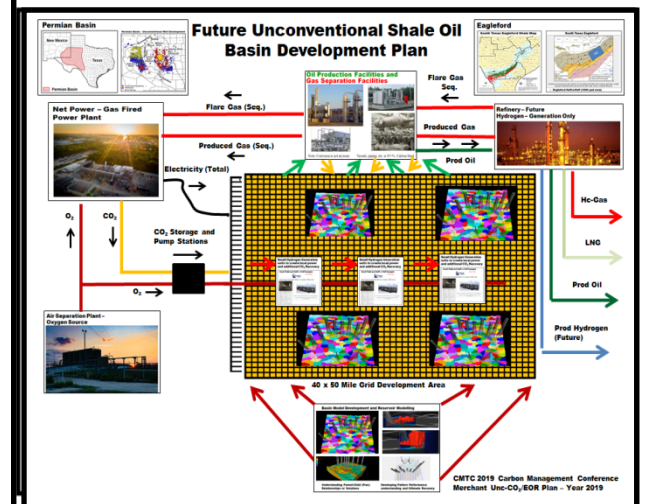


Basin Model Development and Reservoir Modelling



Understanding Parent-Child Relationships w/ Solutions

Developing Pattern Performance understanding and Ultimate Recovery



Tertiary CO₂ Flooding

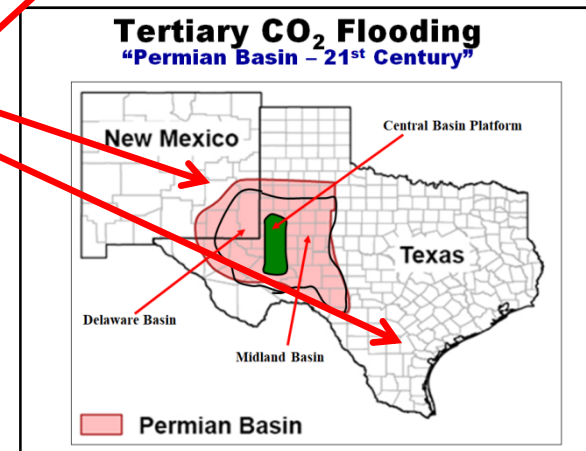
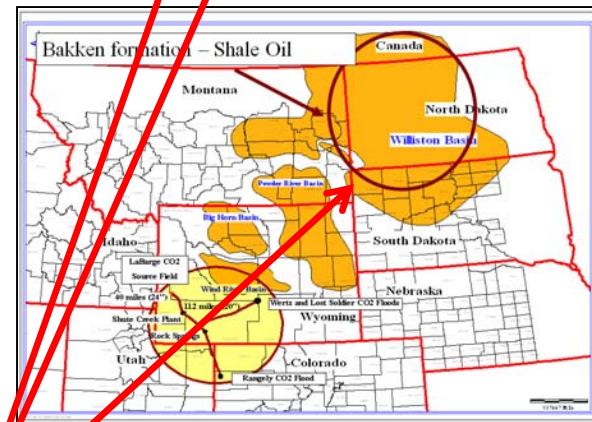
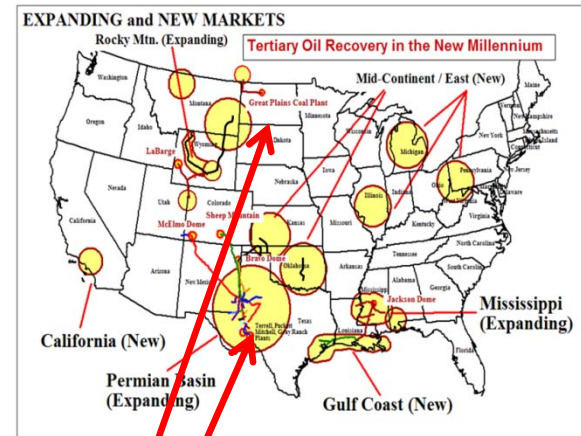
(Unconventional CO₂/EOR in the 21st Century)

Unconventional Shale Oil combined with CO₂ or Hc-gas “Huff-n-Puff”

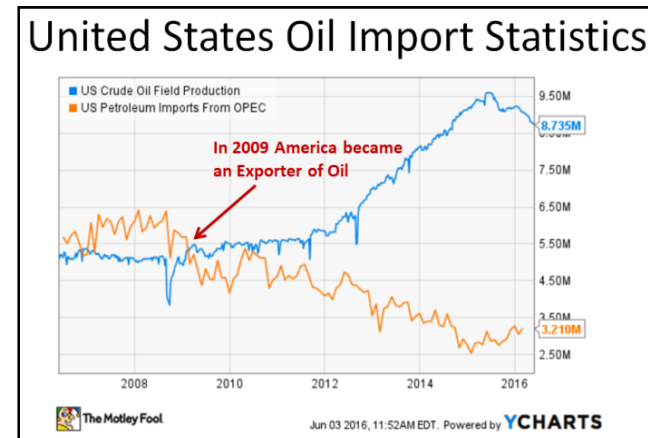
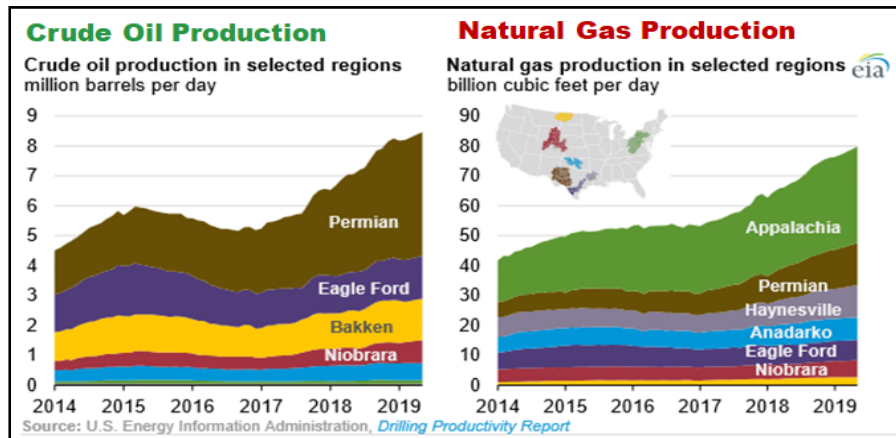
Shale Oil Basins (Permian Basin, Eagleford, Bakken)

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Combine



Shale Oil Revolution: The Good.....

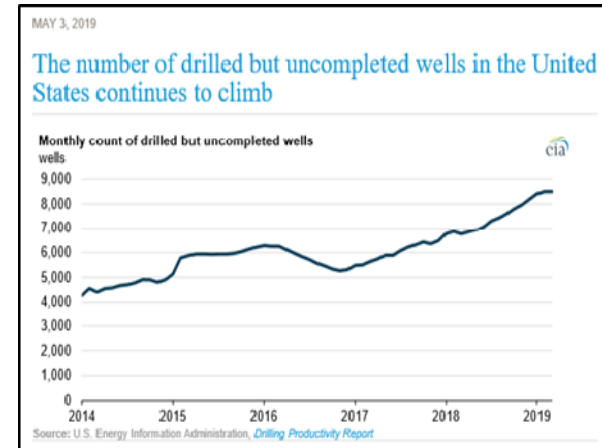
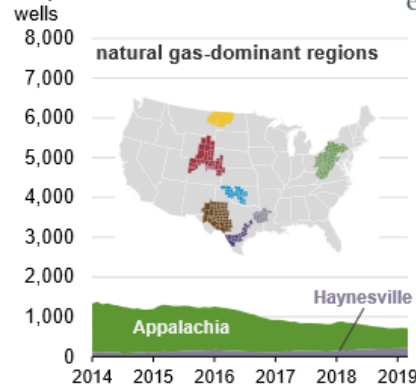
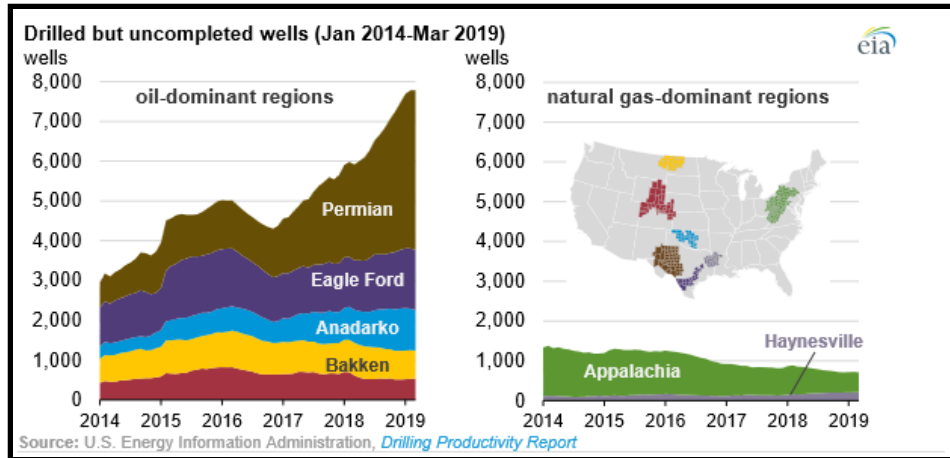


From a United States perspective, the U.S. currently holds the title of Global leader in Recoverable Oil Resources.

With 293 billion barrels of recoverable oil resources, the U.S. beats out both Saudi Arabia and Russia by 20 billion barrels and 100 billion barrels, respectively.

Permian's tight oil plays hold 100 billion barrels of recoverable oil. Recently, with the stabilization in oil prices, oil companies have been focusing more on core development and cash flows rather than new exploration.

Shale Oil Revolution: The Good..... (DUC's)



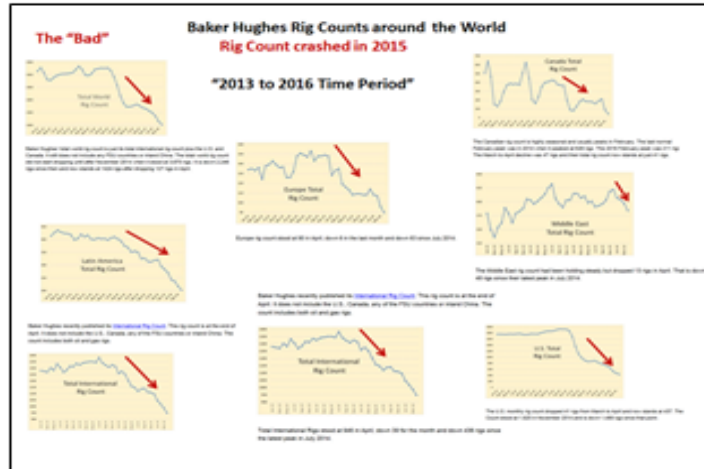
The Permian Basin along with the remaining six regions contains a record number of DUC's (Drilled but Uncompleted wells).

These wells provide a "Nest" full of locations already drilled, but waiting to be completed, providing that safety net to fall back into when oil prices fall.

Since this technology provides a quick entrance back into the Oil Market, the response time utilizing DUC's is much better and quicker to fill the Energy Gap between Supply and Demand when compared to other recovery methods

Shale Oil Revolution: The Bad.....

Total Globe Perspective- Rig Count



North Sea Abandonment



From a **Total World perspective**, this impact of the **Shale Oil Revolution** has been felt all over the World. This is shown below by Baker Hughes Well Rig Count reports over the period 2013 to 2016.

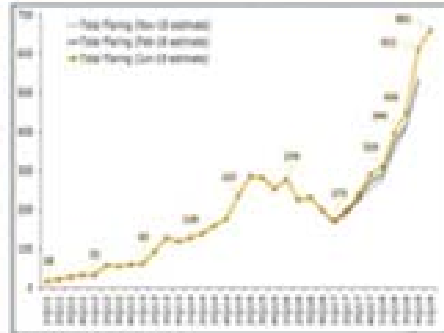
In 2015, Total Rig Count dropped on a Global Basis, impacting the total Global Market. In 2019, WTI oil price settled in between \$50 to \$60 dollars per barrel.

This impact also had an effect on **North Sea Carbon Capture** efforts to recover oil not recoverable under Primary Recovery. As of 2019, North Sea Primary Oil Recovery has recovered 80% of its ultimate Primary Oil Potential. Tertiary CO₂ Recovery would have saved the Oil Industry in the North Sea.

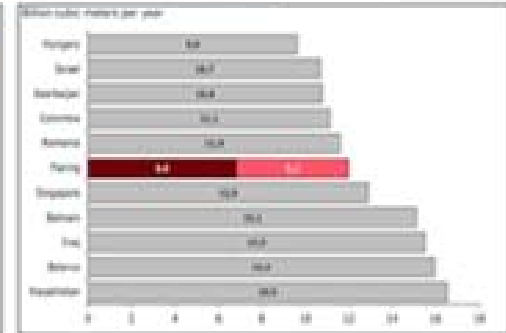
Today, **decommissioning** will plug 4,000 wells, along with the removal of 300 platforms, and 20,000 Km of pipelines at a cost of 35 Billion Pounds.

Shale Oil Revolution: The Ugly.....

Oilfield Flares Provide a Glaring Reminder of the Drive To Produce More Oil



Source: Hydrat Energy



Permian and Bakken Flare History (2011 to 2019)

Flare History across America

In every new basin across the World, the amount of associated gas not available for market is flared. This occurs when rising oil production outstrips processing plant and pipeline production capacity, thus the associated hydrocarbon gas produced with the oil is flared.

The volume of natural gas flared in the Permian basin MMCF/day (million ft³/day) has raised sharply since early 2017. More than half of the total comes from the Permian, which has surpassed the Bakken by more than tripling the volume of gas burned per day since early 2017.

CO₂ Storage Solutions

Permian Basin Goal – Zero Gas Emissions

CO₂ Plant Capture



CO₂ Pipeline Infrastructure



CO₂ Reservoir Storage and Sequestration



The Three Elements of Carbon Capture in Unconventional Shale Oil Reservoirs

Carbon Sequestration:

Question is "How do you put out the **Flare**?"

CO₂ Storage Solutions

Permian Basin Goal – Zero Gas Emissions

CO₂ Plant Capture



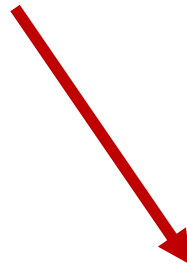
CO₂ Pipeline Infrastructure



CO₂ Reservoir Storage and Sequestration



Six Plant Options



<p>Century Plant</p> <p>Wilson Development: Century Plant</p> <ul style="list-style-type: none">Final Commercial operation by quarter 2020Double capacity capacityBased on 100% natural gasLargest single industrial source CO₂ capture facility in North AmericaCapacity suitable for use with100% natural gas and 100% coal	<p>Shovel Ready Coal Projects</p> <p>Permian Basin – Two Shovel Ready Clean Coal Power Projects</p>	<p>Petra Nova Coal Solution</p> <p>Petra Nova Plant - Ft. Bend County, Texas</p>	<p>NetPower Gas Solution</p> <p>NETPOWER – Bill Brown Big Oil is investing to scale up the world's first zero-emissions fossil-fuel plant</p>	<p>Hydrogen Solution</p> <p>Goal to Support Japanese Clean "Hydrogen Society" Project</p>	<p>Air Capture Solution</p> <p>Oxy Low Carbon Ventures and Carbon Engineering</p> <p>May 21, 2019 Publication: Oxy Low Carbon Ventures and Carbon Engineering begin Engineering of the World's Largest Direct Air Capture and Sequestration Plant</p>
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Goal: Zero Emissions (Eliminate the Gas Flare)

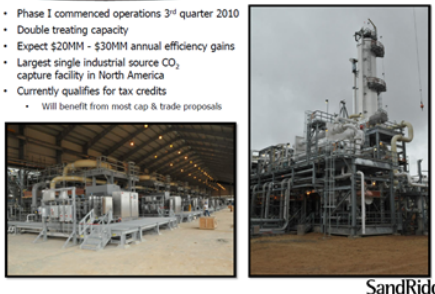
<h3>Century Plant</h3> <p>Piñon Development: Century Plant</p> <ul style="list-style-type: none"> Phase I commenced operations 3rd quarter 2010 Double treating capacity Expect \$20MM - \$30MM annual efficiency gains Largest single industrial source CO₂ capture facility in North America Currently qualifies for tax credits Will benefit from most cap & trade proposals 	<h3>Shovel Ready Coal Projects</h3> <p>Permian Basin - Top Shovel Ready Clean Coal Power Projects</p>  <p>3 New Clean Coal Power Plants in the Permian Basin</p>	<h3>Petra Nova Coal Solution</h3> <p>Petra Nova Plant - Ft. Bend County, Texas</p> 	<h3>NetPower Gas Solution</h3> <p>NETPOWER - Bill Brown</p> <p>Big Oil is investing to scale up the world's first zero-emissions fossil-fuel plant</p> 	<h3>Hydrogen Solution</h3> <p>Coal to Support Japanese Clean "Hydrogen Society" Project</p> 	<h3>Air Capture Solution</h3> <p>Oxy Low Carbon Ventures and Carbon Engineering</p> <p>May 21, 2019 Publication: Oxy Low Carbon Ventures and Carbon Engineering begin Engineering of the World's Largest Direct Air Capture and Sequestration Plant</p> 
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Permian Basin - Existing and Possible Future Anthropogenic CO₂ Sources

Century Plant

Piñon Development: Century Plant

- Phase I commenced operations 3rd quarter 2010
- Double treating capacity
- Expect \$20MM - \$30MM annual efficiency gains
- Largest single industrial source CO₂ capture facility in North America
- Currently qualifies for tax credits
- Will benefit from most cap & trade proposals



SandRidge

The Century Plant in the Permian Basin was the Largest Single Industrial CO₂ Source Capture Facility in the United States in 2011 and provides CO₂ to Oxy Permian; And, qualifies for Q45 Tax Credits (today)

The Summit and Trail Blazer Coal Powered Plants are currently Suspended and put on hold.

Note: The Century Plant generates CO₂ that is used in the Permian Basin today that helps "Put out the Flare"

Goal: Zero Emissions (Eliminate the Gas Flare)



Permian Basin – Two Shovel Ready Clean Coal Plant Projects

Permian Basin – Two Shovel Ready Clean Coal Projects

Odessa Basin (Oxy-Low Carbon Power Plant) Sweetwater Basin (Oxy-Low Carbon Power Plant)

Between 2005 and 2015, two Permian Basin Power Plants utilizing Wyoming Powder River Coal as a source were designed, pursued, but later **SHELVED**

CO₂ Sequestration / EOR

Odessa Basin - Permian Project Sweetwater Basin - Permian Project

Two Shovel Ready Projects in Texas Currently Shelved.

You made a promise to all the Coal Miners in America

Bragging Rights

Imagine: **Three "Clean Coal Projects"** in 2017

1. Petra Nova (Completed **On-time and On-Budget**)
2. Texas Clean Energy Project (**Shovel Ready**)
3. Tenaska Trail Blazer Project (**Shovel Ready**)

Make America Great Again for the Coal Industry
Create **JOBS** in both the Powder River Basin in Wyoming and the Permian Basin in West Texas

Today, **Who** is the Competition?

Wolfcamp at \$45 Break-even EUE estimated at 383,000 BOE CUTOFF

Who's Who? **Who's Who?**

Versus

San Andres formation - Seminole Main Pay EUE Projection estimated at 26% of Original GOR of 968 MMBbl (Decline Curve)

Seminole field – Main Pay Only

Expected Coal-fired Power Plant Closures in 2017-18

In a report issued April 21, 2017 by the Institute for Energy Economics & Financial Analysis, 46 coal-burning units at 15 Power Plants across 16 states will close or greatly reduce production by 2018, resulting in a 39 million-ton decrease in demand for coal.

States include:
Colorado, Florida, Kentucky, Illinois, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, North Dakota, Ohio, Tennessee, Texas, Virginia, West Virginia, and Wisconsin.

Wyoming - Powder River Coal Shovel Ready Coal Projects

Wyoming - Powder River Coal Shovel Ready Coal Projects

When you turn to a Solution to Wyoming's Coal Crisis, you might want to turn to **TEXAS** for a **CCS** Solution

Wyoming - Powder River Coal Shovel Ready Coal Projects

The **Benefits** would be:

1. **Jobs.... Jobs.... Jobs....**
2. **Two 50 Year Long Life Projects**
3. **Shovel Ready (Now)**

The Question Becomes How do you Pay for it?

Permian Basin Future Clean Coal Projects

In the 1980's the Permian Basin infrastructure was built and in 1986 oil price collapsed by 45%, just like in 2015. All major EOR projects still went forward and still continue today after many oil price adjustment periods through time. Today, over 90% of the Oxy's Major CO₂ Field Projects in the Permian basin still produce Tertiary Oil even in a challenging \$45 dollar oil price environment (Date: June, 2017).

Between 2005 and 2015, two Permian basin Power Plant Projects utilizing Wyoming Powder River Coal as a source were designed, pursued, but later **SHELVED**.

Permian Basin – Two Shovel Ready Clean Coal Plant Projects

West Texas - Permian Basin

Clean Coal Power Projects

Two Sites on National Short List

Odessa site

Heart of Brazos site

A Yee Hah Moment

BEO - Scott Tucker

2 New Clean Coal Powered Plants in the Permian Basin

Texas Clean Energy Project

The Texas Clean Energy Project
Speaker: Eric Redman, President - Summit Power Group

1. Project will be built by Siemens, Fluor, and Linde as the equipment suppliers and construction contractors. The design engineering work is well underway.
2. Air permit will be granted by December 17 -- no one requested a hearing on it (cleanest permit in Texas history).
3. The project's long-term performance & availability to be guaranteed by Siemens.
4. The project has received a \$450 million cash grant from DOE and a \$313 million investment tax credit from the IRS.
5. Major lender banks have been selected, and several major investors are currently in discussions to become the majority or minority owners of the project.
6. Project is on schedule for completion of permits and contracts by mid-2011, financing in fall 2011, and start of construction right after financing.
7. Project will produce 200+ megawatts of power for sale, 500,000 tpy of urea (reducing imports by 10%), and 3 million tons per year of CO₂ captured for EOR, which should increase Permian Basin oil production by 6 to 9 million barrels per year.
8. 1200-1500 construction jobs expected through 2014, more than 100 permanent jobs when project is completed.

Odessa Texas (Western Permian) Midland CO₂ Conference - 2009
 Construction: 2012 - 2014
 Produce: 200 MW Power Plant - 150 MMSCFD - 8,750 tons/day - 3 million tons/yr CO₂
 Merckant Consulting - Midland CO₂ Conference - 2009

The Texas Clean Energy Project was designed to deliver CO₂ to the Central Basin Pipeline which supplies CO₂ to oil fields located on the Western edge of the Permian Basin

Tenaska Trail Blazer Project

Tenaska Trail Blazer Project
Speaker: Jeff James, Director of Business Development - Tenaska

- Clean energy: a cutting-edge power plant designed to capture 85-90% of its CO₂ (300 MMSCFD)
- Water conservation: will use highly water efficient dry cooling design
- Jobs and revenue: 1,500 jobs at peak of construction - 100+ for operation. Construction will inject more than \$742 million in economic activity in Nolan County
- Enhanced energy security:
- CO₂ for EOR in the Permian Basin - 17,500 tons per day of CO₂
- Secure power supplies for Texas: a 600 MW (net) pulverized coal-fueled electric generating station powering 600,000 homes
- Expect final Air Permit by end of this year - TCEQ draft agenda December 14, 2010
- Fluor CO₂ Capture Tech, Arch Coal 35% equity interest, Global CCS Institute grant

Sweetwater Texas (Eastern Permian) Midland CO₂ Conference - 2009
 Construction: No Date Set
 Produce: 600 MW Power Plant - 300 MMSCFD - 17,500 tons/day - 6 million tons/yr CO₂
 Merckant Consulting - Midland CO₂ Conference - 2009

The Tenaska Trail Blazer Project was designed to deliver CO₂ to the CRC Pipeline which supplies CO₂ to oil fields located on the Eastern edge of the Permian Basin

Note: These Projects would create jobs... jobs... jobs... in Texas and Wyoming, but would not **“Put out the Flare”**

Goal: Zero Emissions (Eliminate the Gas Flare)



State of Texas – Petra Nova Plant

Petra Nova Plant – Washington Parish - Texas

**Secretary Perry – April 19, 2017
CCS Ribbon Cutting Ceremony
CCS Project: On Budget/On Time**

Petra Nova Clean Coal Plant is the very First Large Scale “Clean Coal” Facility in the USA

Petra Nova – November 2016

NRG and JX Nippon Oil & Gas
The first large scale U.S. “clean coal” facility was declared operational Tuesday by the large energy firm NRG Energy and JX Nippon Oil & Gas Exploration Corp.

*“There are not many coal plants that are being built these days,” said **Manuel Gutierrez**, the president and CEO of NRG. “We think that actually having an experience in installing a carbon capture and storage technology in existing...”*

On-Budget On-Time Congrats..

In 2017, Rick Perry celebrated with the start-up of the Petra Nova Plant which represents the very First Large Scale “Clean Coal” Facility in the USA.

Petra Nova Plant

Southwest of Houston

The West Ranch CO₂-EOR Project


In 2017, Rick Perry celebrated with the start-up of the Petra Nova Plant which represents the very First Large Scale “Clean Coal” Facility in the USA.


Unfortunately, it doesn't solve the **Flare** Problem.

Goal: Zero Emissions (Eliminate the Gas Flare)

<h3>Century Plant</h3> <p>Pylon Development: Century Plant</p> <ul style="list-style-type: none"> Phase 1 Commercial operations 2nd quarter 2018 Double tracking capacity Export 100MW - 1000MW annual offshore power Export 100MW - 1000MW annual onshore power Export 100MW - 1000MW annual onshore power Export 100MW - 1000MW annual onshore power 	<h3>Shovel Ready Coal Projects</h3> <p>Permian Basin - Top Shovel Ready Clean Coal Power Projects</p>  <p>3 New Clean Coal Power Plants in the Permian Basin</p>	<h3>Petra Nova Coal Solution</h3> <p>Petra Nova Plant - Ft. Bend County, Texas</p> 	<h3>NetPower Gas Solution</h3> <p>NETPOWER - Bill Brown</p> <p>Big Oil is investing to scale up the world's first zero-emissions fossil-fuel plant</p> 	<h3>Hydrogen Solution</h3> <p>Hydrogen Solution</p> 	<h3>Air Capture Solution</h3> <p>Oxy Low Carbon Ventures and Carbon Engineering</p> <p>May 21, 2019 Publication: Oxy Low Carbon Ventures and Carbon Engineering begin Engineering of the World's Largest Direct Air Capture and Sequestration Plant</p> 
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Net Power Plant - La Porte - Texas






Plant Demonstration Success - First Fire - May 30, 2018

Pioneering Zero-Emission Natural Gas Power Cycle Achieves First-Fire



The Allam Cycle

<https://www.prnewswire.com/news-releases/net-power-achieves-major-milestone-for-carbon-capture-with-demonstration-plant-first-fire-300656175.html>



A demonstration power plant run by NET Power in Houston, Texas, uses carbon dioxide to drive the turbine that generates electricity. Courtesy of NET Power and McDermott

A Revolutionary Technical Accomplishment - First Fire - May 2018

NET Power, which is based in Durham, North Carolina, and demonstration project partners Exelon Generation, engineering and construction firm McDermott, and 8 Rivers Capital, the firm that invested the Allam Cycle, said on May 30 that the project achieved firing of a commercial-scale 50-MWth combustor made by Toshiba Energy Systems & Solutions. The project is designed to produce low-cost electricity from natural gas while generating near-zero atmospheric emissions, including full CO₂ capture.

First fire of the combustor is a remarkable milestone for the project, which broke ground in March 2016, because it validates the "fundamental operability and technical foundation" of NET Power's power system. Successful operation of the project could allow the company to develop larger 300-MWth commercial-scale plants as early as 2021.

NET Power's Allam Cycle—named for its lead inventor, Rodney Allam—burns natural gas (or synthetic gas from coal gasification) with pure oxygen and uses high-pressure CO₂ as a working fluid in a semi-closed loop to drive a combustion turbine. Its byproducts are liquid water, pipeline-ready CO₂, and argon and nitrogen, which could also be sold as commodities.

The company says its technology is potentially game-changing because it efficiently tackles CO₂ emissions from natural gas-fired power plants. "Existing natural gas plants burn natural gas with air, which is a mix of oxygen and nitrogen. These technologies emit CO₂, which is difficult and expensive to separate from the nitrogen and residual oxygen. Unfortunately, this has made carbon capture uneconomical for traditional power plants. NET Power addresses the cost hurdles of older technologies with a novel process—an oxy-fuel, supercritical CO₂ power cycle—that produces electricity efficiently while inherently eliminating all air emissions." With a "small reduction in efficiency," the technology can also operate without water.

In May 2018, Bill Brown and his team "Fired-up" for the first time their new (Allam Cycle) CO₂ Capture Technology.


Since this technology burns Hc-gas + O₂ to make CO₂, this Carbon Capture technology provides the best solution to address the Flare Problem in the Permian Basin.

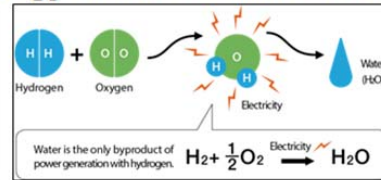
Goal: Zero Emissions (Eliminate the Gas Flare)

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Hydrogen Energy Future -- Year 2020 Olympics (Japan)

Coal to Support Japanese Clean "Hydrogen Society" Project





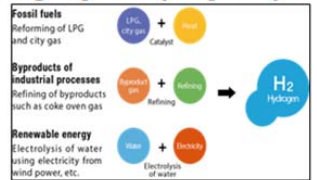
Water is the only byproduct of power generation with hydrogen.

$$H_2 + \frac{1}{2} O_2 \xrightarrow{\text{Electricity}} H_2O$$

Fossil fuels Reforming of LPG and city gas


Byproducts of industrial processes Refining of byproducts such as coke oven gas

Renewable energy Electrolysis of water using electricity from wind power, etc.



Hydrogen Energy will be part of Japan's 2020 Olympics opening a new "Gap Filler" to fill the wedge between Consumption and Supply.

In addition... BP's Vision (Bob Dudley)



Hydrogen Council

"Hydrogen will play an important role in a low carbon future, both as an energy product and as an industrial feedstock. BP is pleased to be joining the Hydrogen Council and will work with its members to promote and develop large-scale, low-carbon hydrogen-based opportunities."

BOB DUDLEY
Group Chief Executive, BP

In the future as we deplete our conventional oil and gas reserves, hydrogen will be the new standard. Since the goal is to be carbon free, the Hydrogen Age is right around the corner. Since this technology creates no emissions, this Carbon Capture technology provides one of the best solutions to address the **Flare** Problem in the Permian Basin.


Goal: Zero Emissions (Eliminate the Gas Flare)

The image shows a row of six informational cards, each representing a different energy or carbon capture solution. From left to right:

- Century Plant:** Pylon Development: Century Plant. Lists milestones like 'Plant Commercial operation 27 October 2016' and 'Scale leading capacity'.
- Shovel Ready Coal Projects:** Permian Basin - Top Shovel Ready Clean Coal Power Projects. Includes a map of the Permian Basin and text: '7 New Clean Coal Power Plants in the Permian Basin'.
- Petra Nova Coal Solution:** Petra Nova Plant - Ft. Bend County, Texas. Shows images of the plant and a map of the location.
- NetPower Gas Solution:** NETPOWER - Bill Brown. States: 'Big Oil is investing to scale up the world's first zero-emissions fossil-fuel plant'.
- Hydrogen Solution:** Coal to Support Japanese Clean Hydrogen Solution Project. Shows a blue car at a hydrogen refueling station.
- Air Capture Solution:** Oxy Low Carbon Ventures and Carbon Engineering. Includes a photo of a large industrial facility and text: 'May 21, 2019 Publication: Oxy Low Carbon Ventures and Carbon Engineering begin Engineering of the World's Largest Direct Air Capture and Sequestration Plant'. This card is circled in red.

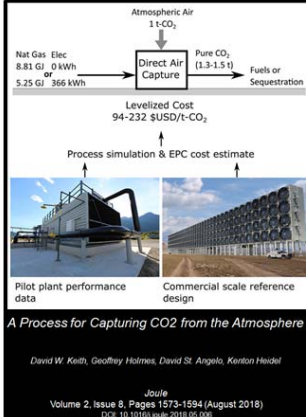
Direct Air CO₂ Capture - 21st Century

Oxy Low Carbon Ventures and Carbon Engineering



May 21, 2019 Publication:
Oxy Low Carbon Ventures and Carbon Engineering begin Engineering of the World's Largest Direct Air Capture and Sequestration Plant

Canadian Direct Air CO₂ Recovery Plant - Joule



Joule in Canada is currently extracting CO₂ from the Atmosphere in their Test Facility

CO₂ Capture Technology from Direct Air is new and currently expensive when compared to other CO₂ Capture Technologies in 2019. However, as the technology advances, the cost of capture will come down.

In May 2019, Occidental Petroleum (Oxy Permian) teamed up with Carbon Engineering to advance this technology in the 21st Century.

CO₂ Storage Solutions

Permian Basin Goal – Zero Gas Emissions

CO₂ Plant Capture



CO₂ Pipeline Infrastructure



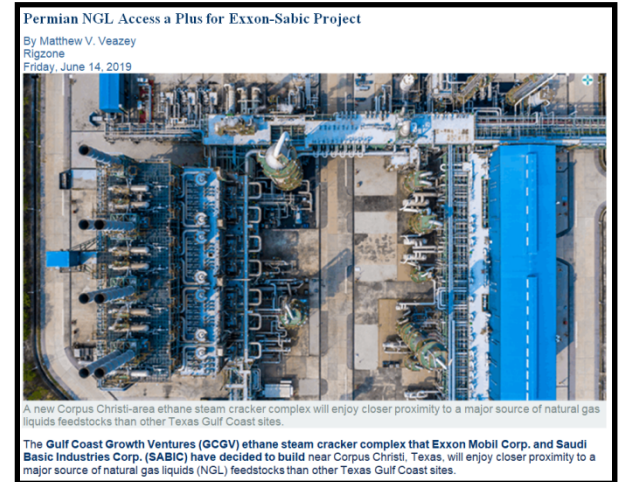
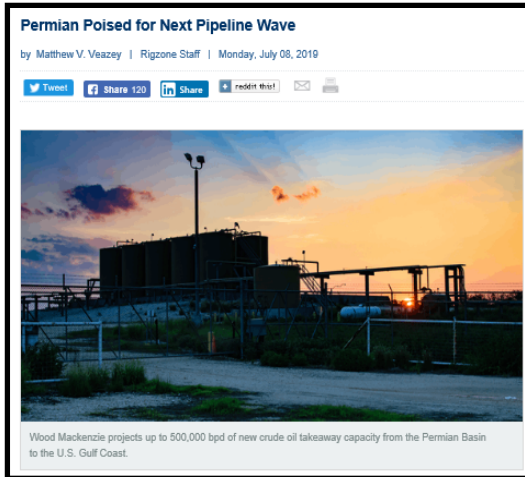
CO₂ Reservoir Storage and Sequestration



Pipeline
Options



Permian Basin and Eagleford Pipelines to Gulf Coast



According to Wood Mackenzie in July 2019, between now and 2022, pipeline operators should add approximately 4 million barrels per day of new production capacity bound for the Gulf Coast with 2 million barrels per day flowing into Corpus Christi for export over seas.

Carbon and Capture Benefits:

First, it will allow the United States to sell NGL to Europe and the rest of the World, thereby allowing the conversion of existing "Coal Powered Plants" in other Countries to newer "Gas fired Generator Plants", thus making the World Greener.

Negative:

It doesn't provide CO₂ /EOR Technology to advance in the Permian Basin or Eagleford and unfortunately, it doesn't solve the Flare Problem in the Permian Basin.

CO₂ Storage Solutions

Permian Basin Goal – Zero Gas Emissions

CO₂ Plant Capture



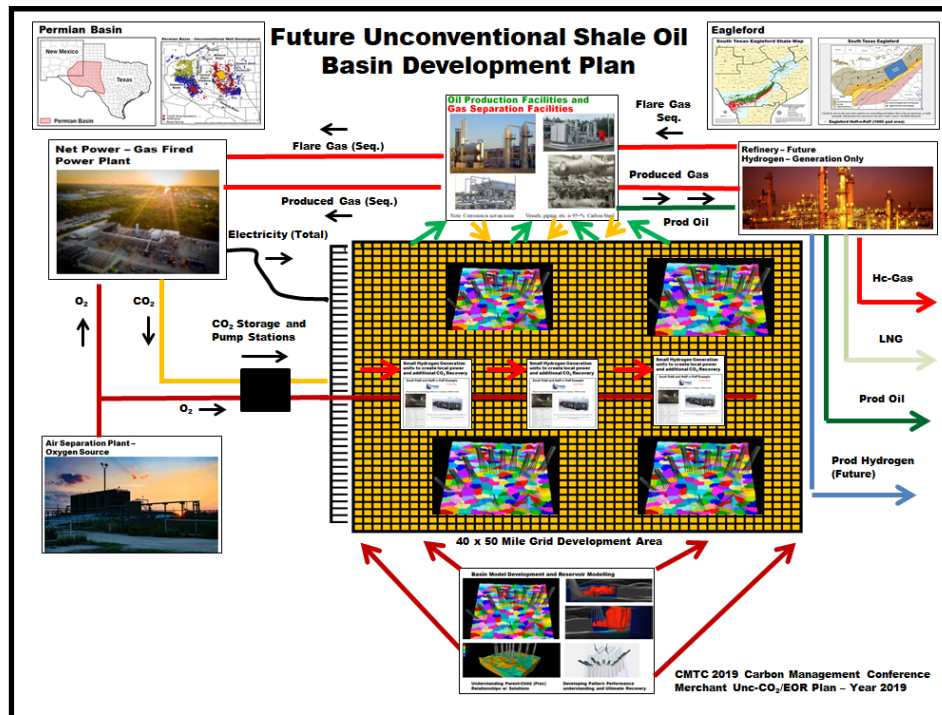
CO₂ Pipeline Infrastructure



CO₂ Reservoir Storage and Sequestration



Reservoir Options



Permian Basin – Unconventional Shale Oil

What is Huff-n-Puff Tertiary Oil Recovery?

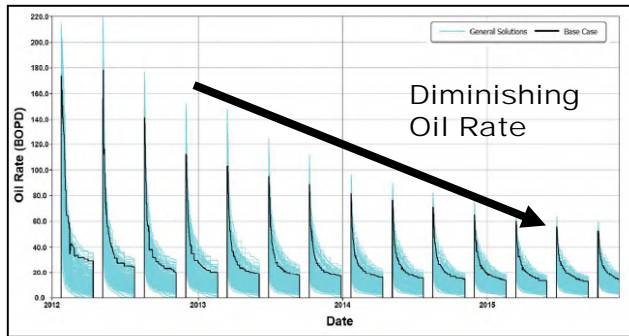


Figure 10: Uncertainty assessment for CO₂ Huff-n-Puff using the optimal cycle scheme

What is Huff-n-Puff?

The Huff-n-Puff Recovery process is a single-well process that has been successfully implemented in conventional reservoirs for several decades.

The injecting fluid can be Methane (C1), Ethane (C2), Propane (C3), CO₂, H₂S, or a combination (C2+C3) of components.

CO₂ Huff-n-Puff for an individual well is a three-step process

Step 1: CO₂ is injected in the production well.

Step 2: The well is shut in for a predetermined time called the “soak period.”

Step 3: The well is returned to production, and oil flows toward the wellbore because of a pressure sink.

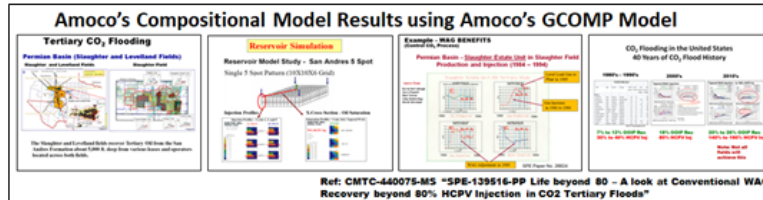
The process repeats itself until an economic limit is reached.

Permian Basin Unconventional (Permian Lab and Well Simulation Results) Oxy Permian - Unconventional CO₂ Learnings

Reservoir Modelling and Simulation efforts

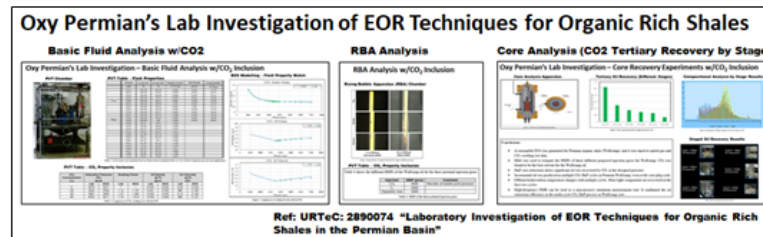
Amoco Production's 1986 Mechanistic Model

Amoco 1986

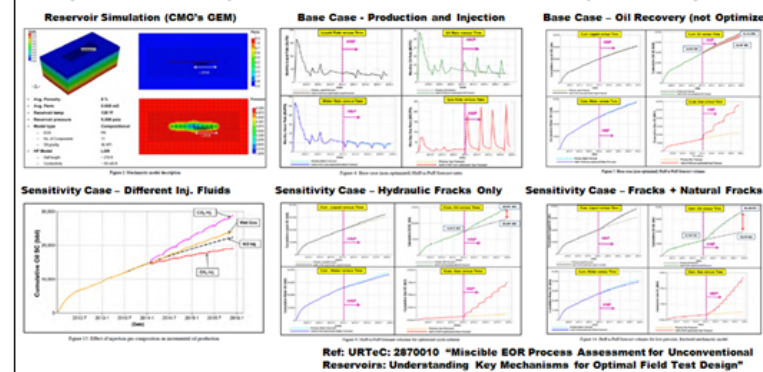


Oxy Permian's 2018 Mechanistic Model

Oxy Permian
2018 Publication



Oxy Permian's Compositional Base Case Model Results w/ Sensitivity Cases



Reservoir Modelling provides an understanding of Reservoir Performance under different scenarios

Permian Basin Unconventional (Permian Lab and Well Simulation Results)

Oxy Permian - Unconventional CO₂ Learnings

Reservoir Simulation (Single Well Predictions)

Compositional Reservoir Modelling is predicated on the ability to properly match field historical performance and lab data. The compositional model developed by Oxy Permian utilized an 11 component description based on the Peng-Robinson Equation of State (PR EOS). The primary recovery history match (Base Case) was calibrated to match Wolfcamp primary performance using assisted history matching techniques. The cycle scheme for the non-optimized (base case) Huff-n-Puff forecast assumed a schedule of 10 days of injection at 1.0 MMSCFD, 7 days of soaking, and 180 days of production.

The incremental oil realized under the un-optimized base case was around 23% over a period of 2 years with a gross utilization of around 22 MSCF/Bbl.

Cycle Scheme Optimization (Sensitivity Case Runs)

Optimizing the injection-soak-production design greatly influences CO₂ Huff-n-Puff performance. The optimized cycle scheme involved 22 days of injection at 1.0 MMSCFD, 2 days of soaking, and 80 days of production.

The Optimized Huff-n-Puff oil recovery oil recovery wedge was 81% higher than primary production (compared with 23% for the non-optimized case). In addition, the gross utilization calculated was 25 MMSCF/BBL (Compared with 22 MMSCF/Bbl for the non-optimized case).

Effect of Natural Fractures on Process Performance

The presence of hydraulic and natural fractures provides a large contact area for injected gas to penetrate into the low-permeability matrix to improve recovery. Therefore, the effect of natural fractures on Huff-n-Puff process performance was incorporated into the model. The Huff-n-Puff cycle scheme modeled involved 30 days of injection at 1.0 MMSCFD, 2 days of soaking, followed by 40 days of production.

The Huff-n-Puff wedge was 250% higher than primary production for the naturally fractured reservoir, compared to 81% higher for the optimized Huff-n-Puff hydraulically fractured case.

In addition, the calculated gross utilization was 18 MMSCF/Bbl for the naturally fractured case, compared to 25 MMSCF/Bbl for the optimized hydraulically fractured case.

Conclusion

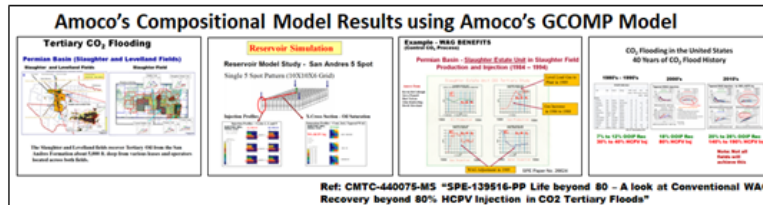
Oxy Permian **proved** through lab and Reservoir Simulation, the Huff-n-Puff CO₂/EOR process could recover significant additional oil with additional cycles for Permian organic rich shales. The multi-cycle incremental recovery – even at the small core plug scale- suggests the significant potential for multiple huff-n-puff cycles for a future

Permian Basin Unconventional (Permian Lab and Well Simulation Results) Oxy Permian - Unconventional CO₂ Learnings

Reservoir Modelling and Simulation efforts

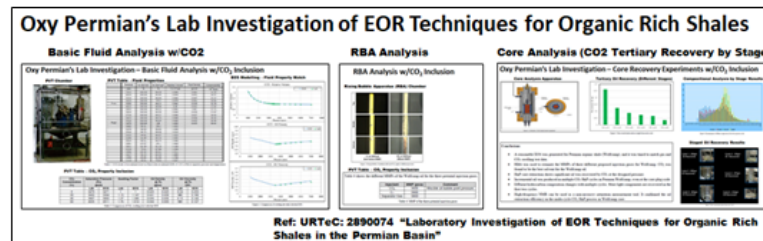
Amoco Production's 1986 Mechanistic Model

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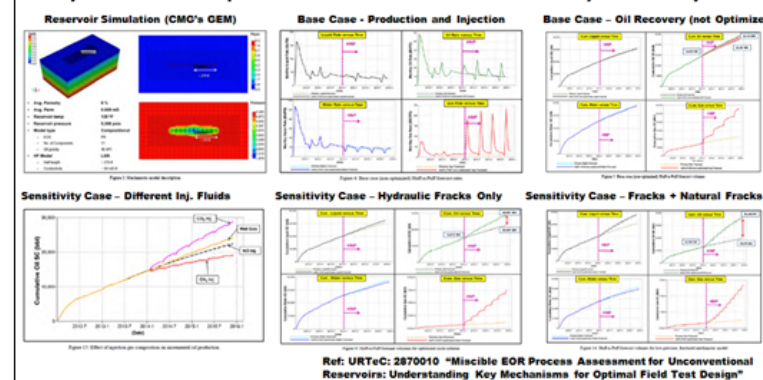


Oxy Permian's 2018 Mechanistic Model

Oxy Permian
2018 Publication

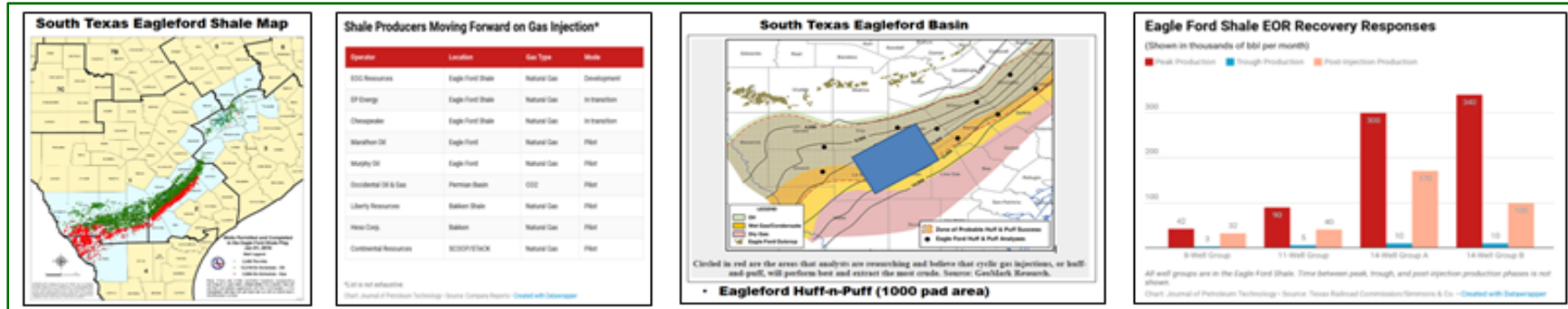


Oxy Permian's Compositional Base Case Model Results w/ Sensitivity Cases



Reservoir Modelling provides an understanding of Reservoir Performance under different scenarios

Eagleford Unconventional (Proven Hydrocarbon Gas Huff-n-Puff Projects) EOG and Others - Unconventional CO₂ Learnings



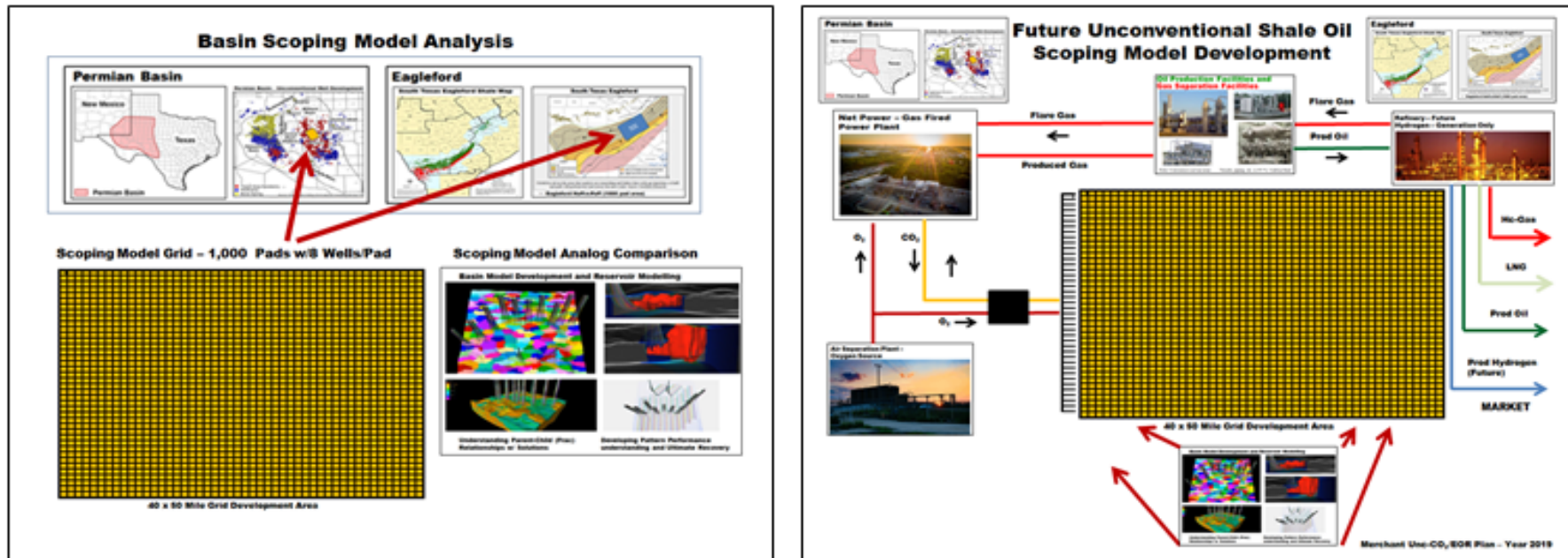
John Watson, a senior research analyst put together a report late last year that highlighted production details of “Shale Oil Hc-gas Huff-n-Puff” projects in the Eagleford.

He found dozens of pad wells that saw a combined 10-fold rise in production above their trough. Among the standouts, a group of 11 wells that reached a combined peak production rate in December, 2011 of about 90,000 bbl a month. By August 2017, these wells were pumping out only 5,000 bbl a month. After gas injections began, the group produced 40,000 bbl a month—an average increase from about 15 BOPD to 117 BOPD per well. Another case involved 14 wells that peaked at 330,000 bbl a month in 2013, and then dropped to 10,000 bbl per month. Post injection, output increased to 170,000 bbl a month.

Pilot Response Proof:

A comparison of Oil Recovery for the different pattern areas is shown above, proving the Huff-n-Puff process works with actual proven results.

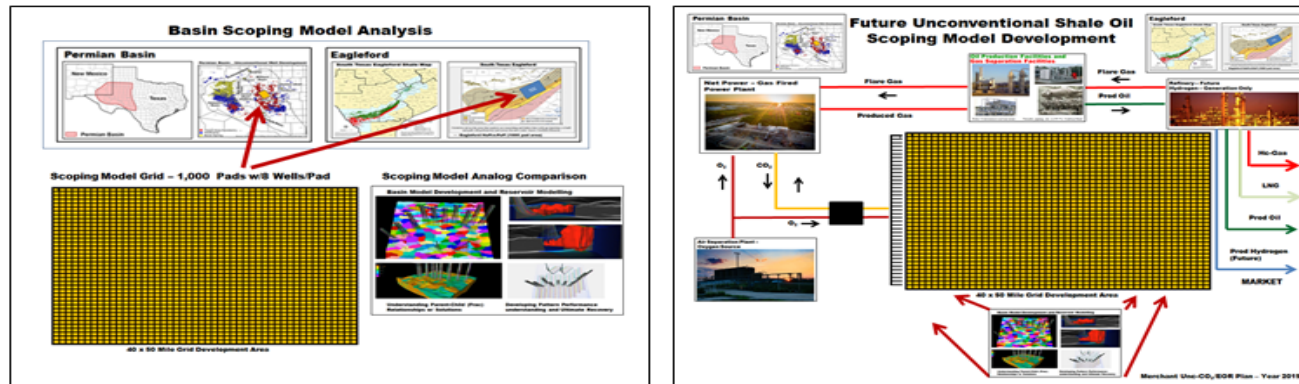
What will the Permian Basin or Eagleford look like with the inclusion of Uncon- CO_2 /EOR in the future by the year 2050?



Permian Basin and Eagleford: What is the CO_2 Storage Capacity of a 1,000 Pad region (40 by 50 square mile area) located within either the Midland or Eagle Ford Basins Look Like?

Reservoir Modelling provides an understanding of Reservoir Performance under different scenarios

Permian Basin and Eagleford: What is the CO₂ Storage Capacity of a 1,000 Pad Region (40 by 50 square mile area) located within either the Midland or Eagle Ford Basins Look Like?



The Scoping Model Prediction of CO₂ Storage and Sequestration was built on the following:

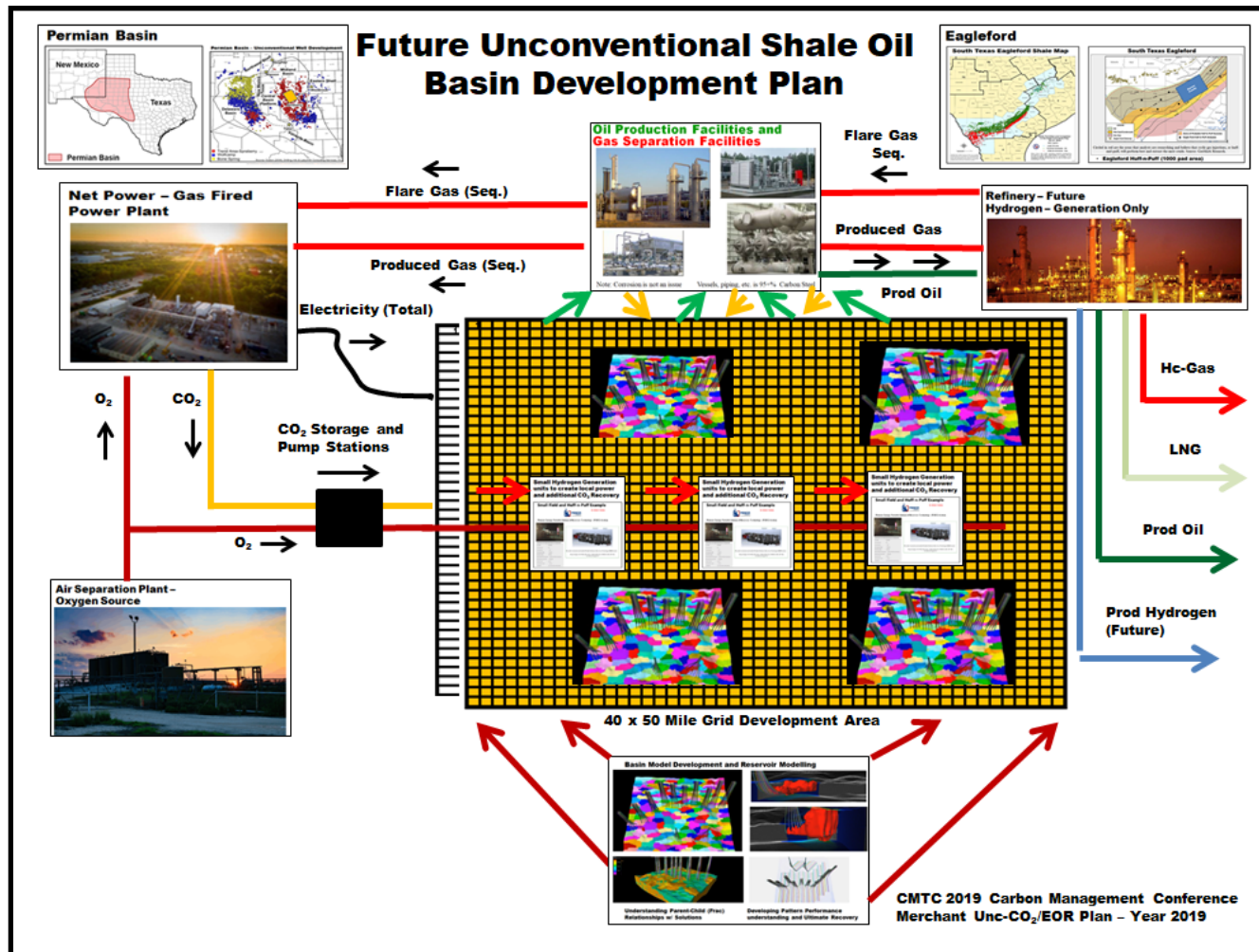
Assumptions

1. Assume that 1000 drilling PADS in the Eagle Ford Formation would be available for future CO₂ sequestration or 1,000 PADS would be located within the Wolfcamp zones A and B, which have similar CO₂ sequestering potential and CO₂/EOR Recovery characteristics, but over a much larger area in the Midland Basin.
2. Assume that each Drill Pad (PAD) was 1 mile by 2 miles in drainage area with 8 horizontal Eagle Ford wells per PAD
3. Assume that 5% of the active Huff-and-Puff (HnP) EOR gas injectant (in this case CO₂, not Rich gas) would be retained during 5 gas injection cycles per well
4. Assume that that 80% of the removed reservoir bbls could be refilled with sequestered CO₂ gas and the wells on each PAD would be abandon (with monitoring) to sequester about 4.5 Bcf per well PAD
5. Assume a conservative 1000 PADs (8000 wells) would be used for CO₂ sequestering at final abandonment (Fifth Cycle wth Huff, but no Puff(Storing CO₂ in Reservoir)

Results

The Scoping Model estimates 4.5 Tcf of CO₂ could be stored or sequestered in the ground permanently over a 50x40 square mile area of the Bakken or Midland Wolfcamp A and B reservoirs.

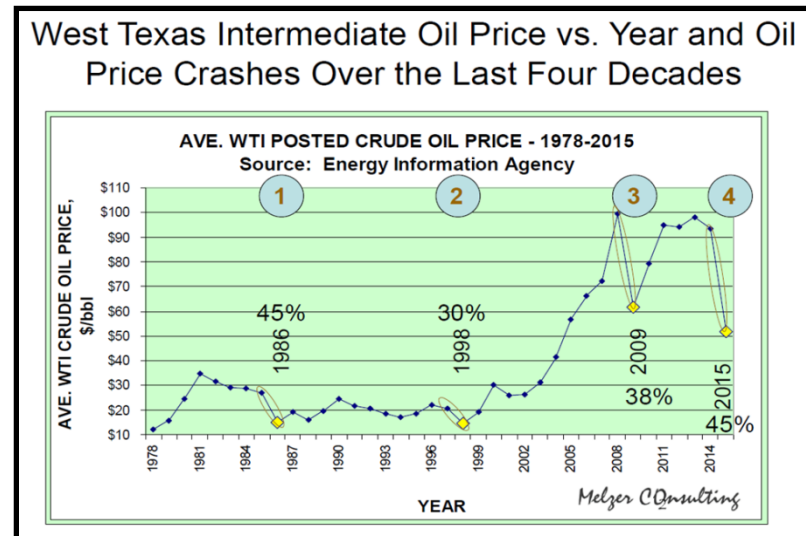
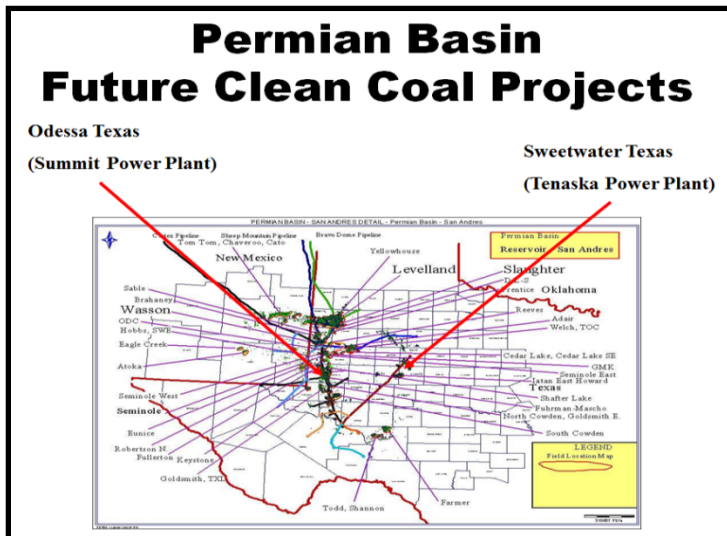
What will the Permian Basin or Eagleford look like with the inclusion of Unconventional CO₂/EOR Huff-n-Puff in the future by the year 2050?



Results

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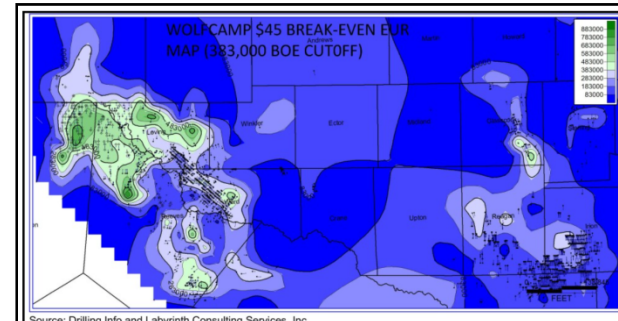
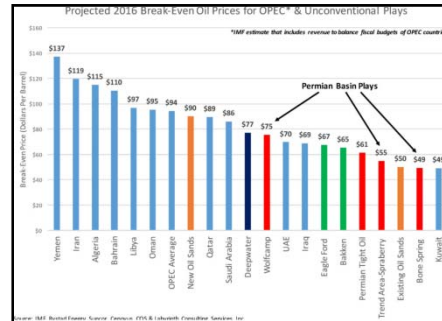
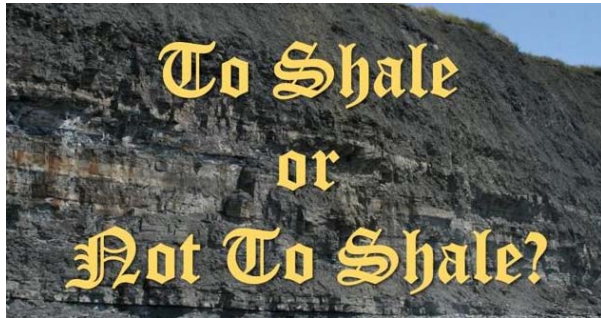
The Question Becomes How do you Pay for it?



In the 1980's the Permian Basin Infrastructure was built and in 1986 oil price collapsed by 45%, just like in 2014. All major EOR projects still went forward and still continue today after many oil price adjustment periods through time. Today, over 90% of the Oxy's Major CO₂ Field Projects in the Permian basin still produce Tertiary Oil even in a challenging \$40to\$50 dollar oil price environment (Date: Jun, 2019).

Today, Who is the Competition?

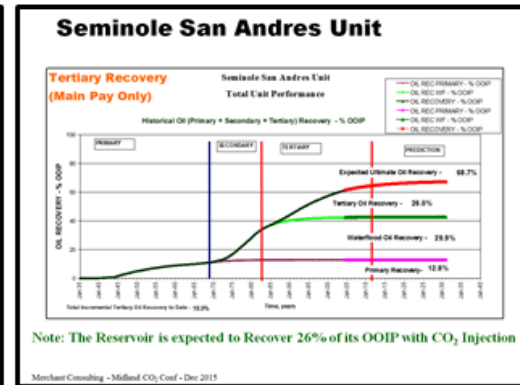
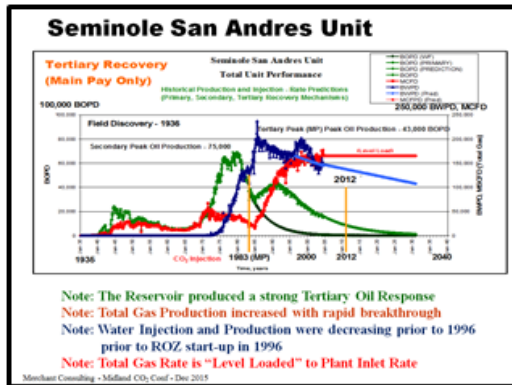
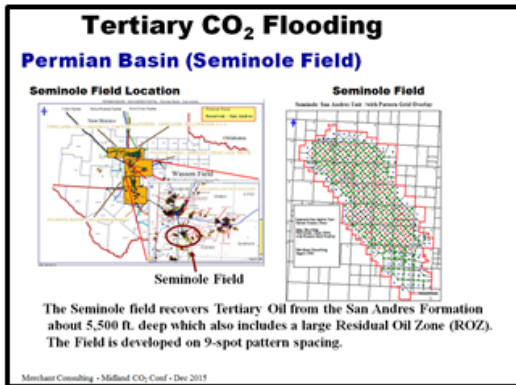
Wolfcamp at \$45 Break-even EUE estimated at 383,000 BOE CUTOFF



Versus

San Andres formation - Seminole Main Pay EUE Projection estimated at 26% of Original OOIP of 968 MMBO (Decline Curve)

Seminole field – Main Pay Only



Tertiary CO₂ Flooding

“CO₂ Flood History since 1972”

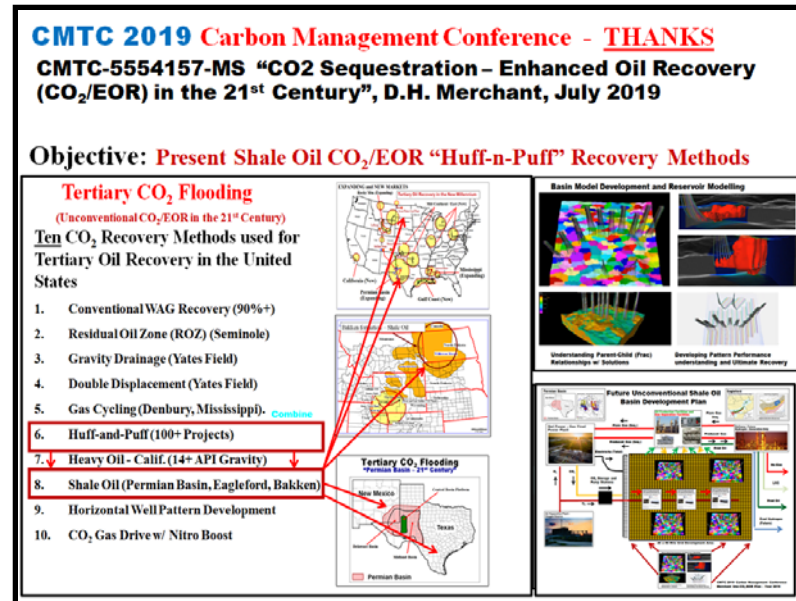
CMTC 2019 Carbon Management Conference - THANKS
CMTC-5554157-MS “CO₂ Sequestration – Enhanced Oil Recovery (CO₂/EOR) in the 21st Century”, D.H. Merchant, July 2019

Objective: Present Shale Oil CO₂/EOR “Huff-n-Puff” Recovery Methods

Tertiary CO₂ Flooding
(Unconventional CO₂/EOR in the 21st Century)

Ten CO₂ Recovery Methods used for Tertiary Oil Recovery in the United States

1. Conventional WAG Recovery (90%+)
2. Residual Oil Zone (ROZ) (Seminole)
3. Gravity Drainage (Yates Field)
4. Double Displacement (Yates Field)
5. Gas Cycling (Denbury, Mississippi) *Combine*
6. Huff-and-Puff (100+ Projects)
7. Heavy Oil - Calif. (14+ API Gravity)
8. Shale Oil (Permian Basin, Eagleford, Bakken)
9. Horizontal Well Pattern Development
10. CO₂ Gas Drive w/ Nitro Boost



I would like to thank the George Koperna and Jose Figueroa for allowing me to publish and present my 2019 CMTC paper.

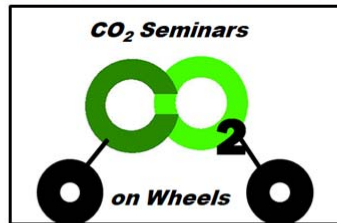
I would also like to thank Mike Uland and Jim Gilman of iReservoir Consulting Services in Denver for their Technical assistance regarding Unconventional Shale Oil Recovery understanding.

CMTC-554157-MS Enhanced Oil Recovery
(Shale CO₂/EOR Huff-n-Puff in the 21st Century

Questions Today or Future Questions?

Merchant Consulting Introduction

“CO₂ Seminars on Wheels”



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Key Words: Merchant Consulting, CO₂ Storage Solutions, CO₂ Seminars on Wheels

When you can't go to a Conference, then
why not have the Conference come to you?