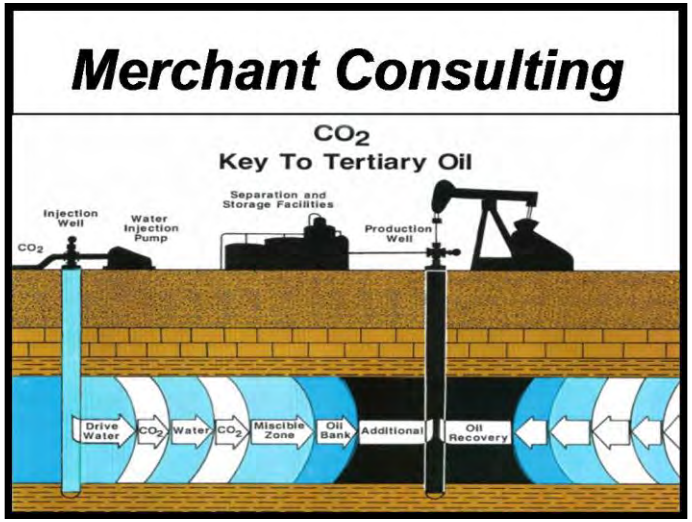
CMTC-440075 "SPE-139516 "Life beyond 80 – A Look at Conventional WAG Recovery beyond 80% HCPV Injection in CO2 Tertiary Floods"

CMTC-440223 "The Energy Gap – How CO_2 Tertiary Oil Recovery will mark its place in the 21st Century"

David H. Merchant



CO_2 Storage Solutions

Merchant Consulting

WEB Site: www.CO2StorageSolutions.com **Email:** merchantconsulting@comcast.net

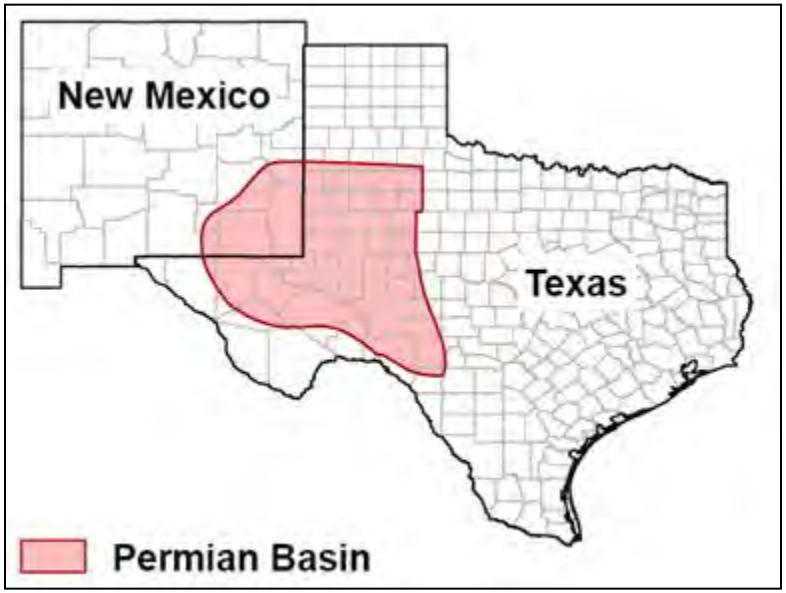
Presented to Midland CO_2 Conference

December 9, 2015

Midland, Texas

Permian Basin

Welcome to the Permian Basin?



300 miles (480 km) North South

250 miles (400 km) East West

Carbon Management Technical Conference
November 2015
Sugarland, Texas

CMTC-440075 "SPE-139516 "Life beyond 80 – A Look at Conventional WAG Recovery beyond 80% HCPV Injection in CO2 Tertiary Floods"

CMTC-440223 "The Energy Gap – How CO_2 Tertiary Oil Recovery will mark its place in the 21st Century"

Thanks: CMTC Management Team
George Koperna (ARI)

Greatly Appreciated, Thank you

Additional Information can be obtained from:

David Merchant

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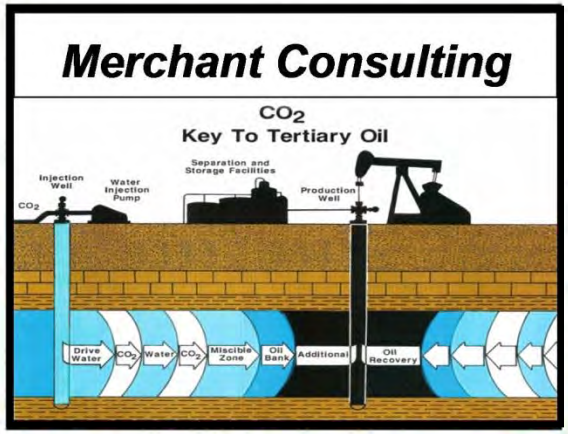
Email: merchantconsulting@comcast.net
WEB: www.CO2StorageSolutions.com
WEB: www.ReservoirManagementSolutions.com



CMTC-440075-MS

SPE-139516 "Life beyond 80 – A Look at Conventional WAG Recovery beyond 80% HCPV Injection in CO2 Tertiary Floods"

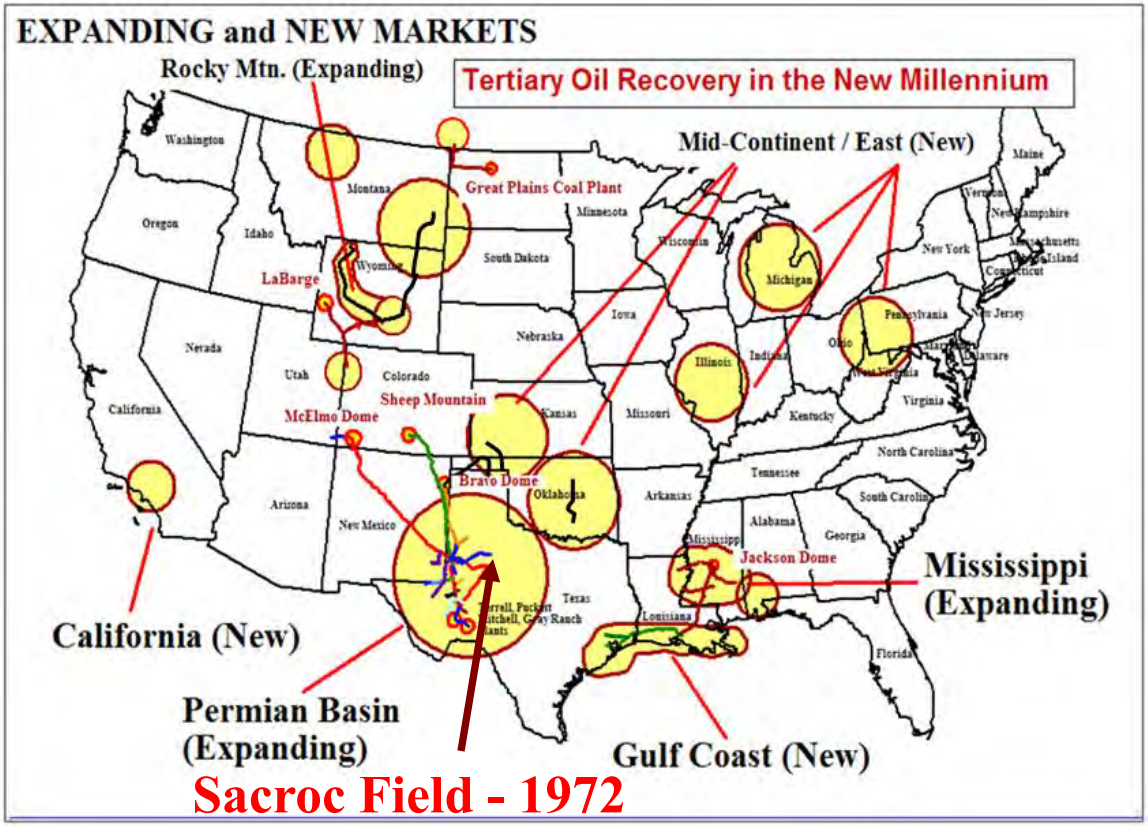
David Merchant, Merchant Consulting

Note: This paper, along with my other SPE and CMTC Publications can be down-loaded from my WEB sites listed above.

What is CO_2 Tertiary Oil Recovery?

Tertiary CO_2 Flooding

"CO_2 Flood History since 1972"



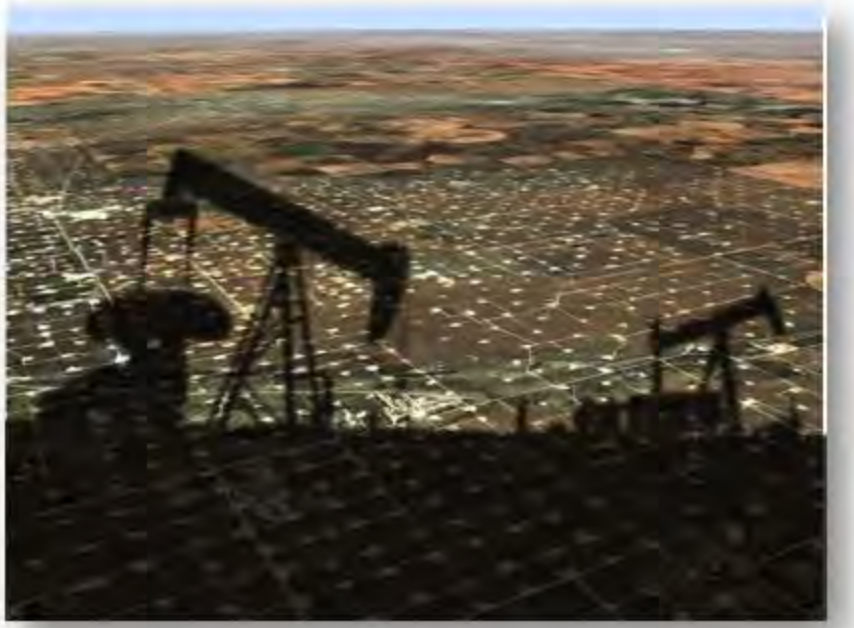
Since 1972 over 130+ CO_2 Tertiary Projects have been implemented in the United States.

Today, CO_2 projects in the United States produce over 350,000 BOPD with CO_2 transported over 4,500 miles of CO_2 pipeline.

Permian Basin Statistics

Permian Basin – Central Basin Platform

- Has produced oil for over 80 years
- Is the 3rd largest petroleum producing area in the U.S. after the Gulf of Mexico and Alaska
- 29 billion barrels produced from the Permian Basin
- 13 billion barrels have been produced from the Central Basin Platform carbonates (45% of Permian total)
  - San Andres > 4 billion barrels
  - Clear Fork > 2 billion barrels



Permian Basin

“First Commercial CO_2 Flood - 1972”

“Latest Success Story”

<u>Sacroc Unit</u> in Kelly Snyder Field

EXISTING MARKETS

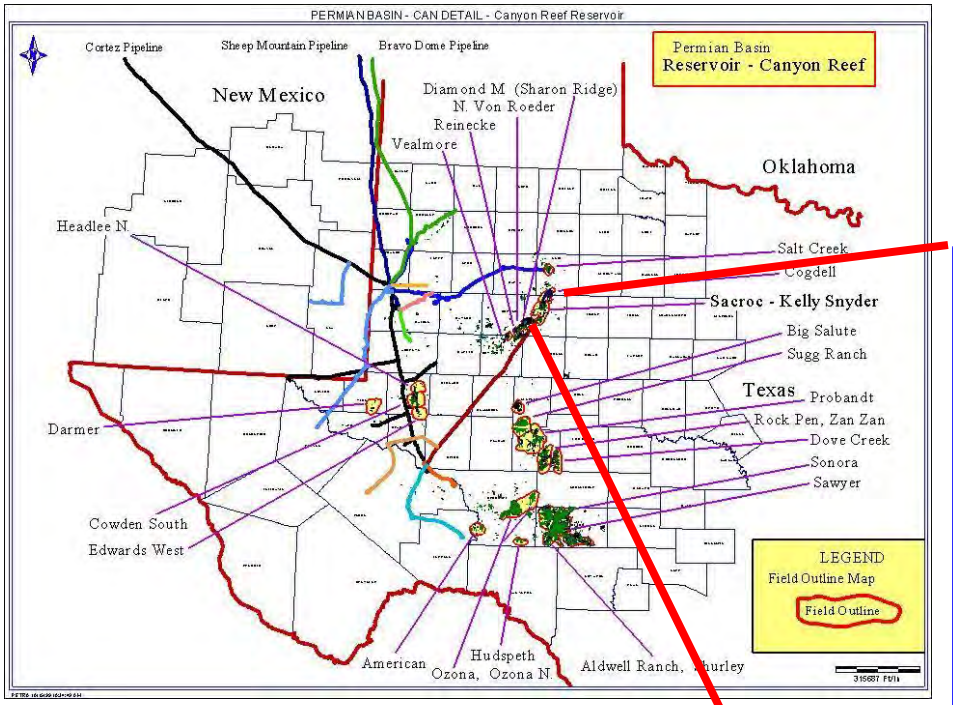
Year - 2000

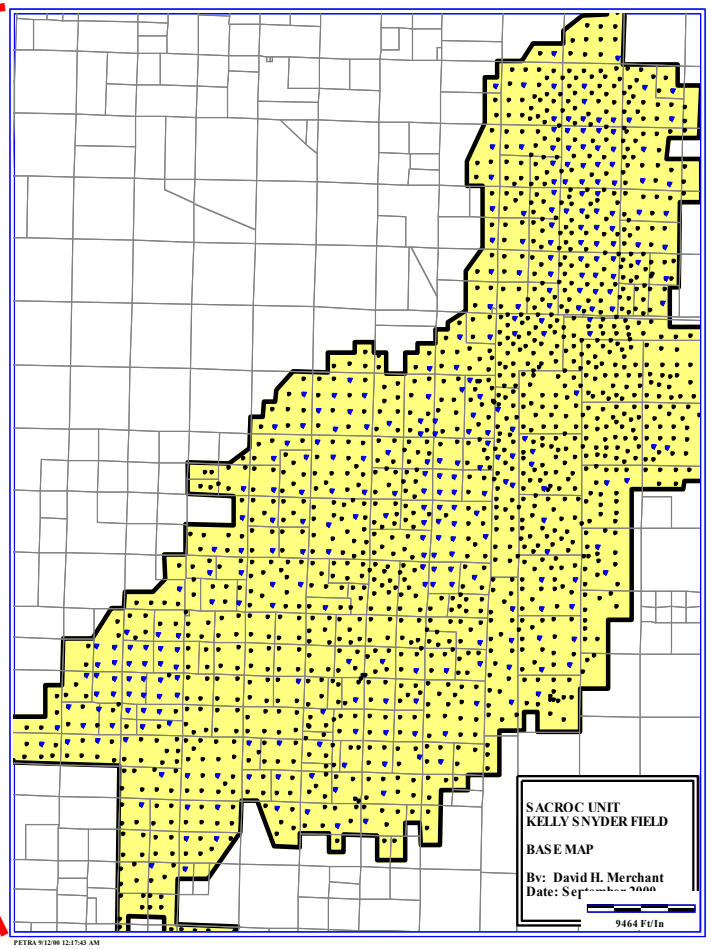
CURRENT CO2 SOURCES and PIPELINES

1561185 Ft/In

PETRA 12/1/99 10:10:02 AM

Canyon Reef Map – Sacroc Unit



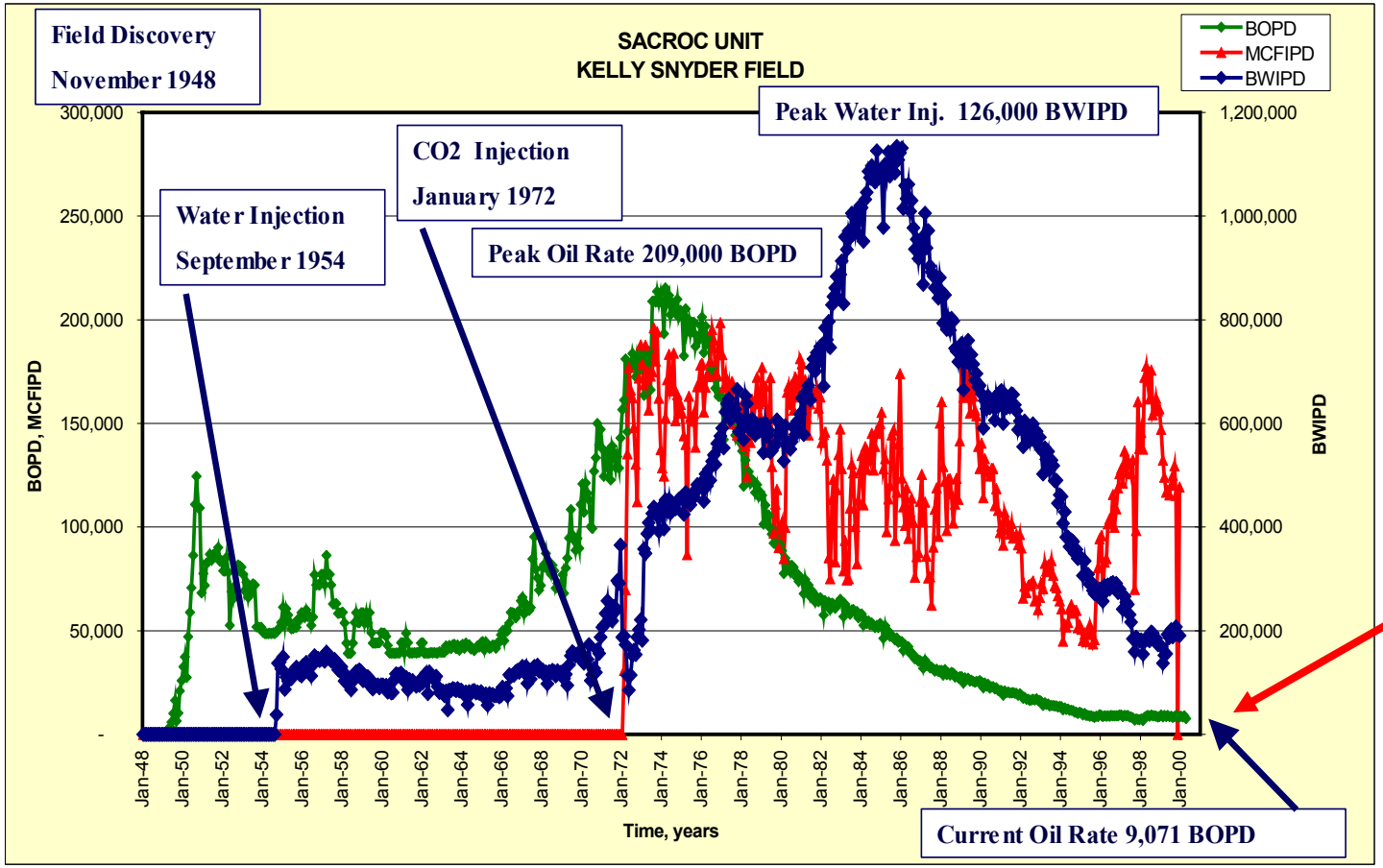


- Date of Discovery: November, 1948
- Total Acreage: 55,000 acres
- Original Oil-in-place: 2.98 Billion stb
- Total Wells: 1,620 wells
- Field Unitization: March, 1953
- Water Injection: September, 1954
- CO2 Flooding: January, 1972

The Kelly Snyder Field (Sacroc Unit) recovers Tertiary Oil from the Canyon Reef Limestone Formation about 6,700 ft. deep

Sacroc Unit – Production History

Historical Production and Injection



Year 2000

1948 **1972** **2000**

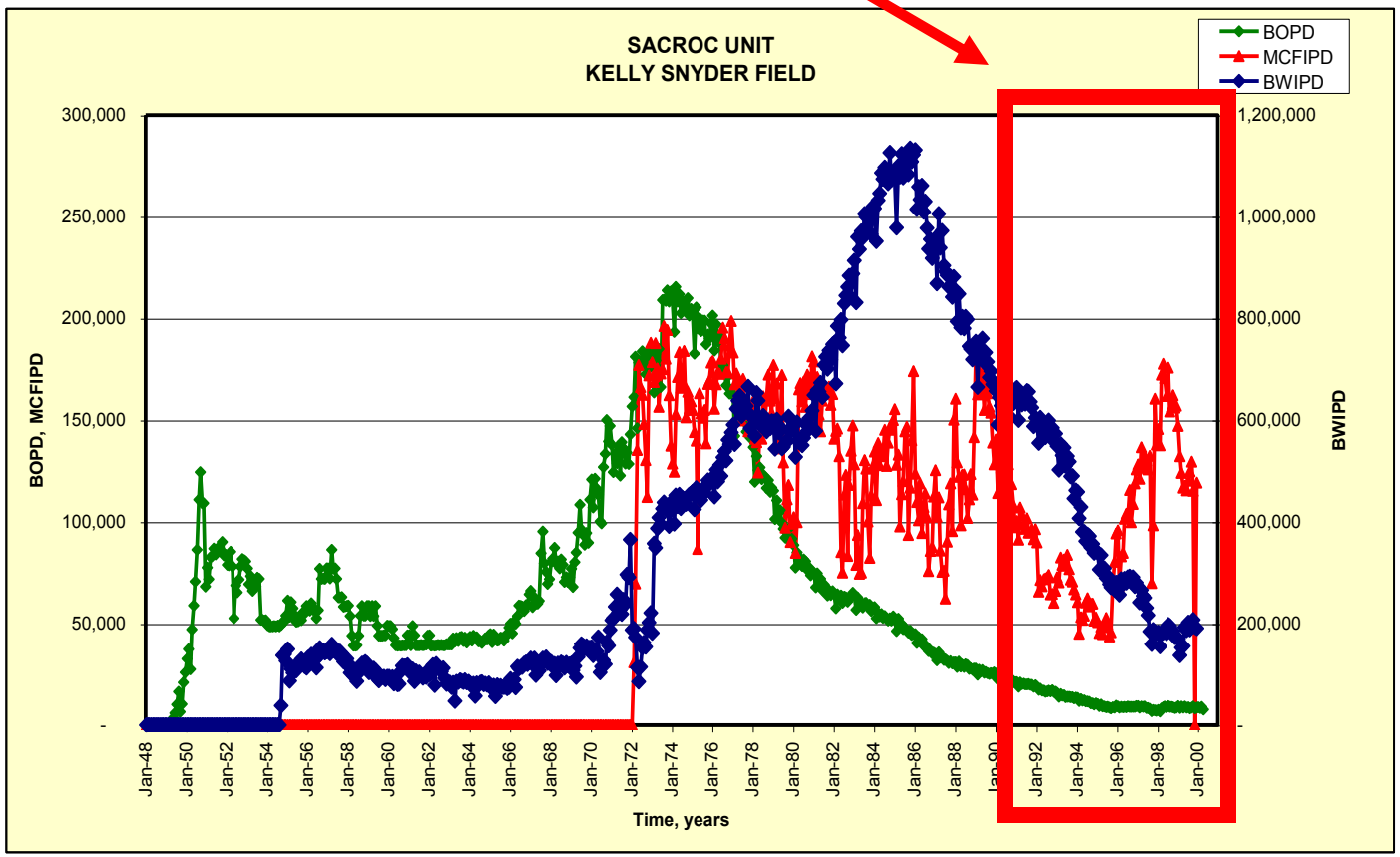
Sacroc Unit

Pennzoil Operatorship

1992 - 1999

Sacroc Unit

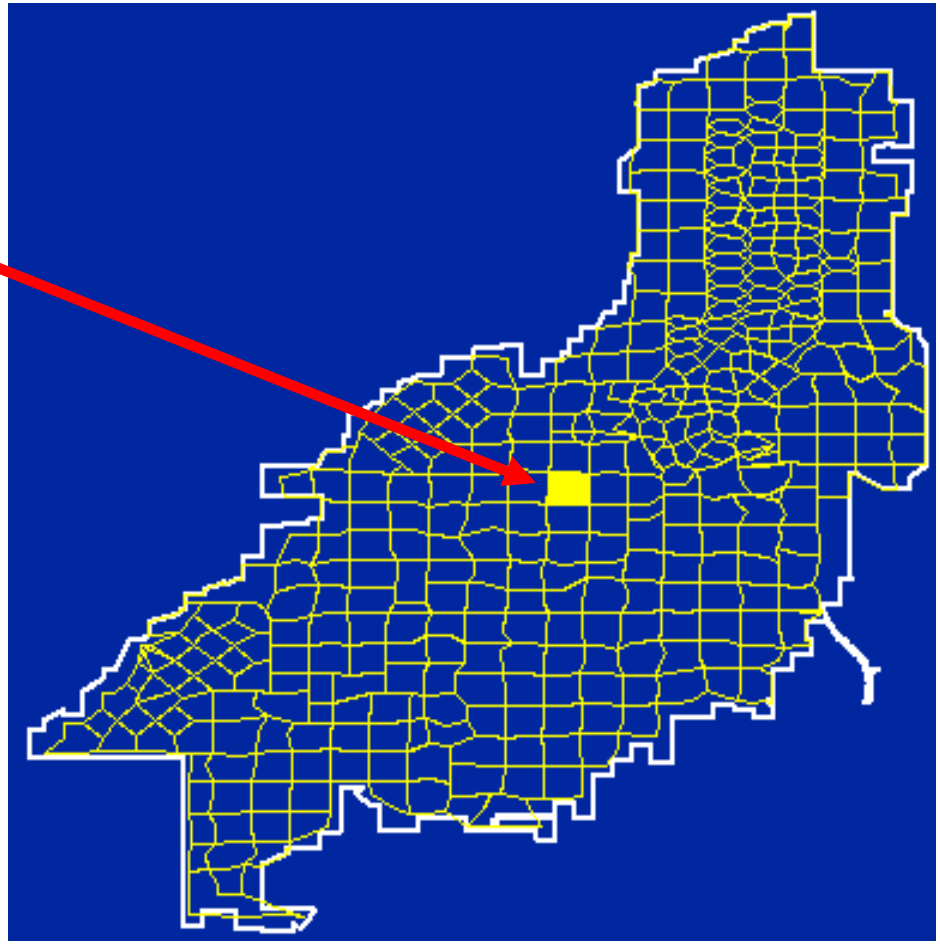
Pennzoil Operatorship
1992 - 1999



Sacroc Unit – Pennzoil Ownership

Center-line Project

1996 CO_2 Pattern Development Plan 300 Acre Pilot

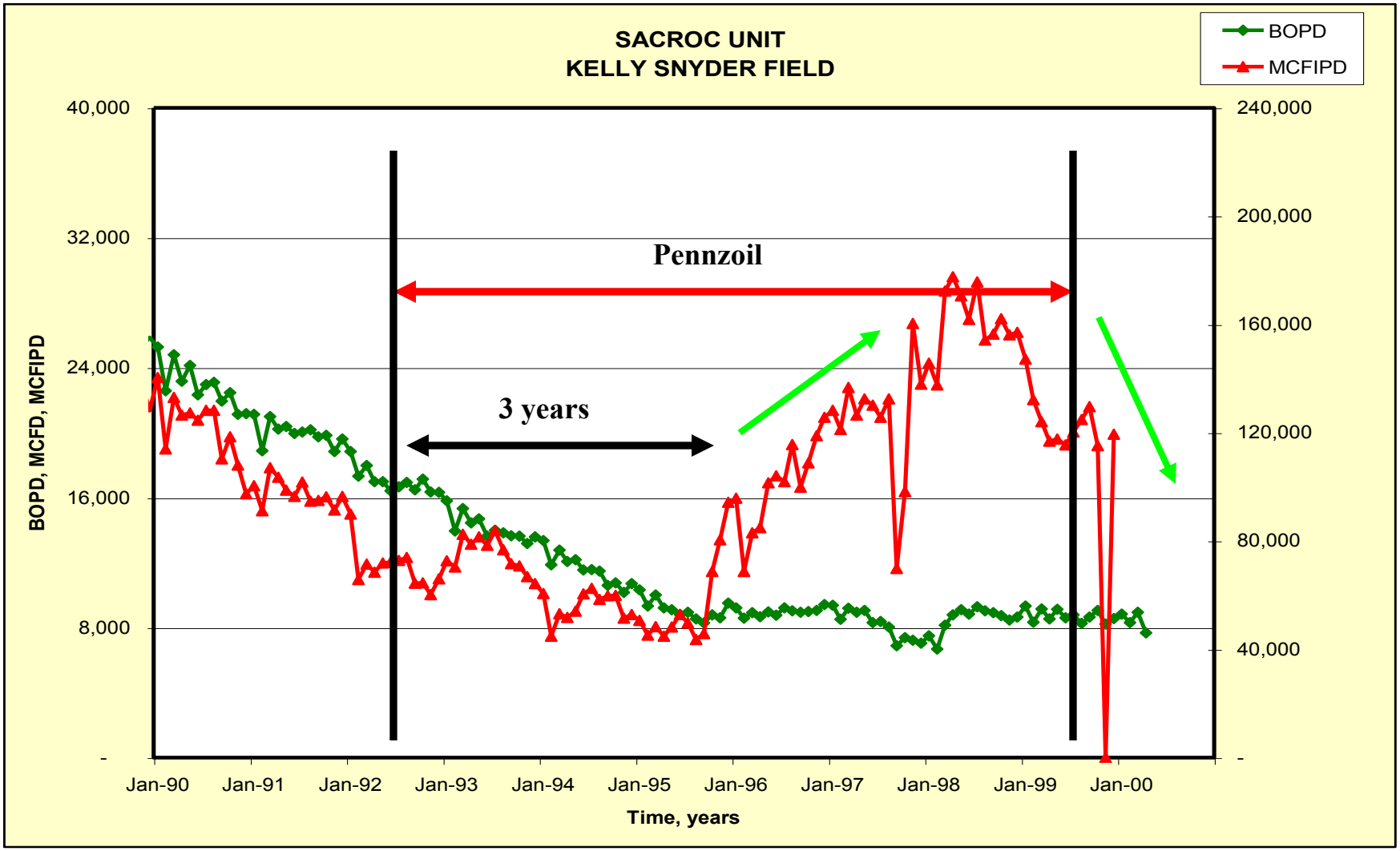


Pennzoil Team

1. Ghasem Bayat
2. Tony Benvegnu
3. Claud Pickard
4. Jack Horkowitz
5. Tom Wingate
6. Don Hartman

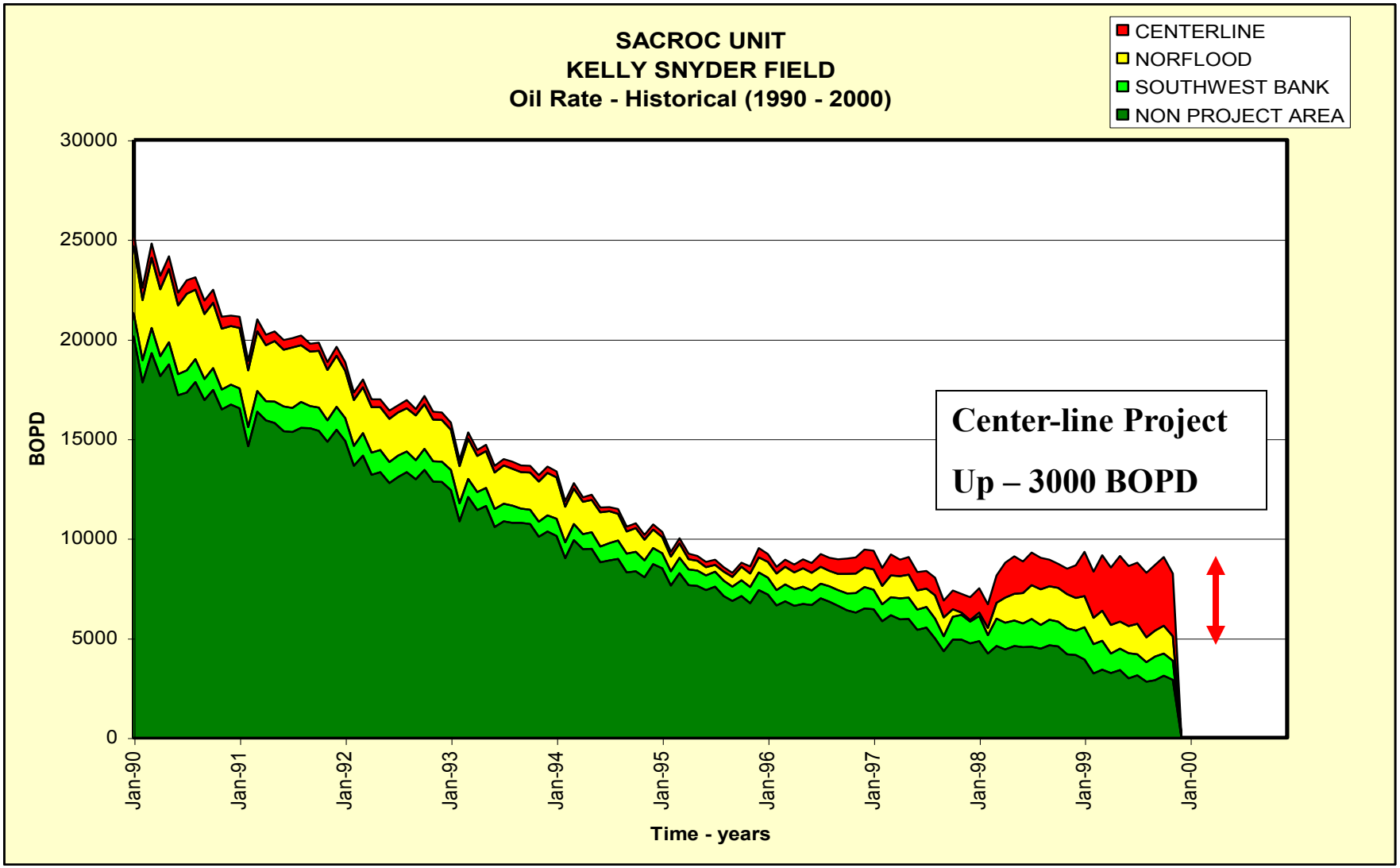
Sacroc Unit – Pennzoil Ownership

Historical Production – Oil Production and CO_2 Injection



Sacroc Unit – Pennzoil Ownership

Historical Production by Project Area



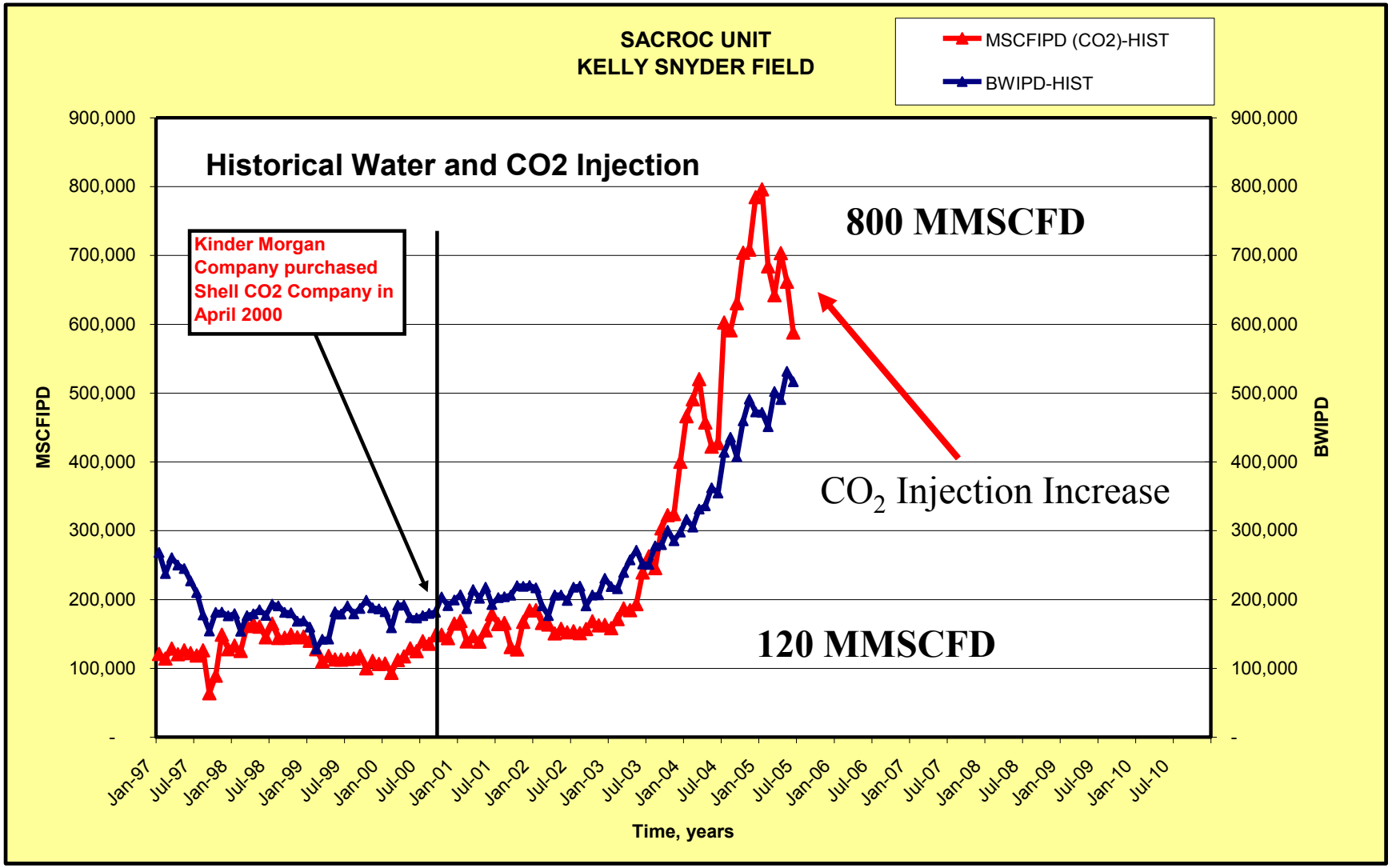
Sacroc Unit

Devon Operatorship
1999 – 2000

Kinder Morgan Ownership
2000 - Today

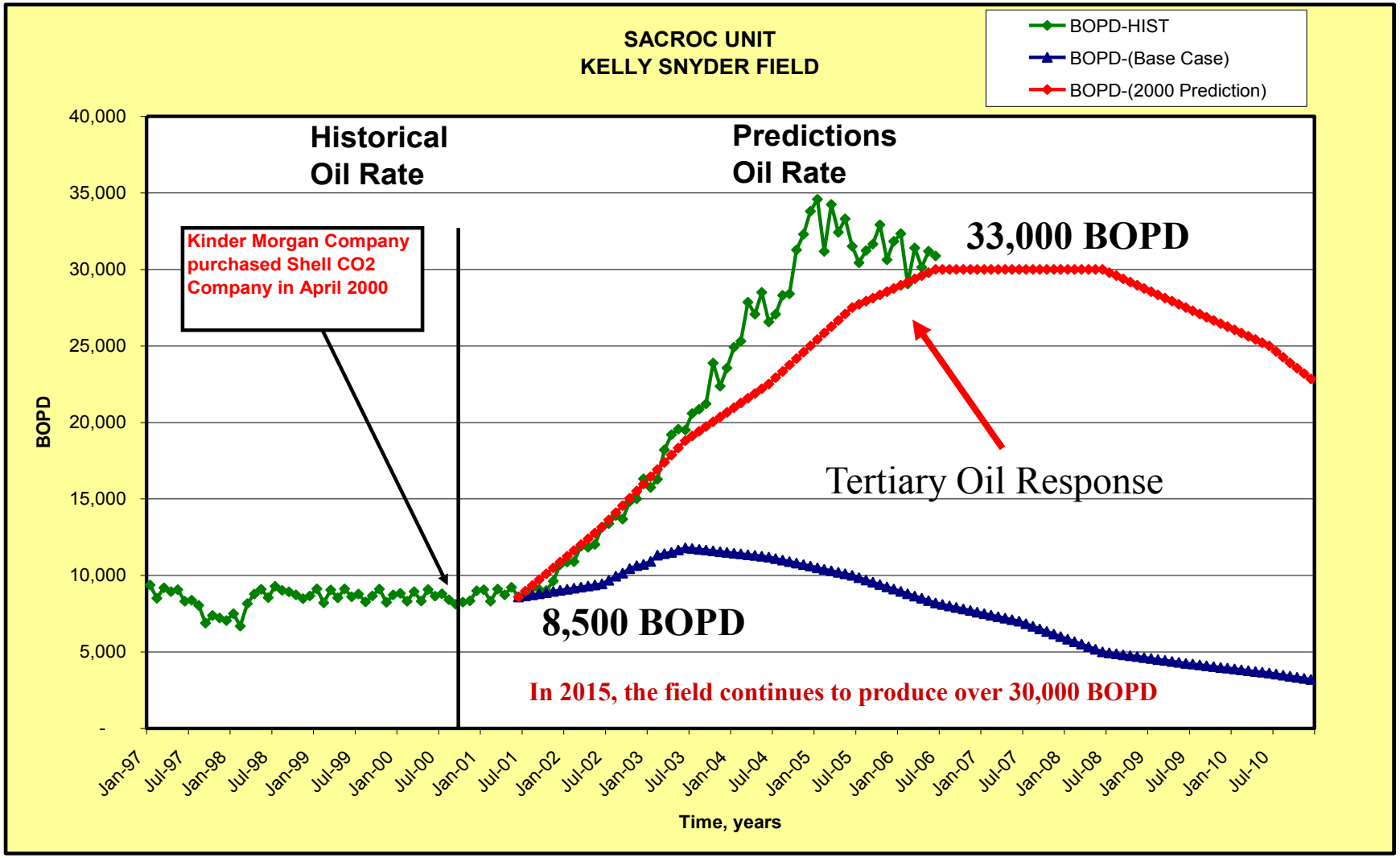
Sacroc Unit

Current CO_2 and Water Injection



1997 2002 2010

Current Oil Production



1997 **2002** **2010**

CO_2 Flooding in the United States
40+Years of CO_2 Flood History

1980's – 1990's

SPE 18977 (1989), Table 1

Field	State	Reservoir	Lithology	%HCPV Injected	Rec Eff. % OOIP	Gross Utilization, Mcf/Bbl	Net Utilization, Mcf/Bbl
Field Scale							
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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
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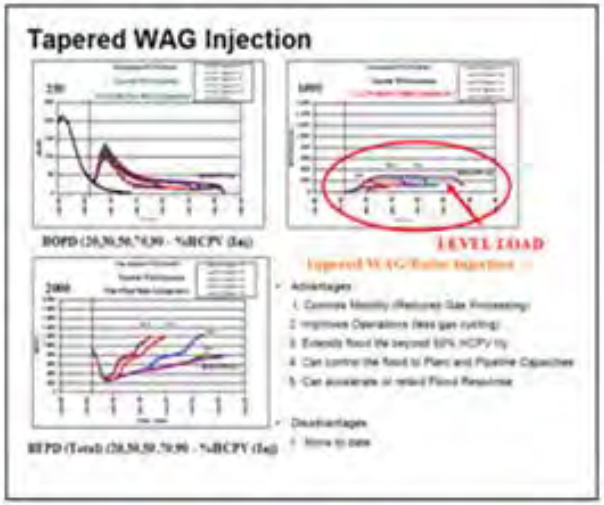
SPE 18977 Brock and Bryan 1989

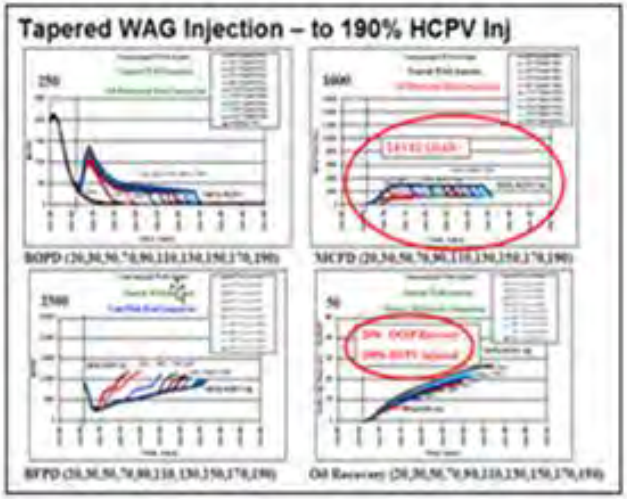
7% to 12% OOIP Rec
30% to 40% HCPV Inj

2000's



18% OOIP Rec
80% HCPV Inj

2010's

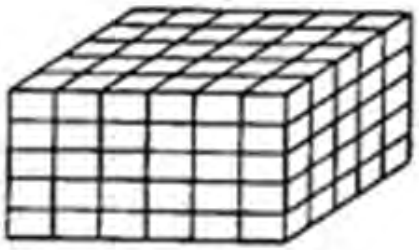


20% to 26% OOIP Rec
140% to 190% HCPV Inj

Note: Not all fields will achieve this

General Material Balance Equation (Mass Balance)

The **General Material Balance Equation** can be written for any material that enters or leaves any process system. This is no different for projects where CO_2 or Water is injected.



Input	=	*generation*	−	*output*	−	*consumption*	=	*accumulation*
(enters through system boundaries)		(produced within system boundaries)		(leaves through system boundaries)		(consumed within system)		(buildup within system)

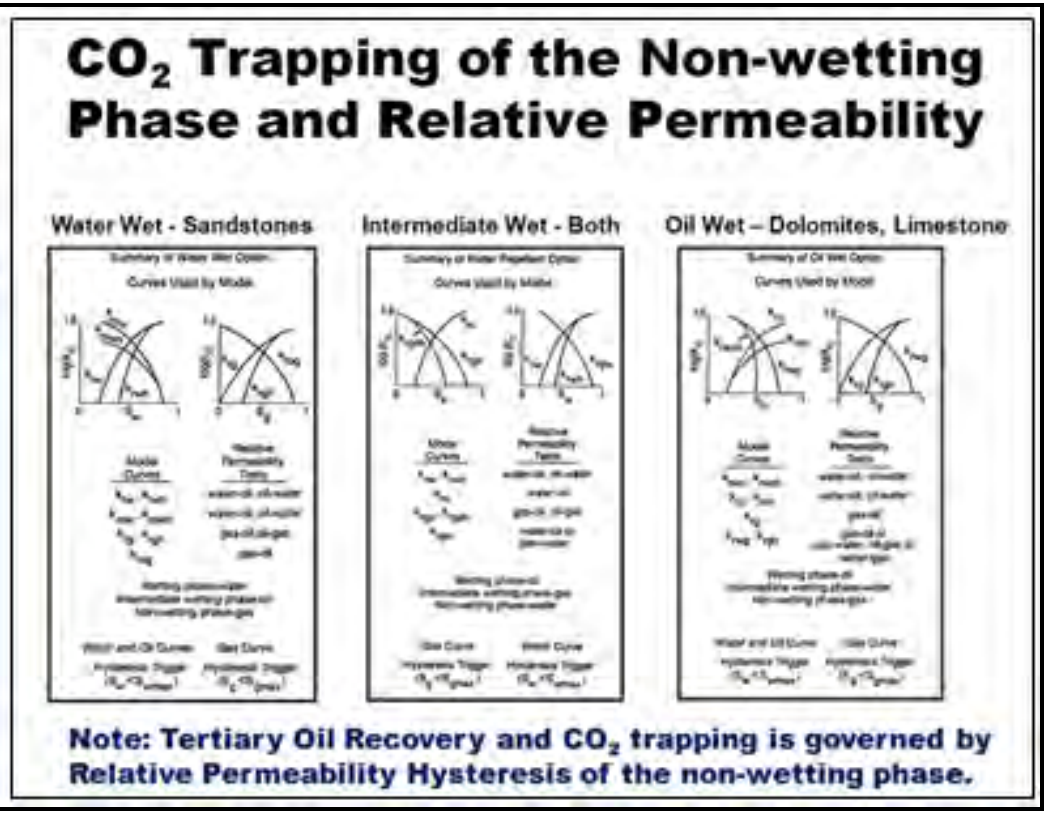
Since there is no chemical reaction, the generation and consumption terms will become zero. Since CO_2 flooding is a displacement process, the amount of Tertiary Oil that can be recovered and CO_2 stored will depend on the simplified equation:

Accumulation = Input - Output

Five Parameters determine the amount of tertiary oil that can be recovered. These are:

1. Reservoir Volume
2. Reservoir Operating Pressure and Fracture Pressure
3. Reservoir Temperature (Non Entity – Little Influence)
4. Reservoir Phase Trapping
5. Reservoir Conformance

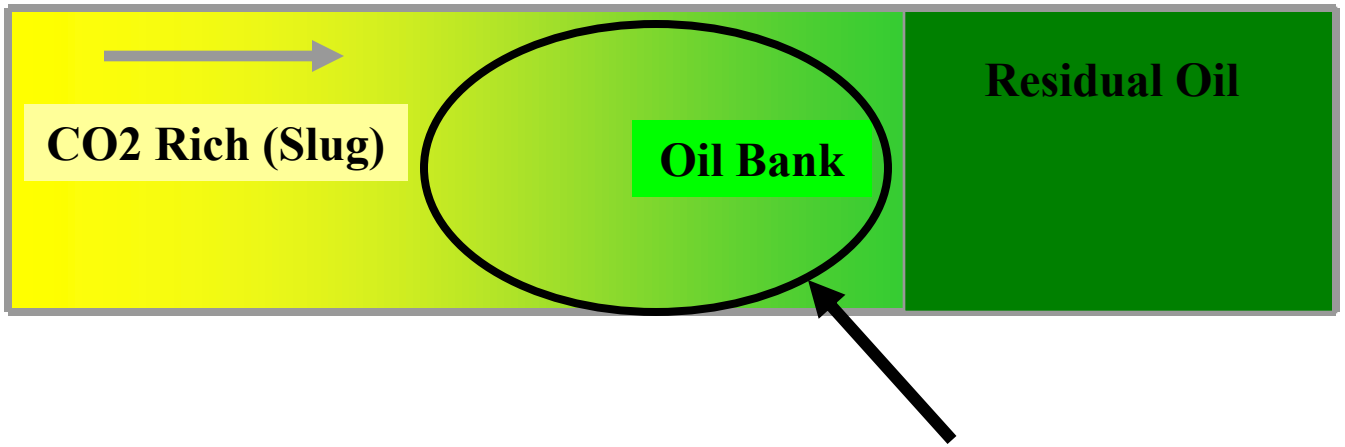
You can't fool Mother Nature…….



The amount of CO_2 <u>TRAPPED</u>, <u>STORED</u>, OR <u>SEQUESTERED</u>
is dependent on the Composition of the Residual Oil Saturation and Phase Trapping of the Non-Wetting Phase, which in this case is CO_2.

CO_2 Miscible Process Compositionally Driven

Oil Bank Transition Zone

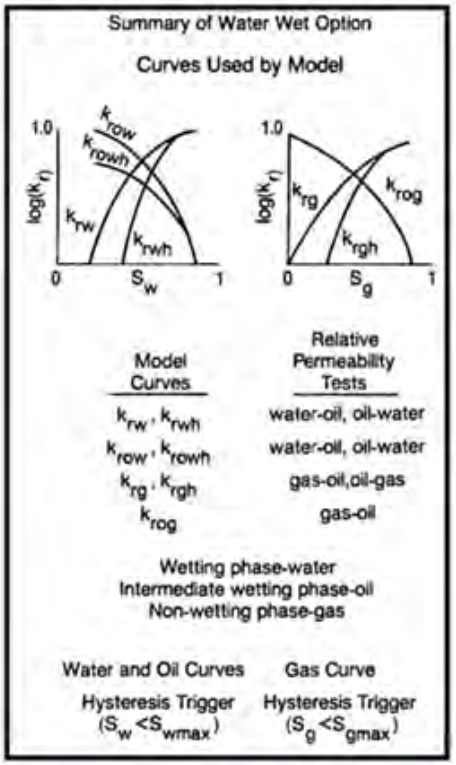


<u>Multiple Contact Miscible Process</u>
(time and compositionally dependent)

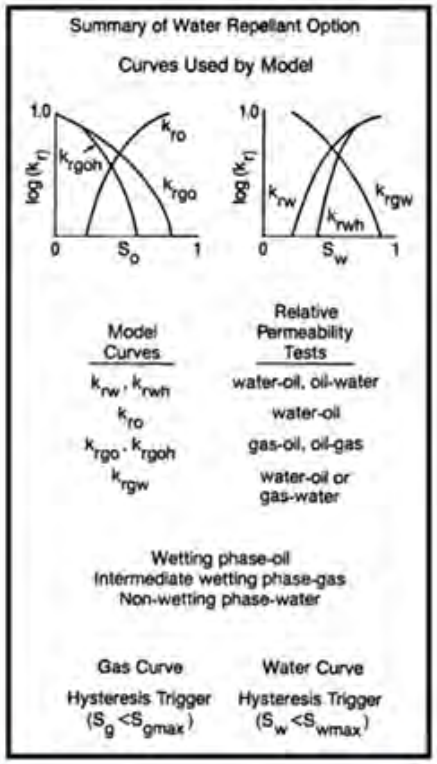
Miscible Zone formed by CO_2 becoming enriched with $C_2 – C_{30}$

CO_2 Trapping of the Non-wetting Phase and Relative Permeability

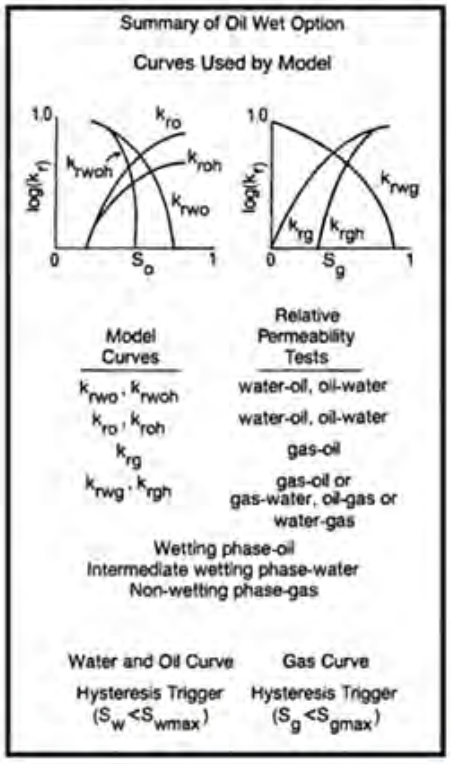
Water Wet - Sandstones



Intermediate Wet - Both

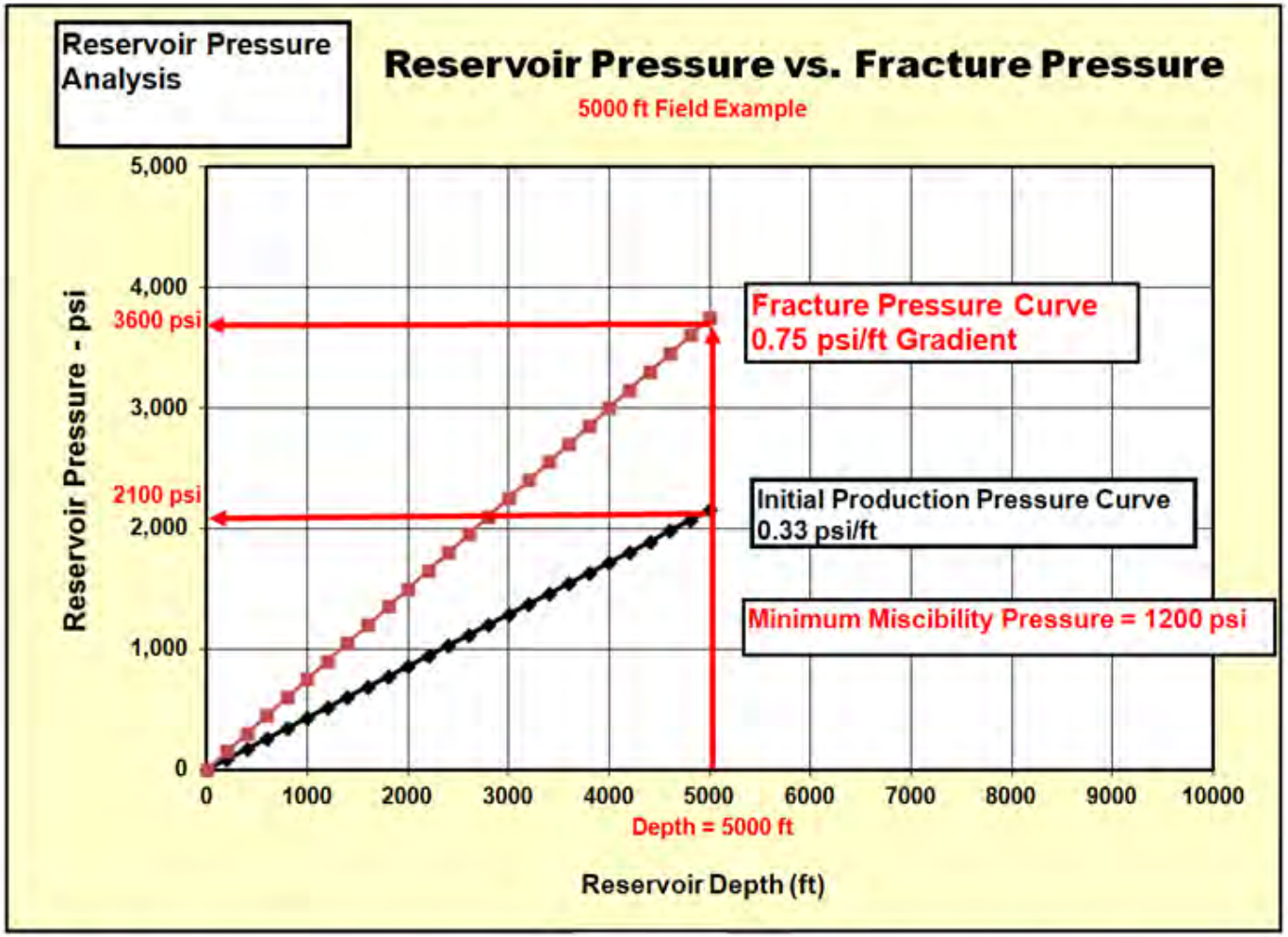


Oil Wet – Dolomites, Limestone



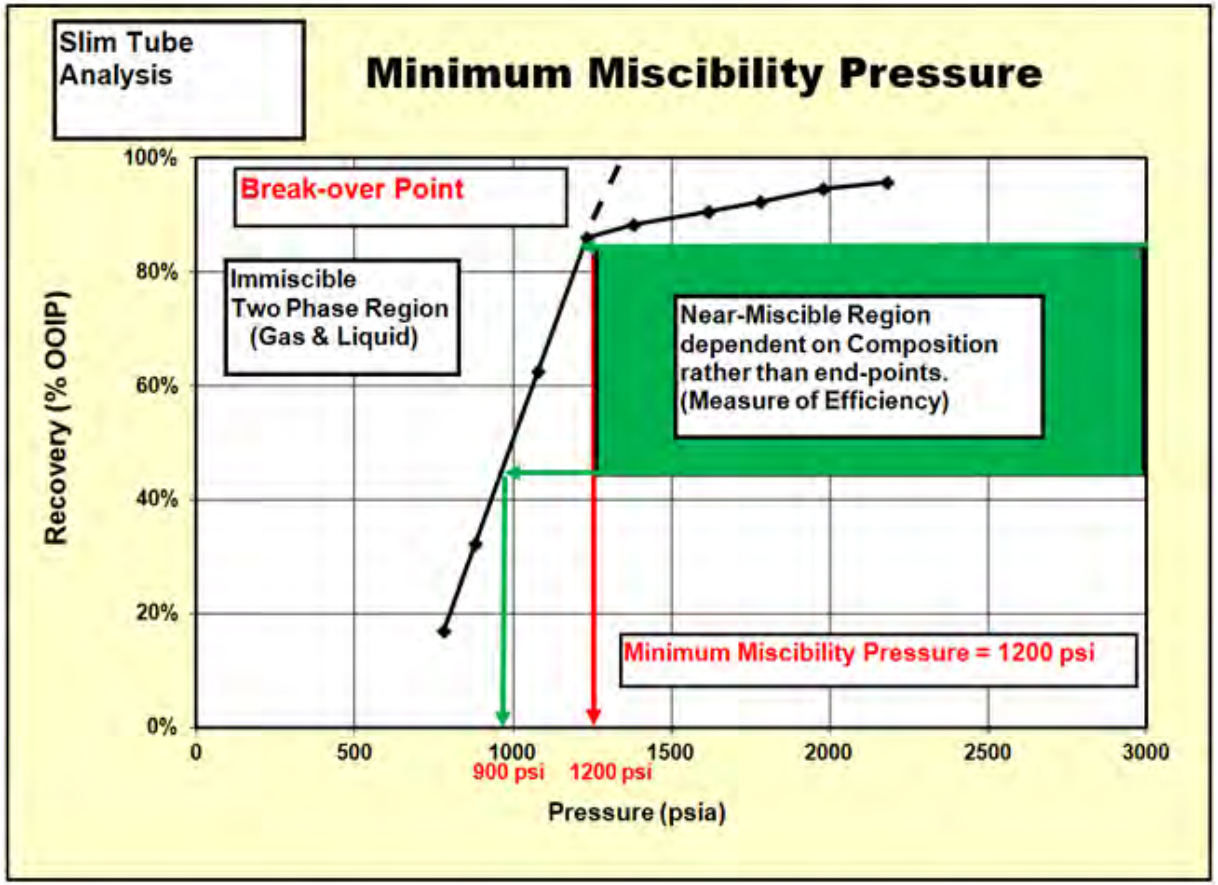
Note: Tertiary Oil Recovery and CO_2 trapping is governed by Relative Permeability Hysteresis of the non-wetting phase.

Reservoir Operating Pressure



Note: All CO_2 Floods should be operated at or just below Formation Fracture Pressure (Amoco Philosophy during the 1980's and 1990's.)

Minimum Miscibility Pressure



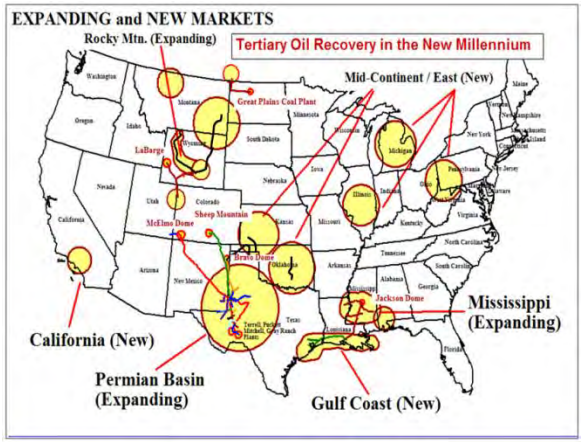
Note: CO_2 Floods are most efficient is operated above Minimum Miscibility Pressure. But, can be operated below MMP, but at a lesser efficiency rating.

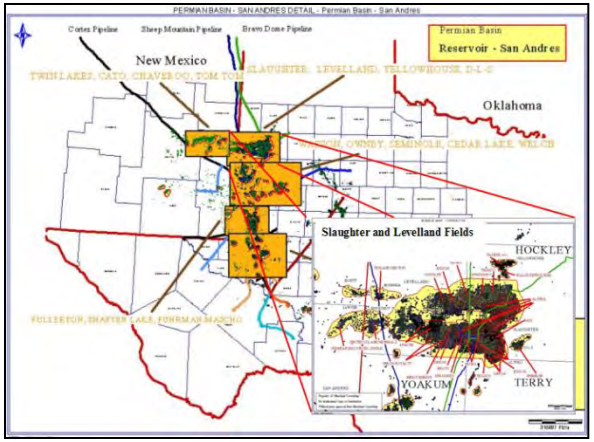
Ten CO_2 Recovery Methods

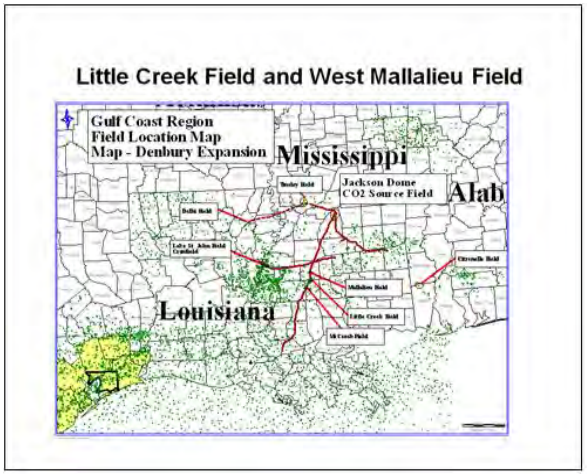
Tertiary CO_2 Flooding

Ten CO_2 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).
6. Huff-and-Puff (100+ Projects)
7. Heavy Oil - Calif. (14+ API Gravity)
8. Shale Oil (Bakken) (Under Investigation)
9. Horizontal Well Pattern Development
10. CO_2 Gas Drive w/ Nitro Boost







Conventional WAG w/ ROZ

Ten CO_2 Recovery Methods used for Tertiary Oil Recovery in the United States

1. Conventional WAG Recovery (90%+)
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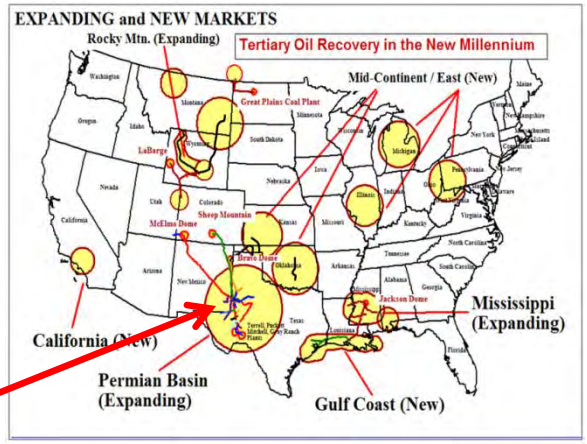
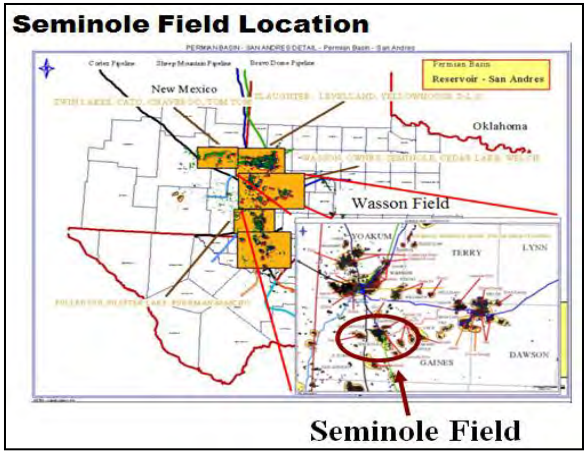
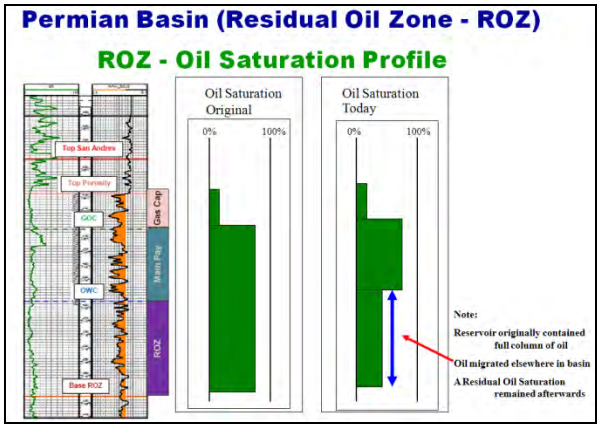
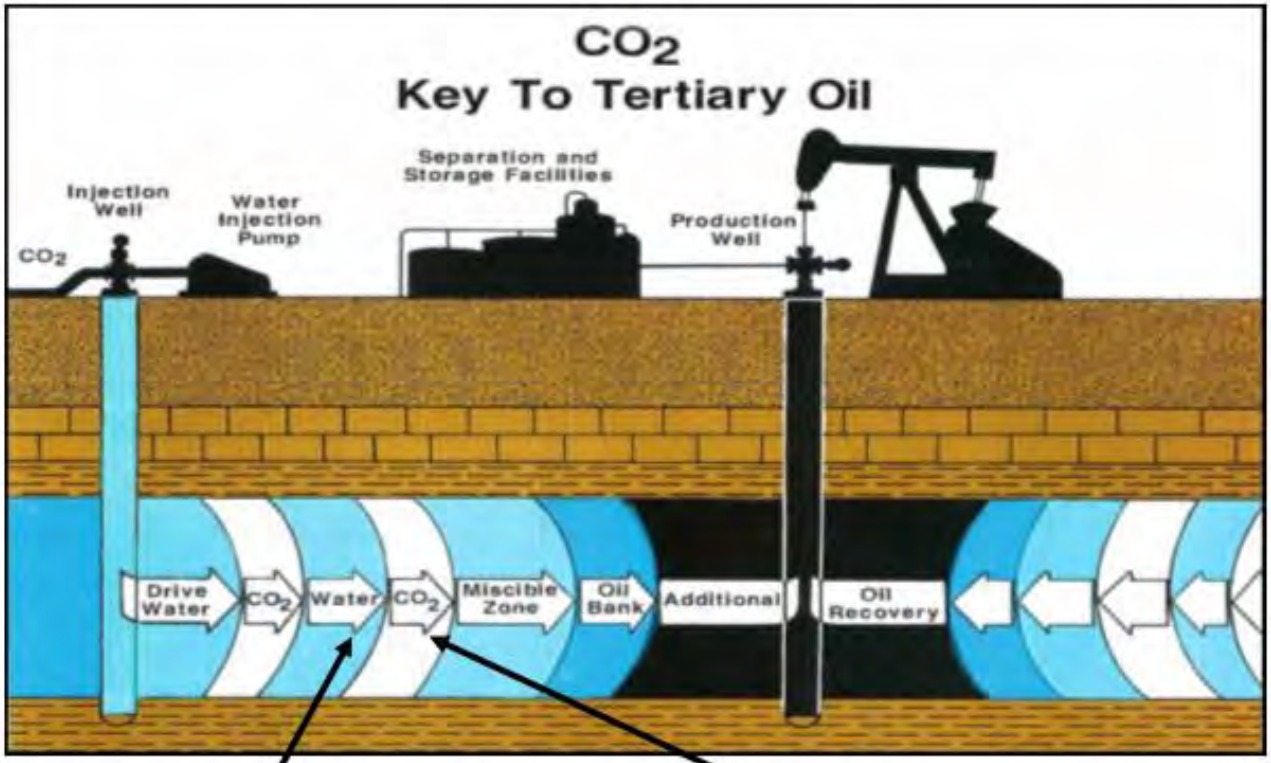
SPE Paper 139516 – "Life Beyond 80 – A look at Conventional WAG Recovery beyond 80% HCPV Injection in CO_2 Tertiary Floods"







Conventional WAG Injection Techniques



Water (% HCPV Inj.) CO_2 (% HCPV Inj.)

Permian Basin – History of "WAG"

1950's – 150 small scale Miscible and Immiscible Projects

1958 – Lab Experiments Caudle and Dyes introduced water to decrease solvent mobility

1972 – Sacroc Field (Constant WAG) First Commercial Large Scale Project

1980's - Early Projects (Constant WAG)

1986 - Reservoir Model (Amoco - Merchant)

1989 - Amoco Implemented Tapered WAG in Slaughter and Wasson Fields

1990's - Tapered WAG adopted most operators

CO_2 Flooding in the United States
40+Years of CO_2 Flood History

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SPE 18977 Brock and Bryan 1989

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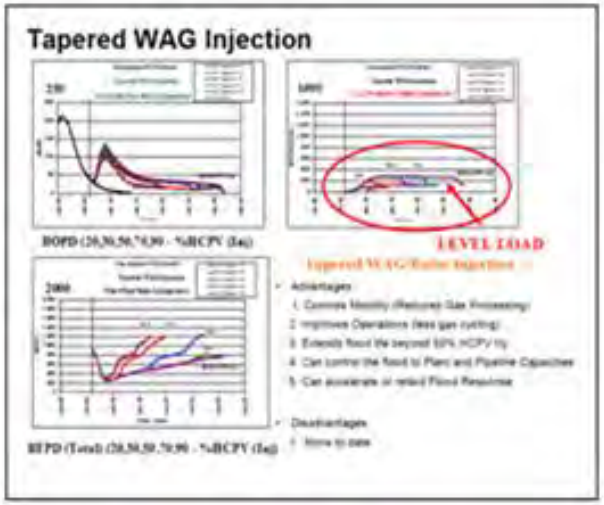
2000's



18% OOIP Rec
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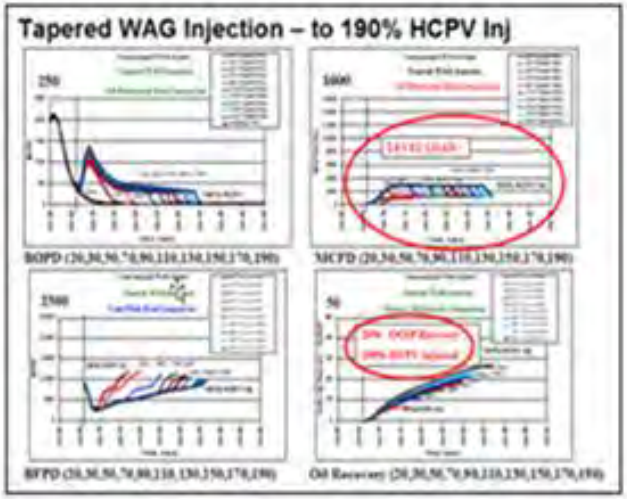


20% to 26% OOIP Rec
140% to 190% HCPV Inj

Note: Not all fields will achieve this

Tertiary CO_2 Flooding

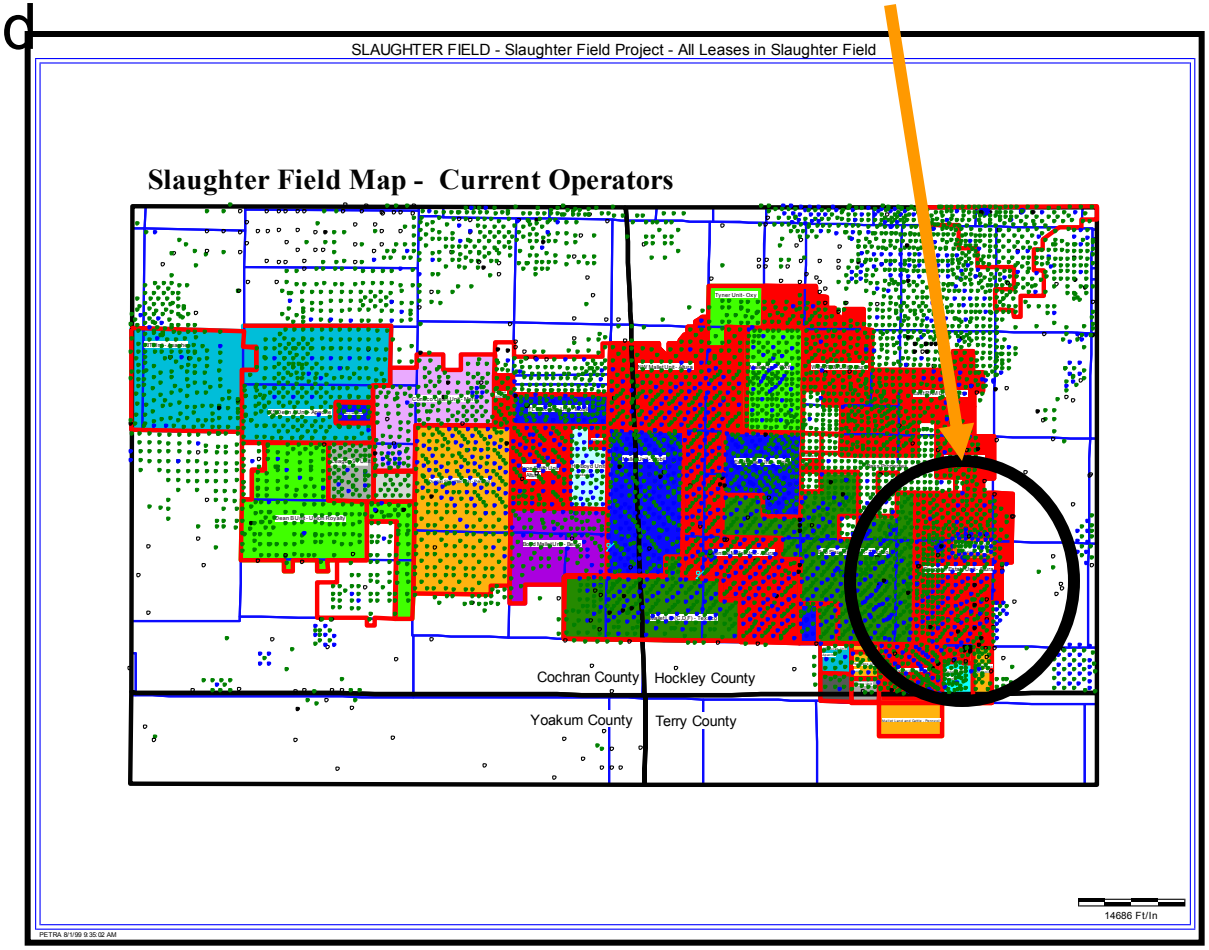
"The Previous Millennium"

20th Century

"Life <u>below</u> 80% HCPV Injected"

Example -WAG BENEFITS
(Control CO_2 Process)

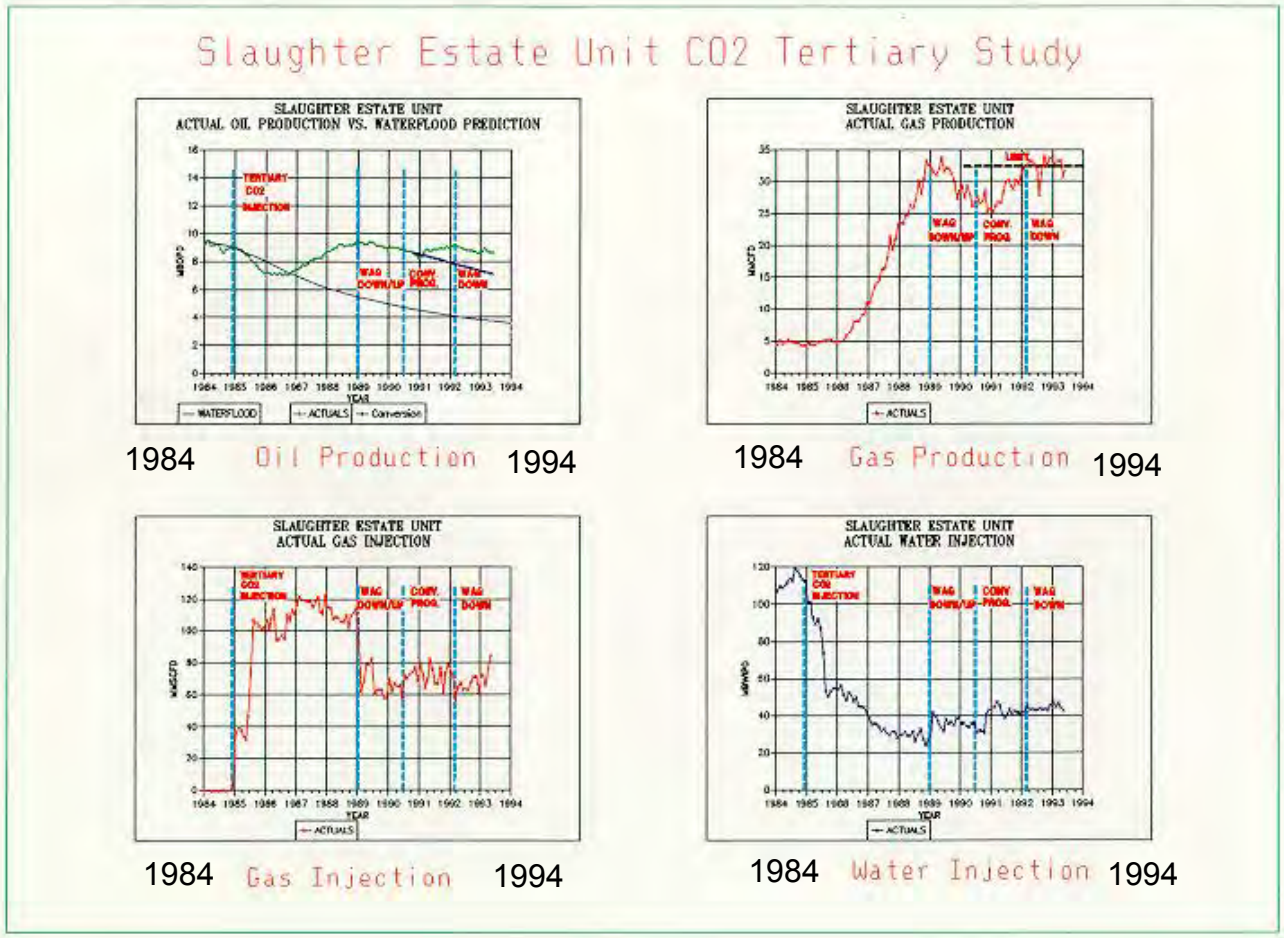
Oxy-Permian - Slaughter Estate Unit in Slaughter Field



SPE Paper No. 26624

Example - WAG BENEFITS
(Control CO_2 Process)

Oxy-Permian - Slaughter Estate Unit in Slaughter Field
Production and Injection (1984 – 1994)



SPE Paper No. 26624

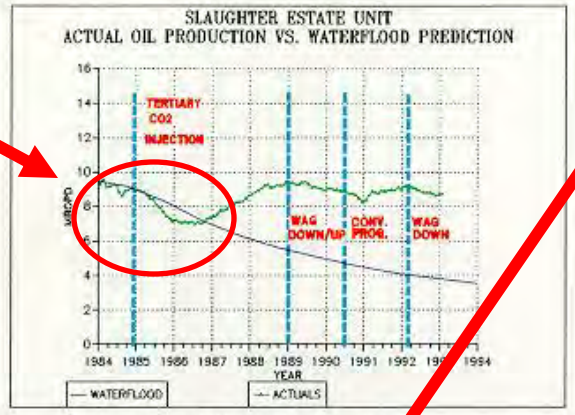
Example - WAG BENEFITS

(Control CO_2 Process)

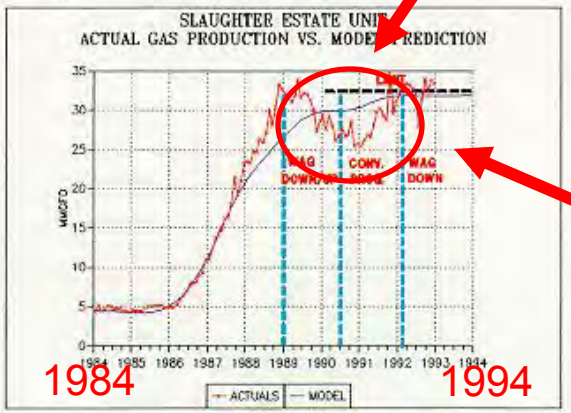
Level Load Gas Production
WAG Change - 1989

Effect of Constant WAG Injection Operations

Oil Prod



Gas Prod



1984

1994

Effect of Over-WAG Ops.

Tertiary CO_2 Flooding

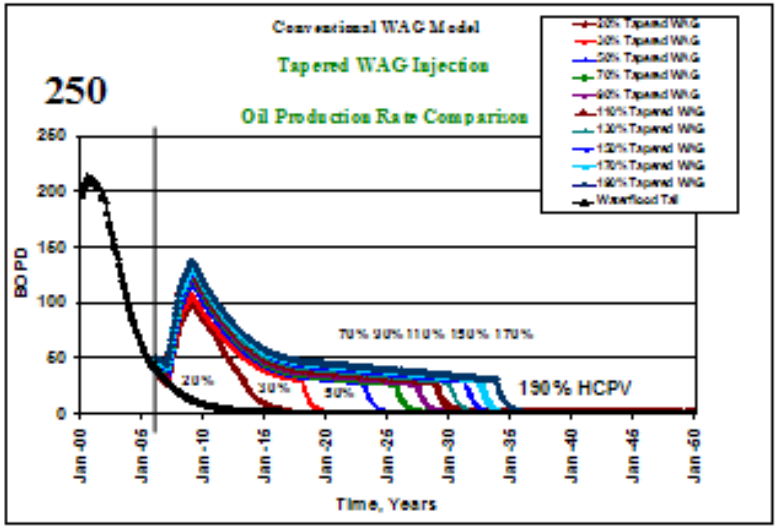
"The New Millennium"

21st Century

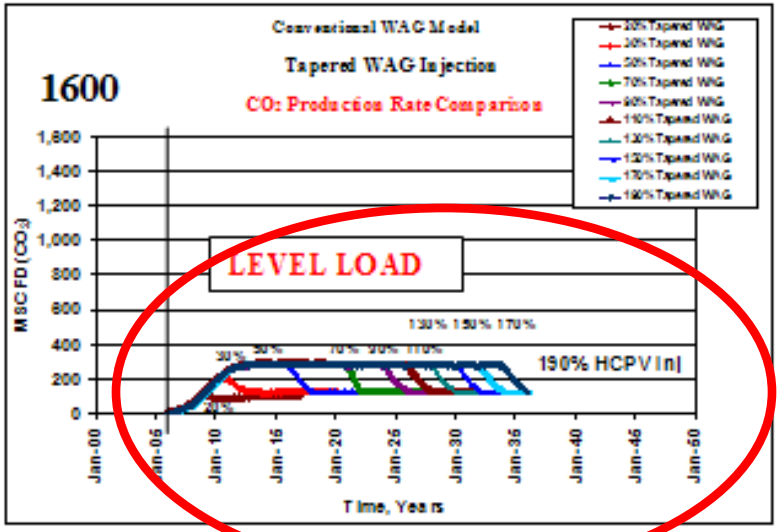
"Life <u>beyond</u> 80% HCPV Injected"

2010's

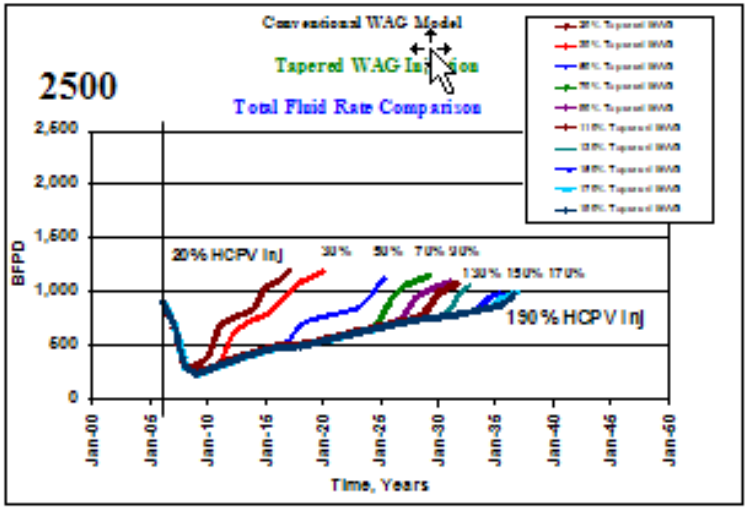
Tapered WAG Injection – to 190% HCPV Inj



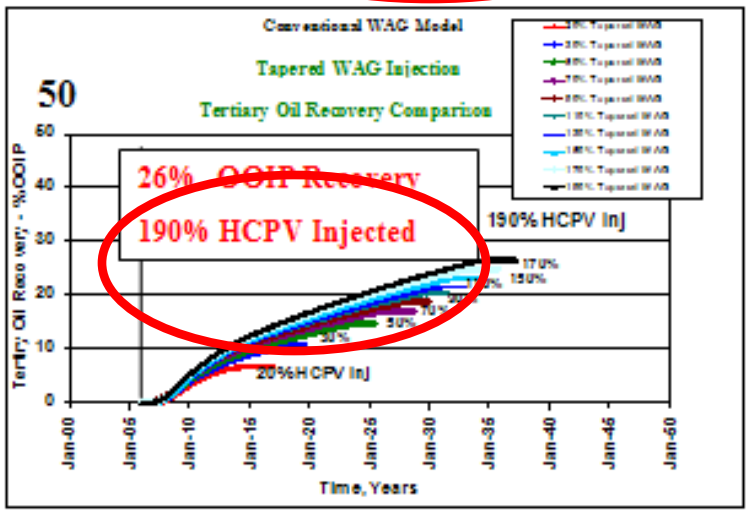
BOPD (20,30,50,70,90,110,130,150,170,190)



MCFD (20,30,50,70,90,110,130,150,170,190)



BFPD (20,30,50,70,90,110,130,150,170,190)

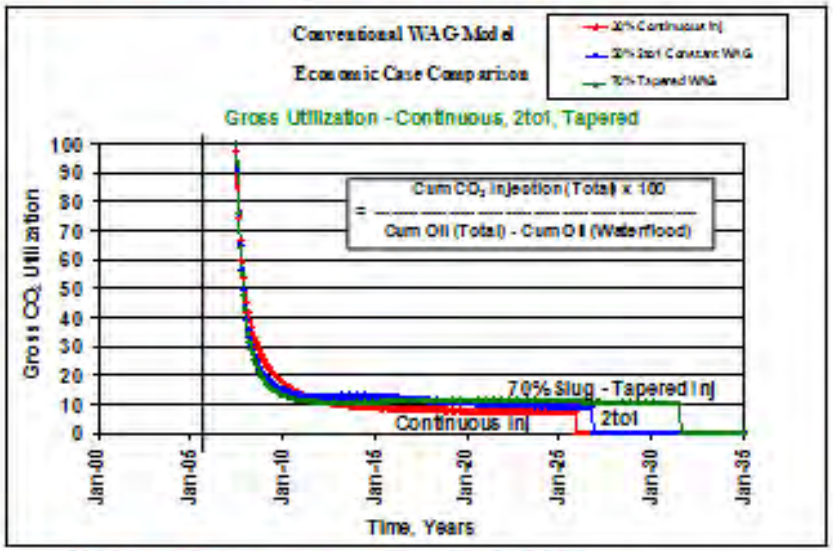


Oil Recovery (20,30,50,70,90,110,130,150,170,190)

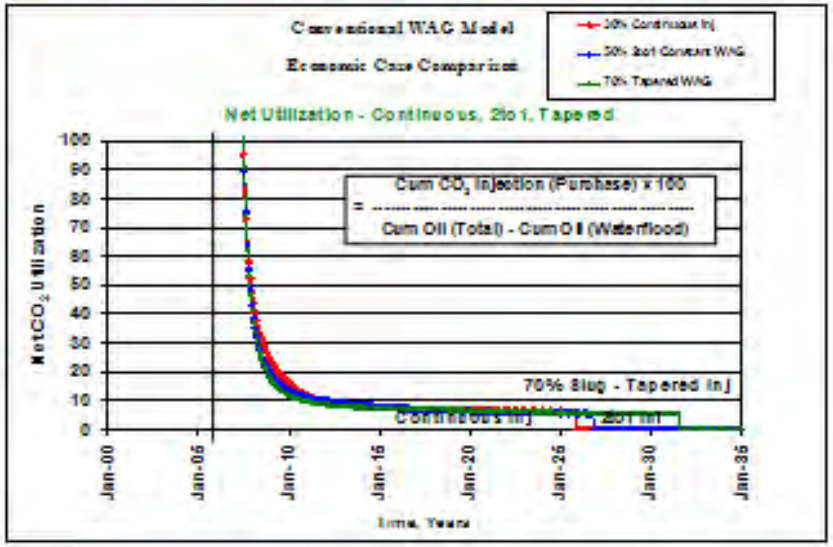
SPE Paper 139516 – "Life Beyond 80 – A look at Conventional WAG Recovery beyond 80% HCPV Injection in CO_2 Tertiary Floods"

Economic Case Comparisons – Continuous 30, Constant WAG 50, Tapered 70)

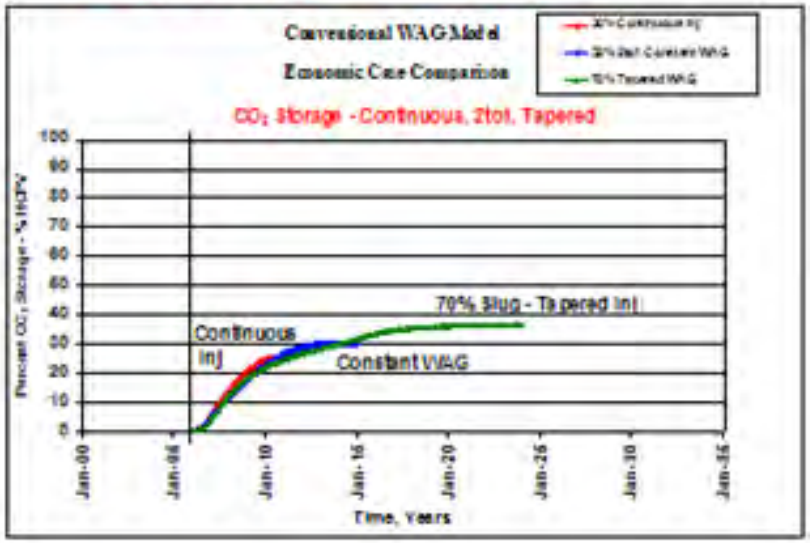
Gross – CO_2 Utilization



Net – CO_2 Utilization



CO_2 Storage - % HCPV



CO_2 Utilization and CO_2 Retention

CO_2 Gross Utilization is a measure of the **Efficiency** of the CO_2 Process (Amount of Total CO_2 Injected per Bbl Tertiary Recovered)

CO_2 Net Utilization is a measure of the **Efficiency** of the CO_2 Process (Amount of Purchased CO_2 Injected per Bbl Tertiary Recovered)

Field Example
Seminole Field

Oil Field Basics

Oil Field History – (All Fields Worldwide)

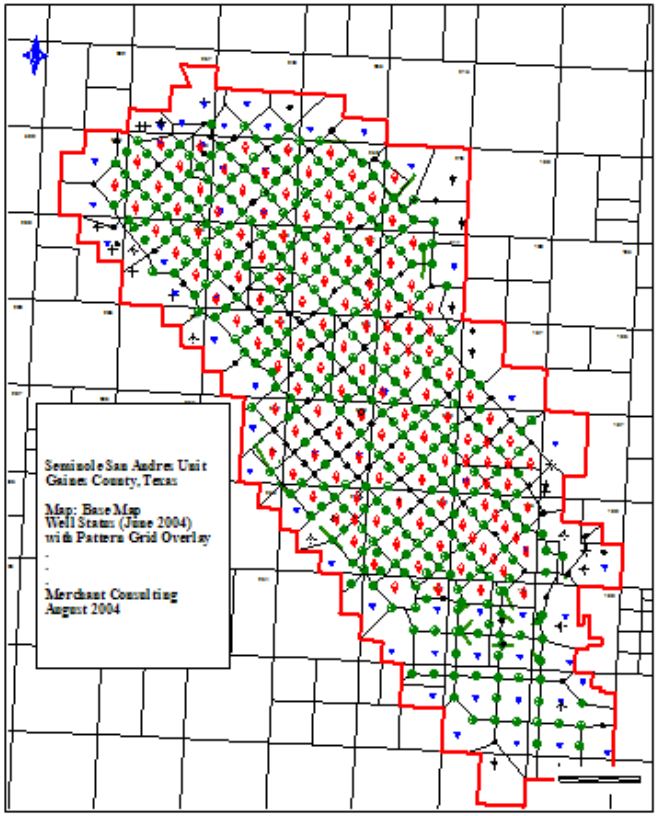
Recovery Mechanisms

Primary Oil Recovery

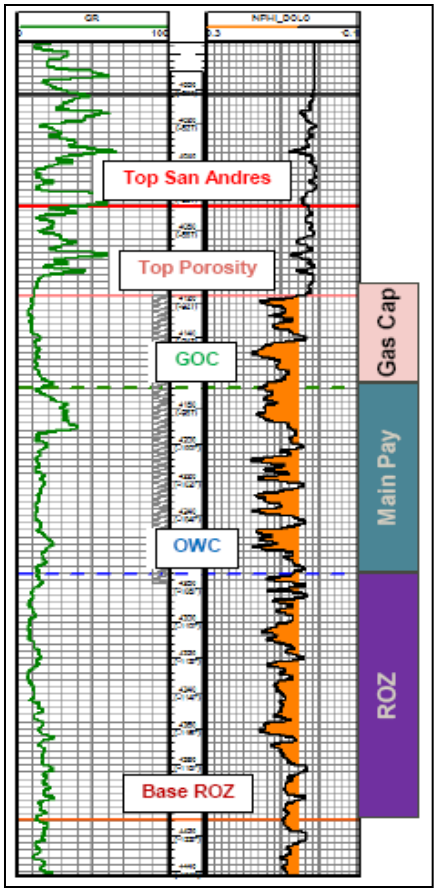
Secondary Recovery

Tertiary Oil Recovery

Seminole San Andres Unit /with Pattern Grid Overlay



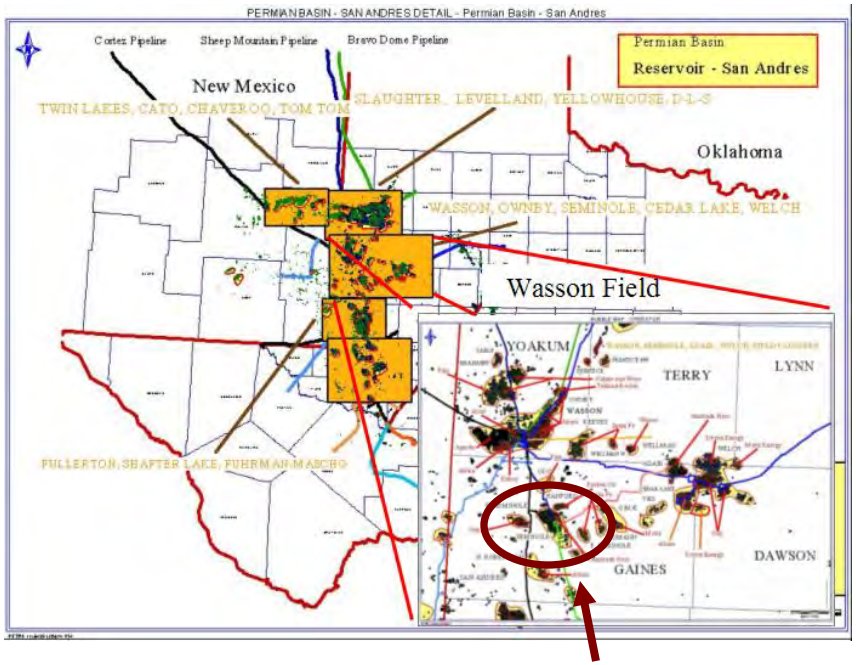
Well Log



Tertiary CO_2 Flooding

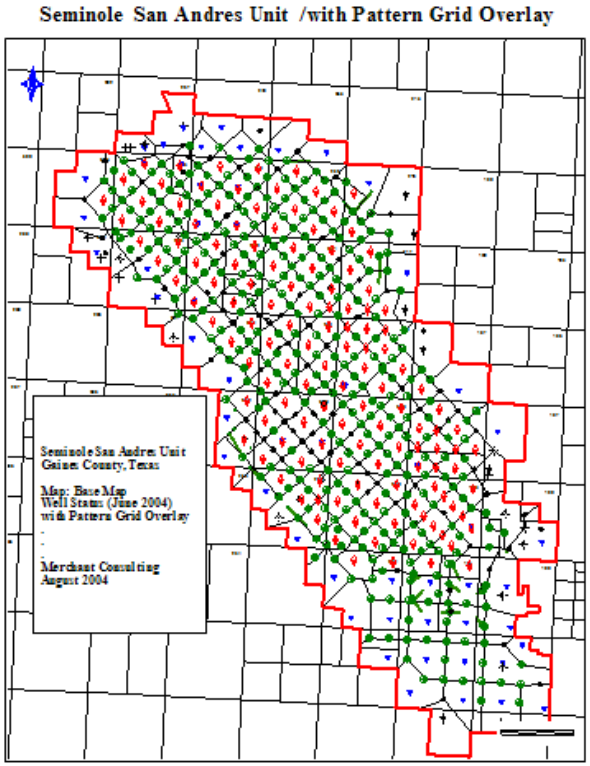
Permian Basin (Seminole Field)

Seminole Field Location



Seminole Field

Seminole Field



The Seminole field recovers Tertiary Oil from the San Andres Formation about 5,500 ft. deep which also includes a large Residual Oil Zone (ROZ). The Field is developed on 9-spot pattern spacing.

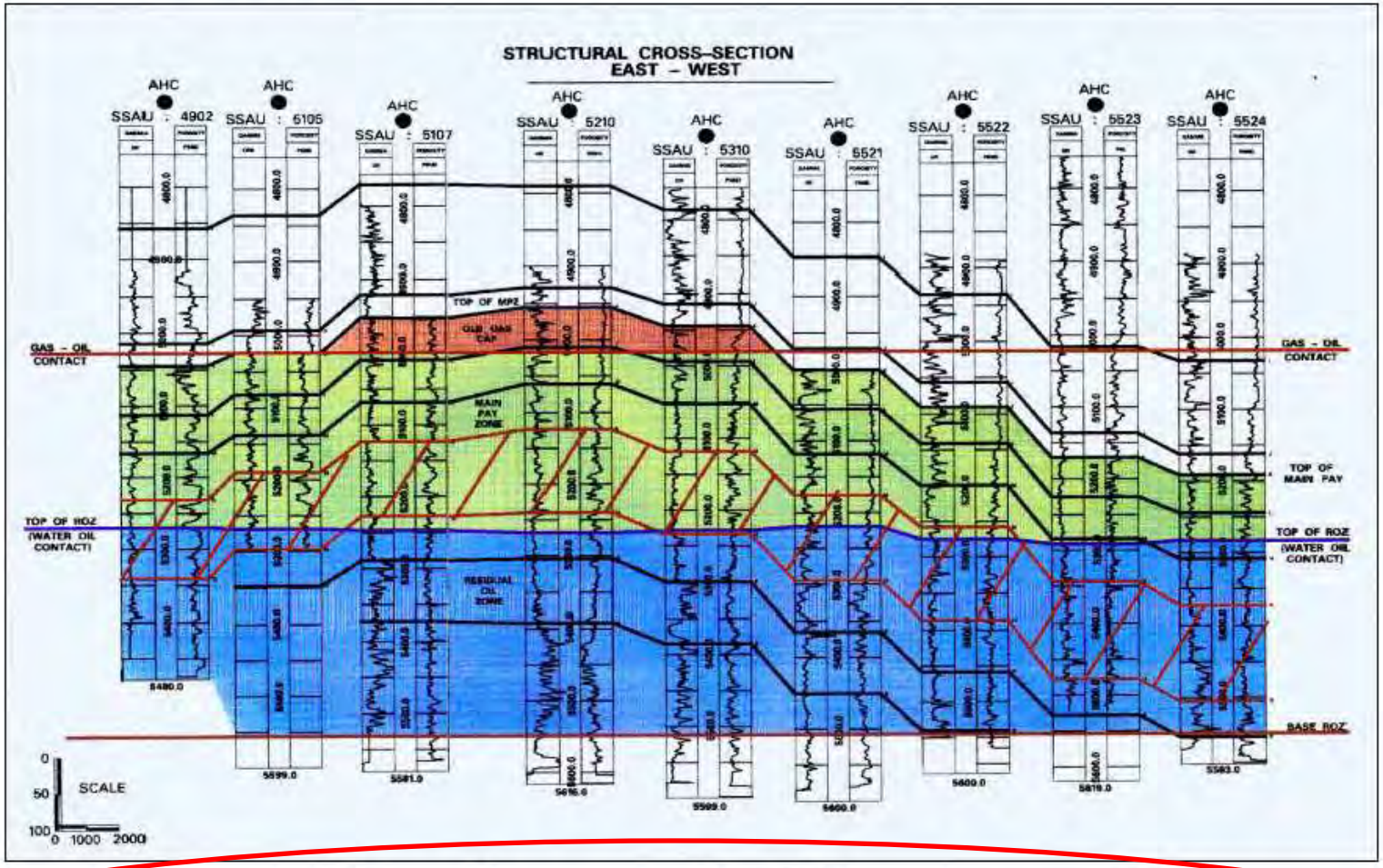
Permian Basin (Residual Oil Zone - ROZ)

SSAU MPZ & ROZ CrossSection and Zonal Attributes

Gas Cap

Main Pay

ROZ



	Gross Thickness	Net Thickness	Porosity	Permeability Range	OOIP	Initial Oil Saturation
Main Pay Zone (MPZ):	160'	126'	12%	0.8-120 md	1 billion stbo	0.84
Residual Oil Zone (ROZ):	246'	197'	12.6%	0.5-270 md	960 million stbo	0.32

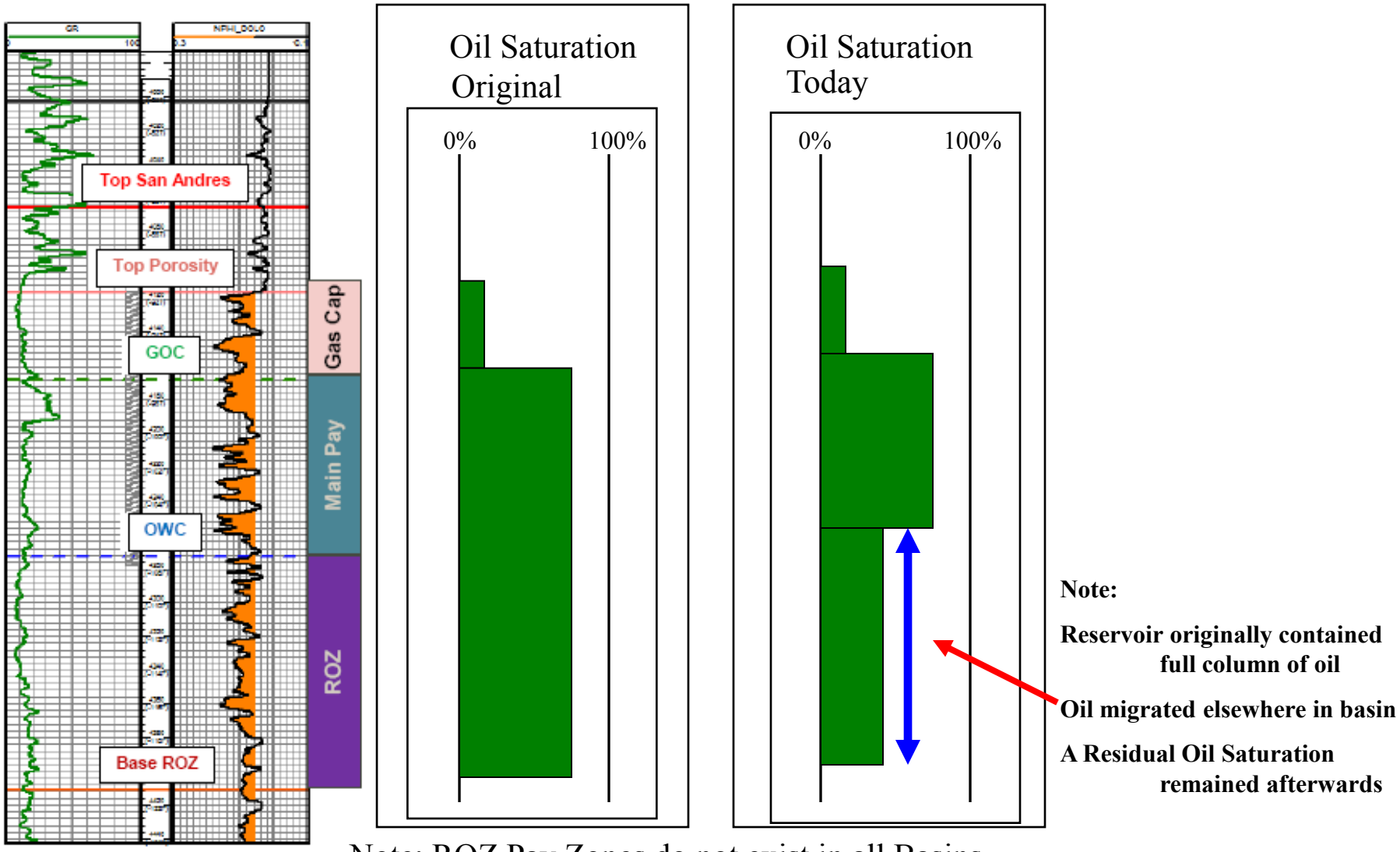
Melzer CO_2 Conf 2011

Merchant Consulting - Midland CO_2 Conf - Dec 2015

Total Gross= 406 ft Total Net= 333 ft

Permian Basin (Residual Oil Zone - ROZ)

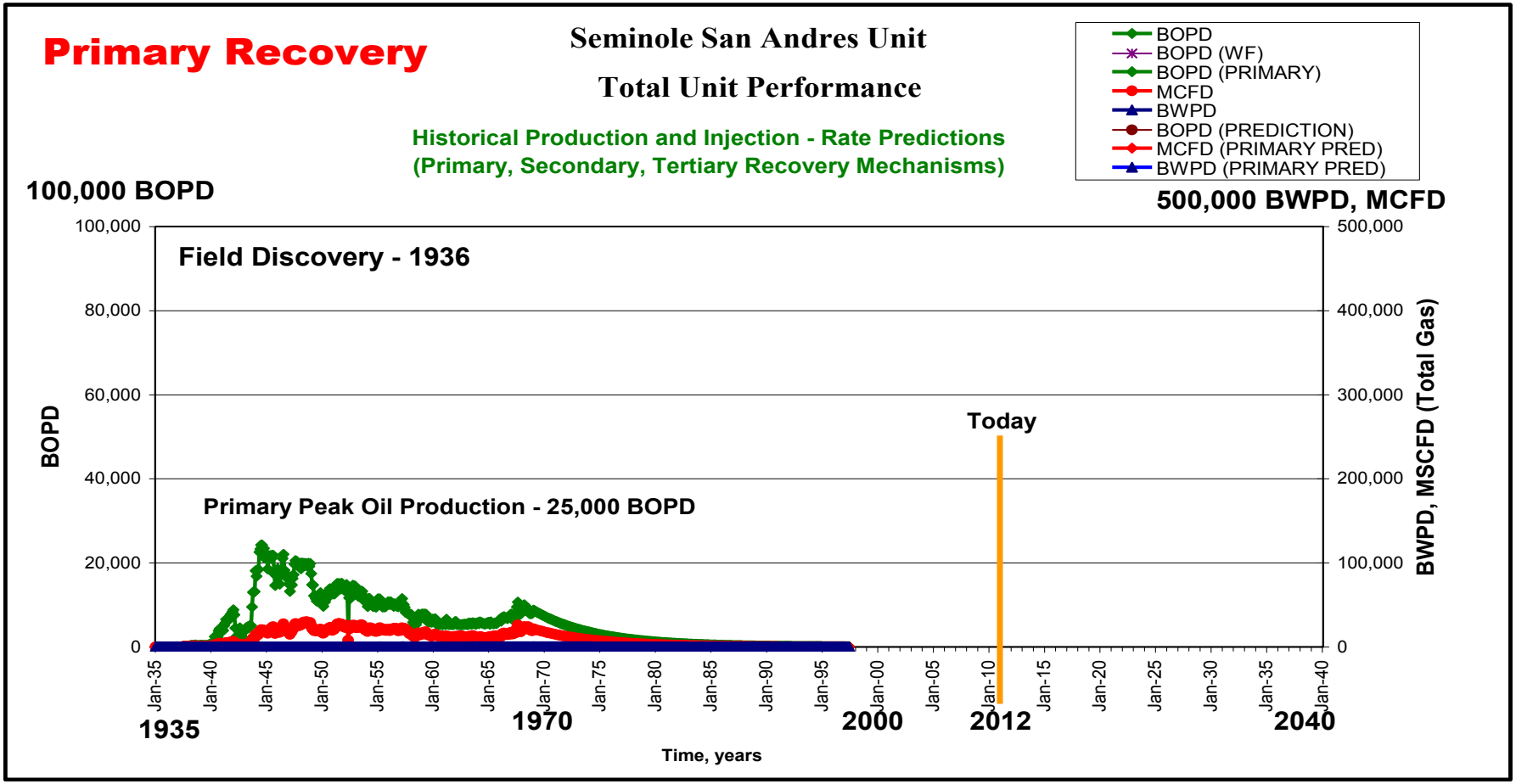
ROZ - Oil Saturation Profile



Note: ROZ Pay Zones do not exist in all Basins

Seminole San Andres Unit

Primary Recovery

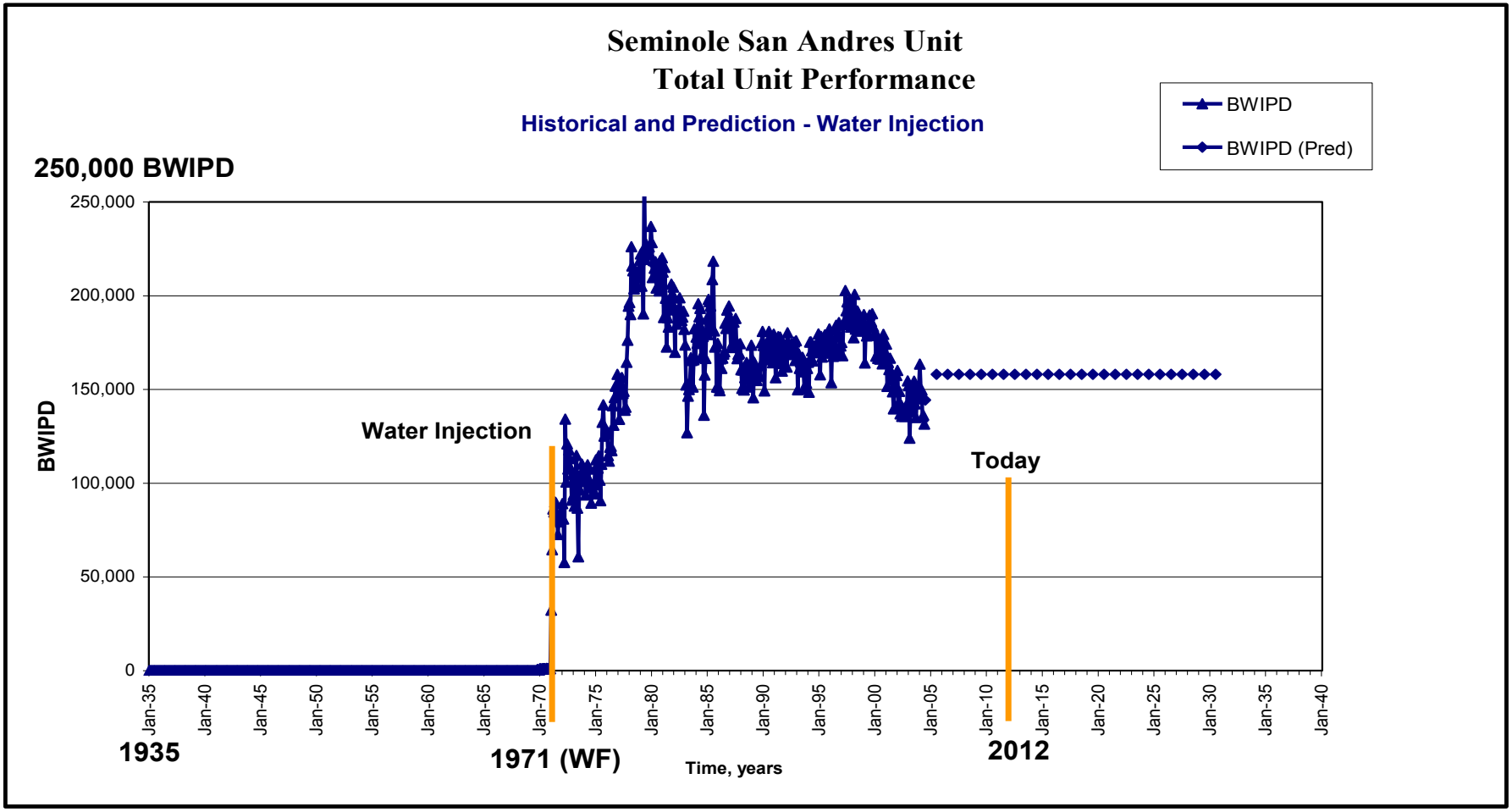


Note: Little Water Production occurred during Primary Recovery

Note: Reservoir Pressure depleted during this time frame

Seminole San Andres Unit

Secondary Recovery - Waterflood

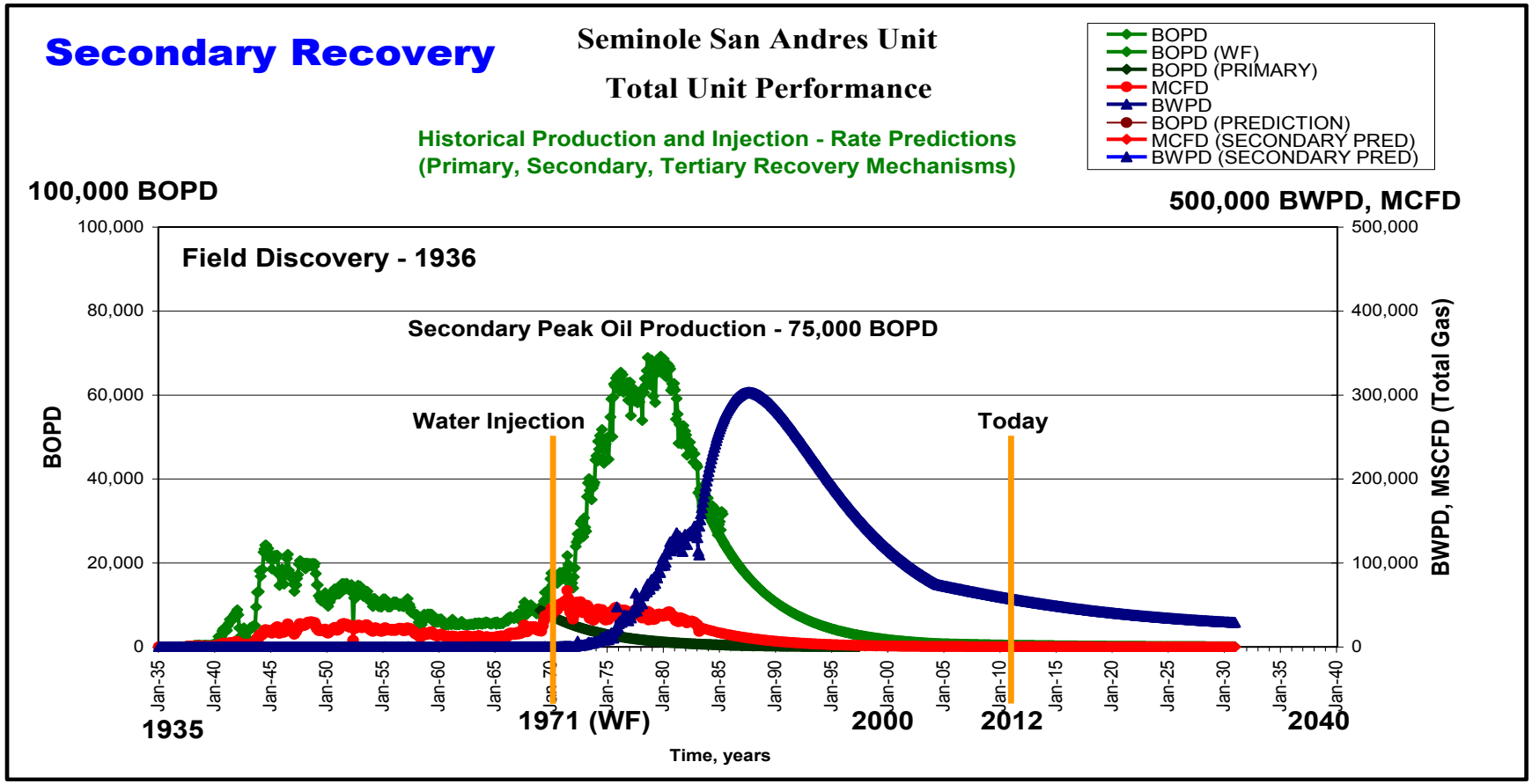


Note: Water Injection is introduced into the Reservoir in 1971

Note: Mass Balance – Water had to be found to initiate Waterflood operations

Seminole San Andres Unit

Secondary Recovery - Waterflood

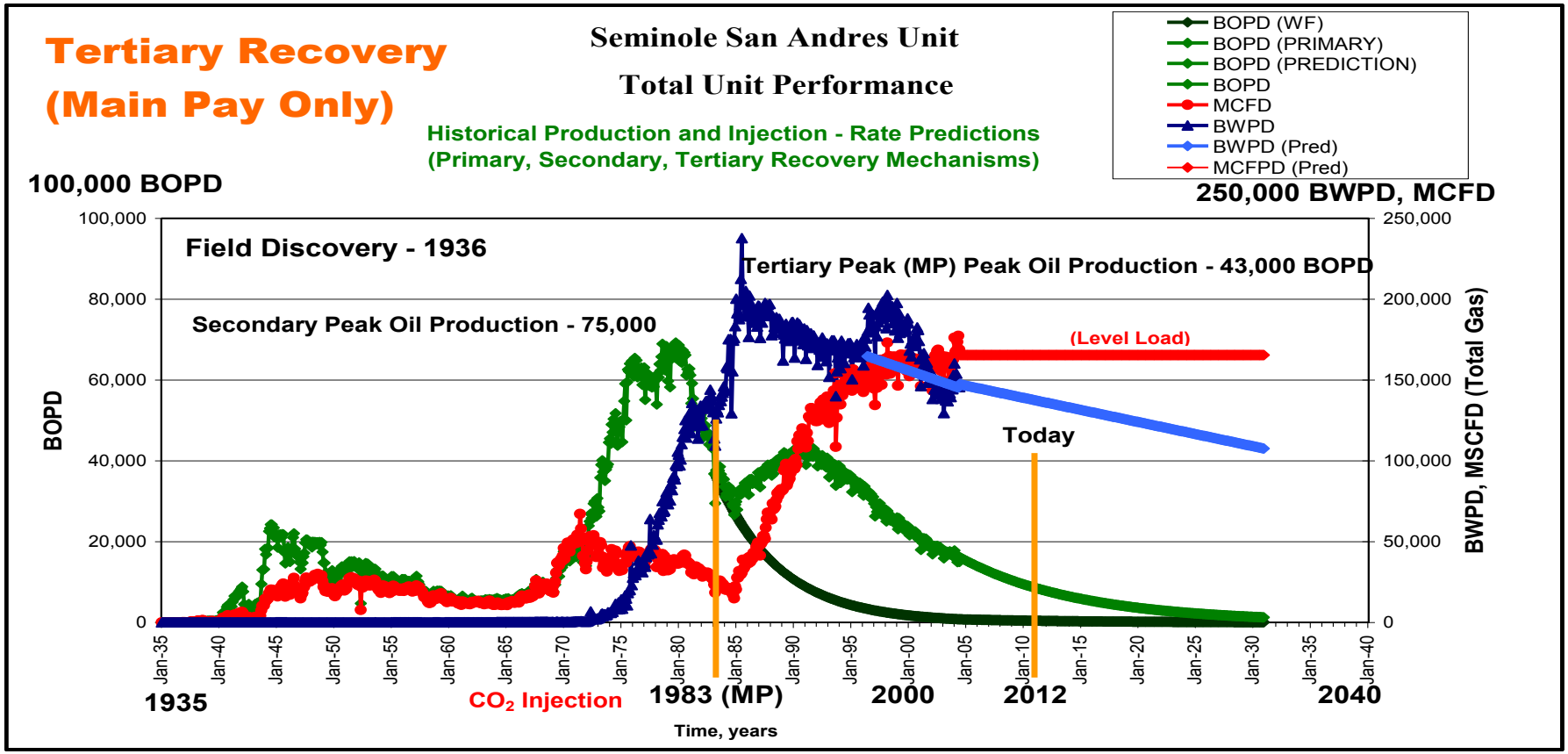


Note: Good Secondary Oil Response after Water Injection

Note: Gas Production collapsed after Water Injection (Pressure-up)

Note: Water Prodution occurred shortly after Water Injection

Seminole San Andres Unit



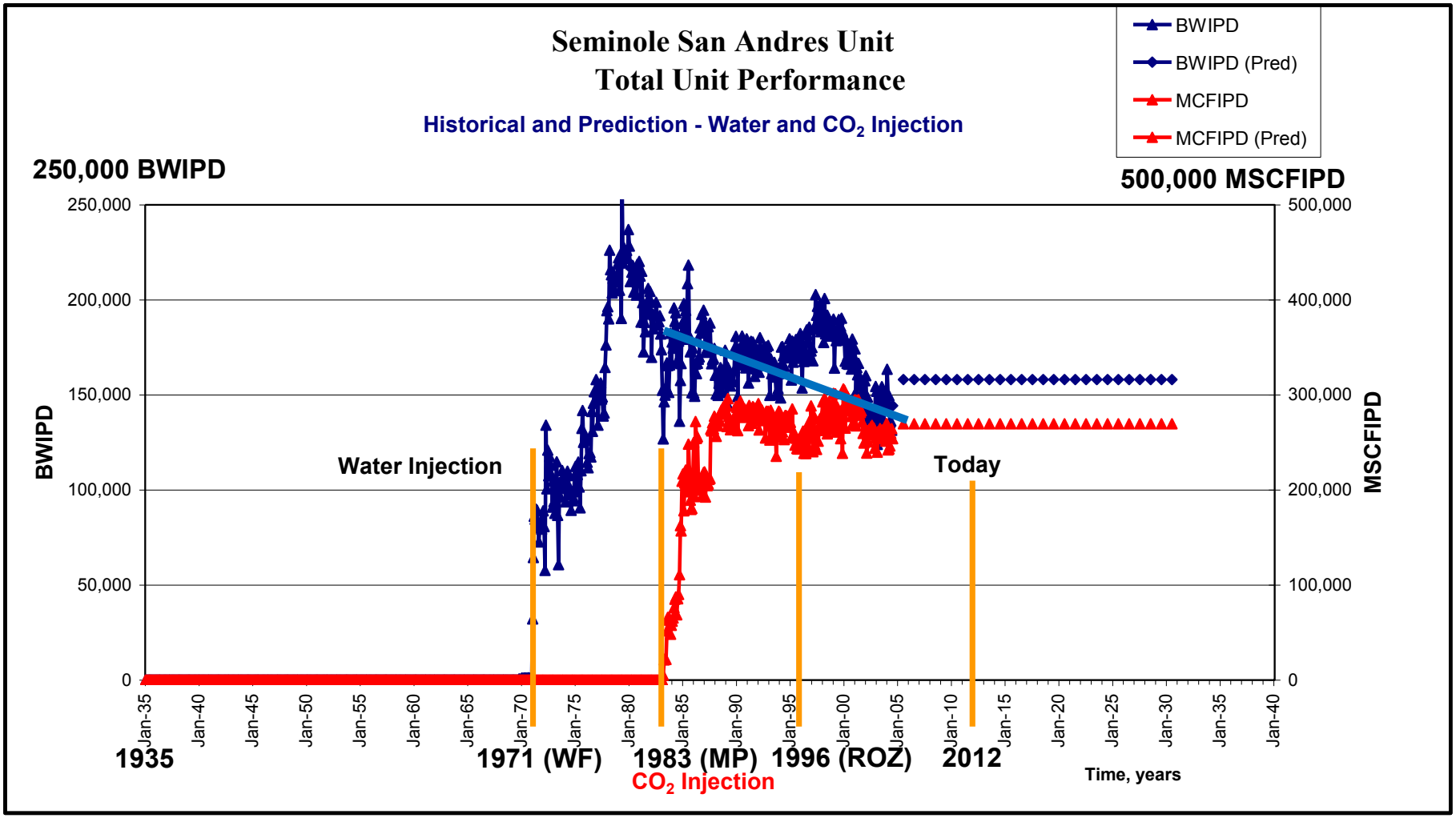
Note: The Reservoir produced a strong Tertiary Oil Response

Note: Total Gas Production increased with rapid breakthrough

Note: Water Injection and Production were decreasing prior to 1996 prior to ROZ start-up in 1996

Note: Total Gas Rate is "Level Loaded" to Plant Inlet Rate

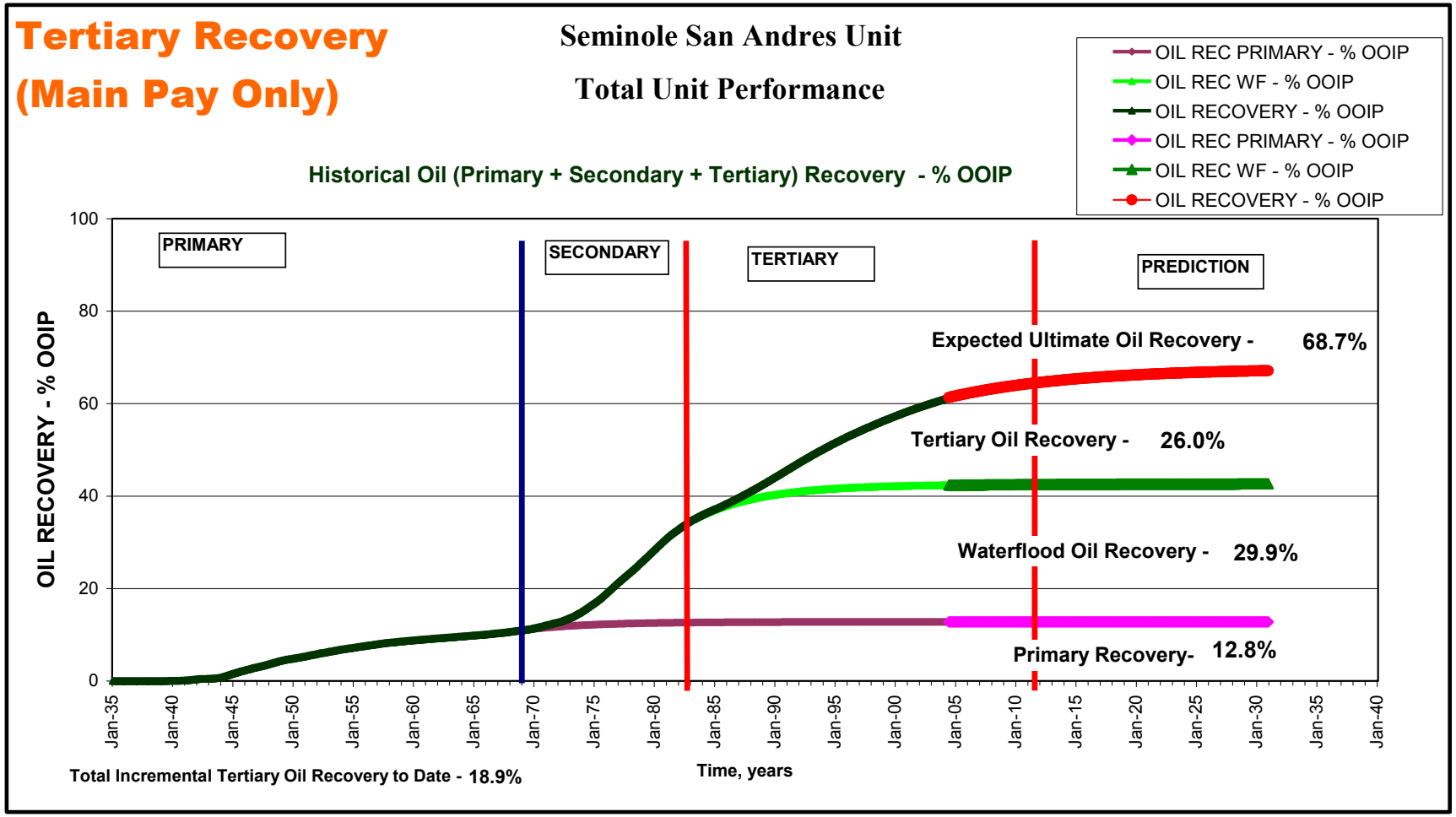
Seminole San Andres Unit



Note: Total Gas Injection has been constant since CO_2 Injection in 1983

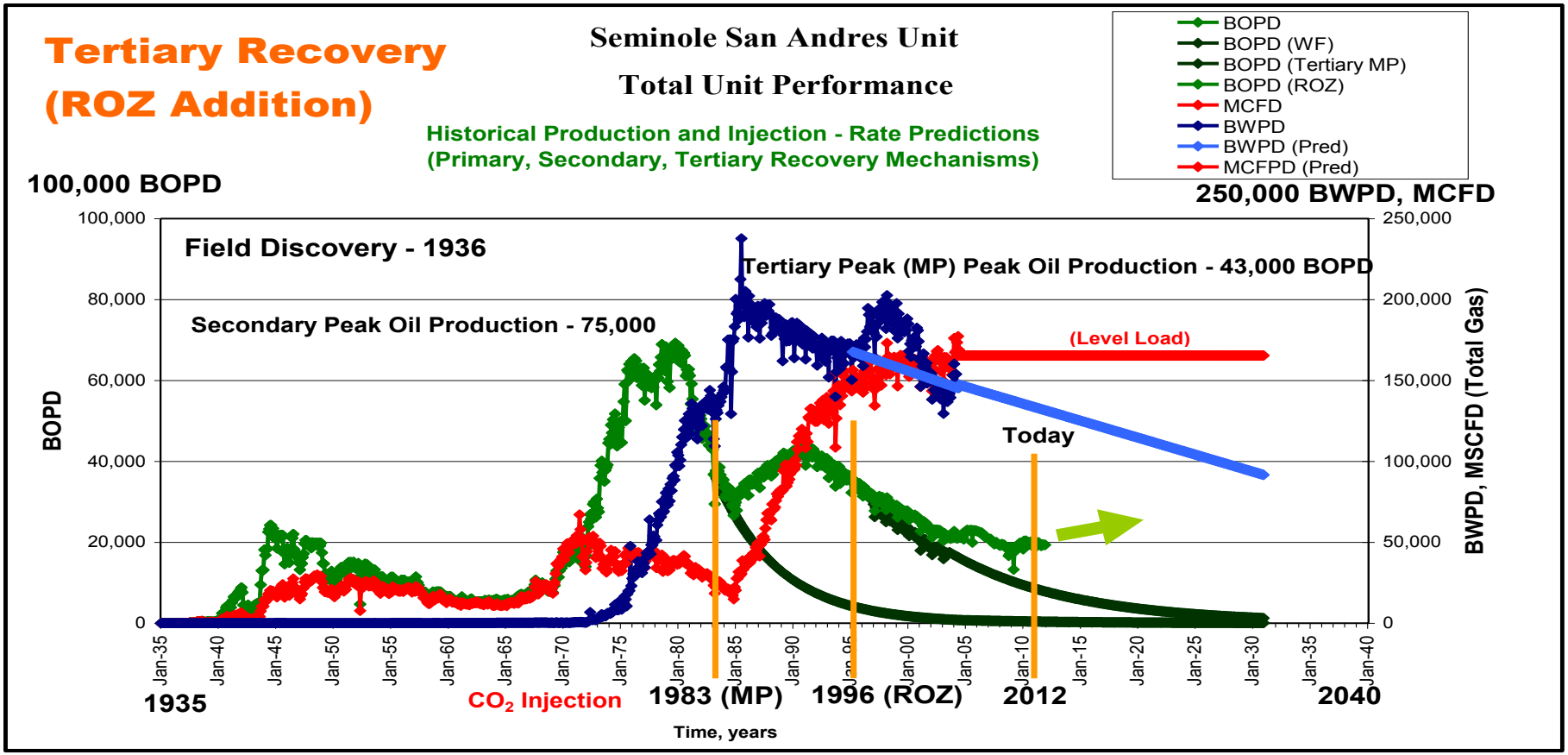
Note: Water Injection was decreasing from 1983 to 1996 (Prior to ROZ)

Seminole San Andres Unit



Note: The Reservoir is expected to Recover 26% of its OOIP with CO_2 Injection

Seminole San Andres Unit

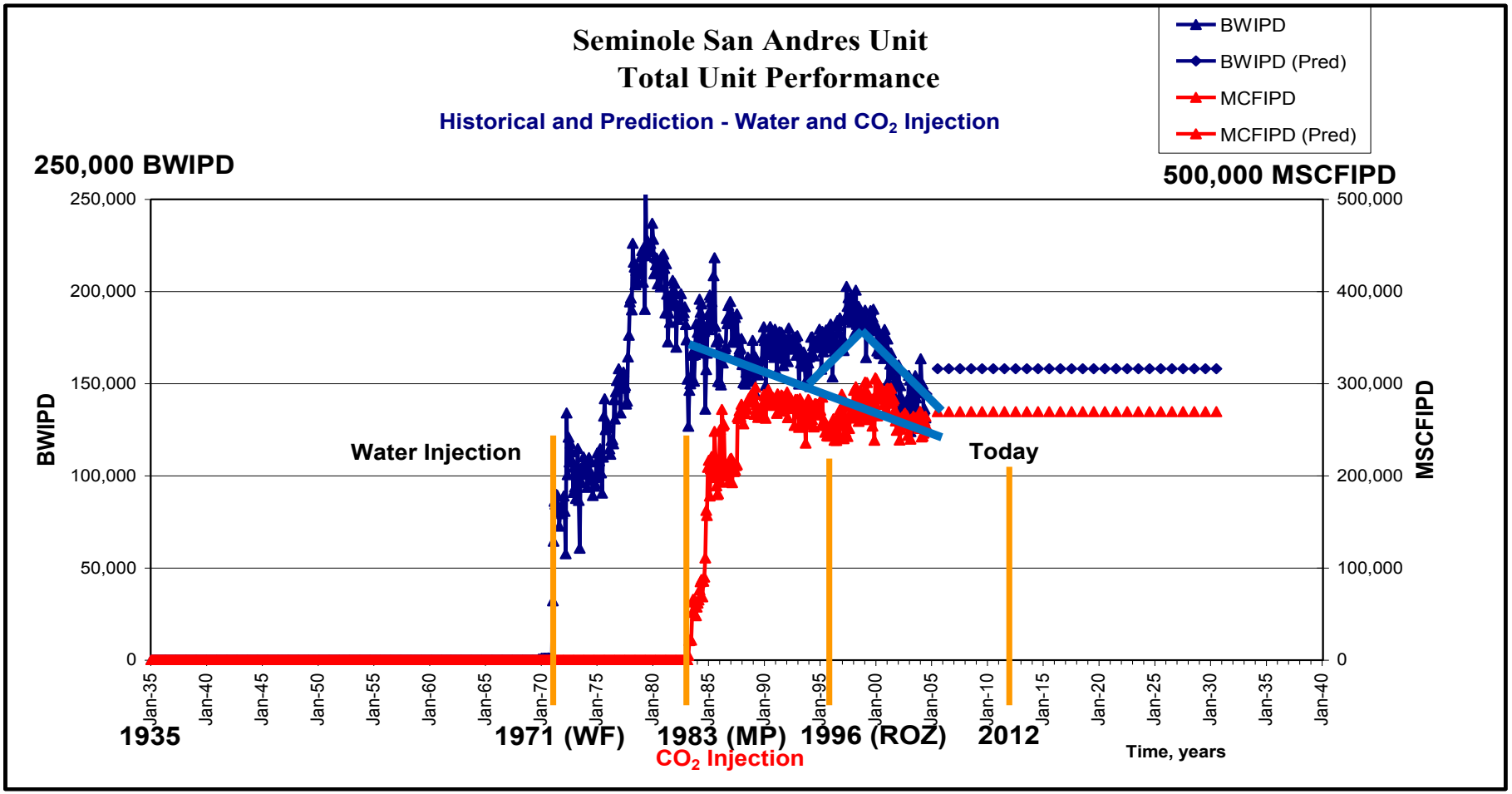


Note: The ROZ produced a strong Tertiary Oil Response

Note: Total Gas Production has been "Level Loaded" to Plant Inlet Rate

Note: ROZ Water Production will be strong initially, but should decrease with time, level out, and then increase as WAG Ratio is increased

Seminole San Andres Unit



Note: Total Gas Injection has been constant since CO_2 Injection in 1988

Note: Water Injection was decreasing from 1983 to 1996 (Prior to ROZ)

Note: ROZ Increase in Water Injection in 1996 and decrease in 2000

Gravity Drainage / Double Displacement

Ten CO_2 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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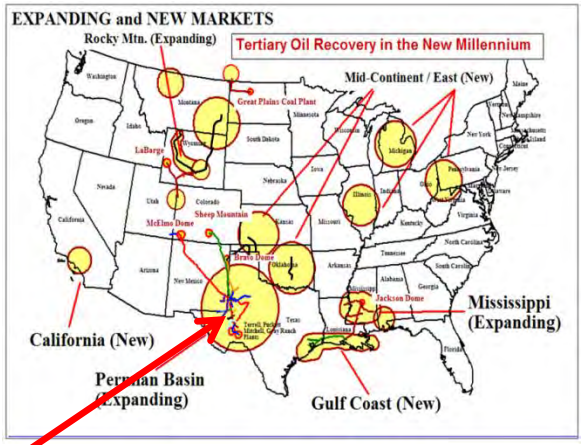
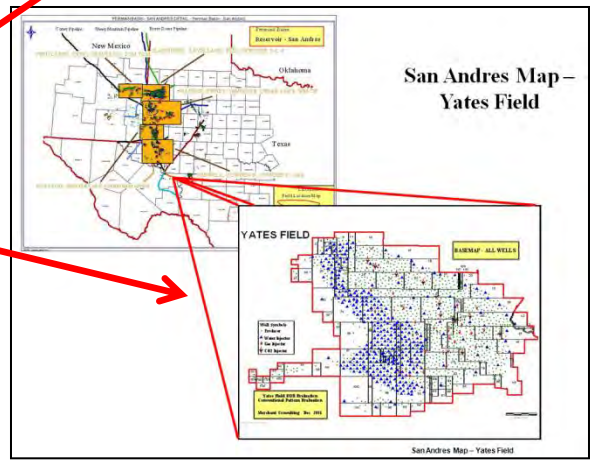
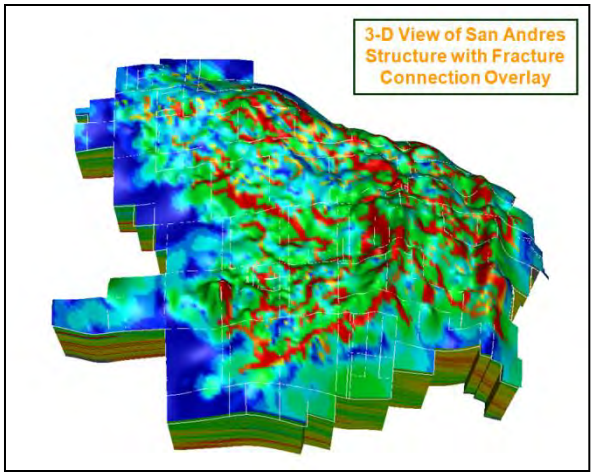
4. Double Displacement (Yates Field)
5. Gas Cycling (Denbury, Mississippi).
6. Huff-and-Puff (100+ Projects)
7. Heavy Oil - Calif. (14+ API Gravity)
8. Shale Oil (Bakken) (Under Investigation)
9. Horizontal Well Pattern Development
10. CO_2 Gas Drive w/ Nitro Boost







CO_2 Sequestration, Gas Storage and Gravity Drainage Projects

Low Dip Reservoir

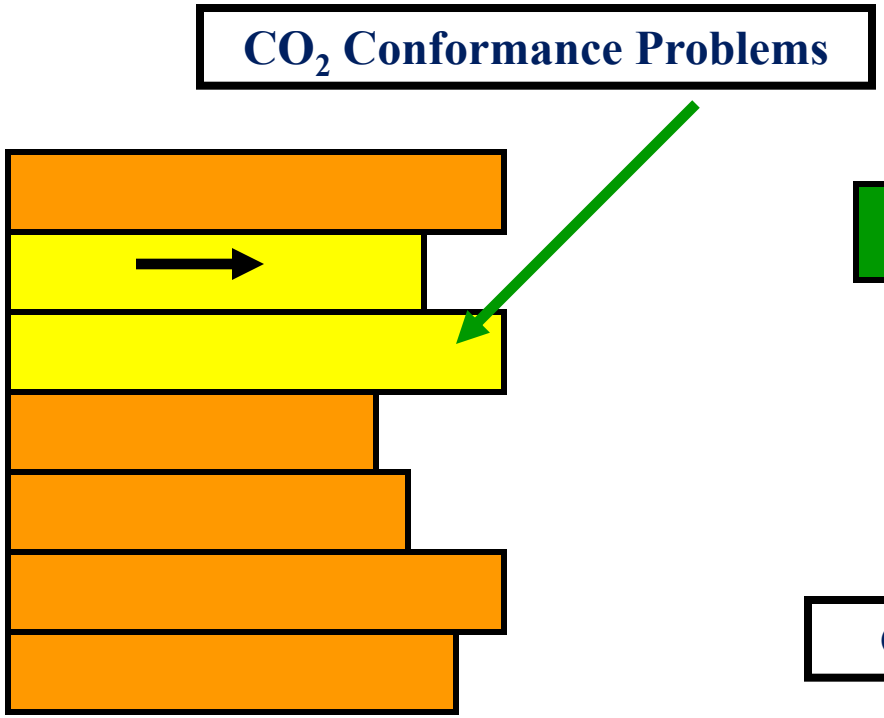
(Conformance can be detrimental)

Gas Cycling is a big problem

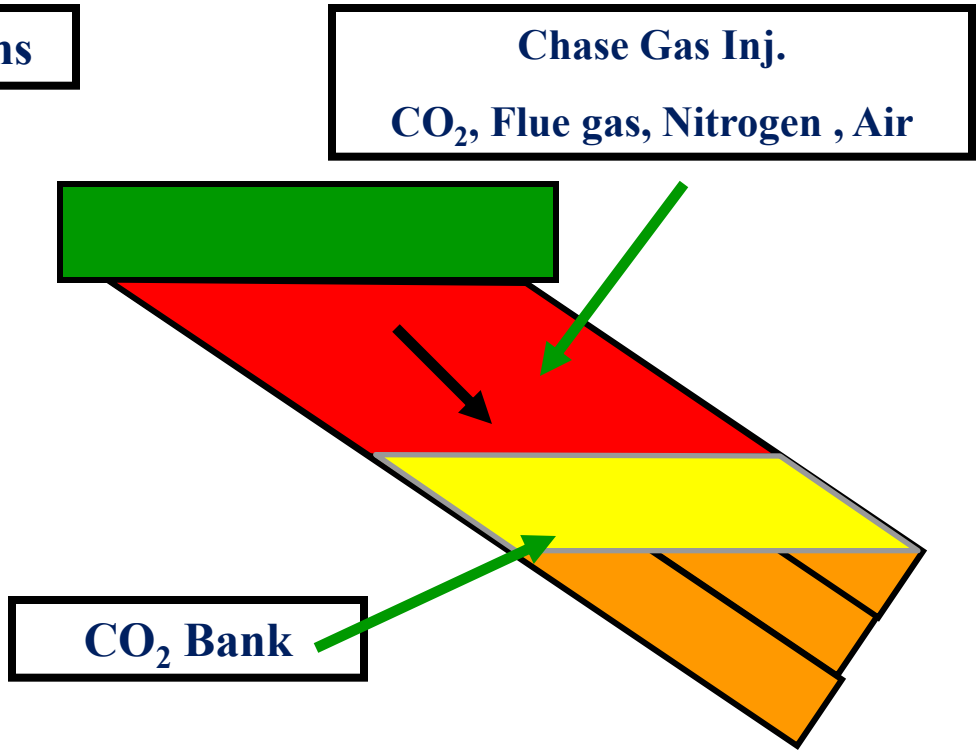
Moderately Low or High Dip Res.

(Can run Miscible or Immiscible)

Conduct a gravity Stabilized CO_2 flood with chase gas

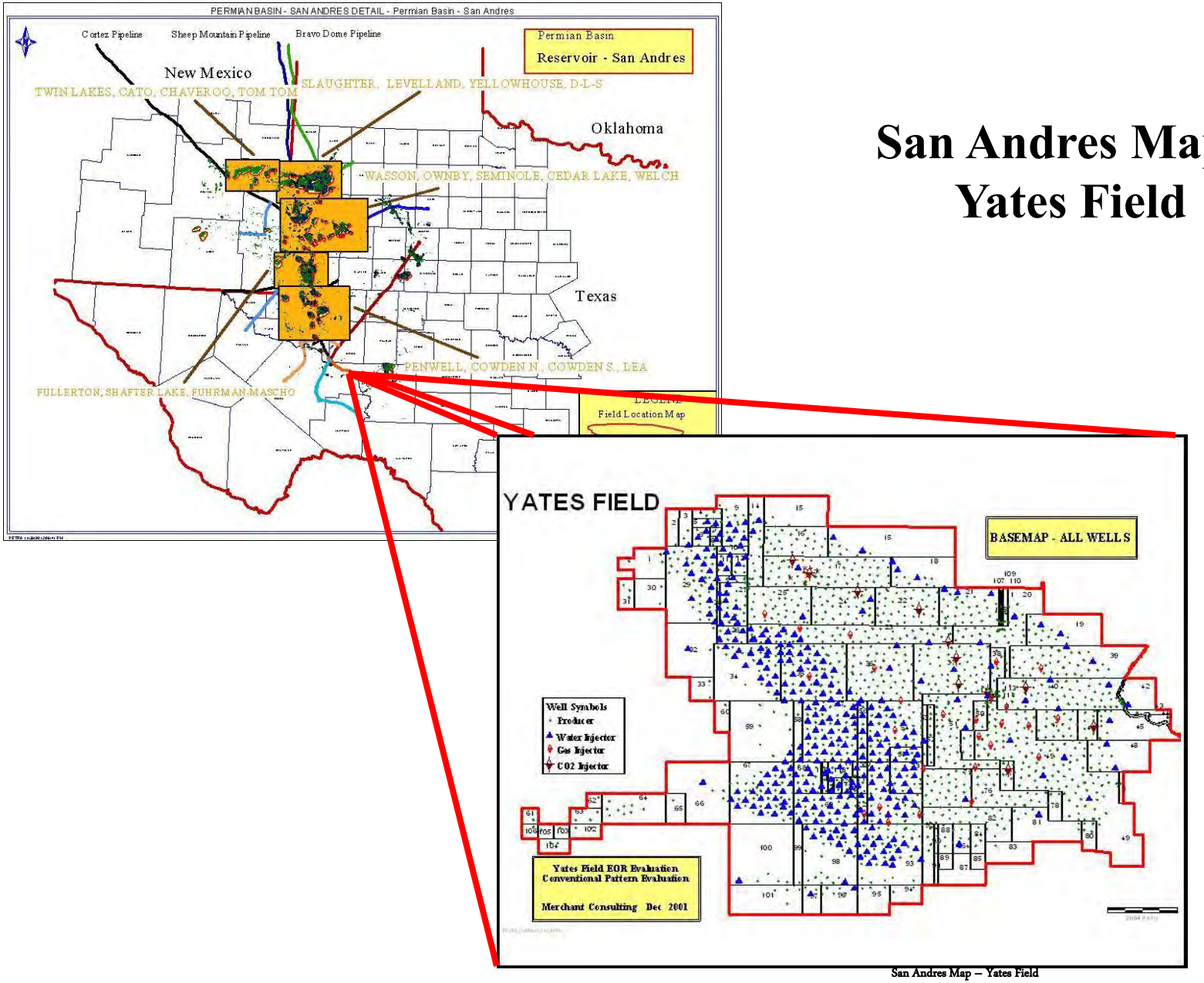


Displacement Process



Replacement Process

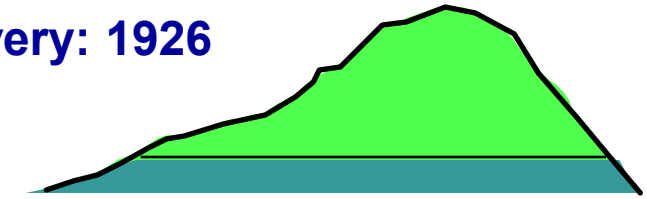
San Andres Map – Yates Field



San Andres Map – Yates Field

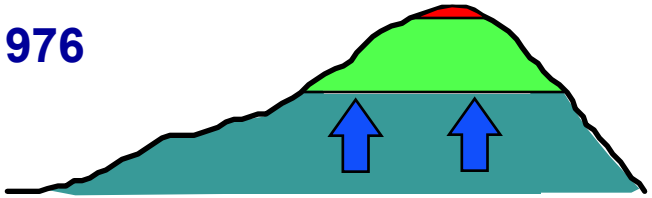
Yates Reservoir History

Discovery: 1926



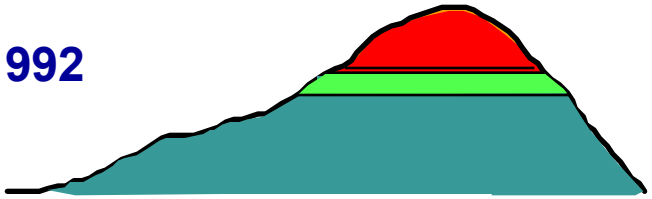
Discovered in 1926
550' of Oil Column at Structure Top

1926 - 1976



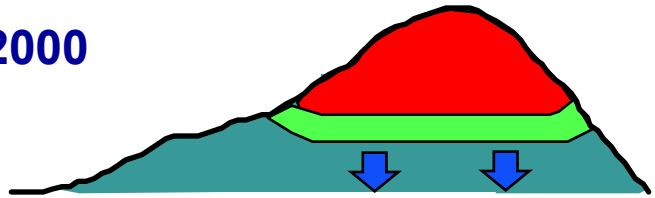
Produced By Individual Operators
Unitized in 1976 to Prevent Aquifer Influx

1976 - 1992



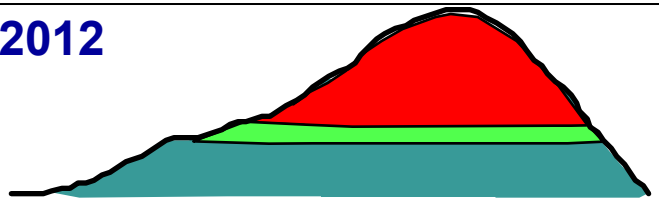
Gas Re-injected,Water Re-injected
Oil Column Thinned

1992 - 2000



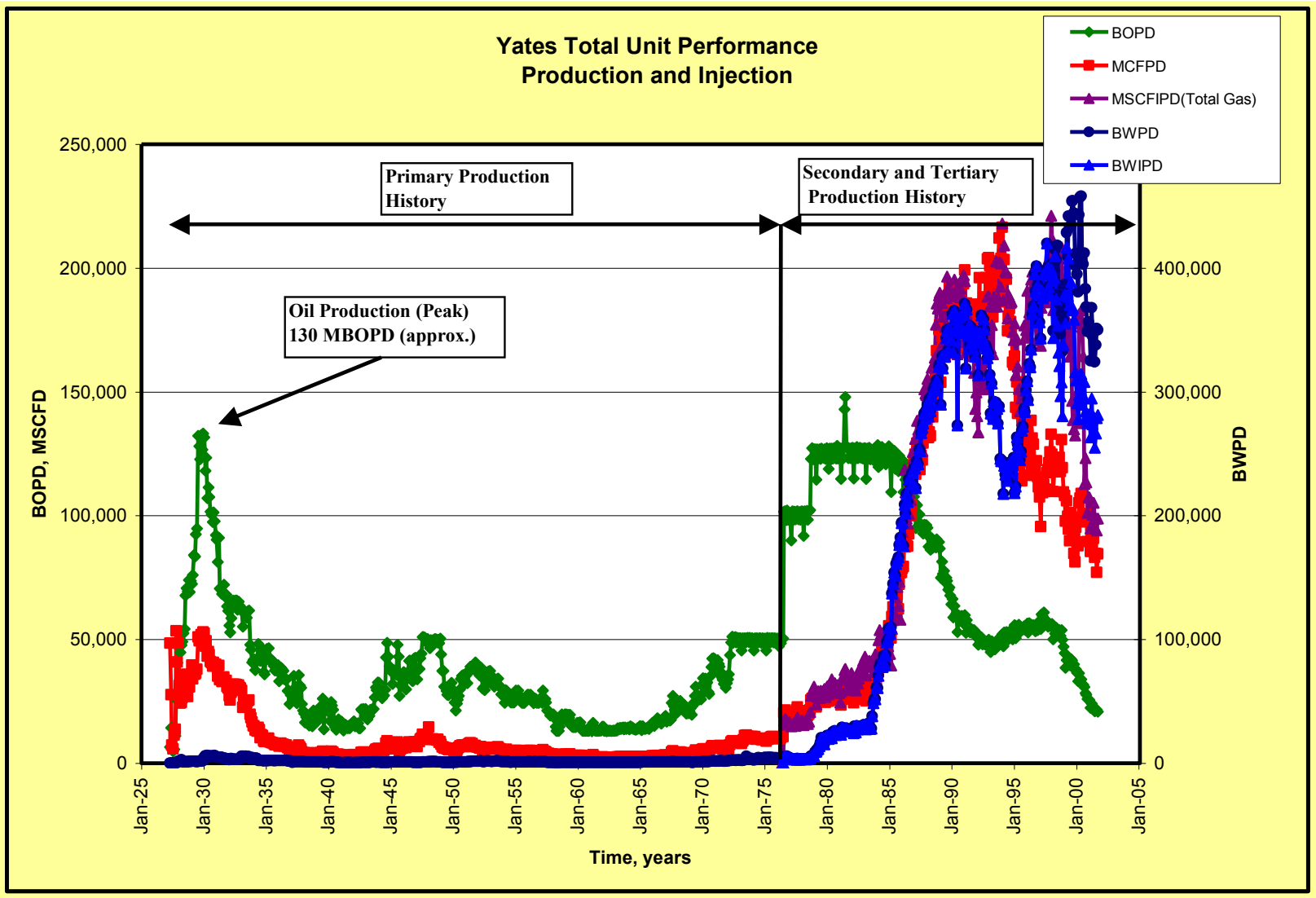
Double Displacement
Reservoir Dewatering
Contact Lowering

2000 - 2012



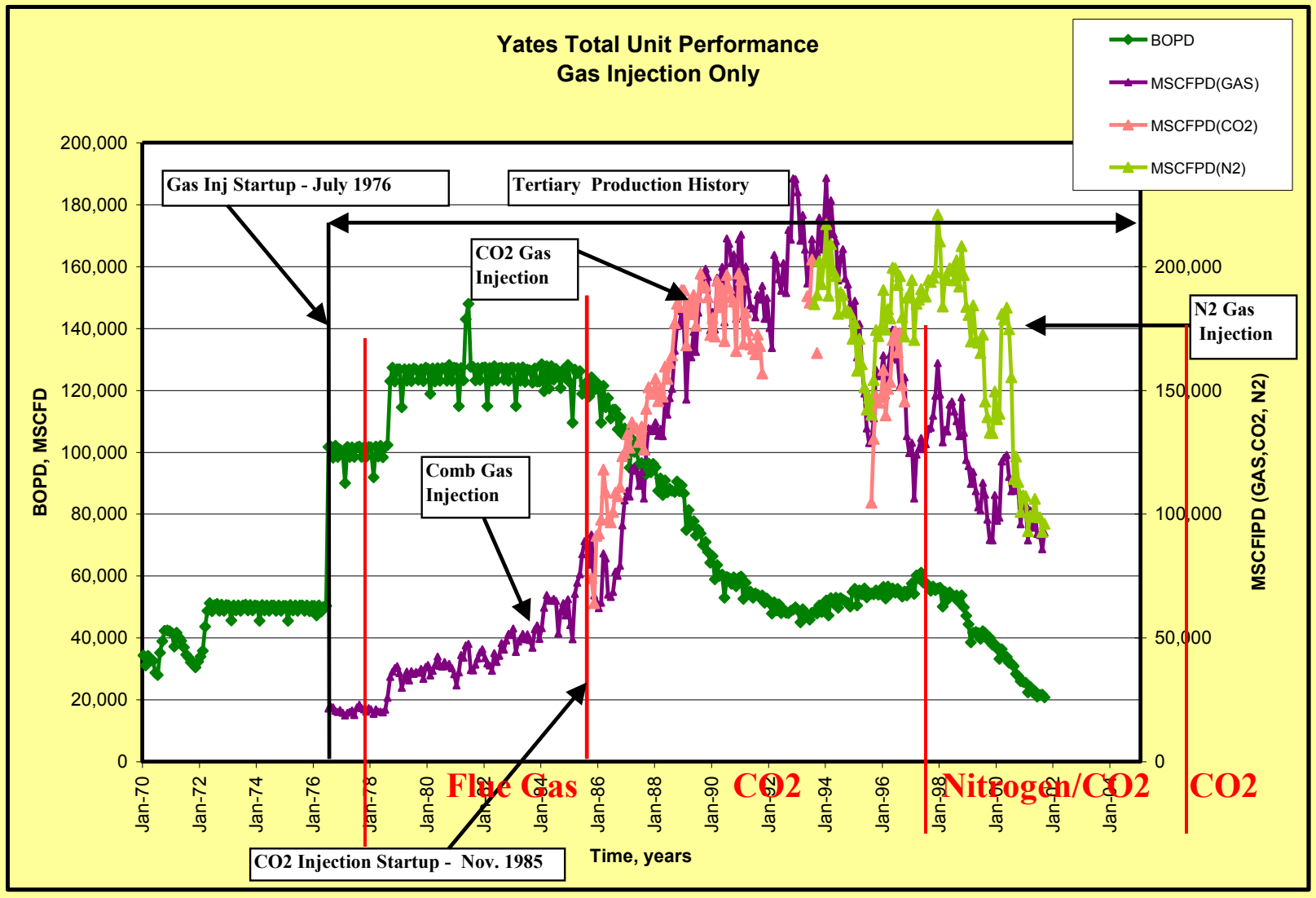
Contact Stabilization (30 ft oil column)
Gas Cap Injection
Aquifer "Maintenance" By Offsite Disposal

Yates Unit Historical Performance



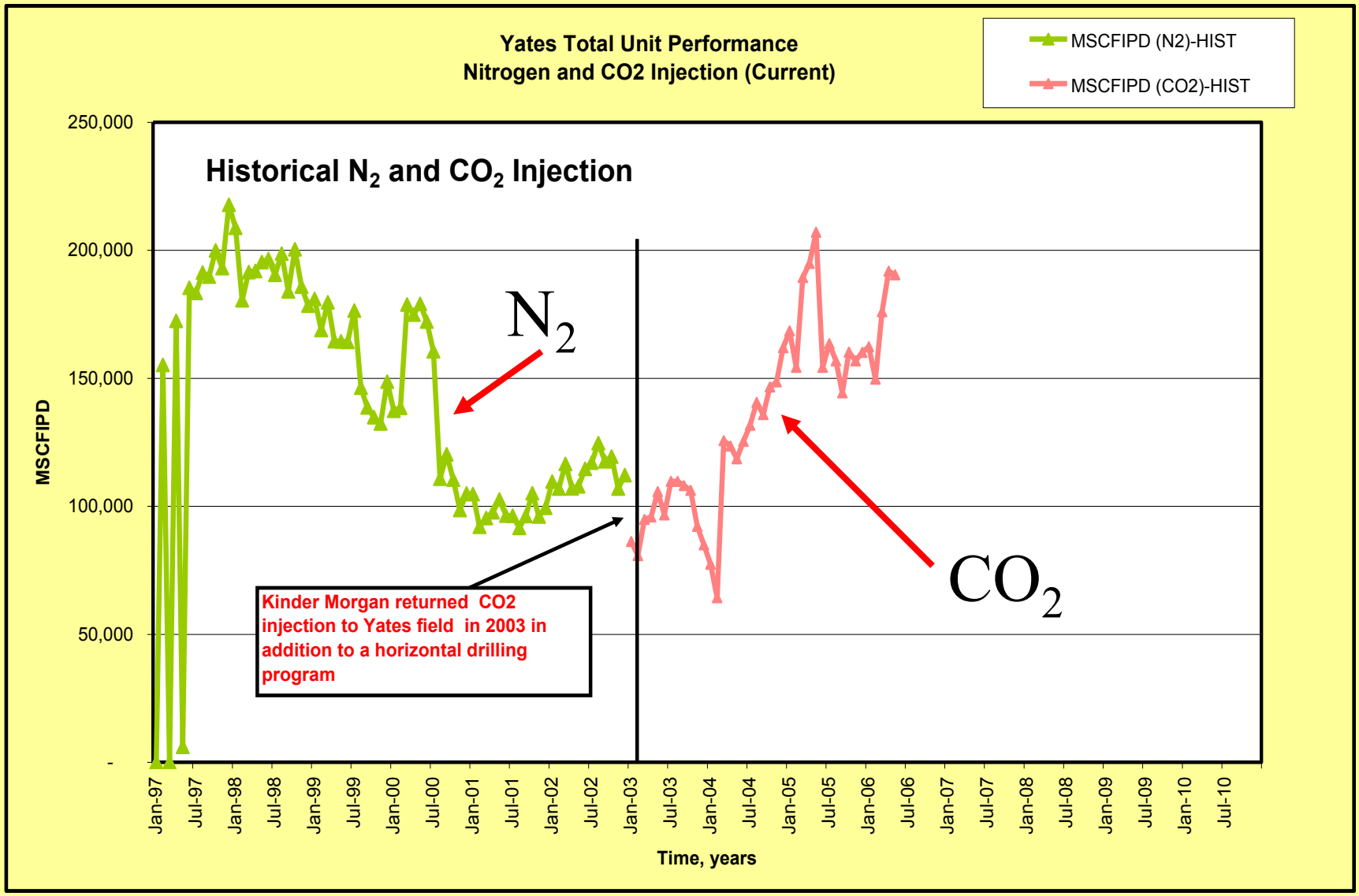
Field Production and Injection

Yates Unit Historical Performance



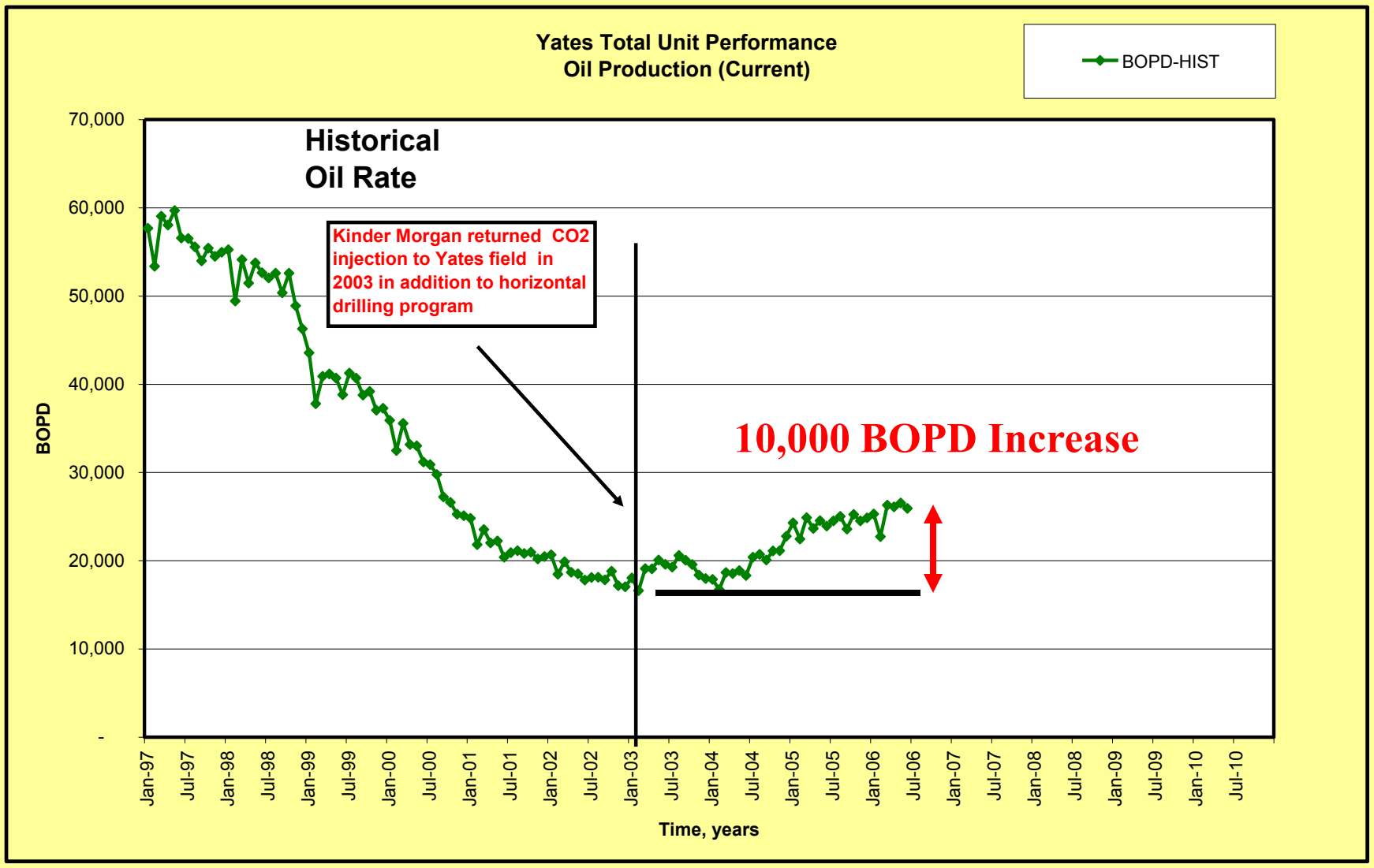
Field Gas Injection Breakout

Yates Unit Historical Performance



Field Injection (Current)

Yates Unit Historical Performance



Field Production (Current)

In 2015, the field continues to produce between 20,000 BOPD and 30,000 BOPD

Gas Cycling – Denbury Resources

<u>Ten</u> CO_2 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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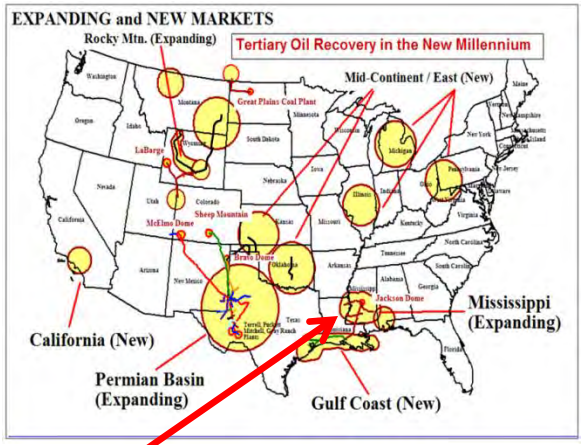
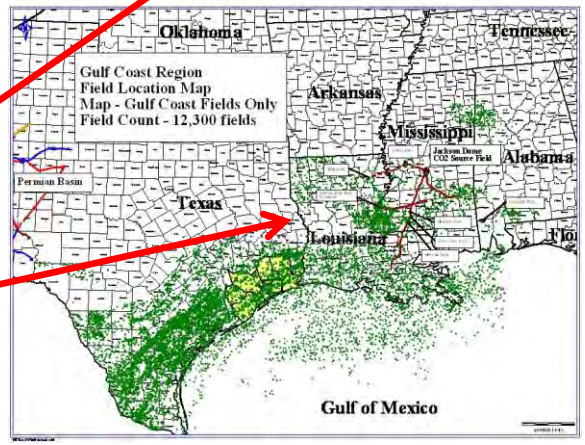
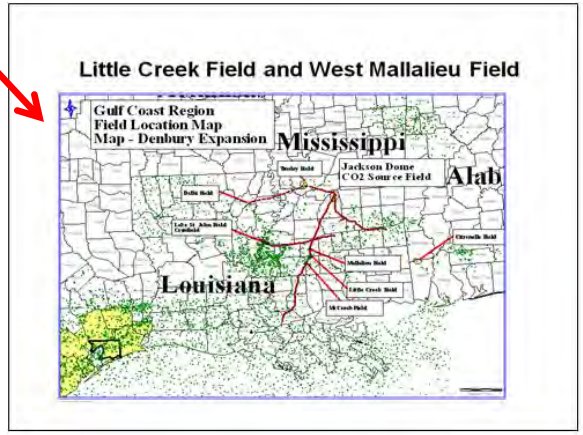
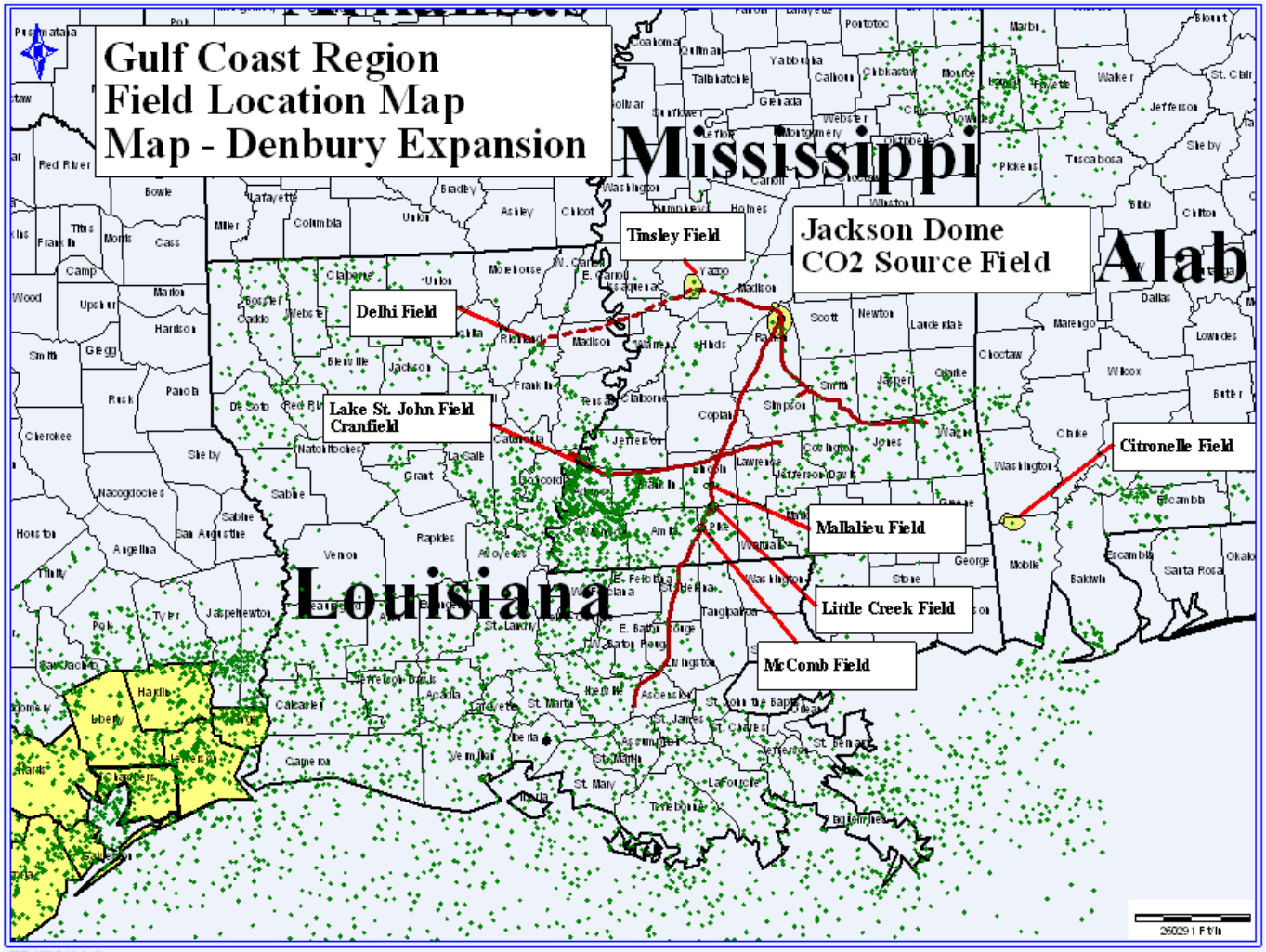






Gas Cycling Example – Denbury

Little Creek Field and West Mallalieu Field



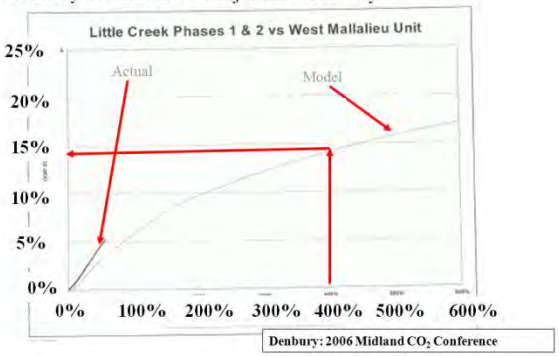
Gas Cycling Example – Denbury

Little Creek Field and West Mallalieu Field

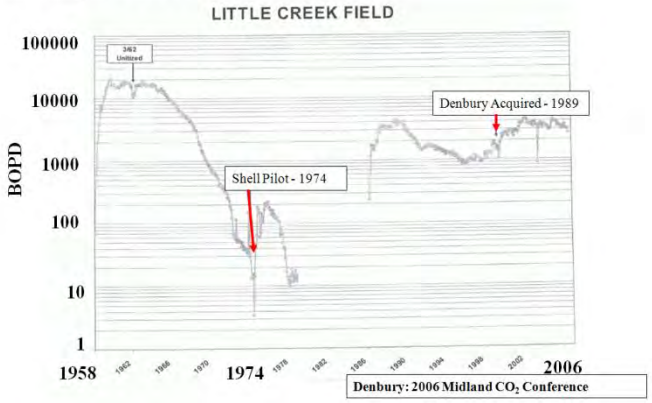
Example –Little Creek Field
West Mallalieu Field

Example –Little Creek Field West Mallalieu Fields

Denbury Resources – Projected Recovery

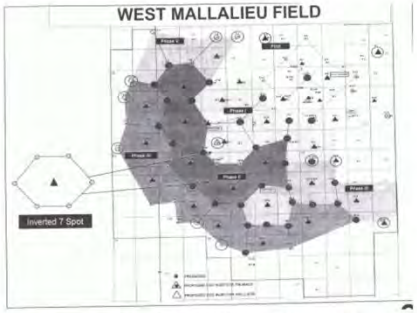


Example –Little Creek Field



Example –West Mallalieu Field

Denbury Resources – Base Map



Note: Good for fields with limited No. of Wells or Patterns

Huff-n-Puff (Single Well Injection)

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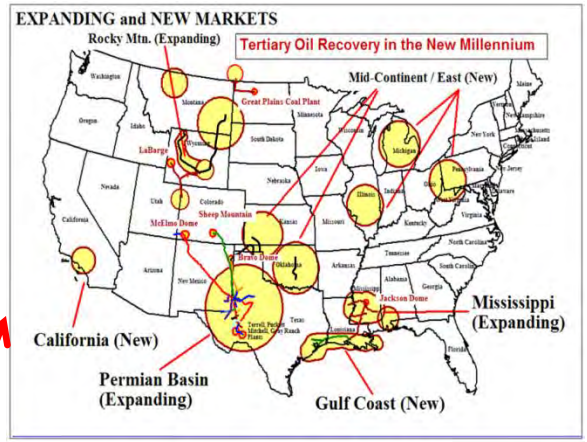
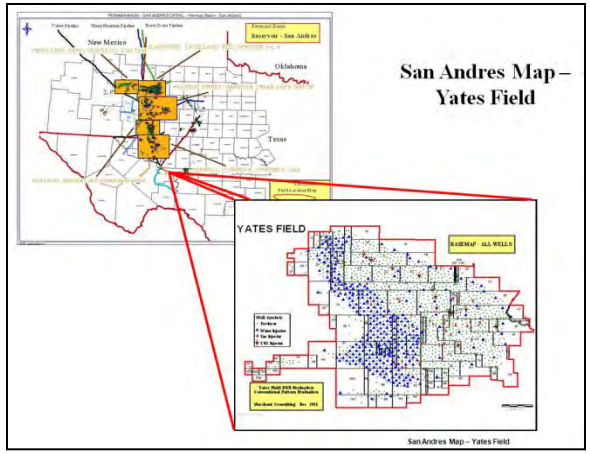
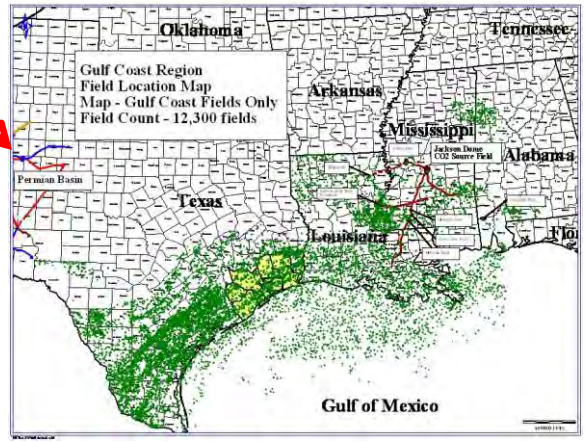
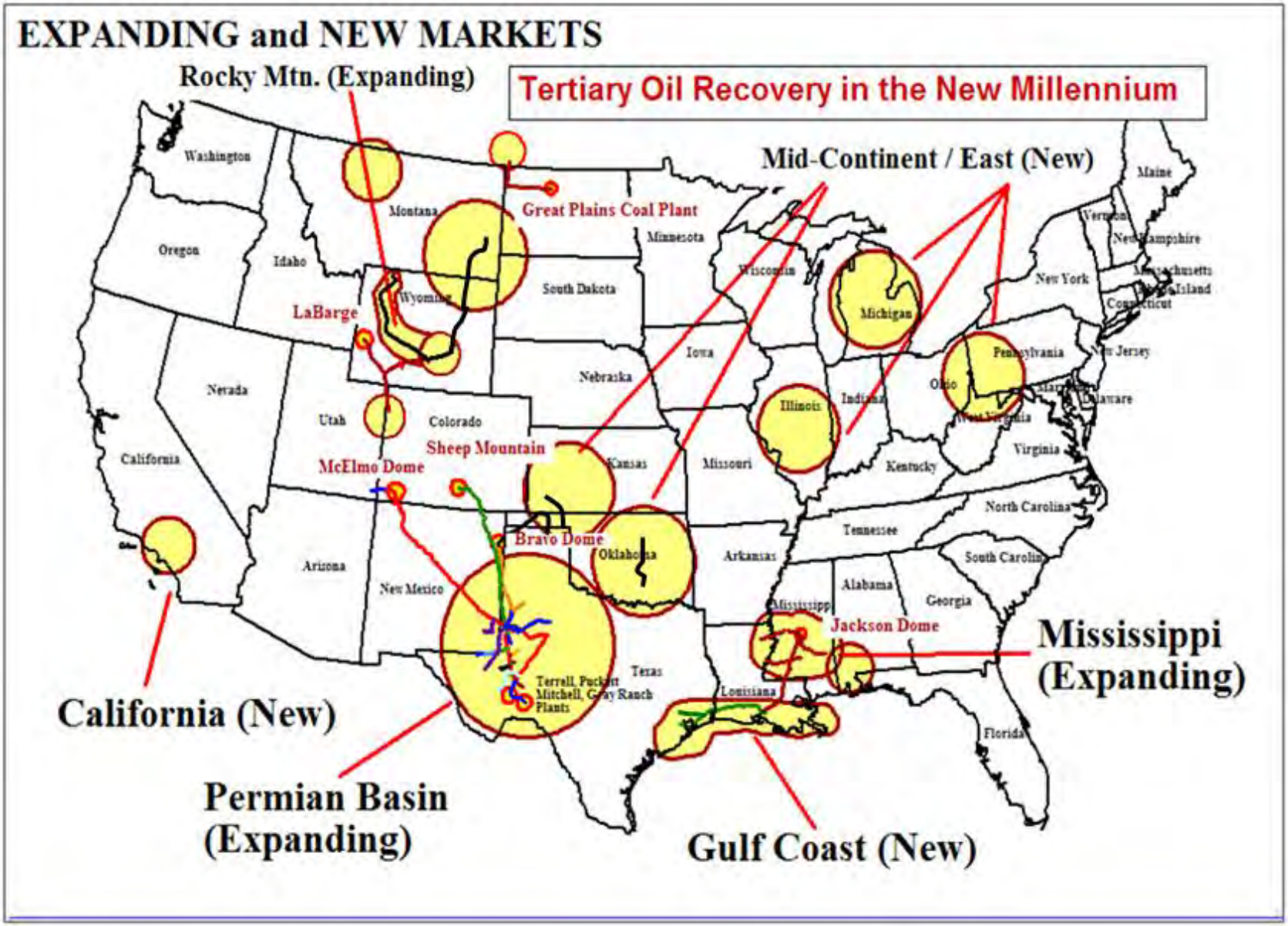






Tertiary CO_2 Flooding



Small Field and Huff-n-Puff Example

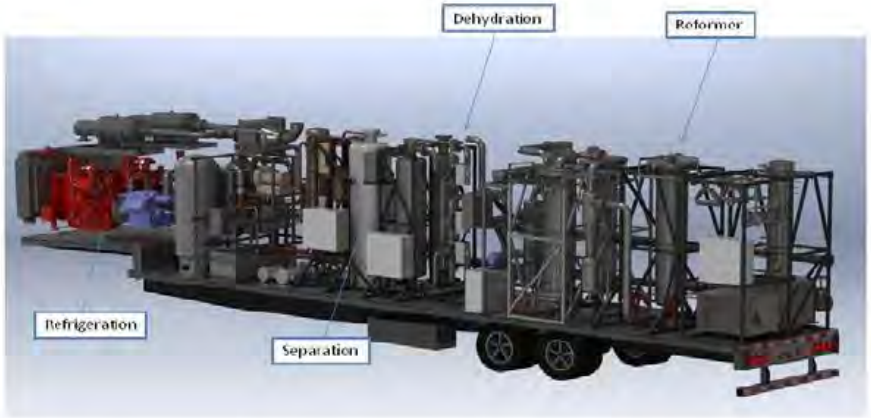
Dr. Robert Zubrin

PIONEER ENERGY
www.pioneerenergy.com

Pioneer Energy Portable Enhanced Recovery Technology (PERT) System

Characteristics of the Portable Enhanced Recovery Technology (PERT)

CO_2 output	500 Mcf/day
CO_2 product purity	94%
CO_2 out pressure	10 bar
Gross electrical output	1500 kWe
Net electrical output	1200 kWe
Power generation CO2 emissions	Less than 10% those of natural gas
Natural gas feed requirement	550 Mcf/day
Oxygen production	Included
CO2 separation system	Included
Configuration	Fully mobile, trailer mounted systems



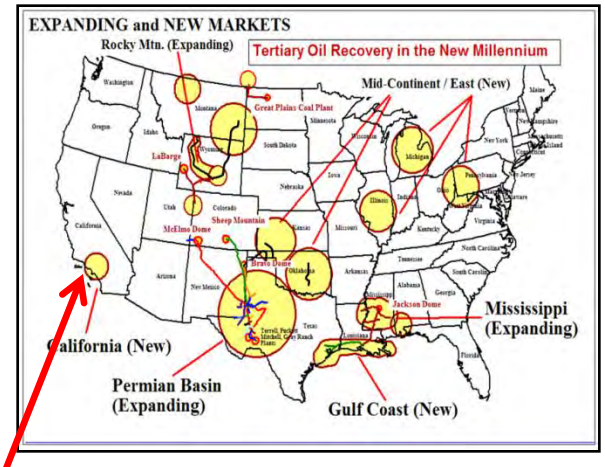
The trailer mounted, truck mobile Portable Enhanced Recovery Technology (PERT) System

Pioneer Energy | 11111 West 8th Avenue, Unit B, Lakewood, CO 80215 | (303) 339-7932
www.pioneerenergy.com

Heavy Oil (14+ API Gravity)

Ten CO_2 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).
6. Huff-and-Puff (100+ Projects)
7. Heavy Oil - Calif. (14+ API Gravity)
8. Shale Oil (Bakken) (Under Investigation)
9. Horizontal Well Pattern Development
10. CO_2 Gas Drive w/ Nitro Boost



Wilmington Onshore CO_2 Pilots

Wilmington Offshore THUMS Unit

Heavy Oil Example – 14+ API Gravity

Wilmington Field – Los Angeles (3 CO_2 Pilots)

Wilmington Field

Wilmington CO_2 Pilot Results

1. Pilots were Demonstration Projects (Not Oil in the Tank Pilots)
2. Wilmington Oil – 10 fold decrease in Viscosity (300 cp to 30 cp)
3. Wilmington Oil – 1.15 fold increase in Oil Swelling
4. Wilmington Oil – Immiscible with 85% CO_2 and 15% N_2
5. Wilmington Oil Response – Single Well Response 30 BOPD to 300 BOPD

Shale Oil – Bakken, Wolfcamp

Ten CO_2 Recovery Methods used for Tertiary Oil Recovery in the United States

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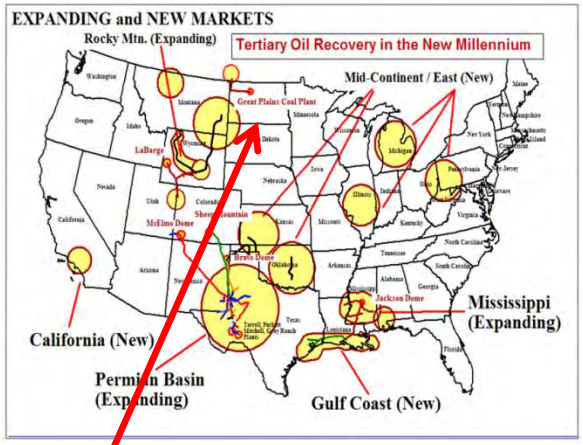
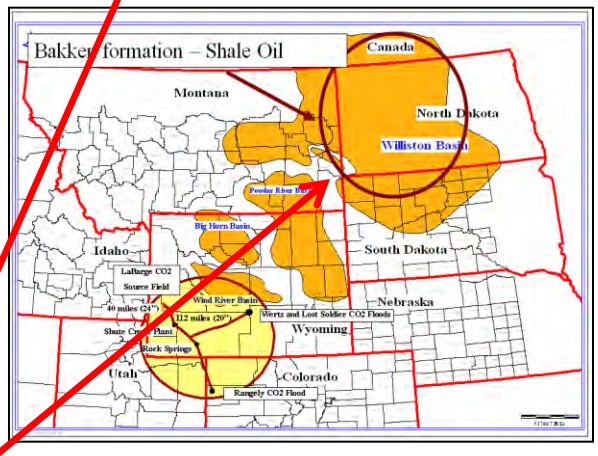
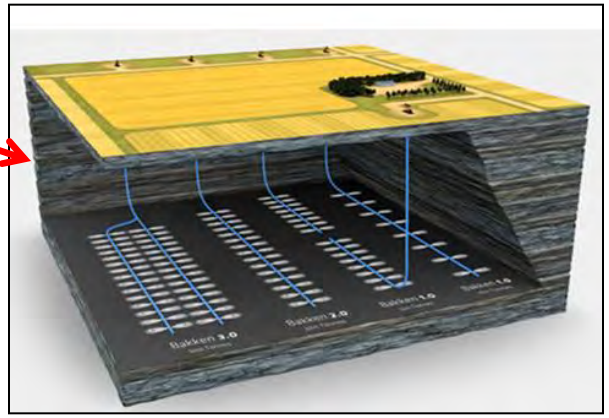
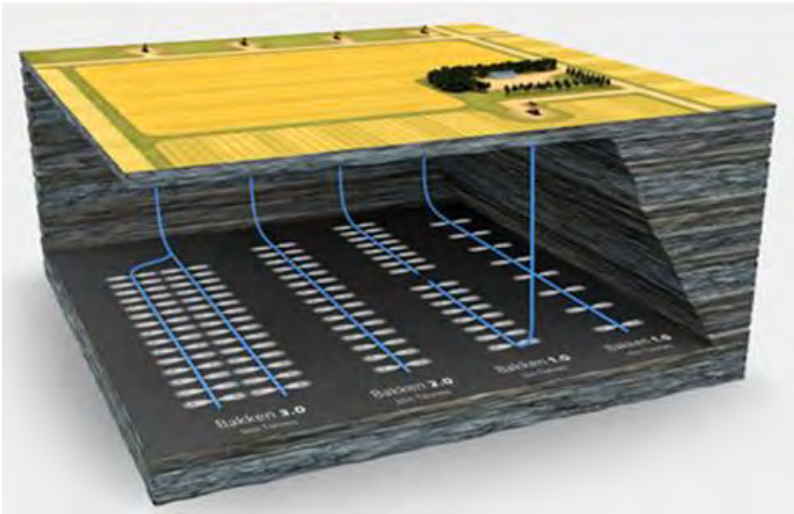


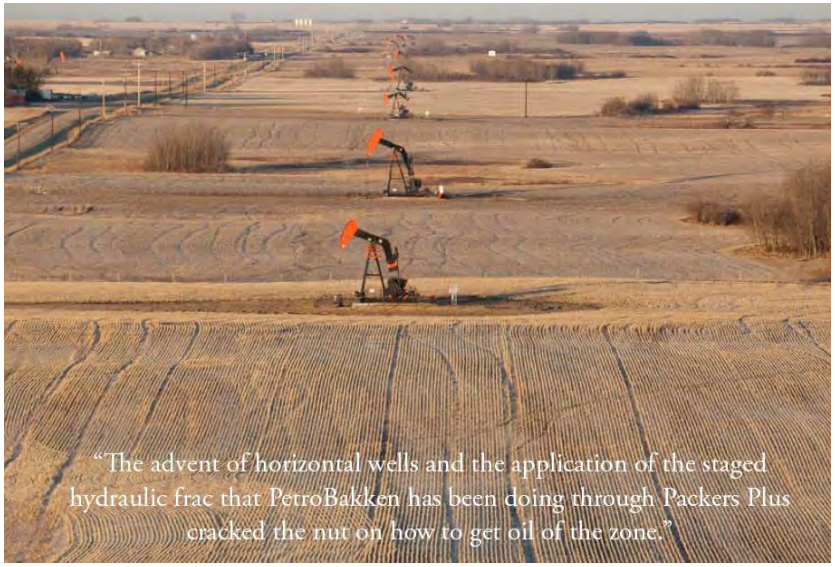




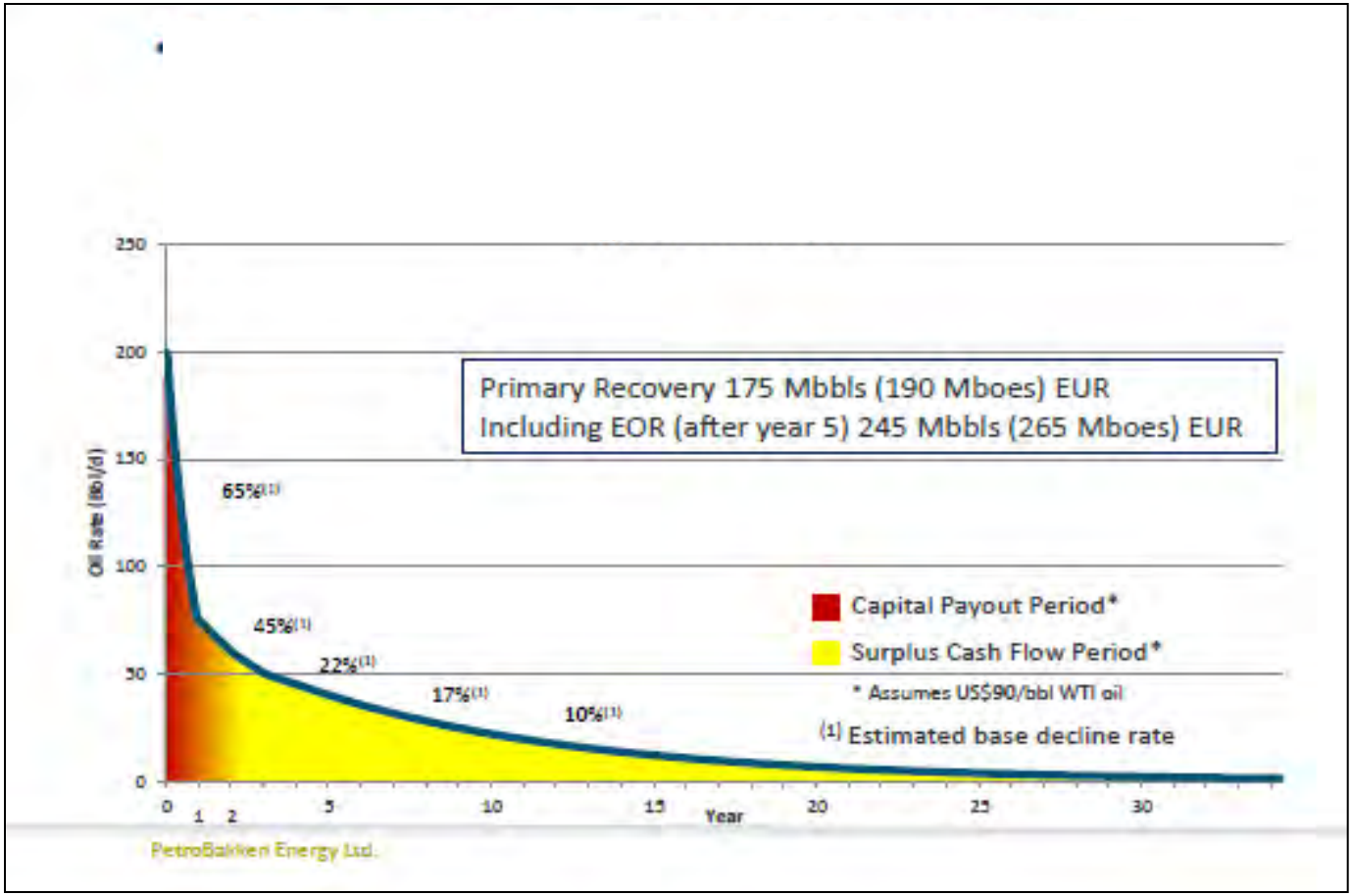
Williston Basin – Bakken Formation – Shale Oil Target

To improve Primary Oil Recovery, operators have resorted from single to bilateral <u>Horizontal Well Completions</u> with massive sand fracture technology to improve Primary Oil Recovery.





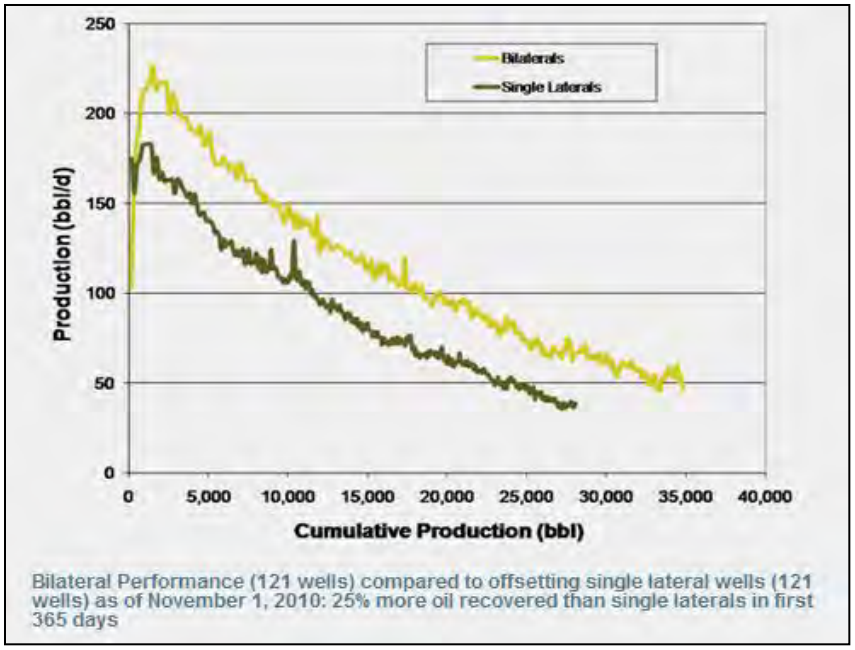
Williston Basin – Bakken Formation

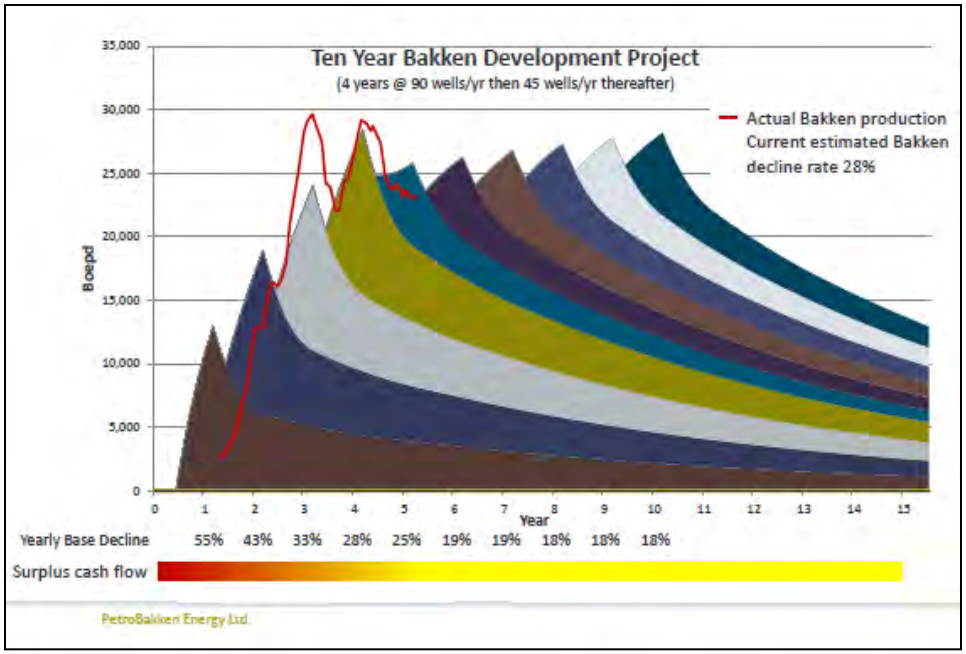


To make this technology work, large investments involving many horizontal wells on steep decline are required to keep a reasonable continuous rate profile. This results in a many well, many year continuous drilling programs.

Williston Basin – Bakken Formation

Results of this effort are shown below

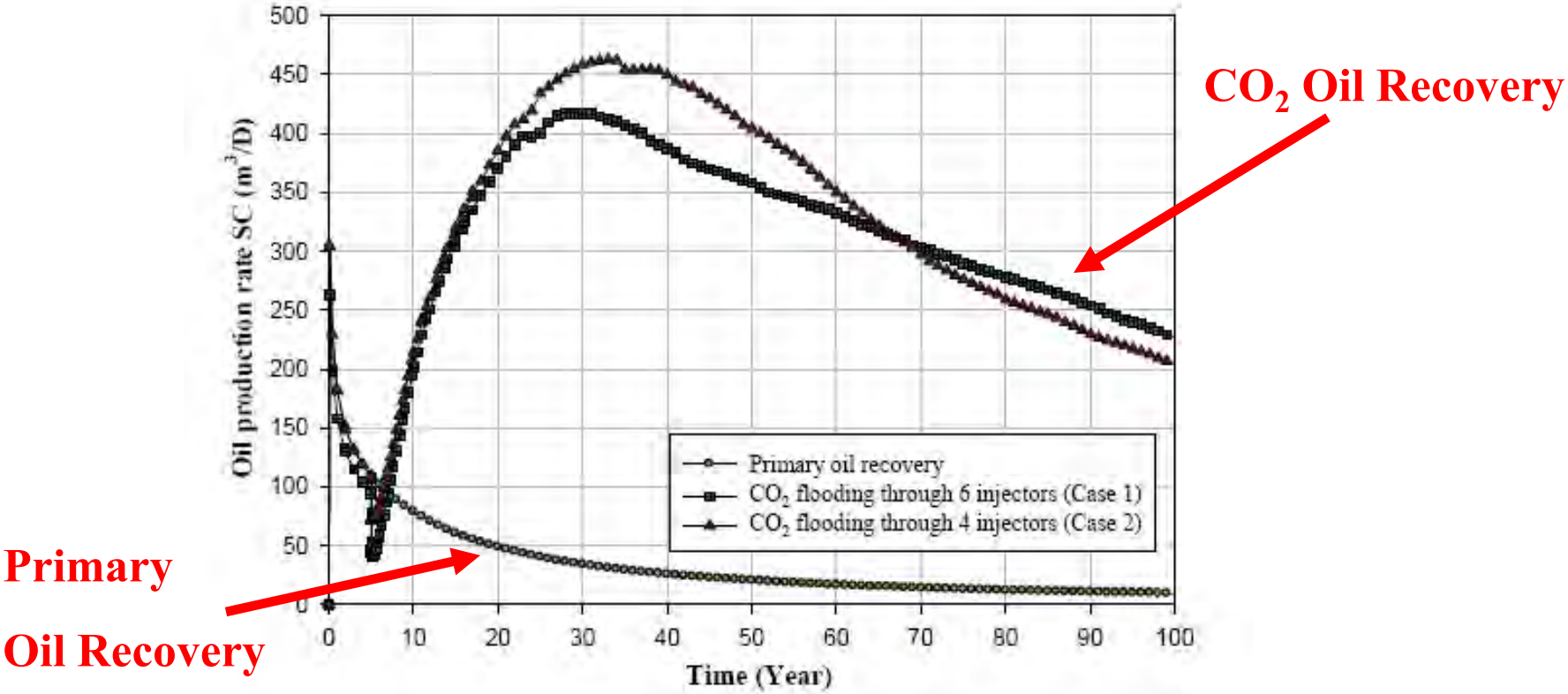




The 10 year Bakken development plan shown above contains 10 one year phases. <u>Ninety wells per phase per year</u> are required for the <u>first four phases</u> with <u>45 wells per phase per year</u> for the <u>last six phases</u>. This results in a total of 635 wells to be drilled over a 10 year period with a single well cost of around 3 million dollars. For other areas of the Bakken drilling costs can exceed 12 million dollars per well.

Williston Basin – Bakken Formation

Reservoir Model Study – CO_2 Tertiary Prediction



Simulation Comparison study results are shown above. Primary recovery was limited to 5 years (3.64% OOIP). With CO_2 Injection over 95 years, Continuous Injection of CO_2 out-performed water injection and other cyclic Huff-n-Puff injection schemes.

Williston Basin – Bakken Formation

Reservoir Model Study – CO_2 Tertiary Prediction

Simulation results of different cases.

No.	Scenario	Oil recovery ($\times 10^6$ m^3)	Oil recovery factor (%)	Gas injected ($\times 10^6$ ton)	Time after injection to breakthrough (year)
1	CO_2 (6 inj.)	11.2	33.0	38.6	0.3
2	CO_2 (4 inj.)	11.7	34.3	4.6	5.0
3	Cyclic CO_2 (4 inj.)	9.8	28.9	3.2	5.0
4	CO_2+CH_4	12.3	36.2	5.9	5.0
5	CO_2+N_2	10.9	32.1	5.4	5.0
6	Water	2.8	8.3	—	35.0
7	Water+CO_2	7.3	21.6	1.9	35.0
8	CO_2 (Hetero model)	10.1	31.5	4.2	5.0

Water flood Recovery

CO_2 Recovery

The simulation results show that CO_2 flooding presents a <u>technically</u> promising method for recovering Bakken oil, but over a very long injection period (95 years of injection). Also, note the long time to breakthrough (several months to many years).

Horizontal Well Development

Ten CO_2 Recovery Methods used for Tertiary Oil Recovery in the United States

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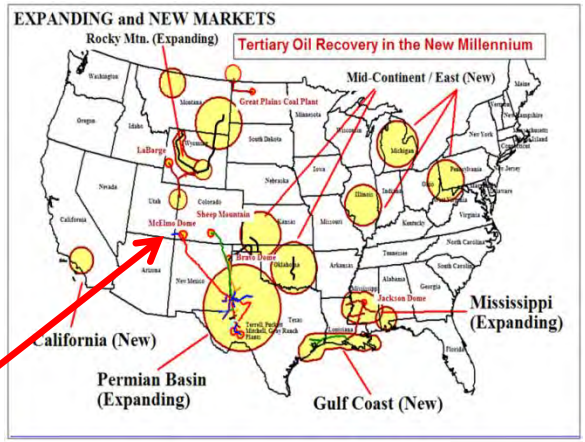
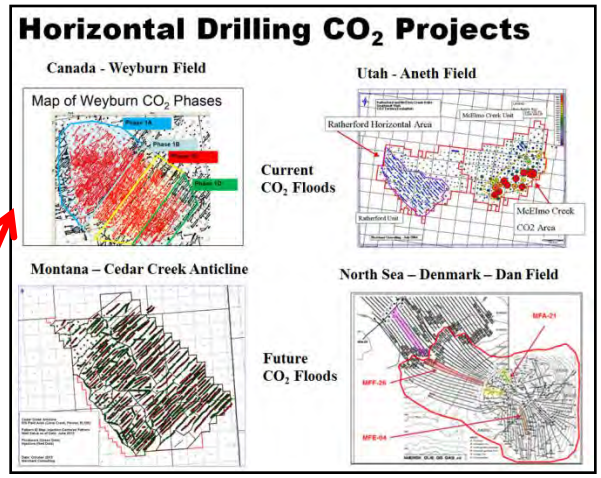
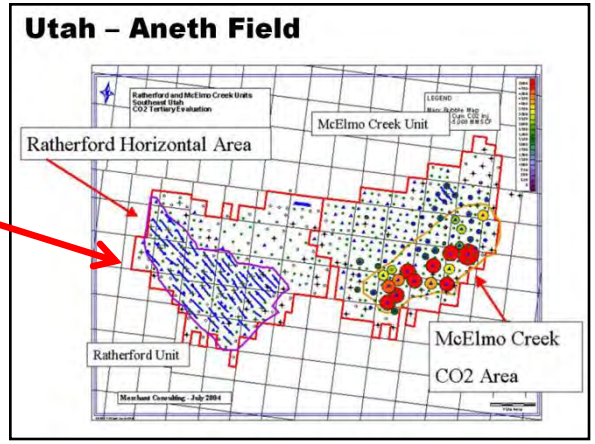
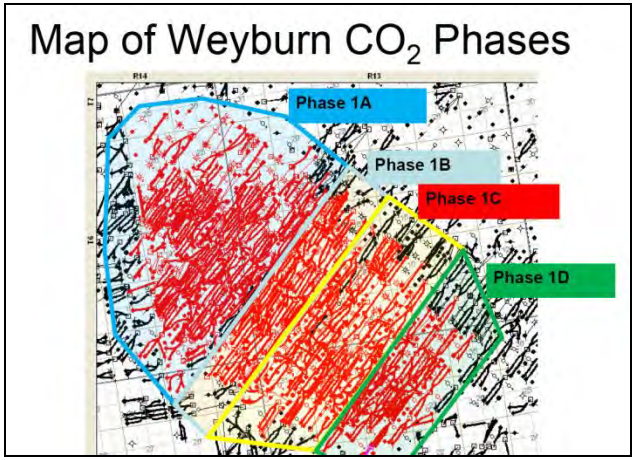




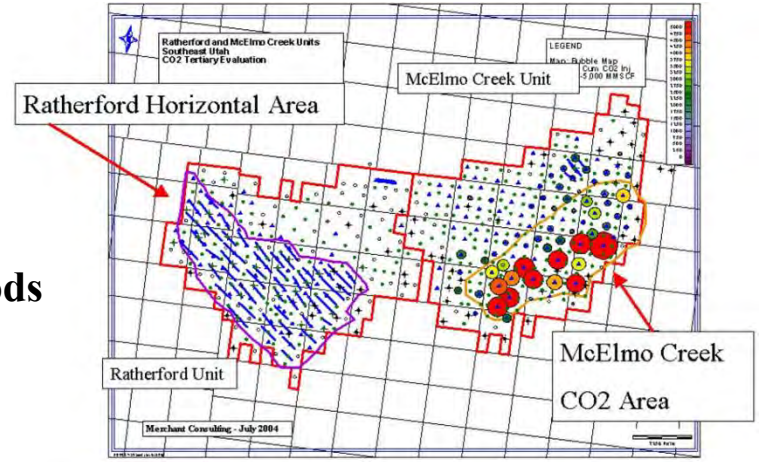


Horizontal Drilling CO_2 Projects

Canada - Weyburn Field

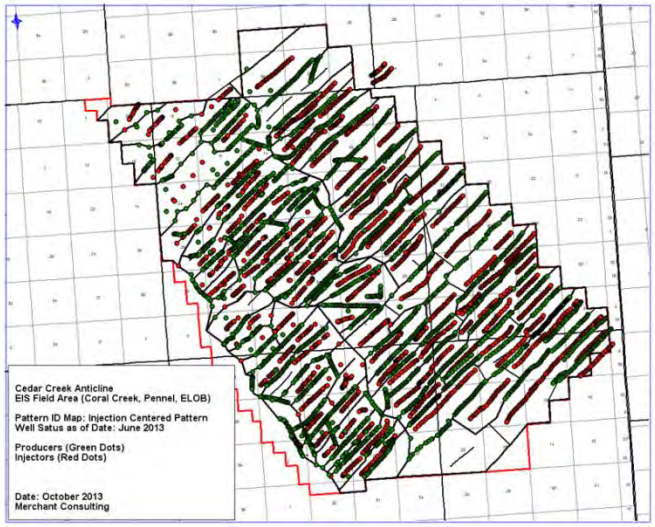


Utah - Aneth Field

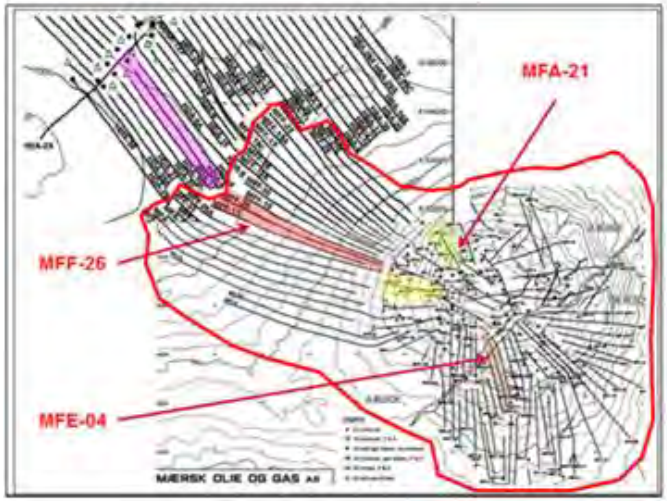


Current CO_2 Floods

Montana – Cedar Creek Anticline



North Sea – Denmark – Dan Field



Future CO_2 Floods

CO_2 Gas Drive w/ Nitro Boost

<u>Ten</u> CO_2 Recovery Methods used for Tertiary Oil Recovery in the United States

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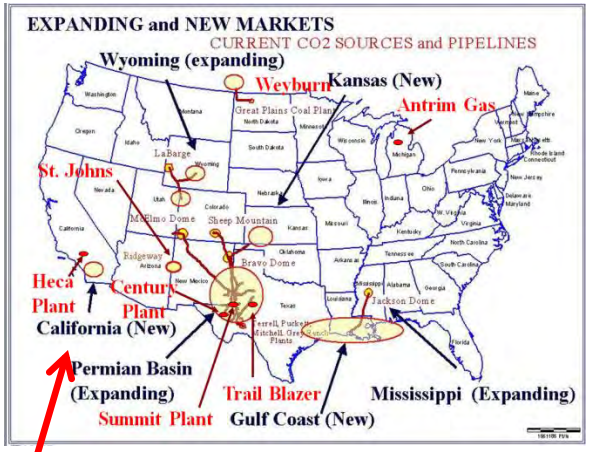
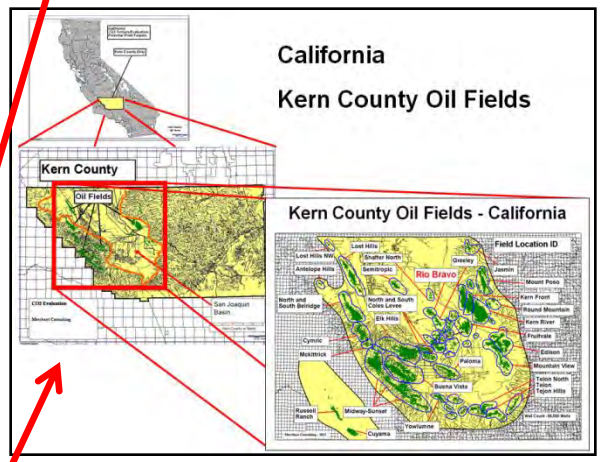
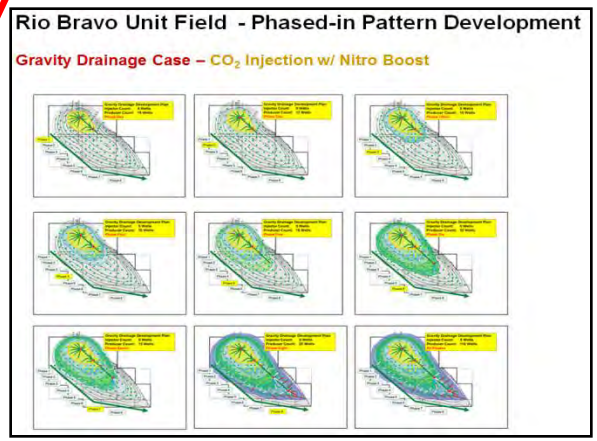
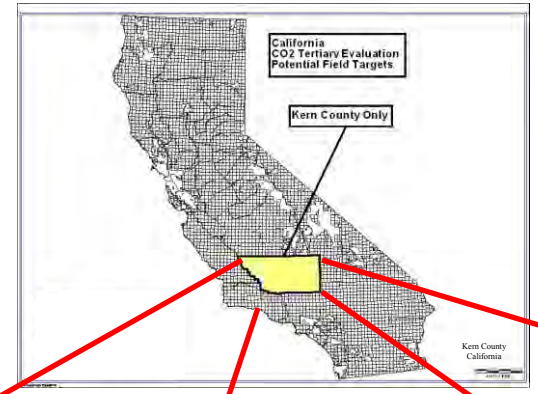


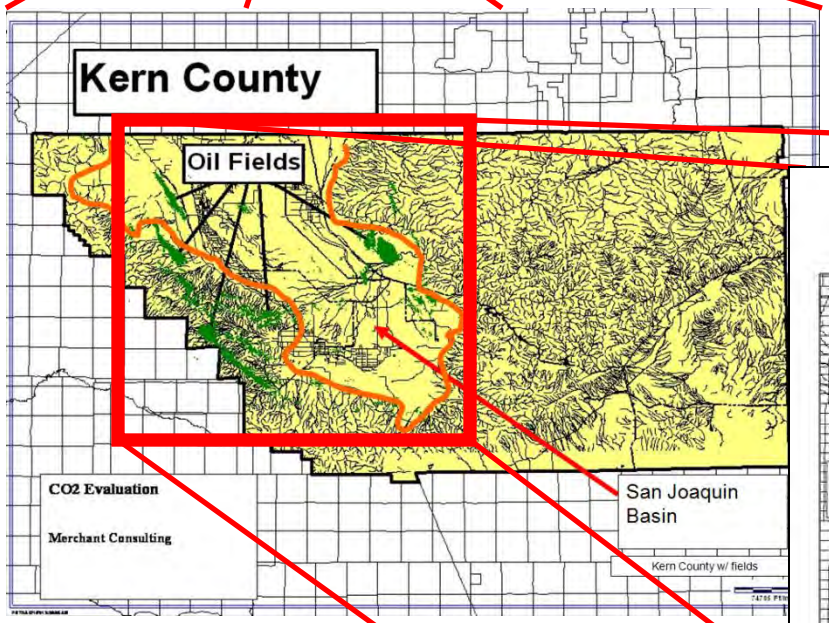


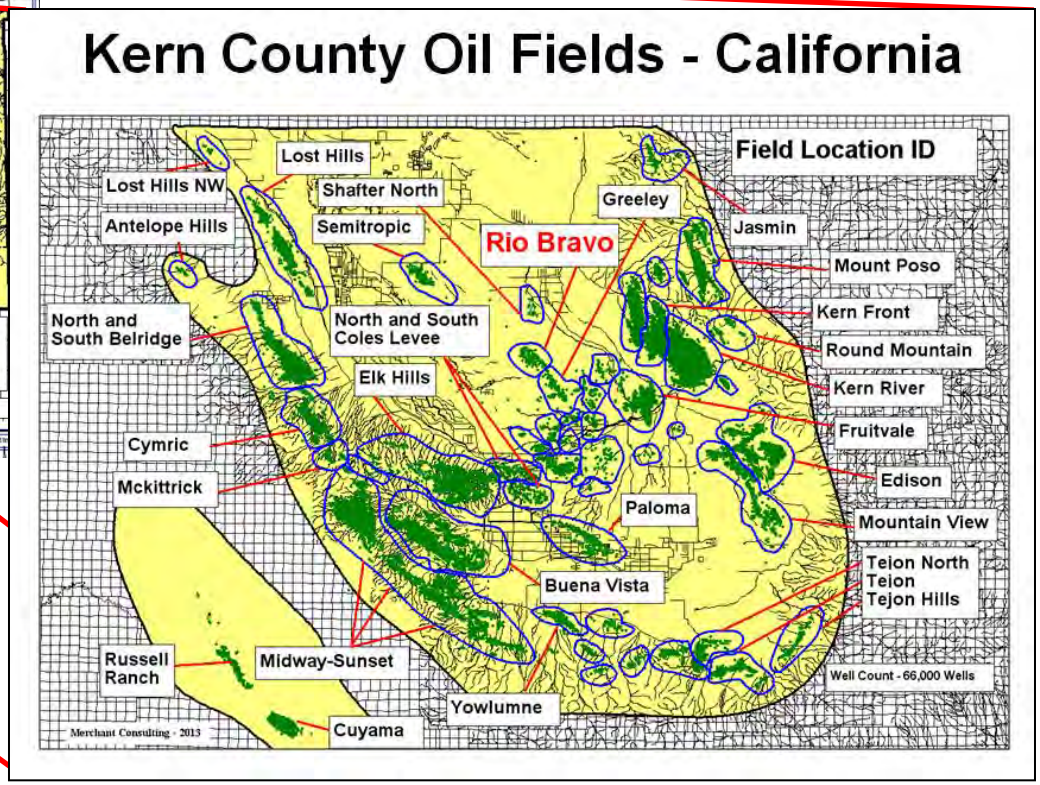


California

Kern County Oil Fields

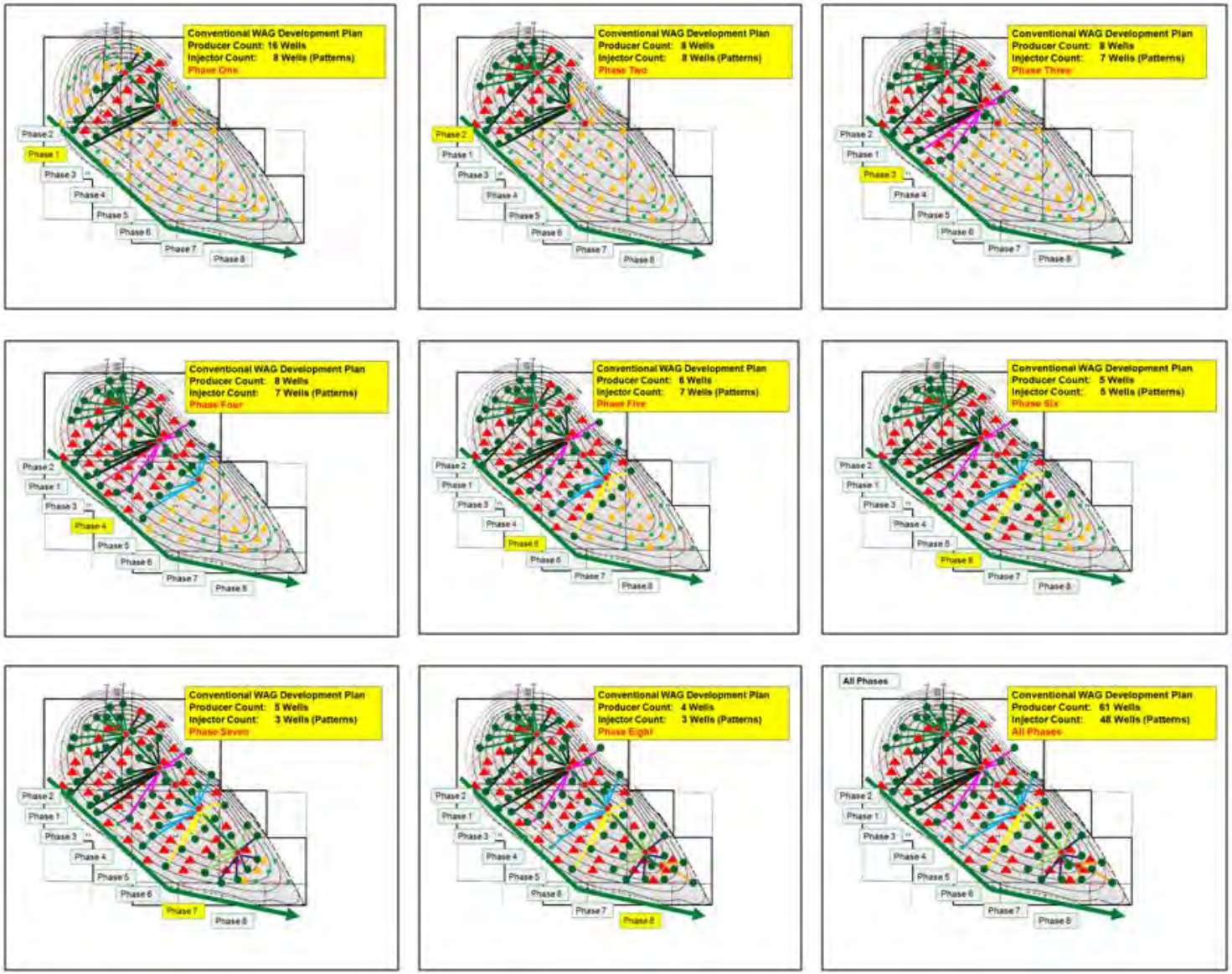






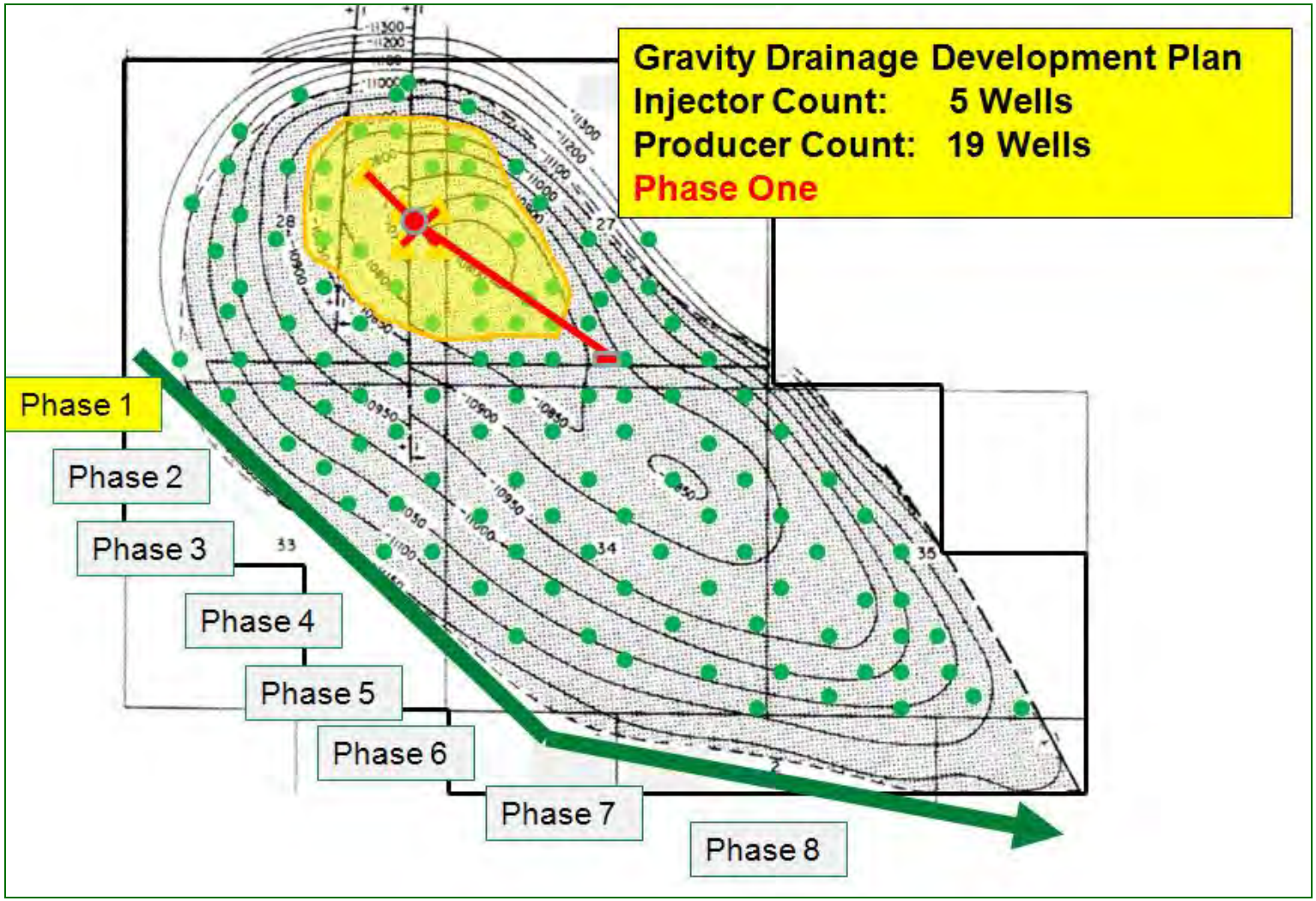
Rio Bravo Field - Phased-in Pattern Development

Conventional WAG Case – Producer and Injector Pattern Development



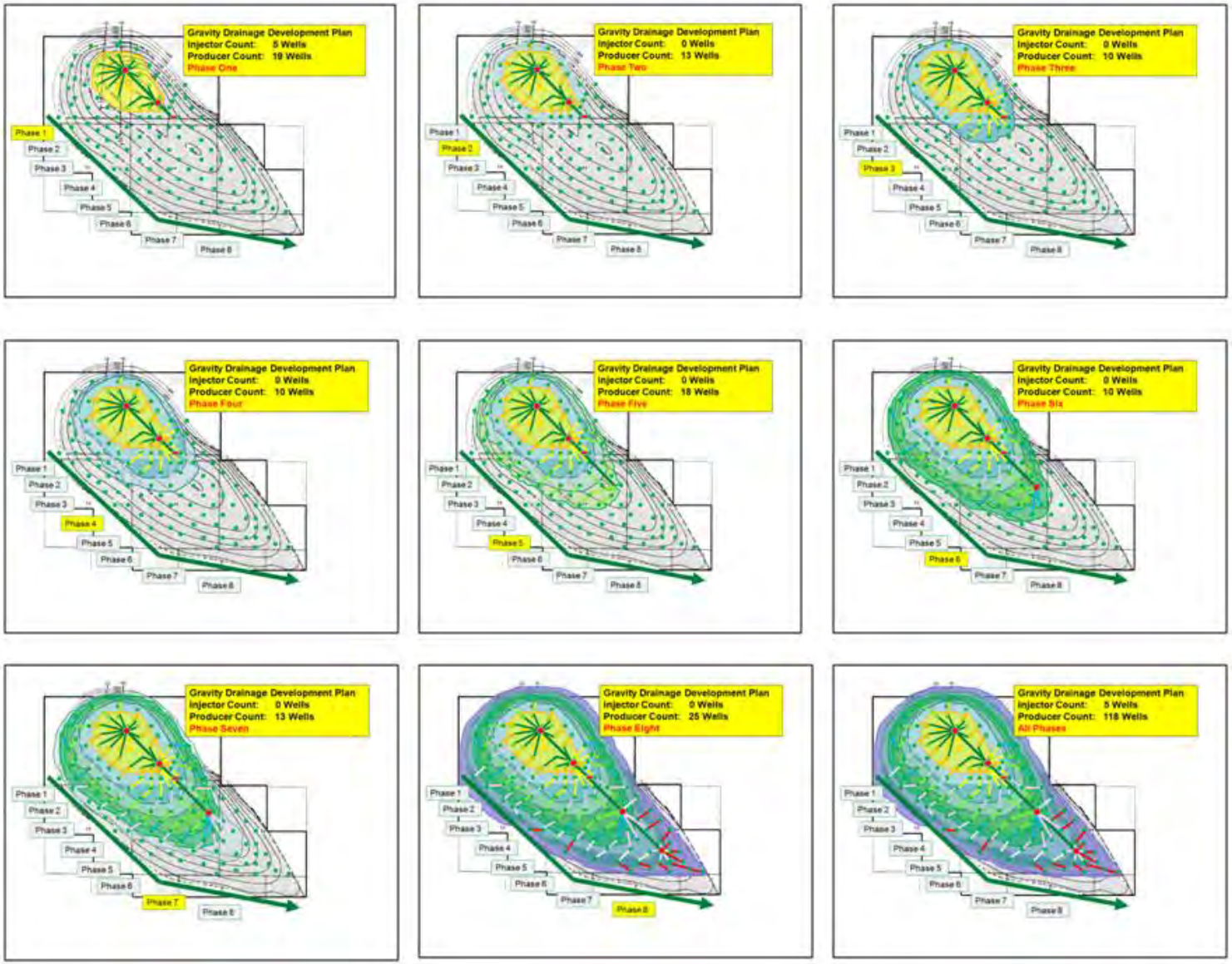
Rio Bravo Field - Phased-in Pattern Development

Gravity Drainage Case - Injectors

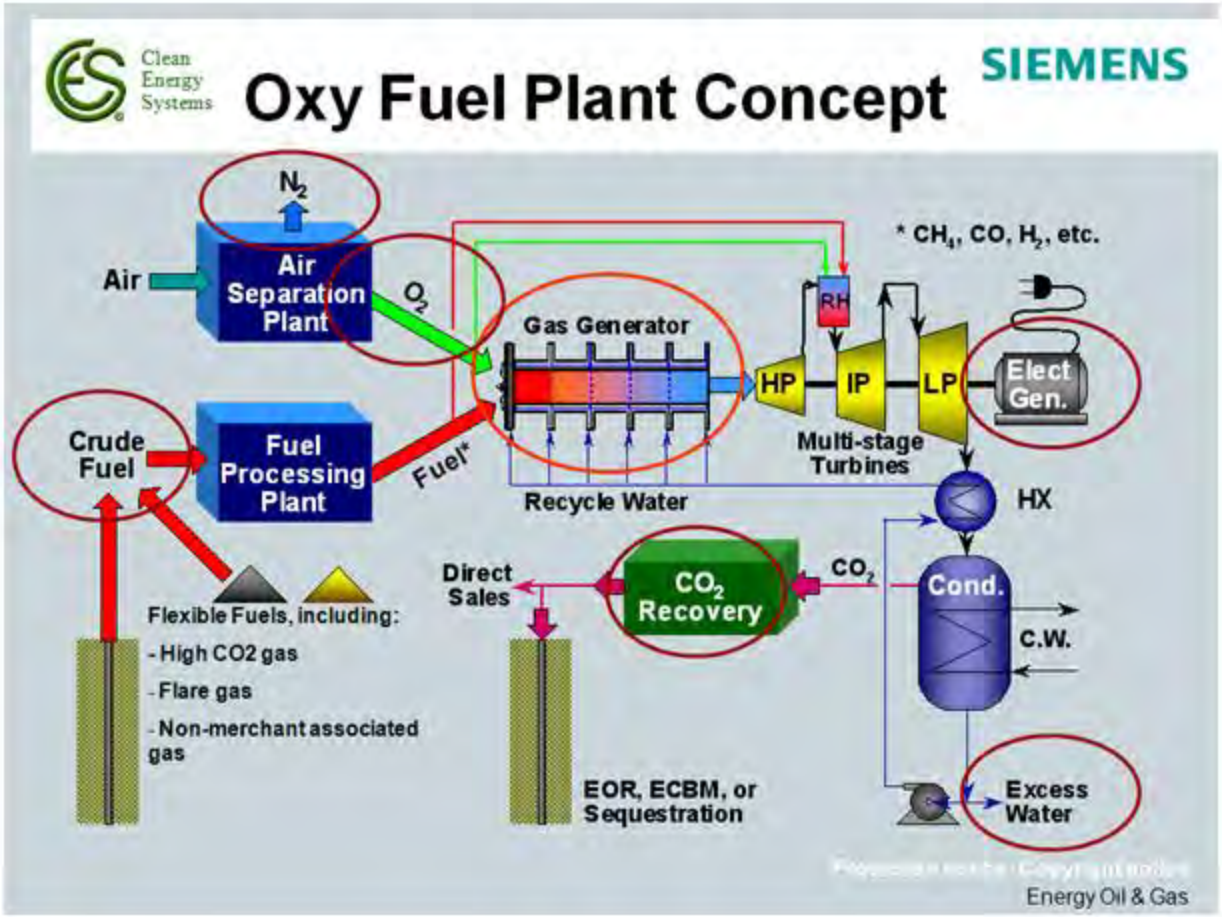


Rio Bravo Field - Phased-in Pattern Development

Gravity Drainage Case - Producers



Oxy Fuel Concept

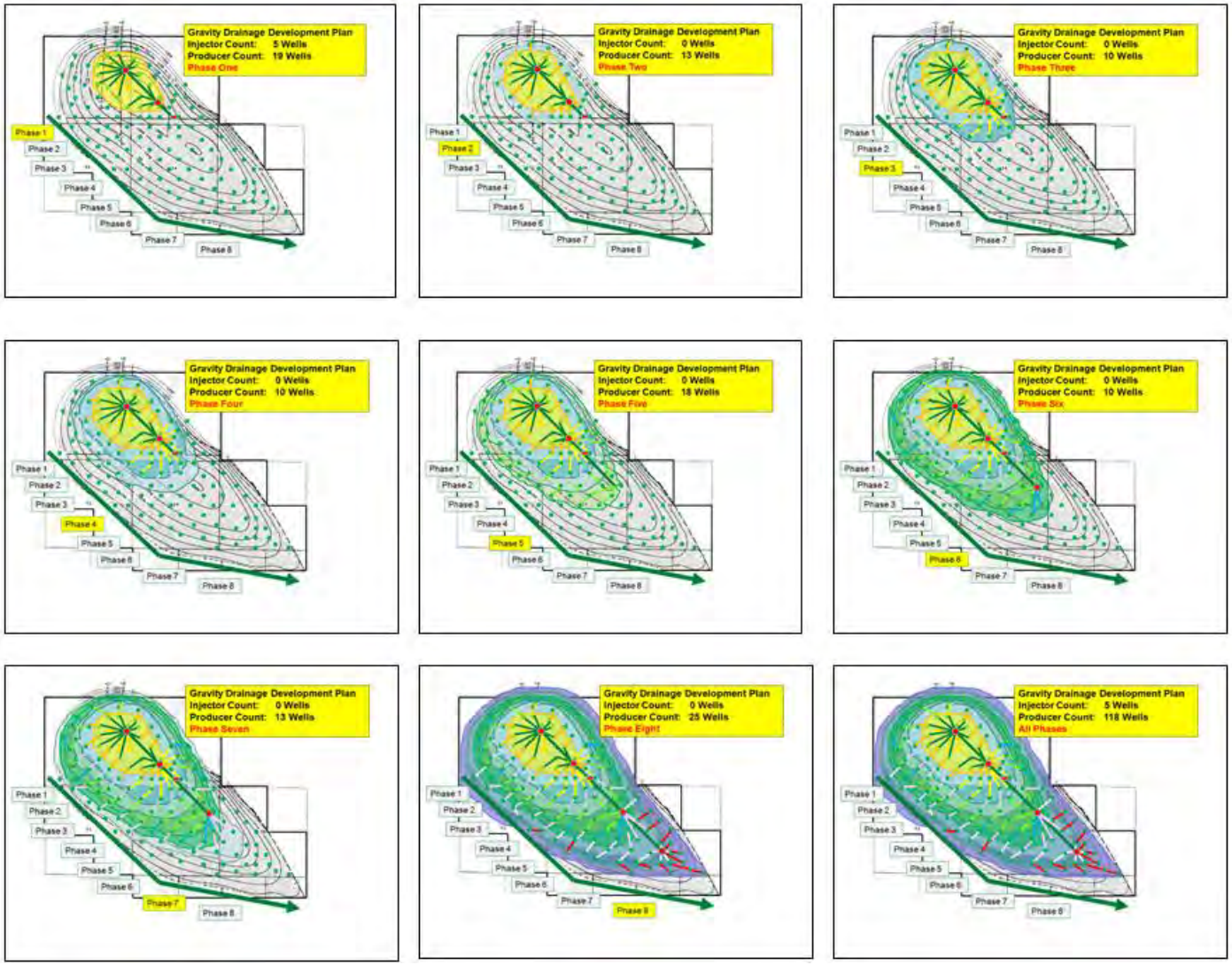


Input: Hc-Gas

Output: CO_2
Electricity
Water
N_2

Rio Bravo Unit Field - Phased-in Pattern Development

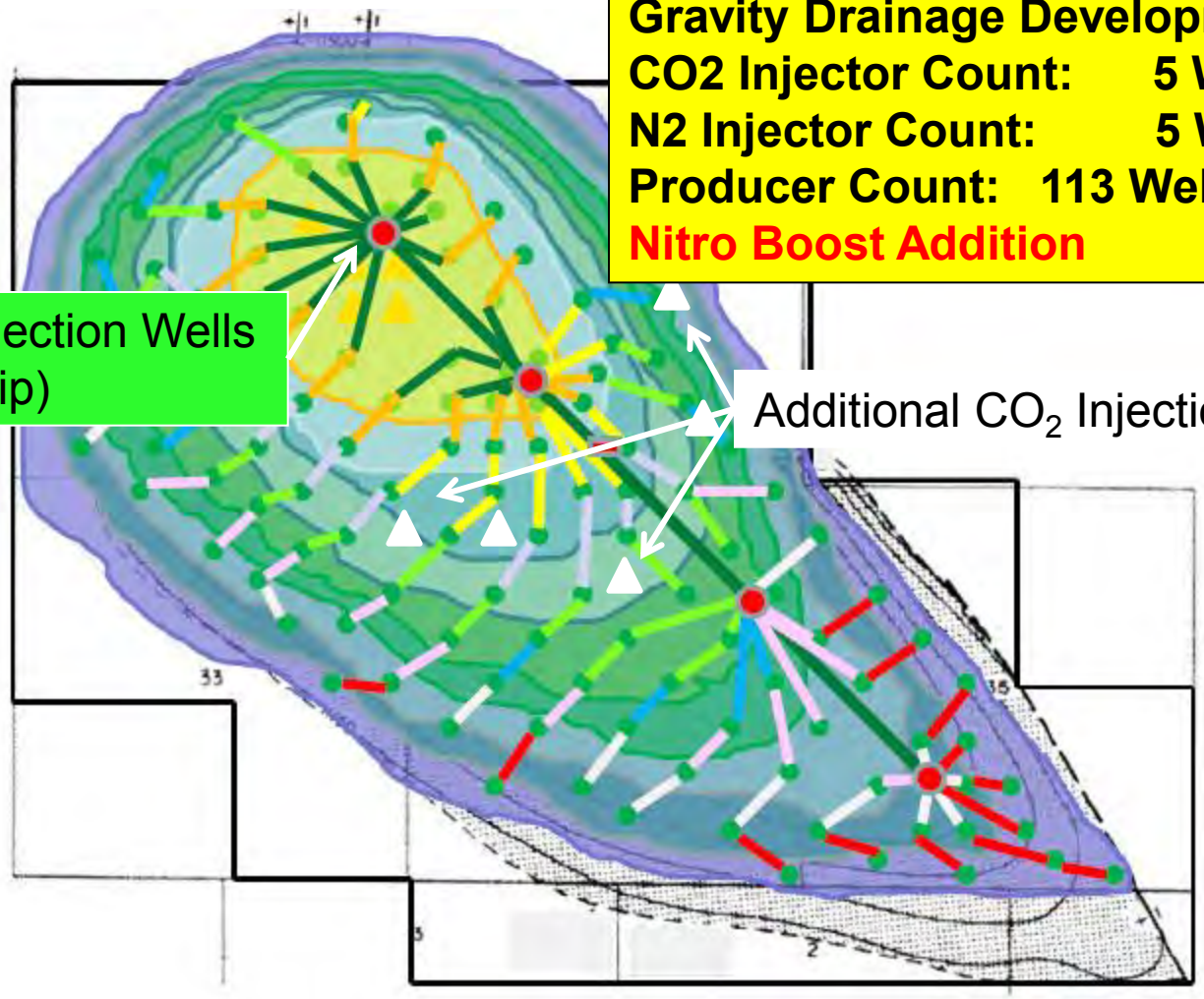
Gravity Drainage Case – CO_2 Injection w/ Nitro Boost



Rio Bravo Field - Phased-in Pattern Development

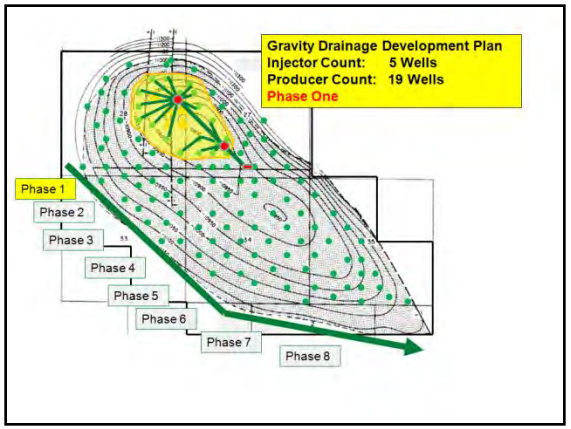
Gravity Drainage Case – with addition of Nitro Boost

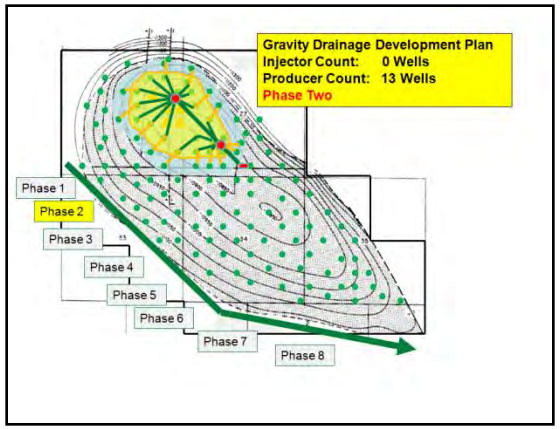
Gravity Drainage Development Plan
CO2 Injector Count: 5 Wells
N2 Injector Count: 5 Wells
Producer Count: 113 Wells
Nitro Boost Addition

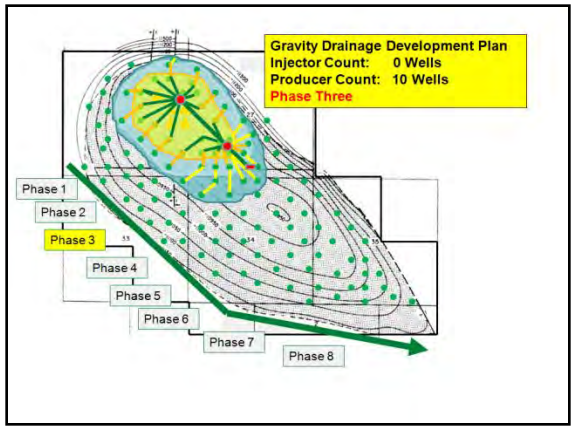


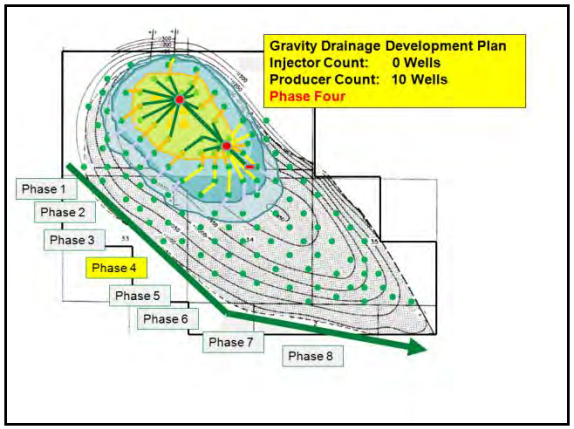
N_2 Injection Wells (up-dip)

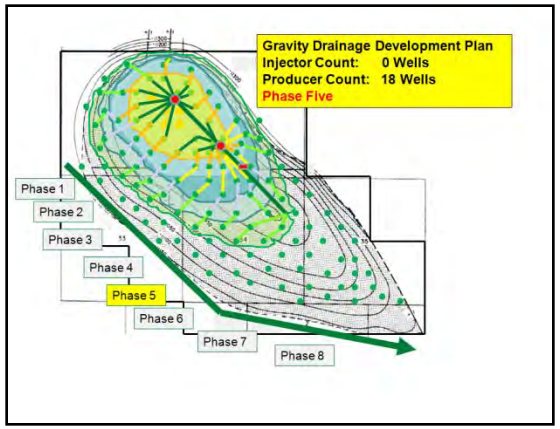
Additional CO_2 Injection Wells (down-dip)

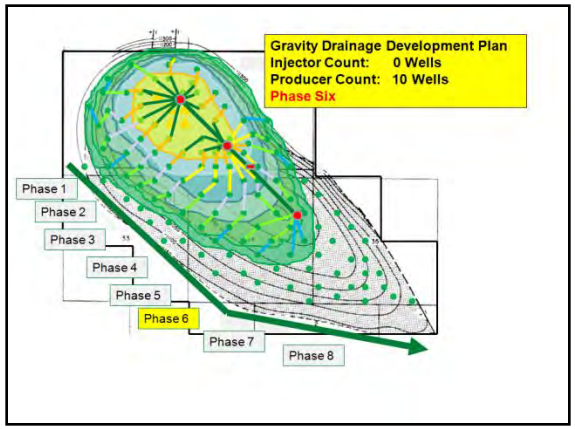

Gravity Drainage Development Plan
Injector Count: 5 Wells
Producer Count: 19 Wells
Phase One
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8

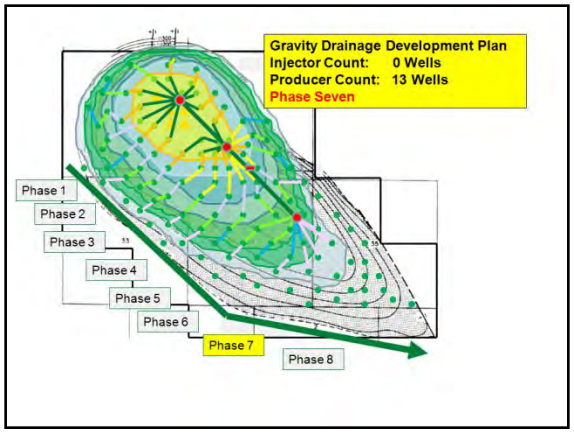

Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 13 Wells
Phase Two
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8

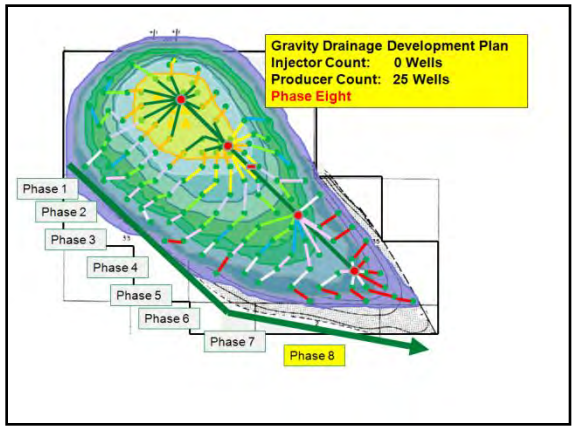

Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 10 Wells
Phase Three
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8

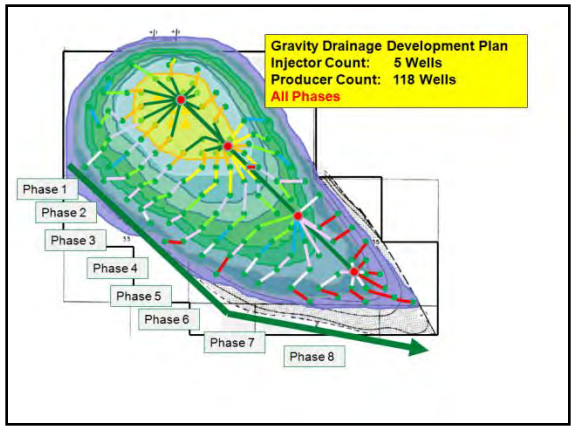

Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 10 Wells
Phase Four
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8


Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 18 Wells
Phase Five
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8


Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 10 Wells
Phase Six
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8


Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 13 Wells
Phase Seven
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8


Gravity Drainage Development Plan
Injector Count: 0 Wells
Producer Count: 25 Wells
Phase Eight
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8


Gravity Drainage Development Plan
Injector Count: 5 Wells
Producer Count: 118 Wells
All Phases
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8

Recover both Tertiary Oil and Water

Eleventh CO_2 Recovery Methods used for Tertiary Oil Recovery in the United States

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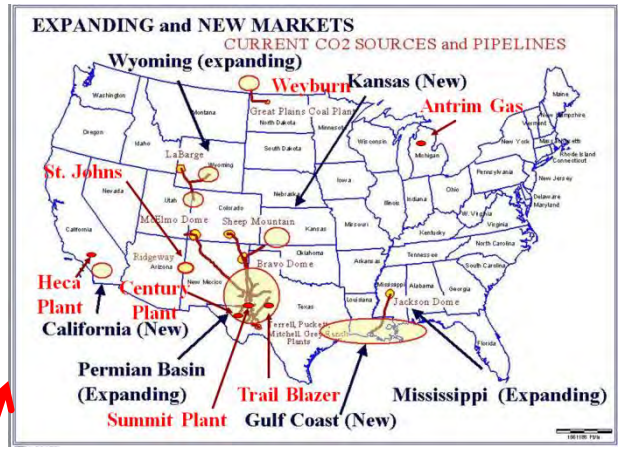
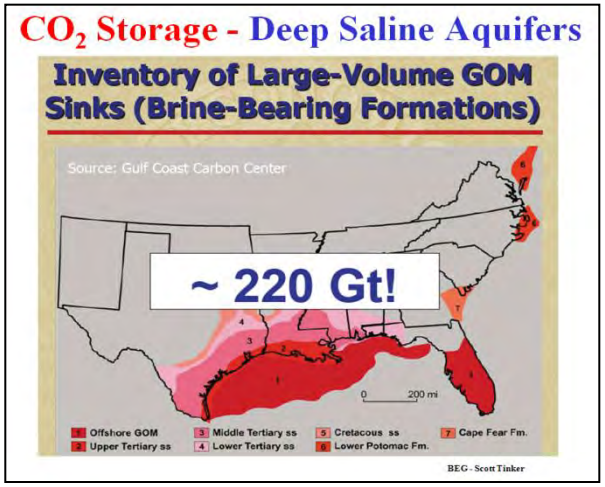
10. CO_2 Gas Drive w/ Nitro Boost

Enhanced Oil Recovery - EOR





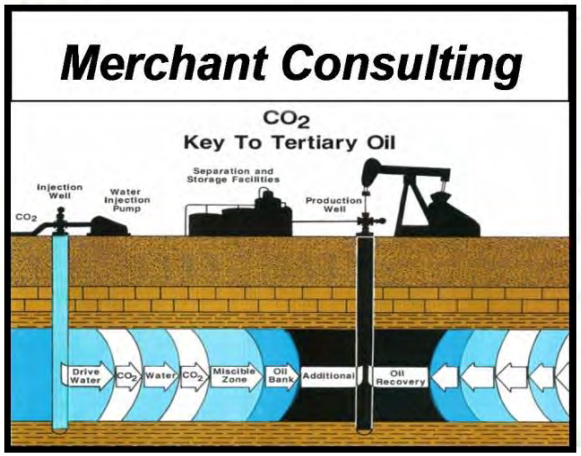
Note: Recover both Tertiary Oil and Water

Eleventh CO_2 Recovery Method used for CO_2 Sequestration

Additional Information can be obtained from:

David Merchant

Merchant Consulting
Magnolia, Texas
Email: merchantconsulting@comcast.net
Office: 281-374-6330
Mobile: 281-686-6320
Email: merchantconsulting@comcast.net
WEB: www.CO2StorageSolutions.com
WEB: www.ReservoirManagementSolutions.com



CMTC-440223-MS

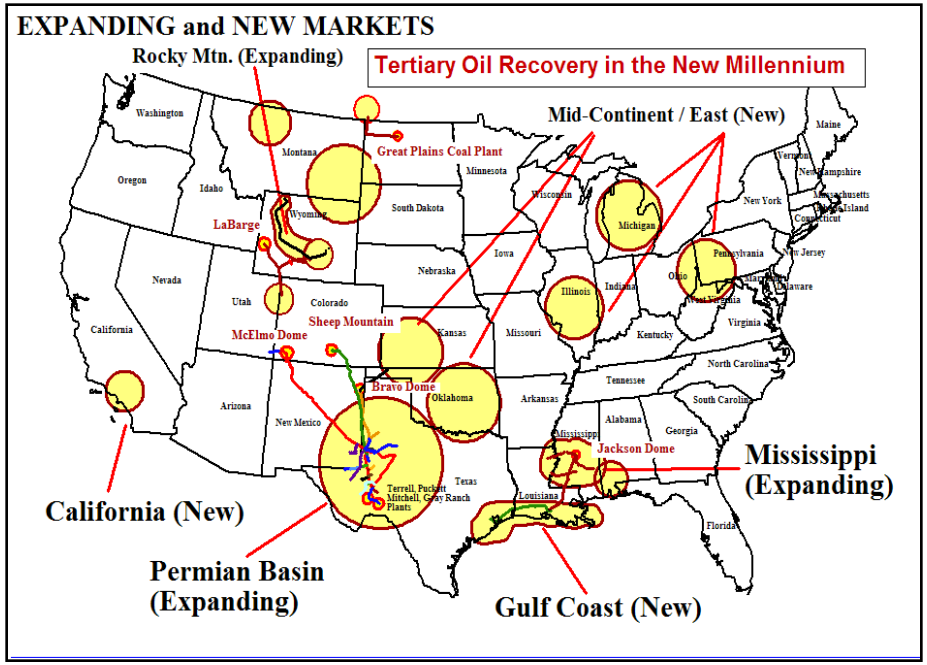
The Energy Gap – How CO_2 Tertiary Oil Recovery will mark its place in the 21st Century

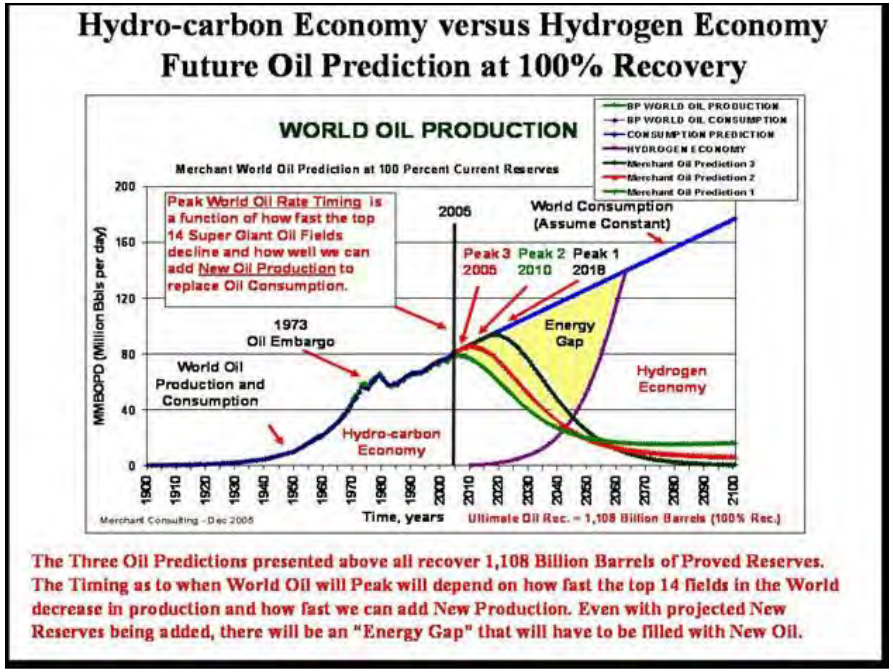
David Merchant, Merchant Consulting

Note: This paper, along with my other SPE and CMTC Publications can be down-loaded from my WEB sites listed above.

Tertiary CO_2 Flooding

"CO_2 Sequestration Future 2005"

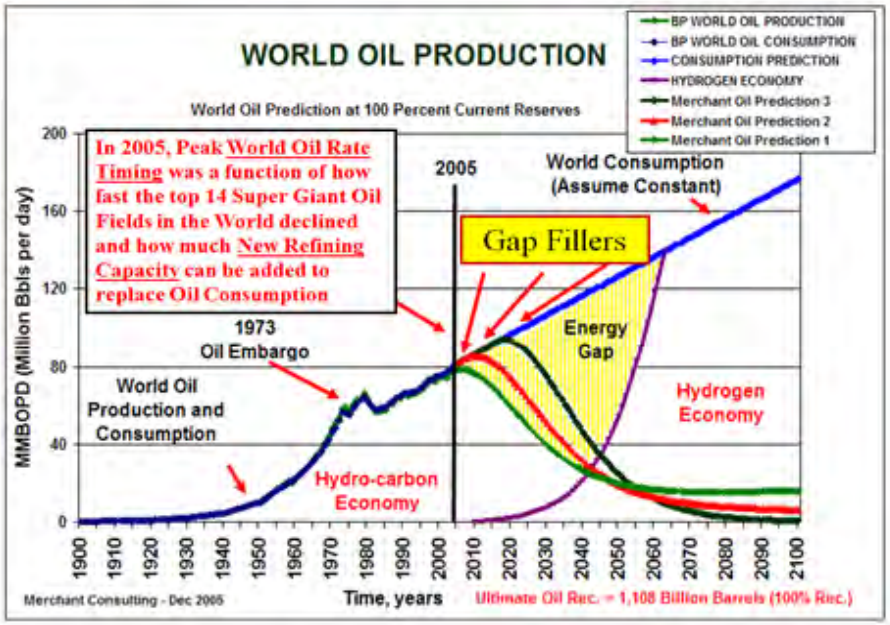




The Three Oil Predictions presented above all recover 1,108 Billion Barrels of Proved Reserves. The Timing as to when World Oil will Peak will depend on how fast the top 14 fields in the World decrease in production and how fast we can add New Production. Even with projected New Reserves being added, there will be an "Energy Gap" that will have to be filled with New Oil.

In the 21st Century, CO_2 Sequestration will provide CO_2 from IGCC Natural Gas and Coal Fired Power Plants, Refineries, and other large scale Anthropogenic CO_2 Sources to fill the <u>Energy Gap</u> that exists between "Peak Oil" and the future "Hydrogen Energy Economy".

Merchant Consulting – "The Energy Gap – How CO_2 Tertiary Recovery will mark its place in the 21st Century"



Hydrogen Economy –"Clean Air Environment"

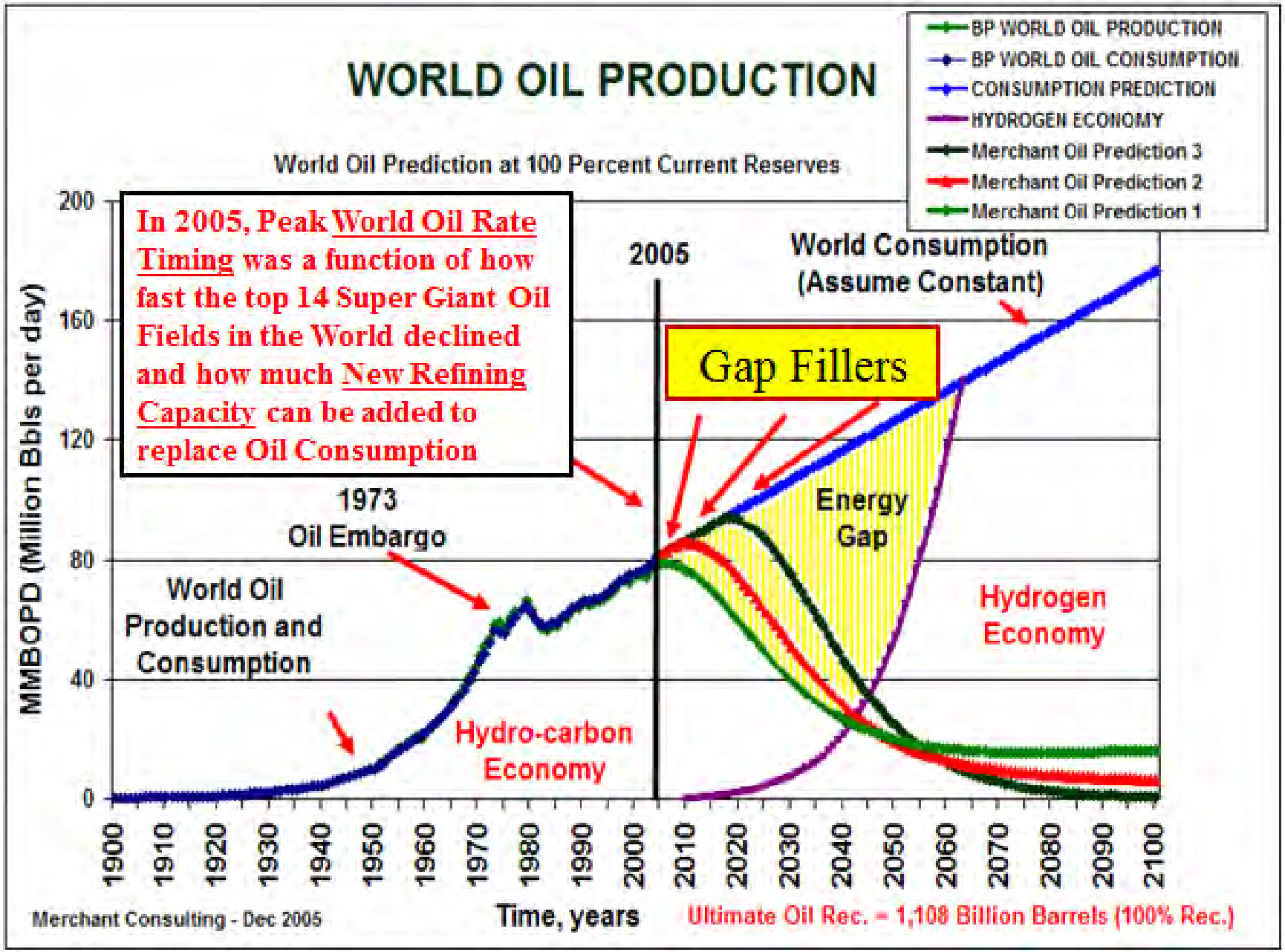
1. Wind Power
2. Solar Power
3. Nuclear (Fission)
4. Nuclear (Fusion)
5. Hydrogen Power (Hydrogen Cars and Hydrogen Fuel Cells)
6. Tertiary CO_2 – EOR and CO_2 Sequestration
7. Mass Transportation (Automobiles poor means to move people)
8. Clean Coal Gasification (Pre-Post Combustion, Oxy-fuel)
9. Clean Natural Gas – (Conventional and Un-Conventional)
10. Biomass – Balance with Mother Nature
11. Nano Tech
12. Algae (Clean Fuels)

Merchant Consulting - Midland CO_2 Conf - Dec 2012

Gap Fillers

1. Primary Oil Recovery
2. Secondary Oil Recovery
3. Tertiary CO_2 - Conventional Tertiary Oil Recovery
4. Tertiary CO_2 - Residual Oil Zone (ROZ)
5. Tertiary CO_2 – Heavy Oil (14+ API)
6. Offshore – Shallow and Deep Water
7. Natural Gas (Conventional Reservoirs)
8. Liquefied Natural Gas (LNG)
9. Shale Oil (Bakken, Others)
10. Shale Gas (Marcellus, Barnett, Eagle Ford)
11. Coal to Gas, Coal to Liquids
12. Steam, Thermal, and MEOR (Bacteria)

Merchant Consulting - Midland CO_2 Conf - Dec 2012


WORLD OIL PRODUCTION
World Oil Prediction at 100 Percent Current Reserves
BP WORLD OIL PRODUCTION
BP WORLD OIL CONSUMPTION
CONSUMPTION PREDICTION
HYDROGEN ECONOMY
Merchant Oil Prediction 3
Merchant Oil Prediction 2
Merchant Oil Prediction 1
In 2005, Peak World Oil Rate Timing was a function of how fast the top 14 Super Giant Oil Fields in the World declined and how much New Refining Capacity can be added to replace Oil Consumption
2005
World Consumption (Assume Constant)
Gap Fillers
1973 Oil Embargo
Energy Gap
World Oil Production and Consumption
Hydrogen Economy
Hydro-carbon Economy
MMBOPD (Million Bbls per day)
200
160
120
80
40
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Time, years
Merchant Consulting - Dec 2005
Ultimate Oil Rec. = 1,108 Billion Barrels (100% Rec.)

Gap Fillers

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BP 2015 Statistical Review

Oil: Total proved reserves

	at end 1994	at end 2004	Inc/Dec over 1994 at end 2004	at end 2014	Inc/Dec over 2004 at end 2014	Share of total	R/P ratio	
	Thousand million barrels	Thousand million barrels	Thousand million barrels	Thousand million barrels	Thousand million barrels			
Total World	**1118.0**	**1366.2**		**1700.1**		**100.0%**	**52.5**	
Venezuela	64.9	79.7	22.9%	298.3	274.2%	17.5%	100.0	Orinoco Belt/Heavy Oil
Saudi Arabia	261.4	264.3	1.1%	267.0	1.0%	15.7%	63.6	
Canada	48.1	179.6	273.0%	172.9	-3.7%	10.2%	100.0	Canadian Oil Sands
Iran	94.3	132.7	40.8%	157.8	18.9%	9.3%	100.0	
Iraq	100.0	115.0	15.0%	150.0	30.4%	8.8%	100.0	
Russian Federation	115.1	105.5	-8.4%	103.2	-2.2%	6.1%	26.1	
Kuwait	96.5	101.5	5.2%	101.5	0.0%	6.0%	89.0	
United Arab Emirates	98.1	97.8	-0.3%	97.8	0.0%	5.8%	72.2	
United States	29.6	29.3	-1.1%	48.5	65.4%	2.9%	11.4	Horizontal Fracking
Libya	22.8	39.1	71.6%	48.4	23.6%	2.8%	100.0	
Nigeria	21.0	35.9	70.9%	37.1	3.3%	2.2%	43.0	
Kazakhstan	5.3	9.0	69.2%	30.0	233.3%	1.8%	48.3	
Qatar	3.5	26.9	667.6%	25.7	-4.3%	1.5%	35.5	
China	16.3	15.5	-4.5%	18.5	19.0%	1.1%	11.9	
Brazil	5.4	11.2	109.2%	16.2	43.7%	1.0%	18.9	
Angola	3.0	9.0	204.8%	12.7	40.2%	0.7%	20.3	
Algeria	10.0	11.8	18.2%	12.2	3.4%	0.7%	21.9	
Mexico	49.8	14.8	-70.3%	11.1	-25.2%	0.7%	10.9	
Ecuador	3.5	5.1	44.9%	8.0	58.1%	0.5%	39.4	
Azerbaijan	1.2	7.0	505.0%	7.0	0.0%	0.4%	22.6	
Norway	9.7	9.7	0.2%	6.5	-32.7%	0.4%	9.5	
India	5.8	5.6	-4.2%	5.7	3.2%	0.3%	17.6	
Oman	5.1	5.6	9.3%	5.2	-7.6%	0.3%	15.0	
Australia	3.8	3.9	1.9%	4.0	2.4%	0.2%	24.3	
Malaysia	5.2	5.2	-0.8%	3.8	-27.3%	0.2%	15.4	
Indonesia	5.0	4.3	-13.7%	3.7	-14.1%	0.2%	11.9	
Colombia	3.1	1.5	-52.9%	2.4	65.5%	0.1%	6.8	
Argentina	2.3	2.5	10.0%	2.3	-6.1%	0.1%	10.1	
Other Europe & Eurasia	2.3	2.2	-1.5%	2.0	-11.7%	0.1%	14.0	
Other S. & Cent. America	1.0	1.5	53.3%	0.5	-64.3%	•	9.6	

Merchant Thanks to Steering Committee!

1995 First CO_2 Conference: Talk on: Montage approach to Reservoir Management in Tertiary CO_2 Floods – SPE 26624

THE FUTURE IS HERE

For decades the Permian Basin has spoken of the day when independents would have share the responsibility of putting ailing fields on CO2 — that day is here.

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Pictured:

Tom McKnight (Union Royalty)

David Merchant (Amoco)

Ron Brockmeyer (Amoco)

Russell Martin (Enron Gas Pipeline)

Newspaper Article celebrates CO_2 Injection start-up into the Elmar field along with the CO_2 Conference scheduled for December 4-5, 1995

Merchant Thanks to Steering Committee!

1995 Montage approach to Reservoir Management in Tertiary CO_2 Floods – SPE 26624

1999 Screening CO_2 Candidate Reservoirs Fundamentals of Pattern Analysis

2000 Setting up the Pieces – What Constitutes a Simulation?

2004 Pattern Performance as a Diagnostic Tool for Reservoir Surveillance

2004 Monitoring the CO_2 Flood - Problem Identification and Solutions

2009 Comparisons of Conventional CO_2 WAG Injection Techniques used in the Permian Basin

2010 Life beyond 80 – A look at Conventional WAG Recovery beyond 80% HCPV in CO_2 Tertiary Floods – SPE 139516

2012 The Energy Gap - "How CO_2 Tertiary Recovery will mark its place in the 21st Century"

2013 Short Course: Surveillance and Monitoring of CO_2 Injection Projects – "Pattern Balancing and Mass Balance"

2014 Short Course: Produced Water Management for CO_2 Injection Projects – "Factors in the Permian Basin Subsurface "Mass Balance"

2015 CMTC440075 Life beyond 80 – A look at Conventional WAG Recovery beyond 80% HCPV in CO_2 Tertiary Floods – SPE 139516

Thanks,

Now its your turn?

David H. Merchant

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CO_2 Storage Solutions

WEB: www.CO2StorageSolutions.com

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

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