STATE OF NEW MEXICO
ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT
OIL CONSERVATION COMMISSION

APPLICATION OF GOODNIGHT MIDSTREAM PERMIAN LLC FOR APPROVAL OF A SALTWATER DISPOSAL WELL, LEA COUNTY, NEW MEXICO. **COMM. CASE NO. 24123**

APPLICATIONS OF GOODNIGHT MIDSTREAM PERMIAN LLC FOR APPROVAL OF SALTWATER DISPOSAL WELLS, LEA COUNTY, NEW MEXICO. **DIV. CASE NOS. 23614-23617**

APPLICATION OF GOODNIGHT MIDSTREAM PERMIAN, LLC TO AMEND ORDER NO. R-22026/SWD-2403 TO INCREASE THE APPROVED INJECTION RATE IN ITS ANDRE DAWSON SWD #1, LEA COUNTY, NEW MEXICO. **DIV. CASE NO. 23775**

APPLICATIONS OF EMPIRE NEW MEXICO LLC TO REVOKE INJECTION AUTHORITY, LEA COUNTY, NEW MEXICO. **DIV. CASE NOS. 24018-24020, 24025**

EMPIRE NEW MEXICO LLC'S
NOTICE OF FILING CROSS-EXAMINATION EXHIBITS

Empire New Mexico, LLC, through its undersigned counsel, hereby provides notice that the following Cross-Examination Exhibits were admitted into the record in the above-captioned matters.

Respectfully submitted,

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CERTIFICATE OF SERVICE

I hereby certify that a true and correct copy of the foregoing was served on the following by electronic mail on May 8, 2025.

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Only 99 grid blocks out of 34,500 have vertical permeability greater than zero, thus allowing water influx from San Andres. Below shows a sample of the KZ of Layer 8.

Vertical Permeability from San Andres into Grayburg Zone
Simulation Model has 115 grid blocks in X direction and 300 grid blocks in Y. Each grid block is 2 acres in size.

	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
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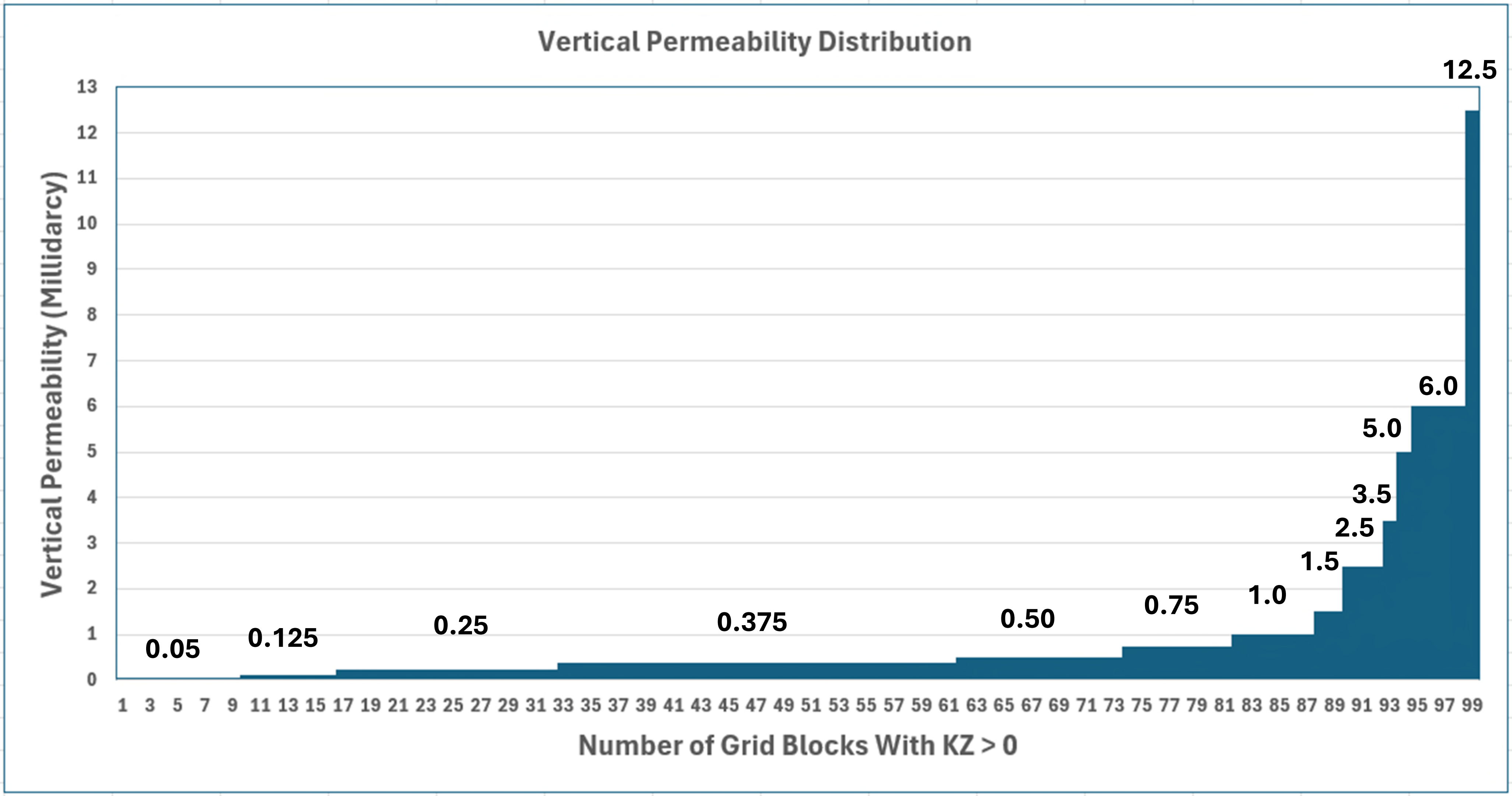
Empire Cross Exhibit 1

Vertical Permeability Controls Fluid Flow From San Andres to Grayburg

The vertical permeability (KZ) between the San Andres and Grayburg was modified on 99 out of 34,500 grid blocks to allow for water to move from San Andres into Grayburg.



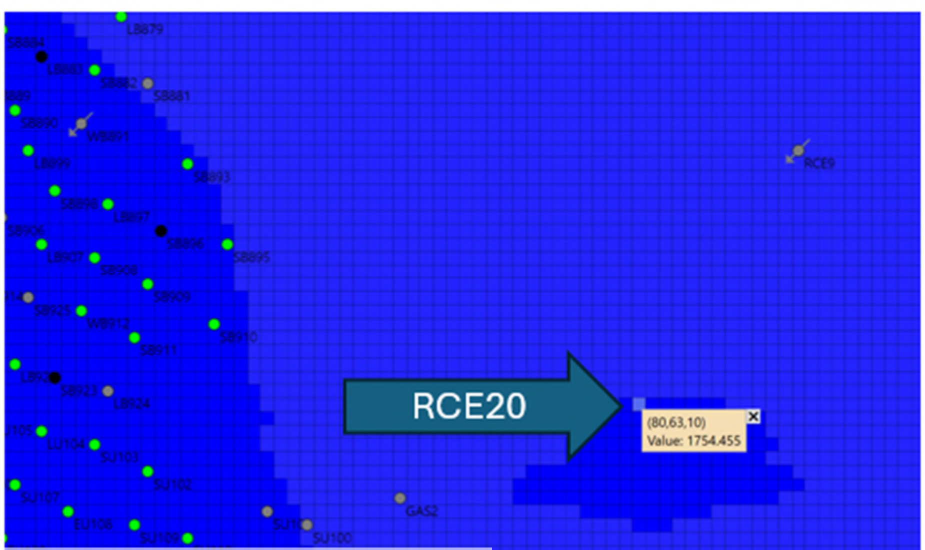
Empire Cross Exhibit 2

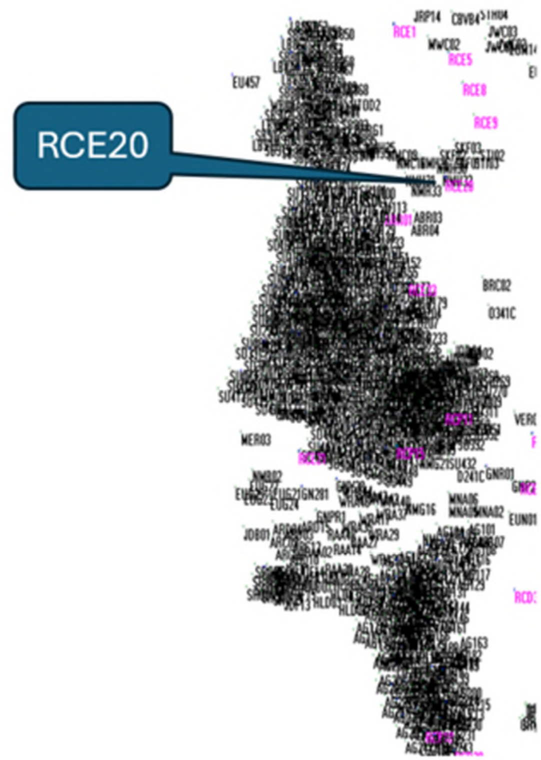
We were provided a bottomhole pressure for the EME-20 SWD by Rice. We asked Dr. Buchwalter to provide the pressures at this well location in his simulation model using the 1450 psi @ -250’ subsea original pressure Base Case Model. Here are the results.

1959 Pressure Calculation for EME#20

- Depth layer 10 in model = 4921 ft
- 1938 pressure @ 4921 ft in model = 2058 psi
- 1959 pressure @ 4921 ft in model = 1754 psi
- 1959 Corrected model pressure to 5000’ =

  1754 psi+(5000-4921)*0.43 = 1788 psi
- 1959 Measured Pressure at 5000’ = 1800 psi
- Variance of 12 psi





TED 28 SWD #001	GN281
ERNIE BANKS SWD 1	GNB01
RYNO SWD 1	GNP01
PENROC STATE E TR 27-2	GNP27
PEDRO SWD 1	GNPR1
NOLAN RYAN SWD 1	GNR01
ROBINSON STATE SWD 1	GNRS1
SCULLY STATE SWD 1	GNS01
SOSA SA 17 SWD 2	GNSS1
ANDRE DAWSON SWD 1	GNW01
YAZ 28 SWD 1	GNY28
BLINEBRY DRINKARD #18	RCB18
BLINEBRY DRINKARD SWD #20	RCD20
BLINEBRY DRINKARD SWD #32	RCD32
E M E SWD #1	RCE1
E M E SWD #20	RCE20
E M E SWD #21	RCE21
STATE E TRACT 27 #1	RCE27
E M E SWD #33M	RCE33
E M E SWD #5	RCE5
E M E SWD #8	RCE8
E M E SWD #9	RCE9
N 7 #1	RCN71
Permian N-11 #1	RCP11
P 15 #1	RCP15

Empire Cross Exhibit 3

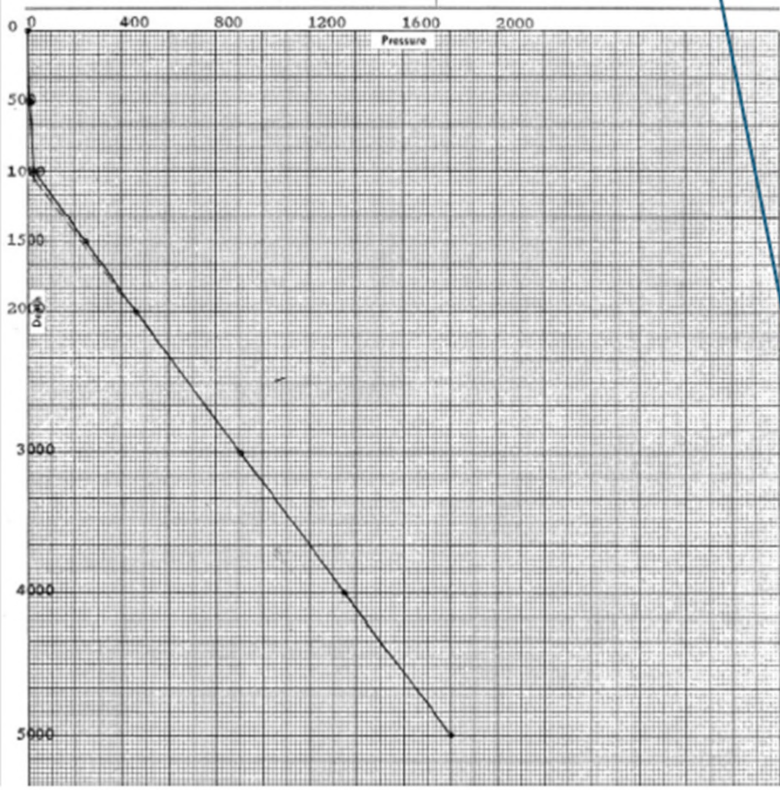
Rice's EME-20 Bottomhole Pressure Survey

BOTTOM HOLE PRESSURE SURVEY REPORT

OPERATOR Rice Engineering & Operating Inc.
LEASE
WELL NO. E. M. E. H-20 (Before injection)
FIELD
DATE July 15, 59 TIME 2:50 P. M.

STATUS Shut in TEST DEPTH 5000
TIME S.I. LAST TEST DATE Initial test
CAS. PRES. BHP LAST TEST
TUB. PRES. 0 BHP CHANGE
ELEV. FLUID TOP 1050
DATUM WATER TOP
TEMP RUN BY B. T.
CLOCK NO. 2547 GAUGE NO. 12434
ELEMENT NO. 14659-N

DEPTH	PRESSURE	GRADIENT
000	0	
500	7	.014
1000	26	.038
1500	247	.442
2000	462	.430
3000	905	.443
4000	1347	.442
5000	1800	.453



San Andres Wtr ~ 21k TDS and 11k Chlorides

Water Type	% Salinity	Chlorides (ppm)	psi/ft
Fresh Water	0	-	0.433
Brackish Water (low)	~1	6,070	0.435
Base EMSUWtr	~2	11,000	0.437
Brackish Water (high)	~3	18,210	0.440
Seawater	~3.5	21,245	0.444
Highly Saline Water	~10	60,700	0.462
Goodnight SWD wtr	~15	90,000	0.475
Fully Saturated Water	~26	157,820	0.507

Point	Depth	Height		Gradien (psi/ft)	psi
Surface Pressure	0	0			0
Gas	1000	1000	X	0.026	26
Water	5000	4000	X	0.4435	1774
				Pressure at tool	1800

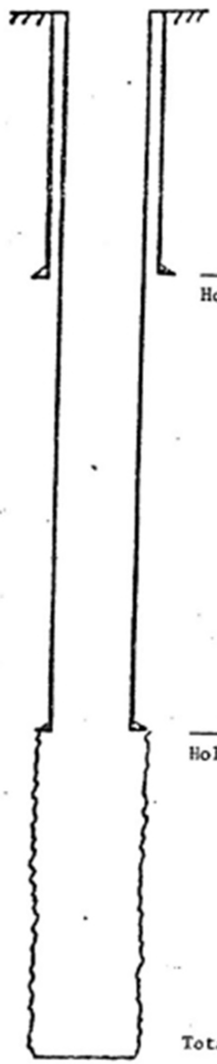
Overall Gradient 1800psi/5000' =0.36 psi/ft

Empire Cross Exhibit 4

Rice's EME-20 Wellbore Diagram

FIELD	OPERATOR	DATE
MONUMENT	RICE ENG & OPR. INC.	APRIL 27, 1976
LEASE	**WELL No. / LOCATION**	
EME SWD SYSTEM	H-20 / SE/4 NE/4 SEC. 20 - T20S - R37E	

EME-20 Wellbore



9 5/8" casing set at 812' with 500 sx of REG NEAT cement
Hole size 12 1/4" CEMENT CIRCULATED.

7" casing set at 4446' with 150 sx of REG NEAT cement
300SX SULFATE RESISTANT CMT + 4% GEL W/300 CU FT POZZOLAN + 50# FLOSEAL
Hole size 8 3/4" TOP OF CEMENT @ 875/SURVEY.

5 1/2" OD TUBING SET @ 4437' w/ANNULUS OIL BLANKET - NO PACKER

Total Depth 5000'

NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico

WELL RECORD

Mail to District Office, Oil Conservation Commission, to which Form C-101 was sent not later than twenty days after completion of well. Follow instructions in Rules and Regulations of the Commission. Submit in QUINTUPLICATE. If State Land submit 6 Copies

AREA 640 ACRES
LOCATE WELL CORRECTLY

Rice Engineering & Operating, Inc. (Company or Operator) — Eunice - Monument - Eumont SWD (Lease)

Well No. H-20, in SE 1/4 of NE 1/4, of Sec. 20, T. 20 S, R. 37 E, NMPM.
Monument Pool, Lea County.
Well is 2475 feet from North line and 165 feet from East line of Section 20. If State Land the Oil and Gas Lease No. is Business Lease 147
Drilling Commenced June 1_, 1959. Drilling was Completed July 11, 1959
Name of Drilling Contractor: Stout & McQueen
Address: 505 W. 15th Street, Odessa, Texas
Elevation above sea level at Top of Tubing Head 3506'. The information given is to be kept confidential until Not confidential, 19__

OIL SANDS OR ZONES

No. 1, from ___ to ___ No. 4, from ___ to ___
No. 2, from ___ to ___ No. 5, from ___ to ___
No. 3, from ___ to ___ No. 6, from ___ to ___

IMPORTANT ~~WATER~~ SALT WATER SANDS

Include data on rate of water inflow and elevation to which water rose in hole.
No. 1, from 4451' to 4503' feet.
No. 2, from 4600' to 4725' feet.
No. 3, from 4862' to 4939' feet.
No. 4, from ___ to ___ feet.

CASING RECORD

SIZE	WEIGHT PER FOOT	NEW OR USED	AMOUNT	KIND OF SHOE	CUT AND PULLED FROM	PERFORATIONS	PURPOSE
9-5/8"	32.3	New	793'	Texas			Surface Casing
7"	20	New	4430'	Guide			Injection Csg.

MUDDING AND CEMENTING RECORD

SIZE OF HOLE	SIZE OF CASING	WHERE SET	NO. SACKS OF CEMENT	METHOD USED	MUD GRAVITY	AMOUNT OF MUD USED
12-1/4	9-5/8"	812'	500	Howco 1 plug	Water	
8-3/4	7"	4445'	752	Howco 1 plug	Water	

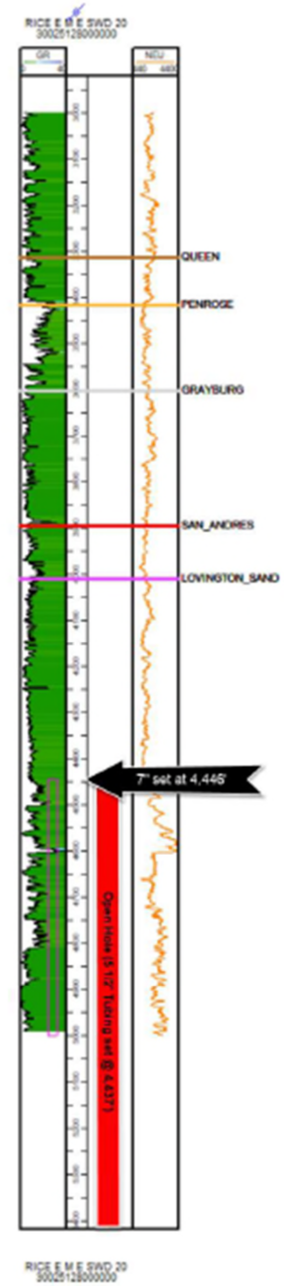
RECORD OF PRODUCTION AND STIMULATION

(Record the Process used, No. of Qts. or Gals. used, interval treated or shot.)

Acidized 4882 - 4939' w/2500 gal. 15 %, 4600 - 4725 w/5200 gal. 15%, and 4451 - 4503' w/2300 gal. 15%.

Result of Production Stimulation: Gravity injection rate down 7" casing before acid-1680 BWPH
Gravity injection rate down 7" casing after acid-2400 BWPH

Depth Cleaned Out 5004'



Empire Cross Exhibit 5

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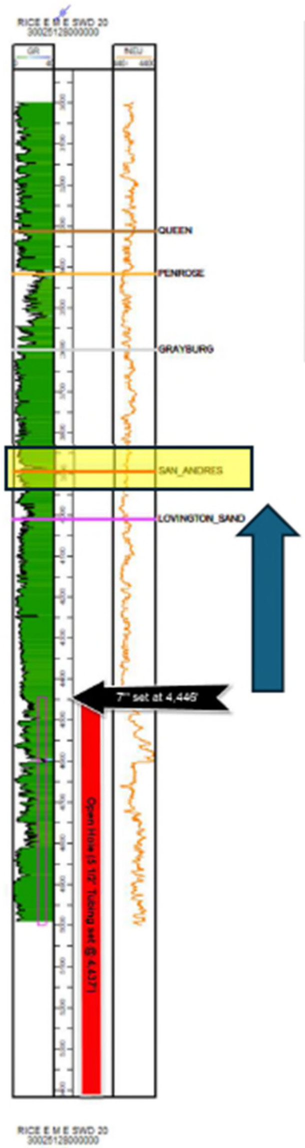
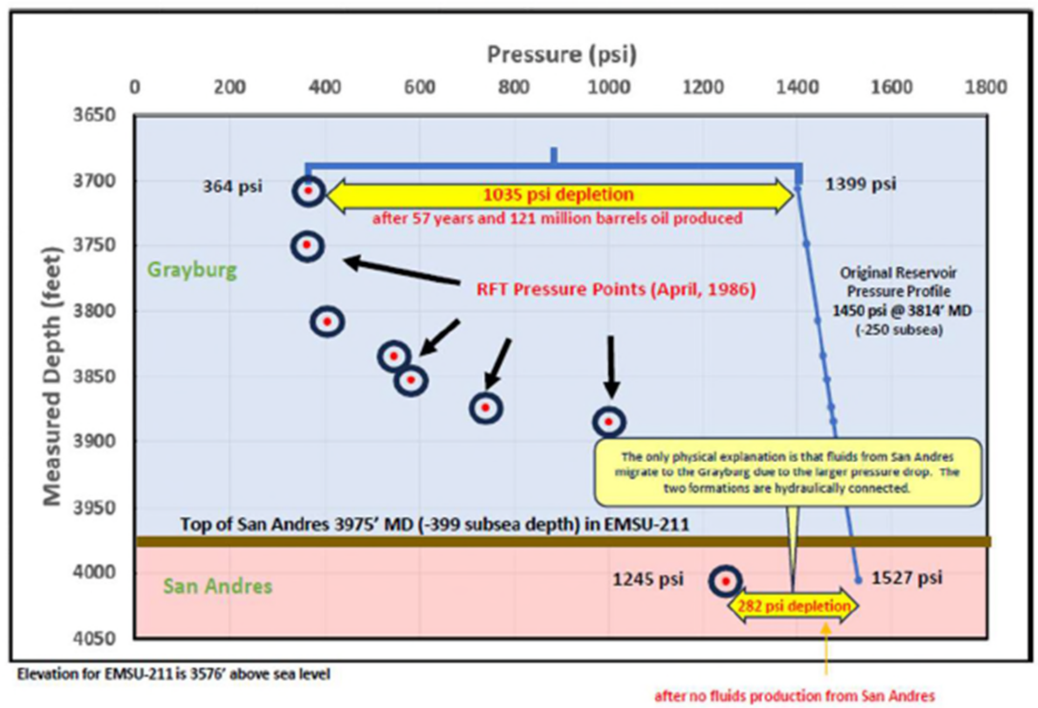
Pressure Depletion from EME-20 BHP in 1959 to RFT Pressure Points in 1986



	EME 20 Depth	SS	Pressure	Stop Gradients	Overall Gradient
	0		0	0	
	500	3022	7	0.014	0.01
	1000	2522	26	0.038	0.03
	1500	2022	247	0.442	0.16
	2000	1522	462	0.43	0.23
	3000	522	905	0.443	0.30
Top SA	**3896**	**-374**	**1312**	**0.442**	0.34
	4000	-478	1347	0.442	0.34
	5000	-1478	1800	0.453	0.36

Top SA = 1800psi-(5000'-3896')*0.442 psi/ft = 1312 psi

EMSU 211 RFTs



Empire Cross Exhibit 6

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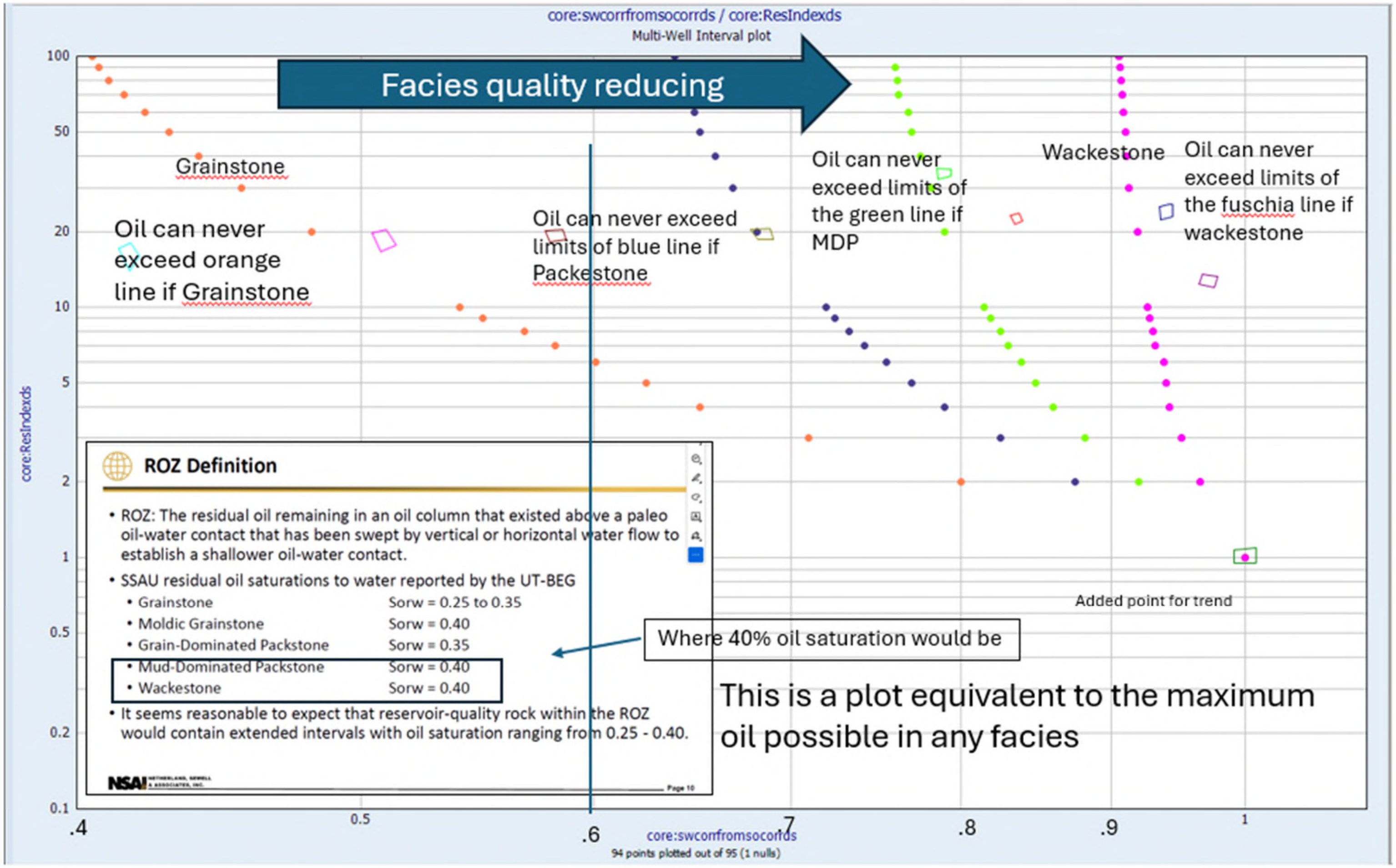
Impact of Rock Facies on Oil Saturation

Dr. Davidson testifies oil saturation of an average of 40% are possible in the San Andres Poorer rock qualities

- Dr. Davidson describes a spectrum of facies.
- Until a facies gets to MDP and an RI of around 15 and it appears to asymptote before it reaches 30% oil saturation.
- Does it look like Dr. Davidson is giving those facies a chance to show that the40% he says is possible?
- Is it standard practice to discount facies that you show are capable of holding 40% hydrocarbon?
- From this plot does it appear the average saturation is generally higher in the "poorer' facies?



Digitized info from Dr. Davidsons plot where he described the Sc value for points along his spectrum of facies.

Empire Cross Exhibit 7

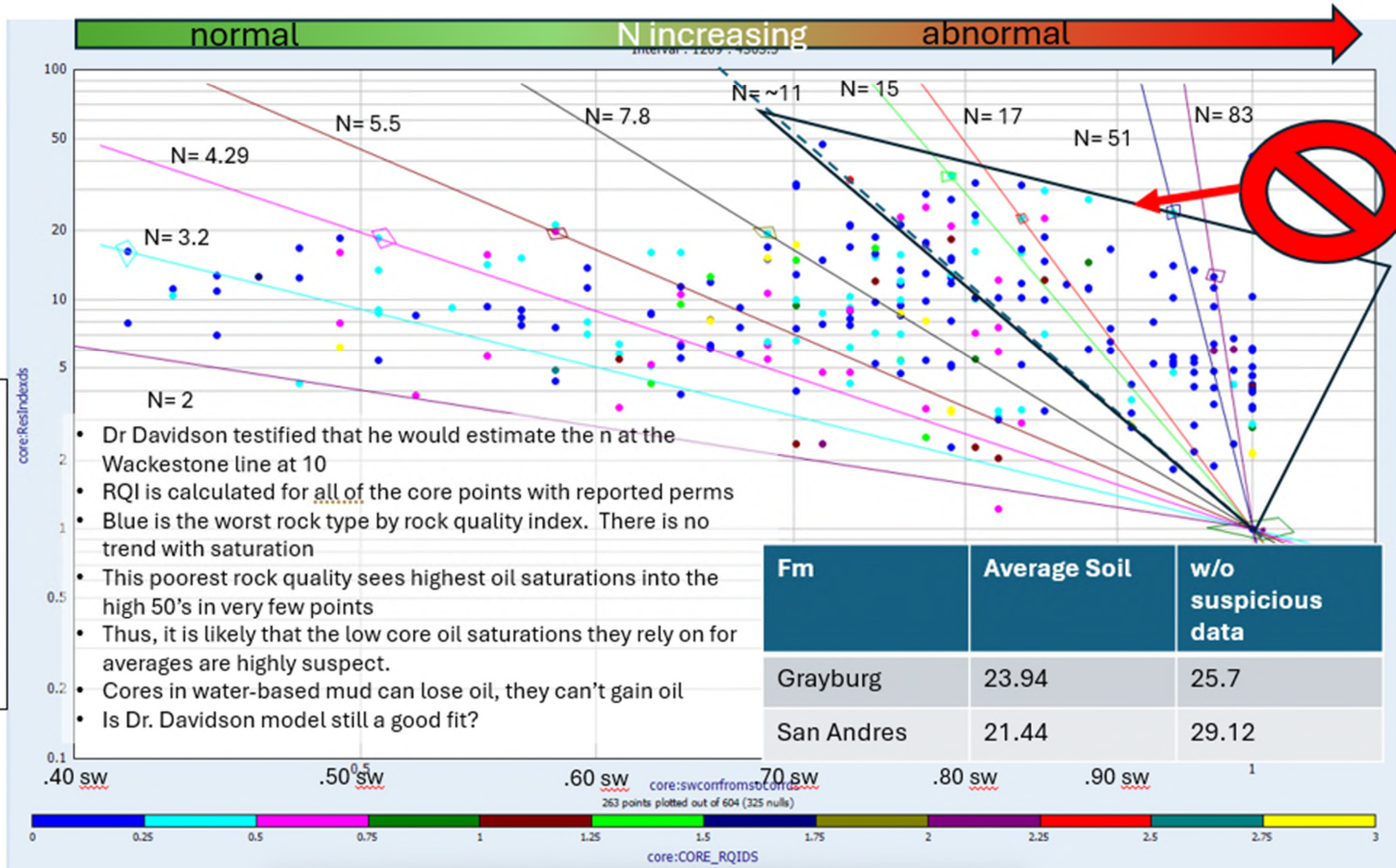
Impact of Rock Facies on Oil Saturation (Corrected Core Oil Saturations) REMOVAL OF SUSPICIOUS DATA

Same plot, same scales, Sc lines are gone. Now plotted with ops geologic (1 – corrected core oil sat)

Dr. Davidson testified that he could have used Archie, he just thought it was inefficient
He showed though, that to match Core oil saturations, you have to use values up to over 100. which would be very strange
Black triangle is data that is very suspicious and absolutely should not be used for modeling!

- X is corrected core sw
- Y is Resistivity index
- Color of points is RQI
- Perm is taken from Kmax, largest of horizontal perm, or only horizontal perm available

- Mr. Knights testified yesterday that we have very little core for the amount of rock we are looking at.
- That is absolutely why we need to use quality control and not exploit inappropriate data in the areas where we don't have core.
- Core Saturations are absolutely the most uncertain



- Dr Davidson testified that he would estimate the n at the Wackestone line at 10
- RQI is calculated for all of the core points with reported perms
- Blue is the worst rock type by rock quality index. There is no trend with saturation
- This poorest rock quality sees highest oil saturations into the high 50's in very few points
- Thus, it is likely that the low core oil saturations they rely on for averages are highly suspect.
- Cores in water-based mud can lose oil, they can't gain oil
- Is Dr. Davidson model still a good fit?

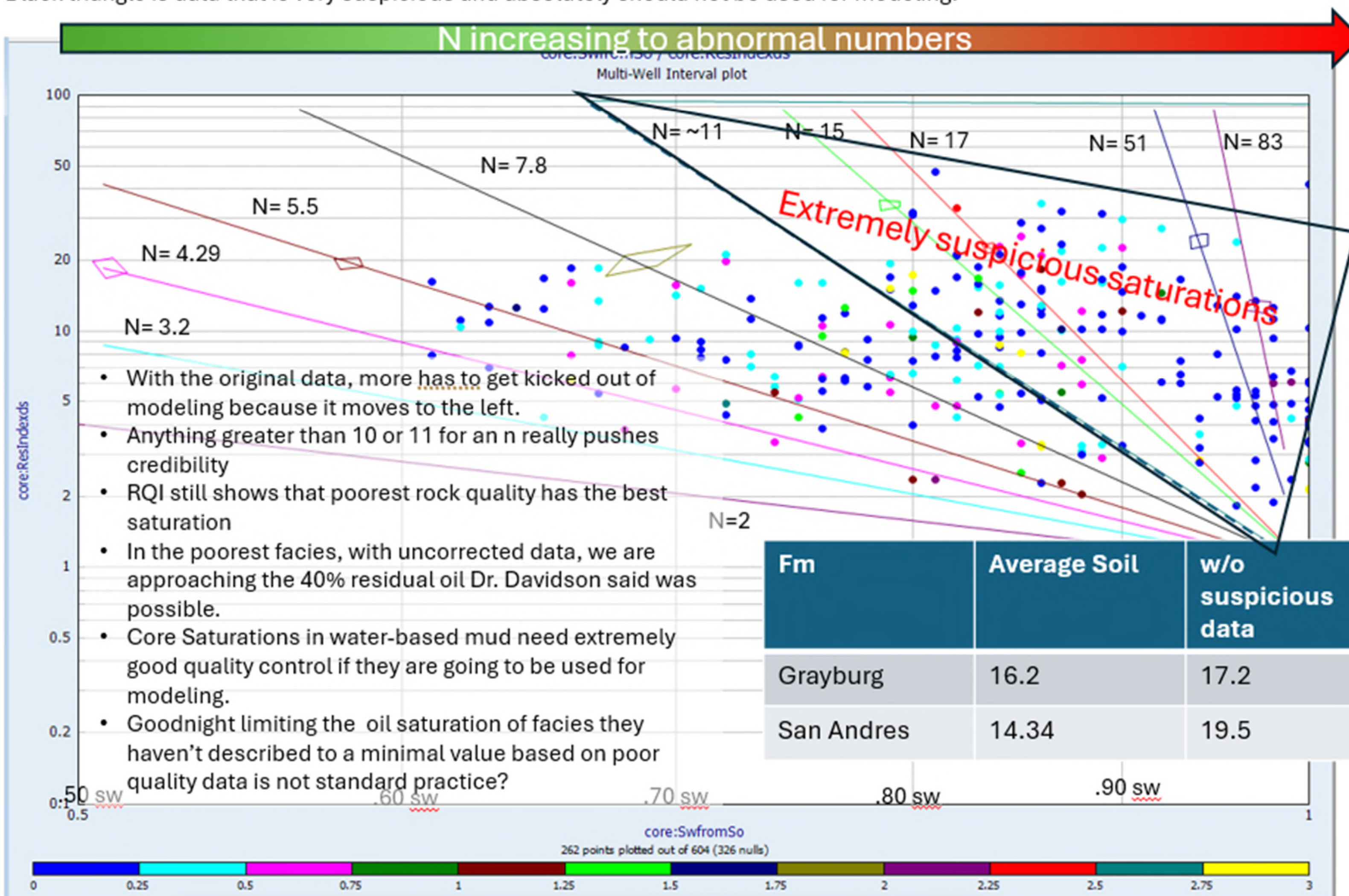
Fm	Average Soil	w/o suspicious data
Grayburg	23.94	25.7
San Andres	21.44	29.12

Impact of Rock Facies on Oil Saturation (Uncorrected Core Oil Saturations) REMOVAL OF SUSPICIOUS DATA

Same plot, same scales, Sc lines are gone. Now plotted with ops geologic (1 – corrected core oil sat)

Dr. Davidson testified that he could have used Archie, he just thought it was inefficient
He showed though, that to match Core oil saturations, you have to use values up to over 100. which would be very strange
Black triangle is data that is very suspicious and absolutely should not be used for modeling!

- X is corrected core sw
- Y is Resistivity index
- Color of points is RQI
- Perm is taken from Kmax, largest of horizontal perm, or only horizontal perm available



- With the original data, more has to get kicked out of modeling because it moves to the left.
- Anything greater than 10 or 11 for an n really pushes credibility
- RQI still shows that poorest rock quality has the best saturation
- In the poorest facies, with uncorrected data, we are approaching the 40% residual oil Dr. Davidson said was possible.
- Core Saturations in water-based mud need extremely good quality control if they are going to be used for modeling.
- Goodnight limiting the oil saturation of facies they haven't described to a minimal value based on poor quality data is not standard practice?

Fm	Average Soil	w/o suspicious data
Grayburg	16.2	17.2
San Andres	14.34	19.5

Grayburg Conventional Core Measurements

EMSU-649

Depth	Permeability (MD) Kmax	K90	Kvert	Por %	% Fluids H2O	Oil
3741	0.55	0.52	0.75	15.00	26.90	15.80
3742	18.21	11.79	1.39	8.30	35.60	12.00
3743	4.83	4.33	0.68	9.00	28.20	20.00
3744	45.59	2.62	6.81	6.90	39.50	27.70
3745	7.40	5.06	6.01	9.60	27.60	18.20
3746	2.89	0.29	2.26	5.70	29.00	21.60
3747	1.85	Kplug	0.01	7.00	27.70	27.20
3748	31.18	24.22	7.97	13.00	21.30	19.80
3749	759.83	729.22	181.02	18.30	18.30	21.00
3750	47.53	41.60	26.58	14.20	19.30	26.00
3751	175.28	45.46	26.75	4.80	42.50	15.00
3752	0.01	Kplug	12.76	7.50	34.60	12.10
3753	1035.96	773.23	95.51	15.50	32.30	28.00
3754	9876.74	1729.59	162.70	17.90	27.00	11.00
3755	680.64	473.80	196.30	18.50	22.40	22.10
3756	886.07	385.45	TBFA	15.80	23.60	16.30
3758	291.64	237.77	91.03	5.70	22.60	16.50
3759	0.01	Kplug	0.01	3.70	65.10	15.20
3760	1806.34	773.23	32.15	14.20	27.20	17.70
3761	66.09	49.03	TBFA	14.60	21.50	24.40
3762	15.29	12.14	22.39	12.90	24.30	23.50
3763	71.14	69.87	50.92	12.80	20.80	24.10
3764	35.24	24.41	35.38	12.80	25.30	20.70
3765	18.95	3.65	5.48	8.40	22.10	24.70
3766	45.34	44.56	52.50	16.30	25.90	18.30

Depth	Permeability (MD) Kmax	K90	Kvert	Por %	% Fluids H2O	Oil
3767	28.22	27.00	19.99	18.00	19.70	10.70
3768	23.49	19.41	17.75	14.40	26.60	37.70
3769	10.47	2.41	4.73	12.40	25.30	17.20
3770	185.79	164.15	17.32	10.30	50.10	15.50
3771	8515.94	248.84	106.88	19.20	21.50	25.60
3772	142.00	24.49	39.28	5.40	68.10	8.50
3773	34.34	18.78	48.89	11.50	25.00	22.50
3774	47.92	35.34	42.28	14.00	20.70	21.30
3775	49.47	41.18	85.16	12.80	19.60	20.30
3776	103.28	69.46	58.07	12.00	20.60	22.20
3777	23.89	6.24	80.28	4.20	30.50	14.30
3778	0.01	Kplug	0.09	13.50	28.80	12.00
3779	0.01	Kplug	TBFA	3.40	37.20	19.90
3780	8868.80	77.73	64.19	3.50	50.70	6.40
3781	54.08	30.13	15.33	2.70	42.30	24.00
3782	4.18	1.55	1.16	3.70	28.50	24.80
3783	126.02	21.58	17.18	9.20	27.90	27.00
3784	26.35	9.04	0.75	3.50	58.10	16.00
3785	376.88	59.66	6.73	6.00	39.50	16.70
3786	6.94	6.11	15.65	8.10	22.90	19.20
3787	37.25	35.61	57.96	12.00	18.60	20.60
3788	58.12	17.85	35.64	11.10	20.50	20.90
3789	168.09	42.45	134.15	10.60	30.80	9.50
3790	20.47	20.24	5.84	10.10	16.70	23.90
3791	14.44	1.96	1.95	10.30	23.40	26.70

Empire Cross Exhibit 8

Grayburg Conventional Core Measurements

EMSU-650

	Permeability (MD)				% Fluids	
Depth	Kmax	K90	Kvert	Por %	H2O	Oil
3756	41.92	8.71	43.99	7.10	24.10	25.10
3757	0.72	0.47	0.02	5.20	22.30	23.40
3758	19.02	11.02	18.09	9.80	20.70	23.20
3759	6.48	2.24	2.53	2.10	43.20	19.40
3760	13.26	0.41	16.40	3.70	44.90	17.70
3761	170.81	65.27	21.97	5.70	22.80	24.10
3762	0.26	0.08	0.36	5.10	30.70	27.40
3763	43.23	TBFA	TBFA	4.90	40.50	21.70
3764	70.09	47.44	0.55	11.70	18.80	19.10
3765	58.96	47.70	6.31	12.90	16.50	19.40
3766	432.60	339.77	16.92	11.20	16.10	20.20
3767	2457.59	Plug	N/A	12.70	22.50	25.40
3768	2123.11	1336.69	1054.60	21.70	21.40	22.80
3769	4059.86	Plug	N/A	4.90	38.80	14.10
3770	133.42	9.73	2.77	5.00	24.60	21.30
3771	53.29	35.95	46.37	13.80	20.50	25.40
3772	166.85	84.25	136.87	15.90	20.00	27.50
3773	3.48	Plug	N/A	12.40	22.50	27.30
3774	0.16	Plug	N/A	7.80	27.30	31.00
3775	1166.24	Plug	N/A	17.60	24.70	31.60
3776	395.63	391.91	20.02	12.40	22.40	26.80
3777	23.78	15.16	6.95	6.20	26.50	25.40
3778	32.34	19.68	29.25	13.30	18.60	23.30
3779	3787.63	51.01	33.58	12.30	21.60	25.20
3780	41.29	0.31	0.07	4.80	35.30	29.70

	Permeability (MD)				% Fluids	
Depth	Kmax	K90	Kvert	Por %	H2O	Oil
3780	41.29	0.31	0.07	4.80	35.30	29.70
3781	17.19	14.14	17.72	4.70	38.90	27.00
3782	6.07	Plug	N/A	7.60	20.20	27.00
3783	1867.59	699.19	12.71	13.60	20.00	23.90
3784	373.82	284.27	182.26	16.30	20.50	27.60
3785	3645.72	531.38	27.32	13.80	20.00	28.50
3786	934.28	517.49	24.33	11.70	24.80	28.90
3787	542.68	330.52	25.46	16.50	18.80	23.90
3788	2386.61	1053.25	21.19	11.20	24.20	28.40
3789	3753.59	486.02	39.25	14.30	18.00	25.40
3790	58.93	3.24	0.07	6.40	34.00	23.30
3791	38.76	26.43	1.38	6.80	28.70	26.40
3792	7.07	1.21	4.00	5.80	35.20	26.00
3793	9.69	4.16	2.91	2.30	40.50	25.00
3794	0.36	0.12	0.58	3.40	41.60	25.60
3795	0.20	0.14	0.09	2.80	41.50	27.80
3796	0.04	0.04	0.01	4.30	56.80	14.60
3797	0.03	0.02	0.01	5.70	50.10	13.00
3798	0.02	0.02	0.01	5.20	33.70	20.20
3799	0.03	0.02	0.01	3.90	46.40	16.00
3800	0.61	0.22	0.01	3.90	47.00	14.30
3801	5.69	5.69	2.87	7.80	28.20	19.30
3802	9.49	9.49	5.52	9.90	18.00	21.80
3803	14.57	14.57	TBFA	9.50	17.50	19.40
3804	64.64	64.64	26.15	11.20	18.30	19.60

Grayburg Conventional Core Measurements

EMSU-653

	Permeability (MD)				Saturation	
Depth	Maximum	90 Deg	Vertical	Porosity	Pore Oil	Pore Water
3737.0	176.00	171.00	80.80	12.4	17.2	32.7
3738.0	0.52	0.22	0.23	9.8	27.0	52.0
3739.0	0.56	0.50	0.26	10.8	29.4	34.6
3740.0	0.09	0.05	0.07	6.2	38.6	51.4
3741.0	627.00	191.00	50.90	17.3	17.6	35.2
3742.0	31.80	3.24	0.71	9.8	14.3	40.5
3743.0	6434.00	2.03	914.00	8.9	14.0	46.8
3744.0	105.00	1.03	210.00	4.9	12.0	42.5
3745.0	312.00	40.80	297.00	16.4	15.4	32.5
3746.0	3286.00	16.30	118.00	15.1	24.8	27.5
3747.0	77.10	76.00	15.30	14.4	19.3	34.0
3748.0	290.00	279.00	58.80	17.9	15.1	35.1
3749.0	116.00	108.00	61.00	14.9	18.4	25.6
3750.0	149.00	5.43	5.40	12.6	20.0	33.4
3751.0	6.28	5.94	1.97	14.1	23.5	30.8
3752.0	237.00	79.90	76.70	14.6	16.9	27.1
3753.0	295.00	201.00	71.50	13.7	26.8	29.8
3754.0	17.90	10.70	10.30	9.1	18.3	38.9
3755.0	52.50	58.50	46.80	12.5	22.2	29.6
3756.0	257.00	146.00	92.10	14.4	19.4	34.9
3757.0	1448.00	80.00	17.00	8.7	11.3	35.5
3758.0	1340.00	113.00	1422.00	10.9	8.3	33.3
3759.0	50.90	49.20	20.70	11.3	7.4	28.4
3760.0	158.00	123.00	14.40	11.7	6.0	28.9
3761.0	194.00	158.00	31.40	11.8	9.4	22.9
3762.0	1160.00	162.00	20.30	11.7	5.9	30.4
3763.0	4900.00	1265.00	27.30	8.5	8.5	31.5
3764.0	937.00	305.00	13.50	11.5	16.0	24.0
3765.0	73.20	46.00	10.60	8.8	4.7	47.2

	Permeability (MD)				Saturation	
Depth	Maximum	90 Deg	Vertical	Porosity	Pore Oil	Pore Water
3766.0	7.43	5.41	0.10	3.0	3.9	62.1
3767.0	333.00	1.82	3.79	10.3	18.3	24.4
3768.0	1097.00	539.00	61.40	11.1	15.4	29.3
3769.0	327.00	11.30	1.30	7.3	17.3	36.3
3770.0	2.52	1.46	0.91	6.2	16.2	59.3
3771.0	35.00	31.10	6.47	14.2	15.6	41.0
3772.0	4.54	4.77	1.99	15.9	26.1	31.2
3773.0	8.78	8.70	4.05	14.9	29.4	29.4
3774.0	1.17	0.84	0.85	9.8	35.2	31.7
3775.0	218.00	213.00	60.80	13.6	18.8	34.6
3776.0	1.12	0.73	1.85	5.0	28.8	60.6
3777.0	27.40	27.00	0.99	14.2	17.3	33.0
3778.0	366.00	248.00	1.95	13.8	22.7	28.4
3779.0	226.00	213.00	4.86	12.3	15.1	28.1
3780.0	17.80	17.70	2.26	12.2	20.8	33.3
3781.0	26.50	25.90	25.60	14.1	24.5	25.6
3782.0	7.96	7.45	3.15	7.9	13.7	47.1
3783.0	5.94	39.20	0.10	8.2	23.9	40.6
3784.0	109.00	83.50	81.50	15.7	22.8	26.0
3785.0	56.70	58.00	68.80	13.9	20.3	29.0
3786.0	42.80	29.60	5.71	10.9	15.7	38.0
3787.0	104.00	49.40	12.80	13.1	20.0	26.6
3788.0	40.80	42.10	18.40	13.4	21.9	23.5
3789.0	4.79	12.90	0.40	5.7	28.8	33.9
3790.0	280.00	280.00	5.05	12.1	2.6	38.5
3791.0	54.30	51.70	43.40	14.4	27.8	21.2
3792.0	36.40	36.80	24.70	13.6	18.2	30.4
3793.0	31.30	27.50	8.18	8.8	15.6	34.6
3794.0	7.21	4.71	1.41	7.2	27.7	30.5

Grayburg Conventional Core Measurements

EMSU-710

		Permeability (MD)			Saturation	
Depth	Porosity	Maximum	90 Deg	Vertical	Pore Oil	Pore Water
3717.0	17.90	9512.00	145.00	140.00	20.30	60.00
3718.0	8.50	3.95	0.80	0.43	30.50	39.80
3719.0	9.60	454.00	387.00	4167.00	17.20	47.40
3720.0	14.50	24.50	22.90	20.50	28.00	36.00
3721.0	11.30	3.91	3.37	3.90	23.10	37.20
3722.0	4.60	0.21	0.21	0.05	23.50	61.10
3723.0	4.90	1036.00	500.00	134.00	9.80	36.50
3724.0	7.30	86.10	0.22	132.00	23.30	51.40
3725.0	9.70	31.50	8.04	9.24	33.90	31.90
3726.0	13.80	1544.00	680.00	38.90	15.60	34.80
3727.0	7.10	411.00	109.00	6.13	15.30	37.10
3728.0	9.20	9578.00	9578.00	15926.00	6.30	29.60
3729.0	6.40	2517.00	7.01	149.00	21.20	58.80
3730.0	10.20	1736.00	443.00	501.00	12.10	46.90
3731.0	9.30	612.00	73.90	297.00	14.30	50.20
3732.0	2.90	184.00	161.00	15.00	7.70	84.30
3733.0	3.90	3.84	2.76	0.29	10.90	58.90
3734.0	4.30	38.40	35.90	10.80	10.60	39.40
3735.0	6.00	112.00	89.80	4.87	14.90	39.80
3736.0	4.40	0.01	1176.00		8.00	48.10
3737.0	11.00	713.00	227.00	26.80	12.00	33.00
3738.0	9.00	7.96	5.55	0.44	12.30	28.20
3739.0	4.20	0.01	0.01		23.50	39.10
3740.0	5.80	0.01	0.04		13.30	34.20
3741.0	6.70	331.00	11.90	0.62	9.70	27.90
3742.0	6.20	0.01	0.22		30.70	32.30
3743.0	9.90	18.40	9.07	2.42	17.10	34.20
3744.0	10.30	0.01	3.51		28.90	33.50
3745.0	14.30	149.00	101.00	39.50	25.60	32.00

		Permeability (MD)			Saturation	
Depth	Porosity	Maximum	90 Deg	Vertical	Pore Oil	Pore Water
3746.0	16.00	174.00	172.00	91.70	28.20	30.70
3747.0	6.20	17.40	15.30	0.18	26.10	40.60
3748.0	3.70	1.69	1.66	0.06	16.00	49.70
3749.0	7.00	0.26	0.10	0.05	33.00	49.50
3750.0	5.00	0.02	0.02	0.03	17.60	79.30
3751.0	5.10	0.12	0.04	0.03	2.50	84.50
3752.0	4.60	0.07	0.05	0.01	8.80	74.50
3753.0	14.00	244.00	232.00	84.40	33.00	31.90
3754.0	4.40	0.25	0.07	0.01	6.40	83.80
3755.0	9.90	0.05	0.02	0.03	7.40	67.80
3756.0	10.10	1.46	0.47	0.10	4.40	74.90
3757.0	7.70	0.01	0.01	0.05	11.00	78.00
3758.0	11.40	13.90	13.00	3.17	23.80	34
3759.0	12.80	29.70	29.10	8.57	14.70	31.60
3760.0	15.10	58.90	56.30	65.60	30.50	28.30
3761.0	13.90	86.30	83.60	30.30	24.80	39.70
3762.0	13.40	17.20	15.80	7.49	27.50	22.90
3763.0	9.40	4.82	3.55	0.46	35.80	39.80
3764.0	7.60	8.74	7.09	0.09	21.00	52.40
3765.0	8.90	3.45	1.28	1.60	35.80	31.80
3766.0	6.80	0.15	0.07	0.03	37.00	51.40
3767.0	6.70	0.43	0.37	0.01	36.10	41.20
3768.0	9.00	0.08	0.07	0.01	15.40	61.70
3769.0	13.10	5.38	3.76	2.19	9.10	48.20
3770.0	15.50	7.71	7.16	1.54	32.30	30.00
3771.0	12.90	16.60	16.20	7.23	31.80	26.70
3772.0	11.90	15.60	11.10	10.10	29.50	28.10
3773.0	9.30	0.15	0.07	0.07	8.20	66.00
3774.0	8.70	13.80	6.13	4.19	19.00	67.00

SPE 122921

Estimates of Potential CO_2 Demand for CO_2 EOR in Wyoming Basins

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This paper was prepared for presentation at the 2009 SPE Rocky Mountain Petroleum Technology Conference held in Denver, Colorado, USA, 14–16 April 2009.

Abstract

A database of Wyoming oil reservoirs is developed to identify candidate reservoirs suitable for miscible or immiscible CO_2 flooding, a method that has already proven to be a viable enhanced oil recovery process at Lost Soldier, Wertz, and Salt Creek fields in Wyoming. Based on the CO_2 usage of existing CO_2-EOR projects in Wyoming and other regions, the initial and total CO_2 demands are estimated for the identified reservoirs and grouped by basins. The simple formulas presented in this paper provide a quick estimation of the required initial and total CO_2 volumes with specified reservoir parameters. Wyoming has produced about seven billion barrels of oil from more than 1200 oil producing fields. 98% of the oil was produced from the top 400 fields, evaluated in this study, each with a cumulative production exceeding one million barrels of oil. More than 500 oil reservoirs, by passing either miscible or immiscible screening criteria, are identified as potential CO_2-EOR candidates. Large fields often have multiple oil producing reservoirs suitable for CO_2 flooding. It is estimated that 1.2 to 1.8 billion barrels of additional oil might be recovered by CO_2 flooding and up to 20 trillion cubic feet of CO_2 could be sequestrated after CO_2 EOR in Wyoming's oil basins.

Introduction

CO_2 flooding has already proven to be a viable enhanced oil recovery process in many geographic locations. Wyoming has significant natural sources of CO_2 in several of its existing gas reservoirs that have relatively high CO_2 concentration in their natural gases (De Bruin, 2001; Nummdeal et al., 2003). ExxonMobil operates one of the world's largest CO_2-producing fields at the La Barge anticline in southwestern Wyoming. Five Wyoming fields are currently under CO_2 flooding using the CO_2 supplied by a CO_2 pipeline network that originates at ExxonMobile's gas plant at Shute Creek (Figure 1). Amoco initiated Lost Soldier and Wertz CO_2 miscible floods in late 1980s. The two fields were purchased by Merit Energy Company in 1999 and are still under CO_2 Injection. In 2003, Anadarko constructed a 125-mile pipeline to transport La Barge CO_2 for its EOR project at the Salt Creek field in the Powder River basin and, in the same year, completed another 33-mile pipeline spur to supply CO_2 to flood the Monell Unit at the Patrick Draw field in the Greater Green River basin. The Beaver Creek CO_2 flood, operated by DevonEnergy Corp, is the newest addition to Wyoming's CO_2-EOR portfolio. The field is located on the west flank of the Wind River basin and has been under CO_2 injection since July 2008. A newly constructed 45-mile pipeline brings the CO_2 from the Bairoil station near Jeffrey City to the Beaver Creek field. The increment oil produced from those CO_2 floods has been substantial. The cumulative oil by CO_2 EOR from the Tensleep reservoir at Lost Soldier alone is more than 22 million barrels of oil (MMBO), or 11% of the estimated original oil-in-place (OOIP). By May 2008, CO_2 flooding has already produced 5.5 MMBO at Salt Creek and 3 MMBO at Monell Unit (Gaines, 2008).

The success of the CO_2 floods has drawn a special interest in Wyoming. Many CO_2-EOR projects are currently under evaluation or in planning. However, the biggest challenge for many small producers is access to CO_2 at an affordable price. With Wyoming's vast coal reserves and an increasing concern over climate change, new coal-fired power plants and coal-to-liquids plants are being designed to have CO_2 capture capability. The captured CO_2 will provide Wyoming oil producers additional CO_2 sources for their CO_2-EOR projects. The purpose of this study is two-fold: first, to screen for Wyoming oil reservoirs that are technically suitable for CO_2 flooding and second, to provide a method that quickly estimates the potential CO_2 demand for CO_2-EOR candidate reservoirs. The resulting database and CO_2 demand estimation should be useful for CO_2 suppliers to foresee the market volume for CO_2 EOR in Wyoming basins.

CO_2 EOR has been tested and developed for more than four decades. It becomes a mature technology as demonstrated by more than 80 projects worldwide. Sequestration of CO_2 in partially depleted oil reservoirs is an attractive option, not only because of the economic benefit from EOR, but also because of the availability of reservoir data and infrastructure that can be utilized to facilitate CO_2 storage projects.

Empire Cross Exhibit 9

Screening of CO_2-EOR Candidate Reservoirs

The primary objective of CO_2 EOR is to remobilize and dramatically reduce the post waterflooding residual oil saturation in reservoir pore space. Miscibility between reservoir oils and injected CO_2 usually develops through a dynamic process of mixing, with component exchange controlled by phase equilibria and local compositional variation along the path of displacement. CO_2 is not miscible on the first contact with reservoir oils. However, with a sufficient high pressure, CO_2 could achieve dynamic miscibility with reservoir oils in a multiple contact process. During this multiple contact process, CO_2 will vaporize the lighter oil fractions into the injected CO_2 phase and CO_2 will condense into the reservoir's oil phase. This leads to two reservoir fluids that become miscible (mixing in all parts), with favorable properties of low viscosity, a mobile fluid and low interfacial tension (Stalk, 1984). As long as a minimum miscibility pressure (MMP) can be achieved in a reservoir, CO_2 flooding should result in an oil recovery greater than 90% OOIP in the swept region (Taber et al., 1997). The slim tube test has been used for decades as a common method for determining MMP. Where no measured MMP is available, MMP is often estimated from empirical correlations, such as the Cronquist correlation, based on reservoir temperature and the molecular weight (MW) of the pentanes and heavier fractions of the reservoir oil.

When reservoir pressure is insufficient or reservoir oil composition is less favorable (heavier), the injected CO_2 is immiscible with reservoir oil. However, the interactions between injected CO_2 and reservoir oil can still remobilize some of the residual oil from waterflooding. The main mechanisms involved in immiscible CO_2 flooding are: (1) oil phase swelling, as the oil becomes saturated with CO_2; (2) viscosity reduction of the swollen oil and CO_2 mixture; (3) extraction of lighter hydrocarbon into the CO_2 phase; and, (4) fluid drive plus pressure (Mungan, 1981; Jarrel, 2002). This combination of mechanisms enables a portion of the reservoir's remaining oil to be mobilized and produced. In general, immiscible CO_2 EOR is less efficient than miscible CO_2 EOR in recovering the remaining oil after waterflooding.

By the end of 2008, Wyoming had produced more than 7.1 billion barrels of oil from 1,237 oil producing fields. However, production from many of the fields is small with a few oil producing wells. About 98% of the total oil was produced from the top 400 fields that have a cumulative production exceeding one million barrels of oil (MMBO). For identifying candidate reservoirs suitable for miscible or immiscible CO_2 flooding, a database of Wyoming oil reservoirs was developed, which includes the production data from Wyoming Oil and Gas Conservation Commission (WOGCC), measurements of 901 Wyoming oil samples from the DOE_coa database and other reservoir parameters digitized from the Wyoming Geological Association (WGA) publications.

A number of screening criteria to identify candidate reservoirs for CO_2 EOR can be found in publications such as Stalkup (1984), Diaz et al. (1996) and Taber et al. (1997). Oil viscosity and API gravity as well as reservoir depth and temperature are commonly used as the key screening parameters. In addition, a good waterflood response, and sufficient porosity (> 7%) and permeability (> 10 md) are also required for a successful CO_2 flood. Because the purpose of this study is to assess the potential CO_2 demand for reservoirs that are technically suitable for CO_2 flooding, economic factors such as oil price and distance to CO_2 source are not included in the screening. Only the top 400 fields were evaluated in this study to exclude fields with a cumulative oil production less than one MMBO. There are 1,368 reservoirs from the top 400 fields generated as the initial pool for screening. 528 reservoirs pass the minimum depth cut off (>1,800 ft), oil gravity cut off (>13 °API), and cumulative production cut off (> 1 MMBO) as CO_2-EOR candidate reservoirs. Figure 2 shows the number of candidate reservoirs, in the inserted table, and their cumulative oil productions grouped by basins. Lost Soldier and Wertz fields are already in their final phase of CO_2 flooding operation and, therefore, are not included in the screening. The candidate reservoirs are further screened into two groups: miscible and immiscible, based on the following screening criteria.

Screening criteria for miscible CO_2 flooding

- Sandstone or carbonate reservoir only
- Porosity porosity > 7% and permeability > 10 md
- Oil gravity > 22 °API
- Reservoir depth > 2,500 ft
- Oil viscosity < 10 cp, at reservoir condition
- Cumulative oil production > 1 MMBO

Screening criteria for immiscible CO_2 flooding

- Sandstone or carbonate reservoir only
- Porosity porosity > 7% and permeability > 10 md
- 13 °API ≤ oil gravity ≤ 22 °API
- 1,800 ft ≤ reservoir depth ≤ 2,500 ft
- 10 cp ≤ oil viscosity < 600 cp, at reservoir condition
- Cumulative oil production > 1 MMBO

The miscibility between reservoir oil and injected CO_2 is a complex process as discussed above. Because of higher reservoir temperature or unfavorable oil composition, a miscible flooding may not be achieved in a reservoir even thought it passes the miscible flooding criteria. Thus, the proposed criteria for miscible CO_2 flooding should be regarded as potentially miscible criteria. As shown in Figures 2 and 3, most of the candidate reservoirs are located within Wyoming's four large oil producing basins: Power River, Bighorn, Wind River and Greater Green River basins. More than half of the total candidate reservoirs are in the Power River basin, which consists of 124 relatively small Minnelusa reservoirs. Large candidate reservoirs are more concentrated in the Bighorn basin, mostly Tensleep, Phosphoria and Madison reservoirs. Tables 1 and 2 list the major reservoirs identified from screening as potentially miscible and immiscible CO_2-EOR candidates, respectively.

Estimation of Total and Initial CO_2 Demand

In many CO_2 flooding projects, CO_2 is injected alternately with water, such as the Lost Soldier and Wertz CO_2 miscible floods in Wyoming. The concept of using CO_2-WAG (water alternating gas) injection technique is to improve injection profile and reduce gas channeling. The performance of CO_2-WAG floods from a similar formation may likely be scaled into one dimensionless curve of incremental oil, as a percentage of hydrocarbon pore volume (HCPV), versus injected WAG volume in HCPV. The dimensionless curve obtained from the CO_2-WAG flood in the Tensleep reservoir of Lost Soldier is shown in Figure 4 and is compared with the typical dimensionless curve from the CO_2-WAG floods in the San Andres reservoirs of west Texas. For similar type of reservoirs using a same CO_2 flood scheme, the dimensionless curve method could provide a quick assessment of potential oil recovery as well as required CO_2 injection volume. In this study, estimation of CO_2 demand is based on the performance of existing CO_2-WAG floods. For reservoirs with large dip angles or high concentration of vertical fractures, gravity stable CO_2 injection could be a more effective flood scheme, which is discussed in the next section.

Estimation of total CO_2 demand for a CO_2-WAG flood

The duration of a CO_2 flood project usually lasts for a few decades and the majority of the injected CO_2 is produced and re-injected. As given in Eq. 1, the estimated total CO_2 demand only takes account of the net CO_2 volume that needs to be purchased.

$$T_{CO2} = \frac{(1-\omega_{CO2}) \times C_{WAG} \times H_{WAG} \times B_o \times OOIP}{B_{CO2}} \quad (1)$$

where B_o and B_{CO2} are the oil and CO_2 formation factors, respectively. ω_{CO2} represents the average fraction of the injected CO_2 that is produced and re-injected. The CO_2 volume fraction in WAG, C_{WAG}, is calculated at reservoir condition. H_{WAG} is the injected total WAG volume in HCPV and T_{CO2} is the estimated total CO_2 volume in MCF. For the CO_2-EOR candidate reservoirs in Wyoming basins, a 70% CO_2 re-injection rate, 1:1 WAG ratio and a total WAG injection of 2.5 HCPV are assumed in this evaluation. Consequently, Eq. 1 is further simplified as

$$T_{CO2} = \frac{0.3 \times 0.5 \times 2.5 \times B_o \times OOIP}{B_{CO2}} \quad (2)$$

Trustworthy OOIP data of Wyoming oil reservoirs are rarely available. Traditionally, volumetric calculation or decline curve analysis is used in the estimation of OOIP but it is difficult to verify the consistency of the methods used in previous estimations, especially if a large number of reservoirs are concerned. In this evaluation, OOIP is estimated from reservoir cumulative production and recovery factor. Most of Wyoming oil reservoirs have been under water-drive production for decades. Many of the reservoirs are naturally fractured and their recovery efficiency can vary substantially depending on reservoir properties and engineering practice. Therefore, instead of assuming one average recovery factor, a low recovery factor of 30% and a high recovery factor of 45% are both used to provide a range of estimated OOIP.

CO_2 formation factor, B_{CO2}, is determined by reservoir pressure and temperature according to the data table provided by Jarrell et al. (2002). For reservoir pressure or temperature that is not included in the table, B_{CO2} is estimated by linear interpolation from the four nearest formation factors that are available in the table. The estimated CO_2 demands for miscible and immiscible CO_2 EOR in Wyoming basins are summarized in Figures 5 and 6, respectively. In combination, the estimated total CO_2 demand ranges from 6.1 to 9.2 TCF in Power River, 4.8 to 7.2 TCF in Bighorn, 1.2 to 1.8 TCF in Wind River, 1 to 1.4 TCF in Greater Green River, 0.68 to 1.02 TCF in Overthrust Belt, 0.09 to 0.13 TCF in Laramie, and 0.08 to 0.12 TCF in Denver-Cheyenne basins.

Estimation of initial CO_2 demand for a CO_2-WAG flood

Reservoir injectivity is another key factor for a successful CO_2 flood. An annual WAG injection between 5% and 10% HCPV is typically required in the design of a field flood project. Higher volume injections, 10-15% HCPV per year, have been observed in projects with good flooding performance. A CO_2 flood project may be economically unviable under very low annual injection volume, i.e. less than 4% HCPV per year. In the initial phase of a WAG flood, no CO_2 will be produced until the breakthrough of CO_2 at the production wells and the injected CO_2 needs to be fully supplied from external sources. The initial CO_2 demand can be estimated from Eq. 3.

$$I_{CO2} = \frac{C_{WAG} \times I_{WAG} \times B_o \times OOIP}{365 \times B_{CO2}} \tag{3}$$

where I_{WAG} is the annual WAG injection volume in HCPV and I_{CO2} is the estimated daily CO_2 injection rate in MCF/day. In this evaluation, a 1:1 WAG ratio and an annual WAG injection of 10% HCPV are used in the estimation of initial CO_2 demand (Eq. 4).

$$I_{CO2} = \frac{0.5 \times 0.1 \times B_o \times OOIP}{365 \times B_{CO2}} \tag{4}$$

The estimated CO_2 demand for the top 100 reservoirs identified as miscible CO_2-EOR candidates is given in Table 1, along with reservoir depth and oil API gravity. A similar table of the top 20 reservoirs of immiscible CO_2-EOR candidates is given in Table 2.

Results and Discussion

Large fields usually have multiple oil producing reservoirs that are suitable for CO_2 flooding. Because the CO_2 demand is ranked by reservoir, not by field, the estimated volumes in Tables 1 and 2 may not reflect the total CO_2 demand of a field if some of its small reservoirs are not included in the tables. Many existing CO_2-EOR projects have been developed by phases, often starting with small scale patterns of pilot flooding. Notice that the estimation of initial CO_2 demand in this study is calculated under the assumption of a full reservoir flooding.

As indicated from the dimensionless curves (Figure 4), the miscible CO_2 flooding has recovered about 11% of OOIP from the Tensleep reservoir at the Lost Soldier field and much higher recoverys have been observed from the CO_2 floods in the San Andres reservoirs of west Texas. The recovery factor from immiscible CO_2 floods is generally lower than miscible floods depending on actual oil and reservoir conditions. By assuming an average recovery factor of 10% OOIP for miscible CO_2 floods and 6.5% for immiscible CO_2 floods, it is estimated that 1.21 to 1.81 billion barrels of additional oil might be recovered from CO_2 EOR in Wyoming, in which the recovery from miscible floods accounts for 79% of the total incremental oil.

The estimation of total and initial CO_2 demand, i.e. Eq. 1 and Eq. 3, is essentially based on the CO_2 usage of existing CO_2-WAG floods. However, for reservoirs with large dip angles or high concentration of vertical fractures, gravity segregation of injected CO_2 and water might leave a large volume of remaining oil uncontacted with injected CO_2 and, consequently, reduce the overall WAG flooding efficiency. For such reservoirs, continuous CO_2 injection at the top of reservoir structure, i.e. gravity stable CO_2 injection, could be more effective than WAG flooding, especially for projects designed for the dual-purpose of CO_2 EOR and CO_2 storage (Wood et al., 2006). Gravity stable CO_2 injection usually requires considerably more CO_2 than WAG injection. For example, the estimated total CO_2 demand for a WAG flood in the Muddy reservoir of Grieve field is between 77 and 116 BCF of CO_2. By comparison, the CO_2 required for gravity stable CO_2 flooding in the same reservoir is estimated to be in the 119 to 188 BCF range depending on the operation duration and CO_2 injection rate (Wo et al., 2008).

Conclusions

Wyoming has a large number of oil reservoirs in the Powder River, Bighorn, Wind River, and Greater Green River basins where CO_2-based EOR is technically feasible. The state is in a unique position to couple the environmental benefits of CO_2 sequestration in mature oil reservoirs with the economic offset through enhanced oil recovery. The main outcomes from this study are listed below:

1. A database of Wyoming oil reservoirs is developed to screen candidate reservoirs suitable for miscible or immiscible CO_2 flooding. 379 reservoirs pass the screening criteria for miscible CO2 flooding, while 138 reservoirs are identified as potential candidates for immiscible CO2 flooding.
2. Based on the CO_2 usage of existing CO_2-EOR projects in Wyoming and other regions, simple formulas are provided for allowing a quick estimation of the required initial and total CO_2 volumes for a candidate reservoir.
3. The estimated total CO_2 demand for CO_2 EOR ranges from 6.1 to 9.2 TCF in Power River, 4.8 to 7.2 TCF in Bighorn, 1.2 to 1.8 TCF in Wind River, 1 to 1.4 TCF in Greater Green River, 0.68 to 1.02 TCF in Overthrust Belt, 0.09 to 0.13 TCF in Laramie, and 0.08 to 0.12 TCF in Denver-Cheyenne basins.
4. It is estimated that 1.2 to1.8 billion barrels of additional oil could be recovered by CO_2 flooding and up to 20 trillion

cubic feet of CO_2 could be sequestrated after CO_2 EOR in Wyoming's oil basins.

Acknowledgements
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Nomenclature

B_{CO2} = CO_2 formation factor
BO = barrel of oil
B_o = oil formation factor
C_{WAG} = fraction of CO_2 volume in total WAG volume
BCF = billion standard cubic feet
EOR = enhance oil recovery
HCPV = hydrocarbon pore volume
H_{WAG} = total WAG injection volume, HCPV
I_{CO2} = initial daily CO_2 demand, MCF/day
I_{WAG} = annual WAG injection volume, HCPV/year
MMP = minimum miscibility pressure
MMBO = million barrels of oil
MCF = thousand standard cubic feet
OOIP = original oil in place
TCF = trillion standard cubic feet
T_{CO2} = total CO_2 demand, MCF
WAG = water alternating gas
WGA = Wyoming Geological Association
WOGCC = Wyoming Oil and Gas Conservation Commission
ω_{CO2} = fraction of recycled CO_2 in total injected CO_2

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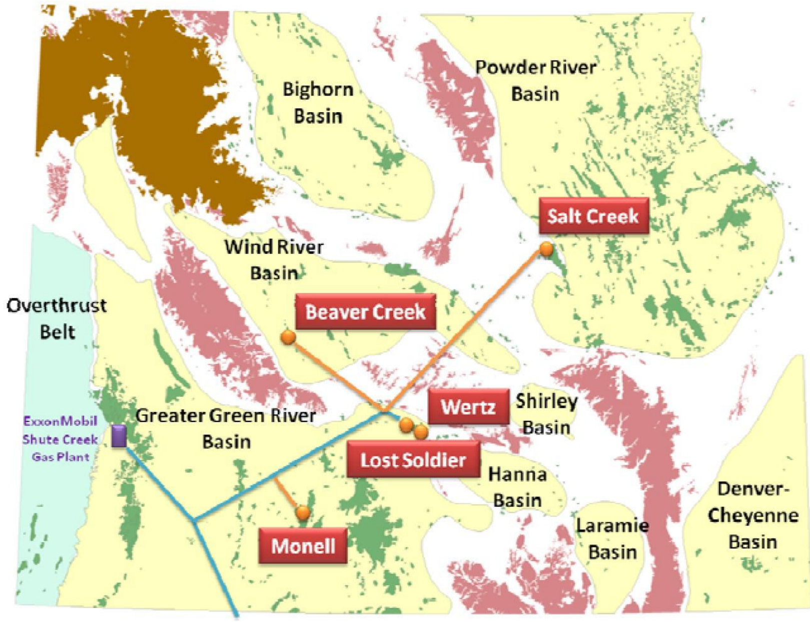


Figure 1. Wyoming basin map with existing CO_2 pipelines and CO_2 flooding fields

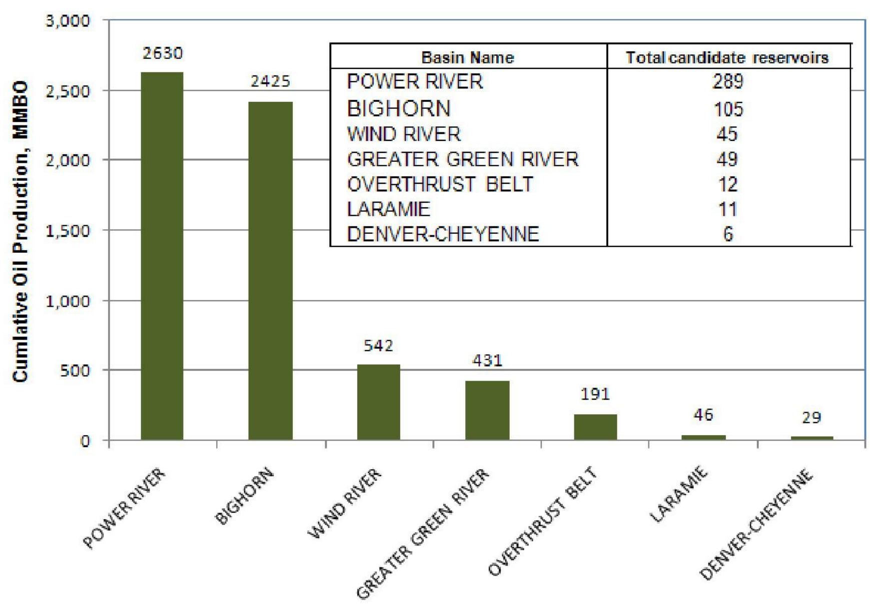


Figure 2. Number of CO_2-EOR candidate reservoirs and their cumulative oil productions by Wyoming basins

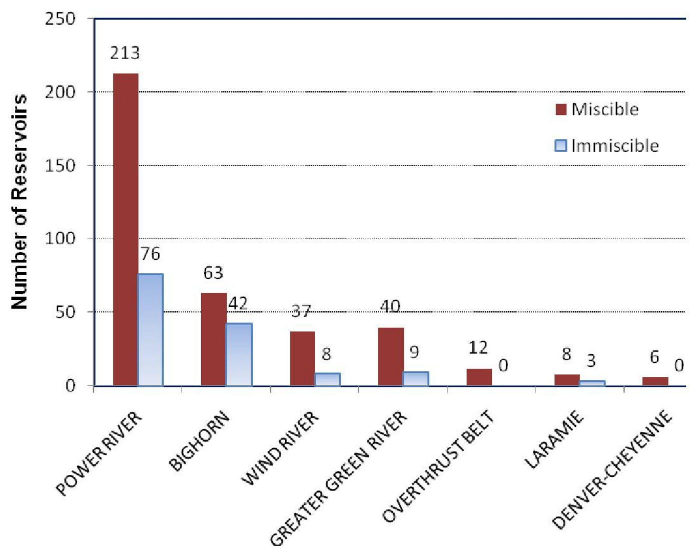


Figure 3. Number of miscible and immiscible CO_2-EOR candidate reservoirs by Wyoming basins

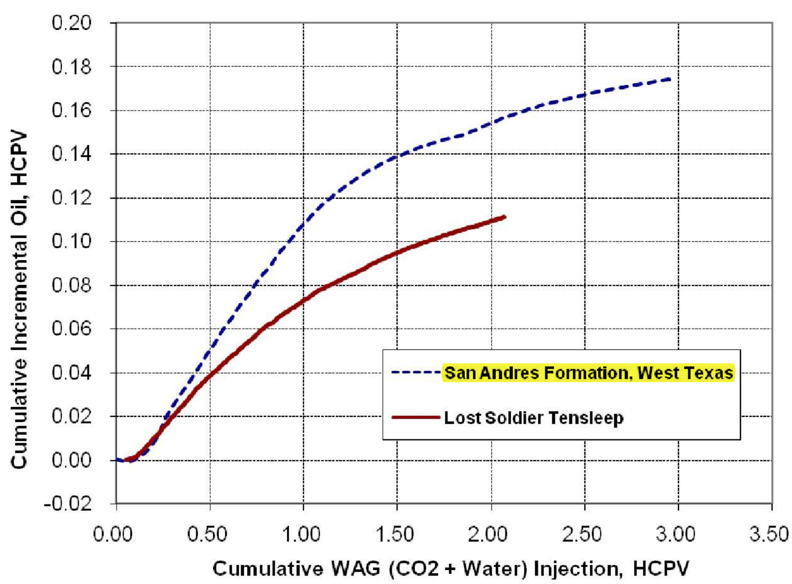


Figure 4. Dimensionless curves of incremental oil versus total WAG injection

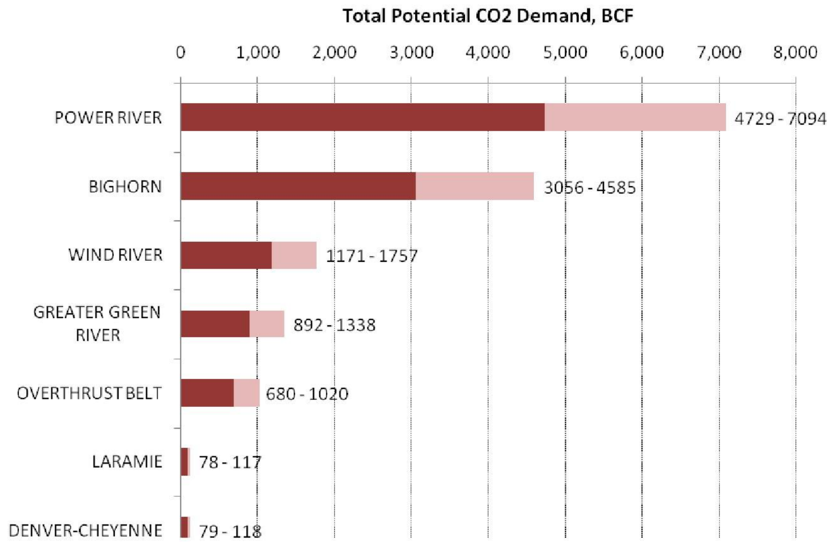


Figure 5. Estimated potential CO_2 demand for miscible CO_2 floods in Wyoming basins

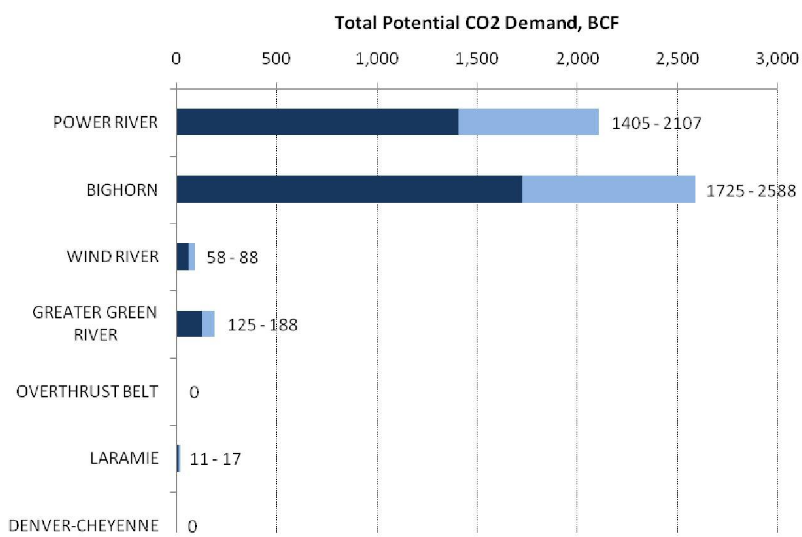


Figure 6. Estimated potential CO_2 demand for immiscible CO_2 floods in Wyoming basins

Table 1. Top 100 ranked reservoires for potentially miscible CO_2 flooding in Wyoming

Rank	Field name	Reservoir Name	Reservoir Depth ft	Oil Gravity API	Est. Total CO2 BCF	Est. Initial CO2 MMCF/D	Basin Name
1	HARTZOG DRAW	SHANNON	9485	36	564 - 846	206 - 309	POWDER RIVER
2	ELK BASIN	MADISON	5156	27.3	520 - 780	190 - 285	BIGHORN
3	ELK BASIN	EMBAR-TENSLEEP	4490	30	403 - 605	147 - 221	BIGHORN
4	PAINTER RESERVOIR EAST	NUGGET	10774	55	269 - 404	98 - 147	OVERTHRUST BELT
5	HILIGHT	MUDDY	9680	41.3	248 - 373	90 - 136	POWDER RIVER
6	BYRON	TENSLEEP	5425	25.2	244 - 366	89 - 133	BIGHORN
7	HAMILTON DOME	TENSLEEP	2863	23.8	233 - 350	85 - 128	BIGHORN
8	LANCE CREEK	LEO	5557	44.1	226 - 339	82 - 124	POWDER RIVER
9	STEAMBOAT BUTTE	TENSLEEP	6830	28.7	219 - 329	80 - 120	WIND RIVER
10	FRANNIE	PHOSPHORIA-TENSLEEP	2574	28.3	209 - 314	76 - 115	BIGHORN
11	GRASS CREEK	PHOSPHORIA-TENSLEEP	3632	24.5	192 - 288	70 - 105	BIGHORN
12	ARCH	ALMOND	5067	43.4	168 - 252	61 - 92	GREATER GREEN RIVER
13	OREGON BASIN	TENSLEEP	3850	23	159 - 238	58 - 87	BIGHORN
14	BRADY	WEBER	12082	54.7	155 - 232	56 - 85	GREATER GREEN RIVER
15	COTTONWOOD CREEK	PHOSPHORIA	7270	28.6	152 - 228	55 - 83	BIGHORN
16	PAINTER RESERVOIR	NUGGET	9958	46	147 - 221	53 - 80	OVERTHRUST BELT
17	GLENROCK SOUTH	DAKOTA	6090	34.4	136 - 204	49 - 74	POWDER RIVER
18	HOUSE CREEK	SUSSEX	8238	48.8	123 - 185	45 - 67	POWDER RIVER
19	BRADY	NUGGET	9876	50.5	122 - 183	44 - 67	GREATER GREEN RIVER
20	SUSSEX	TENSLEEP-AMSDEN	5894	33	120 - 181	44 - 66	POWDER RIVER
21	BEAVER CREEK	MADISON	10666	40.5	117 - 176	42 - 64	WIND RIVER
22	BIG SAND DRAW	TENSLEEP	6606	33.6	116 - 174	42 - 63	WIND RIVER
23	SALT CREEK	TENSLEEP	3908	28.2	100 - 150	36 - 54	POWDER RIVER
24	WELL DRAW	TEAPOT	7048	42.5	91 - 137	33 - 50	POWDER RIVER
25	STEAMBOAT BUTTE	PHOSPHORIA-TENSLEEP	6000	28.2	91 - 136	33 - 49	WIND RIVER
26	WINKLEMAN	TENSLEEP	2915	25	83 - 124	30 - 45	WIND RIVER
27	POWELL	FRONTIER	11943	48.2	79 - 119	29 - 43	POWDER RIVER
28	BYRON	EMBAR-TENSLEEP	5238	24.5	79 - 119	29 - 43	BIGHORN
29	GRIEVE	MUDDY	6723	38.2	77 - 116	28 - 42	WIND RIVER
30	WINKLEMAN	PHOSPHORIA	2600	25.7	74 - 111	27 - 40	WIND RIVER
31	GAS DRAW	MUDDY	7191	37.39	71 - 107	26 - 39	POWDER RIVER
32	BIG MUDDY	DAKOTA	4298	36.8	70 - 106	25 - 38	POWDER RIVER
33	GRASS CREEK	PHOSPHORIA	3632	24.5	68 - 102	24 - 37	BIGHORN
34	KITTY	MUDDY	9201	42	68 - 102	24 - 37	POWDER RIVER
35	GRASS CREEK	CURTIS	3717	24.3	66 - 100	24 - 36	BIGHORN

Table 1 (continued). Top 100 ranked reservoires for potentially miscible CO_2 flooding in Wyoming

Rank	Field name	Reservoir Name	Reservoir Depth ft	Oil Gravity API	Est. Total CO2 BCF	Est. Initial CO2 MMCF/D	Basin Name
36	SAND DUNES	MUDDY	12600	42	65 - 97	23 - 35	POWDER RIVER
37	STEAMBOAT BUTTE	NUGGET	4164	38.5	61 - 92	22 - 33	WIND RIVER
38	DRY PINEY	NUGGET	10988	52	59 - 89	21 - 32	OVERTHRUST BELT
39	BEAVER CREEK	TENSLEEP	10442	45	59 - 89	21 - 32	WIND RIVER
40	WHITNEY CANYON-CARTER CREEK	MADISON	11790	49.4	59 - 88	21 - 32	OVERTHRUST BELT
41	COYOTE CREEK	DAKOTA	6400	41	55 - 83	20 - 30	POWDER RIVER
42	GARLAND	TENSLEEP	4267	23	54 - 81	19 - 29	BIGHORN
43	RYCKMAN CREEK	NUGGET	5800	47.2	52 - 78	19 - 28	OVERTHRUST BELT
44	ROZET	MINNELUSA	8156	34	50 - 75	18 - 27	POWDER RIVER
45	SALT CREEK	SUNDANCE-3	3000	35	49 - 73	17 - 26	POWDER RIVER
46	STEAMBOAT BUTTE	PHOSPHORIA	6732	31.1	48 - 72	17 - 26	WIND RIVER
47	RENO	MINNELUSA	15006	36.5	48 - 72	17 - 26	POWDER RIVER
48	TIMBER CREEK	MINNELUSA	9360	25	47 - 71	17 - 25	POWDER RIVER
49	MEADOW CREEK	TENSLEEP	9060	29.7	46 - 70	17 - 25	POWDER RIVER
50	BIRCH CREEK	BEAR RIVER 7500	7512	46	44 - 67	16 - 24	GREATER GREEN RIVER
51	SCOTT	PARKMAN	6102	37	44 - 66	16 - 24	POWDER RIVER
52	LANCE CREEK	CONVERSE	4394	41.5	42 - 64	15 - 23	POWDER RIVER
53	DILLINGER RANCH	MINNELUSA	9132	37	42 - 63	15 - 23	POWDER RIVER
54	SUSSEX WEST	SHANNON	2914	39.6	41 - 61	15 - 22	POWDER RIVER
55	LUCKEY DITCH	DAKOTA	14400	43	41 - 61	14 - 22	GREATER GREEN RIVER
56	BLACK MOUNTAIN	TENSLEEP	3125	24.9	39 - 59	14 - 21	BIGHORN
57	RAVEN CREEK	MINNELUSA	8354	33.4	39 - 58	14 - 21	POWDER RIVER
58	BIG MUDDY	WALL CREEK	3069	35.6	39 - 58	14 - 21	POWDER RIVER
59	COLE CREEK	DAKOTA	7947	37	37 - 56	13 - 20	POWDER RIVER
60	MIKES DRAW	TEAPOT	7264	39	37 - 56	13 - 20	POWDER RIVER
61	WHITNEY CANYON-CARTER CREEK	MISSION CANYON	14226	49.4	35 - 53	13 - 19	OVERTHRUST BELT
62	HALVERSON	MINNELUSA	8489	24	35 - 53	12 - 19	POWDER RIVER
63	FINN-SHURLEY	TURNER	4886	38	35 - 52	12 - 19	POWDER RIVER
64	RECLUSE	MUDDY	7530	42.1	35 - 52	12 - 19	POWDER RIVER
65	STEWART	MINNELUSA	8024	22.5	34 - 52	12 - 19	POWDER RIVER
66	GEBO	EMBAR-TENSLEEP	4735	24.9	34 - 51	12 - 18	BIGHORN
67	SAGE SPRING CREEK	DAKOTA	7590	39.4	34 - 51	12 - 18	POWDER RIVER
68	ELK BASIN SOUTH	EMBAR-TENSLEEP	6846	28	33 - 50	12 - 18	BIGHORN
69	GARLAND	PHOSPHORIA	3060	24.3	33 - 49	12 - 18	BIGHORN
70	COLE CREEK SOUTH	DAKOTA	8309	35.4	32 - 49	11 - 17	POWDER RIVER

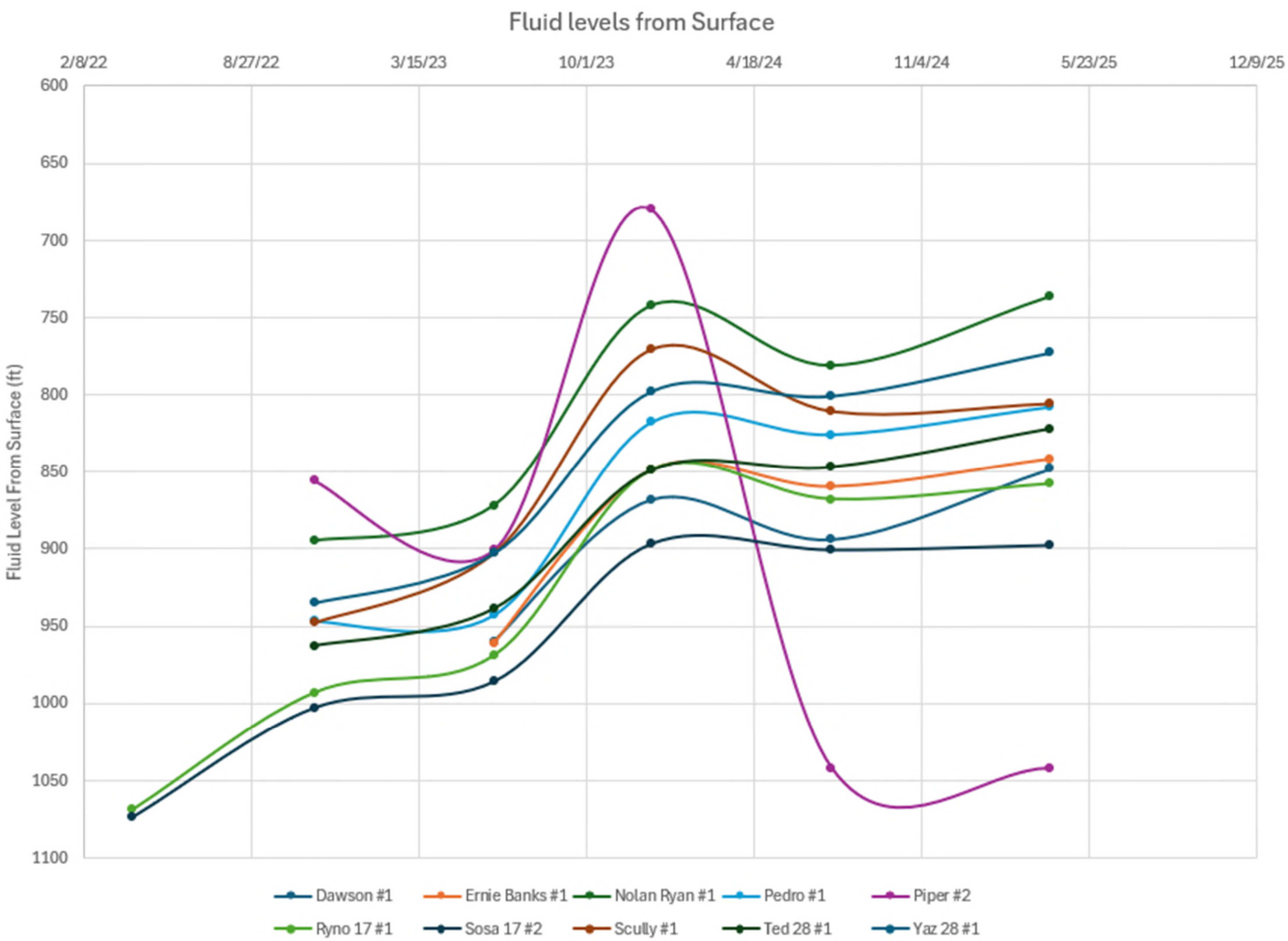
Table 1 (continued). Top 100 ranked reservoires for potentially miscible CO_2 flooding in Wyoming

Rank	Field name	Reservoir Name	Reservoir Depth ft	Oil Gravity API	Est. Total CO2 BCF	Est. Initial CO2 MMCF/D	Basin Name
71	PINE TREE	SHANNON	11720	38	31 - 47	11 - 17	POWDER RIVER
72	SLATTERY	MINNELUSA	6242	30	30 - 45	11 - 16	POWDER RIVER
73	SPRINGEN RANCH	MUDDY	7671	40.4	29 - 43	10 - 16	POWDER RIVER
74	WORLAND	TENSLEEP	9650	24.2	28 - 43	10 - 15	BIGHORN
75	ELK BASIN	BIG HORN	5460	23.3	28 - 42	10 - 15	BIGHORN
76	PATRICK DRAW	ALMOND	5067	43.4	27 - 41	10 - 15	GREATER GREEN RIVER
77	STANDARD DRAW	MESAVERDE	8968	59	27 - 40	9 - 14	GREATER GREEN RIVER
78	SANDBAR EAST	MINNELUSA	7034	23	27 - 40	9 - 14	POWDER RIVER
79	REEL	MINNELUSA	8429	33	26 - 40	9 - 14	POWDER RIVER
80	NOTCHES	TENSLEEP	2865	22.5	26 - 39	9 - 14	WIND RIVER
81	GARLAND	EMBAR	3060	24	26 - 39	9 - 14	BIGHORN
82	SILO	NIOBRARA	8402	35	26 - 39	9 - 14	DENVER-CHEYENNE
83	POWELL	DAKOTA	12955	46	25 - 38	9 - 14	POWDER RIVER
84	GOLDEN EAGLE	PHOSPHORIA	8890	48.8	25 - 38	9 - 14	BIGHORN
85	SKULL CREEK	NEWCASTLE	3170	34	25 - 37	9 - 13	POWDER RIVER
86	POWNALL RANCH	MINNELUSA	6222	259	24 - 37	9 - 13	POWDER RIVER
87	ROCK RIVER	MUDDY-DAKOTA-LAKOTA	2581	37	24 - 36	8 - 13	LARAMIE
88	POISON SPIDER WEST	CODY	10145	45	24 - 36	8 - 13	WIND RIVER
89	LITTLE MITCHELL CREEK	MINNELUSA	7330	26	24 - 36	8 - 13	POWDER RIVER
90	UTE	MUDDY	6382	41.1	23 - 35	8 - 13	POWDER RIVER
91	HENRY	DAKOTA	13393	52	23 - 35	8 - 12	GREATER GREEN RIVER
92	BONE PILE	MINNELUSA	8528	31.5	22 - 34	8 - 12	POWDER RIVER
93	ROZET	MUDDY	6935	35.4	22 - 33	8 - 12	POWDER RIVER
94	BIG SAND DRAW	PHOSPHORIA	6850	62.1	22 - 33	8 - 12	WIND RIVER
95	DONKEY CREEK	MINNELUSA	7845	27.7	22 - 33	8 - 12	POWDER RIVER
96	KAYE	TEAPOT	5512	39	22 - 33	8 - 12	POWDER RIVER
97	SUSSEX	TENSLEEP	9140	30.2	22 - 33	8 - 12	POWDER RIVER
98	GLENROCK SOUTH	MUDDY	6300	38.6	22 - 33	8 - 12	POWDER RIVER
99	GOOSEBERRY	PHOSPHORIA-TENSLEEP	5668	22.6	22 - 33	8 - 12	BIGHORN
100	HELDT DRAW	SHANNON	9400	35.6	22 - 33	8 - 12	POWDER RIVER

Table 2. Top 20 ranked reservoires for immiscible CO_2 flooding in Wyoming

Rank	Field Name	Reservoir Name	Reservoir Depth ft	Oil Gravity API	Est. Total CO2 BCF	Est. Initial CO2 MMCF/D	Basin Name
1	SALT CREEK	WALL CREEK-2	2200	37	852 - 1278	311 - 467	POWDER RIVER
2	OREGON BASIN	EMBAR	3525	21.6	677 - 1016	247 - 371	BIGHORN
3	GARLAND	MADISON	4424	20.5	230 - 345	84 - 126	BIGHORN
4	LITTLE BUFFALO BASIN	TENSLEEP	3348	19.6	137 - 206	50 - 75	BIGHORN
5	LITTLE BUFFALO BASIN	EMBAR	4781	19.6	99 - 149	36 - 54	BIGHORN
6	OREGON BASIN	MADISON	4465	22	93 - 140	34 - 51	BIGHORN
7	HAMILTON DOME	PHOSPHORIA	2400	26	82 - 123	30 - 45	BIGHORN
8	BYRON	EMBAR	5252	19.5	64 - 96	23 - 35	BIGHORN
9	PITCHFORK	TENSLEEP	3463	18.2	57 - 86	20 - 31	BIGHORN
10	NORTH FORK	TENSLEEP	6484	21.5	48 - 72	17 - 26	POWDER RIVER
11	BIRCH CREEK	MESAVERDE-3	1874	46	46 - 69	16 - 25	GREATER GREEN RIVER
12	SALT CREEK	WALL CREEK 1-2	2235	37	29 - 44	10 - 16	POWDER RIVER
13	TORCHLIGHT	MADISON	3550	20.5	28 - 42	10 - 15	BIGHORN
14	SPRING CREEK SOUTH	TENSLEEP	3796	15.3	27 - 40	9 - 14	BIGHORN
15	LITTLE BUFFALO BASIN	EMBAR-TENSLEEP	4781	19.6	26 - 39	9 - 14	BIGHORN
16	ROCKY POINT	MINNELUSA	5592	16.8	25 - 38	9 - 13	POWDER RIVER
17	FOURBEAR	DINWOODY-PHOSPH-TENSLEEP-DARWIN-MADISON	2900	13.5	24 - 37	9 - 13	BIGHORN
18	KUMMERFELD	MINNELUSA	5962	19	22 - 33	8 - 12	POWDER RIVER
19	ROZET WEST	MINNELUSA	8692	21	20 - 30	7 - 11	POWDER RIVER
20	LABARGE	MESAVERDE	1960	45.6	18 - 27	6 - 10	GREATER GREEN RIVER

Goodnight Fluid Level Data Indicates San Andres Pressure is Increasing



Well Name	Date	SI Time	TP	FL FS
Dawson #1	6/13/23	~18-days	-13	960
Dawson #1	12/18/23	~20-min	-13	868
Dawson #1	7/20/24	72-min	-13	894
Dawson #1	4/7/25	132-min	-13	848
Ernie Banks #1	6/13/23	~20-min	-13	961
Ernie Banks #1	12/18/23	~20-min	-13	849
Ernie Banks #1	7/20/24	110-min	-13	860
Ernie Banks #1	4/7/25	97-min	-13	842
Nolan Ryan #1	11/11/22	~20-min	-12	895
Nolan Ryan #1	6/13/23	~20-min	-12	872
Nolan Ryan #1	12/18/23	~20-min	-13	742
Nolan Ryan #1	7/20/24	52-min	-13	781
Nolan Ryan #1	4/7/25	75-min	-12	736
Pedro #1	11/11/22	~20-min	-10	947
Pedro #1	6/13/23	~20-min	-10	943
Pedro #1	12/18/23	~20-min	-12	818
Pedro #1	7/20/24	90-min	-10	826
Pedro #1	4/7/25	80-min	-12	808
Piper #2	11/11/22	~20-min	-10	856
Piper #2	6/13/23	~11-hours	-12	901
Piper #2	12/18/23	~20-min	-13	680
Piper #2	7/20/24	~2 months	-10	1042
Piper #2	4/7/25	~1 month	-11	1042
Ryno 17 #1	4/7/22	~20-min	-9	1069
Ryno 17 #1	11/11/22	~20-min	-10	993
Ryno 17 #1	6/13/23	~20-min	-10	969
Ryno 17 #1	12/18/23	~20-min	-12	849
Ryno 17 #1	7/20/24	95-min	-13	868
Ryno 17 #1	4/7/25	110-min	-13	858
Sosa 17 #2	4/7/22	~20-min	-11	1074
Sosa 17 #2	11/11/22	~20-min	-10	1003
Sosa 17 #2	6/13/23	~20-min	-12	986
Sosa 17 #2	12/18/23	~20-min	-13	897
Sosa 17 #2	7/20/24	126-min	-13	901
Sosa 17 #2	4/7/25	138-Min	-12	898
Scully #1	11/11/22	~20-min	-11	948
Scully #1	6/13/23	~20-min	-13	903
Scully #1	12/18/23	~20-min	-13	771
Scully #1	7/20/24	126-min	-11	811
Scully #1	4/7/25	80-min	-12	806
Ted 28 #1	11/11/22	~20-min	-10	963
Ted 28 #1	6/13/23	~20-min	-10	939
Ted 28 #1	12/18/23	~20-min	-11	849
Ted 28 #1	7/20/24	90-min	-10	847
Ted 28 #1	4/7/25	115-min	-12	822
Yaz 28 #1	11/11/22	~2-days	-9	935
Yaz 28 #1	6/13/23	~3-days	-8	903
Yaz 28 #1	12/18/23	~20-min	-10	798
Yaz 28 #1	7/20/24	90-min	-10	801
Yaz 28 #2	4/7/25	90-min	-12	773

GNM Fluid Levels 4-7-25 xls

Empire Cross Exhibit 10

Dr. James Buckwalter Simulation Model – Initial Water Saturation (Model used 35% instead of 30%)

EUNICE MONUMENT SOUTH UNIT

EUNICE MONUMENT SOUTH UNIT EXPANSION

WORKING INTEREST OWNERS' MEETING

FEBRUARY 27, 1990

EMSU RESERVOIR PARAMETERS

UNIT AREA	14190 ACRES
INITIAL RESERVOIR PRESSURE	1450 PSI
RESERVOIR PRESSURE AT START OF WATERFLOOD	250 PSI
SATURATION PRESSURE	1372 PSI
SOLUTION GOR	423 SCF/STB
CURRENT PRODUCING GOR	4007 SCF/STB
RESERVOIR TEMPERATURE	90 DEG F
OIL GRAVITY	32 DEG API
INITIAL FORMATION VOLUME FACTOR	1.20 RB/STB
CURRENT FORMATION VOLUME FACTOR	1.05 RB/STB
AVERAGE NET PAY	134 FT
AVERAGE POROSITY	8.0 %
INITIAL WATER SATURATION	30.0 %

Empire Cross Exhibit 11