Offshore Storage Resource Assessment
DE-FE0026392

Project Update

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Pittsburgh, PA

Presentation Outline

Phase 1 (Milestone No. 3 – Feb. 10, 2016)

- Task 2.0 - Identify and rank depleted fields
- Task 3.0 – Validate field OOIP/OGIP
- Task 4.0 – CO_2 sequestration volume calculation (DOE equation)

Phase 2 (Work in Progress)

- Task 5.0 – CO_2 sequestration volume validation and refinement
- Task 6.0 – CO_2 Oil Production Assessment
- Task 7.0 – Document Project

Technical Status

Task 2.0 - Identify and rank depleted fields (Complete)

- BOEM Reserves database (12/31/2013)
  - 1295 fields, 13,289 sands
- IHS GOM well and production database leased
- 675 depleted fields identified and extracted from the BOEM database and a project database created
- 675 fields containing 3514 individual sands
  - 8 contain only oil reservoirs
  - 573 contain only gas reservoirs
  - 94 contain oil reservoirs with gas cap

Task 3.0 - Validate field OOIP/OGIP (Complete)

- Five fields containing 16 productive sands selected for OOIP/OGIP validation
- An industry standard evaluation process was followed to integrate geological, petrophysical and engineering data
- ✓ Total difference for 14 “matched” sands is +2.5%
- ✓ Difference is consistent for oil and gas sands
- ✓ Variance is well within the error associated with the individual properties involved in the evaluation
- ✓ NITEC believes the BOEM reported values for OOIP and OGIP are reasonable based on this validation process.

Task 4.0 – CO_2 sequestration volume calculation DOE equation (Complete)

- Depleted field database “created” in Task 2.0 utilized
- Contained 675 fields and 3514 sands
- Honored the BOEM reported OOIP and OGIP for each sand
- Applied the DOE CO_2 Resource Estimate equation

$$G_{CO2} = A\, h_n\, f_e\, (1-S_w)\, B\, \rho\, E_{oil/gas}$$

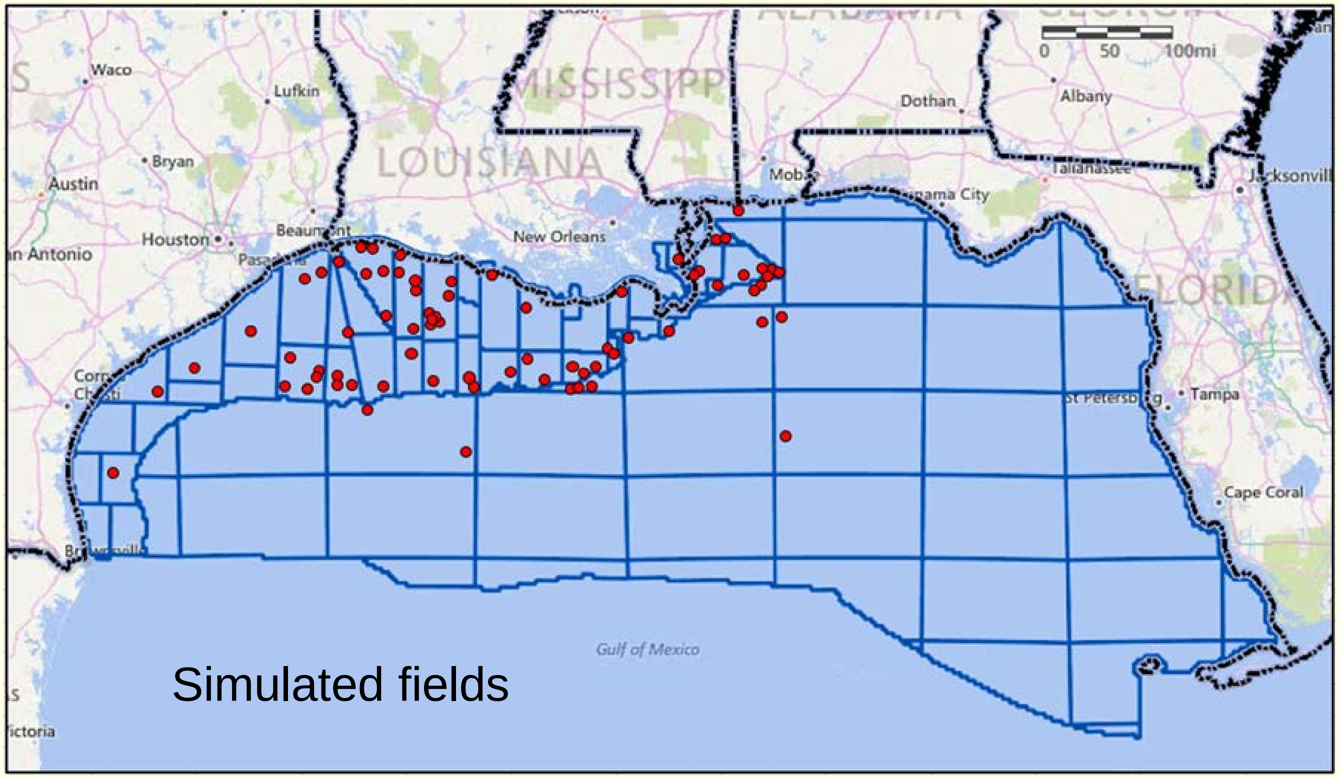
- Computed CO_2 storage volumes (tons) based on
  - CO_2 volumetric efficiencies of 10%, 20%, 50%
  - Oil sands ranged from 0.001 to 1.351 million tons
  - Gas sands ranged from 0.001 to 4.229 million tons

- This initial estimate has proven to be highly understated, particularly for gas sands

Task 5.0 - CO_2 sequestration volume validation and refinement

- ✓ Three reservoir simulation engineers working full-time
- ✓ Utilizing NITEC developed COZ simulator funded by DOE
- ✓ **453 sands have been simulated to date; 73 fields**
  - ✓ **35 oil only, 350 gas only, 68 oil/gas**
- ✓ Each sand modeled separately
  - ✓ Utilized proprietary map data from BOEM under an NDA
  - ✓ Sand model calibrated to BOEM reported OOIP (OGIP) and cumulative production at depletion (OIP or GIP)
  - ✓ Depletion pressure estimated based on IHS pressure test data
  - ✓ Calibrated model used to investigate multiple CO_2 injection scenarios to maximize CO_2 storage

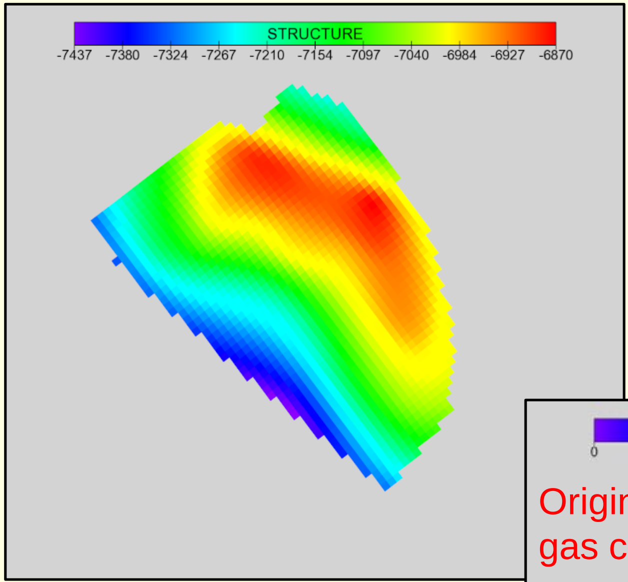
Task 5.0 -

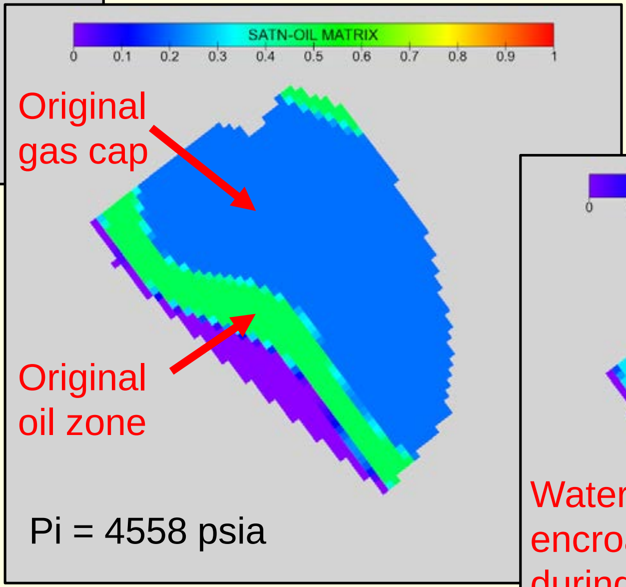


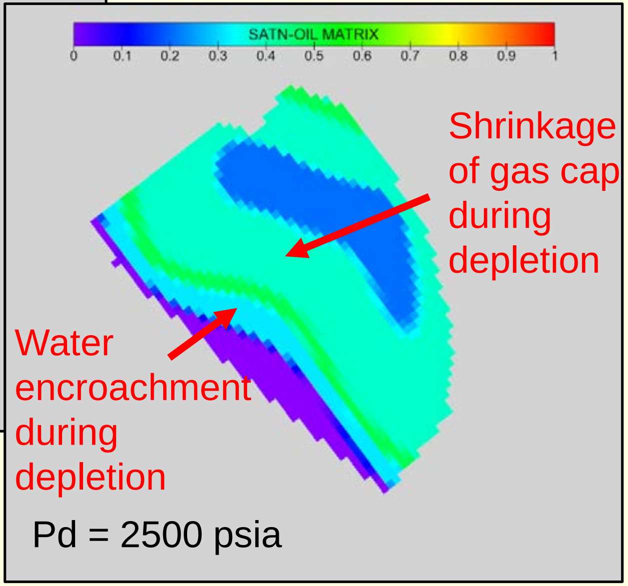
- OOIP 0.2 to 44.8 MMSTB per field; 631.0 MMSTB total (47.4% all depleted fields)
- OGIP 1.3 to 1,227 BSCF per field; 19.5 TSCF total (25.9% all depleted fields)
- 1 to 25 sands per field

Task 5.0 -

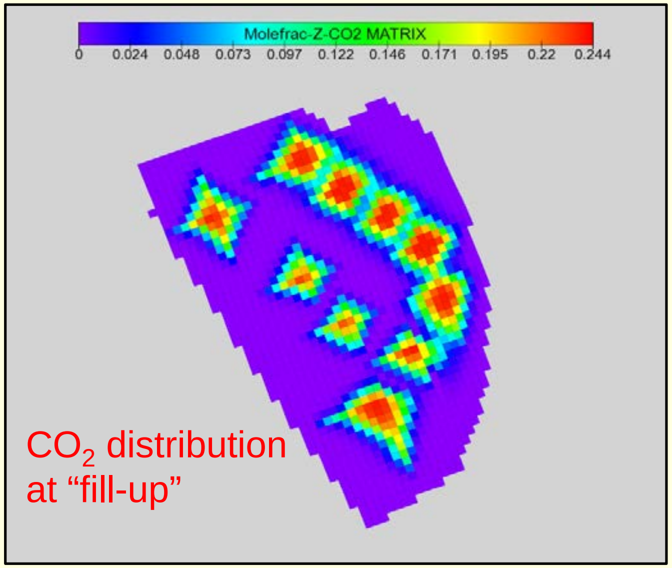
Property	BOEM	Model	Difference	% Difference
OOIP,MMSTB	10.011	10.07	-0.059	-0.59
OGIP,BSCF	54.021	54.029	-0.008	-0.01
P_CUMOIL,MMSTB	1.401	1.424	-0.023	-1.64
P_CUMGAS, BSCF	32.847	32.291	0.556	1.69
P_CUMWAT, MMSTB	1.970	1.880	0.090	4.57
Current OIP,MMSTB	8.610	8.546	0.064	0.74
Current GIP,BSCF	22.197	21.738	0.459	2.07



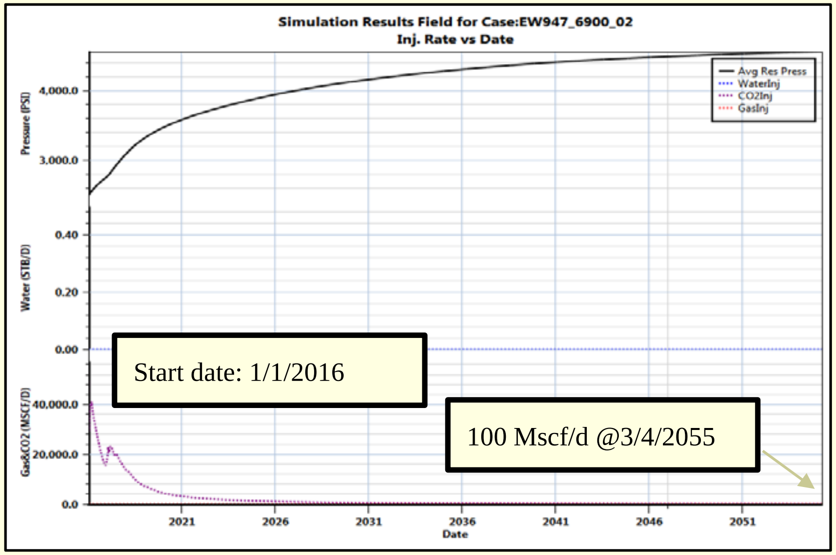


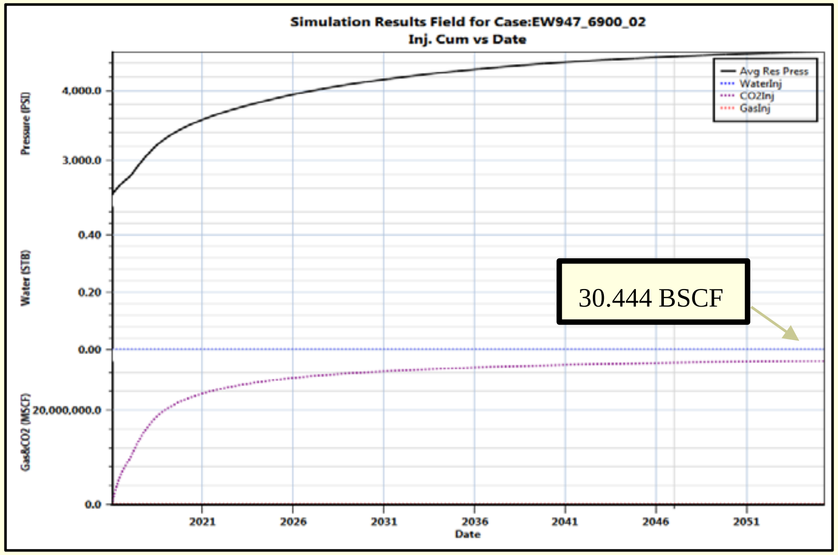


Task 5.0 -



Return reservoir to initial pressure



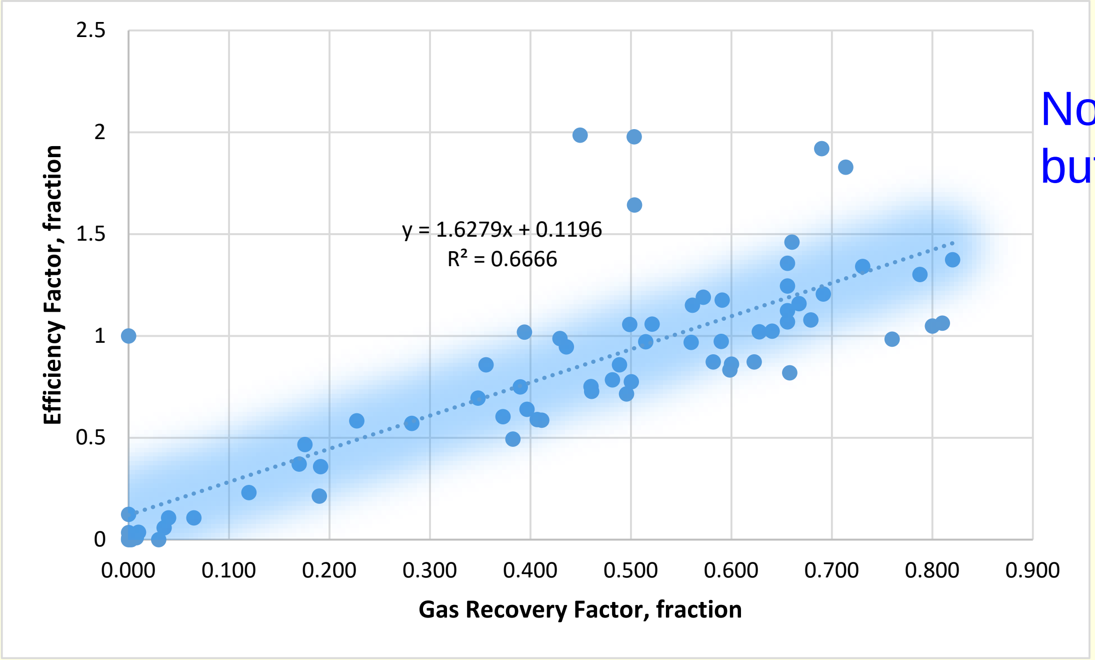


Task 5.0 -

$$G_{CO2} = A\ h_n\ f_e\ (1-S_w)B\ \rho\ E_{oil/gas}\ ;\quad V_{CO2} = A\ h_n\ f_e\ (1-S_w)B\ \ E_{oil/gas}$$

$E_{oil/gas}$ = CO_2 storage volume/OGIP

- ✓ Simulation results indicate much higher $E_{oil/gas}$ in <u>gas sands</u> than estimated in Task 4.0
- ✓ $E_{oil/gas}$ appears to correlated well with gas recovery factor.

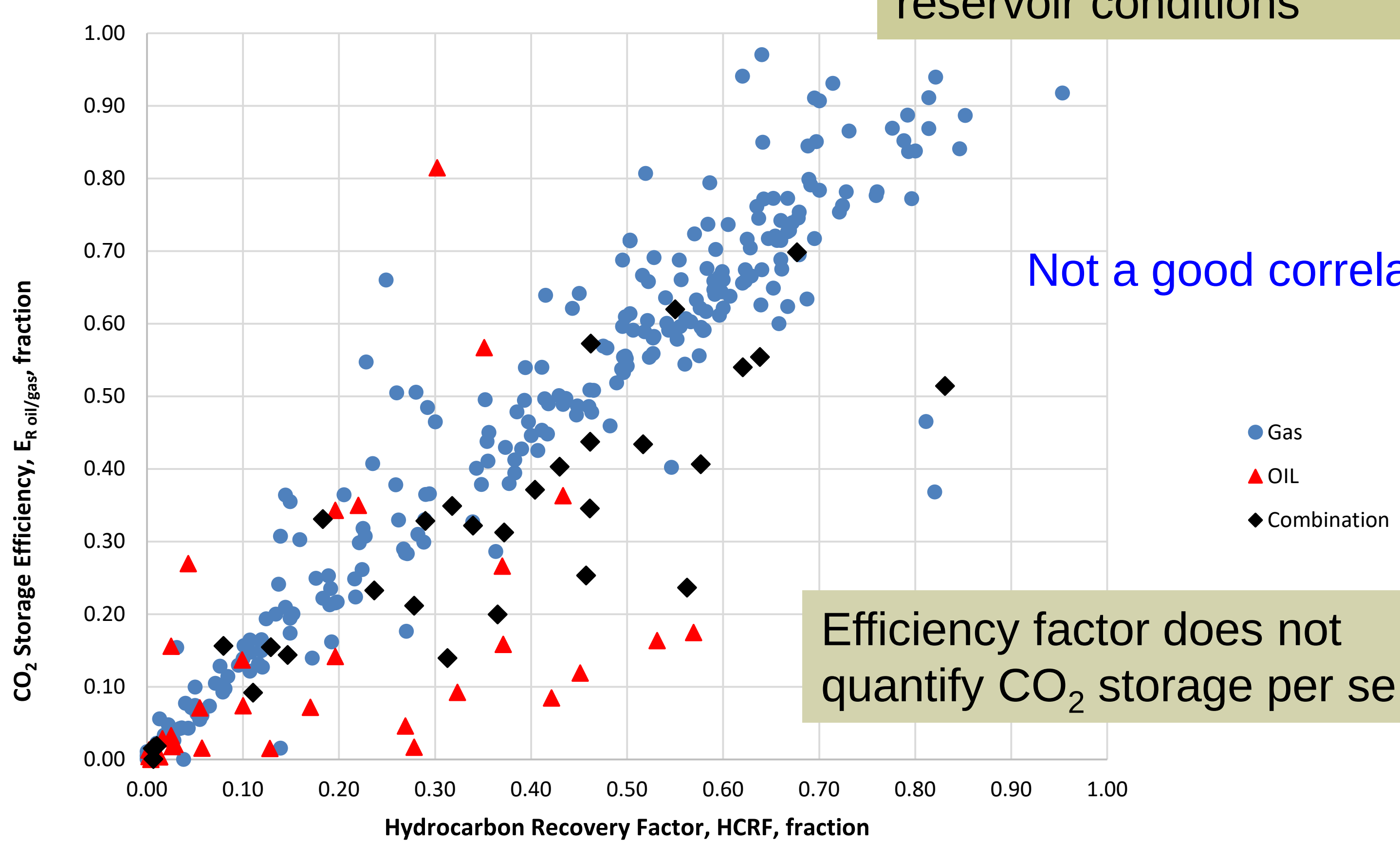


Not a bad correlation, but $E_{oil/gas}$ >100%

Task 5.0 -

Looking at All sands

Efficiency now based on reservoir conditions



Not a good correlation

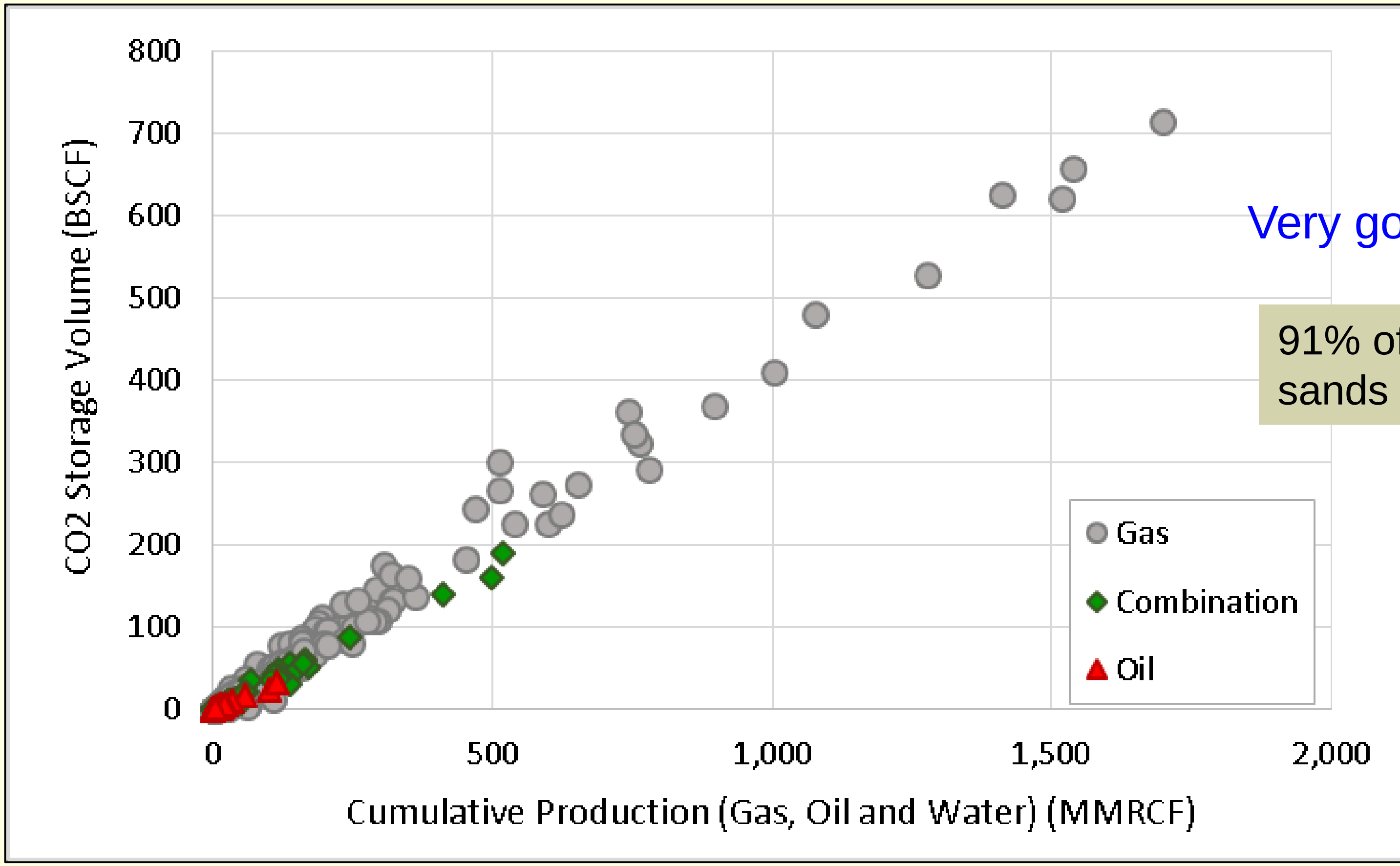
Efficiency factor does not quantify CO_2 storage per se

Task 5.0 -

All sands

Production-CO_2 Storage Correlation

***V_{CO2} = slope * Cum Production** Reservoir conditions*



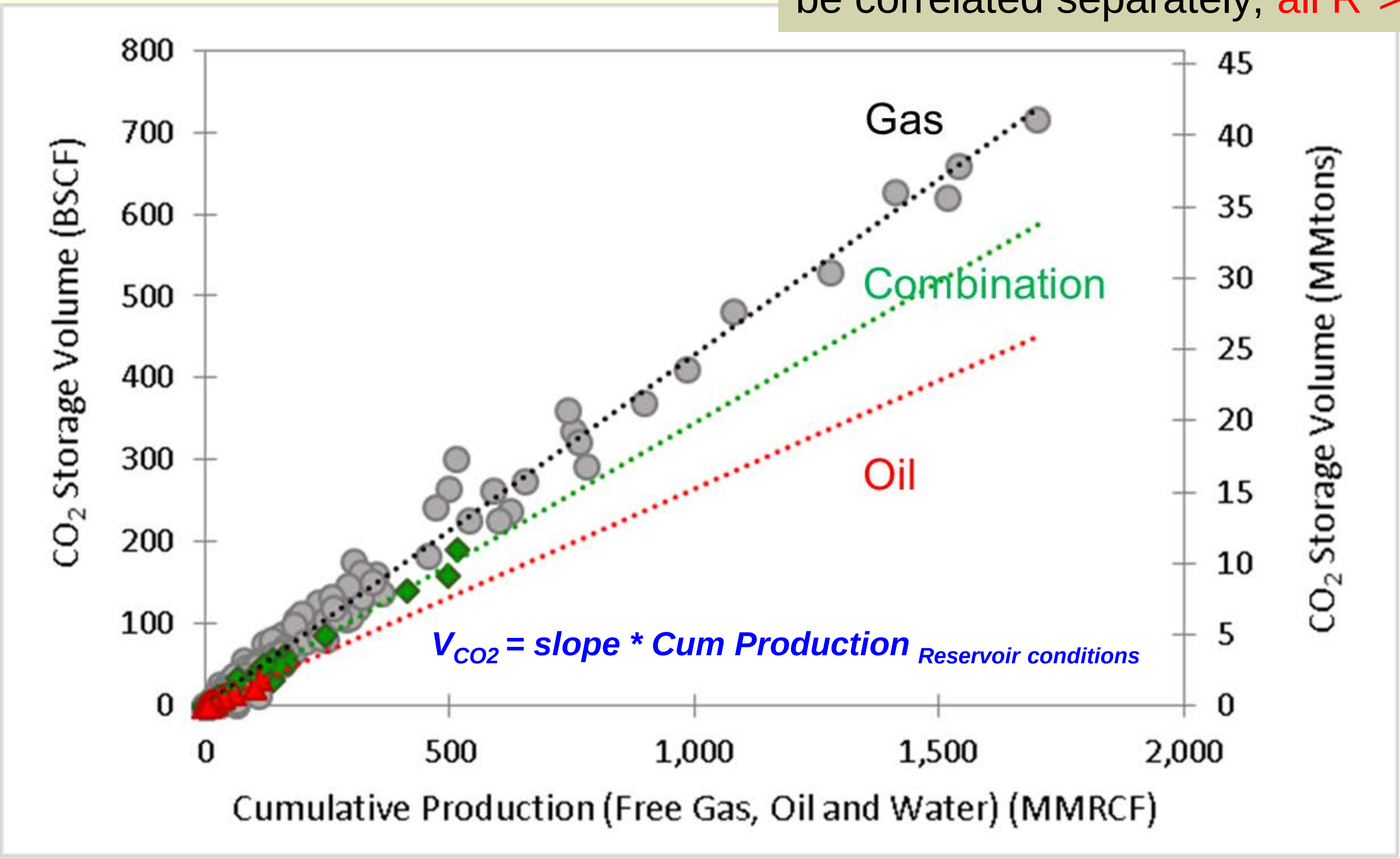
Very good correlation

91% of depleted sands are gas only

Task 5.0 -

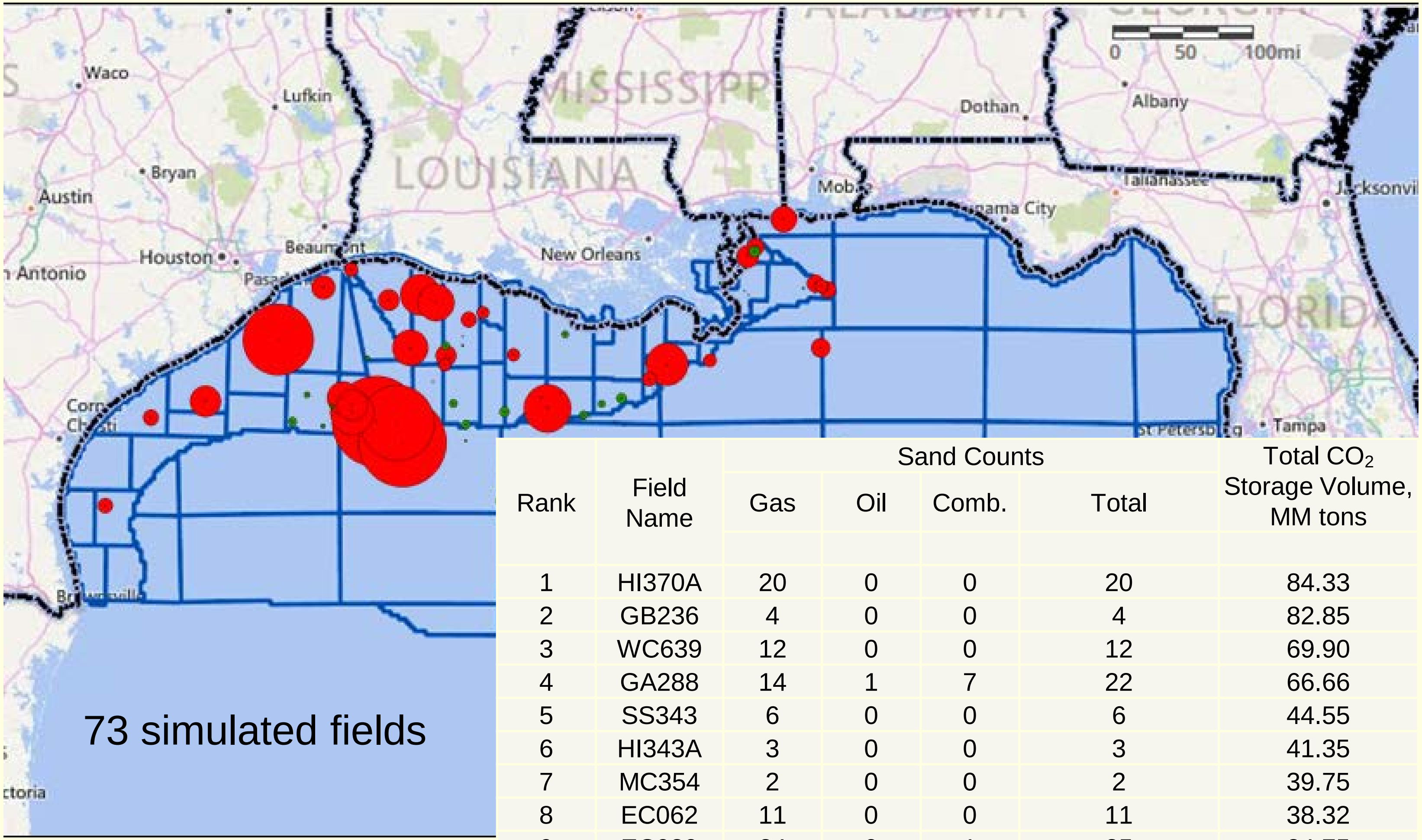
Production-CO2 Storage Correlation

Gas, oil and combination sands can be correlated separately; all R^2>0.96



Task 5.0 -

CO_2 storage volumes by simulated field



Rank	Field Name	Sand Counts				Total CO_2 Storage Volume, MM tons
		Gas	Oil	Comb.	Total	
1	HI370A	20	0	0	20	84.33
2	GB236	4	0	0	4	82.85
3	WC639	12	0	0	12	69.90
4	GA288	14	1	7	22	66.66
5	SS343	6	0	0	6	44.55
6	HI343A	3	0	0	3	41.35
7	MC354	2	0	0	2	39.75
8	EC062	11	0	0	11	38.32
9	EC089	24	0	1	25	34.75
10	WC280	23	0	0	23	33.84

Task 5.0 -

CO_2 Storage ALL 675 Depleted Fields

- Using this base-correlation we estimate CO_2 storage in ALL Federal GOM depleted fields as 82.6 TSCF (4,748 MM tons, 4316 MM metric tons)
- If surface injection pressures are limited to less than 5000 psia, estimated CO_2 storage declines to 70.9 TSCF (4,077 MM tons, 3706 MM metric tons) – 14% reduction

Task 5.0 -

Heterogeneity

- Heterogeneity of porosity and permeability impacts the CO_2 injection rate time-profile
- Heterogeneity does not have a significant impact on CO_2 storage volume, particularly when permeability >50 md

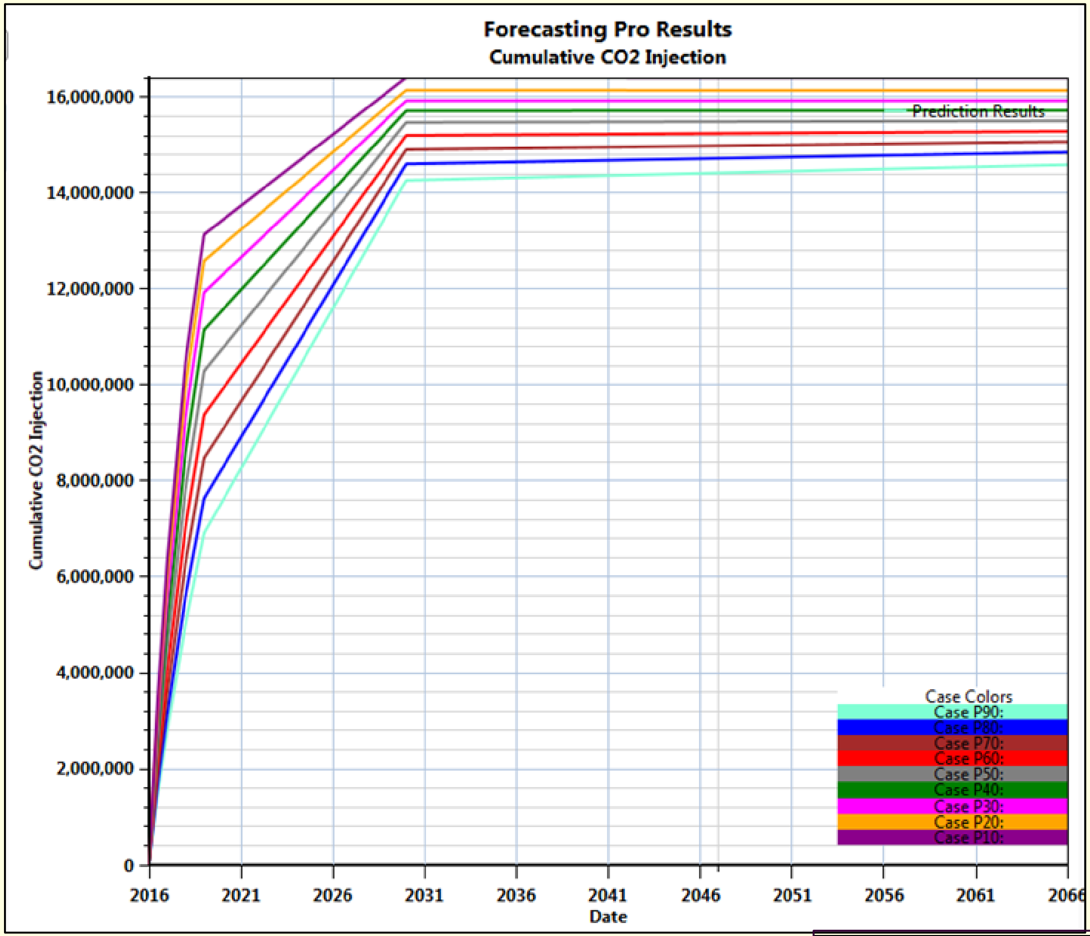
Task 5.0 -

Uncertainty

Parameter	Uncertainty, %
Porosity, fraction	+/- 5
Permeability, mD	+/- 50
Bottom-hole Injection Pressure, psia	+/- 10
Maximum Well CO_2 Injection Rate, Mscf/d	+/- 50
Maximum Field CO_2 Injection Rate, Mscf/d	+/- 50
SORM, fraction (oil sands only)	+/- 50

Parameter	Base case	Minimum	Maximum
Porosity, fraction	0.27	0.2565	0.2835
Permeability, mD	15.00	7.50	22.50
Bottom-hole Injection Pressure, psia	5,033	4,530	5,536
Maximum Well CO_2 Injection Rate, Mscf/d	20,000	10,000	30,000
Maximum Field CO_2 Injection Rate, Mscf/d	80,000	40,000	120,000

Task 5.0 -

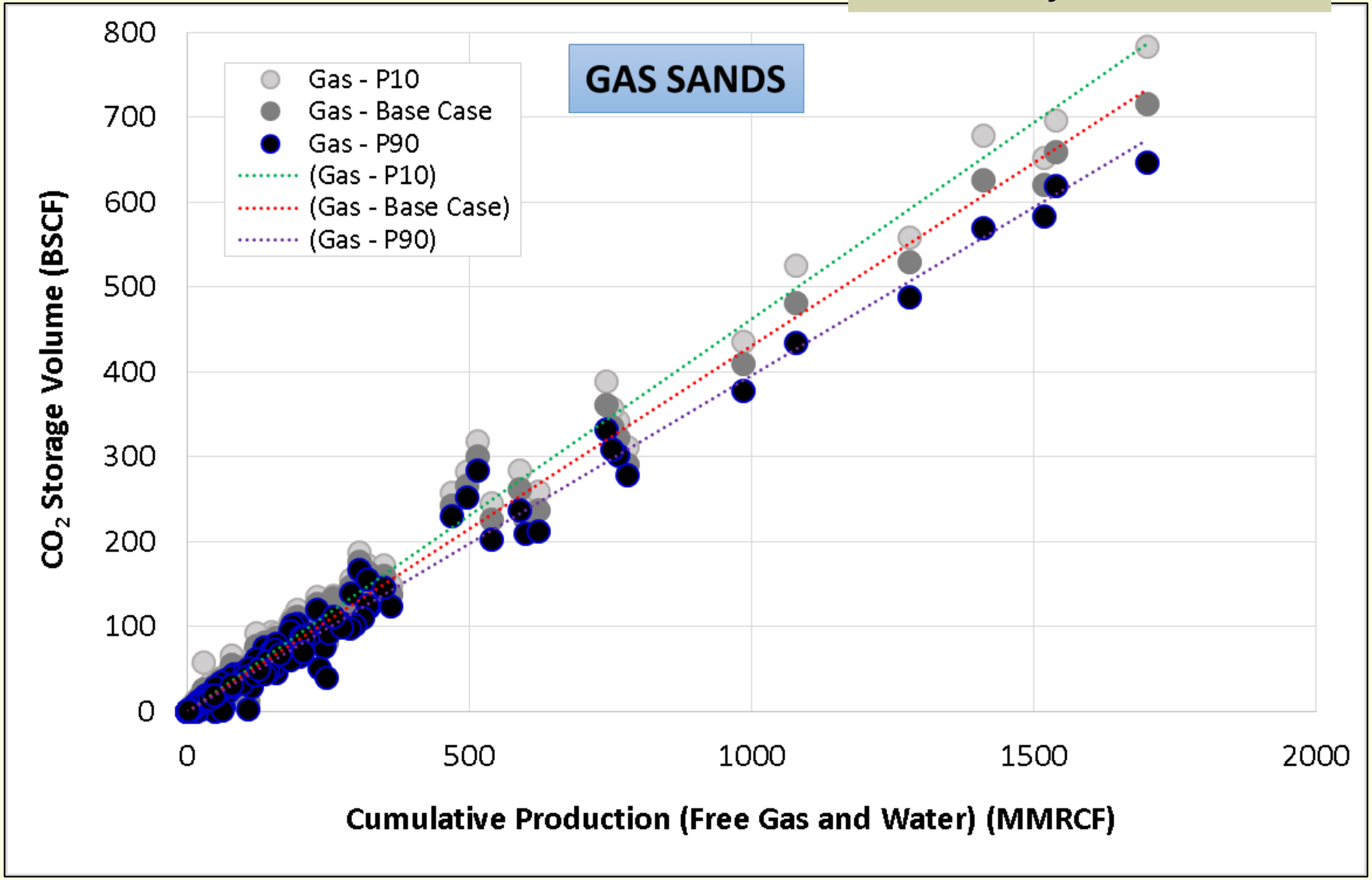


Injection pressure has the most significant impact on CO_2 storage volumes

Probability	Cumulative CO_2 injection, BSCF
Base case	15.52
P10	16.13
P50	15.50
P90	14.58

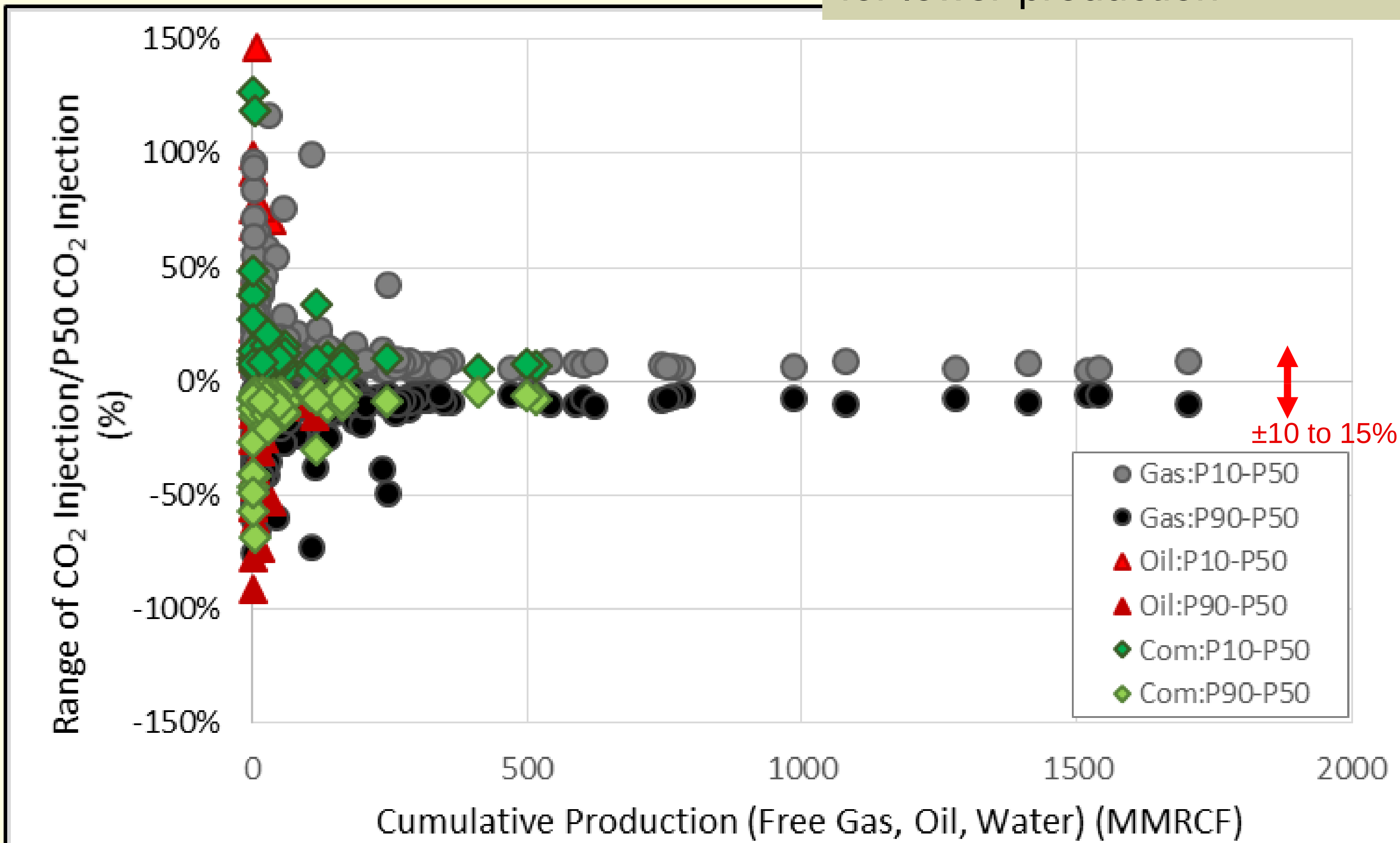
Task 5.0 -

Working to quantify uncertainty



Task 5.0 -

Clearly % variation is greater for lower production

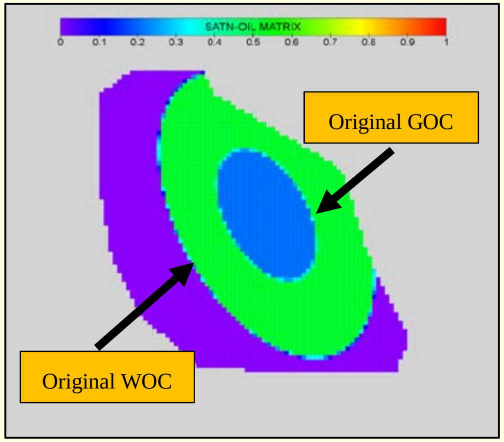


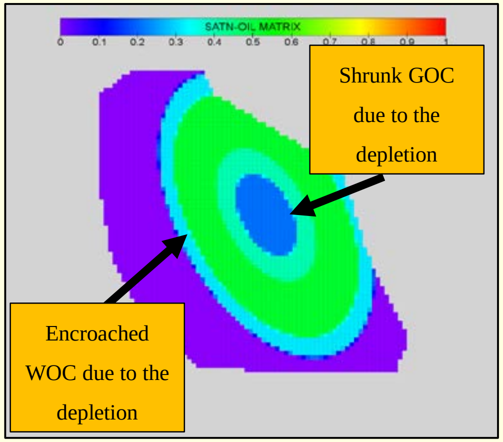
Task 6.0 - CO_2–EOR Oil Production Assessment

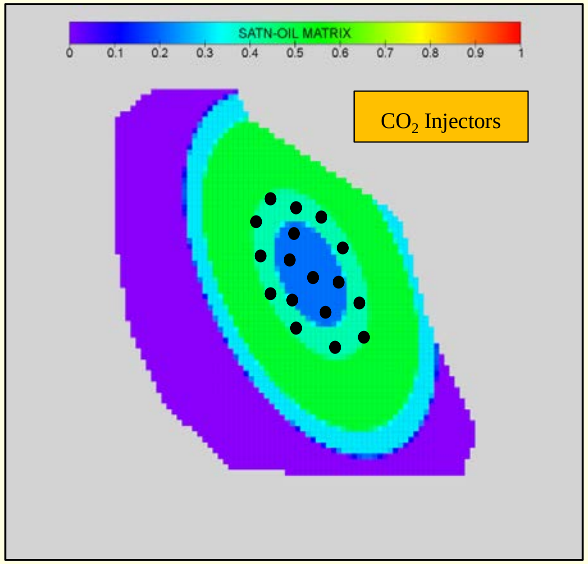
- ✓ Initially selected 5 oil sands for CO_2-EOR evaluation; expanded to 11 sands

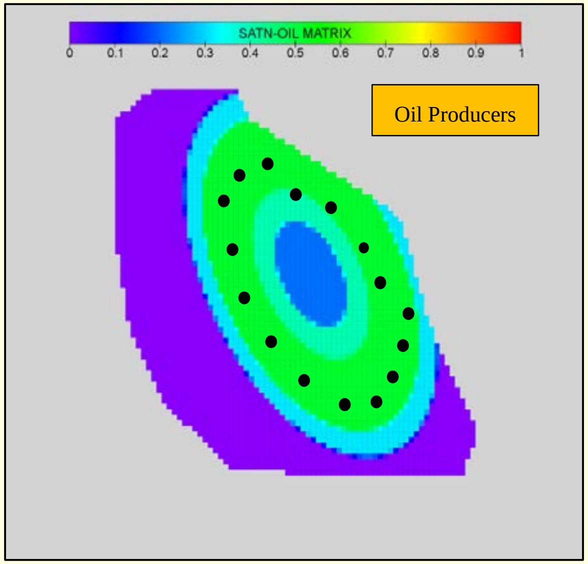
Field Sand Name	OOIP	OGIP*	Cumulative Oil Production	Primary Oil Recovery	Initial Pressure	Depletion Pressure	Depth
	MMSTB	BSCF	MMSTB	%	psia	psia	ft. SS.
BS053_RCP1	15.01	NA	4.54	30.25	4,086	1,700	9,066
EI198_F3_01	16.91	115.66	3.29	19.50	7,840	3,130	**13,085**
EW947_6900	10.07	60.13	1.40	13.91	4,558	2,500	7,182
EW947_8100L	**33.60**	17.30	1.40	4.10	5,443	3,200	8,350
GB208_HB	10.78	35.63	0.09	0.83	4,239	1920	6,860
GI020_X	19.30	NA	7.145	37.00	9,565	3,750	12,631
GC029_09400	9.02	NA	0.02	0.22	6,523	6,490	9,516
HI561A_8500	**3.40**	NA	1.48	**43.40**	5,949	1,100	7,415
MP253_LK1	30.80	2.4	0.05	**0.20**	4,040	4,020	8,656
MP306_K10	17.00	NA	3.80	22.0	2,395	950	**5,117**
VR348_AB4	14.20	NA	0.42	2.90	2,480	1,300	5,300

Task 6.0 -

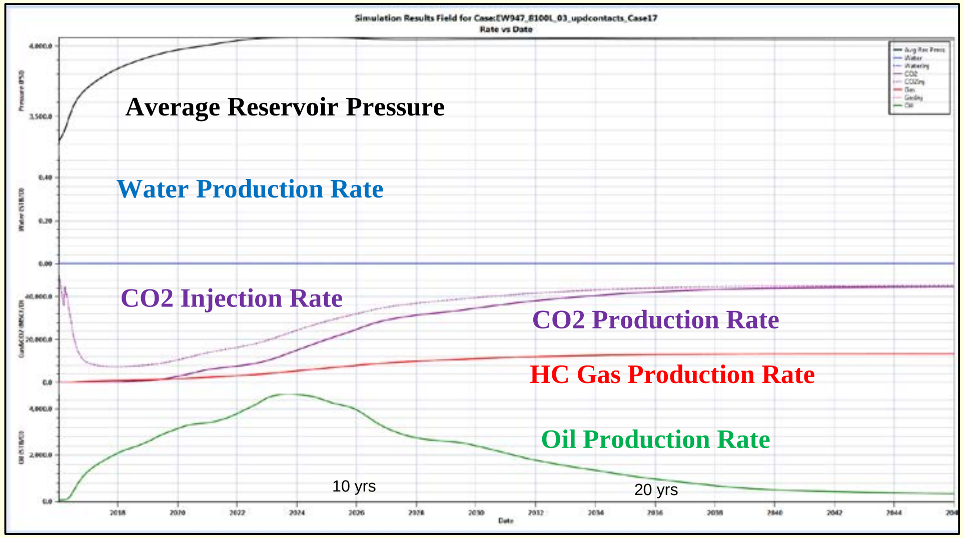

SATN-OIL MATRIX
Original GOC
Original WOC


SATN-OIL MATRIX
Shrunk GOC due to the depletion
Encroached WOC due to the depletion

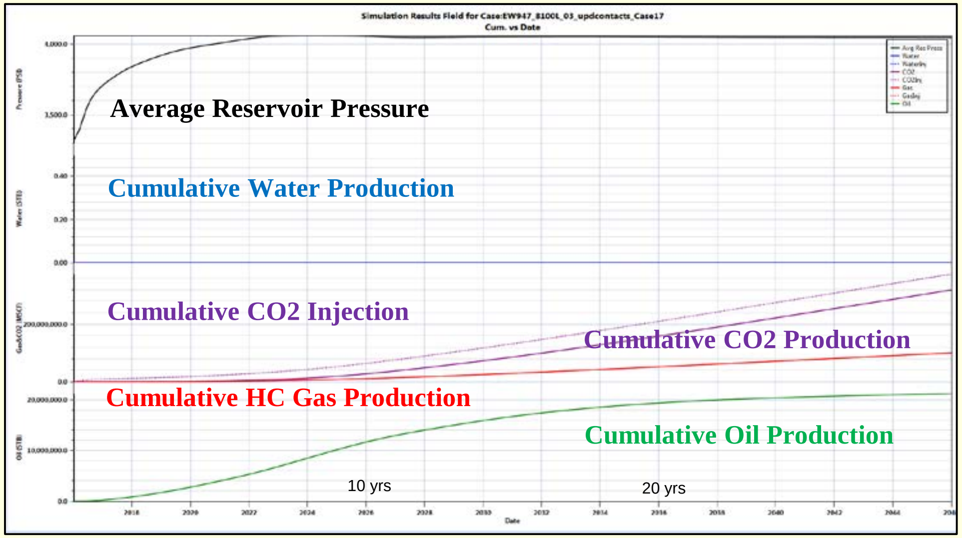

SATN-OIL MATRIX
CO_2 Injectors


SATN-OIL MATRIX
Oil Producers

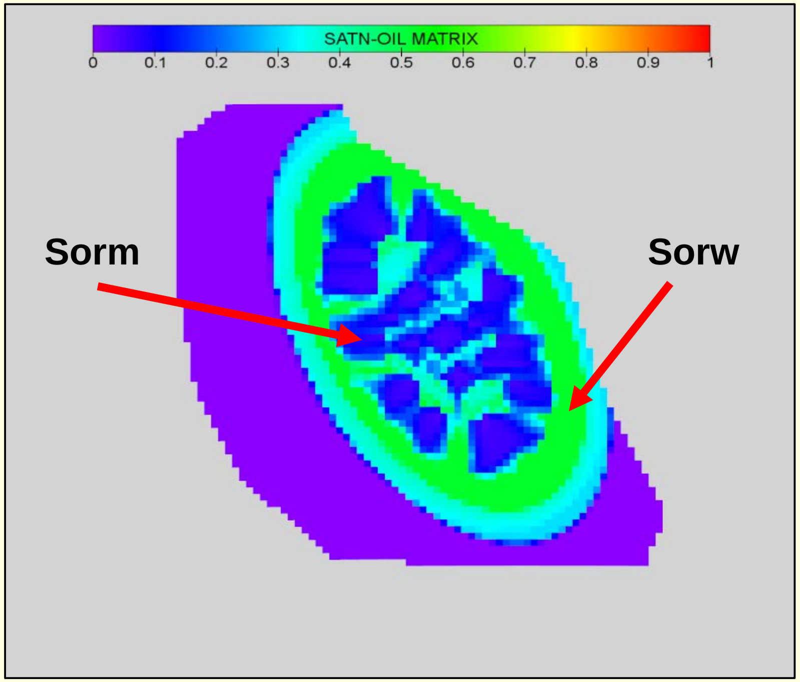
Task 6.0 -



CO$_2$-EOR performance

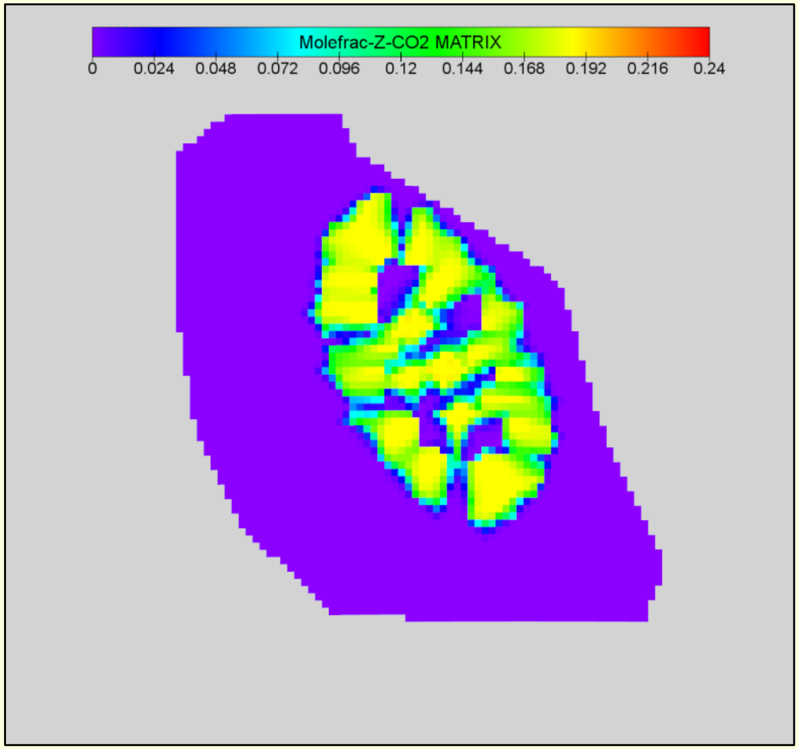


Task 6.0 -



Oil Saturation at End of CO_2-EOR

CO_2 Concentration at End of CO_2-EOR



Task 6.0 -

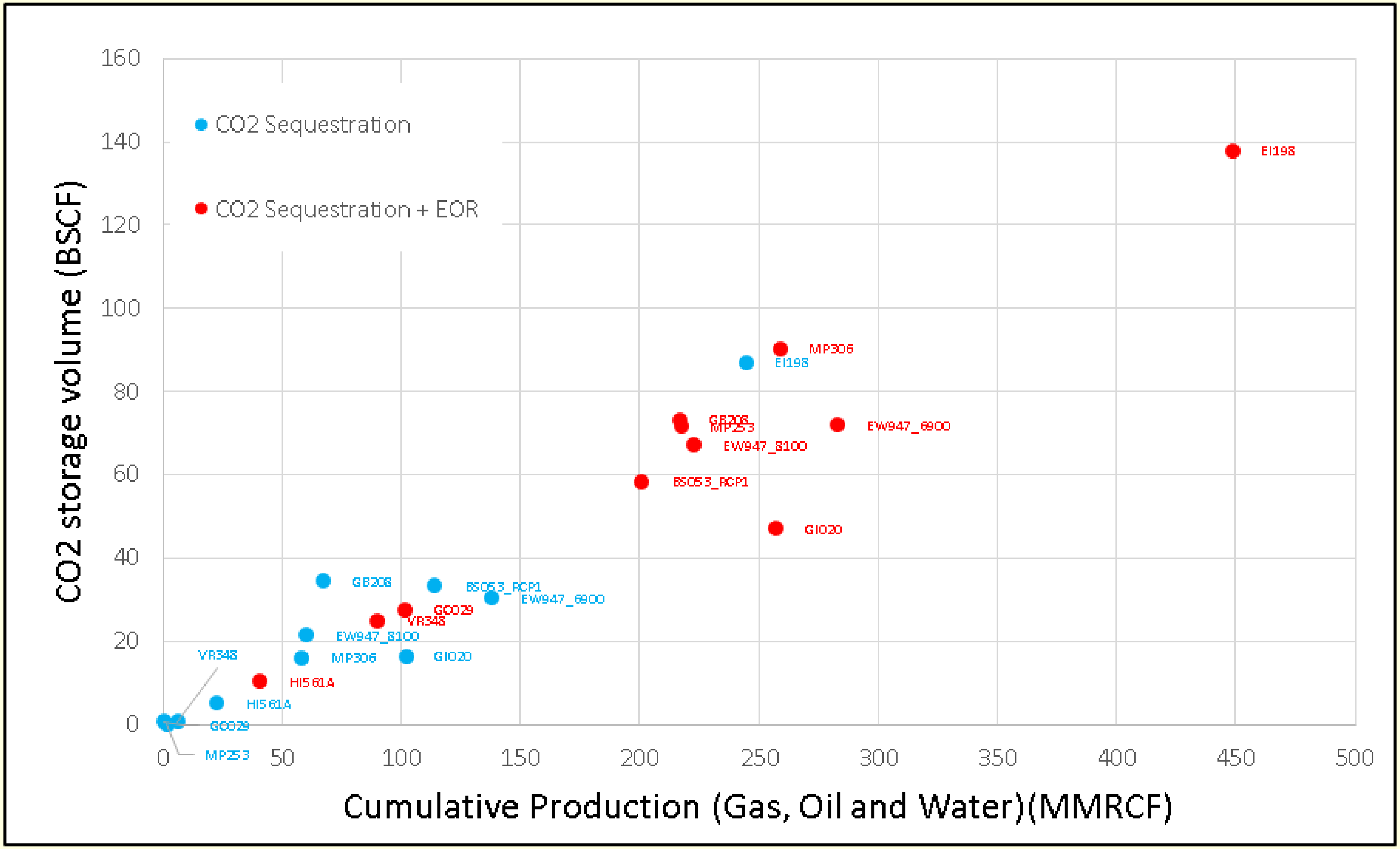
Field_Sand Name	OOIP	Primary Oil Production	CO_2-EOR Oil Production	CO_2 Storage after Primary	CO_2 Storage during & after CO_2-EOR	Incremental CO_2 Storage	EOR CO_2 Utilization Factor
	MMSTB	MMSTB	MMSTB	BSCF	BSCF	BSCF	MSCF/STB
BS053_RCP1	15.01	4.54	9.49	33.26	58.40	25.14	6.2
EI198_F3_01	16.91	3.30	18.43	86.98	137.90	50.91	7.5
EW947_6900	10.07	1.40	18.55	34.26	72.00	37.74	3.9
EW947_8100L	33.60	1.40	21.22	20.60	67.08	46.48	3.2
GB208_HB	10.78	0.09	14.70	34.48	73.30	38.82	5.0
GI020_X	19.30	7.40	9.33	22.888	52.1	29.22	5.58
GC029_09400	9.02	0.02	7.92	0.62	27.60	26.98	3.5
HI561A_8500	3.40	1.48	1.631	5.16	10.30	5.14	6.4
MP253_LK1	30.80	0.05	26.77	0.04	71.60	71.56	2.7
MP306_K10	17.02	3.75	10.53	16.06	90.4	74.34	8.58
VR348_AB4	14.20	0.42	11.80	2.40	25.00	22.60	2.1

Sorm = 6.0%

Return average reservoir pressure to Pi

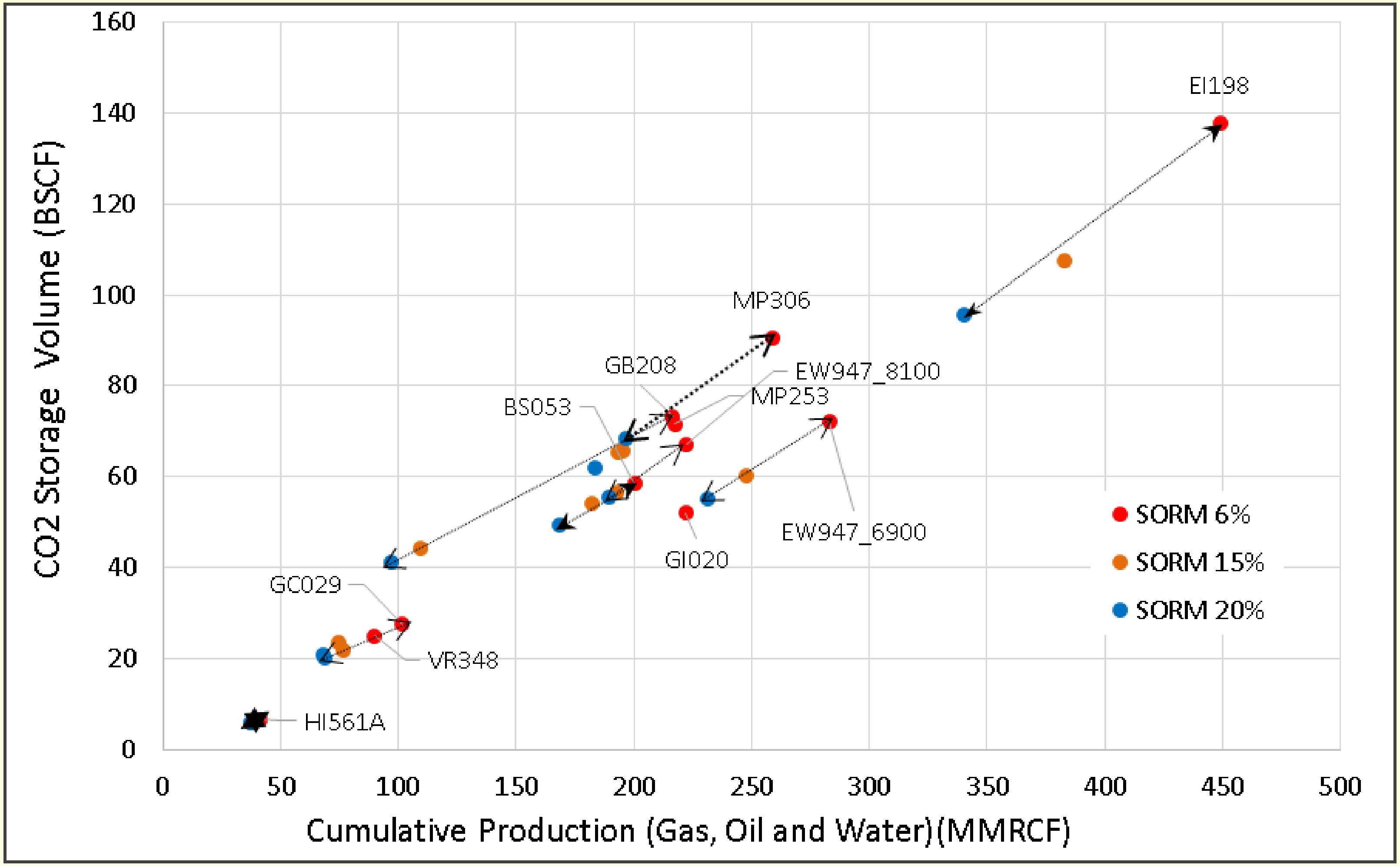
Task 6.0 -

Incremental CO_2 Storage Benefit



Task 6.0 -

Impact of Residual Oil Saturation (Sorm) to Miscible Displacement on CO_2 Storage



Accomplishments to Date

- Exceeded number of proposed fields and reservoirs to be simulated
- Developed a more accurate correlation for estimating CO_2 storage in depleted reservoirs

  $V_{CO2} = slope * Cum\ Production_{Reservoir\ conditions}$
- Validated the benefit of CO_2 EOR for enhancing CO_2 storage

Lessons Learned

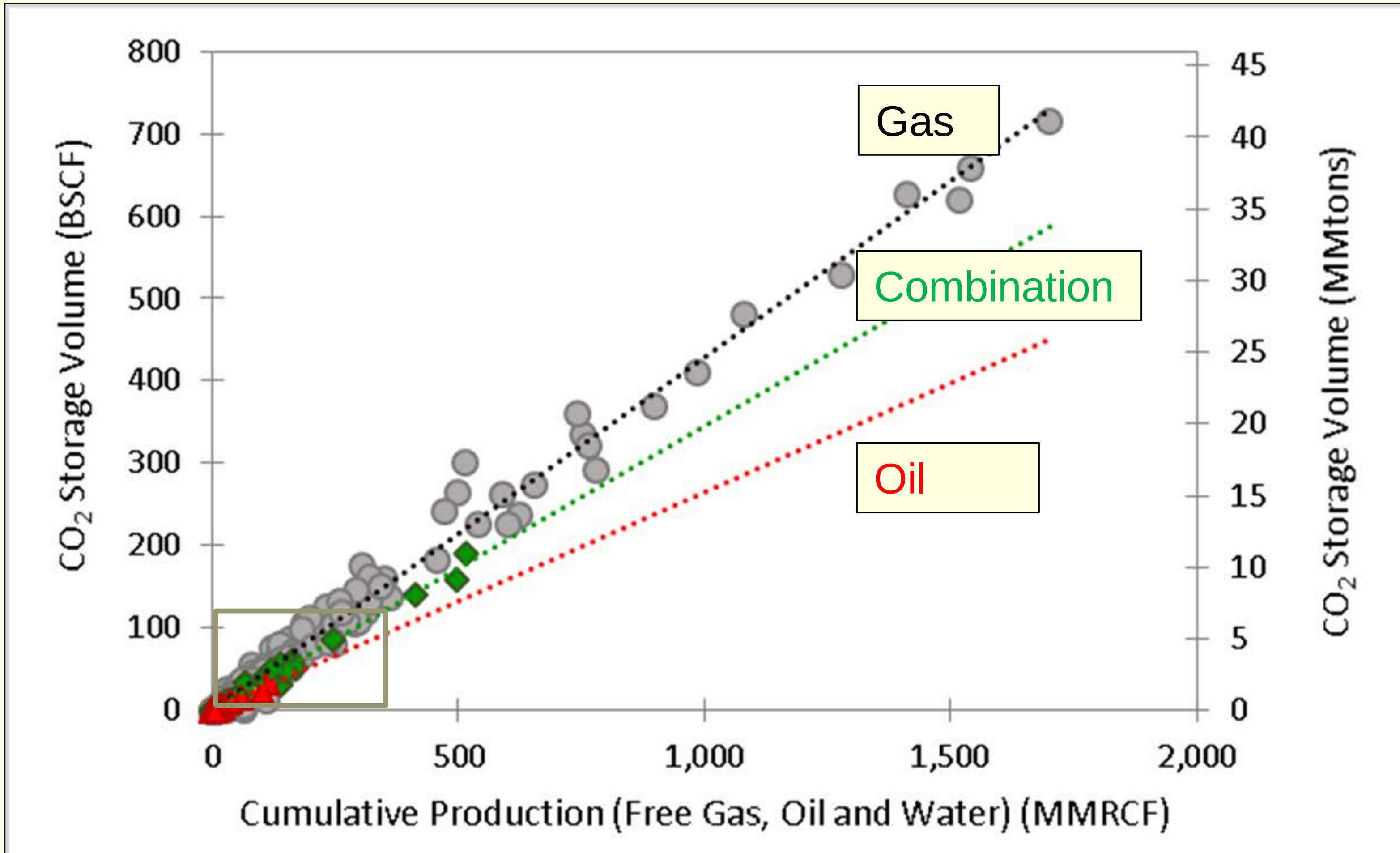
- General quality of BOEM Reserves data is good
- Realistic simulation models can be developed for CO_2 storage predictions from BOEM data
- DOE CO_2 Resource Estimate Equation can be improved
- Gas, oil and combination reservoir CO_2 storage potentials are consistent
- A CO_2 storage predictive correlation with a high degree of confidence has been developed

Lessons Learned

- CO_2 storage volumes are very sensitive to bottom hole injection pressure
- CO_2 EOR can increase potential CO_2 storage
- CO_2 storage may be limited to shallow to moderate depth reservoirs due to surface injection pressure constraints.

Lessons Learned

***V_{CO2} = slope * Cum Production** $_{\text{Reservoir conditions}}$*



Project Summary

- BOEM Reserves database (12/31/2013) is reliable
- 90.8% of ALL depleted reservoirs are gas sands
- A significant CO_2 storage potential exists in gas reservoirs in the Federal GOM
- A lesser CO_2 storage potential exists in oil reservoirs

Project Summary

- While CO_2 EOR improves the CO_2 storage potential, gas reservoirs provide the dominant storage potential
- Estimate 4.7 Gigatons CO_2 storage for ALL depleted fields in Federal GOM (94% in gas sands)
- Estimate reduced by 14% if surface injection pressure is limited to less than 5000 psia

The END

Thank you!

Appendix

Benefit to the Program

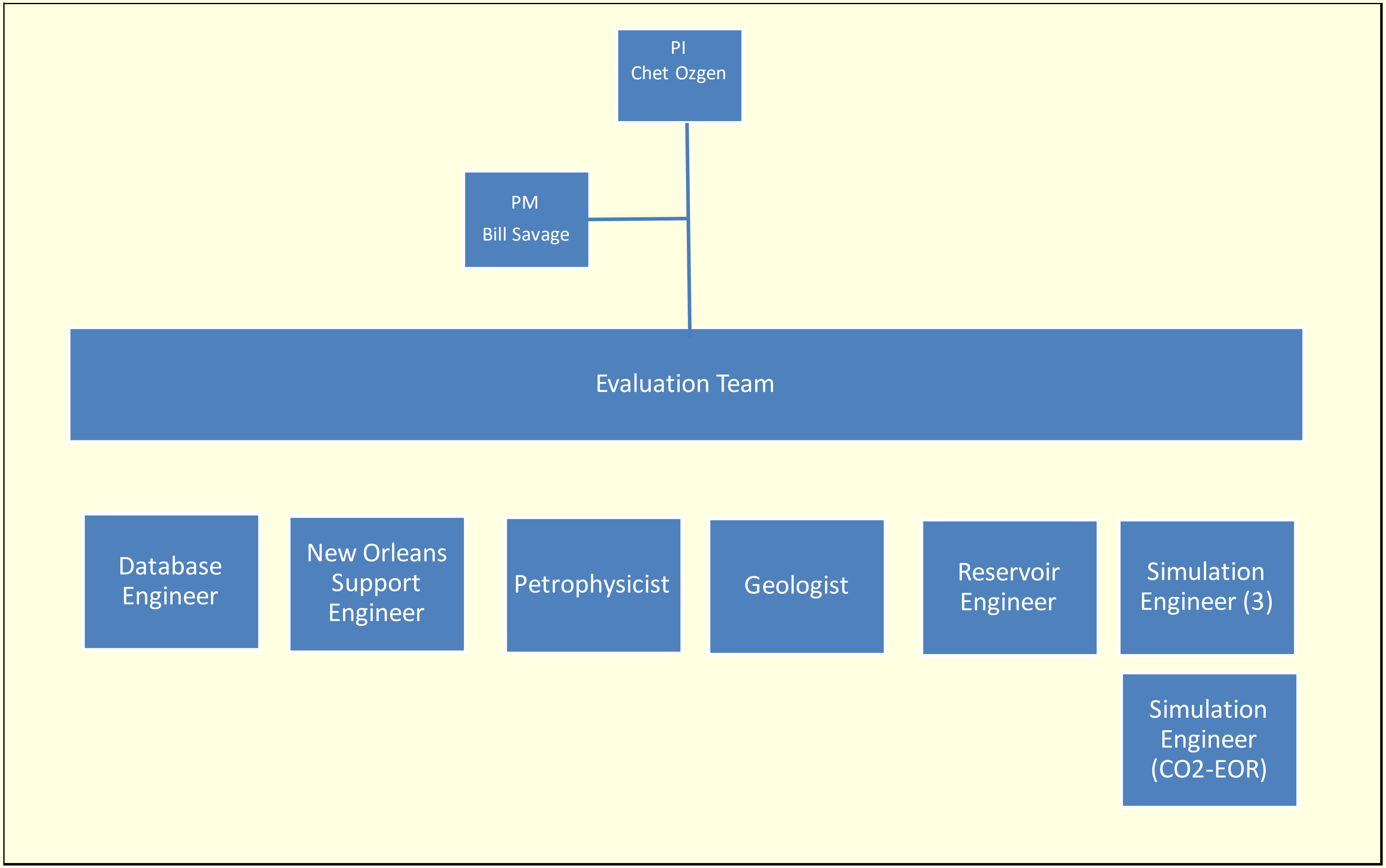
This project provides quantitative estimates of CO_2 volumes that may be stored in Federal offshore GOM **depleted** oil and natural gas reservoirs at some time in the future. The impact of CO_2 EOR on CO_2 storage potential is assessed. An improved predictive capability has been developed.

This reservoir by reservoir assessment can be used for strategic planning as the U.S. moves forward with options for CO_2 emissions mitigation.

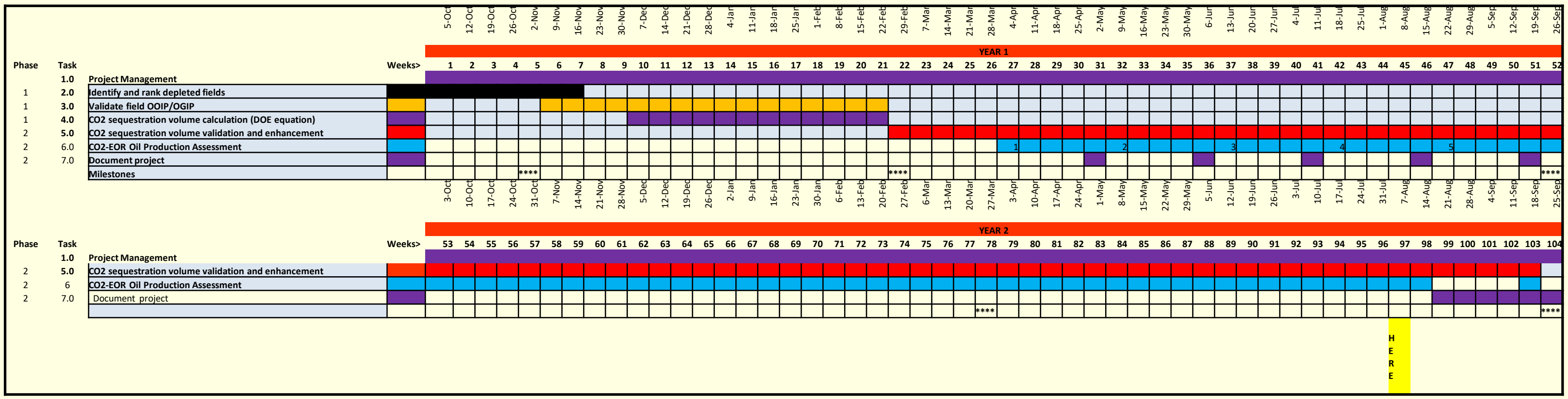
Project Overview

- Objectives
  - Provide a high level assessment of CO_2 storage potential in depleted Federal offshore GOM reservoirs.
  - Assess change in CO_2 storage volume due to implementation of CO_2 EOR
- Success Criteria
  - Developed improved predictive correlation for estimating CO_2 storage in depleted reservoirs
  - Quantified benefit of CO_2 EOR on CO_2 storage
  - Identified prospective CO_2 storage candidate fields based on CO_2 storage volume

Organization Chart



Gantt Chart



Phase	Task		Weeks>
	1.0	**Project Management**	
1	**2.0**	**Identify and rank depleted fields**	
1	**3.0**	**Validate field OOIP/OGIP**	
1	**4.0**	**CO2 sequestration volume calculation (DOE equation)**	
2	**5.0**	**CO2 sequestration volume validation and enhancement**	
2	6.0	**CO2-EOR Oil Production Assessment**	
2	7.0	**Document project**	
		Milestones	
Phase	**Task**		**Weeks>**
	1.0	**Project Management**	
2	**5.0**	**CO2 sequestration volume validation and enhancement**	
2	6	**CO2-EOR Oil Production Assessment**	
2	7.0	Document project	

1. Met all milestones
2. Exceeded proposed fields simulated
3. Exceeded proposed CO_2 EOR studies
4. Under proposed budget

Bibliography

- Agartan, E.; Gaddipati, M.;Yip, Y.; Savage, B.; Ozgen, C.; “CO_2 Storage in Depleted Oil and Gas Fields in the Gulf of Mexico.” *Energy Conversion and Management.* (in progress)

- Gaddipati, M.; Agartan, E.; Yip, Y.; Savage, B.; Ozgen, C.; “Evaluation of CO_2 Storage in Conjunction with Oil Recovery in Depleted Fields in the Gulf of Mexico.” *Energy Conversion and Management.* (in progress)