

The U.S. Gas Flooding Experience

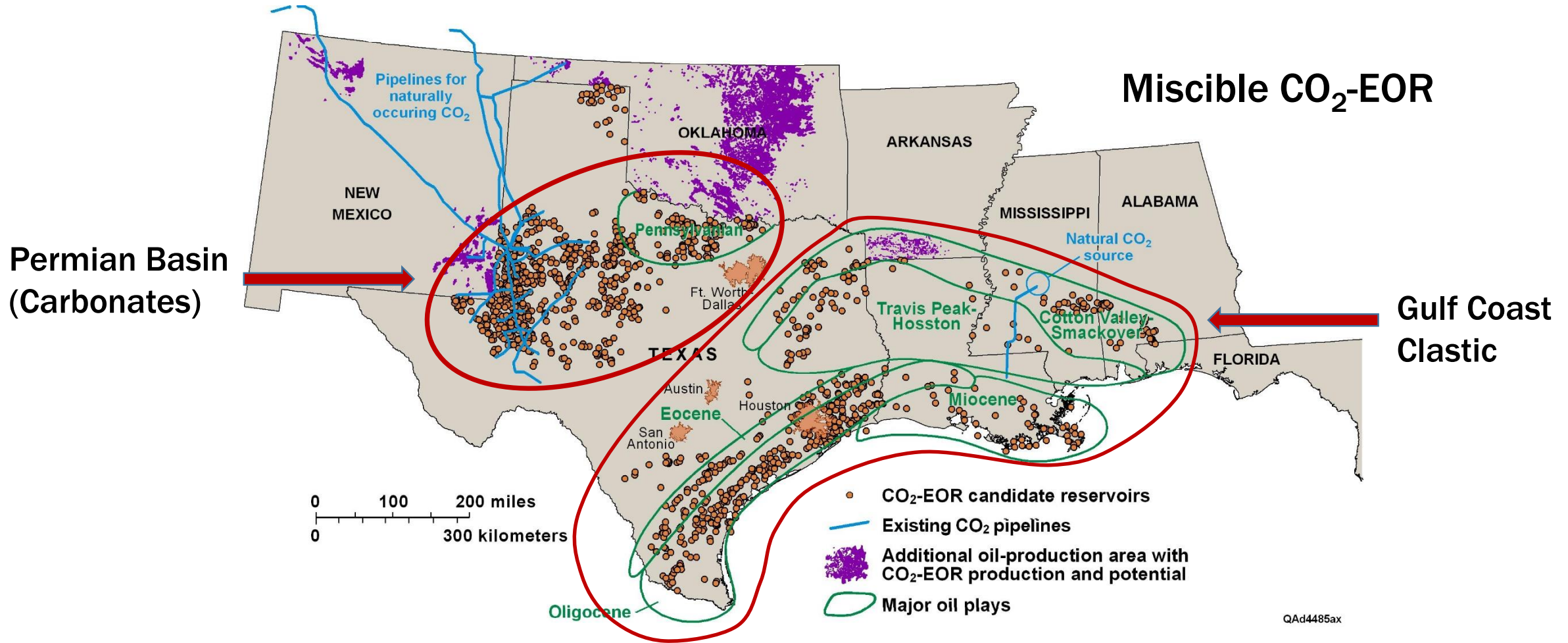
CO₂ Injection Strategies and Impact on Ultimate Recovery

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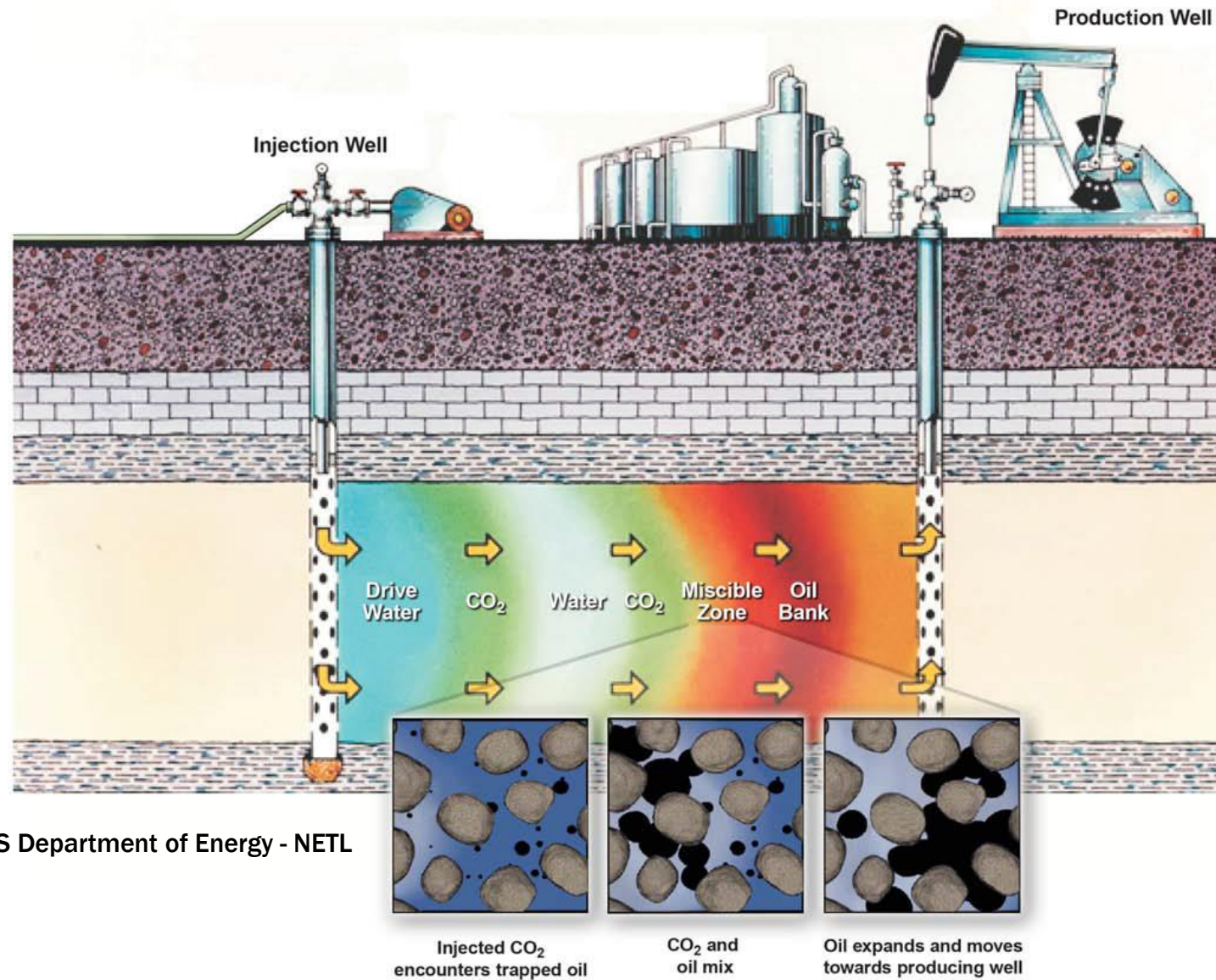
Bureau of Economic Geology

38th IEA-EOR Workshop & Symposium
Mexico, September 26-29, 2017

CO₂-EOR Potential in the U.S. Gulf Coast

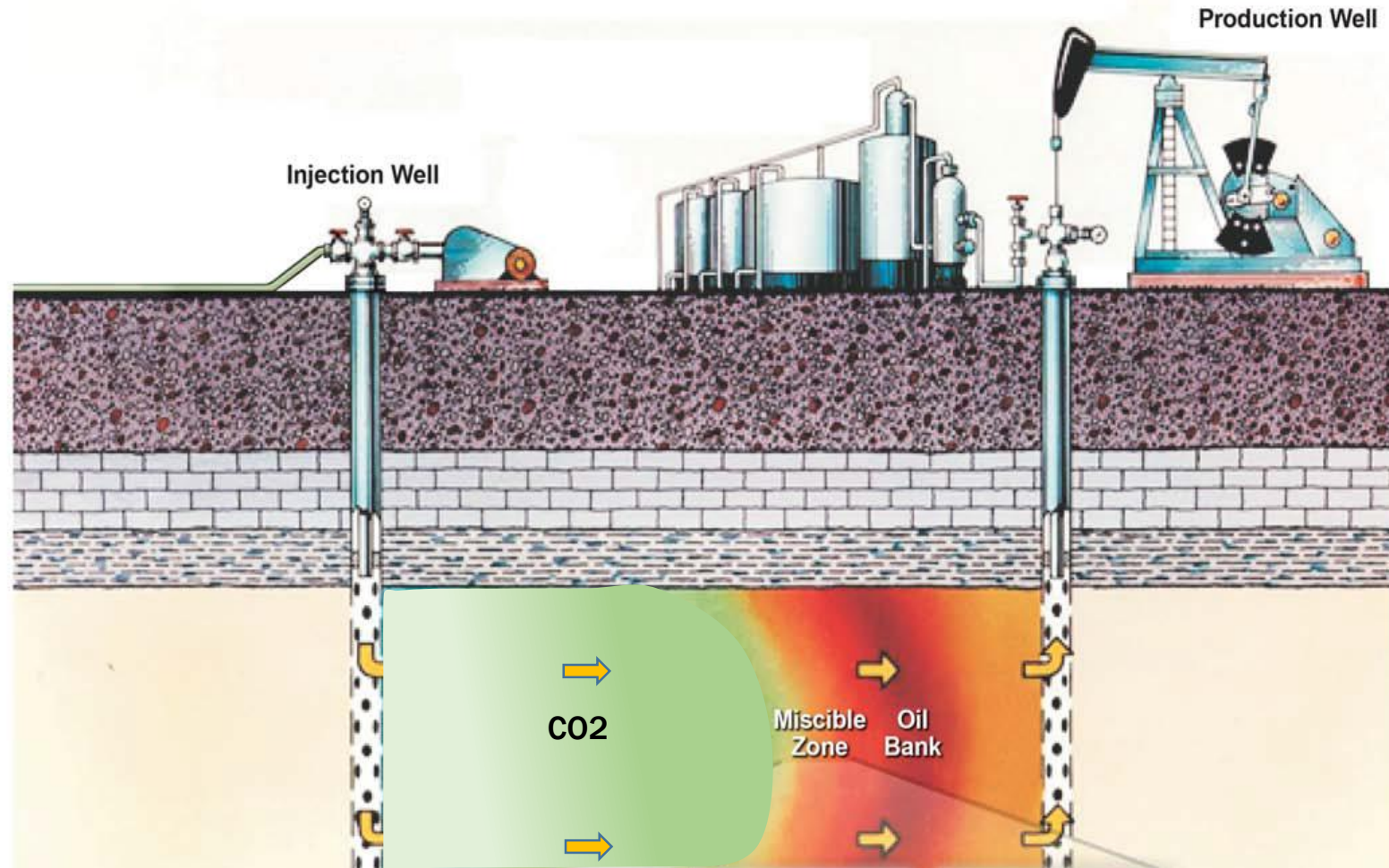


Scenario 1: Water Alternating Gas (WAG)



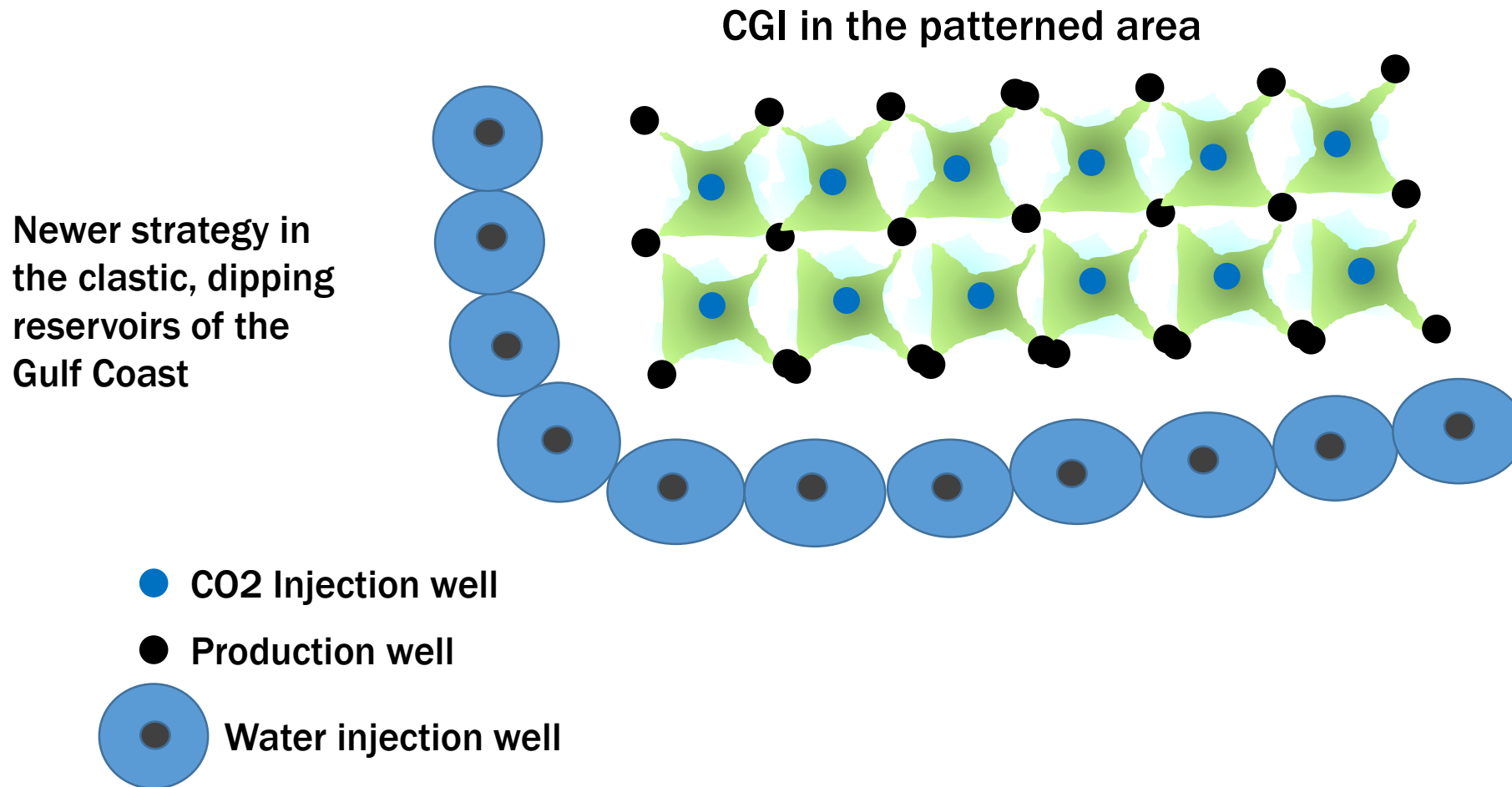
U.S Department of Energy - NETL

Scenario 2: Continuous Gas Injection (CGI)



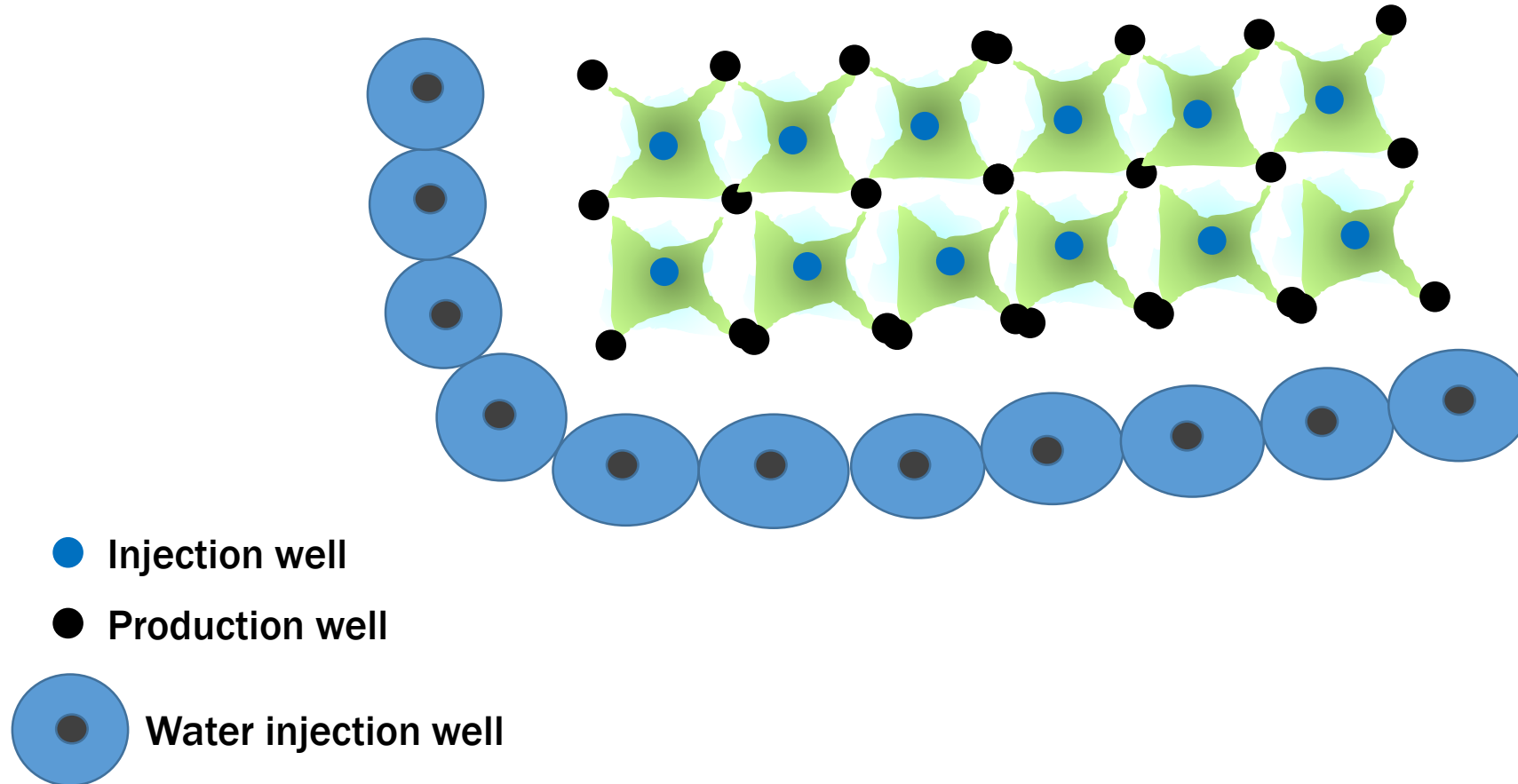
Adapted from U.S Department of Energy - NETL

Scenario 3: Water Curtain Injection (WCI)

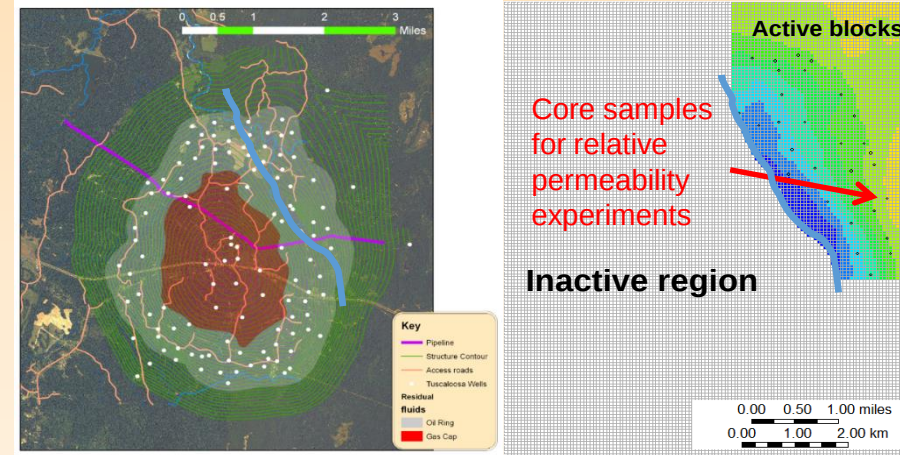
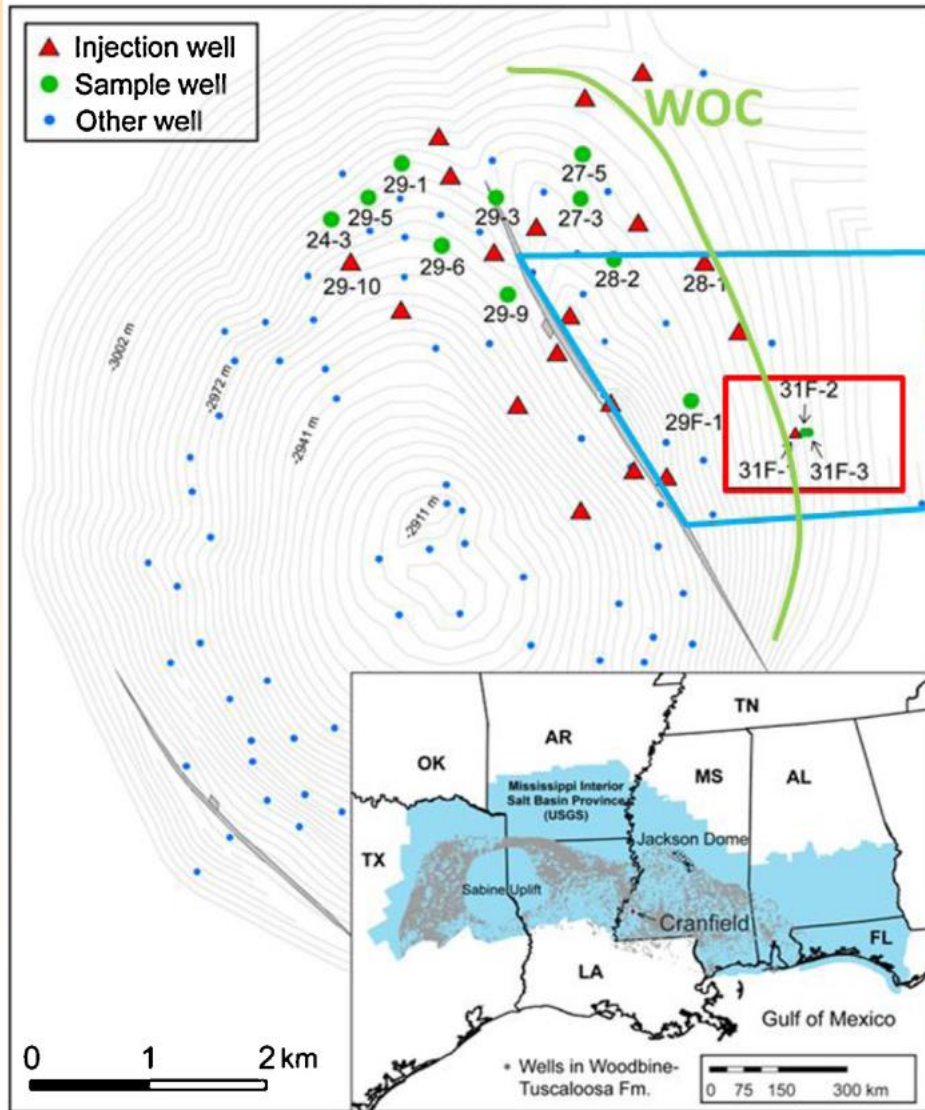


Scenario 4: WAG + WCI

WAG in the patterned area



Cranfield Static Model

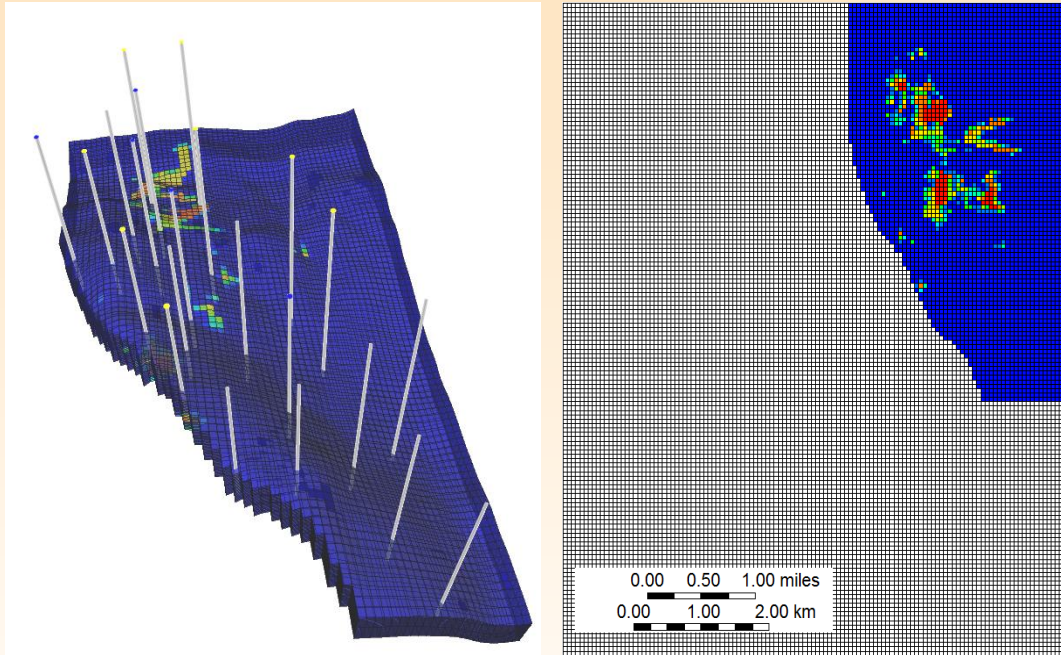


Cranfield overview:

- Clastic Mississippi field
- Apex of 4-way closed anticline
- Main pay is ~10,000 ft deep
- $P_i = 4,600$ psi, $T_i = 150^\circ\text{F}$
- Original gas cap
- Productive during 1940s and 50s
- CO_2 injection started in 2007
- Available mass accounting data as required by SECARB's monitoring program.

Compositional Numerical Simulation

Compositional model simulates CO₂ injection

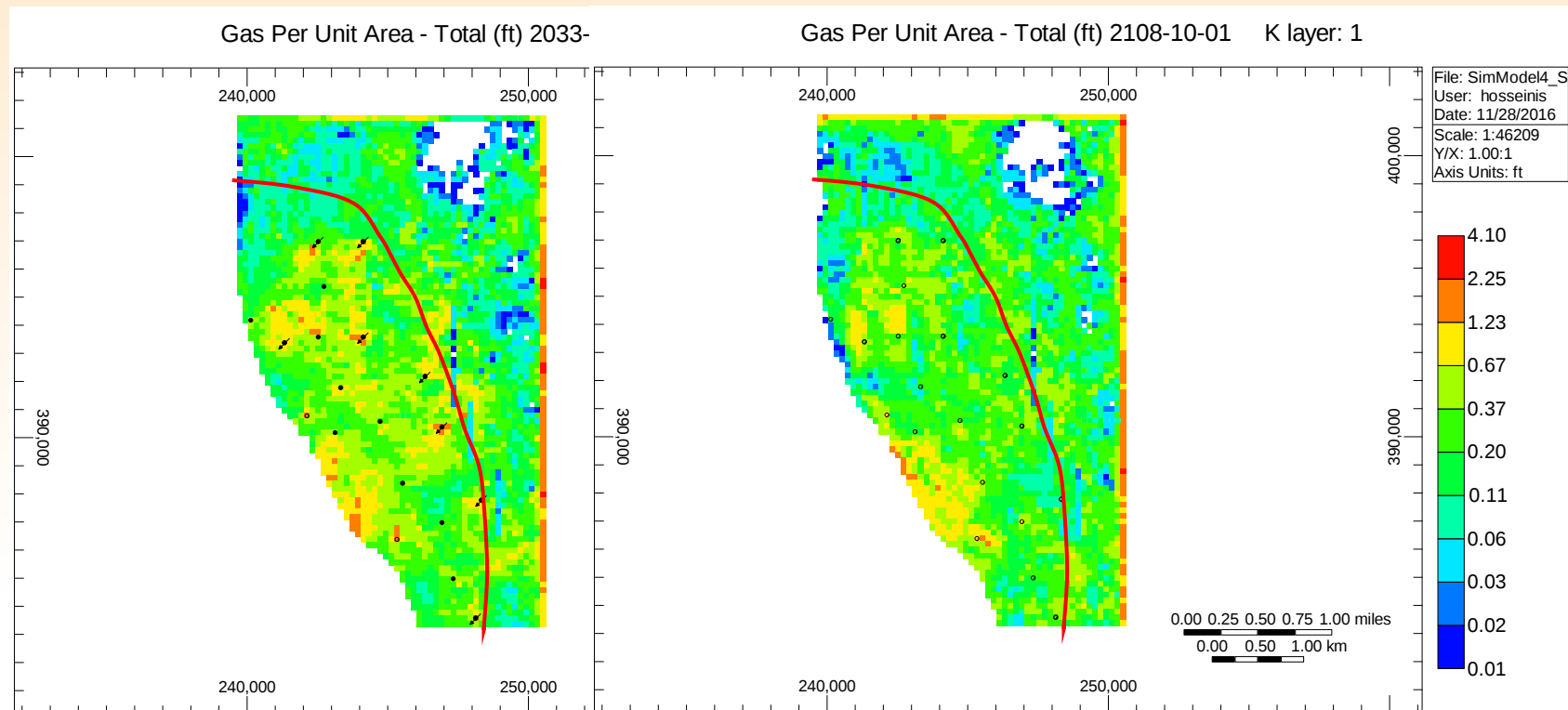


- Compositional simulation
- Total number of block = 82,500
- 25 yrs injection +75 yrs of post injection
- CMG-GEM compositional package
- Solubility modeled with Henry's law
- Oil and gas PVT tuned
- History matched historic production data (1944-1964)
- History matched EOR production data (2009-2013)
- Shut-in period (1964-2008)

Water Alternating Gas (WAG)

CO₂ phase partitioning, fraction

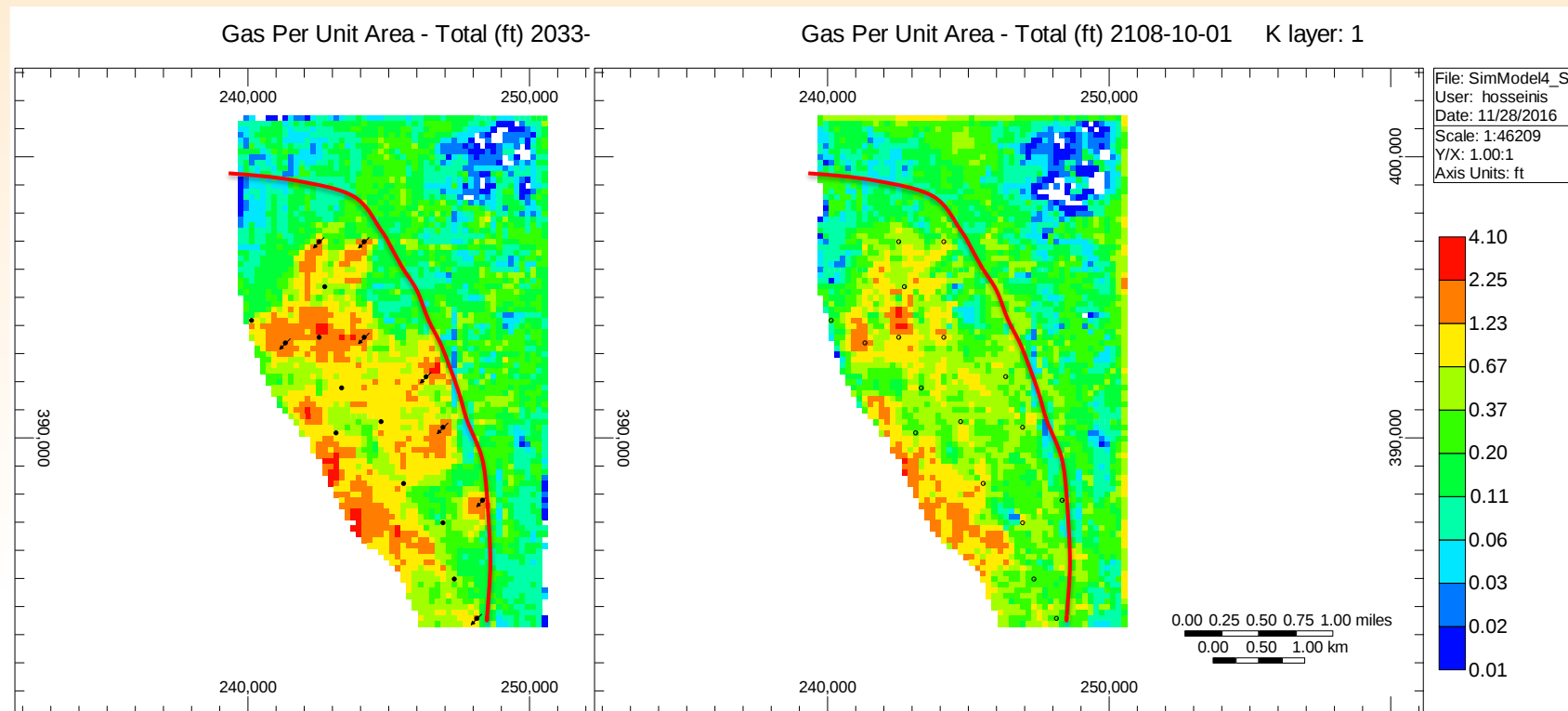
WAG	2033			2083		
	Above WOC	Below WOC	Total	Above WOC	Below WOC	Total
Oil	0.221	0.007	0.228	0.245	0.008	0.253
Brine	0.110	0.211	0.321	0.115	0.232	0.346
Gas (mobile)	0.174	0.206	0.379	0.155	0.175	0.330
Gas (immobile)	0.031	0.041	0.072	0.028	0.043	0.071
Total	0.535	0.465	1.000	0.542	0.458	1.000



Continuous Gas Injection (CGI)

CO₂ phase partitioning, fraction

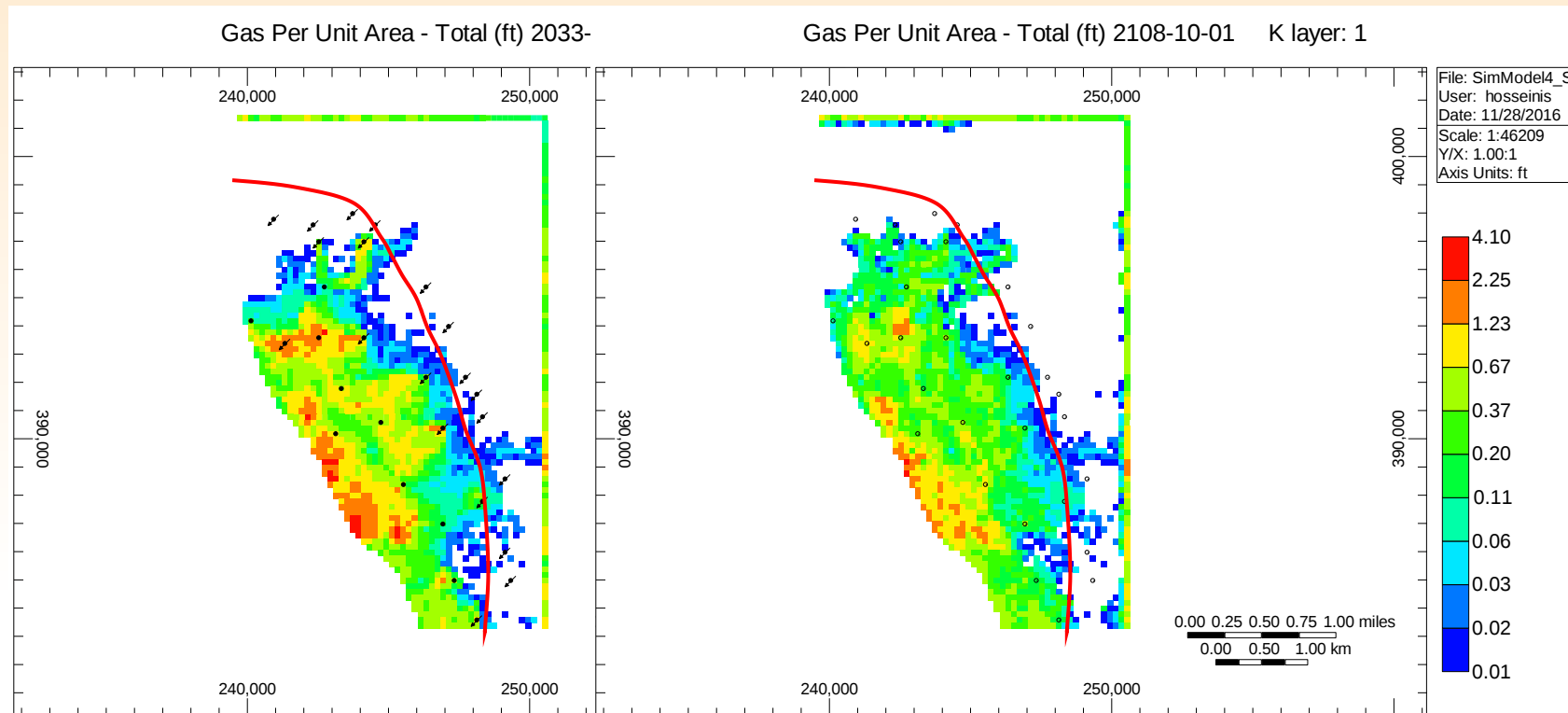
CGI	2033			2083		
	Above WOC	Below WOC	Total	Above WOC	Below WOC	Total
Oil	0.103	0.005	0.107	0.128	0.006	0.135
Brine	0.088	0.228	0.315	0.098	0.250	0.348
Gas (mobile)	0.332	0.176	0.508	0.307	0.140	.447
Gas (immobile)	0.026	0.043	0.069	0.025	0.045	0.070
Total	0.548	0.452	1.000	0.559	0.441	1.000



Water Curtain Injection (WCI)

CO₂ phase partitioning, fraction

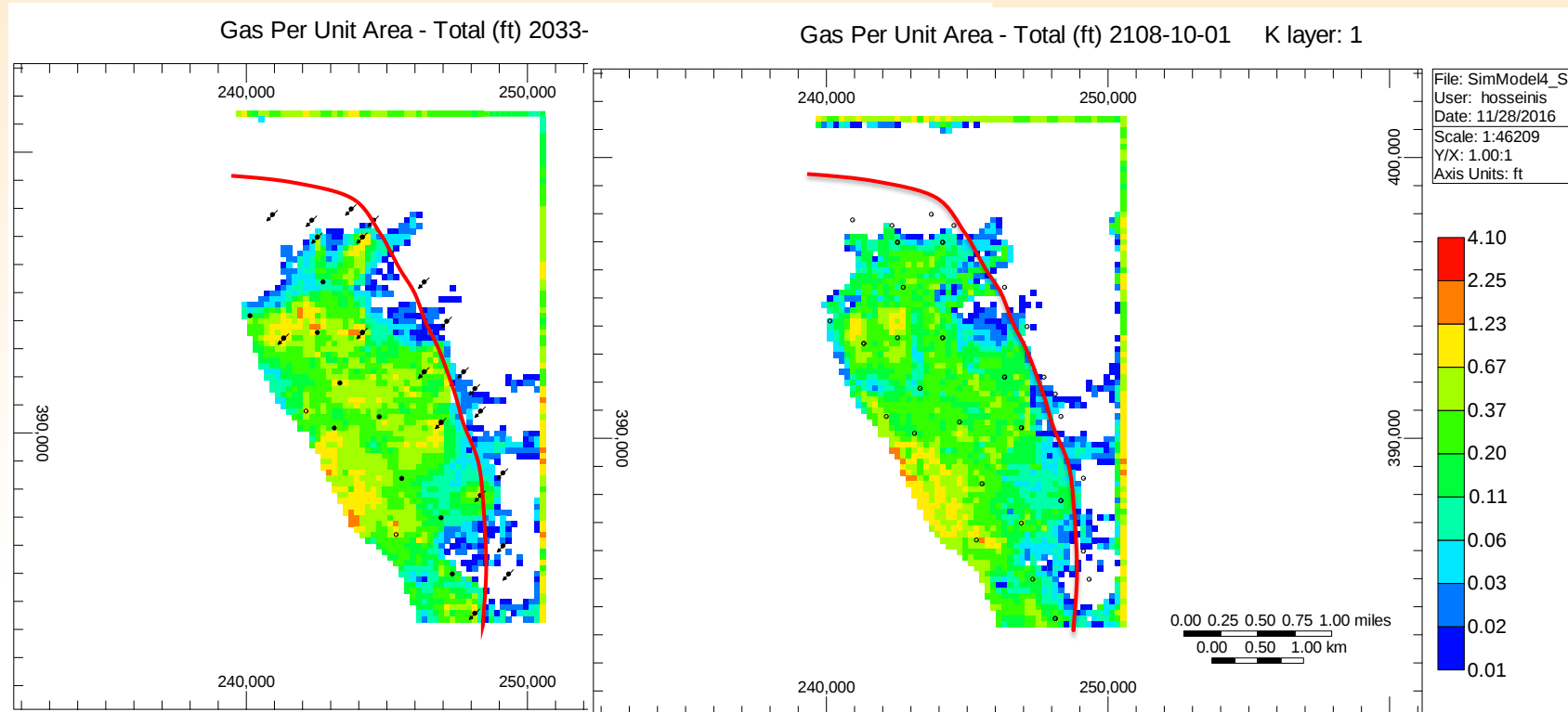
WCI	2033			2083		
	Above WOC	Below WOC	Total	Above WOC	Below WOC	Total
Oil	0.288	0.002	0.289	0.352	0.002	0.354
Brine	0.156	0.058	0.214	0.179	0.069	0.248
Gas (mobile)	0.410	0.035	0.445	0.336	0.014	0.350
Gas (immobile)	0.042	0.010	0.052	0.039	0.010	0.048
Total	0.896	0.104	1.000	0.905	0.095	1.000



WAG+WCI

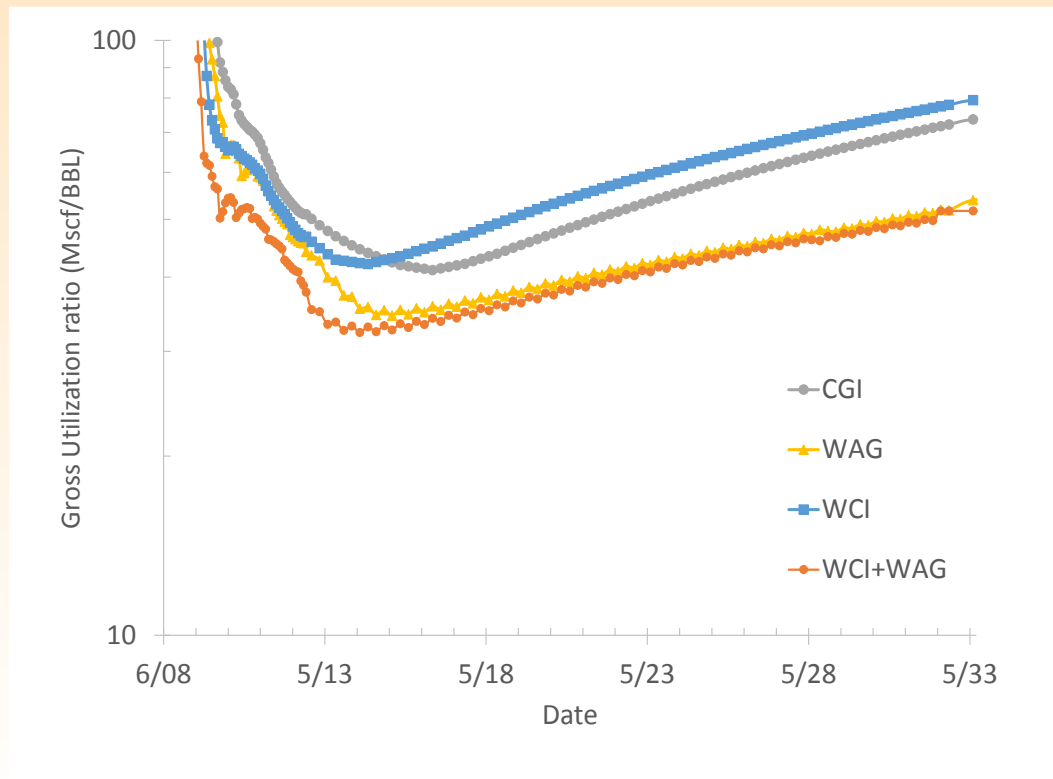
CO₂ phase partitioning, fraction

WAG+WCI	2033			2083		
	Above WOC	Below WOC	Total	Above WOC	Below WOC	Total
Oil	0.372	0.004	0.376	0.404	0.005	0.409
Brine	0.165	0.113	0.278	0.172	0.126	0.298
Gas (mobile)	0.223	0.059	0.282	0.199	0.031	0.230
Gas (immobile)	0.045	0.019	0.064	0.044	0.020	0.064
Total	0.805	0.195	1.000	0.819	0.181	1.000

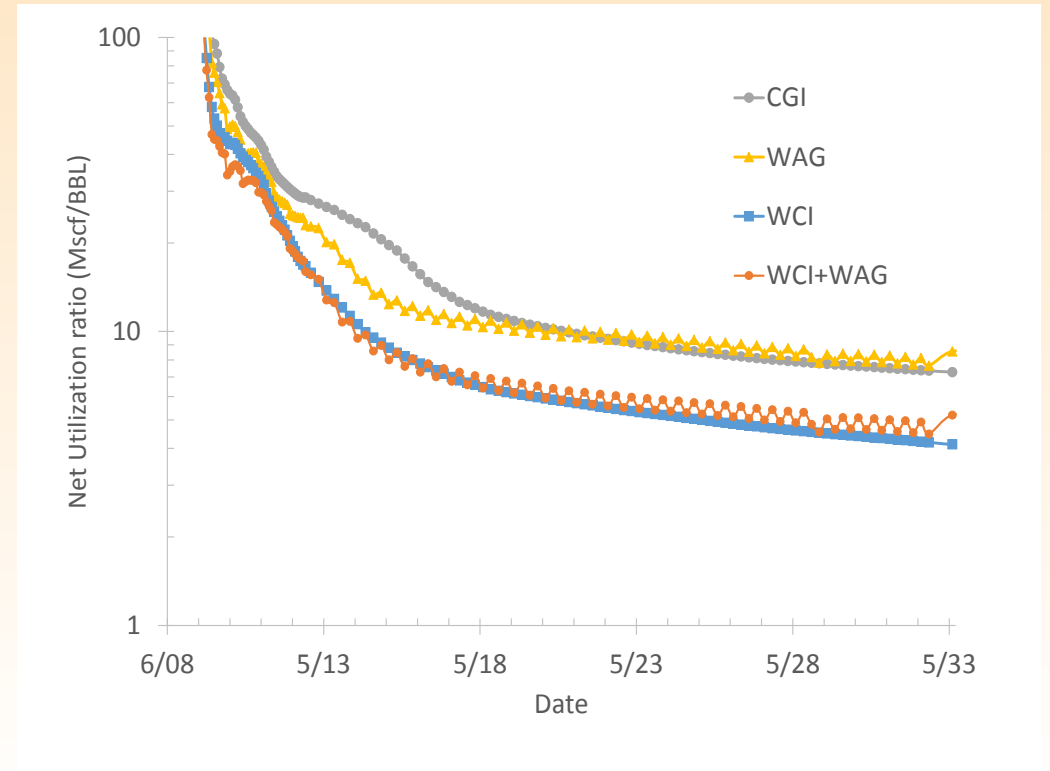


CO₂ Utilization Ratios

Gross Utilization Ratios

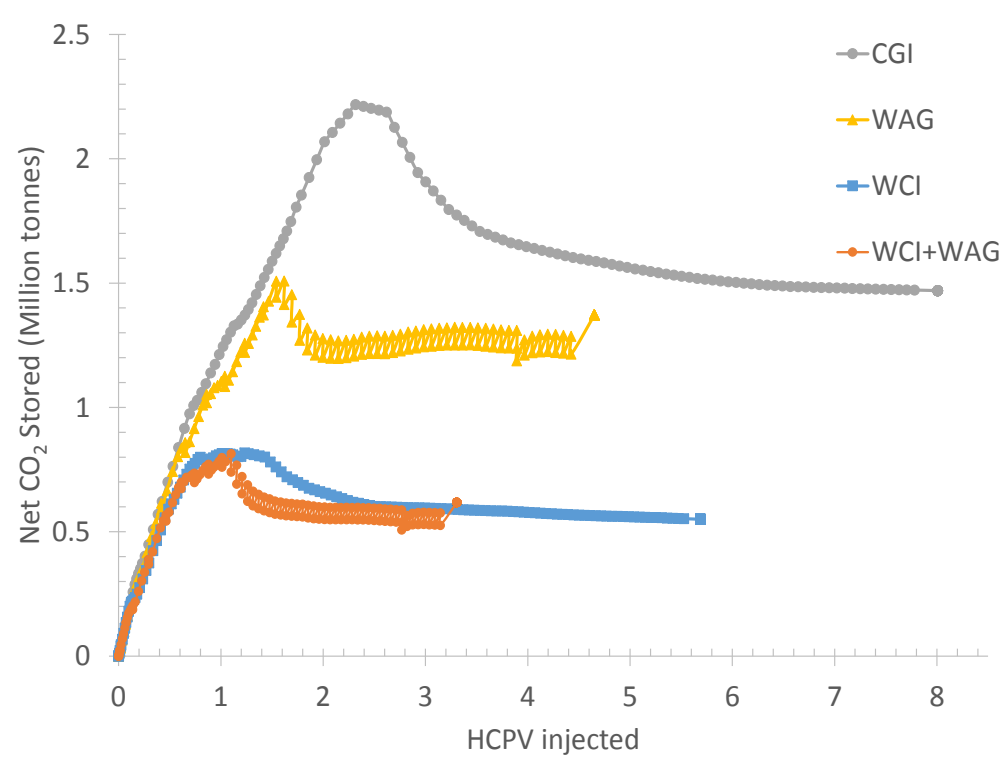


Net Utilization Ratios

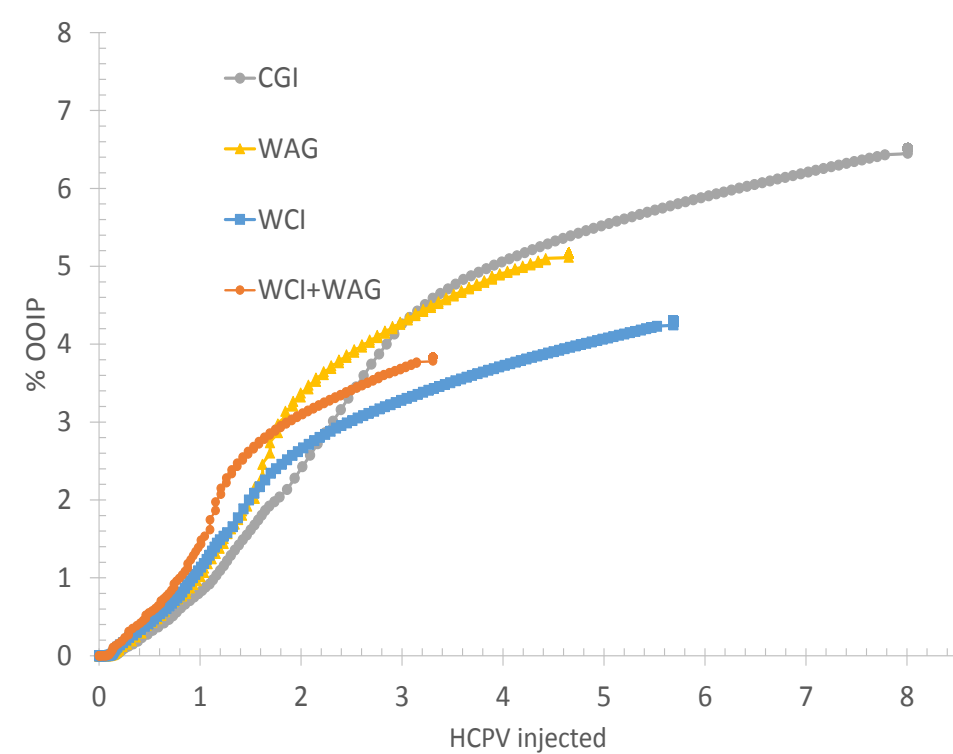


CO₂ Storage vs. Oil Recovery

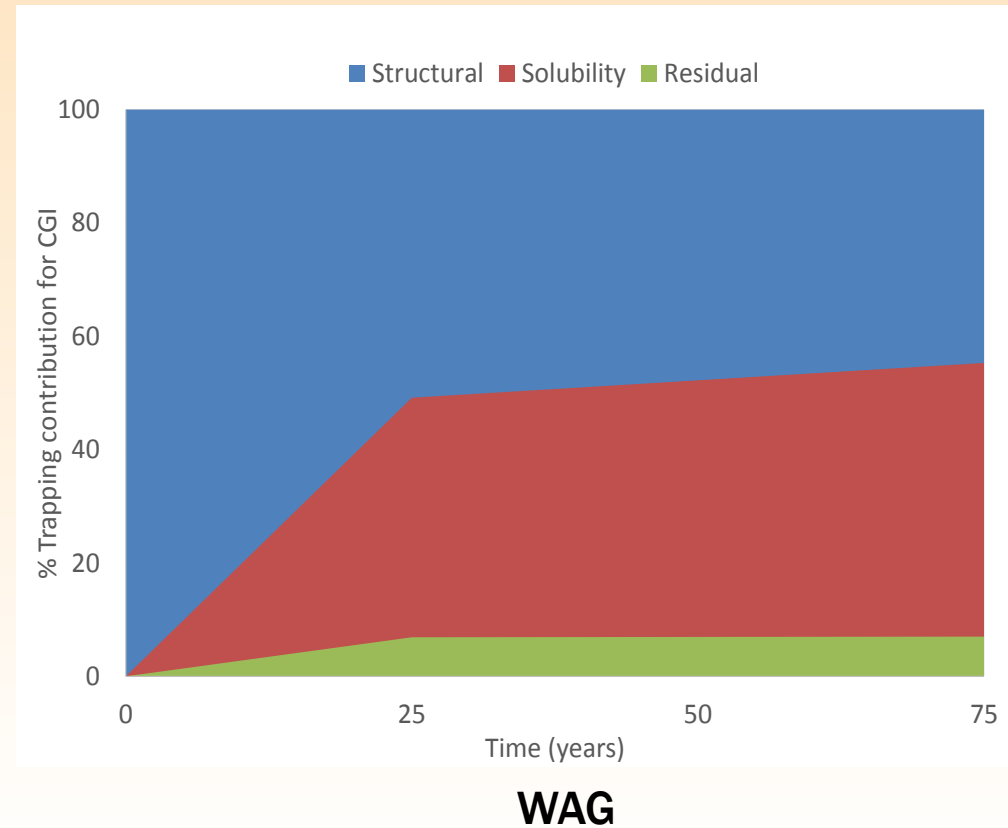
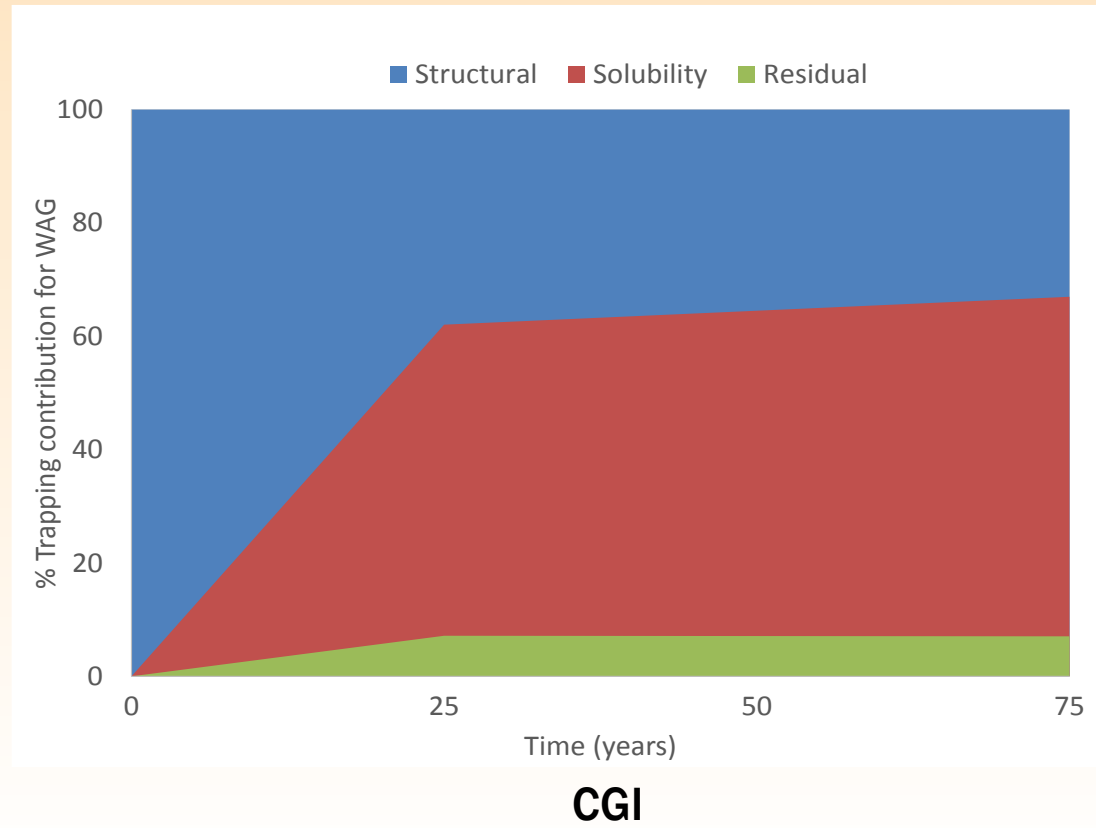
Net CO₂ Stored



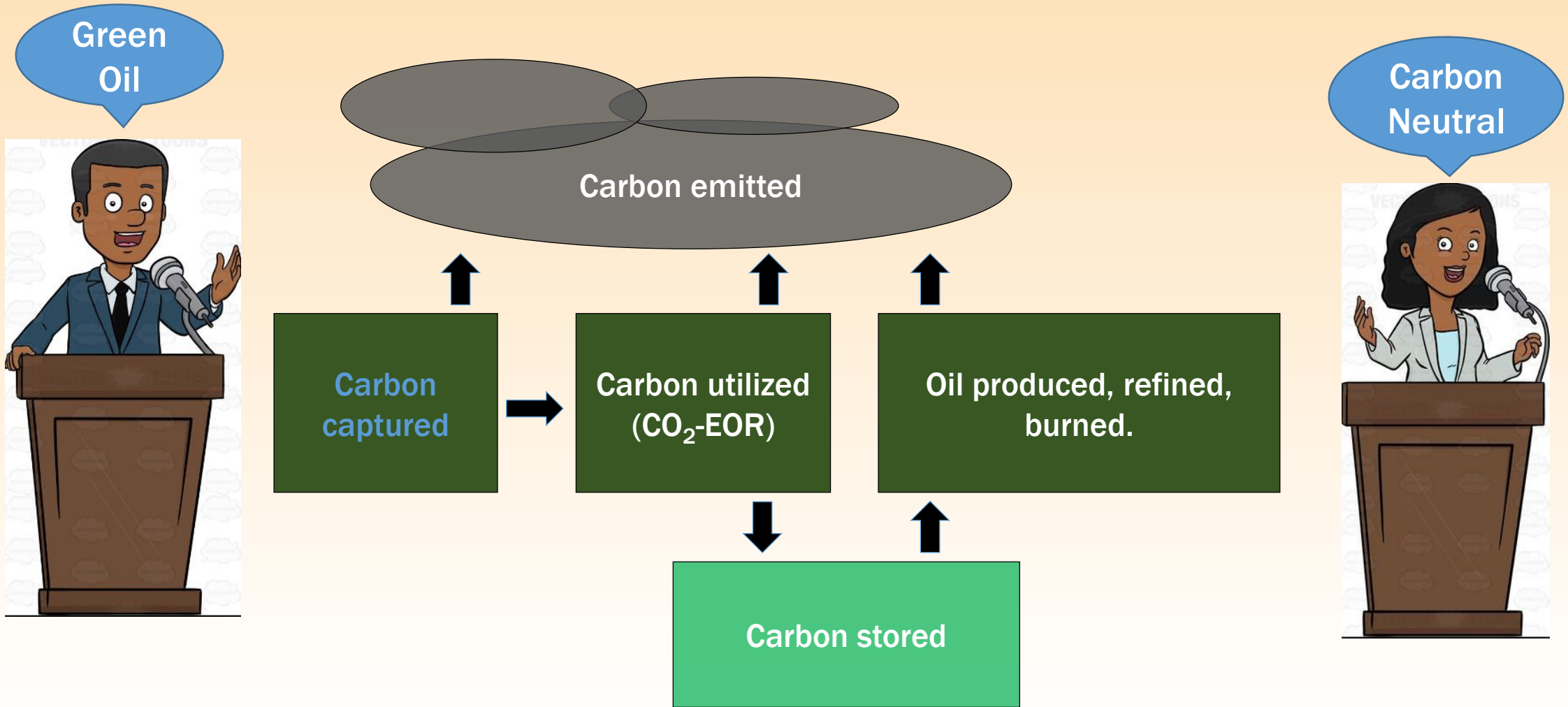
Oil Recovery Factor



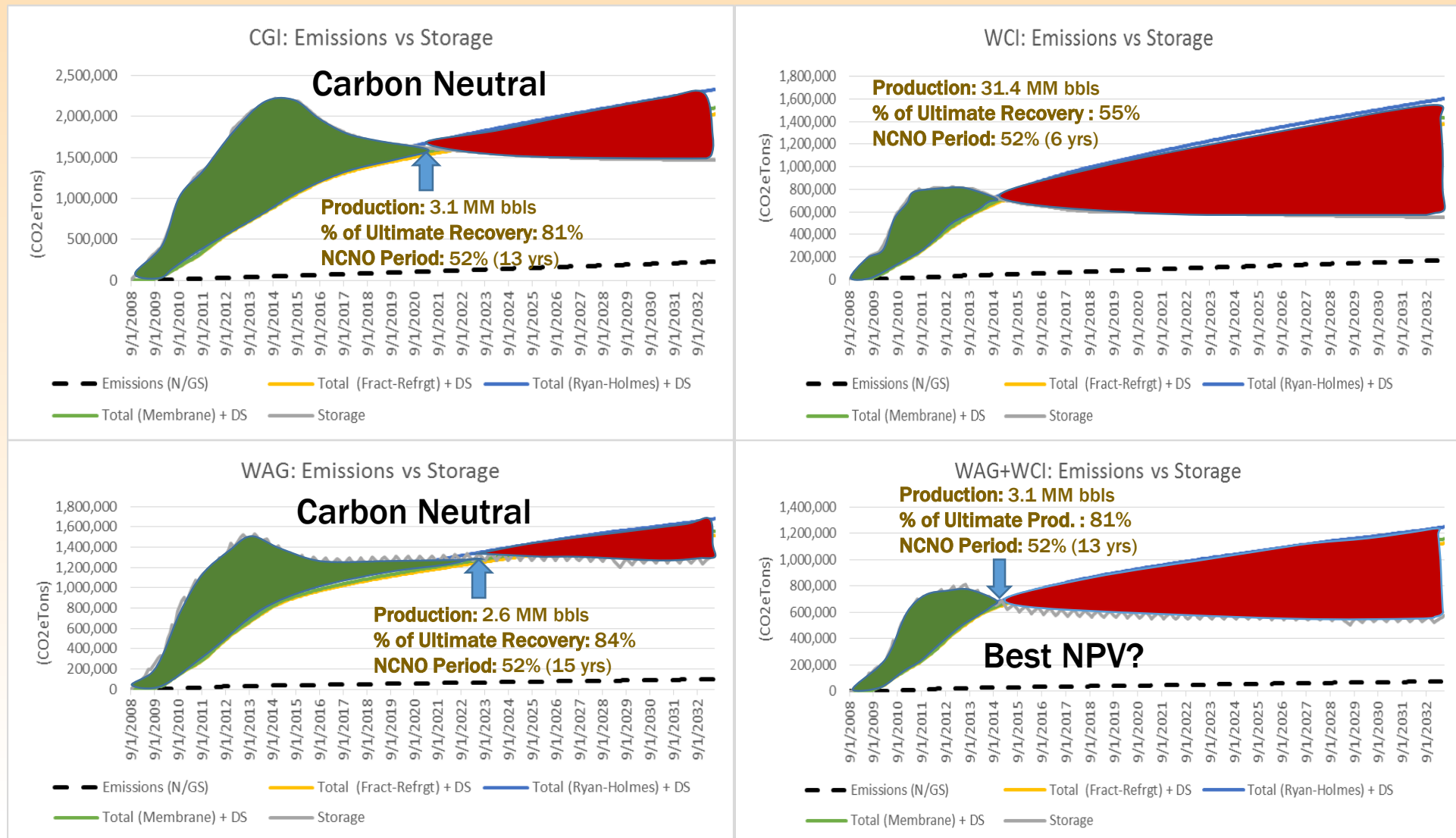
Trapping Mechanisms: CGI, WAG evolution



Can CO₂-EOR produce Net Carbon Negative Oil?



Can CO₂-EOR be Carbon Neutral?



Conclusions

- Flood efficiency as a function of CO₂ net utilization ratios, is best for the hybrid WAG+WCI scenario. In addition, oil is recovered faster producing earlier revenues and the best NPV.
- CO₂ storage is largest in the CGI scenario, as larger gross volumes of CO₂ are injected and a larger volume is left in the reservoir.
- ***WAG offers the best compromise between oil production and CO₂ storage, and it has a better potential to be optimized for flood performance in the field especially when analyzed on hydrocarbon pore volume (HCPV) injected.***
- The assessment of the Carbon Balance of CO₂-EOR needs to be dynamic, as it evolves in time. All projects transition from Net Carbon Negative to Net Carbon Positive in a Gate to Grave system (EOR site + refining + combustion of end product).
- In our Cranfield example, CGI and WAG have the potential of achieving a carbon neutral status at the end of operations.