

Current CO₂ EOR Perspectives

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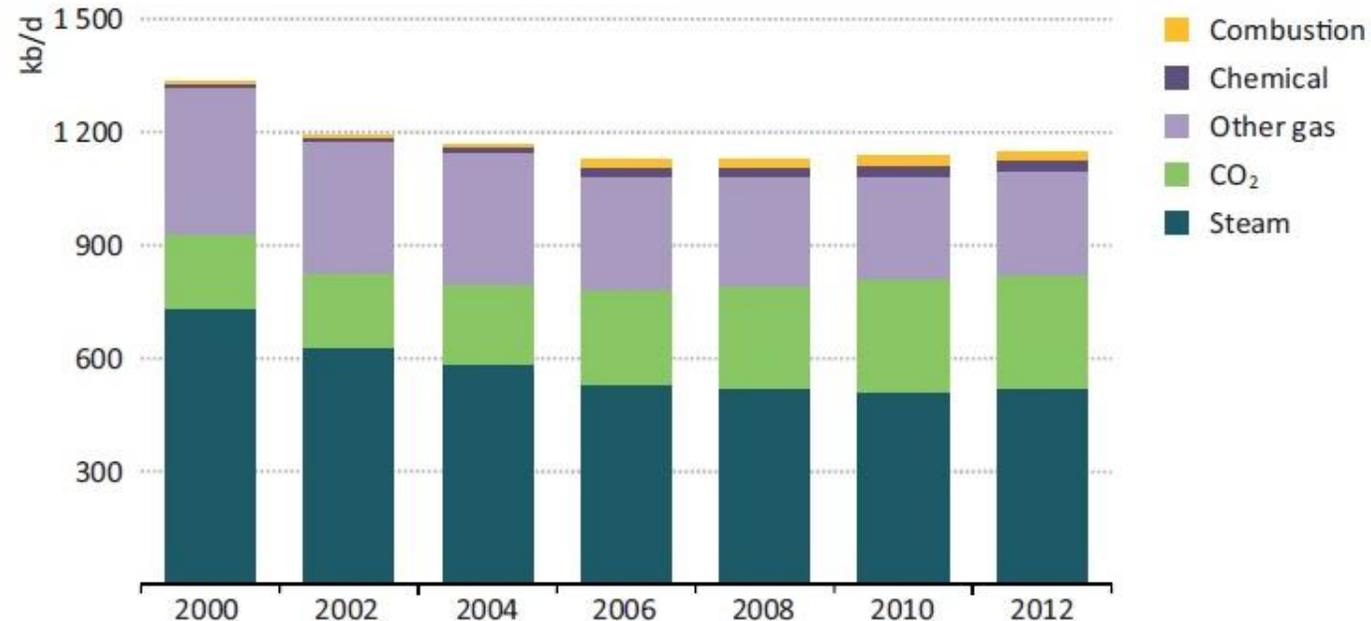
Outline

- **Major EOR Global Statistics**
- **CO₂ EOR Process and Statistics**
- **Location of Major CO₂ EOR Projects in the US**
- **Delaware Midland Basin and Yates Field**
- **Weyburn Field – A Commercial CO₂ EOR CCUS Project**
- **Worldwide EOR Projection**
- **Prospect of CO₂ EOR in Shale Reservoirs**

In the Nutshell

- EOR oil daily production a very small fraction of World daily oil production
- EOR oil daily production is much smaller than oil from shale reservoirs
- CO₂ EOR is a blessing in disguise because ½ of injected CO₂ is sequestered
- Flaring HC creates more CO₂ than we hope to sequester!
- CO₂ in shale cannot compete with Ethane and Propane!
- Petroleum reservoirs provide ample safe space for CO₂ sequestration

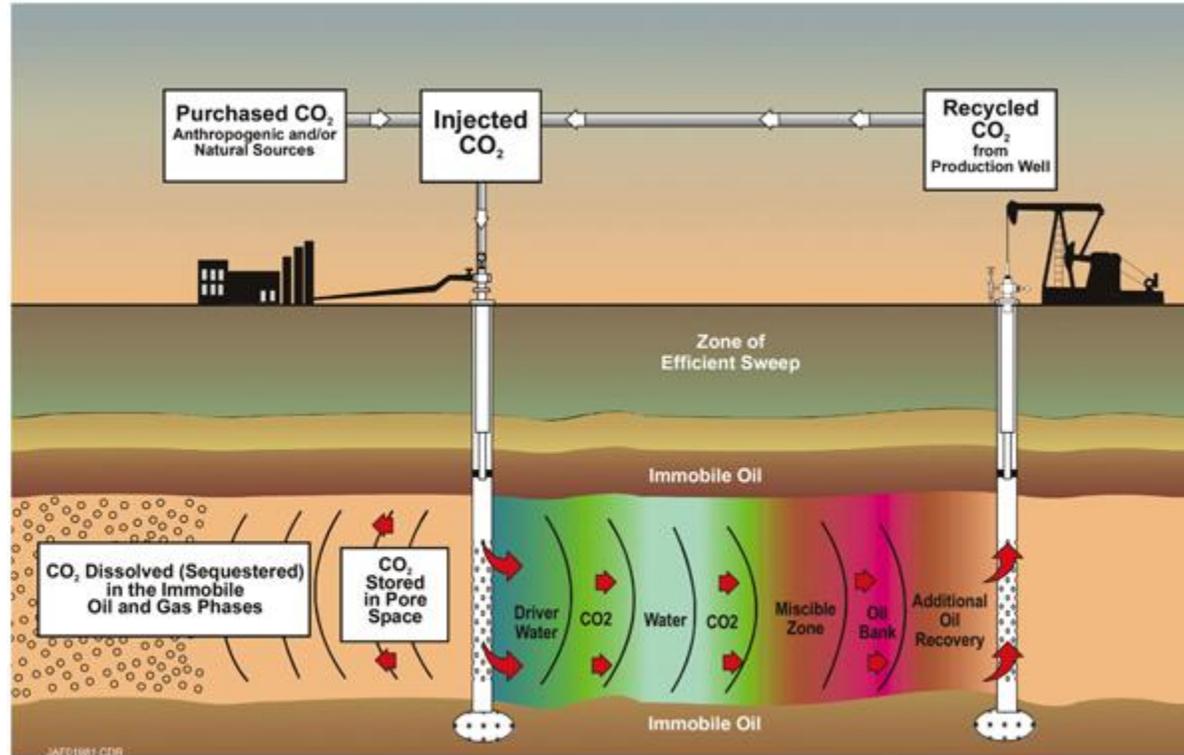
Estimated Global EOR Production (excluding China) from Five Major EOR Methods (IEA_WEO_2013)



Notes: The estimate excludes fields that we classify as unconventional, *e.g.* Canadian oil sands and Venezuelan Orinoco belt extra-heavy oil (steam-based technologies are extensively used for such unconventional reservoirs as the main recovery technique, as traditional primary and secondary recovery techniques are generally ineffective). The figure excludes China, because the data series for China are incomplete; China is estimated to produce about 170 kb/d: 150 kb/d from steam technologies and 20 kb/d with polymer injection.

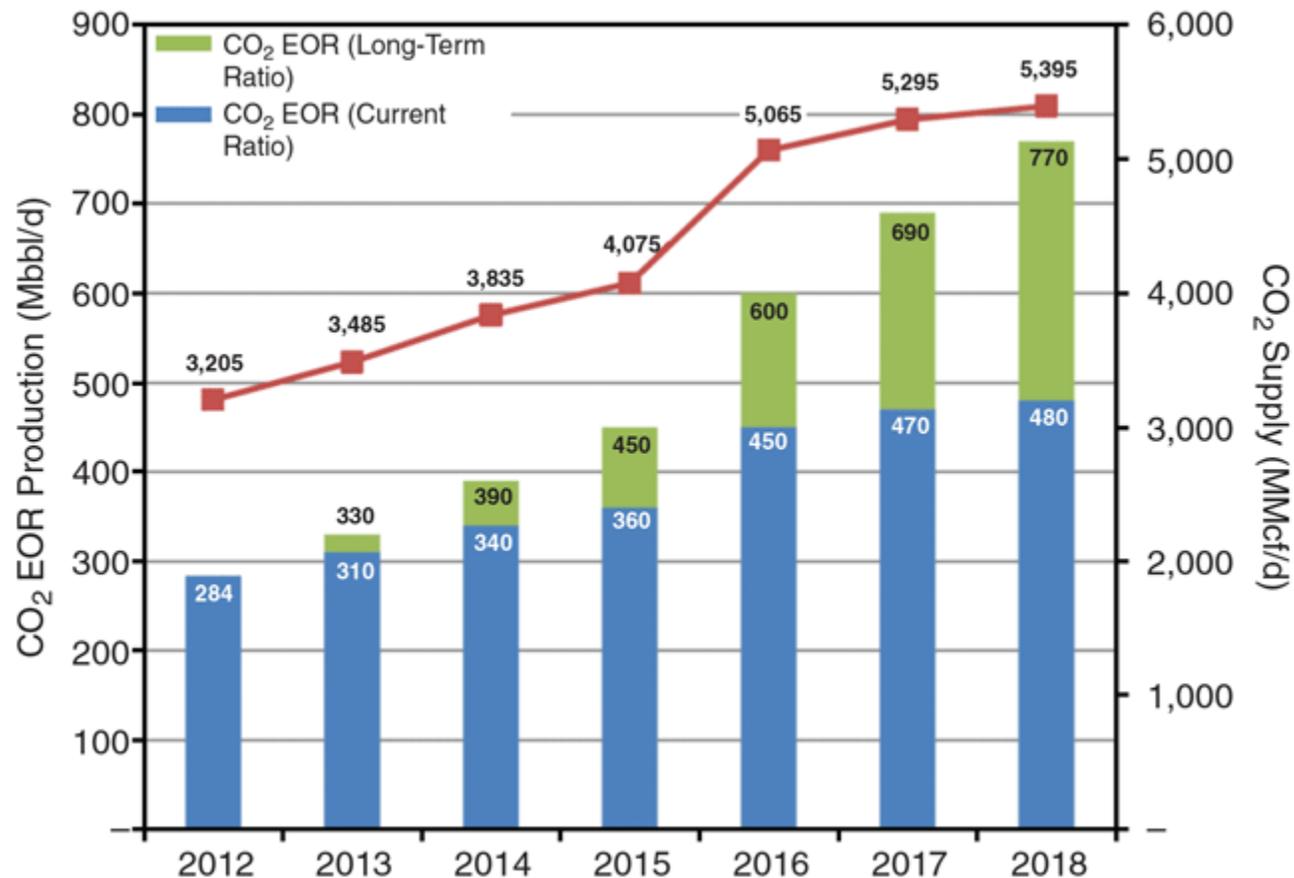
CO₂ EOR Process

(UK Department of Energy, 2010)



Source: Advanced Resources International and Melzer Consulting, Optimization of CO₂ Storage in CO₂ Enhanced Oil Recovery Projects, prepared for UK Department of Energy & Climate Change, November 2010.

World CO₂ EOR Daily Oil Contribution



Location of Current CO₂ EOR Projects, Pipeline Infrastructure, and CO₂ Source in the US (O&GJ, 2014)



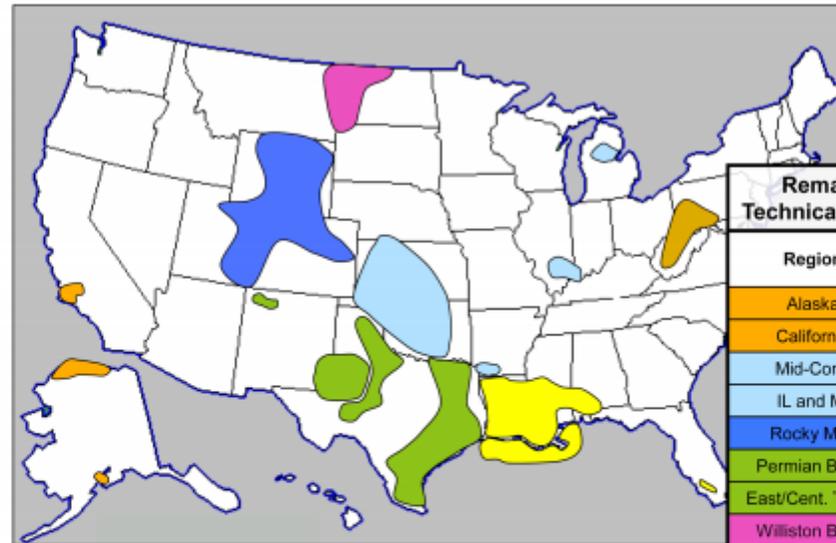
Location of Current CO₂ EOR Projects and Pipeline Infrastructure

CO₂ EOR Statistics

- **Current CO₂ EOR source is mainly from natural CO₂ reservoirs -- not from anthropogenic sources.**
- **CO₂ EOR is a small fraction of the world daily oil production -- 480,000 STB/D vs. 100,000,000 STB/D.**
- **The 2018 Projected CO₂ use for EOR is 5,400,000,000 scf/D CO₂ for 480,000 STB/D oil. This is equivalent to CO₂ gross utilization of 11,240 scf of CO₂ per one STB of oil.**

Potentially Recoverable Incremental Oil Using Best CO₂ EOR Practices (ARI, Feb 2009)

Potential Technically Recoverable Incremental Oil with "best practices" CO₂ EOR Technology



Source: ARI, February 2009

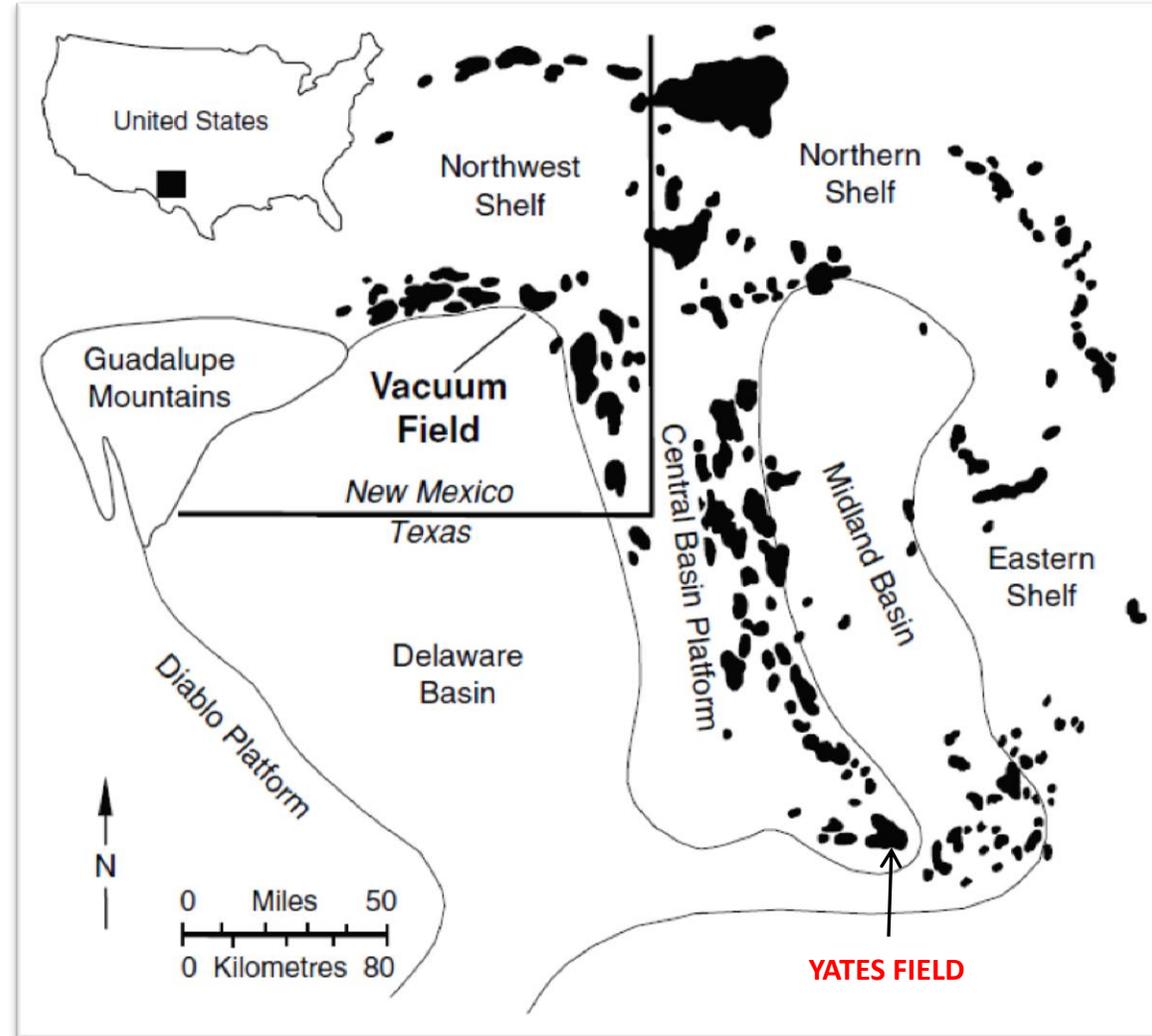
Remaining Oil in Place and Technically Recoverable Oil (BBIs)		
Region	ROIP*	Technically Recoverable
Alaska	45.0	12.4
California	57.3	6.3
Mid-Cont.	65.6	10.6
IL and MI	11.5	1.2
Rocky Mts.	22.6	3.9
Permian Basin	61.7	15.9
East/Cent. Texas	73.6	17.6
Williston Basin	9.4	2.5
Gulf Coast	27.5	7.0
LA Offshore	15.7	5.8
Appalachia	10.1	1.6
Total	400	84.8

* Remaining Oil in Place

Producible if costs, oil price and risks justify investment

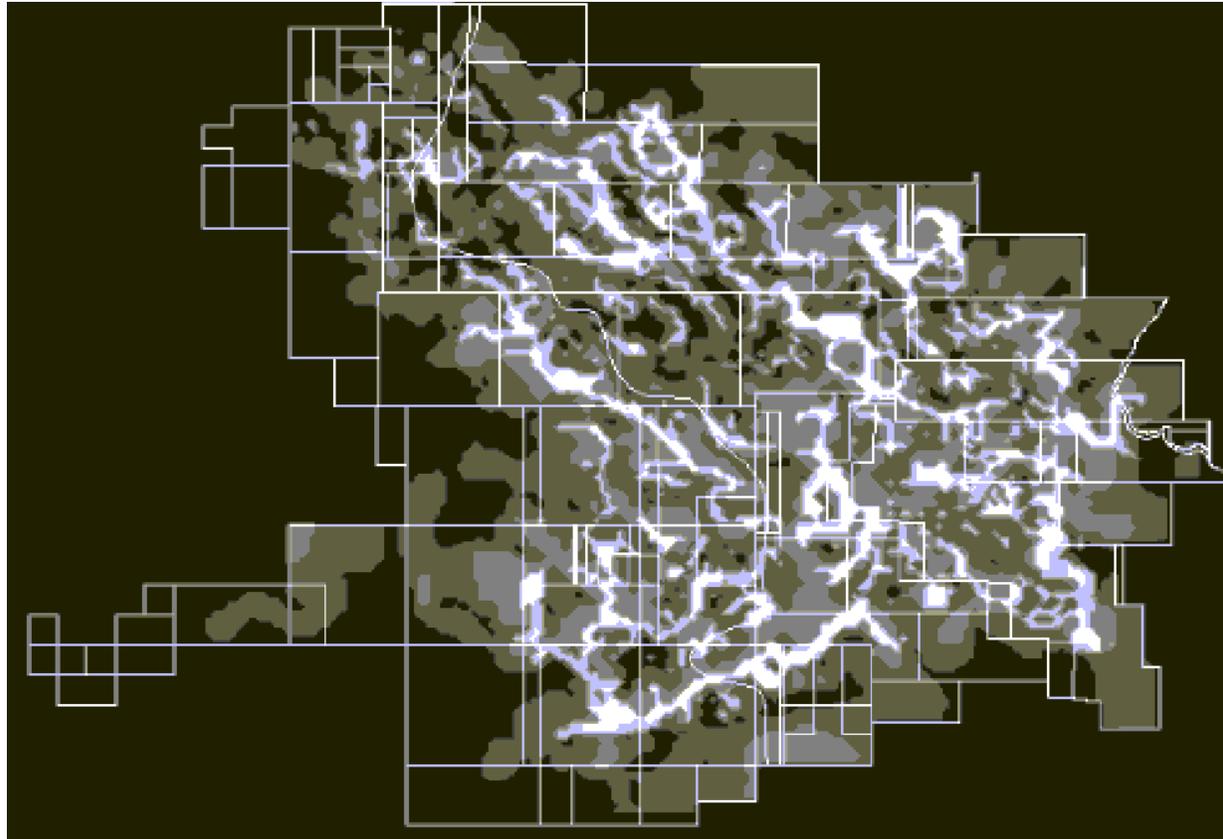
Delaware Midland Basins

(Pranter, et al: *Petroleum Geoscience*, 10, 2004; adopted from Hills, J. M., *AAPG Bulletin*, 68, 250–267, 1984)

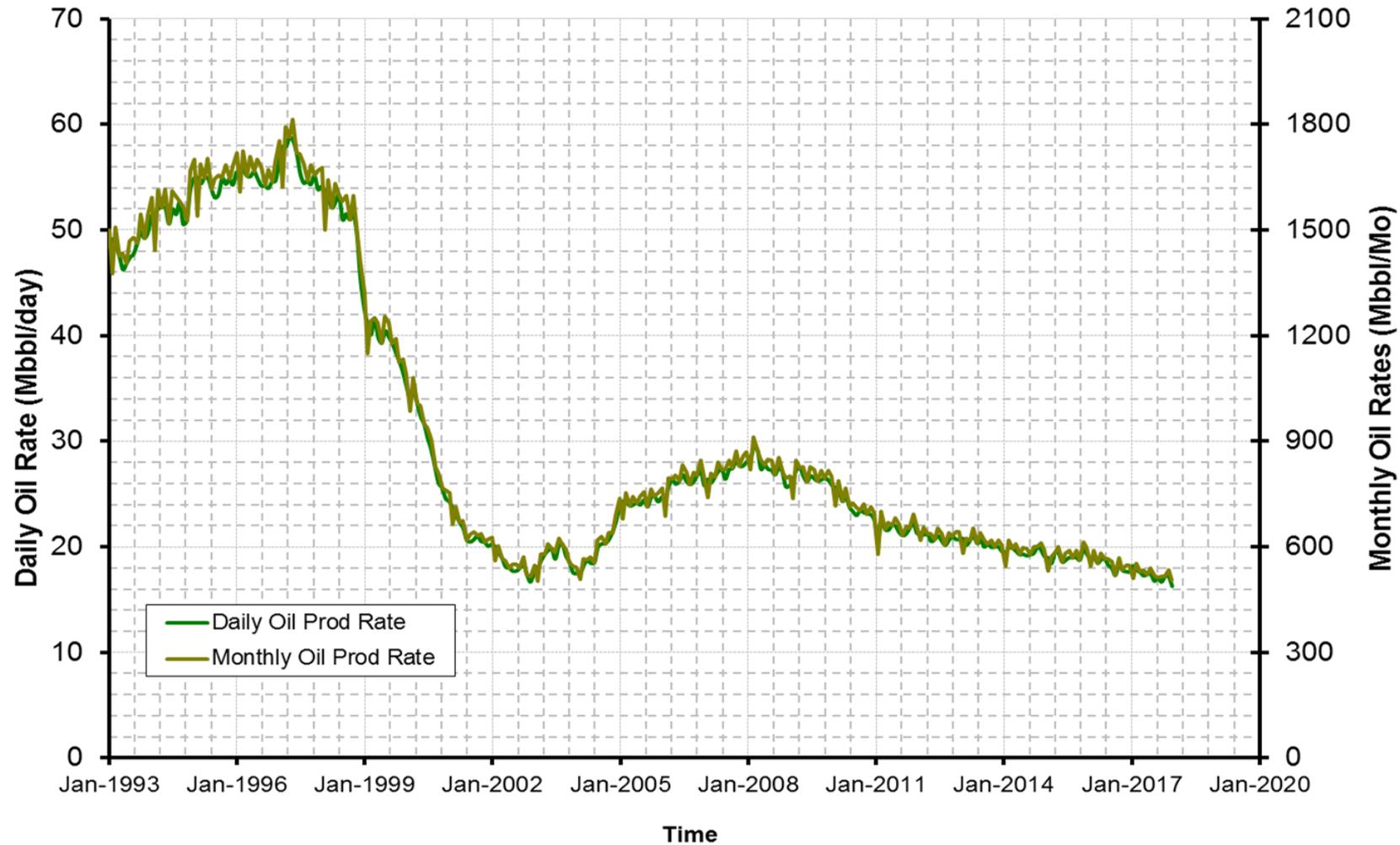


Connection Probability Map

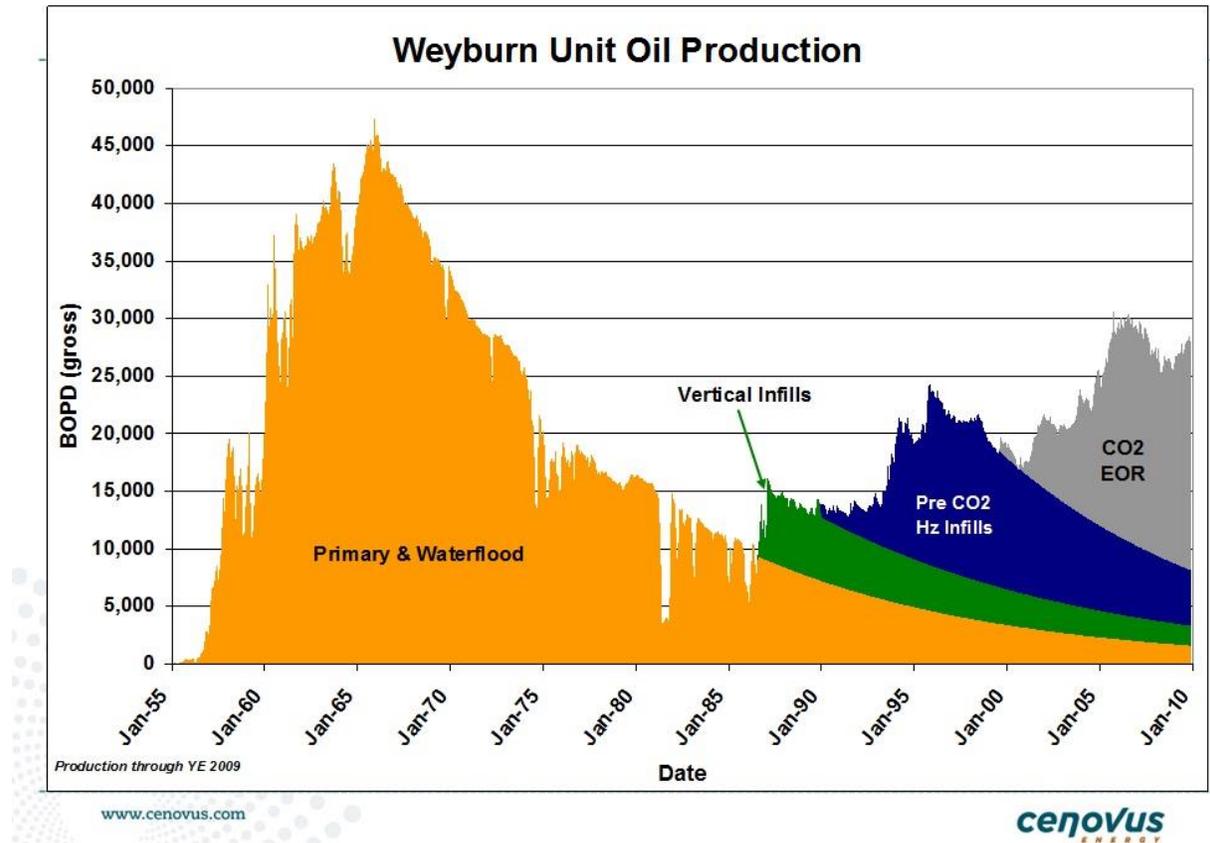
Karst Surface of San Andres: The white areas have the highest probability of connection to major flow features. SPE 58996 – Campanella et al. (2000)



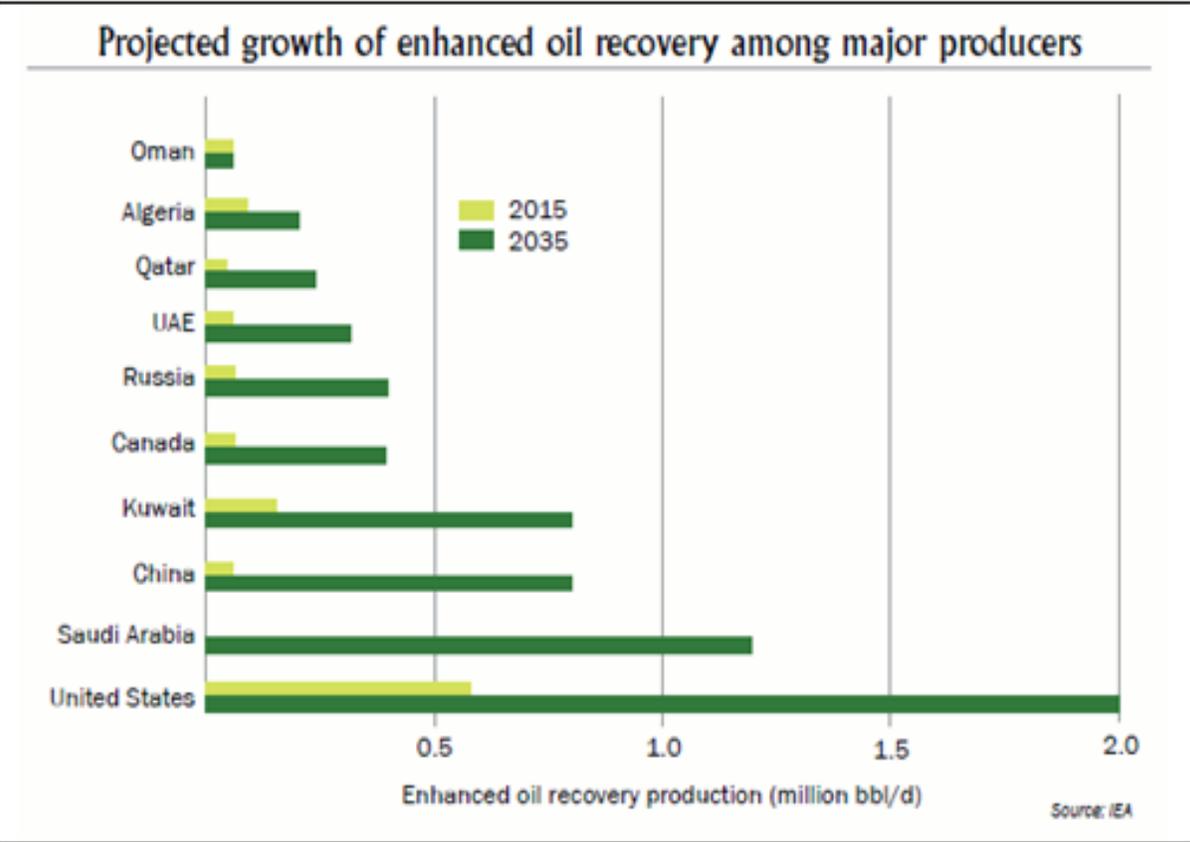
Yates Field Oil Production Rate



Weyburn Unit Oil Production History. CO₂ EOR Utilizes CO₂ from a Power Plant in North Dakota



EOR by All Techniques Is a Small Fraction of the Daily Total Oil Production (Global Water Intelligence)

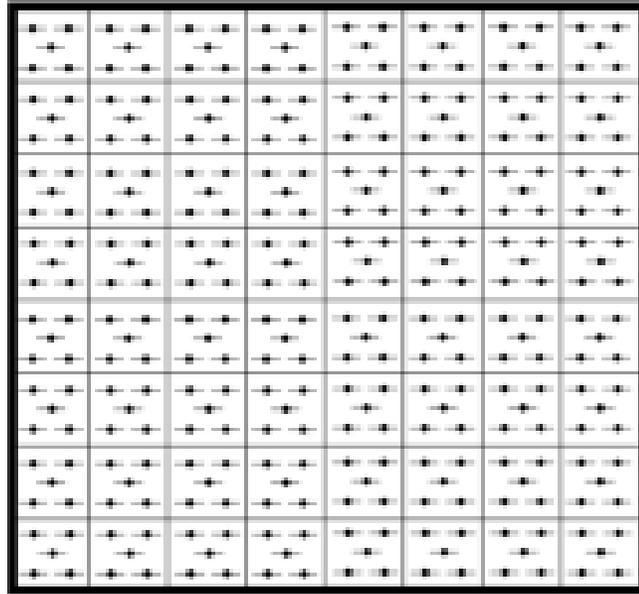


Source- Global Water Intelligence

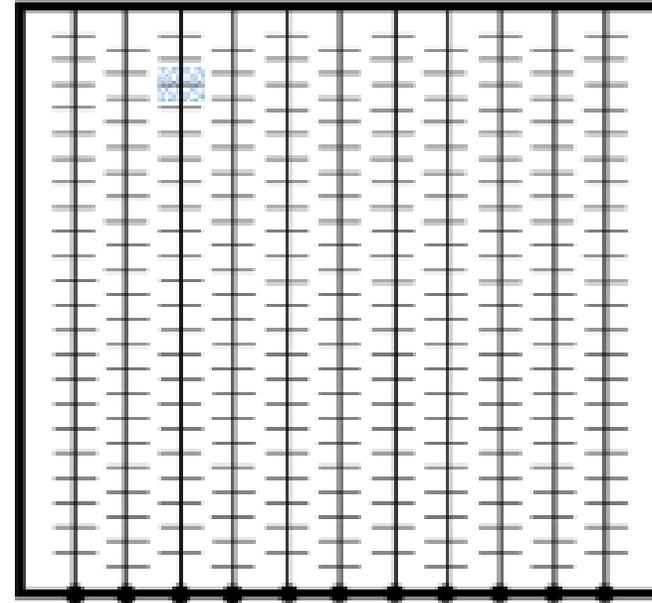
Observations

- Much of the research on CO₂ EOR pertains to conventional **uniform permeability** sandstone and carbonate reservoirs. Unfortunately, many reservoirs, including the carbonate reservoirs of the Permian basin, are highly heterogeneous, and many are inundated by fractures. An example is the Yates field in Permian basin, where the oil production by CO₂ is not purely by oil **displacement**.
- In **unconventional shale** reservoirs, the CO₂ oil recovery is via mass transfer between fractures and matrix. Furthermore, the shale's mobile oil saturation is so small that the incremental oil recovery will not be economically favorable. The use of **abundant ethane and propane** provide a better economic option.

Hydraulic Fractures Placed in One Square Mile in DJ Basin Compared with Equivalent Vertical Well Placements in the Same Area



**320 fraced vertical wells in
one square mile**



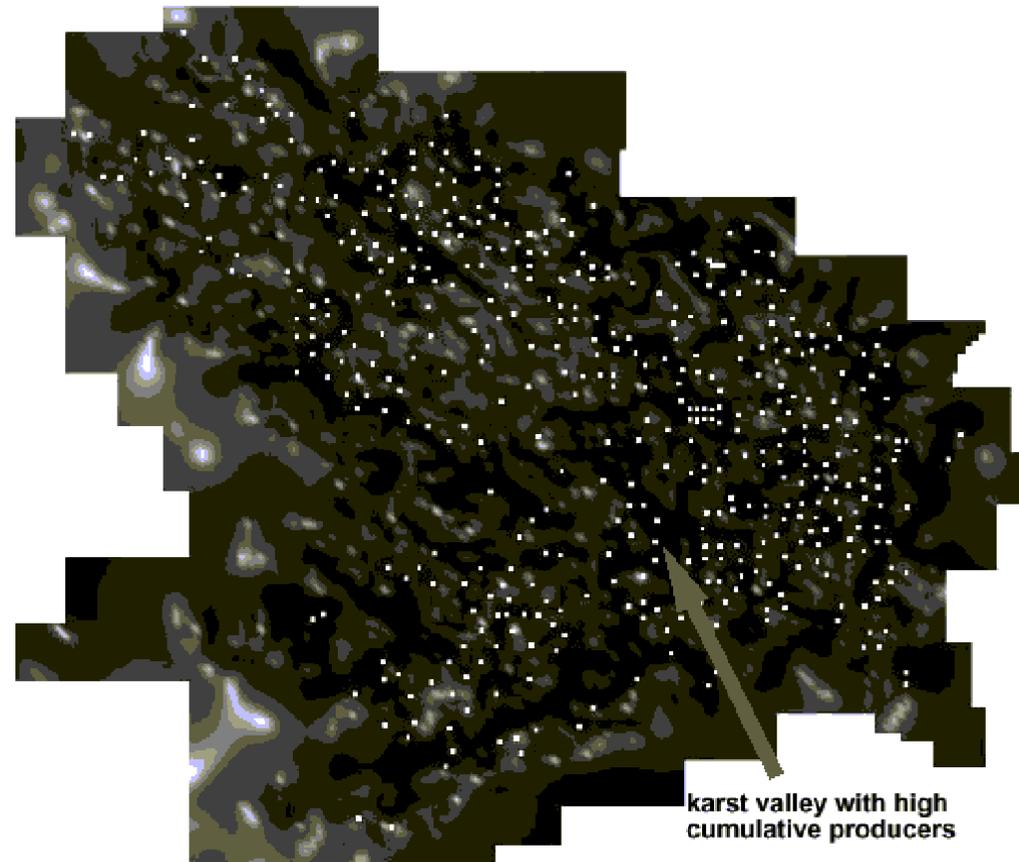
**11 zipper fraced horizontal
wells in one square mile**

Concluding Remarks

- CO₂ EOR is currently the major CCUS in the US – a blessing in disguise.
- Depleted oil reservoirs can be used to sequester CO₂ without reliance on incremental oil recovery.
- In 2014 the **US CO₂ EOR was 110 million STB/Yr**, with CO₂ utilization of **1.278 Tcf/ Yr**.
- The **global flaring** of HC gas in 2017 was **4.779 Tcf/Yr** (1.416×10^{11} m³/ Yr, or 2.520×10^8 ton/ Yr).

Thank You

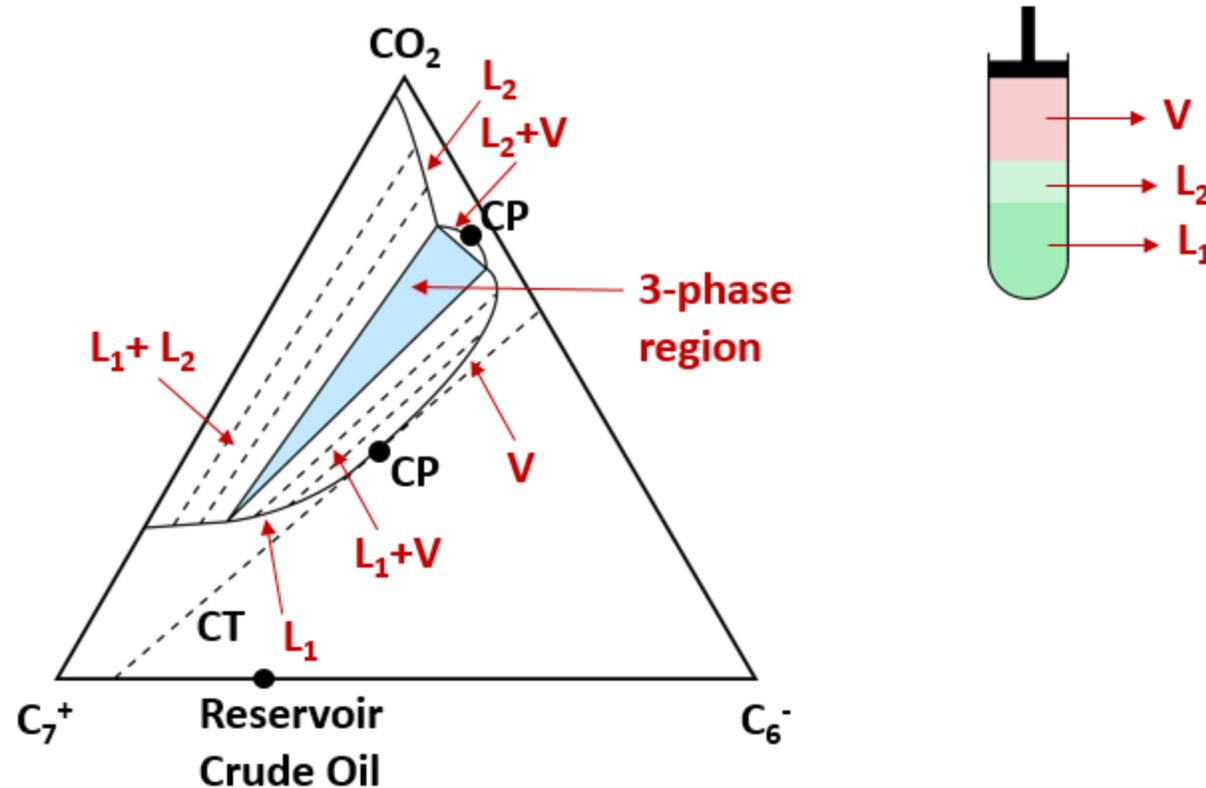
Yates Field



White squares are high cumulative producers. SPE 58996 – Campanella et al. (2000)

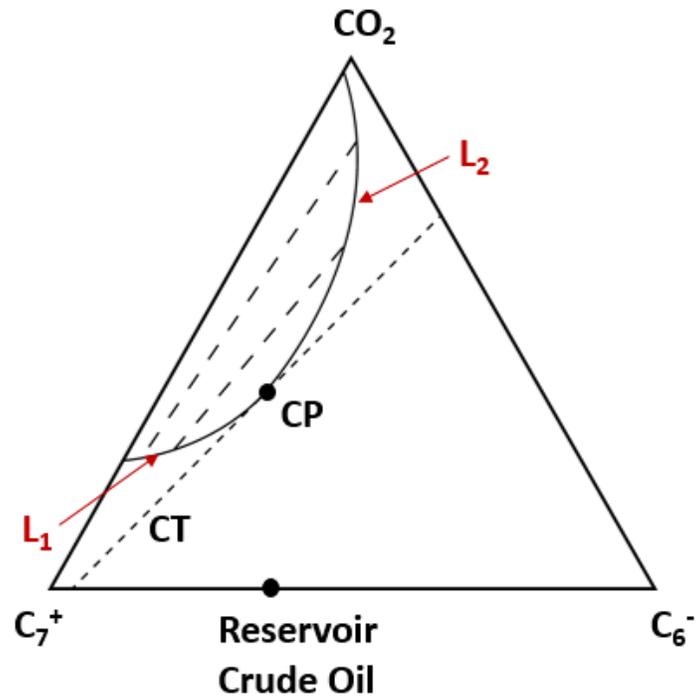
An Idealized Wasson Crude-CO₂ System

(Redrawn from Gardner et al., 1981)

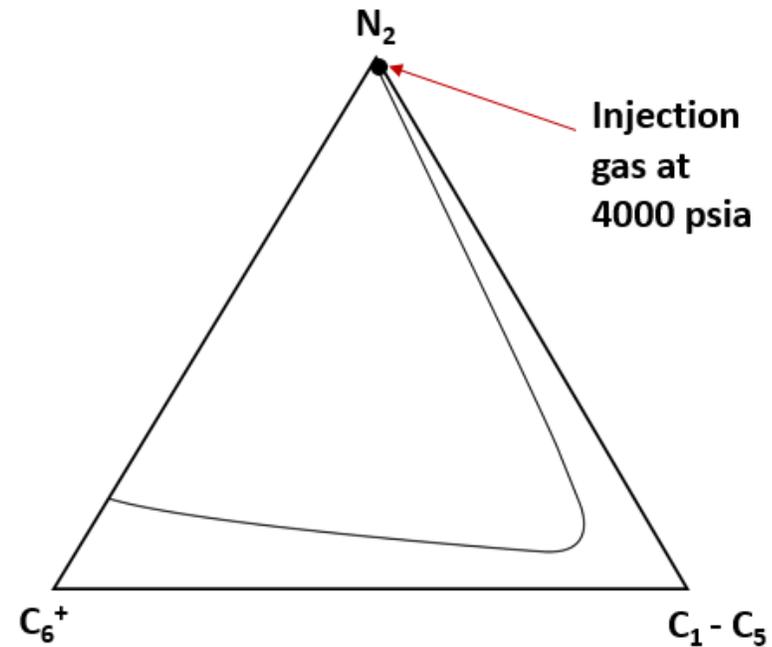


Idealized Wasson Crude-CO₂ System at $T = 105\text{ }^\circ\text{F}$ and $p = 1350\text{ psia}$

Phase Behavior of CO₂-Crude and N₂-Crude Systems



Idealized Wasson Crude – CO₂ System
at T = 105 °F and p = 2000 psia
(Redrawn from Gardner et al., 1981)



Idealized Crude – N₂ System at p=4000 psi
(Redrawn from Ahmed et al., 1981)

Note: The phase behavior of CO₂-crude and N₂-crude are highly temperature and pressure dependent . In low temperature, low pressure reservoirs, one may observe three hydrocarbon phases (L₁, L₂, V) in addition to a solid phase, such as asphaltenes

Gas Flaring Data 2013-2017 (m³) (NOAA and GGFR)

Country	2013 mcm	2014 mcm	2015 mcm	2016 mcm	2017 mcm
Albania	0	6	19	36	16
Algeria	8,188	8,698	9,130	9,100	8,803
Angola	3,163	3,489	4,185	4,495	3,800
Argentina	687	738	648	559	511
Australia	802	1,138	1,138	729	656
Azerbaijan	437	310	193	201	151
Bahrain	84	44	41	111	132
Bangladesh	9	16	31	13	6
Belarus	3	2	9	4	5
Bolivia	46	50	53	38	26
Brazil	1,341	1,534	1,328	1,444	1,105
Brunei	184	197	211	282	298
Cameroon	831	897	1,083	1,098	1,043
Canada	1,536	2,063	1,814	1,298	1,343
Chad	135	163	239	260	234
Chile	25	34	48	61	31
China	1,908	2,102	2,075	1,956	1,556

Country	2013 mcm	2014 mcm	2015 mcm	2016 mcm	2017 mcm
Colombia	884	865	821	612	550
Rep of the Congo	1,428	1,259	1,176	1,136	1,137
Cote d'Ivoire	82	87	79	106	75
Croatia	9	9	8	13	7
Cuba	54	89	82	45	4
Democratic Republic of the Congo	197	222	211	214	186
Denmark	104	115	106	132	109
Ecuador	793	1,004	1,057	1,154	1,068
Egypt	2,378	2,783	2,826	2,831	2,336
Equatorial Guinea	676	659	578	460	306
France	13	23	24	14	13
Gabon	1,367	1,479	1,560	1,560	1,503
Georgia	2	2	3	2	1
Ghana	85	117	130	155	323
Guatemala	15	22	34	62	71

Gas Flaring Data 2013-2017 (m³) (NOAA and GGFR)

Country	2013 mcm	2014 mcm	2015 mcm	2016 mcm	2017 mcm
Guyana			5		0
Hungary	3	4	4	8	6
India	1,737	1,877	2,201	2,060	1,502
Indonesia	3,138	3,066	2,905	2,766	2,334
Iran	11,095	12,210	12,096	16,405	17,670
Iraq	13,282	14,012	16,213	17,730	17,843
Israel	0	0	0	0	3
Italy	3	2	2	4	1
Kazakhstan	3,764	3,932	3,694	2,665	2,422
Kuwait	1,296	1,407	890	1,143	791
Libya	4,145	2,901	2,612	2,353	3,908
Malaysia	2,831	3,365	3,724	3,164	2,826
Mauritania	56	36	42	54	40
Mexico	4,309	4,858	4,997	4,776	3,789
Mongolia	8	14	19	11	3
Morocco			9		0
Mozambique	3	11	5	2	12
Myanmar	84	71	58	44	36

Country	2013 mcm	2014 mcm	2015 mcm	2016 mcm	2017 mcm
Netherlands	15	5	8	4	8
New Zealand	75	73	128	103	100
Niger	96	91	53	47	39
Nigeria	9,341	8,419	7,658	7,315	7,646
Norway	429	341	336	356	215
Oman	2,355	2,594	2,433	2,816	2,601
Pakistan	607	460	477	454	363
Papua New Guinea	52	292	74	118	50
Peru	137	196	226	136	94
Philippines	129	161	163	169	132
Poland	17	11	19	43	31
Qatar	1,446	1,256	1,110	1,076	1,034
Romania	26	41	34	20	10
Russian Federation	19,922	18,322	19,619	22,372	19,916
Saudi Arabia	1,999	1,944	2,153	2,382	2,315
Serbia	12	10	15	6	6
South Africa	27	28	24	21	16
Spain	25	31	12	3	6

Source: NOAA/GGFR

Gas Flaring Data 2013-2017 (m³) (NOAA and GGFR)

Country	2013 mcm	2014 mcm	2015 mcm	2016 mcm	2017 mcm
Sudan	443	474	544	392	383
Syria	427	389	521	553	1,191
Taiwan	36	28	25	27	24
Thailand	429	395	427	403	372
Timor-Leste	142	100	86	71	75
Trinidad and Tobago	313	270	233	190	197
Tunisia	590	604	496	372	281
Turkey	2	5	17	26	19
Turkmenistan	2,252	1,991	1,843	1,837	1,665
Ukraine	230	243	235	239	156

Country	2013 mcm	2014 mcm	2015 mcm	2016 mcm	2017 mcm
United Arab Emirates	1,240	927	958	837	976
United Kingdom	1,354	1,350	1,321	1,336	1,355
United States	9,191	11,329	11,852	8,862	9,475
Uzbekistan	1,494	1,301	1,115	1,043	849
Venezuela	9,256	9,957	9,332	9,350	6,997
Vietnam	1,082	1,073	1,027	920	977
Yemen	1,162	1,203	666	350	407
Total	139,576	143,896	145,639	147,628	140,570