CO_2 EOR Assessment

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September 26, 2019

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Presentation Objectives

Why the Oil & Gas Industry must begin reducing our carbon intensity - now

Show CO_2 EOR has the potential for immediate impact

Review powerful Incentives in place

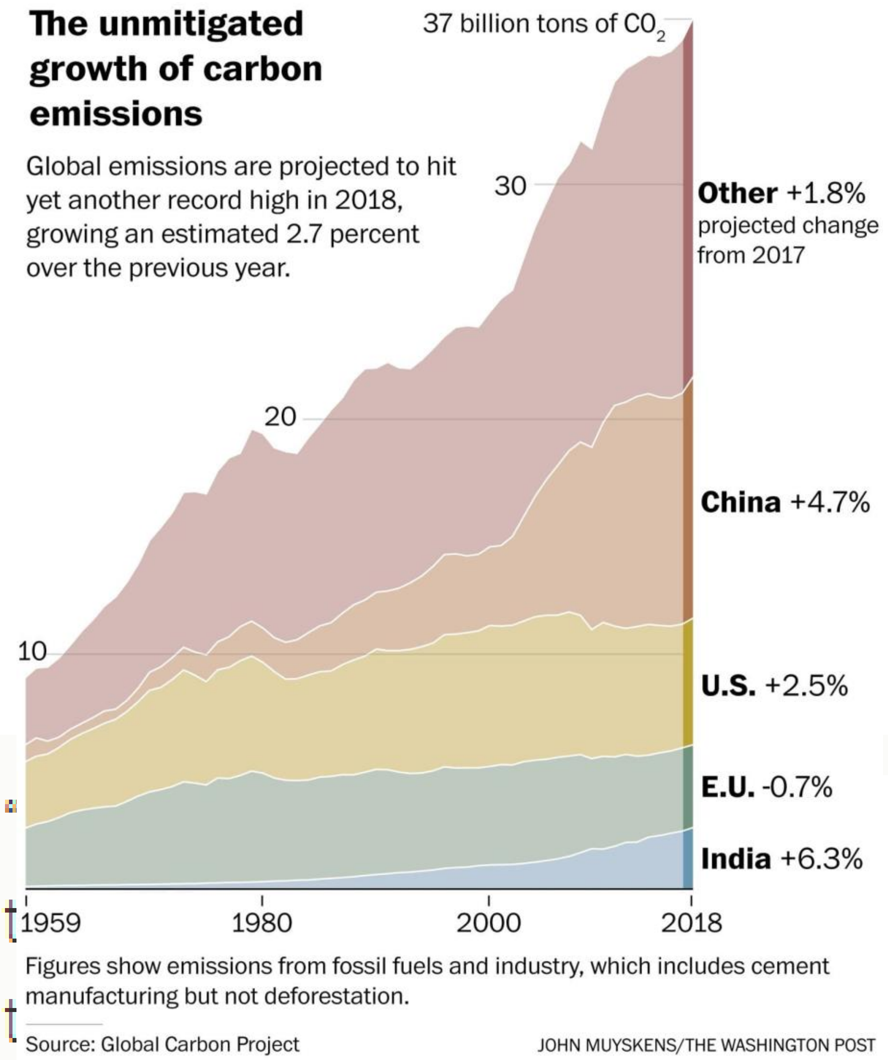
Show the emerging opportunities for expanding CO_2 EOR

Present a workflow for identifying CO_2 EOR opportunities

Rank oil fields with high recovery potential

Match with low capture cost sources

Motivate action



(Image credit for all photos: Dawn Harmer)

Gates said. "The 'climate is easy to solve' group is our biggest problem."

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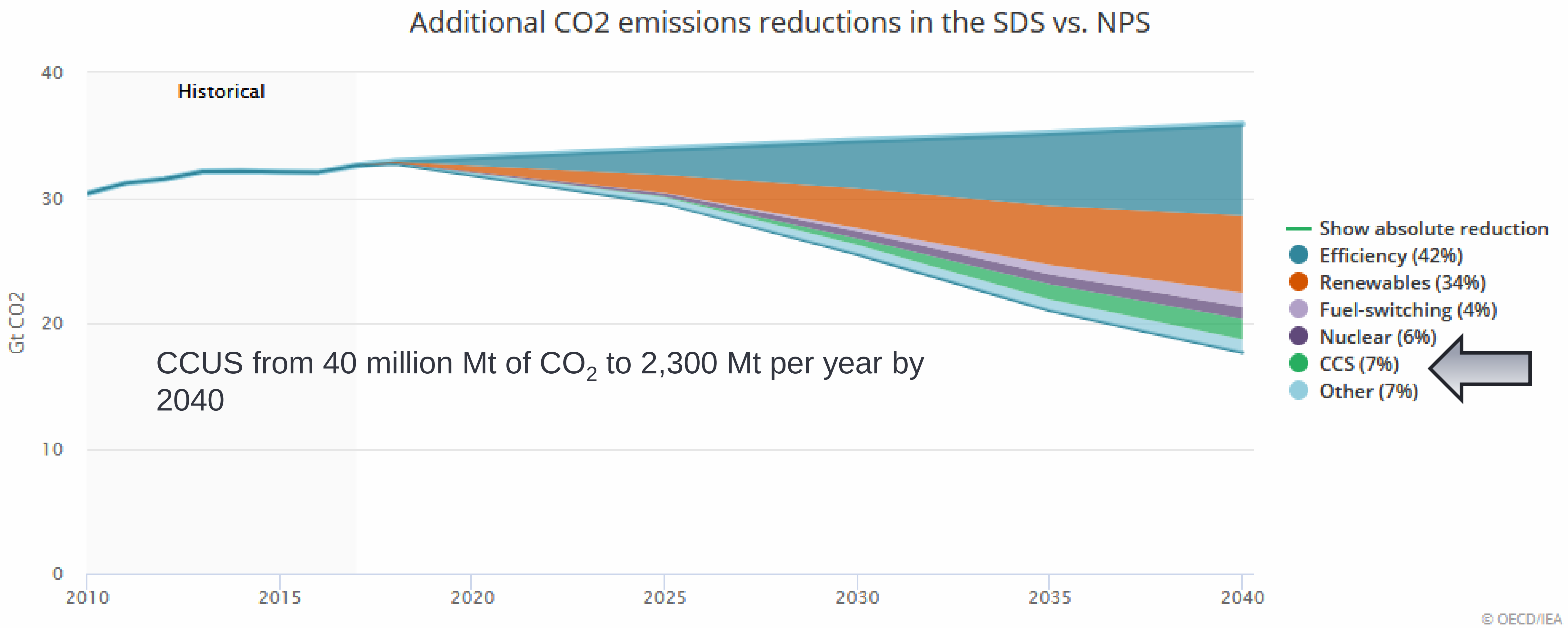

CCUS from 40 million Mt of CO_2 to 2,300 Mt per year by 2040

IEA Sustainable Development Scenario

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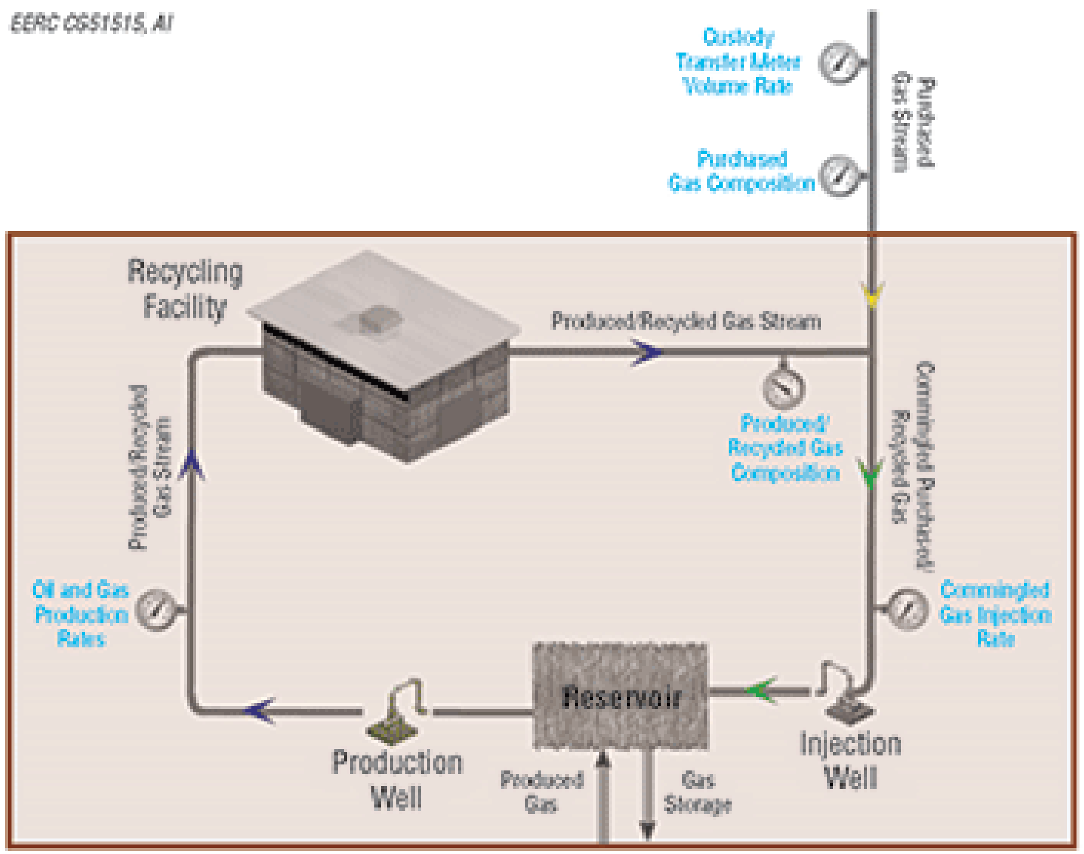
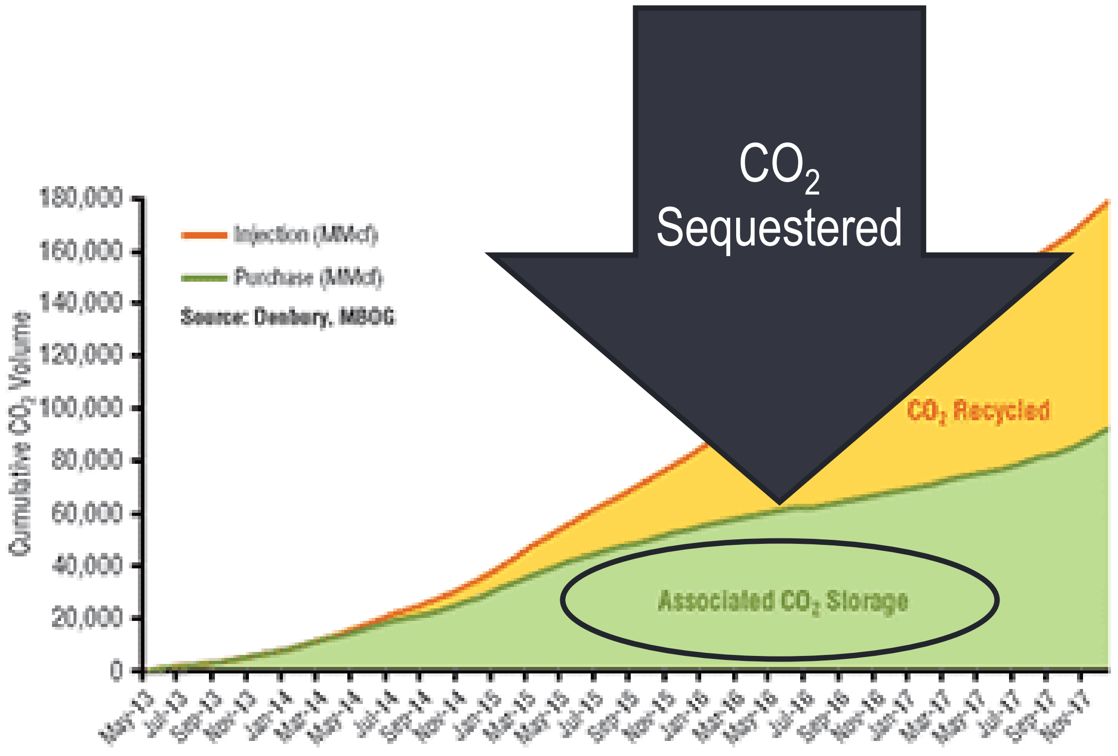
ccUs –
Carbon Sequestration from CO_2 Utilization for EOR





Enhanced Oil Recovery - Carbon Capture Boosting Oil Recovery

By J. Greg Schnacke (Denbury), John Harju, John Hamling, James Sorensen and Neil Wildgust (Energy & Environmental Research Center

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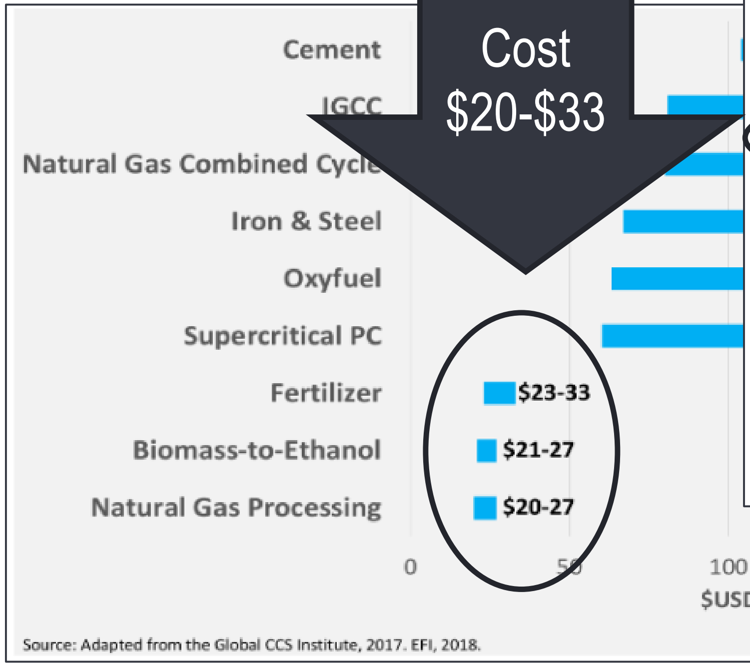
45Q Tax Credit – A Powerful Incentive

Slide 6

Capture Costs



Source: Adapted from the Global CCS Institute, 2017. EFI, 2018.

	Minimum Size of Eligible Carbon Capture Plant by Type ($ktCO_2$/yr)			Relevant Level of Tax Credit in a Given Operational Year ($USD/$tCO_2$)									
Type of CO_2 Storage/Use	Power Plant	Other Industrial Facility	Direct Air Capture	2018	2019	2020	2021	2022	2023	2024	[illegible]	2026	
Dedicated Geological Storage	500	100	100	28	31	34	36	39	42	45	47	[illegible]	Indexed to Inflation
Storage via EOR	500	100	100	17	19	22	24	26	28	31	33	35	
Other Utilization Processes[1]	25	25	25	17[2]	19	22	24	26	28	31	33	35	

Credit
$35

[1] Each CO_2 source cannot be greater than 500 $ktCO_2$/yr
[2] Any credit will only apply to the portion of the converted CO_2 that can be shown to reduce overall emissions

ENERGY FUTURES INITIATIVE

Source: Closely adapted from Simon Bennett and Tristan Stanley, Commentary: US budget bill may help carbon capture get back on track, International Energy Agency.

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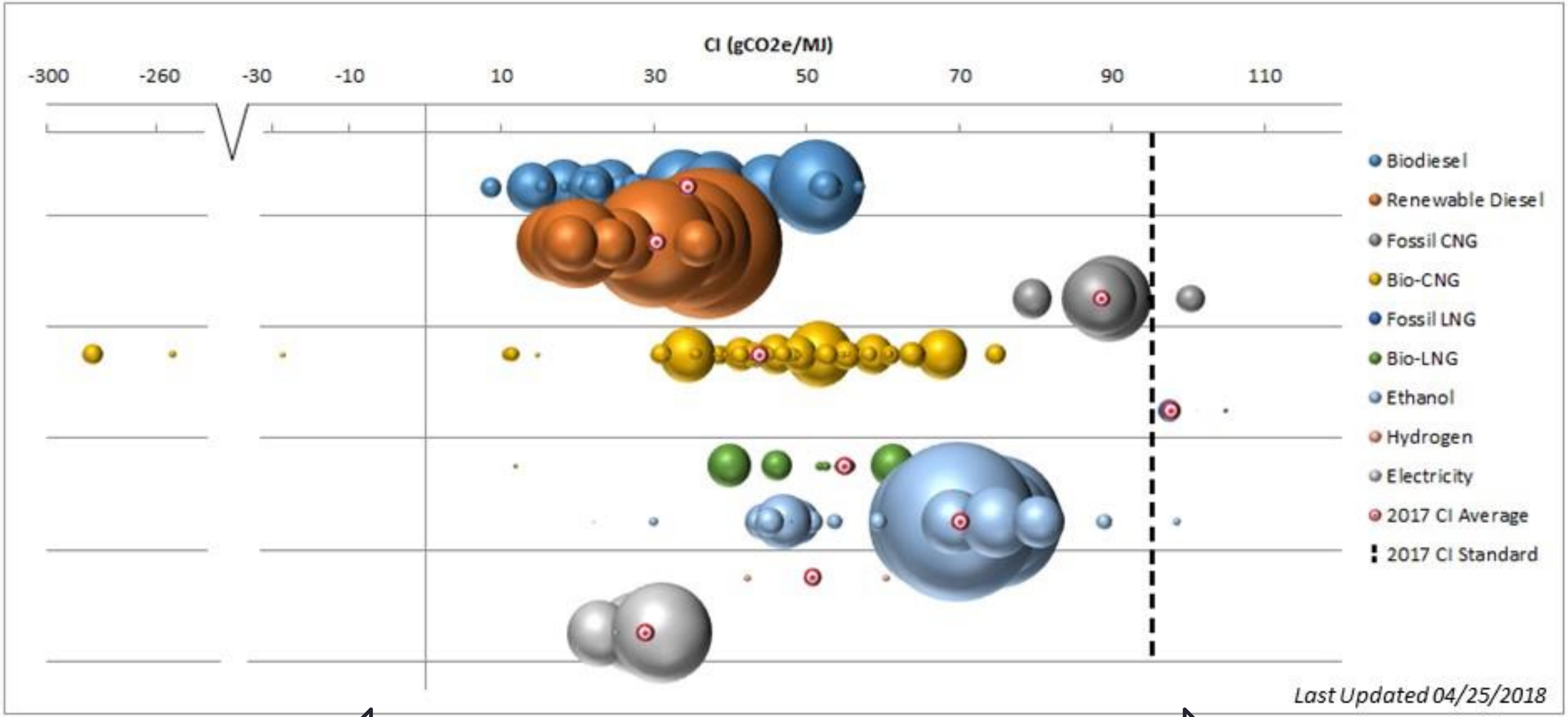
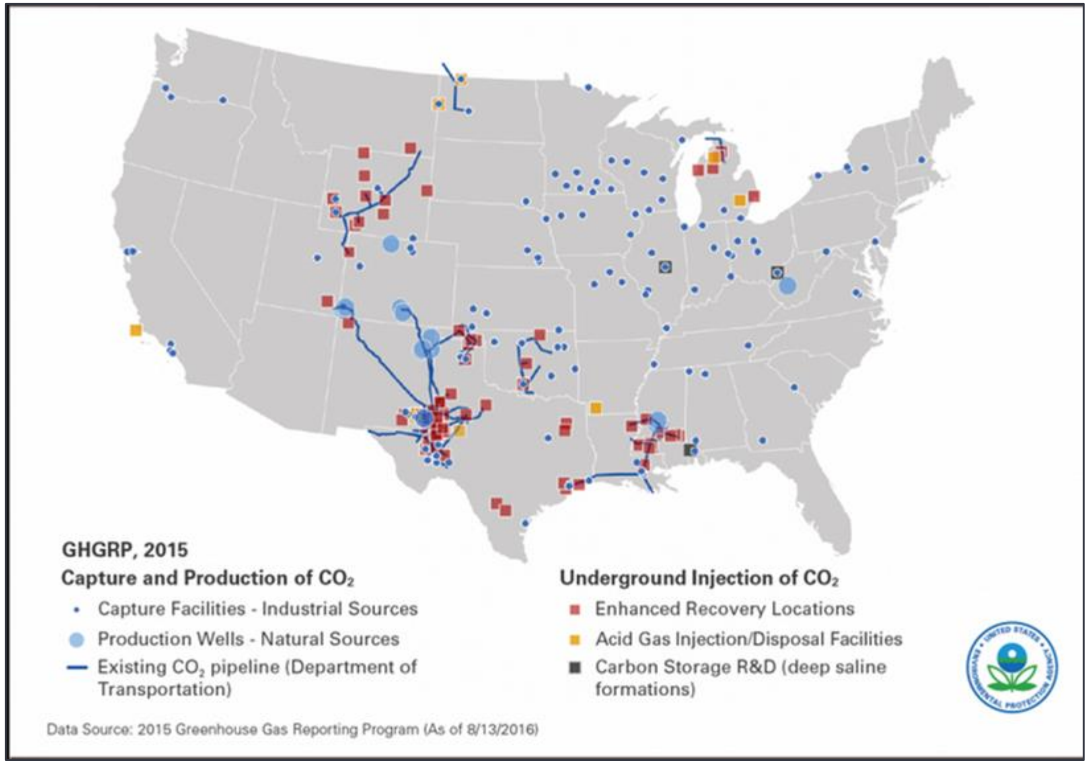
California Low Carbon Fuel Standards

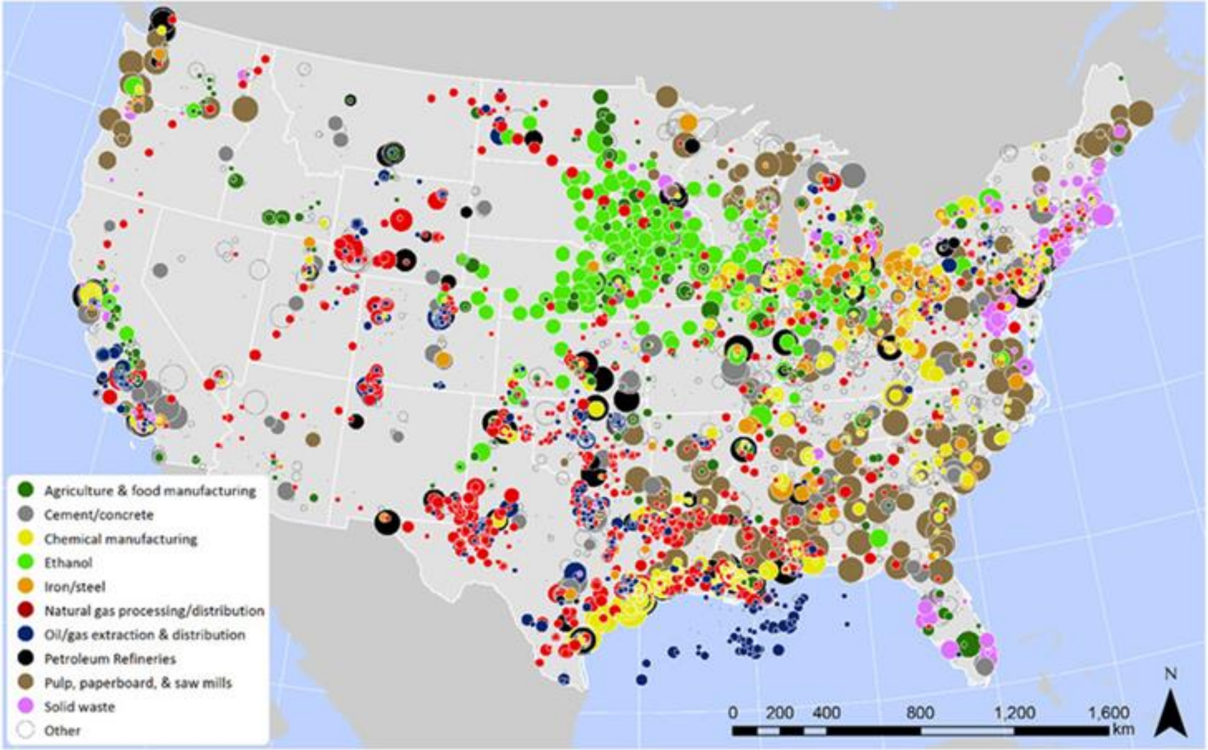


Current CO_2 Infrastructure VS. High Volume Emitters

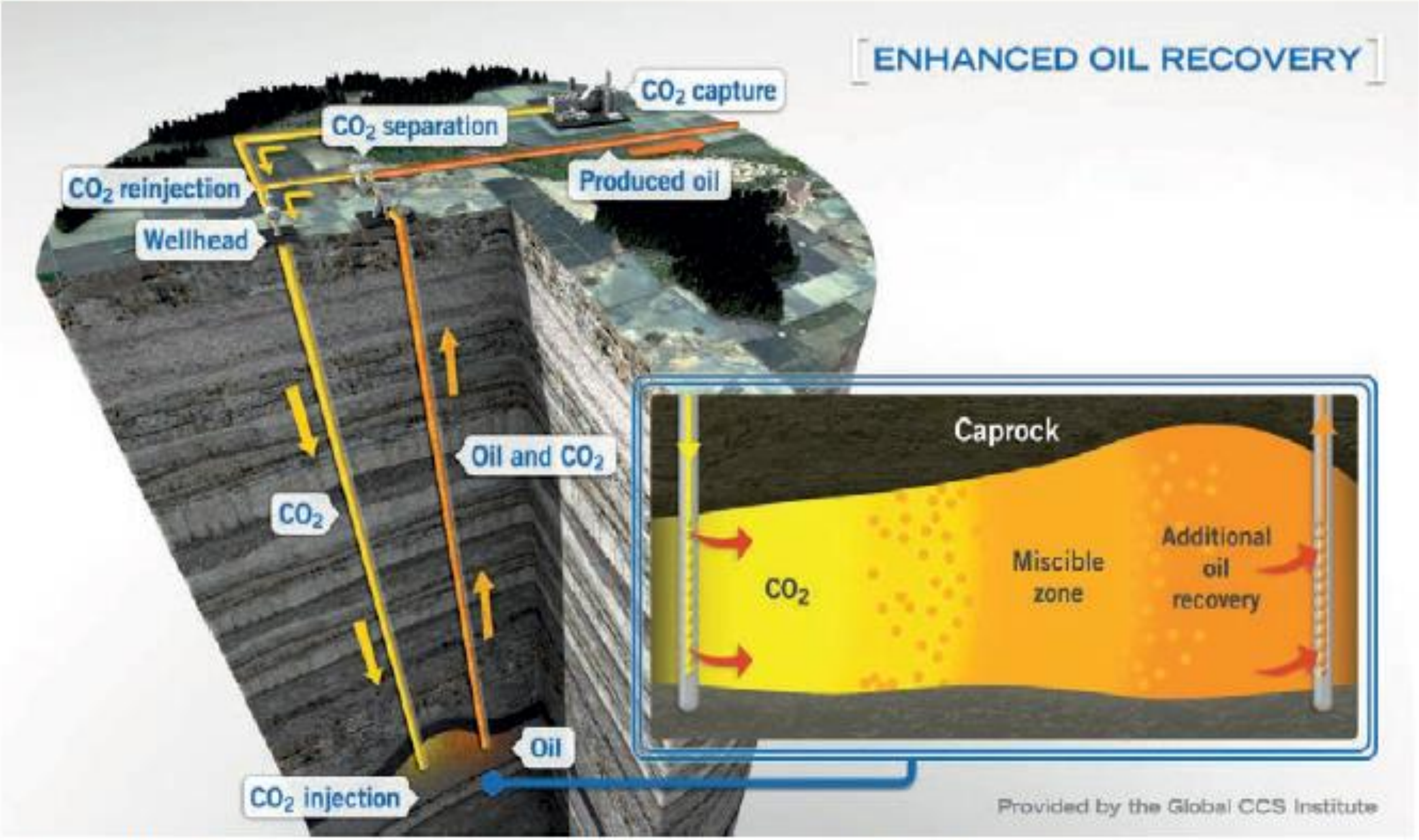
CO_2 EOR Infrastructure



CO_2 Emissions



CO_2 – EOR Minimal Miscible Pressure



Source: Global CCS Institute (2015), website, www.globalccsinstitute.com/content/information-resources.

Minimal Miscible Pressure Vs API Gravity

API	Base MMP (psi)
<27	4000
27-30	3000
>30	1200

Simple correlation for calculating CO_2 MMP

Minimal Miscible Pressure Vs Temperature

Temperature (F)	Additional pressure (psi)
<120	0
[120,150)	200
[150,200)	350
[200,250)	500

MMP for CO_2 = Base MMP+ Additional pressure

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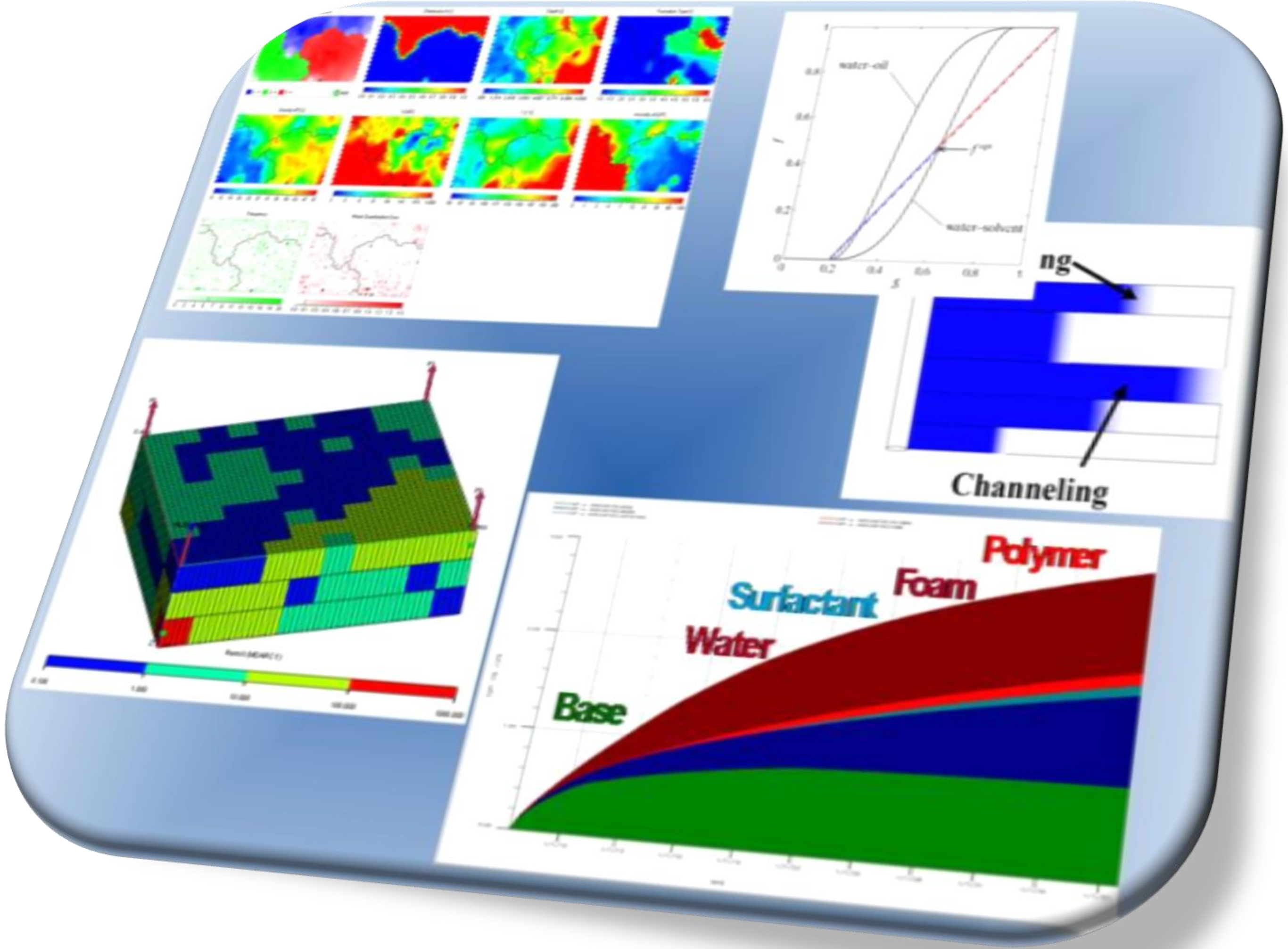
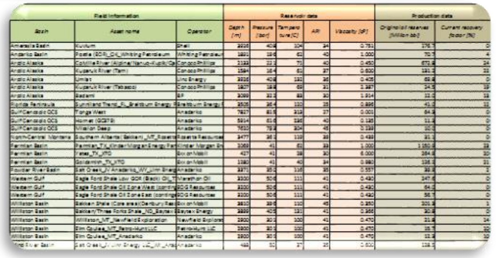
Suitable Reservoirs for CO_2-EOR

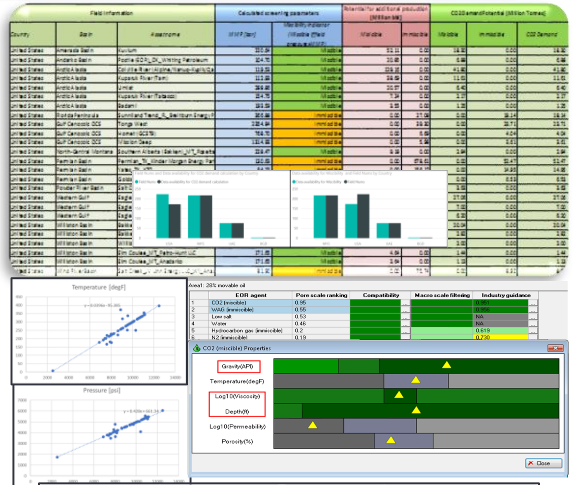
- Sandstone or Carbonates OK
- Low Complexity Better
- Pressure Above MMP
- Successful Water Flood Good



Opportunity Identification Process

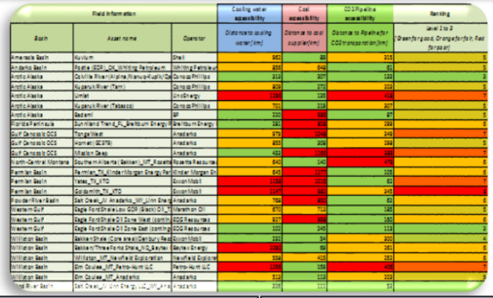
1. Field info. [Input data]
2. Field data review [Data processing]
3. CO_2 Demand analysis and Field Ranking [Result ranking]
4. Plant Location Selection

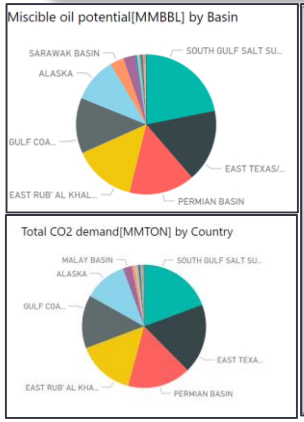




API	Base MMP (psi)	Temperature (F)	Additional pressure (psi)
<27	4000	<120	0
27-30	3000	[120,150)	200
>30	1200	[150,200)	350
		[200,250)	500

MMP for CO_2 = Base MMP+ Additional pressure





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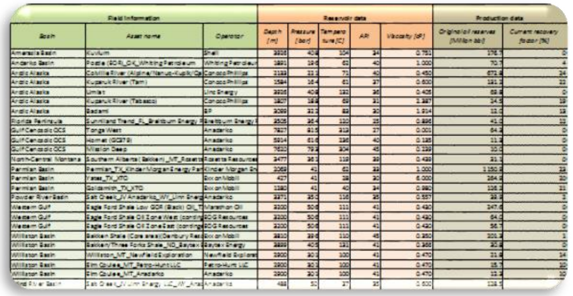
Processing Flow

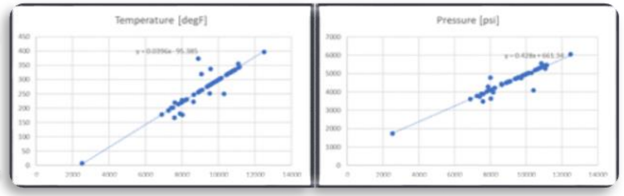
1. Gathering all field data from all available sources.
2. Fitting the press/temp. gradient
3. Apply CO_2 EOR screening process
4. Calculate MMP
5. Identifying the CO_2 miscible potential
6. Plant logistics evaluations
7. Rank the fields

1



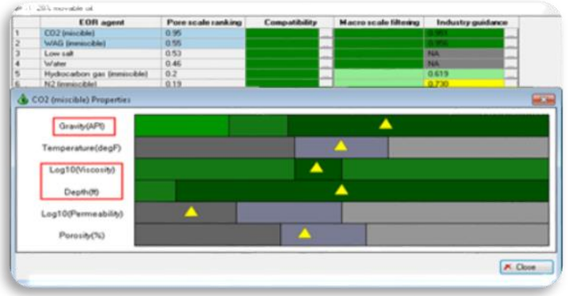
Input Data

2



Temp / Press Gradients

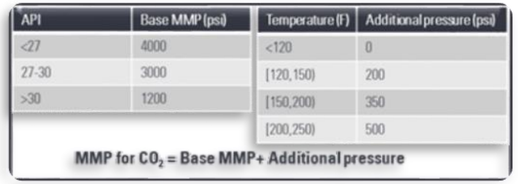
3



Bayesian Network

4

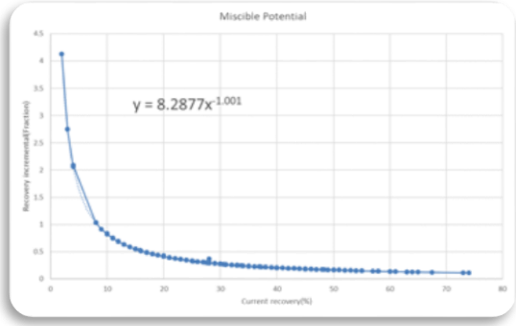
MMP Converstions



API	Base MMP (psi)	Temperature (F)	Additional pressure (psi)
<27	4000	<120	0
27-30	3000	[120,150)	200
>30	1200	[150,200)	350
		[200,250)	500

MMP for CO_2 = Base MMP+ Additional pressure

5

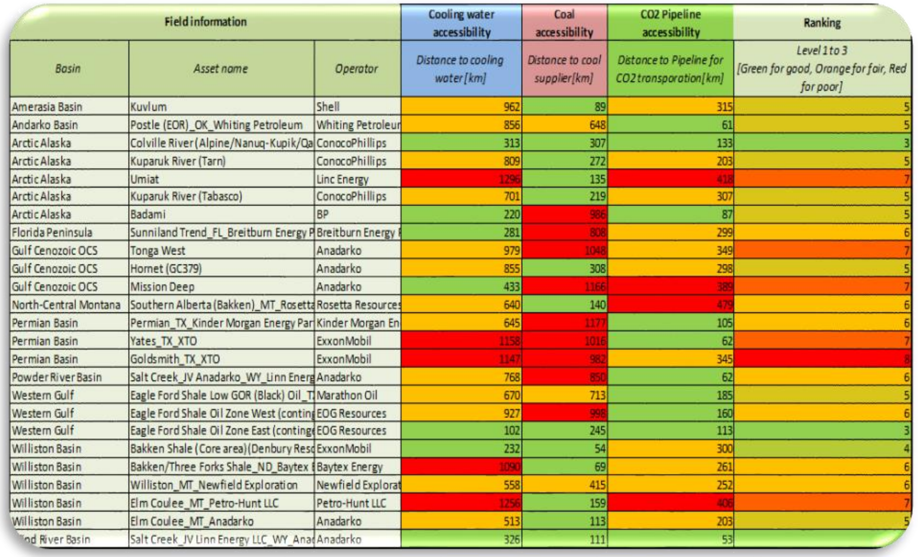


Curve matched from exiting CO_2 projects (IEA2015)

6

Plant and Infrastructure Factors

7



Field information			Cooling water accessibility	Coal accessibility	CO2 Pipeline accessibility	Ranking
Basin	Asset name	Operator	Distance to cooling water [km]	Distance to coal supplier [km]	Distance to Pipeline for CO2 transporation [km]	Level 1 to 3 [Green for good, Orange for fair, Red for poor]
Amerasia Basin	Kuvlum	Shell	962	89	315	5
Andarko Basin	Postle (EOR)_OK_Whiting Petroleum	Whiting Petroleur	856	648	61	5
Arctic Alaska	Colville River (Alpine/Nanuq-Kupik/Qa	ConocoPhillips	313	307	133	3
Arctic Alaska	Kuparuk River (Tarn)	ConocoPhillips	809	272	203	5
Arctic Alaska	Umiat	Linc Energy	1296	135	418	7
Arctic Alaska	Kuparuk River (Tabasco)	ConocoPhillips	701	219	307	5
Arctic Alaska	Badami	BP	220	986	87	5
Florida Peninsula	Sunniland Trend_FL_Breitburn Energy P	Breitburn Energy	281	808	299	6
Gulf Cenozoic OCS	Tonga West	Anadarko	979	1048	349	7
Gulf Cenozoic OCS	Hornet (GC379)	Anadarko	855	308	298	5
Gulf Cenozoic OCS	Mission Deep	Anadarko	433	1166	389	7
North-Central Montana	Southern Alberta (Bakken)_MT_Rosetta	Rosetta Resources	640	140	479	6
Permian Basin	Permian_TX_Kinder Morgan Energy Par	Kinder Morgan En	645	1177	105	6
Permian Basin	Yates_TX_XTO	ExxonMobil	1158	1016	62	7
Permian Basin	Goldsmith_TX_XTO	ExxonMobil	1147	982	345	8
Powder River Basin	Salt Creek_JV Anadarko_WY_Linn Energ	Anadarko	768	850	62	6
Western Gulf	Eagle Ford Shale Low GOR (Black) Oil_T	Marathon Oil	670	713	185	5
Western Gulf	Eagle Ford Shale Oil Zone West (contin	EOG Resources	927	998	160	6
Western Gulf	Eagle Ford Shale Oil Zone East (conting	EOG Resources	102	245	113	3
Williston Basin	Bakken Shale (Core area) (Denbury Reso	ExxonMobil	232	54	300	4
Williston Basin	Bakken/Three Forks Shale_ND_Baytex	Baytex Energy	1090	69	261	6
Williston Basin	Williston_MT_Newfield Exploration	Newfield Explorat	558	415	252	6
Williston Basin	Elm Coulee_MT_Petro-Hunt LLC	Petro-Hunt LLC	1256	159	406	7
Williston Basin	Elm Coulee_MT_Anadarko	Anadarko	513	113	203	5
ind River Basin	Salt Creek_JV Linn Energy LLC_WY_Ana	Anadarko	326	111	53	

Field Ranking

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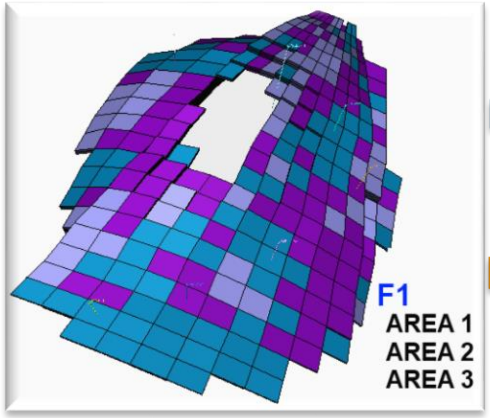
Input Field Data

Required field information

- Oil API
- Pressure
- Temperature
- Depth
- Original Oil in Place
- Current recovery

Field information			Calculated screening parameters		Potential for additional production [Million bbl]		CO2 DemandPotential [Million Tonnes]		
Country	*Basin*	*Asset name*	*MMP [bar]*	*Miscibility indicator (Miscible if field pressure>MMP)*	*Misicible*	*Immiscible*	*Misicible*	*Immiscible*	*CO2 Demand*
United States	Amerasia Basin	Kuvlum	220.64	Miscible	52.11	0.00	18.30	0.00	18.30
United States	Andarko Basin	Postle (EOR)_OK_Whiting Petroleum	104.70	Miscible	20.85	0.00	6.88	0.00	6.88
United States	Arctic Alaska	Colville River (Alpine/Nanuq-Kupik/Qa	119.53	Miscible	129.16	0.00	41.80	0.00	41.80
United States	Arctic Alaska	Kuparuk River (Tarn)	112.93	Miscible	38.69	0.00	11.61	0.00	11.61
United States	Arctic Alaska	Umiat	288.86	Miscible	20.57	0.00	6.40	0.00	6.40
United States	Arctic Alaska	Kuparuk River (Tabasco)	154.75	Miscible	7.24	0.00	2.17	0.00	2.17
United States	Arctic Alaska	Badami	193.59	Miscible	3.55	0.00	1.25	0.00	1.25
United States	Florida Peninsula	Sunniland Trend_FL_Breitburn Energy P	366.88	Immiscible	0.00	27.08	0.00	18.14	18.14
United States	Gulf Cenozoic OCS	Tonga West	2354.84	Immiscible	0.00	39.30	0.00	23.71	23.71
United States	Gulf Cenozoic OCS	Hornet (GC379)	768.70	Immiscible	0.00	6.69	0.00	4.04	4.04
United States	Gulf Cenozoic OCS	Mission Deep	1314.93	Immiscible	0.00	5.98	0.00	3.61	3.61
United States	North-Central Montana	Southern Alberta (Bakken)_MT_Rosetta	228.47	Miscible	9.18	0.00	2.84	0.00	2.84
United States	Permian Basin	Permian_TX_Kinder Morgan Energy Par	130.63	Immiscible	0.00	678.61	0.00	52.47	52.47
United States	Permian Basin	Yates_TX_XTO	84.23	Immiscible	0.00	156.17	0.00	14.95	14.95
United States	Permian Basin	Goldsmith_TX_XTO	89.36	Immiscible	0.00	74.39	0.00	6.53	6.53
United States	Powder River Basin	Salt Creek_JV Anadarko_WY_Linn Energ	247.17	Miscible	11.75	0.00	3.63	0.00	3.63
United States	Western Gulf	Eagle Ford Shale Low GOR (Black) Oil_T	196.77	Miscible	72.98	0.00	27.06	0.00	27.06
United States	Western Gulf	Eagle Ford Shale Oil Zone West (conting	196.77	Miscible	18.88	0.00	7.00	0.00	7.00
United States	Western Gulf	Eagle Ford Shale Oil Zone East (continge	196.77	Miscible	16.71	0.00	6.20	0.00	6.20
United States	Williston Basin	Bakken Shale (Core area)(Denbury Reso	175.77	Miscible	59.33	0.00	20.04	0.00	20.04
United States	Williston Basin	Bakken/Three Forks Shale_ND_Baytex E	249.30	Miscible	9.07	0.00	2.82	0.00	2.82
United States	Williston Basin	Williston_MT_Newfield Exploration	171.65	Miscible	6.44	0.00	2.00	0.00	2.00
United States	Williston Basin	Elm Coulee_MT_Petro-Hunt LLC	171.65	Miscible	4.64	0.00	1.44	0.00	1.44
United States	Williston Basin	Elm Coulee_MT_Anadarko	171.65	Miscible	3.64	0.00	1.13	0.00	1.13
ited States	Wind River Basin	Salt Creek_JV Linn Energy LLC_WY_Anad	81.90	Immiscible	0.00	75.74	0.00	8.92	[illegible]

CO_2 EOR Screening Process



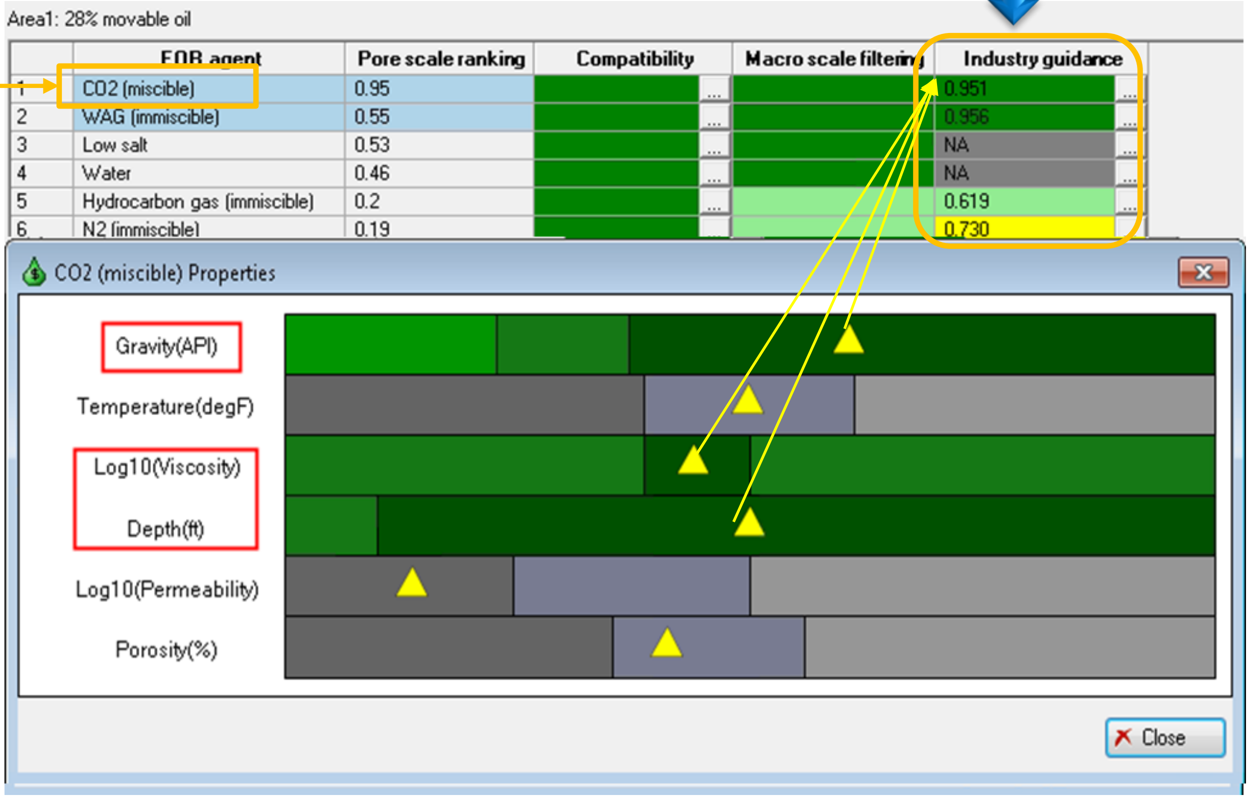
OIL API GRAVITY
OIL VISCOSITY
RESERVOIR DEPTH

Data mining by Bayesian networks

OIL API GRAVITY
RESERVOIR TEMPERATURE

MMP

Miscibility check



Screening Ranges for CO_2 EOR

Reservoir type	Miscibility	Gravity (Deg API)	Viscosity(cp)	Depth(ft)
Clastic	Miscible	26~70	0.2-2.82	1000~13000
	Immiscible	13~38	1~100	3000~7000
Carbonate	Miscible	26~70	0.2-2.82	1000~13000
	Immiscible	>13	2.9~794	>2000

Bayesian network for clastic reservoir was trained by 89 CO_2 Miscible EOR projects
Bayesian network for carbonate reservoir was trained by 129 CO_2 Miscible EOR projects

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CO_2 Demand analysis and Field Ranking

Field information			Cooling water accessibility	Coal accessibility	CO2 Pipeline accessibility	Ranking
Basin	*Asset name*	*Operator*	*Distance to cooling water [km]*	*Distance to coal supplier [km]*	*Distance to Pipeline for CO2 transporation [km]*	*Level 1 to 3 [Green for good, Orange for fair, Red for poor]*
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Development Strategy – Recovery VS Storage

Scenario	Description	Incremental recovery % OOIP	Utilisation tCO_2/bbl
Conventional EOR+	Miscible WAG flood with vertical injector and producer wells in a "five spot" or similar pattern. Operational practices seek to minimise CO_2 use.	6.5	0.3
Advanced EOR+	Miscible flooding following current best practices optimised for oil recovery. May also involve some "second-generation" approaches that boost utilisation and recovery.	13	0.6
Maximum Storage EOR+	Miscible flooding where injection is designed and operated with the explicit goal of increasing storage. Could include approaches in which water is removed from reservoir to increase available pore volume.	13	0.9

Summary

CO_2 EOR has the potential for immediate impact

Powerful Incentives in place now

Not locked in to existing pipeline infrastructure

Rank oil fields with high recovery potential

Match with low capture cost sources

We can do this now!

Thank You

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