What it All Means: CO_2-EOR Greenhouse Gas Life-Cycle Analysis of 22 Years of Class II UIC Field Operations and Monitoring

MRCSP
MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP

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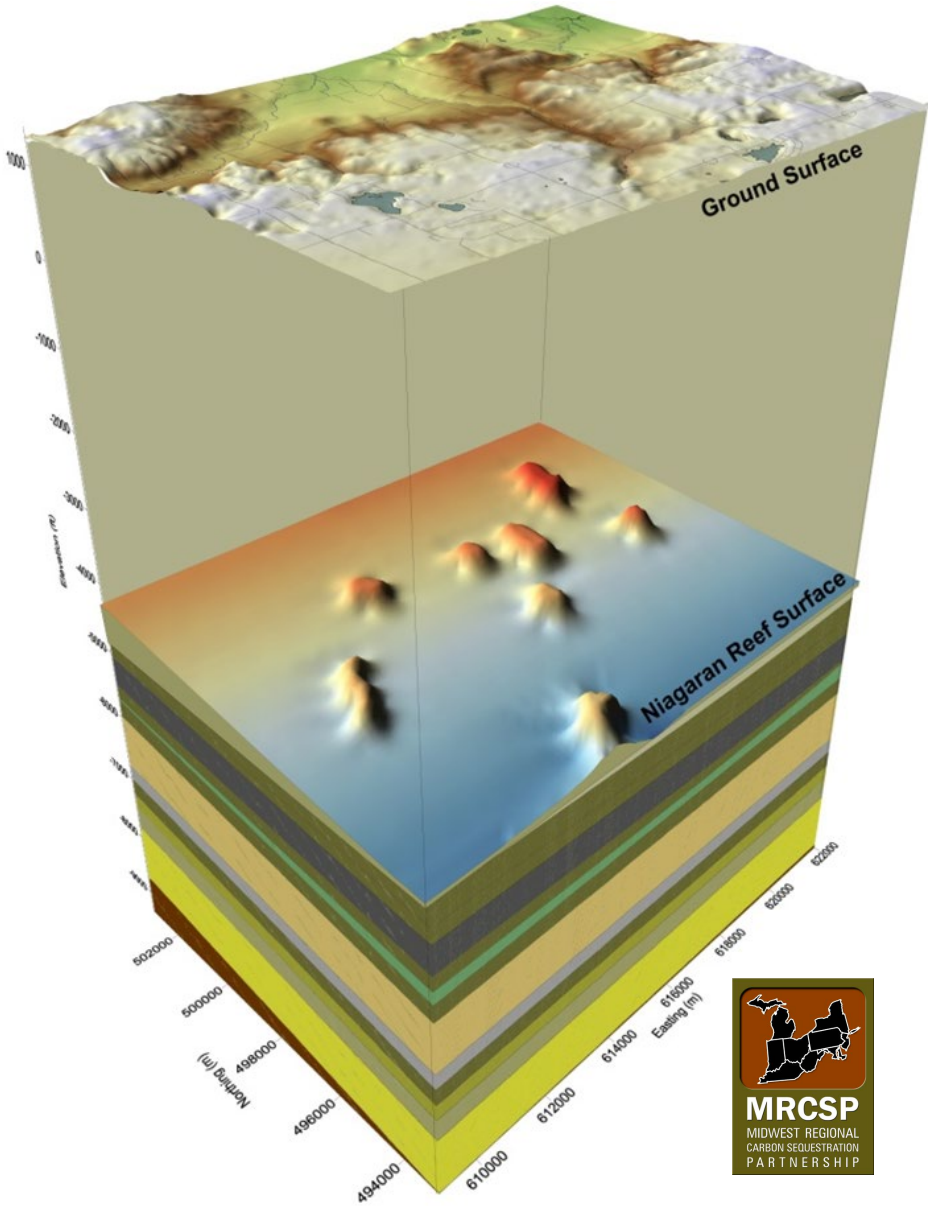
Outline

1. Background
2. Objectives
3. MRCSP Project
4. Integration with UIC
5. Greenhouse Gas Emissions Life Cycle Analysis
6. Results/Conclusions



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- USEPA Region 5 UIC Program.
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- DOE-NETL LCA program.

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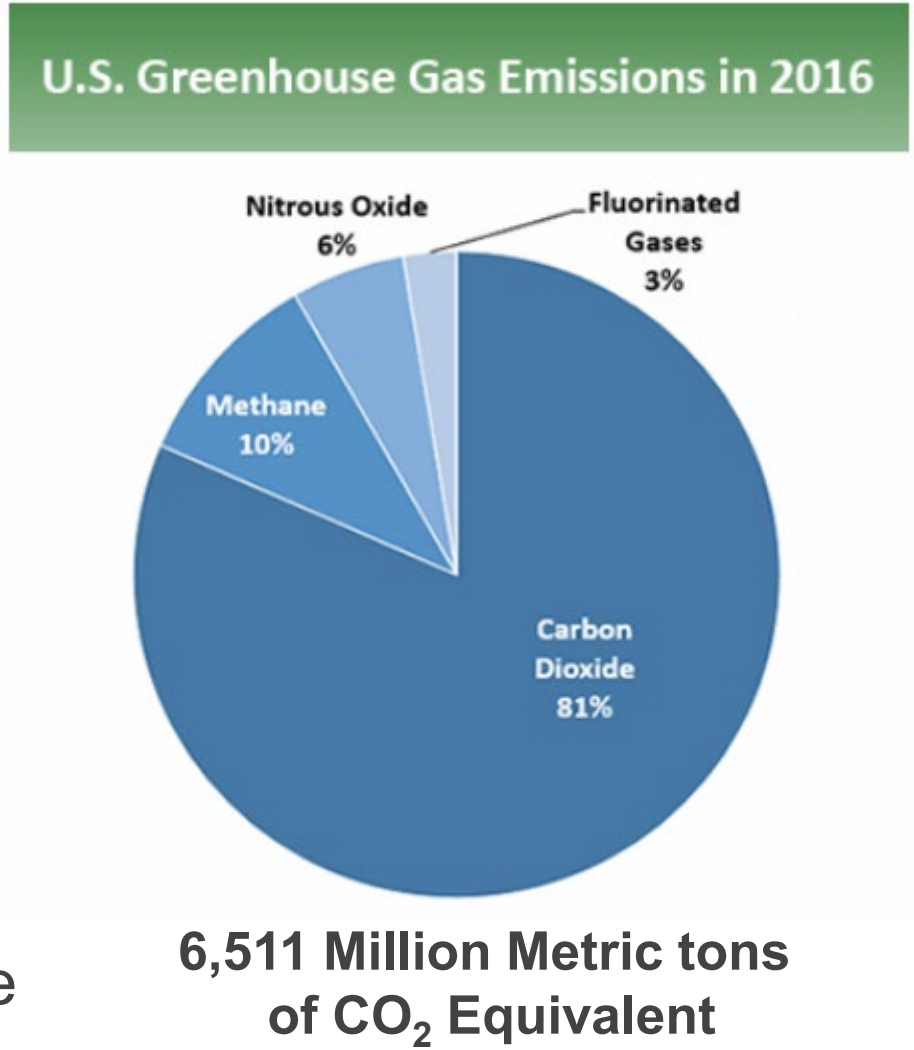
1. Background

- Life cycle analysis for greenhouse gas emissions accounts for all emissions generated for a process.
- Emissions expressed as CO_2 equivalent (**kg CO_2e**).
- Combustion of fuel products from 1 barrel (42 gallon) of oil has ~430 kg CO_2e/bbl emission factor.
- LCA helps understand the net benefit of carbon capture and storage projects.



USEPA- Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016.
https://www.epa.gov/ghgemissions/overview-greenhouse-gases

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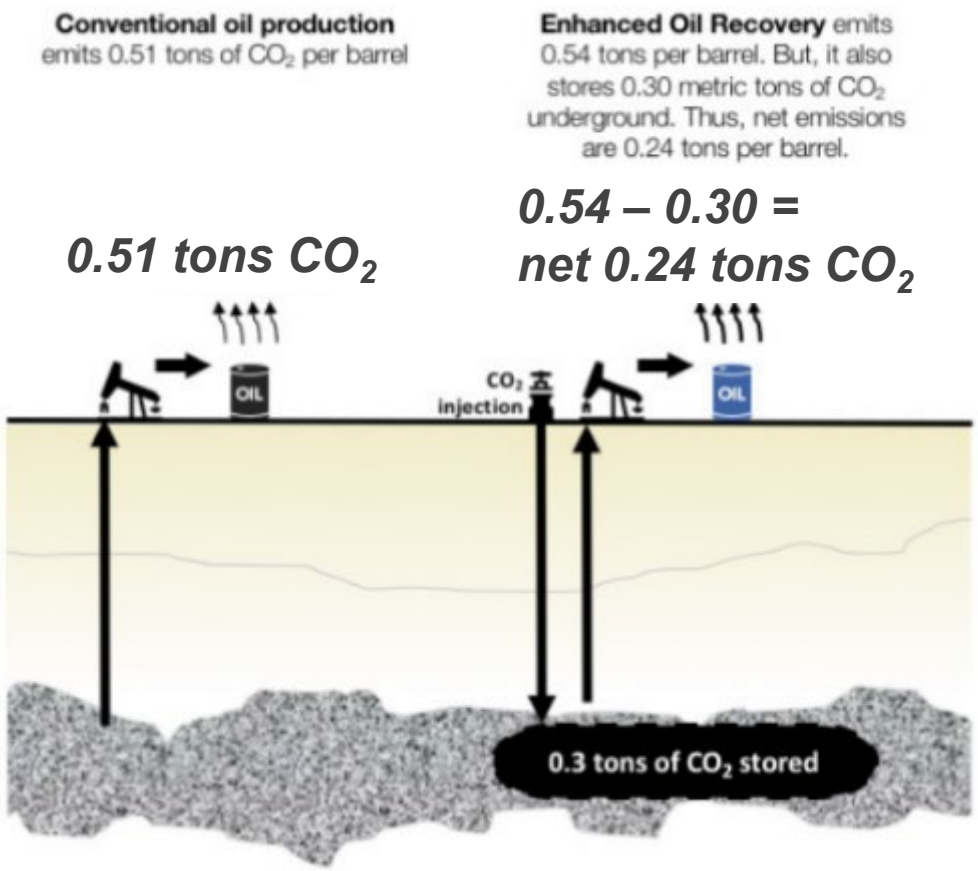
2. Carbon Storage LCA Objectives

- How much greenhouse gas emissions were emitted through Carbon Capture Utilization and Storage operations?
  - capture, compression, pipeline transport, drilling, injection fugitive emissions, embodied emissions, etc.
- How CO_2 much was left in the ground?
- What is the net carbon balance?

Example: CO_2 EOR GHG Emissions



Nagabhushan and Waltzer, 2016, The emission reduction benefits of carbon capture utilization and Storage using CO2 EOR, clean air task force fact sheet.

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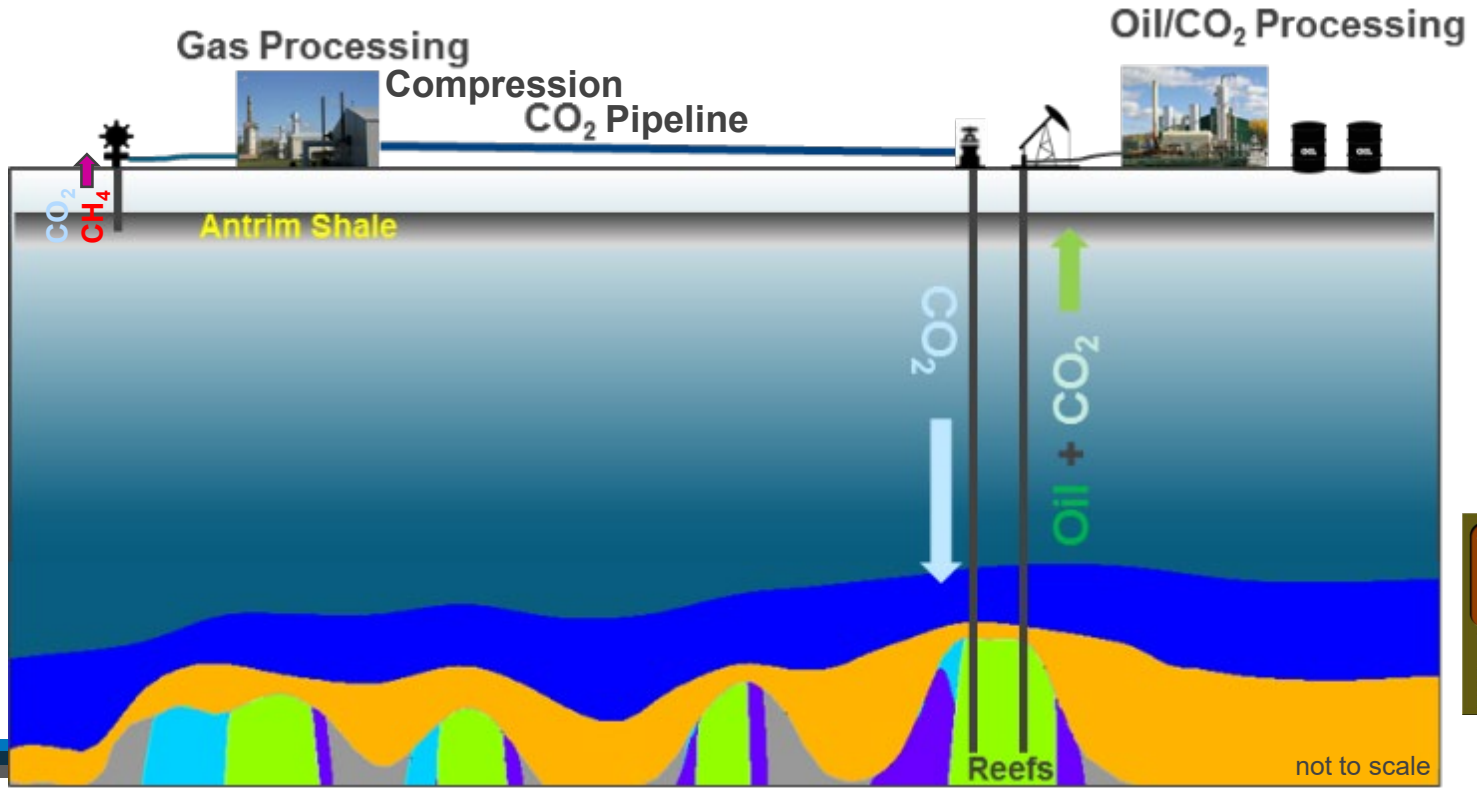
2. MRCSP Carbon Storage LCA Objectives

- Bottom-up analysis to determine the net greenhouse gas emission footprint of CO_2 EOR for this specific operation.
- Base on site specific data on CO_2 metering, fuel, electricity, construction/wells, fugitive emissions.



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3. Midwest Regional Carbon Sequestration Partnership Phase III Demonstration

Primary goal: To execute a large-scale scale CO_2 injection test to evaluate best practices and technologies required to implement carbon sequestration.

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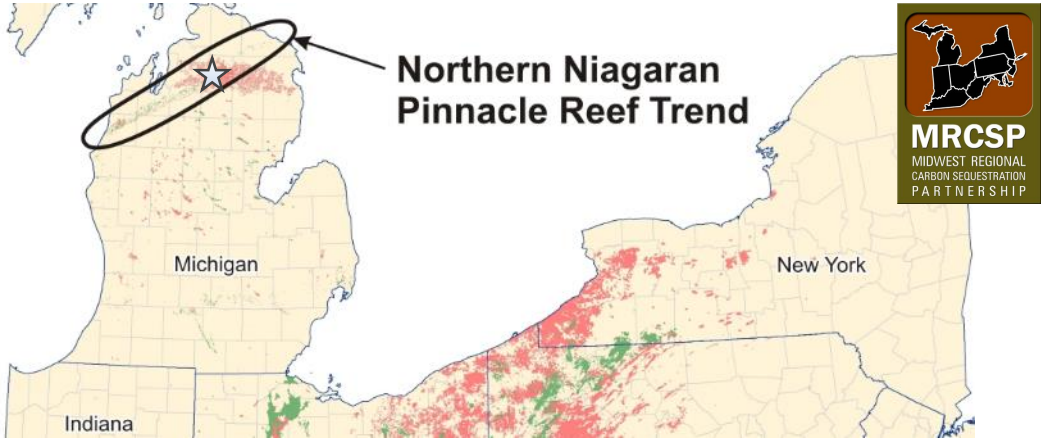
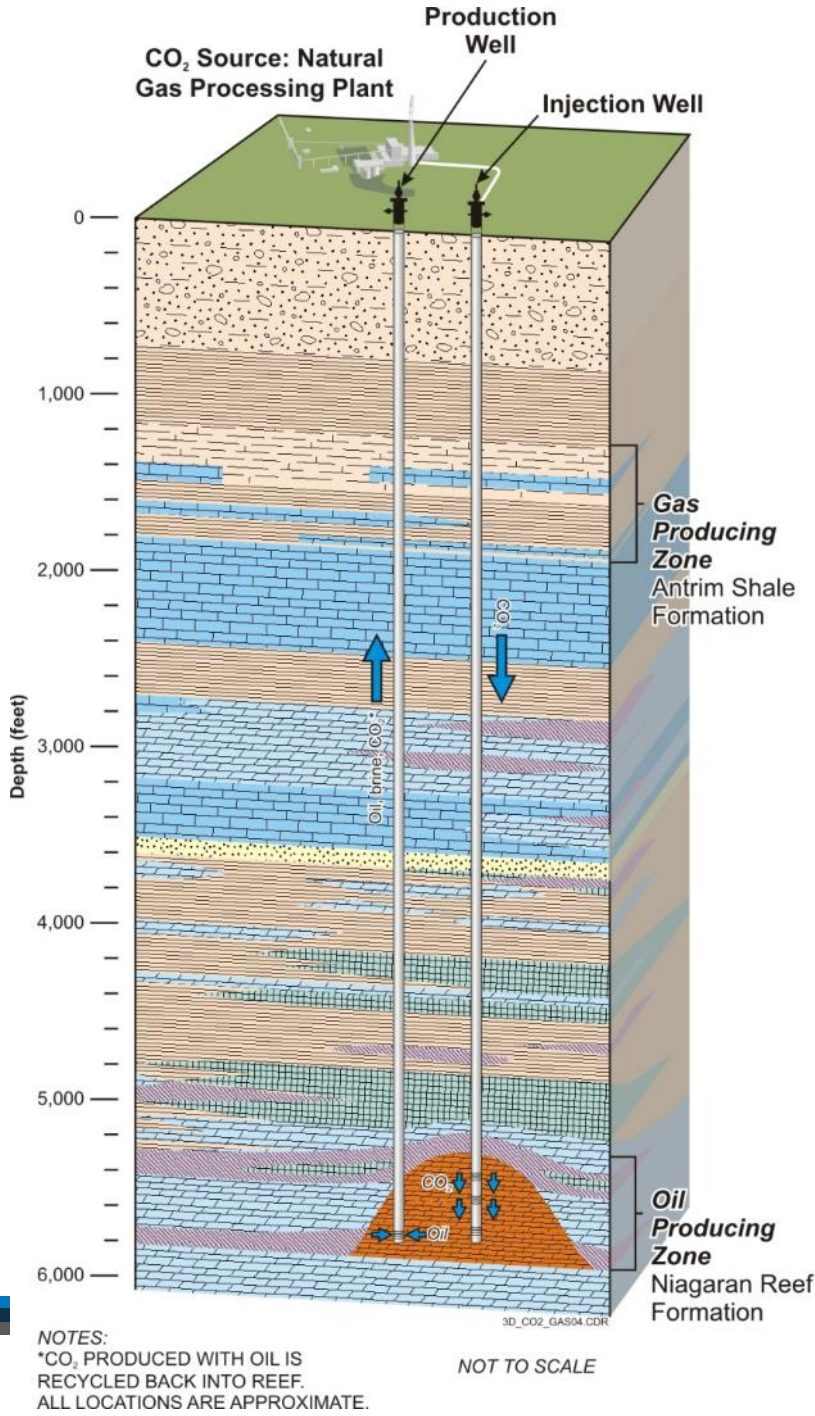
3. MRCSP Phase III Large Scale CCUS Demonstration



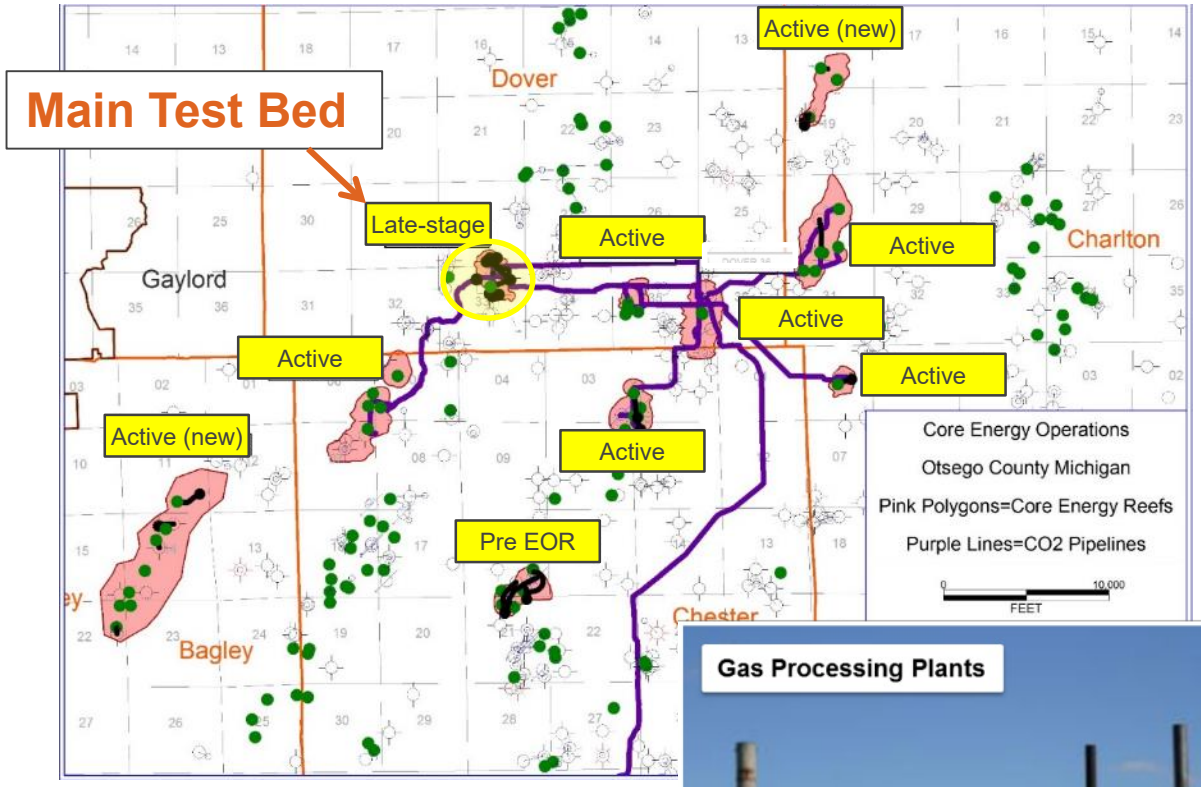
- **Location:** Otsego County, Michigan
- **Source of CO_2:** Local Natural Gas Processing Plant (Antrim Shale Gas ~15% CO_2 content)
- **Reservoir Type:** Closely-spaced, highly compartmentalized oil & gas fields located in the Northern Michigan's Niagaran Reef Trend
- **Injection Goal:** 1,000,000 metric tons

  (U.S. emissions per person =

  15-20 metric tons per year)



3. The MRCSP site included 10 reefs in different stages of the oil production life cycle



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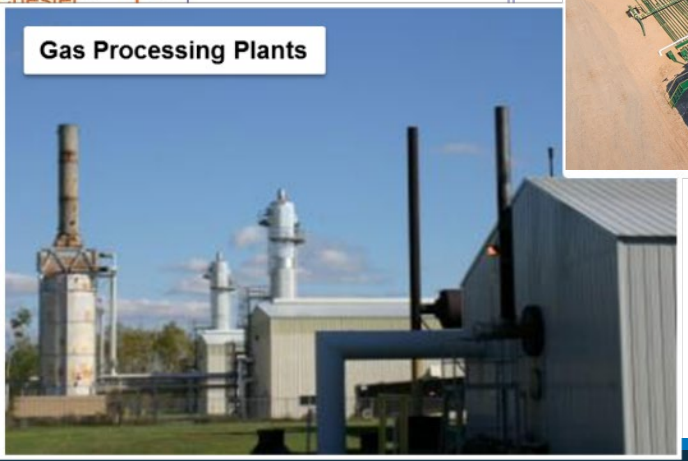
Central Processing Facility




Compressor

Natural gas processing is the source of **the CO_2**

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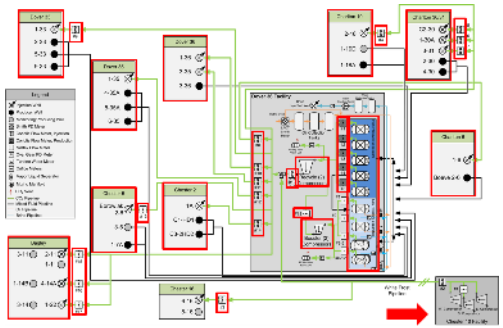
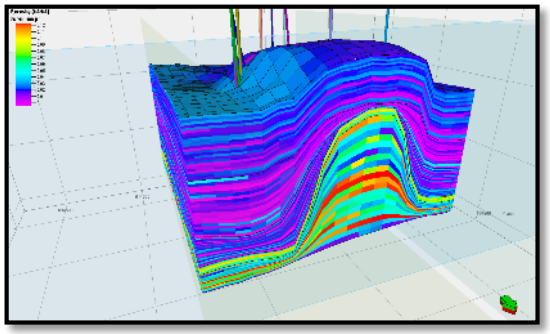
4. Integration with UIC

- CO_2 injection wells were permitted through USEPA Class II regulations Region 5/Michigan EGLE (more than 10 Class II wells over 22 years).
- EPA Monitoring Reporting & Verification plan prepared for CO_2 accounting and metering for 45Q credits (monitoring, leakage, mass balance calculations).
- EPA Greenhouse Gas Report, subpart W, calculations for petroleum and natural gas systems fixed systems.
- EPA Greenhouse Gas Report, subpart C, General Stationary Fuel Combustion.





5. LCA: Establishing Boundary Conditions

- CO_2 EOR is part of a bigger hydrocarbon life cycle, including upstream, gate to gate, and downstream components (i.e. “Cradle to Grave.”)
- This analysis focused on **Gate to Gate** portion of LCA.
- Time Period = 1996-2017.

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Upstream		Gate to Gate		Downstream			
Natural Gas Production	CO_2 Separation	CO_2 Compression and Pipeline Transport	CO_2 EOR	Pipeline Crude Transport	Petroleum Refining	Gasoline Product Transp.	Gasoline Combustion

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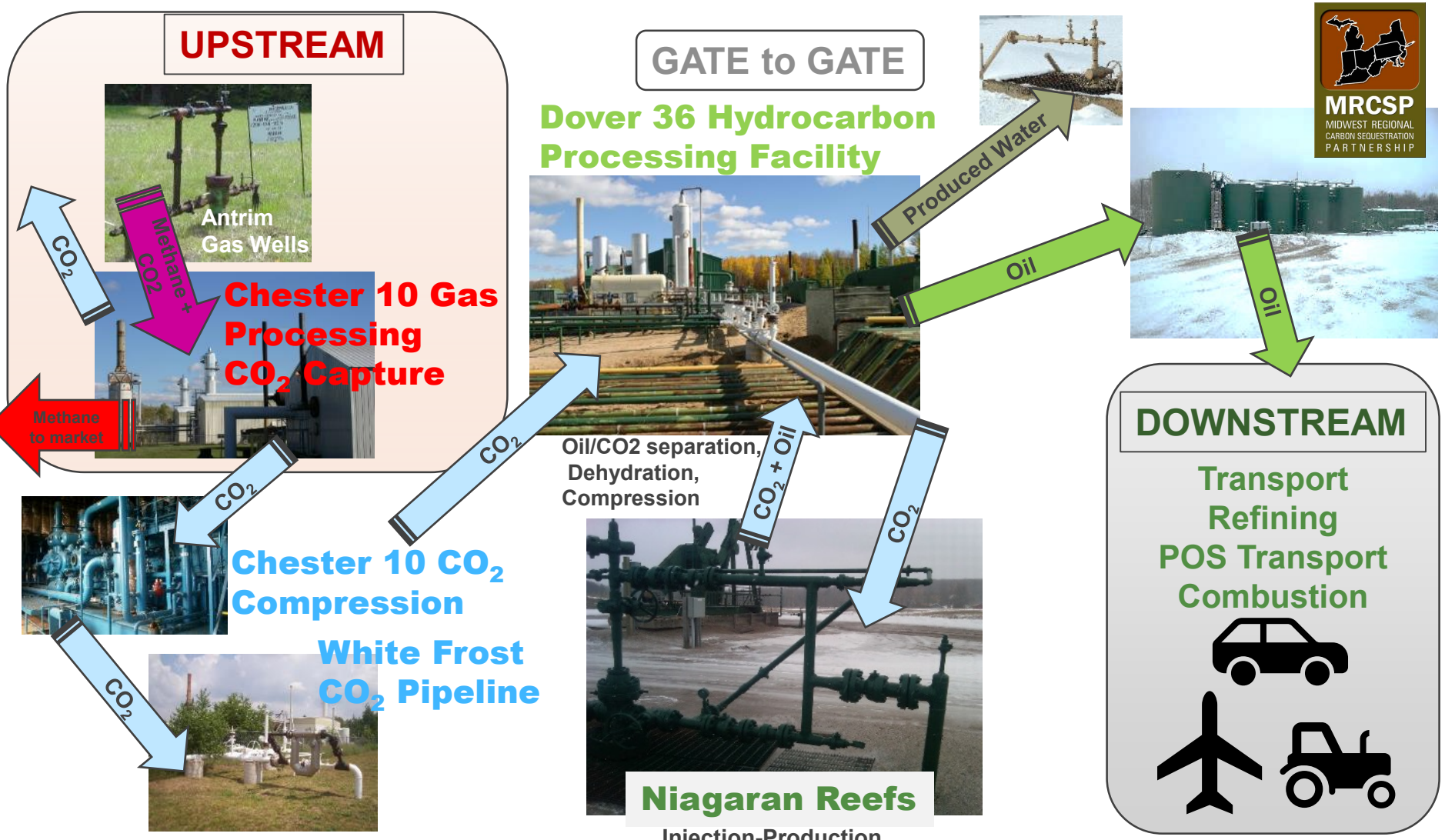
5. LCA: Establishing Boundary Conditions



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5. Life Cycle Assessment of CO_2-EOR

- Niagaran Reefs CO_2 EOR operations in place since 1996.
- CO_2 EOR expanded to 10 reefs over ~22 years.
- 2.2 million metric tons net CO_2 in reefs thru 2018.
- 2.3 million barrels oil produced (294,326 metric tons).

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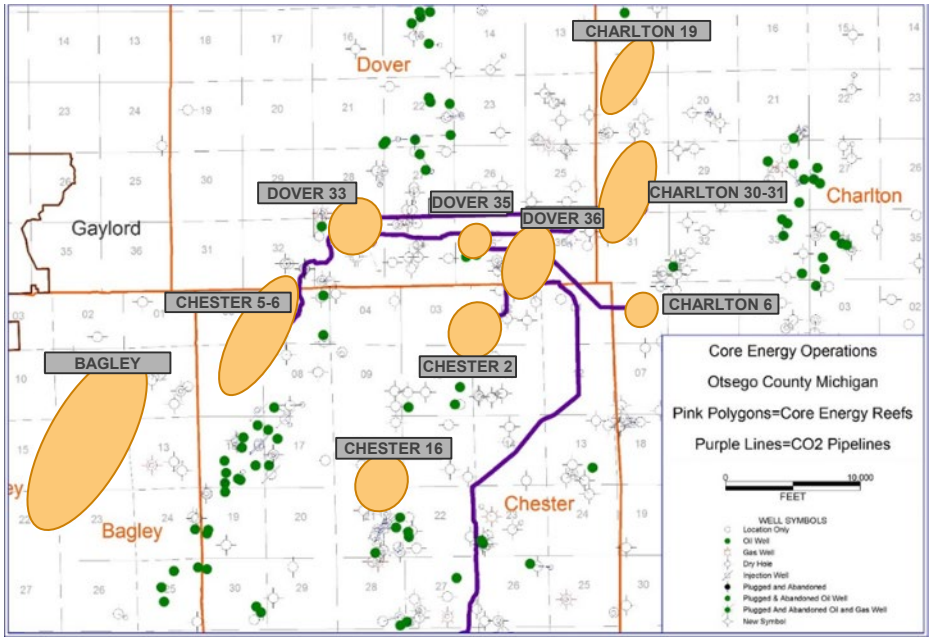
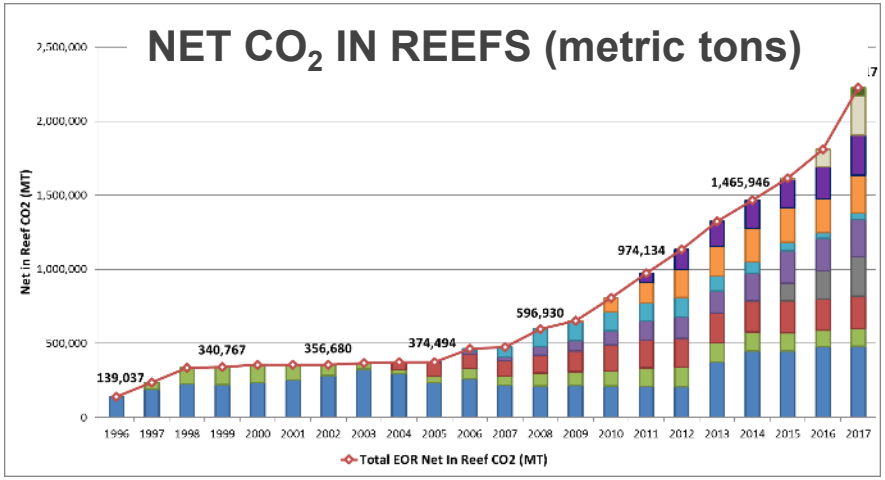
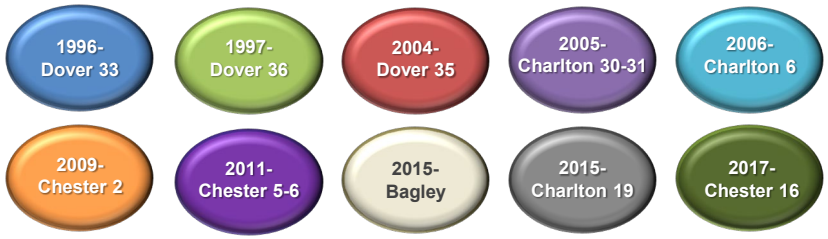
INDEX MAP OF REEFS



NET CO_2 IN REEFS (metric tons)





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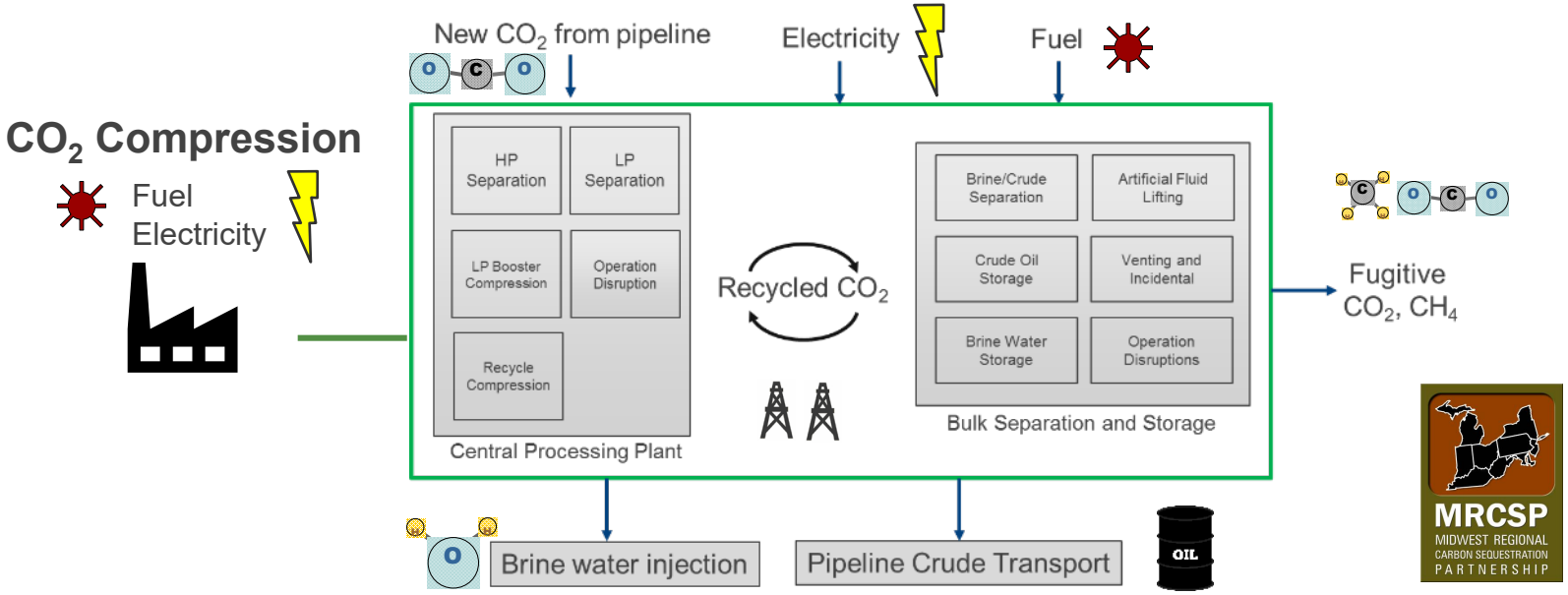
5. LCA: Gate-to-Gate Operations Data

- Detailed Gate-to-Gate data from MRCSP, Core Energy
  - CO_2 injected, CO_2 recycle, new CO_2, oil produced, brine produced
- Emission Sources
  - Compression natural gas use (MCF), facility electricity use (kWhr), fugitive emissions (CO_2 & methane), venting/flaring, facility construction, new wells, produced water/brine injection, land use.



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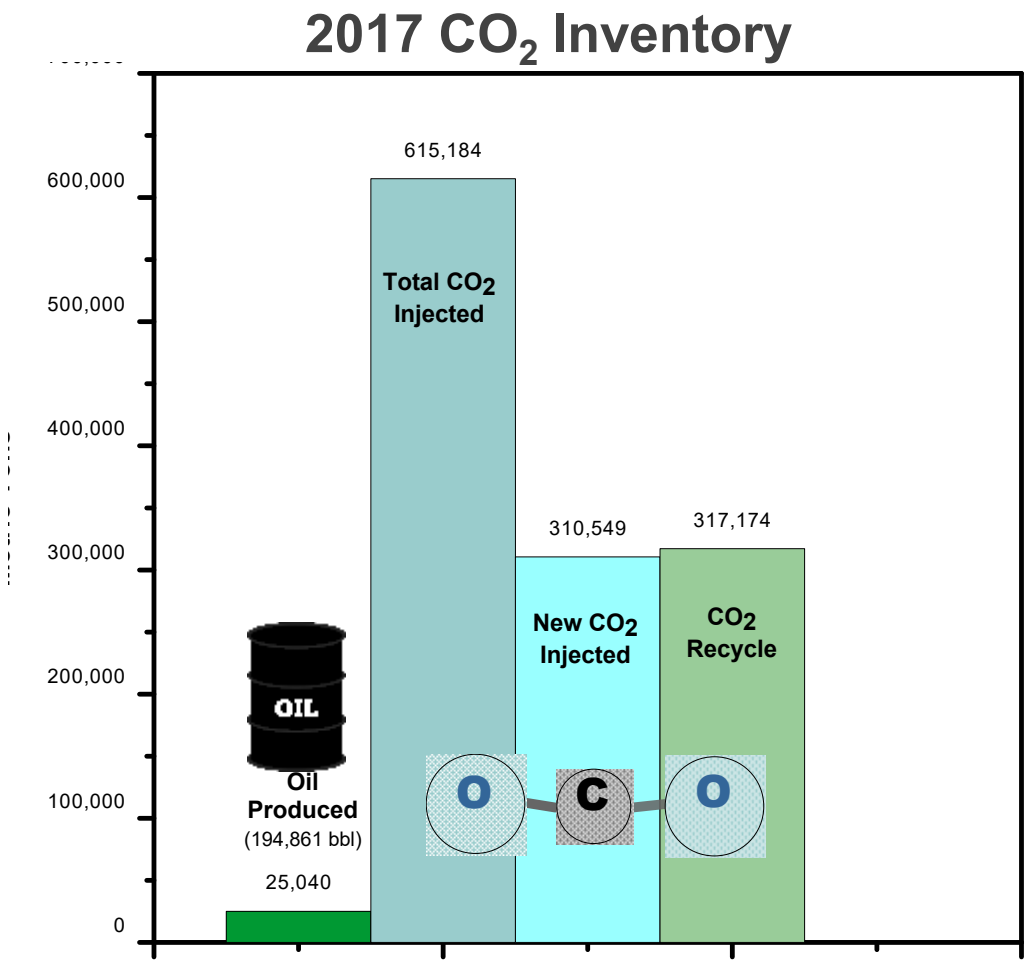
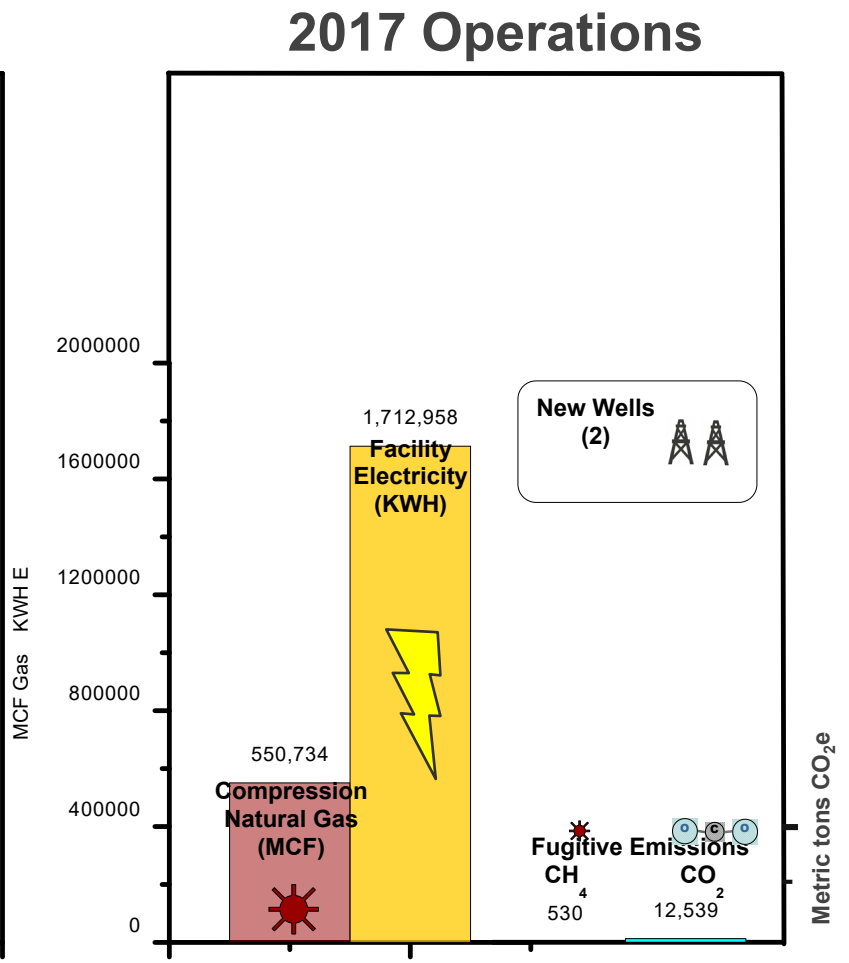
5. LCA: Gate-to-Gate Operations Key Input

- Example- snapshot of 2017 key input.





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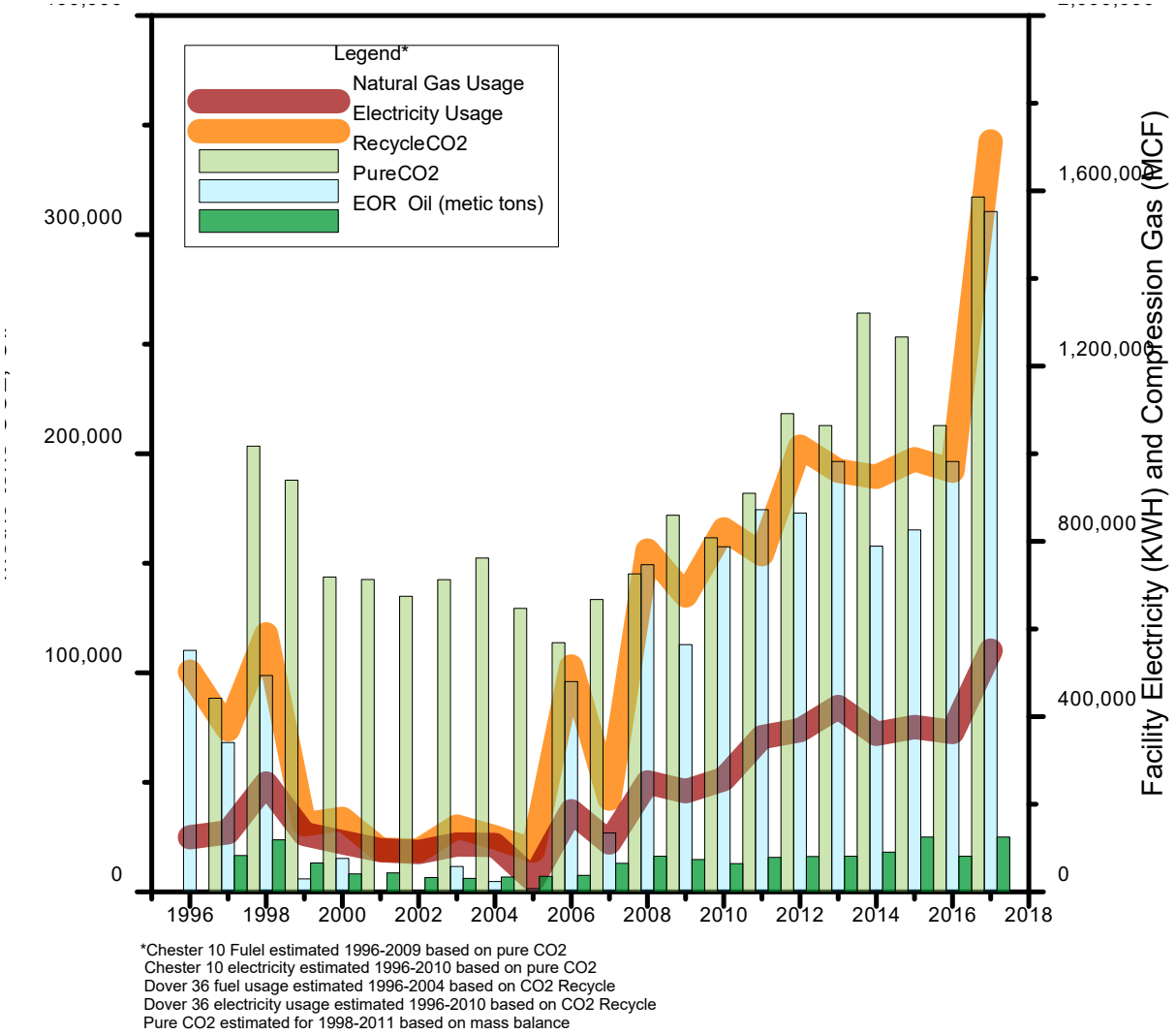
5. LCA: Gate-to-Gate Operations Data

- Operations trends reflect CO_2-EOR cycles and additional reefs.



*Chester 10 Fulel estimated 1996-2009 based on pure CO2
Chester 10 electricity estimated 1996-2010 based on pure CO2
Dover 36 fuel usage estimated 1996-2004 based on CO2 Recycle
Dover 36 electricity usage estimated 1996-2010 based on CO2 Recycle
Pure CO2 estimated for 1998-2011 based on mass balance

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5. CO_2 EOR LCA Model

- Modified version of Azzolina/EERC (2016) CO_2 EOR LCA model framework used to calculate GHG emissions factors
- Direct measurements entered from CO_2 EOR system monitoring, operations, and new reef developments.

SEGMENT	SUB-SEGMENT	PARAMETER DESCRIPTION	UNITS	LOW VALUE	EXPECTED	HIGH VALUE	SOURCE	NOTES	BASE CASE
Gate-to-Gate	ell Operations – Artificial L	Crude artificial lift pump electricity rate	kWh / kg crude		1.00E-03		System Data	Assume minor artificial lift, p	1.00E-03
Gate-to-Gate	ell Operations – Artificial L	Crude artificial lift pump electricity	kWh				Derived	Derived from the artificial lif	25,040
Gate-to-Gate	ell Operations – Artificial L	Crude artificial lift pump electricity	MWh				Derived	Unit conversion from kWh to	25
Gate-to-Gate	ell Operations – Artificial L	CO_2 emissions	kg CO_2e				Derived	Derived from the MWh and t	16,526
Gate-to-Gate	ell Operations – Artificial L	CO_2 emissions factor	kg CO_2e / bbl				Derived	Derived from the CO_2 emissi	0.1
GATE-TO-GATE: WELL OPERATIONS – CO_2 COMPRESSION AND INJECTION ELECTRICTIY									
Gate-to-Gate	– CO_2 Compression and In	Compressor power factor	MW/[tonne recycled CO_2/day]		2.70E-03		Literature	NA, Cooney et al. (2015)	2.70E-03
Gate-to-Gate	– CO_2 Compression and In	Compressor power	MW				Derived	NA,Derived from the compre	2.35E+00
Gate-to-Gate	– CO_2 Compression and In	Compressor energy	MWh				Derived	NA, Derived from the compr	20,553
Gate-to-Gate	– CO_2 Compression and In	CO_2 emissions	kg CO_2e	29136000	29136000	29136000	System Data	Combustion data from Core E	29,136,000
Gate-to-Gate	– CO_2 Compression and In	CO_2 emissions factor	kg CO_2e / bbl				Derived	Derived from the CO_2 emissi	149.5
Gate-to-Gate	– CO_2 Compression and In	CO_2 pump power factor	MW/[tonne injected CO_2/day]	0.00E+00	0.00E+00	0.00E+00	System Data	See Line 115	0.00E+00
Gate-to-Gate	– CO_2 Compression and In	CO_2 pump power	MW				Derived	Derived from the pump pow	0.000
Gate-to-Gate	– CO_2 Compression and In	CO_2 pump energy	MWh				Derived	Derived from the pump pow	0
Gate-to-Gate	– CO_2 Compression and In	CO_2 emissions	kg CO_2e	6591500	6591500	6591500	System Data	Gas Processing data from Cor	6,591,500
Gate-to-Gate	– CO_2 Compression and In	CO_2 emissions factor	kg CO_2e / bbl				Derived	Derived from the CO_2 emissi	33.8
Gate-to-Gate	– CO_2 Compression and In	CO_2 emissions (total)	kg CO_2e				Derived	Derived from the sum of com	35,727,500
Gate-to-Gate	– CO_2 Compression and In	CO_2 emissions factor (total)	kg CO_2e / bbl				Derived	Derived from the CO_2 emissi	183.3
GATE-TO-GATE: WELL OPERATIONS – CO_2 COMPRESSOR FUGITIVE EMISSIONS									
Gate-to-Gate	rations – CO_2 Compressor	Compressor CO_2 emissions rate (direct to atmosphere)	kg CO_2e / MW-day		63.6		Literature	NA,Cooney et al. (2015)	63.6
Gate-to-Gate	rations – CO_2 Compressor	Compressor CO_2 emissions (direct to atmosphere)	kg CO_2e	549	549	549	System Data	Subpart C Core forms	549

Azzolina, N.A., Peck, W.D., Hamling, J.A., Gorecki, C.D., Ayash, S.C., Doll, T.E., Nakles, D.V., and Melzer, L.S., 2016, How green is my oil? A detailed look at greenhouse gas accounting for CO2-enhanced oil recovery (CO2-EOR) sites: International Journal of Greenhouse Gas Control, v. 51,p. 369–379.

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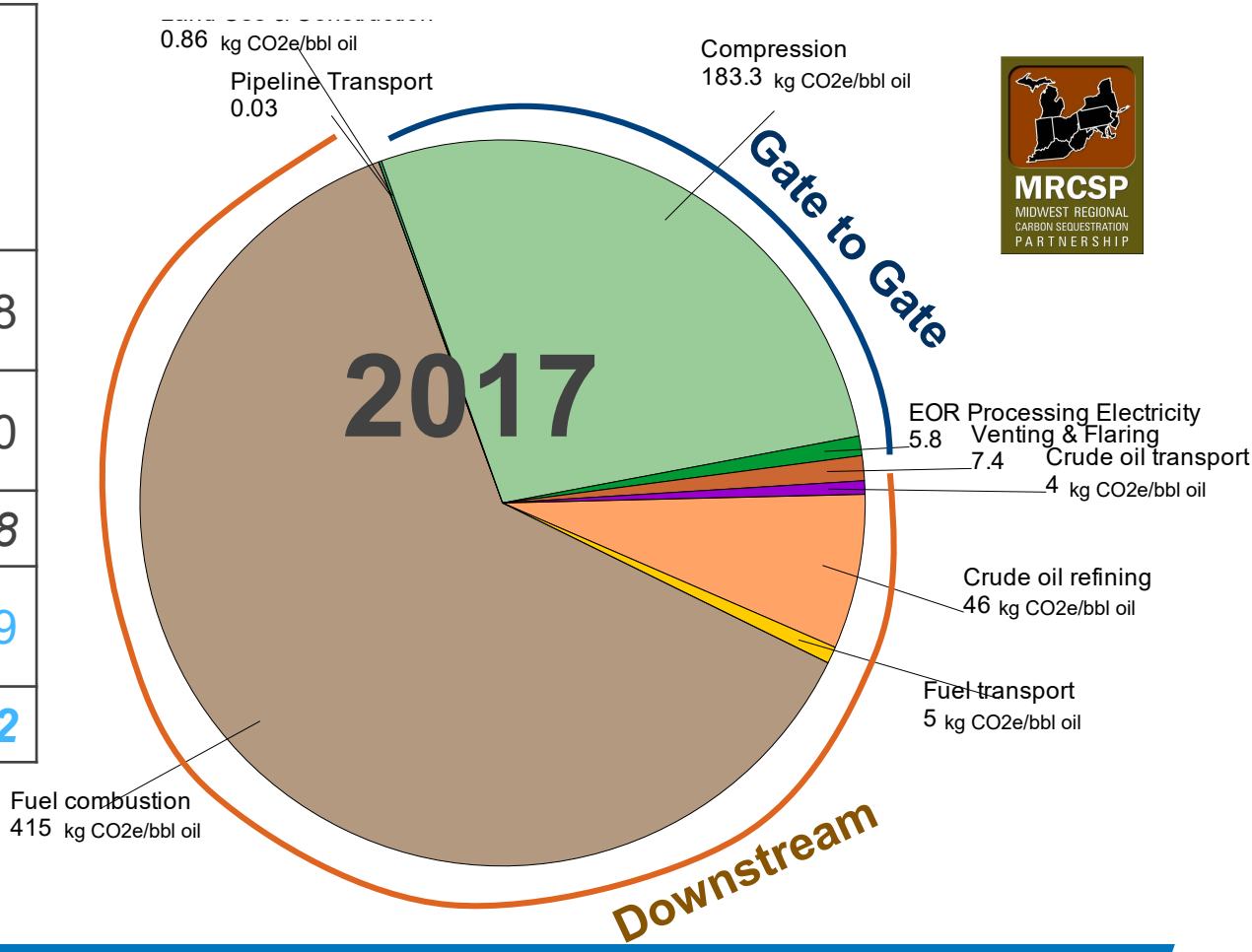
5. CO_2 EOR LCA Model Results

- Highest emission factors from compression & downstream.

Category	2017 Emisson Factor $kgCO_2e/bbl$
Gate to Gate	198
Downstream	470
Total	*668*
CO_2 Storage	-1529
Net	***-862***



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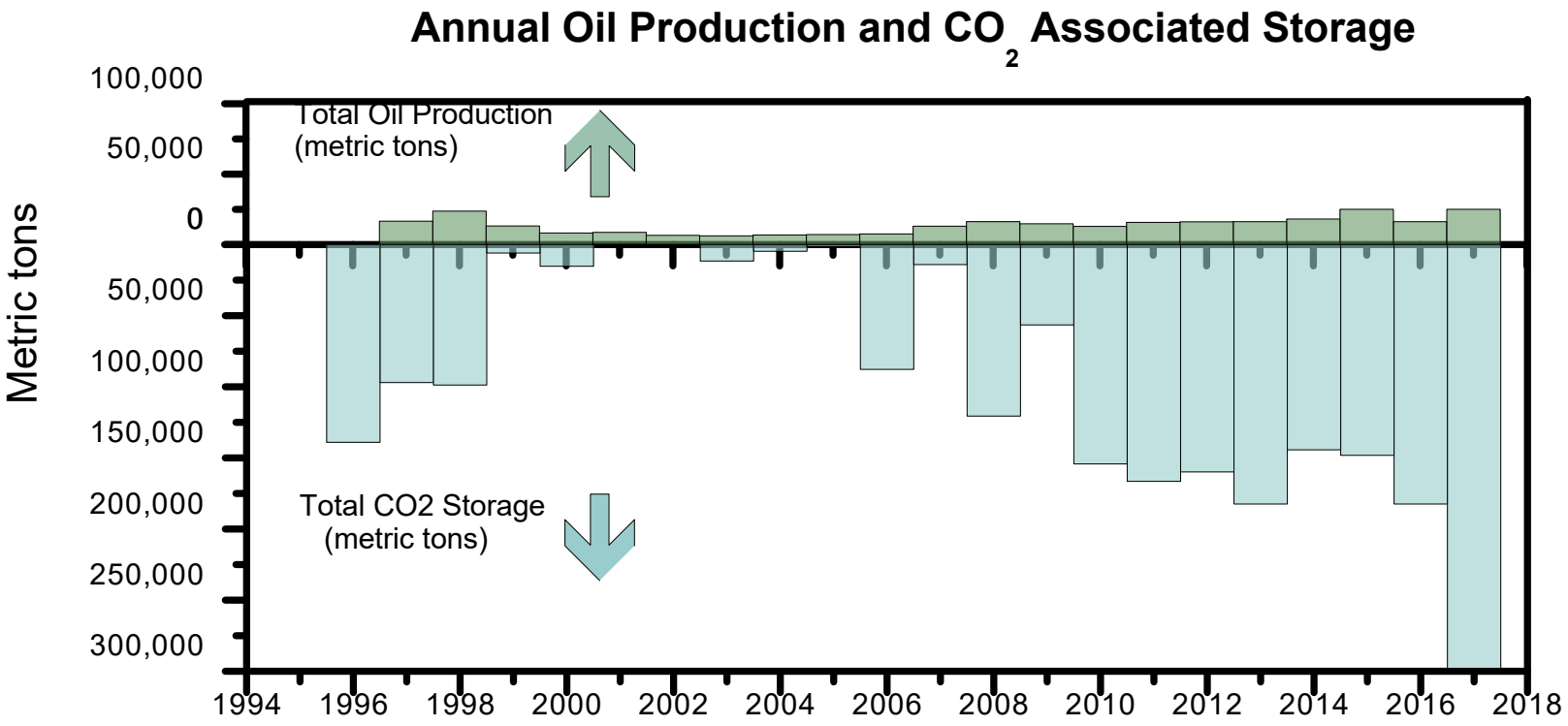
5. LCA Model Output- “Gate to Gate”

- Large amount of variability in gate to gate EF over 20 years.



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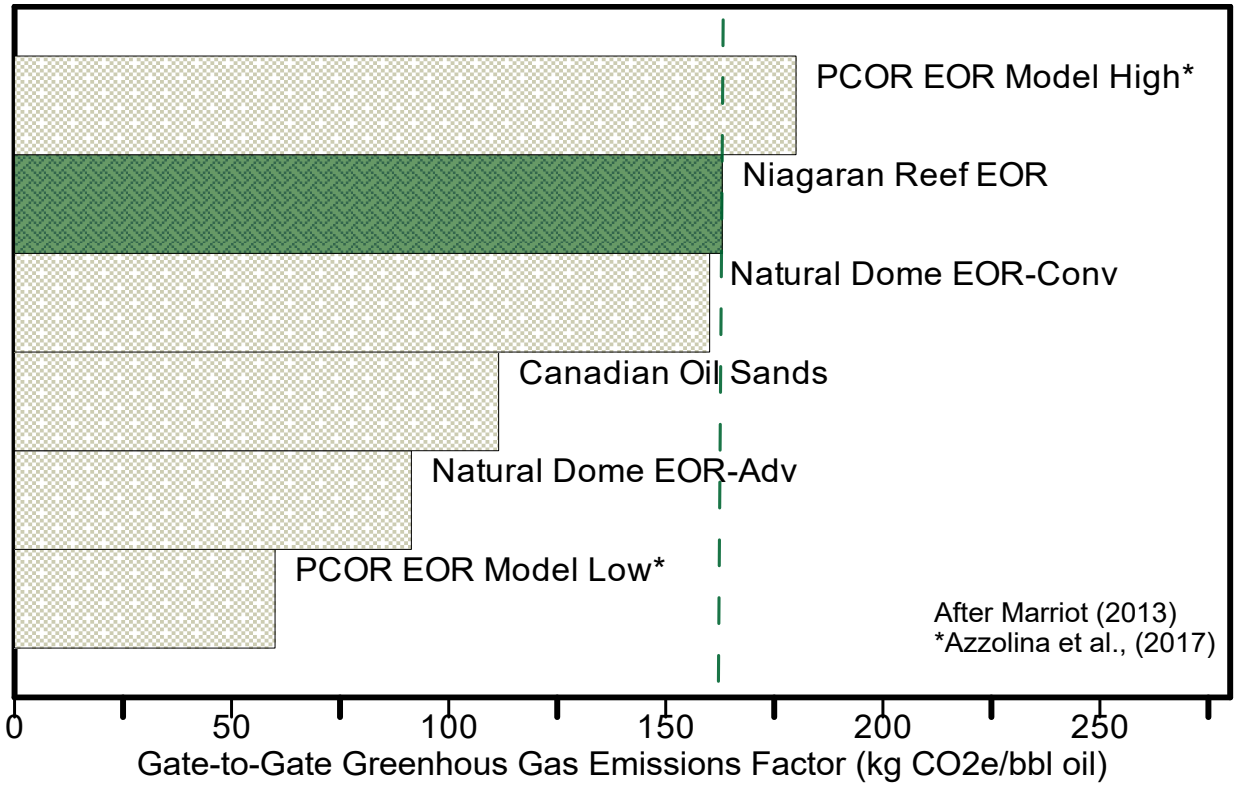
5. LCA Model Output-“Gate to Gate”

- “Gate to Gate” EOR EF = 163 kgCO2e/bbl GHG life cycle emissions factor (371,576,000 kg CO_2 / 2,290,473 BBL).



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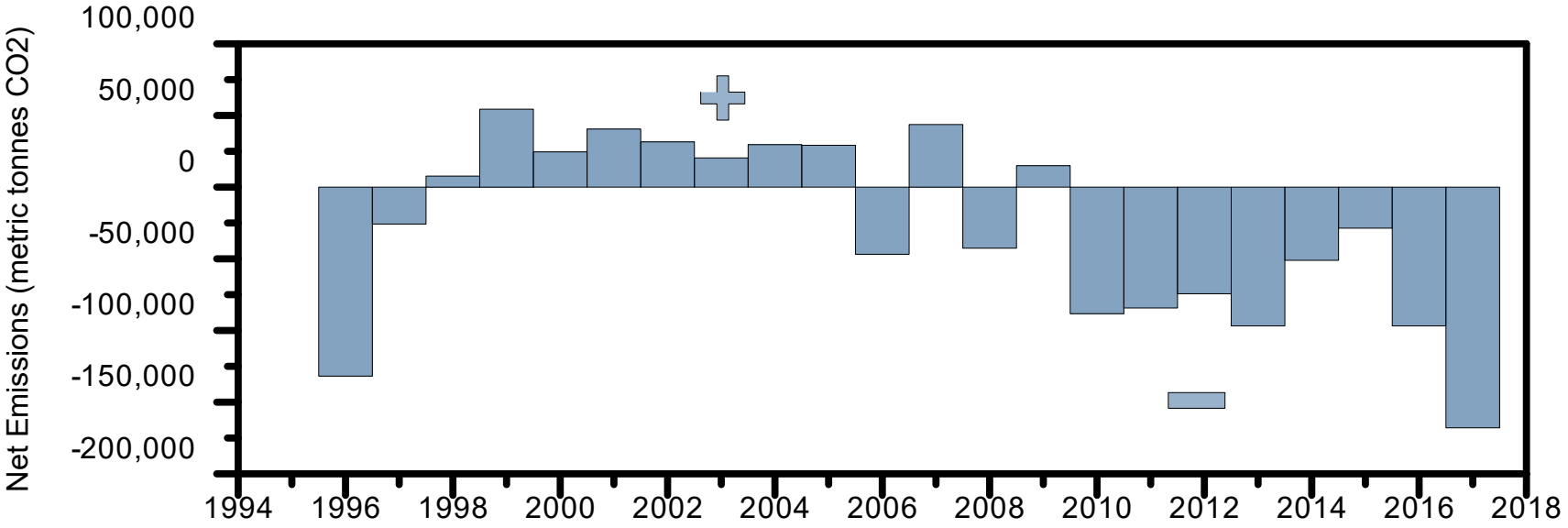
5. LCA Model Output-"Gate to Grave"

- "Gate to Grave" **net emissions** accounts for CO_2 stored.
- Analysis reflects ups and downs of operations.



5. LCA Model Output- "Cradle to Grave"

- "Cradle to Grave" results suggest there is a net negative CO_2 emissions of -159,860 metric tons.

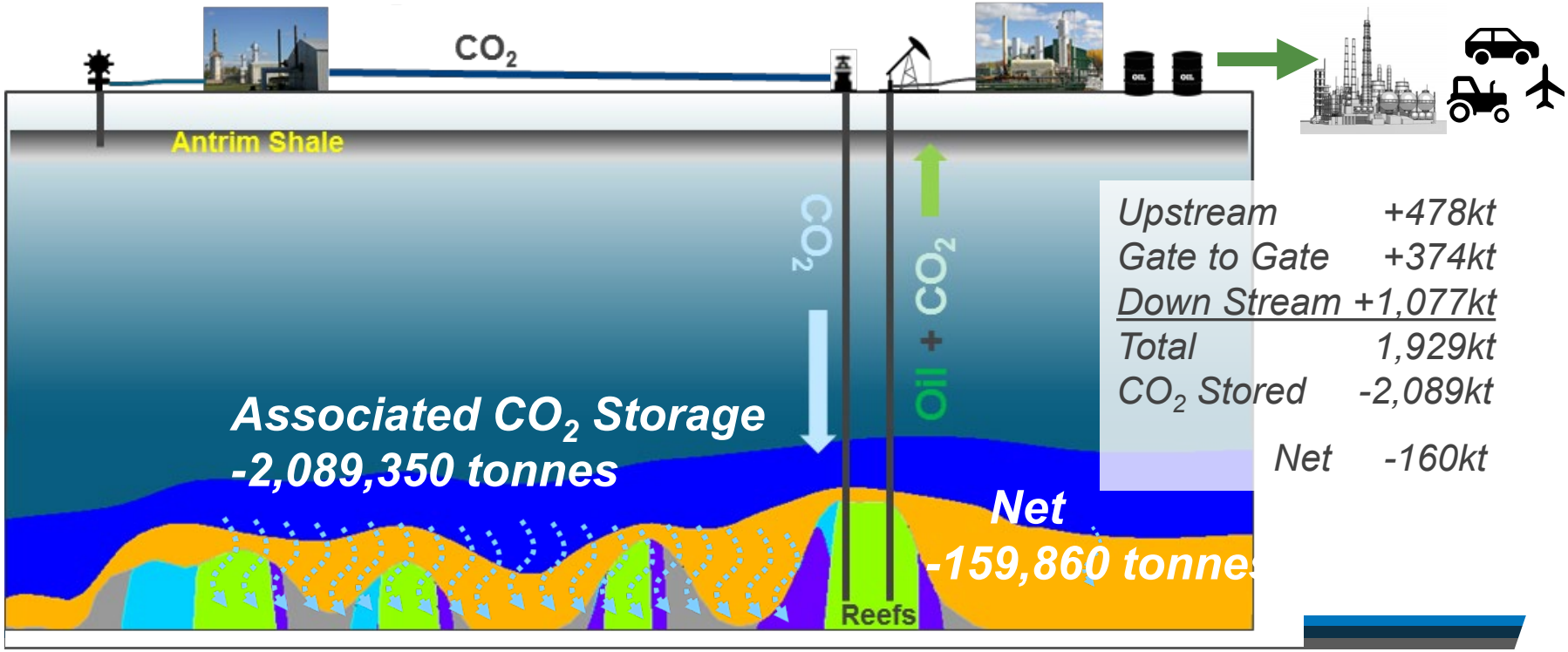
Year	Upstream Capture Emissions* (metric tonnes)	Gate to Gate total Emssions (metric tons)	Downstream Total Emissions (Metric tons)	Total CO2 Associated Storage (metric tonnes)	Net CO2e Emissions (metric tonnes)
1996	22,872	7,166	47	139,037	-108,952
1997	14,142	10,511	60,767	97,026	-11,606
1998	38,543	19,554	86,924	98,763	46,257
1999	1,289	12,025	48,312	5,941	55,684
2000	2,061	9,786	30,084	15,259	26,673
2001	-	8,759	31,757	-12	40,529
2002	72	8,237	24,005	665	31,649
2003	1,174	9,397	22,580	11,585	21,566
2004	528	9,521	24,859	4,728	30,180
2005	175	4,697	26,011	1,500	29,383
2006	19,916	13,308	27,620	87,763	-26,918
2007	5,574	10,042	47,732	14,079	49,269
2008	30,986	18,472	59,543	120,595	-11,594
2009	23,417	17,449	54,040	56,505	38,402
2010	32,682	18,740	47,226	154,237	-55,589
2011	36,195	24,530	57,638	166,463	-48,100
2012	35,879	26,342	59,147	159,857	-38,489
2013	40,759	26,118	59,495	182,417	-56,045
2014	32,740	26,908	66,357	144,313	-18,309
2015	34,280	27,971	91,614	148,202	5,664
2016	40,759	26,118	59,495	182,417	-56,045
2017	64,433	38,495	91,614	298,010	-103,468
Total	478,476	374,147	1,076,867	2,089,350	-159,860

6. Results- Total LCA results 1996-2017

Upstream
CO_2 Capture Plant Operations
478,476 tonnes
CO_2e Generated

Gate to Gate
(compression, EOR, & gas processing)
374,147 tonnes
CO_2e Generated

Downstream
1,076,867
tonnes CO_2e
Generated



Upstream	*+478kt*
Gate to Gate	*+374kt*
Down Stream	*+1,077kt*
Total	*1,929kt*
CO_2 Stored	*-2,089kt*
Net	*-160kt*

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6. Conclusions

- Greenhouse gas emissions life cycle analysis helps us understand the benefits of carbon capture and storage.
- The greenhouse gas life cycle analysis highlights the value of integrating Class II UIC operations and site-specific data over a long period of CO_2-EOR operations.
- The system benefited from a ready source of CO_2, short pipeline system, natural gas fueled compression, highly contained reservoir, and basic oil processing system.
- Analysis of 22 years of CO_2-EOR operations and monitoring shows it is possible to have negative net emissions if you store a large amount of CO_2 in association with EOR operations.

(Marriot/DOE-NETL, 2013)

Thanks!

Questions?