CARBON CAPTURE, UTILIZATION & STORAGE CONFERENCE

JUNE 14-16, 2016 | SHERATON TYSONS CORNER | TYSONS, VA

www.ccusconference.com

#CCUS

CARBON CAPTURE, UTILIZATION & STORAGE CONFERENCE

CO_2 Capture Technologies Appropriate/Feasible for Utilization for EOR/EGR

Mobile CO_2-Enhanced Oil Recovery Utilizing Wasted Flare Gas Resources

Dan Hussain,[1,2,3] Robert M. Zubrin,[2] Mark Berggren,[2] Satyajeet Salvi,[3] Steven Malliaris[3]

[1]Dept. of Civil & Env. Engineering, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213

[2]Pioneer Energy Inc., 11111 West 8th Ave, Unit A, Lakewood, CO 80215

[3]American Pioneer Ventures (APV), 845 Third Avenue, 6th Floor, New York, NY 10022

Acknowledgements & Disclaimer

This is preliminary analysis that has not gone through peer-review yet.

The authors and Pioneer Energy acknowledge the support of DOE/*RPSEA (Research Partnership to Secure Energy for America)* on the predecessor system R&D.

The authors acknowledge Pioneer Energy for providing access to the pilot plant data and access to technology development. However, the information and opinions disclosed in this presentation represent the views of the authors and do not necessarily reflect the opinions of Pioneer Energy or its management.

The authors acknowledge David Dzombak, Greg Lowry, and Paulina Jaramillo at Carnegie Mellon University for assistance in modeling.

All inquiries with respect to this presentation should be addressed to:
Dan Hussain, Graduate Student, Carnegie Mellon University
daniarh@andrew.cmu.edu or dan@apvusa.com
Any inquiries with respect to Pioneer Energy products or services should be addressed to:
Dr. Robert Zubrin, President, Zubrin@aol.com / John Henri, Chief Chemist, jhenri@pioneerenergy.com

Abstract

This work shows the synergies between flare gas capture and CO_2-EOR in North Dakota (Bakken) and Alberta, Canada. If waste flare gas could be utilized for enhancing recovery from EOR fields, significant environmental and economic benefits would accrue. Unfortunately, as currently practiced, EOR requires pipelines to deliver CO_2 to oil fields from natural sources or a handful of artificial sources capable of producing high quality CO_2. This technique is only practical for oilfields within limited distance from such sources, as the capital cost of building pipelines over long distances is prohibitive. In addition, the timelines involved in pipeline construction generally make such projects uninteresting to small producers. Finally, there is a big chicken-and-egg problem with CO_2-EOR projects even for large fields, as CO_2 floods cannot be tested until pipelines are built, and industry is reluctant to invest the enormous expense up-front before proving the viability of CO_2-EOR in particular fields as field conditions vary. The current practice is to use trucks to carry CO_2 to pilot projects, which is both expensive and logistically cumbersome. Therefore, what is needed is a system that can provide CO_2 directly to producers at a cost of $1-2/mcf, wherever they may be, without major capital expenditures, in a timely fashion after a decision has been made to undertake EOR, on a scale relevant for field trials on large fields ahead of pipeline construction and for operations on small- and medium- sized fields. Accordingly, Pioneer has developed and patented in U.S. and Canada the Portable Enhanced Recovery Technology (PERT) that can be transported by trailer to the site of an oil field. The PERT can be used to generate high-purity CO_2, methanol, and electricity from raw flare gas or field gas on-site of the oil field. Unlike a conventional power plant, our equipment is fully truck-portable, and has many additional applications, such as CO_2-fracking. This work demonstrates the synergies between flare gas capture and utilization in CO_2-EOR using candidate pipeline networks, and demonstrates the potential lifecycle (LCA) CO_2 emissions reductions from utilizing flare gas for CO_2-EOR.

Wasted flare gas is both an economic & environmental problem

North Dakota from Space

Alberta from Space

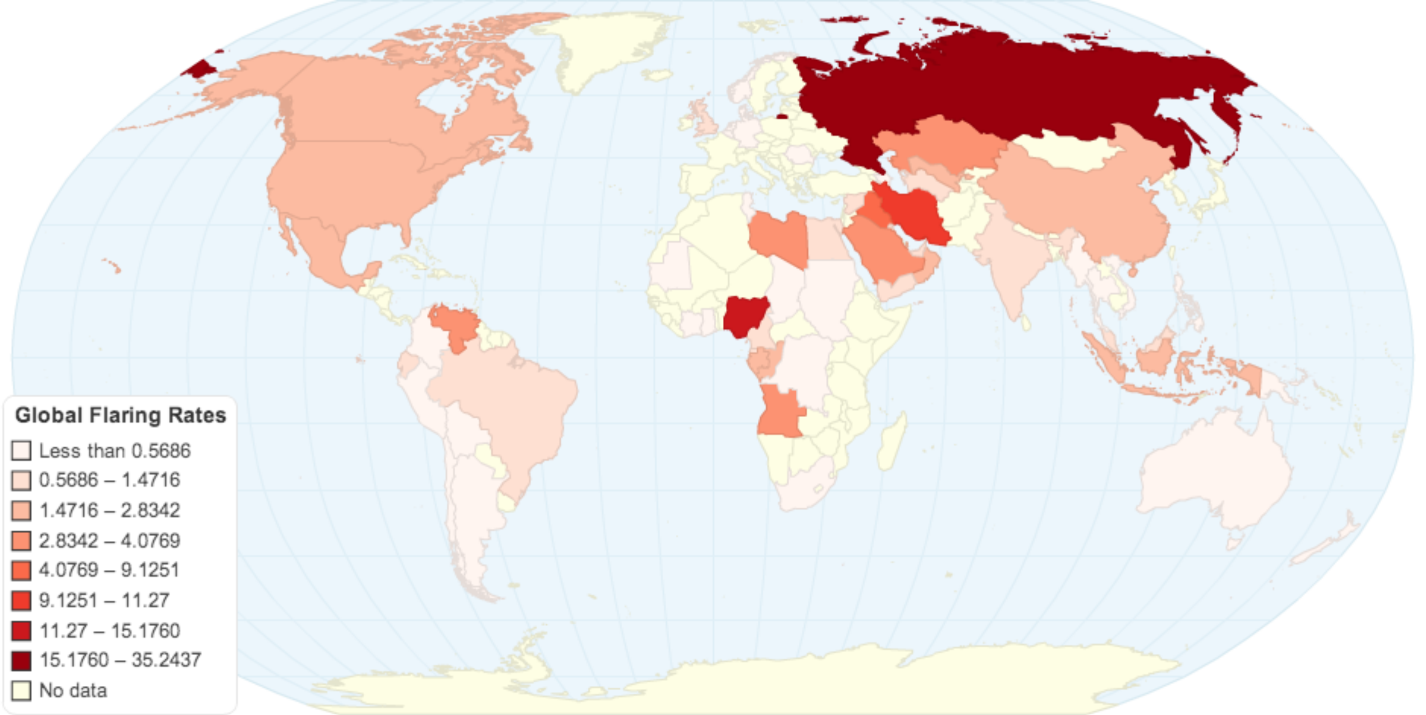
***In 2014…** only 10% reduction in ND from oil price drop in 2016*

Alberta, Canada flared 1.1 **billion** cubic **meters** per year ……. 39 BCF/yr

North Dakota flared 120 **billion ft³** per year ……………………..120 BCF/yr *[107 BCF/yr in 2016]*

World flared 7 **trillion** ft³ (TCF) per year ………………………. 7,000 BCF/yr

Flaring is a Worldwide Problem

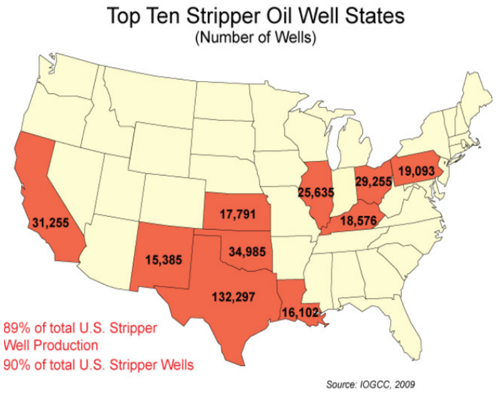


World-wide flaring, BCM/year in 2013

Meanwhile, CO_2 is not available for EOR!

- Pipeline CO_2 unavailable in most places for Enhanced Oil Recovery (EOR)
- Even in regions where pipelines exist, they are unavailable to small producers
- Projects by large producers are held back by high capital costs, remote locations, long construction lead-times, and prohibitive cost of pilots

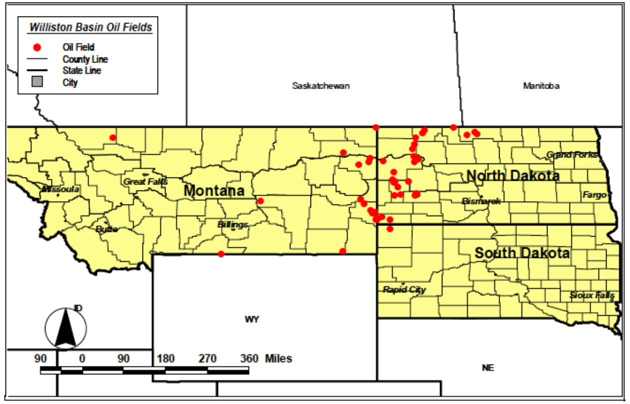
Oil fields in the U.S. amenable to CO_2-EOR versus existing CO_2 pipelines



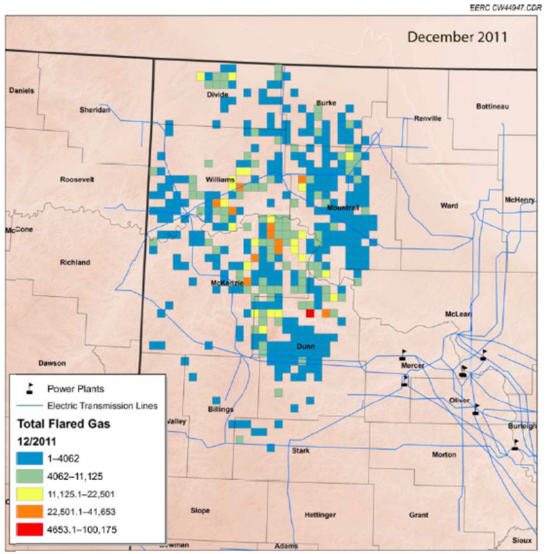
Note: It could take 5-10 years to build a new CO_2 pipeline

…but in North Dakota, flare sites are close to fields with CO_2-EOR potential

Fields amenable to EOR in ND



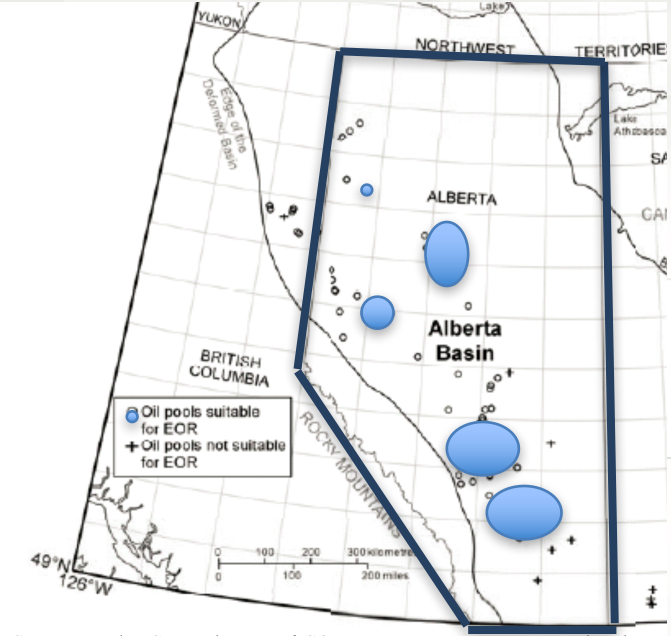
Flare sites in ND



CARBON CAPTURE, UTILIZATION & STORAGE CONFERENCE

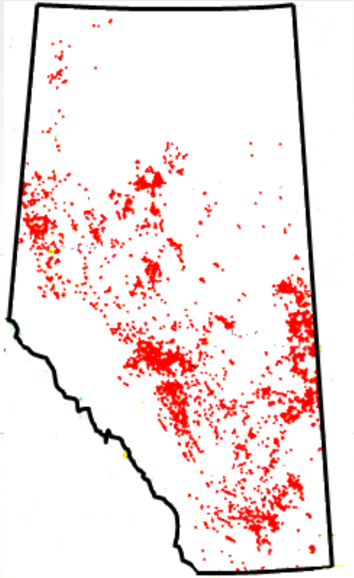
…also in Alberta, flare sites are close to fields with CO_2-EOR potential

Fields amenable to CO_2-EOR in Alberta



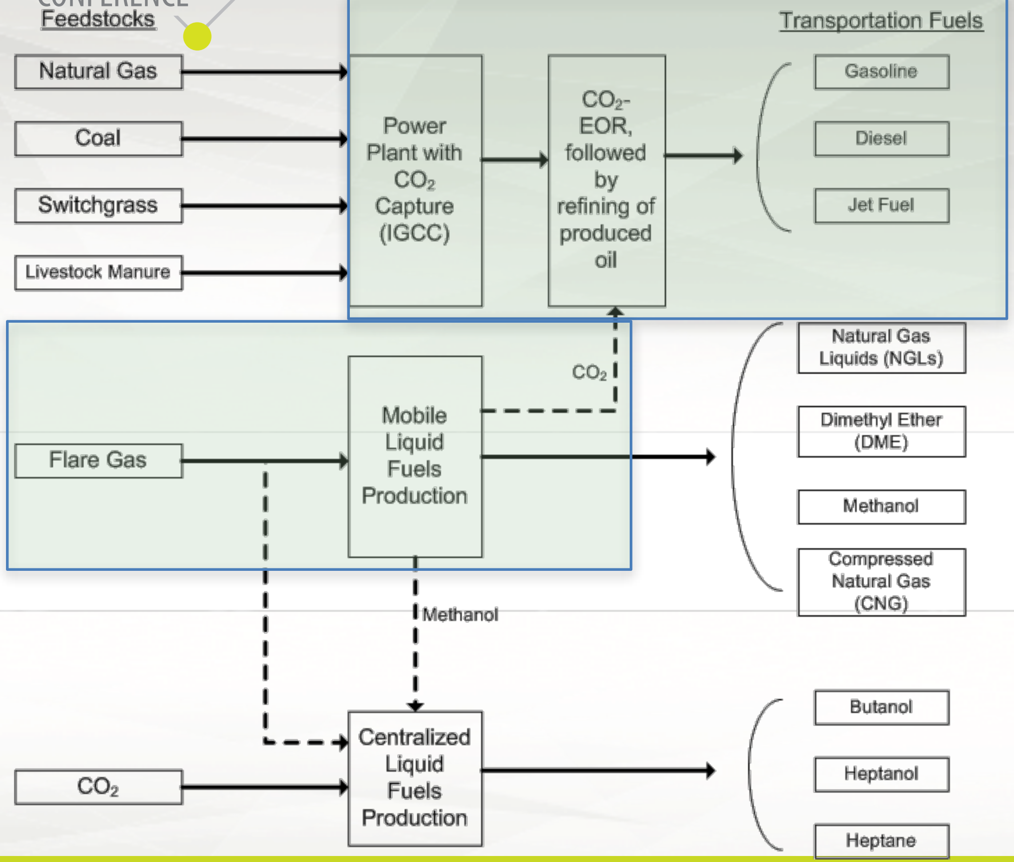
Source: Bachu, S., *Evaluation of CO_2 sequestration capacity in oil and gas reservoirs in the Western Canada sedimentary basin*, Alberta Geological Survey, Edmonton, Canada, March **2004**.

Flare gas sites in Alberta



Source: Johnson, M.R., and Coderre, A.R., *Opportunities for CO_2 equivalent emissions reductions via flare and vent mitigation: A case study for Alberta, Canada.* International Journal Greenhouse Gas Control, 121-131, **2012**.

Flare gas as a source of CO_2 for EOR



Full Scope of the CO_2-EOR Opportunity

- The Williston Basin (ND, SD, MT) has at least **0.8 to 1.8 billion barrels** of technically recoverable oil with CO_2-flooding, allowing for the sequestration of **209 to 470 million metric tons (Mt) CO_2**, or ***the equivalent of 17-38 years of 2014 flare gas emissions in volume***
  - *About 60% of this is concentrated in North Dakota*

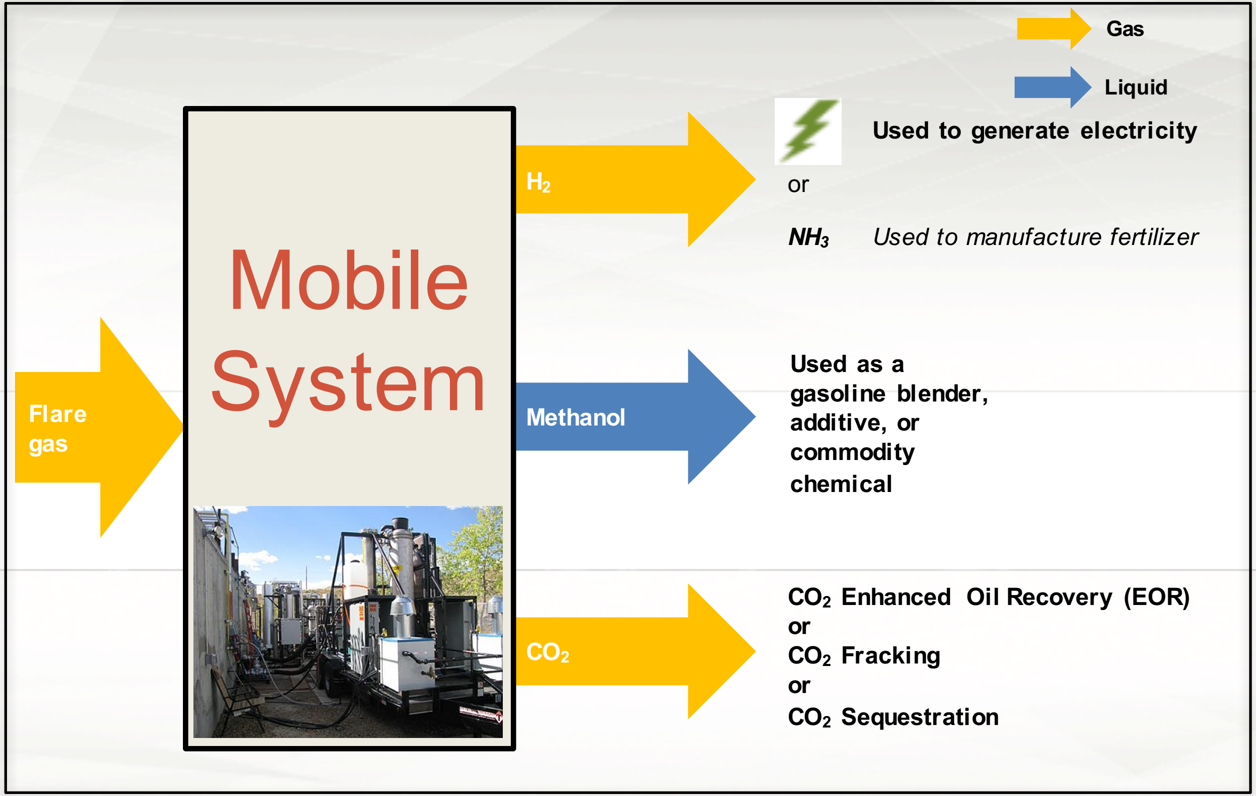
- Western Canada has at least 4,700 oil reservoirs suitable for CO_2-flooding, which collectively contain **2.9 billion barrels (350 million m^3) of technically recoverable oil**, providing for the sequestration of **570 million metric tons (Mt) CO_2**
  - *About 90% of this is concentrated in Alberta*

Sources:

- Advanced Resources International, *Basin oriented strategies for CO_2 enhanced oil recovery: Williston Basin of North Dakota, South Dakota, and Montana,* National Energy Technology Laboratory, Pittsburgh, PA, Feb. 2006.
- Bachu, S., *Evaluation of CO_2 sequestration capacity in oil and gas reservoirs in the Western Canada sedimentary basin*, Alberta Geological Survey, Edmonton, Canada, March 2004 .

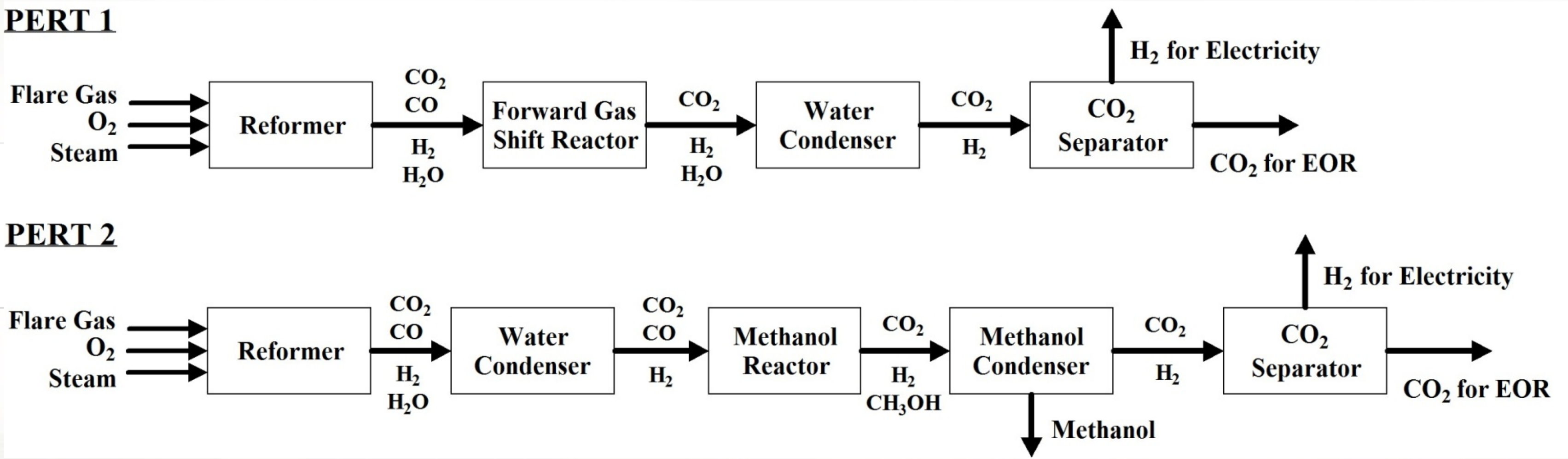
CARBON CAPTURE, UTILIZATION & STORAGE CONFERENCE

Solution: Mobile CO_2-EOR

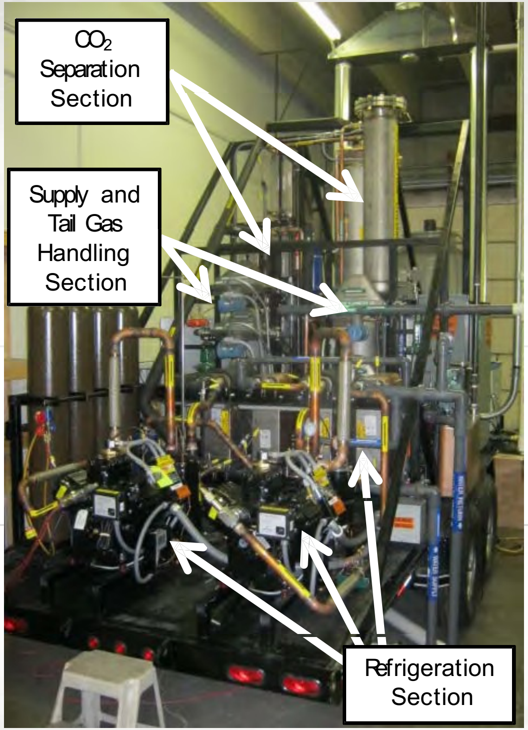


Improving System Economics with Methanol Production

- PERT-2 improves economics by producing methanol from the reformer CO output, without the complexity of a complete methanol system

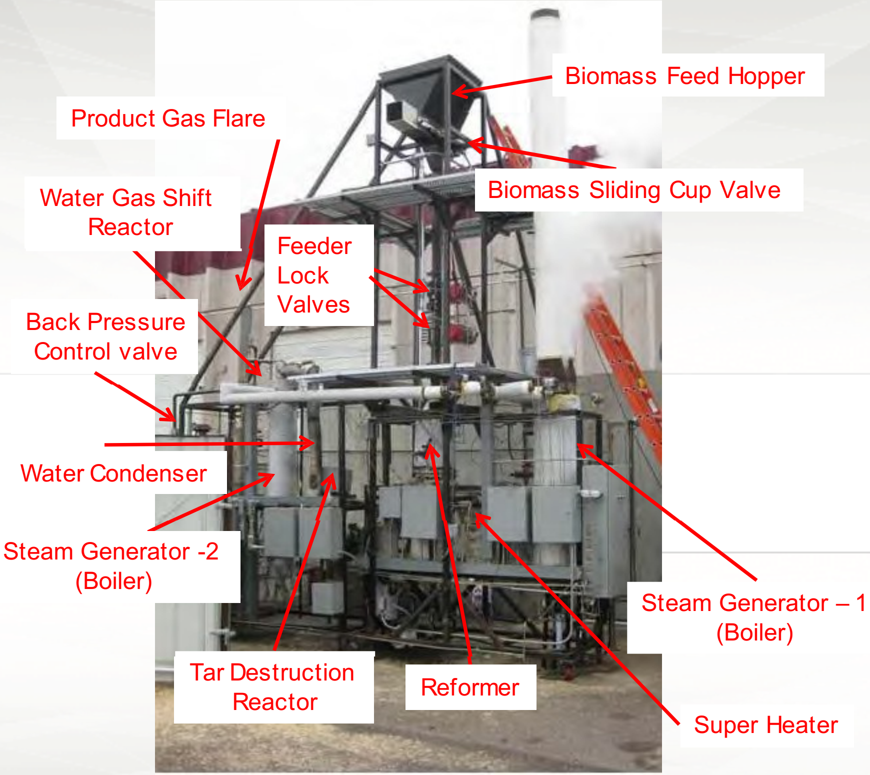


Portable CO_2 – H_2 Separator



- Methanol Temperature-Swing Separation System developed internally by Pioneer Energy
- 180 MCF/day scale for RPSEA
- Successfully operated to recover >92% of CO_2 from 25% CO_2 feed (output of the reformer)
- Became the basis for the Flarecatcher™ flare gas capture system deployed to the Bakken

Alternative Biomass-Fueled Reformer



- Modular assembly
  - Two skids, can be put on a mobile platform for transporting
- System fully instrumented with temperature, pressure, fluid level and flow control sensors, and automated valve control
- Slipstreams for gas analysis
- Built and tested for RPSEA

Role of Mobile CO_2-EOR in CCS Challenge

Mobile CO_2-EOR enables the CO_2-EOR "bridge"

- Pipeline construction costs >$100M and takes years to permit and construct
- Small scale demonstration projects and pilots solve "chicken-and-egg" problem
- Mobile CO_2-EOR operations will develop CO_2 sequestration infrastructure
- Early implementation of CO_2-EOR will drive costs down through "learning by doing"

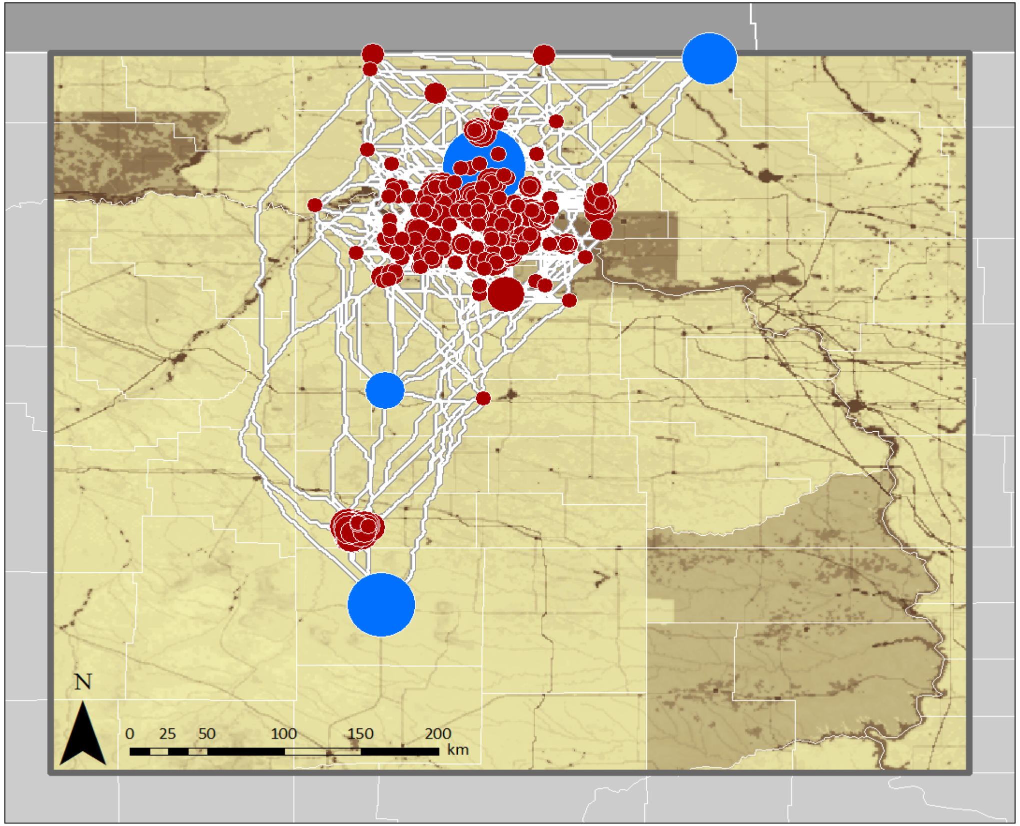
Small Scale Pilots & Demonstration Projects using Mobile CO_2-EOR

Widespread Market Penetration of CO_2-EOR & CCS Technology

Source: Adapted from Robert Ferguson, et al., Advanced Resources International, 8th Annual CCS Conference, Pittsburgh, PA, 2009.

Candidate Pipeline Networks

- Locations of flare sites (red dots), oil fields amenable to CO_2-EOR (blue dots), and candidate pipeline networks (white lines)
- Large clustering of flare sites next to large CO_2-EOR amenable oil reservoirs means required pipelines can be minimized
- Full simulation run would result in optimal pipelines selected from among these candidate pipelines (coming soon)
- SimCCS software provided by LANL (We acknowledge Richard S. Middleton of LANL and Jeffrey M. Bielicki of OSU)



Methodology for Evaluating CO_2 Emission Reductions

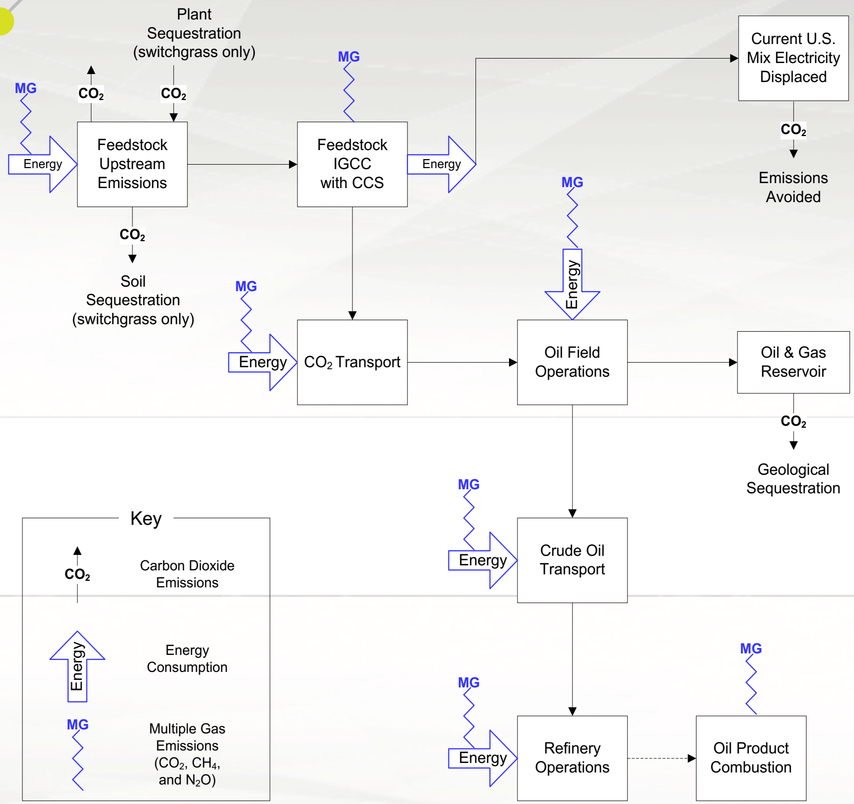
- ***We used Alberta as a case study, and these results can be easily generalized to ND & other areas***

- **Performed Lifecycle Assessments (LCA) in compliance with *ISO 14400*, utilizing data from Mobile CO_2-EOR pilot unit and published data sources on other subsystem operations**

- **A baseline was established for existing conditions. The baseline included:**
  - Traditional Tertiary Oil Recovery (Marginal Oil – SAGD Oil Sands in Alberta)
  - Gasoline *(Or Methanol)* Produced from Average Alberta Oil
  - Average Alberta Electricity Production *(Or Diesel Electricity Production)*
  - Flaring *(Or Conventional Alberta Natural Gas)*

- **This baseline was compared to the GHG emissions associated with the system**

CO_2-EOR LCA System Boundary



Source: Hussain, D., et al., *Comparative lifecycle inventory (LCI) of greenhouse gas (GHG) emissions of enhanced oil recovery (EOR) methods using different CO_2 sources*, **IJGCC**, 2013.

LCA Cases Analyzed: Flare Gas Utilization in CO_2-EOR

Feedstock	Liquid Fuel Displaced		Electricity Type Displaced
	Gasoline	Conventional Methanol	
Flare Gas	**Case 0**		Grid
Flare Gas	**Case 1**	**Case 2**	On-Site Diesel
Natural Gas			Grid
Natural Gas	**Case 3**	**Case 4**	On-Site Diesel

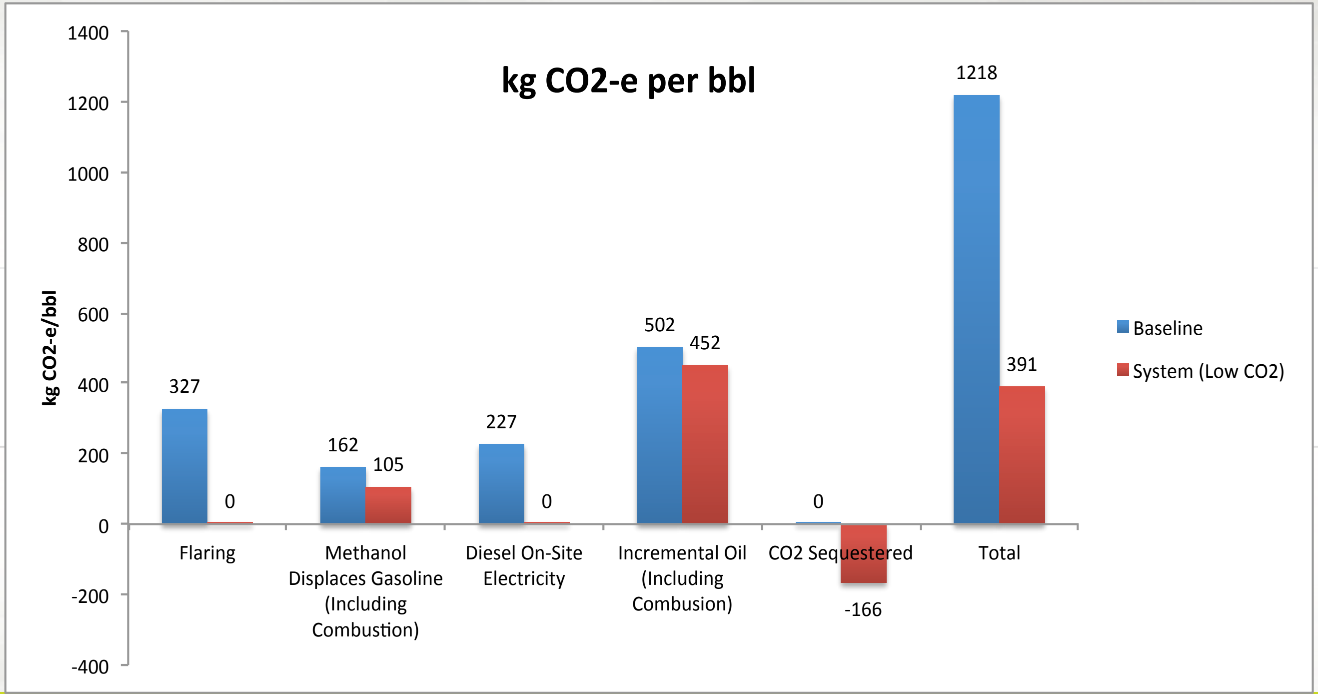
Only results for Cases 1 and 2 are presented here; full results in forthcoming paper

CARBON CAPTURE, UTILIZATION & STORAGE CONFERENCE

Case 1 Emission Reductions Estimates

(Gasoline Displaced & On-Site Diesel Electricity Displaced)

- **Significant GHG emission reductions of 830 kg CO_2-e (68%) per incremental barrel of oil**



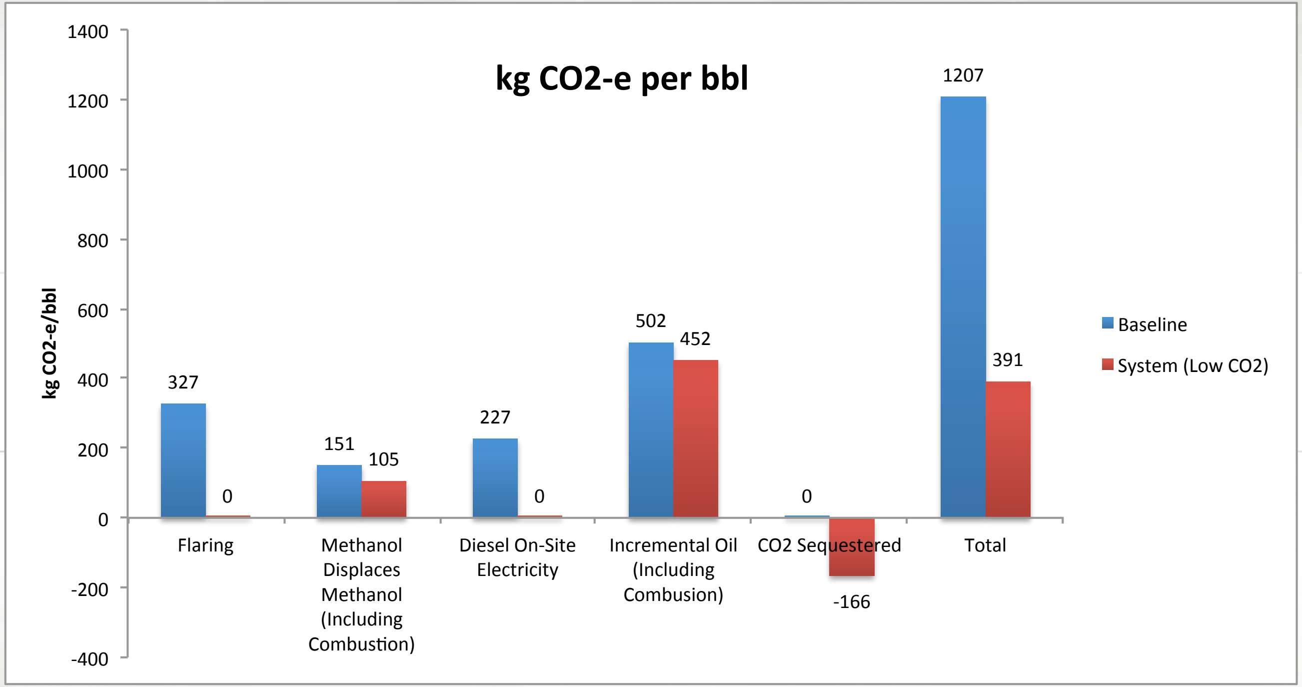
Cases Analyzed: Flare Gas Utilization in CO_2-EOR

Feedstock	Liquid Fuel Displaced		Electricity Type Displaced
	Gasoline	Conventional Methanol	
Flare Gas	**Case 0**		Grid
Flare Gas	**Case 1**	**Case 2**	On-Site Diesel
Natural Gas			Grid
Natural Gas	**Case 3**	**Case 4**	On-Site Diesel

Case 2 Emission Reductions Estimates

(Conventional Methanol Displaced & Diesel Displaced)

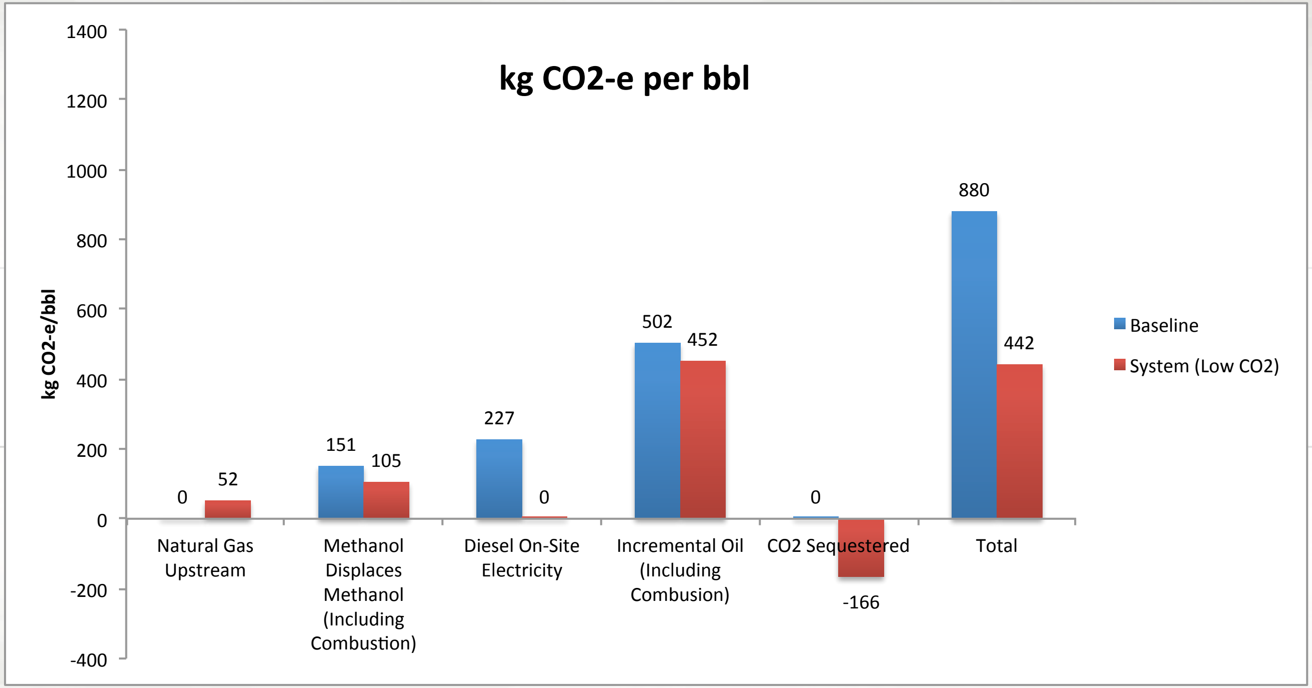
- Slightly lower reductions of 820 kg CO_2-e (68%) per bbl when methanol displaced



Case 4 Emission Reductions Estimates

(Same as Case 2, but Commercial Natural Gas Feedstock)

- Emission reductions of 440 kg CO_2-e (50%) per bbl when NG used & methanol displaced



What happens when higher CO_2 injection ratios per barrel are utilized with low-cost CO_2?

Advanced Resources International DOE Study – Next-Generation CO_2-EOR addresses:

"So far, except for a handful of cases, the actual performance of CO_2-EOR has been less than optimum due to:

- Geologically complex reservoirs
- Limited process control
- **Insufficient CO_2 injection**

Source: Adapted from Robert Ferguson, et al., Advanced Resources International, 8th Annual CCS Conference, Pittsburgh, PA, 2009.

Mobile CO_2-EOR Coupled with "Next Generation" CO_2 Injection Strategies

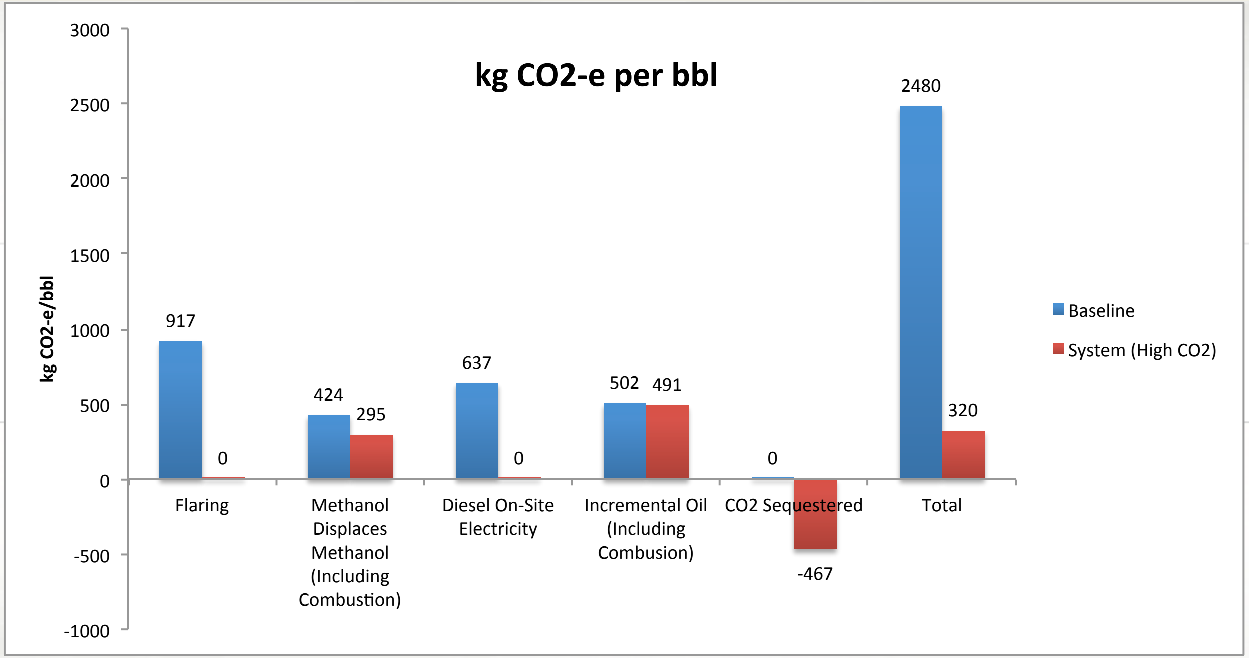
Accordingly, a case was developed coupling Mobile CO_2-EOR with "Next-Generation" CO_2 injection strategies (subcase 2B):

- **Default case: "Current practices" storage of ~3.8 mcf/bbl net CO_2 stored (0.22 t CO_2/bbl)**
    - This is the default case presented above
- **Subcase 2B: "Next-generation" storage of 11.7 mcf/bbl net CO_2 stored (0.61 t CO_2/bbl) coupled with Mobile CO_2-EOR**

Case 2B Emission Reductions Estimates

(Flare gas feed, Methanol displaced, & "Next-generation" CO_2-EOR)

- Significantly higher reductions of 2,200 kg CO_2-e (90%) per bbl when 11.7 mcf/bbl used
- Results suggest essentially "carbon-free" or "carbon-neutral" oil production (90%)



Mobile CO_2 solves key market barrier for EOR

- Most oil fields cannot achieve financially viable CO_2-EOR production because "**currently, CO_2 supply cost (capture and transportation infrastructure) is too high in Alberta.**"
- "By far the bulk of the CO_2 waste streams are dilute CO_2 from combustion and cost in the range of $100/ton **($5.39/mcf)** for capture (including dehydration and compression)."
- "CO_2-EOR projects, on the other can nominally afford CO_2 in the range of $20 to $40/ton **(~$1 to $2/mcf)** depending on the reservoir."
- **Mobile CO_2-EOR can achieved <$2/mcf CO_2**

Source: Gunter, B., Longworth, H., *Overcoming the barriers to commercial CO_2-EOR in Alberta, Canada*, AIEES, May **2013**.

Concluding Remarks

- **LCA Assessment reveals that mobile CO_2-EOR utilizing flare gas resources can produce "carbon-neutral" oil**
- **In the process, we also produce:**
  - **On-site emission-free electricity, displacing diesel**
  - **Valuable liquid fuels (methanol)**
  - **Incremental oil production**

- **Mobile CO_2 enables:**
  - Pilot EOR projects before building a CO_2 pipeline
  - EOR in small and medium-sized fields, and in fields that are far from CO_2 pipelines
  - CO_2 fracking (the subject of another CCUS 2016 talk)

Pioneer Energy Background

Founder
- Astronautical engineer Dr. Robert Zubrin

Resources
- $30+ million private capital
- $550,000 DOE (RPSEA) grant
- $500,000 Canadian grant
- $2.7M NASA-funded research
- IP portfolio of 30+ issued U.S. patents, 3 in Canada

Product lines
- Field mobile natural gas processing plant
- Field mobile CO_2-EOR systems
- Synthetic fuel technology for butanol and C4+ chemicals/fuels

Team
- 15 engineers, chemists, technicians, and machinists

Partners

McMaster University

CLEMSON UNIVERSITY