Thirteenth Annual Conference on Carbon Capture, Utilization & Storage

3-G: Capture/Utilization of CO_2 from & for Liquid Fuel Production

Reducing Greenhouse Gas Emissions through Mobile Systems for Methanol Production, Electricity Generation, & CO_2-Enhanced Oil Recovery utilizing North America's Flare Gas Resources

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April 28-May 1, 2014 • David L. Lawrence Convention Center • Pittsburgh, Pennsylvania

Acknowledgements & Disclaimer

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

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.

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North Dakota from Space: Wasted flare gas is both an economic & environmental problem

North Dakota flares 190 **million** ft^3 per **day** = 69 billion ft^3 per year (69 BCF/yr)
World flares 7 **trillion** ft^3 (TCF) per **year** (7,000 BCF/yr)

Alberta, Canada from Space: Similar Situation

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

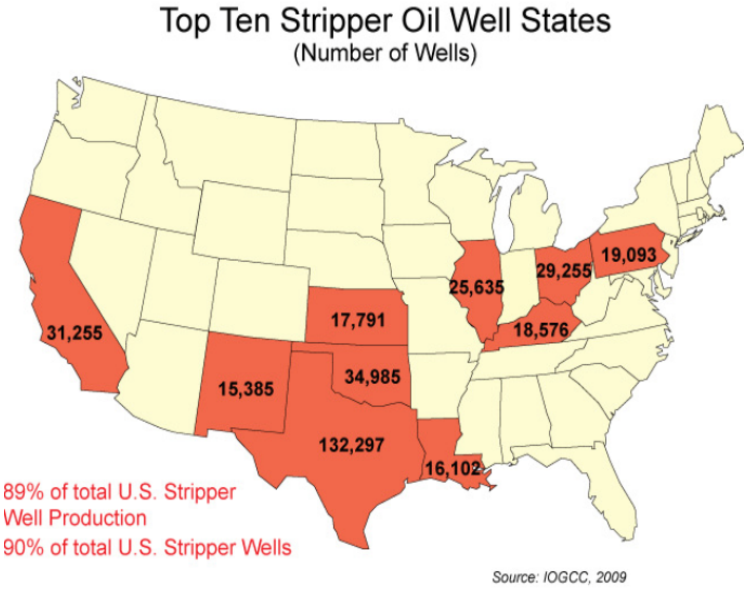
North Dakota flares 69 billion ft^3 per year ……………………… 69 BCF/yr

World flares 7 **trillion** ft^3 (TCF) per year …………………… 7,000 BCF/yr

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



Top Ten Stripper Oil Well States

(Number of Wells)

89% of total U.S. Stripper Well Production

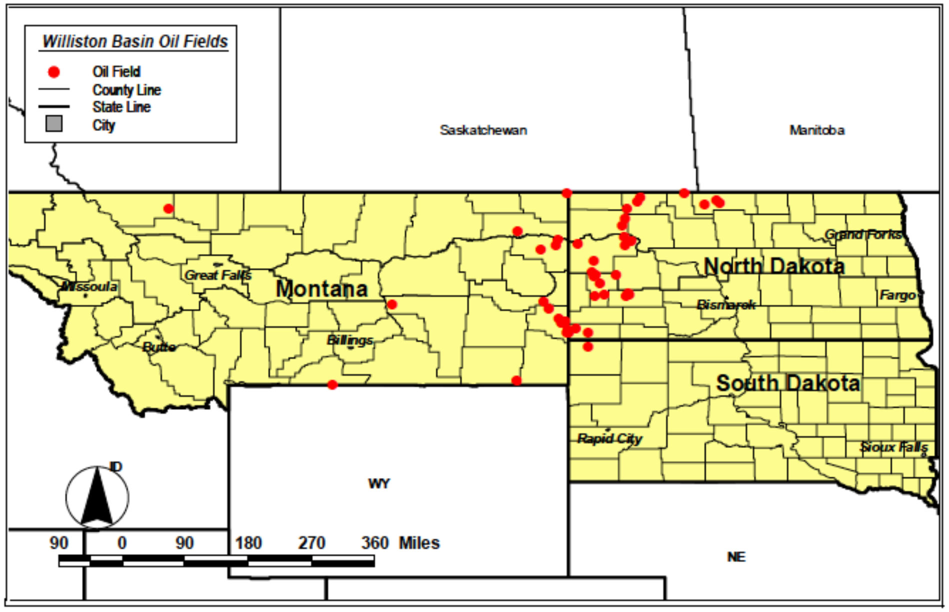
90% of total U.S. Stripper Wells

Source: IOGCC, 2009

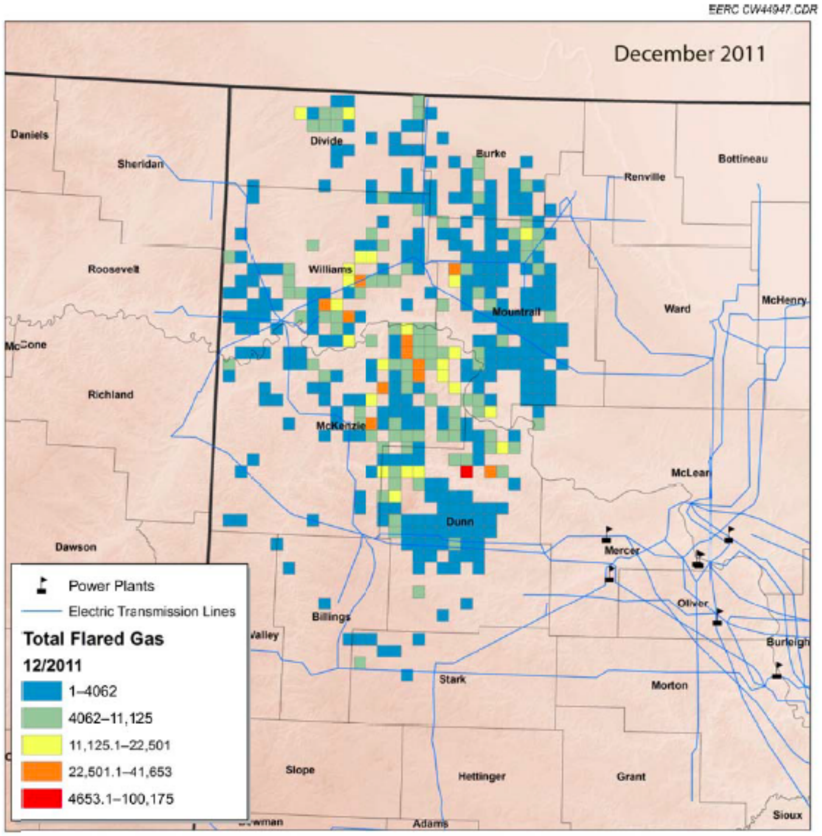
Note: It could take 5-10 years to build a new CO_2 pipeline

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

Fields amenable to EOR in ND

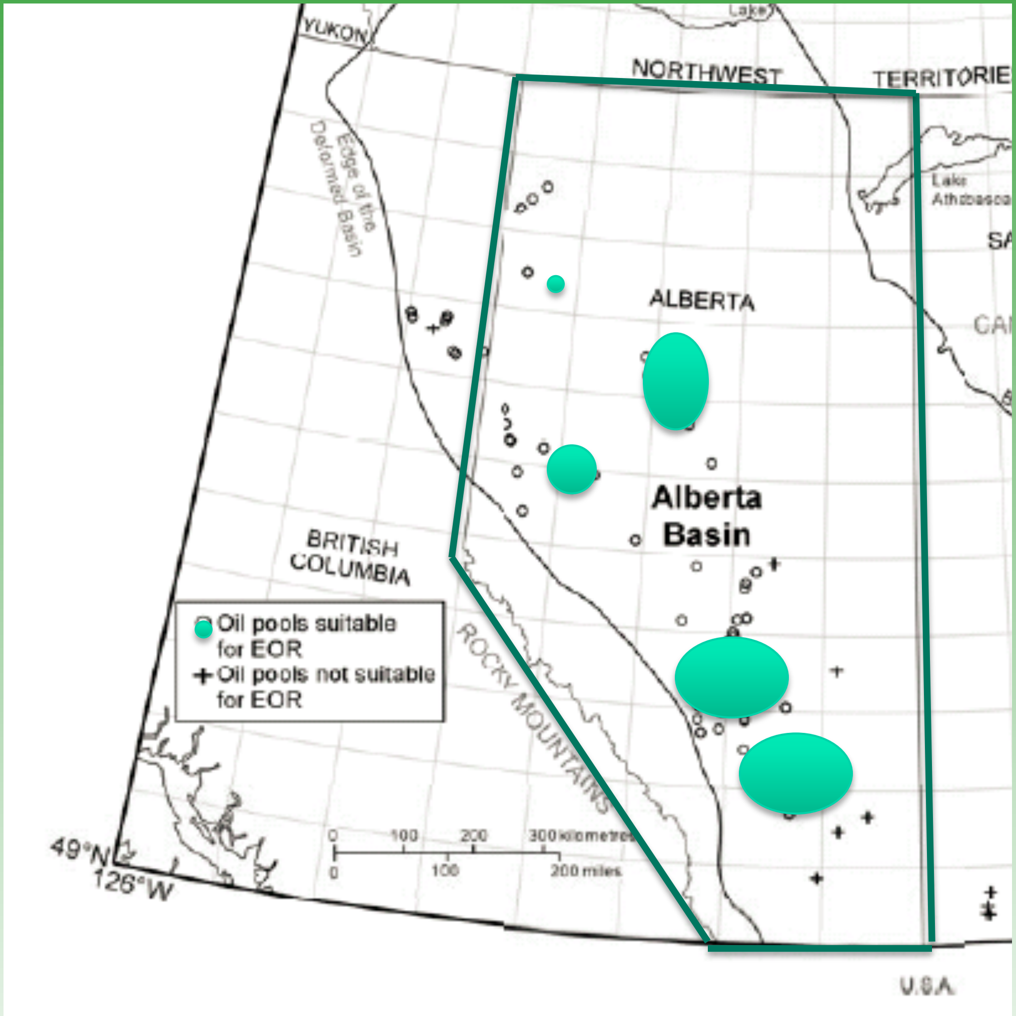


Flare sites in ND



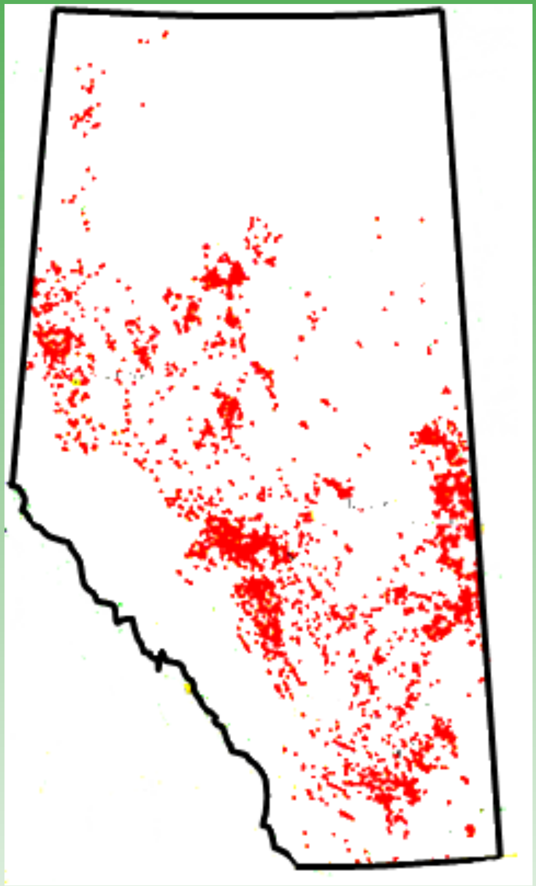
…also in Alberta, flare sites are close to fields with CO_2-EOR potential

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**.

Full Scope of the Opportunity

- The Williston Basin (ND, SD, MT) has at least **2.5 to 5.2 billion barrels** of incrementally recoverable oil with CO_2-flooding, allowing for the sequestration of **120 to 130 million metric tons (Mt) CO_2**.

- 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 incrementally 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 .

Solution: A mobile system to convert flare gas into H_2, CO_2, and liquid fuel

➡ Gas
➡ Liquid

Flare gas

Mobile System

H_2

Used to generate electricity

or

NH_3 *Used to manufacture fertilizer*

Methanol

Can be sold as a commodity chemical OR

Used as a gasoline extender

CO_2

CO_2 Enhanced Oil Recovery (EOR)

and/or

CO_2 Sequestration

Introducing Mobile CO_2-EOR

Mobile equipment processes flare gas and produces CO_2 *in-situ,* eliminating the cost of transporting the gas, large capital outlay, and time required for pipeline construction

- **The system steam-reforms natural gas to EOR-grade CO_2 and H_2 at the oil field location**
- **CO_2 is injected into an injection well, H_2 is burned in a generator**
- **Produces near-zero-emission electricity for local use or sale to the grid**
- **Revenue from electricity offsets the cost of unit operation**
- **The system can also produce methanol (gasoline extender and commodity chemical worth $0.60/kg)**

Evaluating CO_2 Emission Reductions: Methodology

We used Alberta as a case study, and these results will be generalized to Bakken and other locations in Future Work.

- **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. The system emissions included:**
    - **Incremental Oil from CO_2-EOR**
    - **Methanol**
    - **Electricity from the produced H_2 consumed on-site *(Or sold to the grid)***
    - **Carbon sequestered incidental to oil recovery ("Current practices" of about 4.2 mcf/bbl and "Next-generation" of 11.7 mcf/bbl)**

Cases Modeled in this Study

- **Case 0 – Feedstock: Flare Gas**
  - Displacement: Gasoline and Grid Electricity

- **Case 1 – Feedstock: Flare Gas**
  - Displacement: Gasoline and On-Site Diesel Electricity
- **Case 2 – Feedstock: Flare Gas**
  - Displacement: Conventional Methanol and On-Site Diesel Electricity

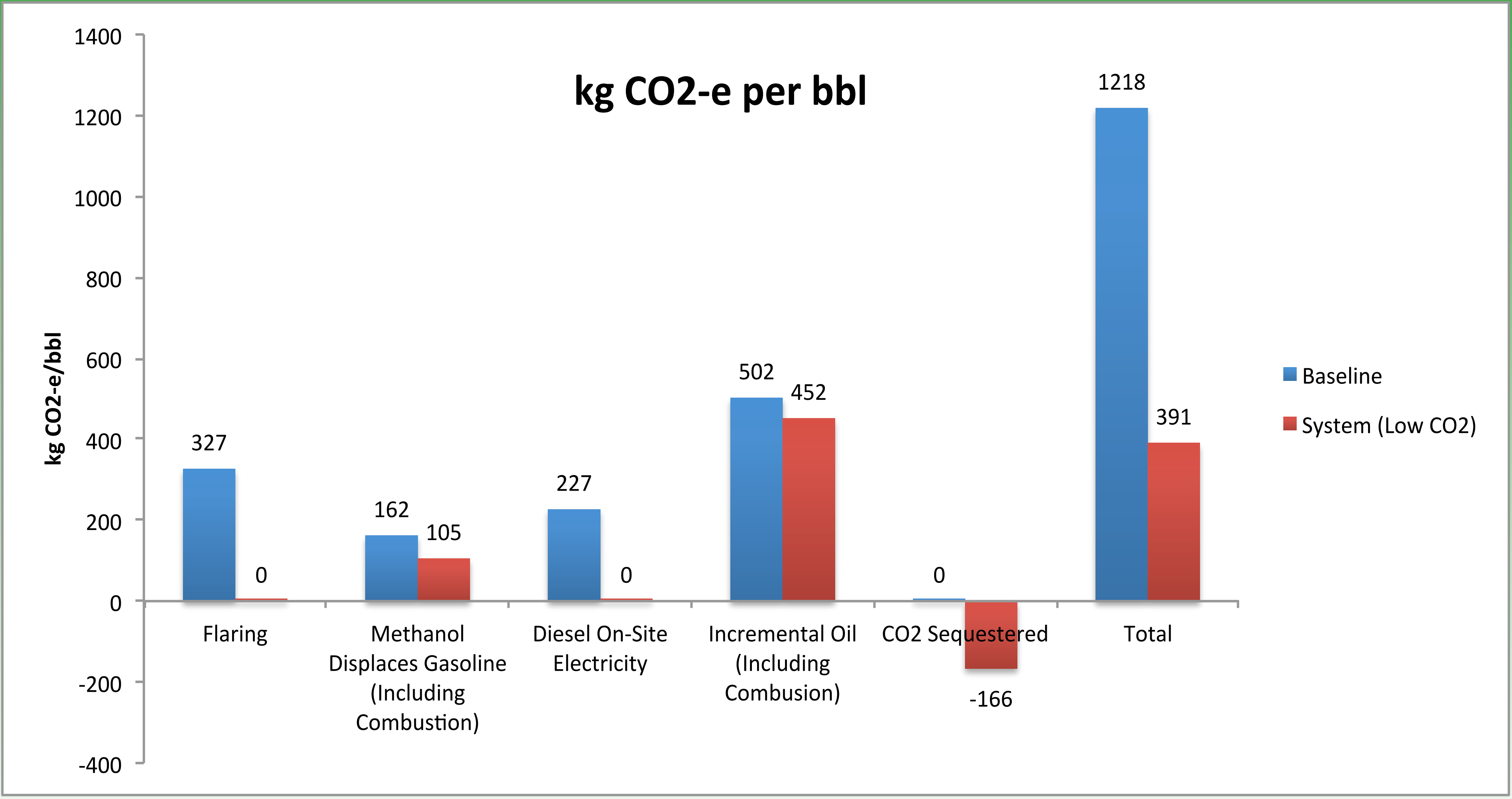
- **Case 3 – Feedstock: Natural Gas**
  - Displacement: Gasoline and On-Site Diesel Electricity
- **Case 4 – Feedstock: Natural Gas**
  - Displacement: Conventional Methanol and On-Site Diesel Electricity

For brevity, only results for Cases 1, 2, and 4 are presented; full results in forthcoming paper.

Results: Case 1 Emission Reductions

(Gasoline Displaced & On-Site Diesel Electricity Displaced)

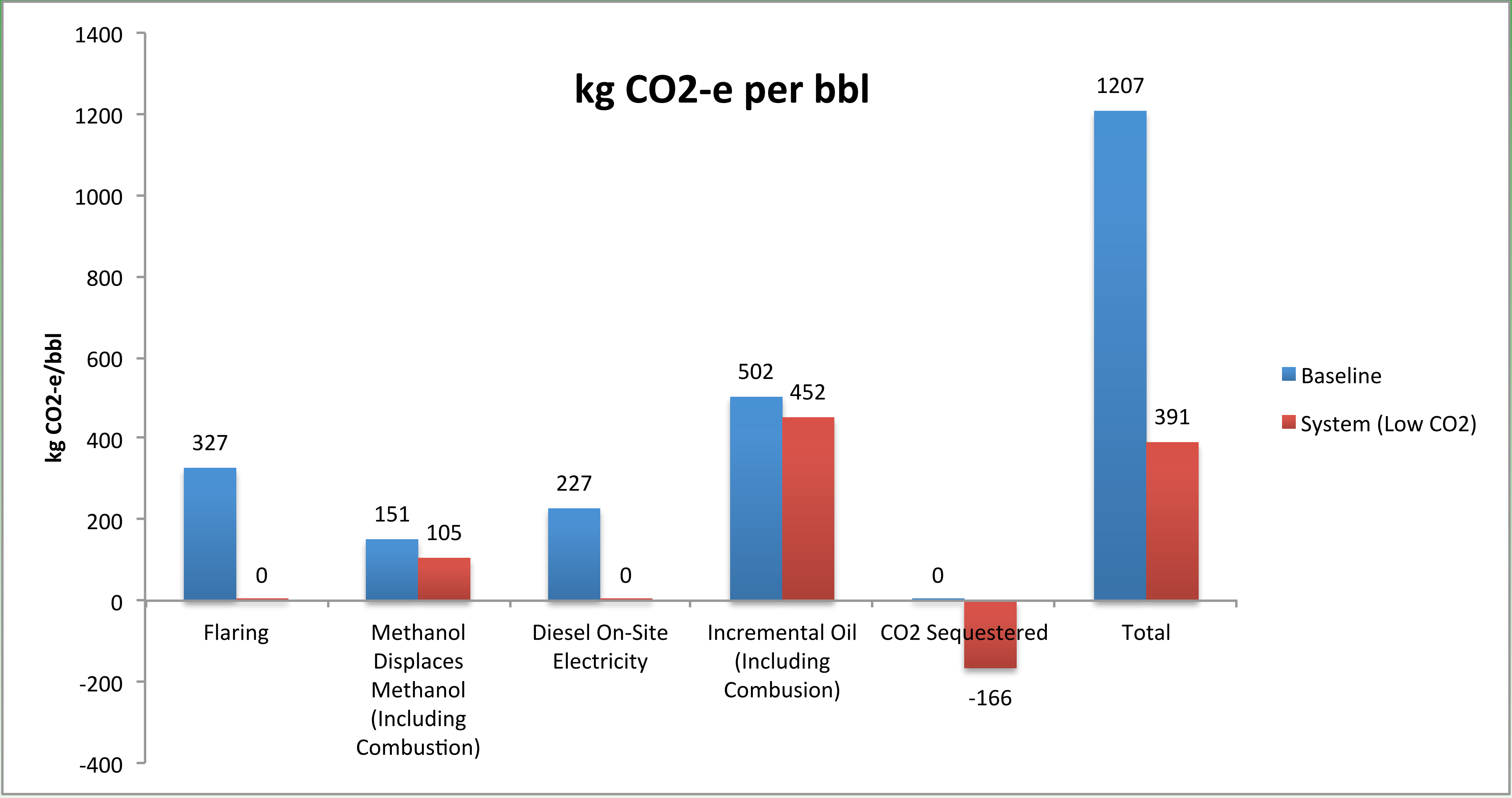
- **Significant GHG emission reductions of 830 kg CO_2-e (68%) per incremental barrel of oil**



Results: Case 2 Emission Reductions

(Conventional Methanol Displaced & Diesel Displaced)

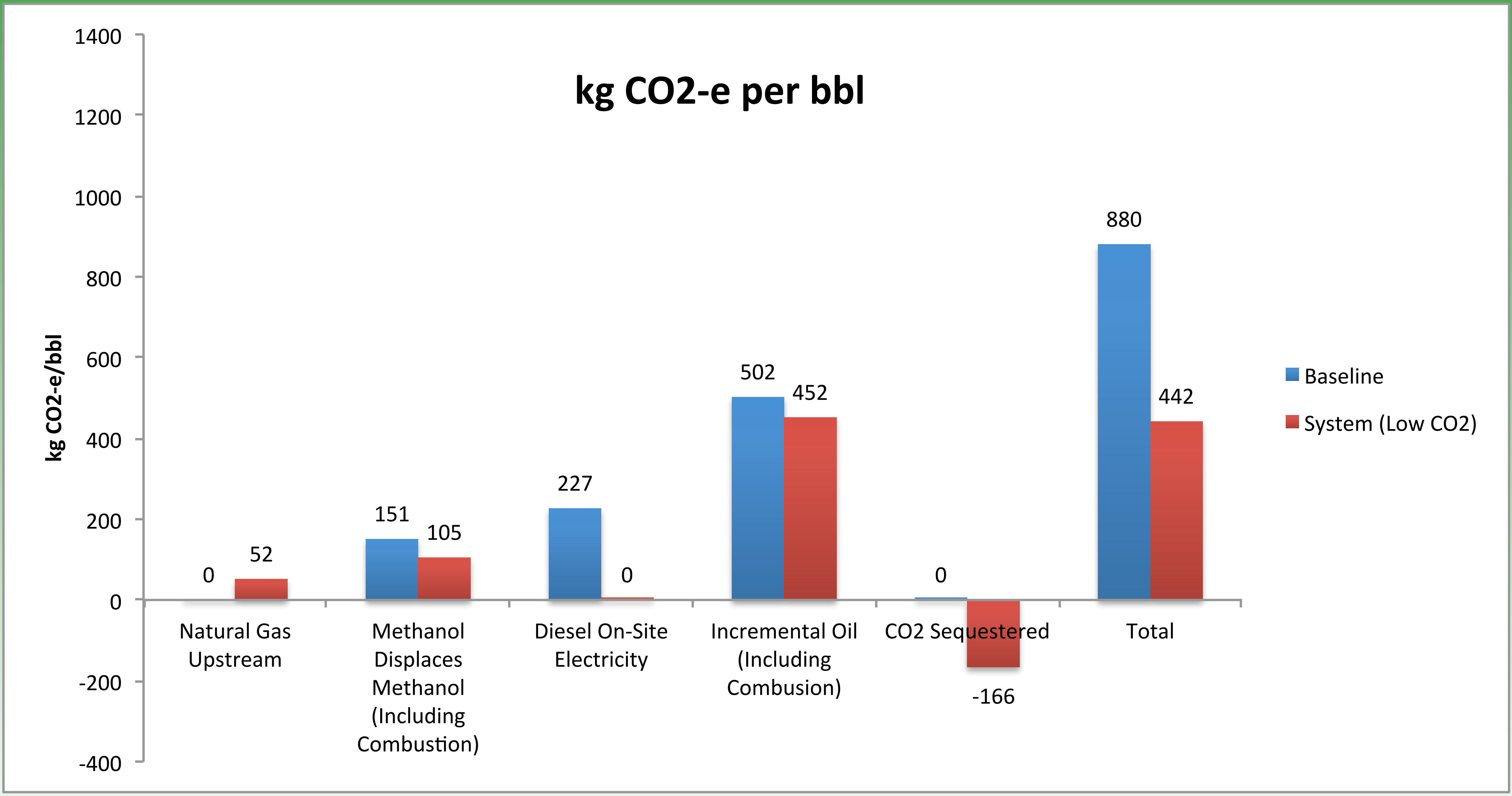
- **Slightly lower reductions of 820 kg CO_2-e (68%) per bbl when methanol displaced**



Results: Case 4 Emission Reductions

(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 when low-cost CO_2 is available?

U.S. DOE's Definition of "Next Generation" CO_2-EOR Technologies

"Reservoir modeling and selected field tests show that high oil recovery efficiencies are possible with innovative applications of CO_2-EOR.

"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.

Low-Cost CO_2 enables Integrated CO_2-EOR & CO_2 Storage

- **With alternative CO_2 storage and EOR design, enabled by low-cost CO_2 provided by mobile CO_2, much more CO_2 can be stored <u>and</u> more oil can be recovered**
- **Even though more oil is produced, the over-all carbon-intensity of the oil is reduced, potentially producing "carbon-free" or "carbon-neutral" oil**

	Traditional CO_2-EOR (High-Cost CO_2)	**"Next-Generation" Low-Cost CO_2**
CO_2 Storage (million tons)	14	109
Storage Capacity Utilization (%)	13%	76%
Oil Recovery (million bbls)	64	180
% Carbon Neutral (CO_2 Sequestered / CO_2 in Produced Oil)	**60%**	**160%**
CO_2 Storage Per Barrel Recovered (t/bbl)	**0.22**	**0.61**
CO_2 Storage Per Barrel Recovered (mcf/bbl)	**4.2**	**11.7**

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

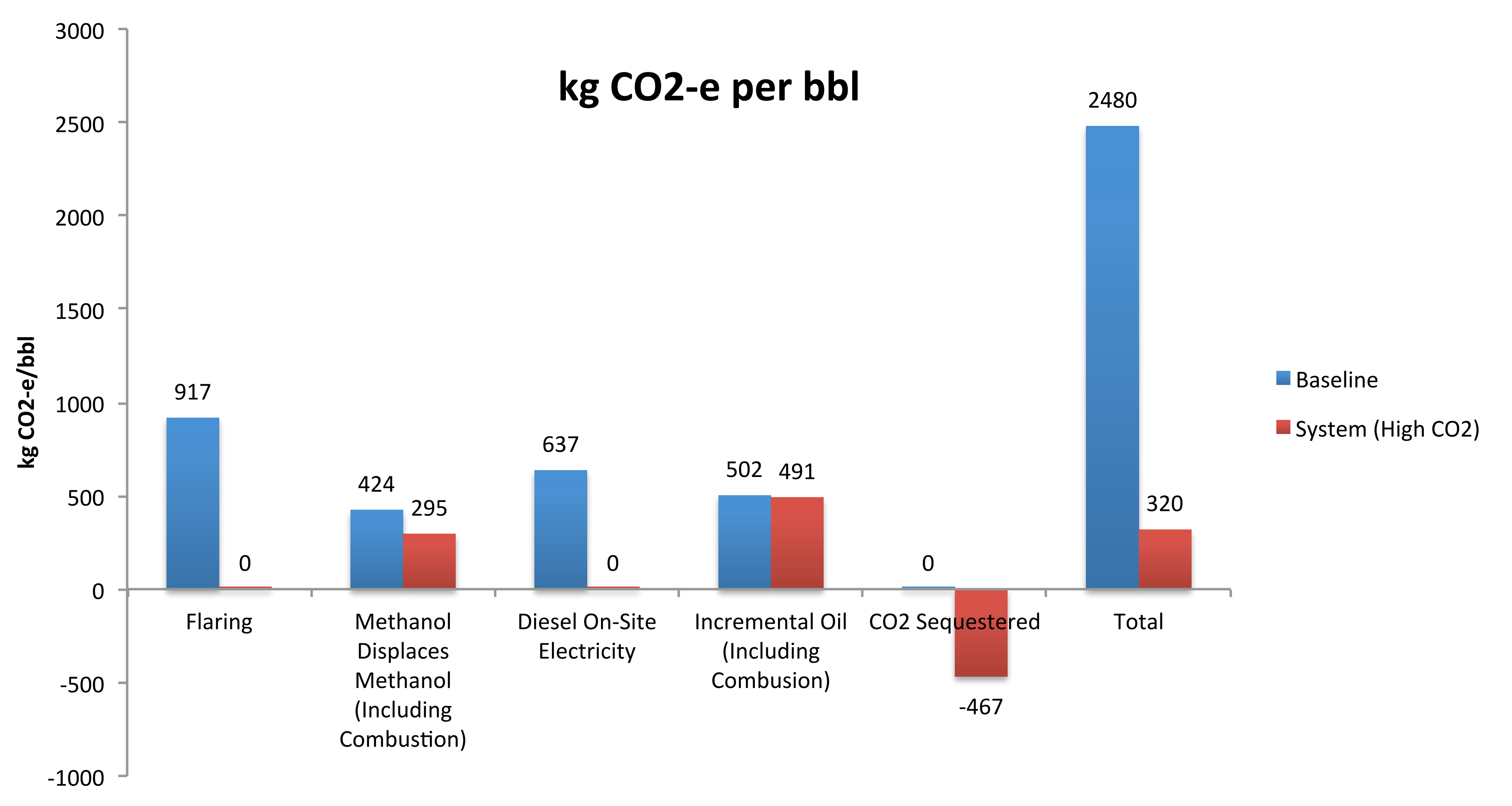
Mobile CO_2-EOR Coupled with "Next Generation" CO_2-EOR Injection Strategies

- **Accordingly, each case was also modeled with subcase B:**
  - **Default case: "Current practices" storage of ~4.2 mcf/bbl net CO_2 stored (0.22 t CO_2/bbl)**
    - This is the default case presented above
  - **Subcase B: "Next-generation" storage of 11.7 mcf/bbl net CO_2 stored (0.61 t CO_2/bbl)**
- ***For brevity, only results for subcase 2B are presented***

Results: Case 2B Emission Reductions

(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%)**



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
- Revenue from oil and methanol offset costs of CO_2 capture
- CO_2-EOR operations will develop CO_2 sequestration infrastructure
- Early implementation of CCS will drive costs down through "learning by doing"

Small Scale Pilots & Demonstration Projects using Mobile CO_2-EOR

Widespread Market Penetration of CCS Technology

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

Cheap CO_2 enables early application of CO_2-EOR

- **Through the early application of CO_2-EOR, more oil is recovered in a shorter period of time and more CO_2 sequestered**
- **Combining integrated CO_2-EOR and storage together with early application of CO_2-EOR substantially improves carbon footprint of oil**

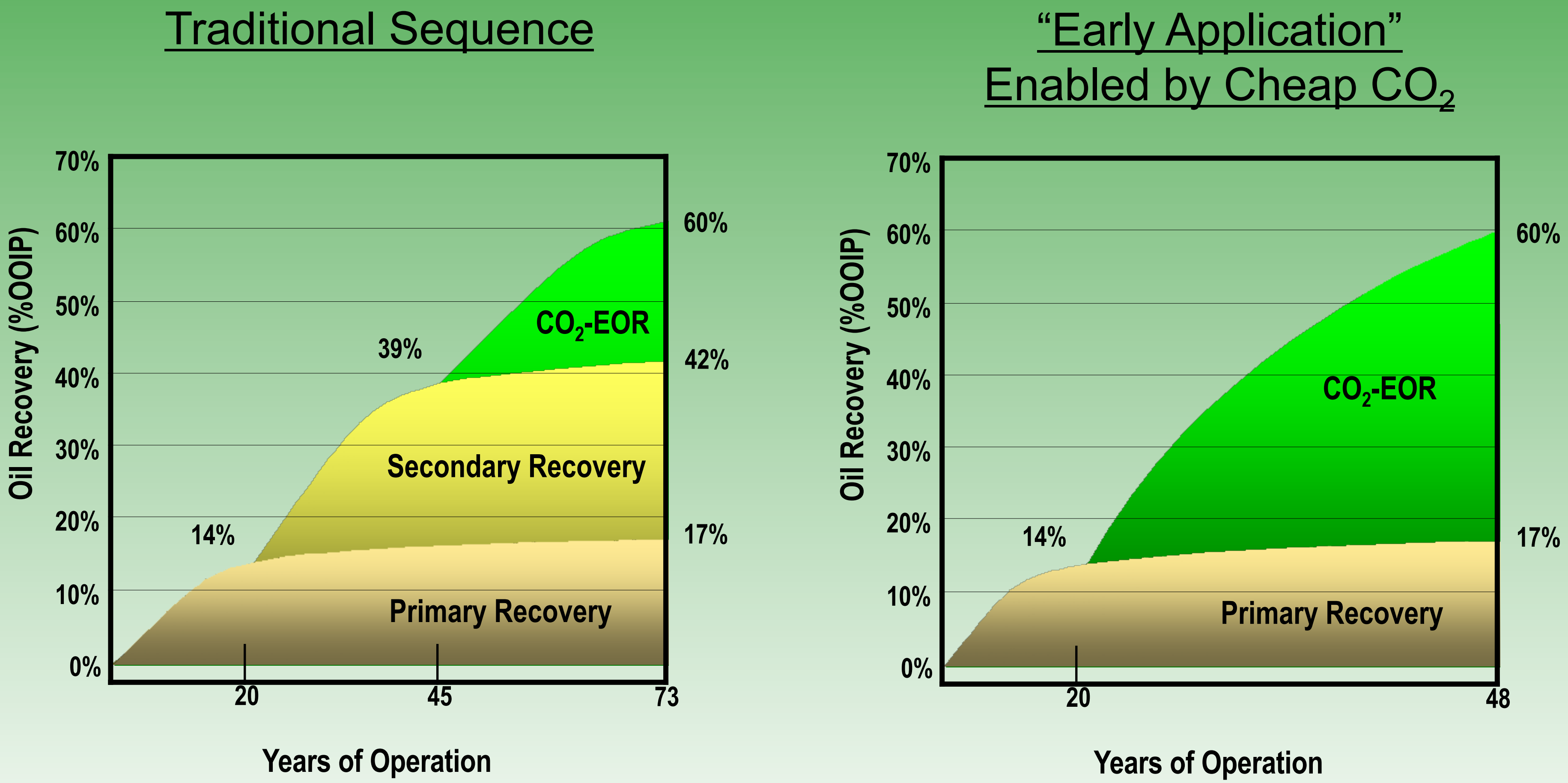


Figure Source: Adapted from Robert Ferguson, et al., Advanced Resources International, 8th Annual CCS Conference, Pittsburgh, PA, 2009.

Mobile CO_2 solves a key market barrier for CO_2-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 [and around the world].**

- "The cheapest streams are those from chemical plants which only have to be dehydrated and brought to pressure for pipelining, nominally $20/tonne ($1.08/mcf) of CO_2. By far the bulk of the CO_2 waste streams are dilute CO_2 from combustion and cost in the range of $100/tonne ($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/tonne (~$1 to $2/mcf) depending on the reservoir. **Therein lies the dilemma or the so called economic gap.**"

Source: Gunter, B., Longworth, H., *Overcoming the barriers to commercial CO_2-EOR in Alberta, Canada*, Alberta Innovates – Energy and Environment Solutions (AIEES), May **2013**.

Transforming currently-wasted gas into valuable resources

Example: Flaring in Alberta today

2.1 %	of Alberta's GHGs originate from flaring & venting
868 million m^3	gas flared/year
333 million m^3	gas vented/year
6-8 million tons	CO_2-e/year

5 units could capture 17,200 tons methane/year and produce:

27,000 t methanol	**$11 M**
900 MMCF CO_2 → **150,000 bbl oil from CO_2-EOR[2]**	**$15 M**
6 MWe clean energy[3]	**$2.6 – $21 M**

All numbers calculated yearly for 5 PERT-2 units, corresponding to 5,000 mcf/d flare gas input

1 Johnson & Coderre, 2012

2 Assuming 6 MCF CO_2 per incremental barrel from EOR (not including recycled CO_2)

3 Assuming all electricity generated is fed to grid ($.05/kWh). In practice, energy generated could replace expensive diesel fuel ($0.40kWh), resulting in $21M of savings.

Concluding Remarks

- **We put carbon that would otherwise be released as CO_2 from flare gas back into the Earth by CO_2-EOR and/or sequestration**
- **In the process, we also produce:**
  - **Valuable liquid fuels (methanol)**
  - **On-site emission-free electricity, displacing diesel**
  - **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
  - waterless fracking
- Large EOR opportunities in the U.S. & Canada

Additional Support Slides

“New drilling and exploration might be more romantic than secondary work but often not as profitable.”

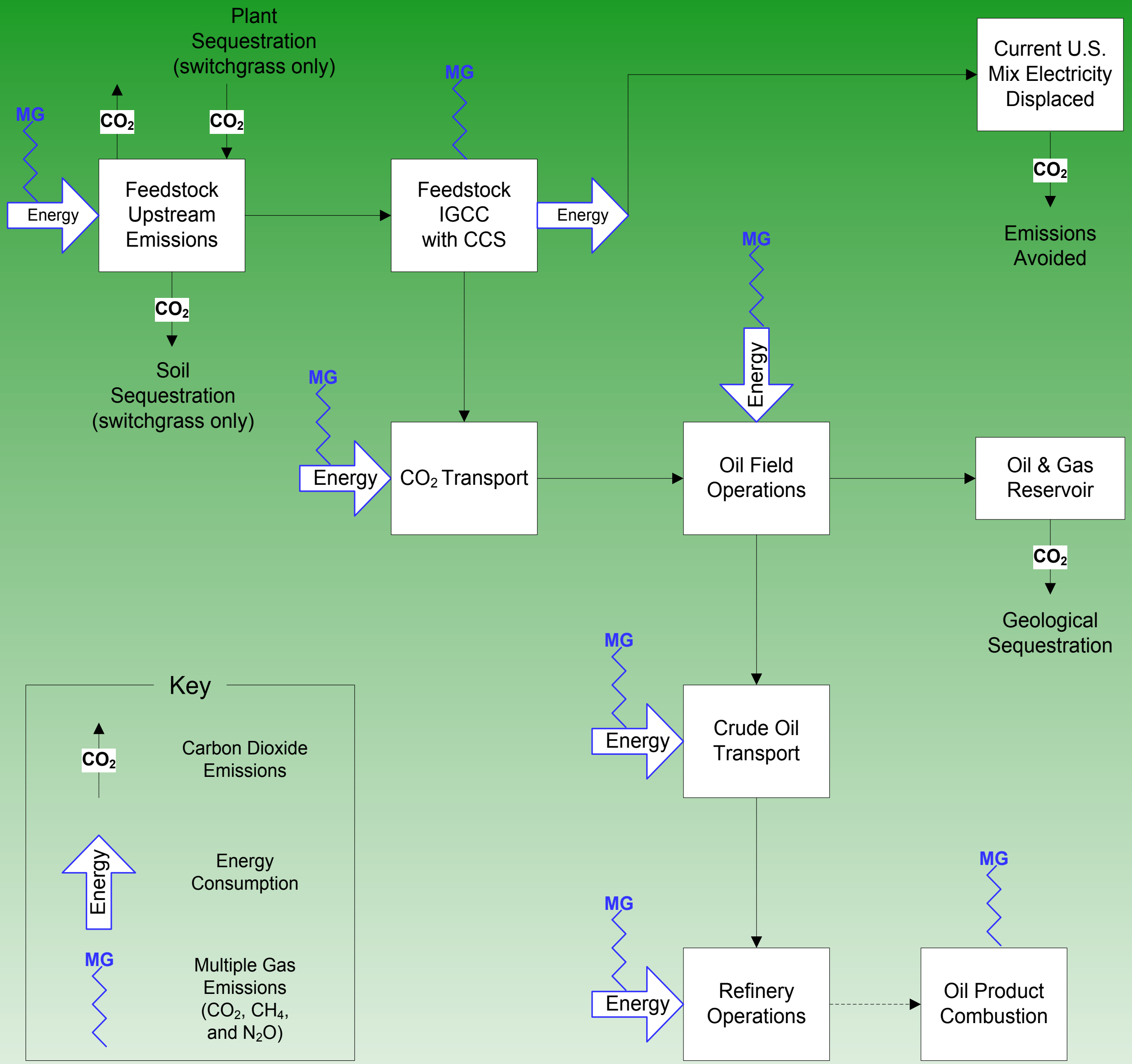
E. V. O’Rourke, 1940, AAPG Bulletin,
Recent Secondary Recovery of Oil in Ohio

Expanding CO_2-EOR market opportunities

- Streamlines EOR projects by deploying mobile CO_2 generation where needed
- Validate the field's probable EOR results before risking the Cap-Ex on a stationary pipeline

- Expand CO_2-EOR industry by making pilots more affordable
- Operate a cost-effective EOR project using a mobile unit
- Or build a permanent pipeline and move the mobile CO_2 infrastructure to the next field
- Start a full EOR project in a year, practically anywhere
- Opens huge markets for fields out of reach of pipeline CO_2

LCA System Boundary used in Study



<u>Source:</u> Hussain, D., et al., *Comparative lifecycle inventory (LCI) of greenhouse gas (GHG) emissions of enhanced oil recovery (EOR) methods using different CO_2 sources*, **International Journal of Greenhouse Gas Control**, 2013.

Baseline Emission Data

- **Flare Gas Emissions:** **2.75 g CO_2e / g CH_4**

- **Alberta Average Gasoline Production:** **25.5 g CO_2e / MJ**
- **Gasoline Combustion:** **64.6 g CO_2e / MJ**
- **Alberta Average Methanol Production:** **25.5 g CO_2e / MJ**
- **Methanol Combustion:** **58.5 g CO_2e / MJ**

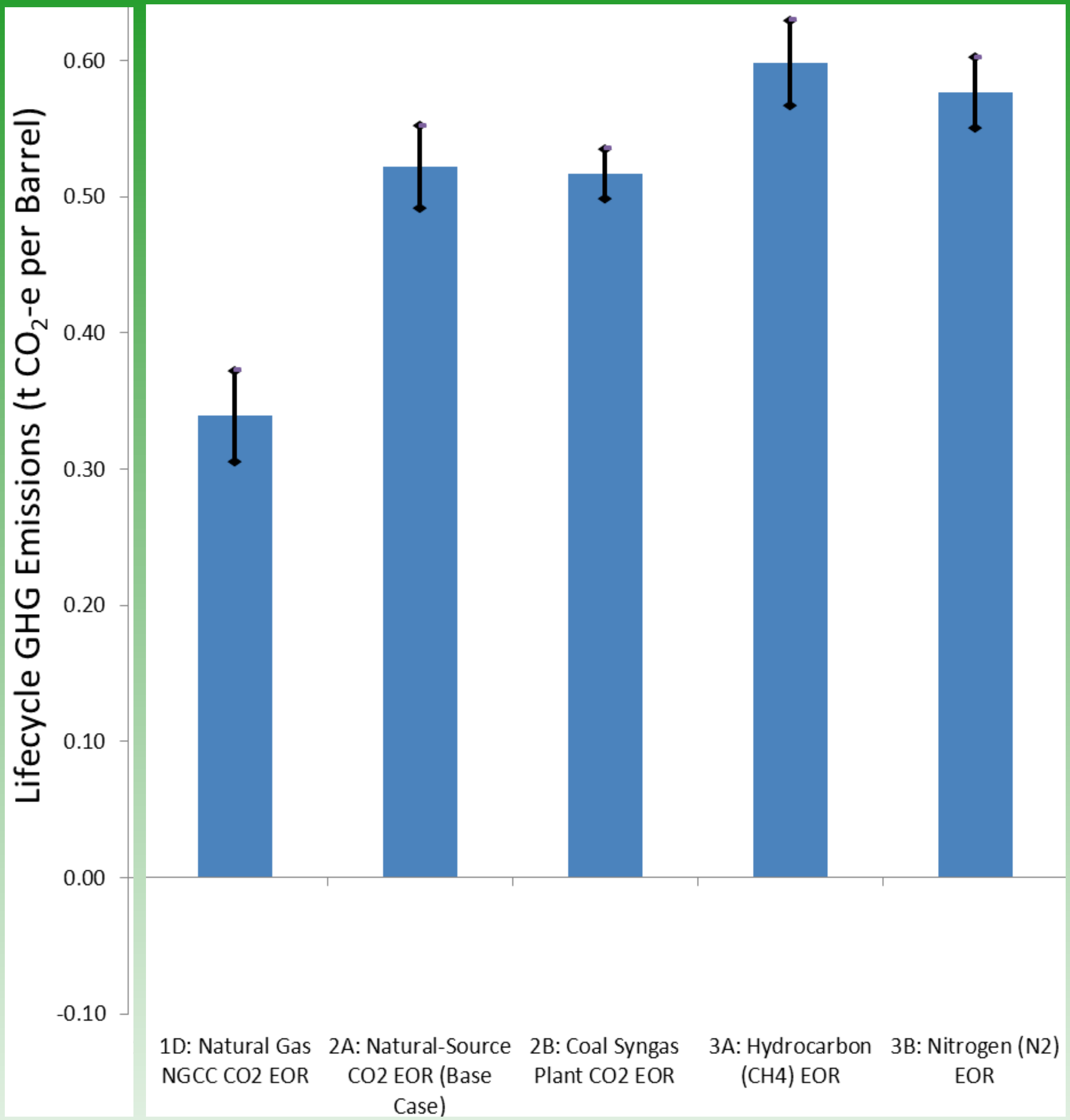
- **Alberta Average Grid Electricity:** **0.65 kg CO_2e / kWh**
- **On-Site Diesel Electricity:** **0.80 kg CO_2e / kWh**

- **Average Alberta Oil Production Emissions:** **72.4 kg CO_2e / bbl**
- **Oil Combustion:** **430 kg CO_2e / bbl**

System Emission Data

- **Those system emissions that are the same as the baseline are marked as (same)**
- **Flare Gas Capture: 99%**
- **Upstream Natural Gas Emissions: 0.43 g CO_2e / g CH_4**
- **Methanol Combustion: 58.5 g CO_2e / MJ (same)**
- **Electricity from H_2: 0 kg CO_2 / kWh**
- **On-Site Electricity Consumption: 63.4 kWh / bbl**
- **Fugitive System CO_2 Emissions: 21.7 kg / bbl (10%)**
- **Oil Combustion: 430 kg CO_2e / bbl (same)**
- **CO_2 Sequestered (Net Stored) in Oil Field:**
  - **Subcase A: Conservative assumption on oil recovery efficiency based on “current best practices” of 4.6 bbl/t CO_2 recovered (4.2 mcf/bbl) (Source: Previous work, Hussain et al., 2013)**
  - **Subcase B: “Next-generation” CO_2-EOR of 11.7 mcf/bbl (Source: DOE)**

Previous Lifecycle Assessment (LCA) Results



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*, **International Journal of Greenhouse Gas Control**, 2013.