Economics for CO$_2$ Capture, Compression and Transportation in the Mid-Continent

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In collaboration with
Kansas Geological Survey
Why we are here today

45 Q is a game changer, making a variety of CCUS projects technically and economically feasible.

4.3 million tonne/yr could be captured in NE and KS ethanol plants and transported to Kansas oil fields for $14 per tonne (0.75/mcf).

- Kansas oil recovery could increase by 28% (10 million BO/yr) through EOR by injecting 4.3 Mt/yr (221 mmcf/d).

Small ethanol plants could capture and directly inject CO₂ into a saline aquifer

- 22% ROI after $85 Million in 45Q credits are applied.
- Might also derive significant benefits with a substantially lowered carbon intensity (i.e.: CA LCFS)
Source for Economic Modeling and Resources

**Pipeline CapEx and OpEx** are derived from FE/NELT CO2 Transport Cost Model (Grant & Morgan, 2014), modified by Dubois and McFarlane (2017) – see poster.

**Capture and compression CapEx and OpEx** are based on cost data from three DOE-funded projects (Details in White Paper: Capturing and Utilizing CO2 from Ethanol)

See your reference sheet for:
- Acronyms
- Conversions
- Rules of thumb

See me at the posters for:
- Pipeline cost model details
- Economic model inputs and assumptions
Capture and Storage at Variable Scales

Project types and scales are nearly limitless in MidCon

Range from

- **Simple**: point-to-point (150,000 tonnes/yr)
- **Somewhat complex**: multiple sources to single market for EOR
- **Very complex**: multiple sources to multiple fields for EOR

### Scenarios presented involve the highlighted boxes

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Description</th>
<th>Ethanol Volume (Mg/yr)</th>
<th>CO2 Volume (Mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol plants</td>
<td>Single Small</td>
<td>55-110</td>
<td>0.15-0.3</td>
</tr>
<tr>
<td></td>
<td>Single Large</td>
<td>300</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Multiple - 15 plants</td>
<td>1575</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>Multiple - 34 plants</td>
<td>3643</td>
<td>9.9</td>
</tr>
<tr>
<td>Coal Power</td>
<td>Single</td>
<td></td>
<td>1-4</td>
</tr>
<tr>
<td>Storage (Market)</td>
<td>EOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single field - small (KS)</td>
<td></td>
<td>0.15-0.3</td>
</tr>
<tr>
<td></td>
<td>Multiple small fields (KS)</td>
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<td>2-4</td>
</tr>
<tr>
<td></td>
<td>Large market (W. TX)</td>
<td></td>
<td>4-10</td>
</tr>
<tr>
<td>Saline aquifer</td>
<td>Small local (KS)</td>
<td></td>
<td>0.15-0.3</td>
</tr>
<tr>
<td></td>
<td>Single structure (KS)</td>
<td></td>
<td>1.5-3</td>
</tr>
<tr>
<td></td>
<td>Multi-structure storage complex (KS)</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

**CO₂ volume is 90% of calculated nameplate**
Four cases discussed today

1. **Small-scale Point-to-Point for EOR** (0.15 Mt/yr – 2.9 BCF/yr)

2. **Small-scale Capture and Inject for Saline Storage** (0.15 Mt/yr – 2.9 BCF/yr)

3. **Aggregate 15 ethanol plants and transport to multiple Kansas fields** (4.3 Mt/yr – 82 BCF/yr)

4. **Aggregate 34 ethanol plants and transport to Permian Basin** (9.9 Mt/yr – 188 BCF/yr)
But what about Coal-Power CO$_2$

**Petra Nova, Houston**
- Operational for 18 months
- 1.4 Mt/yr captured & compressed
- Transported - 82 mile 12" pipeline to West Ranch oil field
- $1B capital costs (no details)

**Kansas Coal-Power CO$_2$ possibilities**
- Westar, Sunflower, KCBPU (power) and CHS (refinery) are participants in the KGS – ICKan project
- Preliminary engineering study
  - Capture 2.5 Mt/yr from Westar’s JEC
  - Cost for Capture/Compression $46-$78/tonne over 20-yr project.
- Getting closer – needs to stay in the mix
Case 1: Small-scale Point-to-Point for EOR, *Oil Operator Owns CCT System*

Current Kansas example: Conestoga’s (Garden City KS) to Stewart Oil Field since 2012: 55 mgy plant, 15 miles to field

Future EOR example? Russell Ethanol to Hall-Gurney field via 10-mile line

Generic economic model assumptions

- Capture and compress 150 kt CO$_2$/yr
- 20-mile, 4” pipeline
- Owner equity and secured note (net 5% interest)
- 14-yr project, 2 yrs construction, 12 yrs operations
- Injection begins in 2022
- 45Q credits ($25-$35, avg. $33)
- No inflation is factored
- Pay Ethanol plant $10/tonne CO$_2$
Case 1: Economic Summary

### Cost per tonne CO₂

<table>
<thead>
<tr>
<th>Component</th>
<th>CapEx</th>
<th>OpEx (annual)</th>
<th>Cost with 45Q tax credits</th>
<th>Cost without 45Q tax credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture/Compression</td>
<td>$0.66</td>
<td>$8.58</td>
<td>$0.79 $1.74</td>
<td>$34.25 $1.80</td>
</tr>
<tr>
<td>Pipeline</td>
<td>$0.51</td>
<td>$1.71</td>
<td>$1.22 $2.20</td>
<td>$34.75 $2.20</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$11.45</strong></td>
<td><strong>$20.29</strong></td>
<td><strong>$21.81</strong> $4.94</td>
<td><strong>$34.00</strong> $4.94</td>
</tr>
</tbody>
</table>

- **Market CO₂ value with WTI = $60:**
  - $22.90/t ($1.20/mcf)

- **Cost of 45Q tax credits make this case economically viable:**

### Cost

<table>
<thead>
<tr>
<th>Component</th>
<th>CapEx</th>
<th>OpEx (annual)</th>
<th>Cost with 45Q tax credits</th>
<th>Cost without 45Q tax credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture/Compression</td>
<td>$17.25</td>
<td>$1.28</td>
<td>$18.53 $2.56</td>
<td>$34.53 $2.56</td>
</tr>
<tr>
<td>Pipeline (20 mi, 4&quot;)</td>
<td>$13.21</td>
<td>$0.25</td>
<td>$13.46 $0.25</td>
<td>$34.46 $0.25</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$30.46</strong></td>
<td><strong>$1.53</strong></td>
<td><strong>$32.00</strong> $2.78</td>
<td><strong>$34.53</strong> $2.78</td>
</tr>
</tbody>
</table>

**CCUS in Kansas, July 26, 2018, KS**
### Case 1: Risk and Benefit

#### Oil Operator

**Risks**
1. Capital exposure
   - $30 M for CCT
   - $10s of M for field upgrade
2. Oil field flood failure
3. CO₂ source (ethanol plant failure)
4. MVA and long-term liability

**Benefit**
1. Low-cost CO₂ \( \text{because of } $59 \text{ Million } 45Q \text{ tax credits} \)

#### Ethanol Plant

**Risks**
1. Almost none
2. Loss of lower carbon intensity

**Benefit**
1. Revenue: $1.5 M/yr ($0.027/gal) – for this case
2. Greatly reduced carbon intensity
Case 2: Small-scale Point-to-Point for Saline Storage

*Ethanol Plant Owns CC System*

### Saline Aquifer Storage

**Planned ND example:** Red Trail Energy, Richardson ND inject CO₂ direct into 6500-ft well

- 50 mgy plant, inject 160 kt CO₂/yr

**Economic model assumptions**

- Capture and compress 150 kt CO₂/yr
- Inject onsite, or very close by, into a Class VI well
- Financed with owner equity
- 14-yr project, 2 yrs construction, 12 yrs operations
- Injection begins 2022
- 45Q credits ($39-$50/t, avg. $47.47/t)
- No inflation is factored

*See poster on this project*
Case 2: Economic Summary

<table>
<thead>
<tr>
<th>Cost</th>
<th>CapEx</th>
<th>OpEx (annual)</th>
<th>$ Million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture/Compression</td>
<td>$17.25</td>
<td>$1.28</td>
<td></td>
</tr>
<tr>
<td>Class VI well</td>
<td>$2.5</td>
<td>$0.2</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$19.75</td>
<td>$1.48</td>
<td></td>
</tr>
</tbody>
</table>

Risks
1. $20 Million capital exposure
2. Class VI well permitting
3. Class VI injectivity (rate)
4. CO₂ source (ethanol plant)
5. Unable to capture low-carbon potential

Benefits
1. 22% ROI
2. $5.6M Annual Net Cash Flow
3. $85 Million in 45Q tax credits
4. Greatly reduced carbon intensity
Case 3: Fifteen plants to Kansas oil fields

- 4.3 Mt/yr CO₂ (80.9 BCF/yr)
- 737 miles of pipeline
- 4 to 12 inch diameter
- 15 ethanol plants (1575 MGY capacity)

Gather CO₂ from the largest ethanol plants in NE and KS
Deliver 4.3 Mt/yr to CO₂-ready oil fields in Kansas
10 mmbo/yr possible increased production
Case 3 Economics

Estimated Project Costs

<table>
<thead>
<tr>
<th>Cost $million</th>
<th>Plant Capture</th>
<th>Pipeline Transport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapX</td>
<td>$364</td>
<td>$642</td>
<td>$1,006</td>
</tr>
<tr>
<td>Annual OpX</td>
<td>$37</td>
<td>$16</td>
<td>$53</td>
</tr>
</tbody>
</table>

Note: Rule of thumb
$100k/inch-mile yields $613 million CapX for pipeline

Summary:
- Total CapEx $1,006 M
- 45Q tax credits $1,774 M
- Cost of Capital = 10%
- 2-yr construction and 20 yrs operations (ops in 2024)
- 12 yrs of 45Q credits - Avg. $34.48/t

Costs per Unit of CO₂

<table>
<thead>
<tr>
<th></th>
<th>Pipeline</th>
<th>Capture &amp; Compress</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapEx ($/t)</td>
<td>$1.71</td>
<td>$0.69</td>
<td>$1.90</td>
</tr>
<tr>
<td>OpEx ($/t)</td>
<td>$3.80</td>
<td>$8.58</td>
<td>$12.39</td>
</tr>
<tr>
<td>Total ($/t)</td>
<td>$5.02</td>
<td>$9.27</td>
<td>$14.29</td>
</tr>
</tbody>
</table>

Tax credits applied directly to CapEx in model to calculate price/tonne

Without 45Q
$42 / tonne ($2.19 / mcf)

$/mcf $0.75
Case 4: Large-scale, 10 Mt/yr

- 9.85 Mt/yr CO₂ (187 BCF/yr, 513 mmcfd)
- 1546 miles of pipeline
- 4 to 20 inch diameter
- 34 ethanol plants (32 locations)
  (3643 MGY capacity)

Gather CO₂ from largest ethanol plants in upper Midwest.
Deliver 9.85 Mt/yr through Kansas to Permian Basin

KEY:
- Ethanol Plants
- Other Sources
- Existing CO₂ Lines
- Potential CO₂ Lines
Case 4 Economics

Estimated Project Costs

<table>
<thead>
<tr>
<th>Cost $million</th>
<th>Plant Capture</th>
<th>Pipeline Transport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapX</td>
<td>$809</td>
<td>$1,857</td>
<td>$2,667</td>
</tr>
<tr>
<td>Annual OpX</td>
<td>$85</td>
<td>$47</td>
<td>$131</td>
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</tbody>
</table>

Note: Rule of thumb $100k/inch-mile yields $1821 million CapX for pipeline

Summary:
- Total CapEx $2,667 M
- 45Q tax credits $4,064 M
- Cost of Capital = 10%
- 2-yr construction and 20 yrs operations (ops in 2024)
- 12 yrs of 45Q credits, Avg. $34.48/t

Costs per Unit of CO₂

<table>
<thead>
<tr>
<th></th>
<th>Pipeline</th>
<th>Capture &amp; Compress</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapEx ($/t)</td>
<td>$4.28</td>
<td>$1.86</td>
<td>$6.14</td>
</tr>
<tr>
<td>OpEx ($/t)</td>
<td>$4.77</td>
<td>$8.58</td>
<td>$13.35</td>
</tr>
<tr>
<td>Total ($/t)</td>
<td>$9.05</td>
<td>$10.44</td>
<td>$19.49</td>
</tr>
</tbody>
</table>

Without 45Q
$47 / tonne ($2.46 / mcf)

Tax credits applied directly to CapEx in model to calculate price/tonne $/mcf $1.03
Parting Comments

45Q extension and expansion is now the law

Preliminary economics favorable for myriad of scenarios
  • Saline aquifer storage (small and large-scale)
  • EOR storage (small and large-scale)

Lots of issues yet to be resolved

Later today in breakout session – get involved
  • Define critical issues by sector and cross-cutting sector
  • Discuss remedies and how we can collectively tackle the issues
  • What’s next?
45 Q Tax Credits Applied

45Q specifics*

*Enacted 2/9/2018 as part of a Federal budget bill

- Begin construction before February 9, 2025
- Credits claimed 12 yrs from day capture begins
- Can be claimed by capture facility, transferred to the storage facility, but not directly by transporter
- 2017 tax credits are $12.83/tonne for EOR and $22.66/tonne for saline storage.
- Credit escalates linearly through 2026 to $35 for EOR and $50 for saline storage and is flat beyond.
- Adjusted for inflation after 2026
- Injected into a qualified EOR project in a secure geologic storage or injected and sequestered in a secure geologic storage

* Sources: NEORI (Kurt Walzer), CLATF, State CO2 EOR Workgroup (Brad Crabtree), and S. 1535 document

Credit Values
($/tonne)

<table>
<thead>
<tr>
<th>Credits (no inflation)</th>
<th>EOR</th>
<th>Saline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>$12.83</td>
<td>$22.66</td>
</tr>
<tr>
<td>2018</td>
<td>$15.29</td>
<td>$25.70</td>
</tr>
<tr>
<td>2019</td>
<td>$17.76</td>
<td>$28.74</td>
</tr>
<tr>
<td>2020</td>
<td>$20.22</td>
<td>$31.77</td>
</tr>
<tr>
<td>2021</td>
<td>$22.68</td>
<td>$34.81</td>
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<td>2022</td>
<td>$25.15</td>
<td>$37.85</td>
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<td>2023</td>
<td>$27.61</td>
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<td>2024</td>
<td>$30.07</td>
<td>$43.92</td>
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<tr>
<td>2025</td>
<td>$32.54</td>
<td>$46.96</td>
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<tr>
<td>2026 - 2035</td>
<td>$35.00</td>
<td>$50.00</td>
</tr>
</tbody>
</table>

Inflation adjustment after 2026 not applied here