INITIAL ENGINEERING AND DESIGN FOR CO₂ CAPTURE FROM ETHANOL FACILITIES

Project Number: DE-FE0031938
U.S. Department of Energy National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15–19, 2022

Jason Laumb
Director of Advanced Energy Systems Initiatives
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PROJECT MANAGEMENT

Jason Laumb
*Principal Investigator (PI)*
Task 1.0 – Project Management and Planning

Kerryanne Leroux
Task 2.0 – Project Engineering and Design

John Kay
Task 3.0 – Determine Pre-FEED Cost Estimate
AGENDA

• Project Overview
• Red Trail Energy, LLC (RTE) CCS
• Technology and Scope
• Project Status
• Summary and Questions
• Project Budget: $1,949,954
  – $1,559,954 DOE funds
  – $390,000 cost share
    ♦ $375,000 RTE
    ♦ $15,000 EERC
• Period of Performance (POP): Oct 1, 2020 – Sep 30, 2022
• Goal: Develop an initial engineering design (IED) and estimated cost for capture and compression of CO₂ generated from an operational ethanol production facility
PROJECT OBJECTIVES

- Design a hybrid capture system using CO$_2$ emissions from both bioprocessing and heat production at the RTE facility.
- Complete a pre-front-end engineering and design (FEED) analysis of the hybrid capture system, which includes environmental health and safety (EH&S), constructability report, identification of permits, and corporate approvals.
- Complete a techno-economic assessment (TEA) in accordance with DOE’s methodology, as demonstrated by the bituminous baseline study.
The first North Dakota Class VI permit approved October 19, 2021.
**RTE SITE: Excellent CCS Case Study**

- **Broom Creek Formation:** >10 billion tonnes CO₂ storage potential

- **RTE CCS:** ~6 million tonnes CO₂ (assuming 20-year injection period)

**CO₂ capture potential**
- ~310,000 tonnes/yr of CO₂ from bioprocessing, heat production.
- Bioprocessing CO₂ stream is nearly pure.

**Geologic storage potential:**
- Broom Creek Formation
- 6400 ft directly underlying RTE facility, ~300 ft thick
RTE CCS IMPLEMENTATION

First commercial-scale CCS operations in North Dakota (June 2022)

Flow Line (underground, > 6ft)

Capture System

+groundwater wells and soil gas profile stations at each wellsite

Monitoring Well

Injection Well

Richardson

EERC | UNIVERSITY OF NORTH DAKOTA
PROJECT TECHNOLOGY

Hybrid Capture System

- CO₂ from Bioprocessing
- Steam/Electricity
- CO₂ from Heat Production

Injection for Geologic Storage

Image Credit: Energy & Environmental Research Center
ETHANOL–CCS PROCESS WITH NOVEL HYBRID CAPTURE SYSTEM

- Corn Feedstock
- Centrifuge Evaporators Dryers
- Byproducts*
- Natural Gas Steam Boilers
- Heat Production CO₂ Stream
- Steam Heat
- Bioprocessing CO₂ Stream
- Chemical Absorption
- Liquefaction
- Hybrid Capture System
- Energy
- CO₂ Pipeline**
- Geologic Storage
- **Developing separately

*Includes distillers grains, etc.

Image Credit: Energy & Environmental Research Center
1. Project Management and Planning
2. Project Engineering and Design
3. Determine Pre-FEED Cost Estimate

POP: Oct 1, 2020 – Sep 30, 2022

<table>
<thead>
<tr>
<th>Milestone Title</th>
<th>Planned Completion Date</th>
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<tbody>
<tr>
<td>M1 – Design Basis Determined</td>
<td>End of Month 4</td>
</tr>
<tr>
<td>M2 – Complete Pre-FEED Analysis</td>
<td>End of Month 12</td>
</tr>
<tr>
<td>M3 – Complete Design</td>
<td>End of Month 12</td>
</tr>
<tr>
<td>M4 – Complete TEA</td>
<td>End of Month 15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Oct</td>
<td>Nov</td>
<td>Dec</td>
</tr>
<tr>
<td>1.0</td>
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<tr>
<td>2.0</td>
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<td></td>
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</tr>
<tr>
<td>3.0</td>
<td></td>
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</tbody>
</table>
SUCCESS CRITERIA

✓ Completion of design basis for hybrid capture at RTE.

✓ Completion of TEA for design basis at RTE.

✓ Pre-FEED-level cost estimate for implementation of hybrid capture technology at RTE.

✓ Designed capture process that provides negative CO₂ emissions for RTE.

☐ RTE management approval of hybrid capture design such that it is considered by the RTE Board.

Photograph by Lars Plougmann
HYBRID–CCS SCENARIOS:
*Design Basis and Operational Estimates*

<table>
<thead>
<tr>
<th>Scenario:</th>
<th>Maximum Amine Capture</th>
<th>Alternative Amine Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Capture Design</td>
<td>90% of CO₂ from boiler flue gas</td>
<td>45% of CO₂ from boiler flue gas</td>
</tr>
<tr>
<td>Annual CO₂ Rate</td>
<td>~130,000 tonnes (~310,000 tonnes total)</td>
<td>~65,000 tonnes (~245,000 tonnes total)</td>
</tr>
<tr>
<td>Equipment Differences</td>
<td>New boiler and flue gas blower; added compression and dehydration</td>
<td>Smaller amine unit</td>
</tr>
<tr>
<td>Power</td>
<td>3.3 MW</td>
<td>0.8 MW</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>54 MMBtu/hr</td>
<td>27 MMBtu/hr</td>
</tr>
</tbody>
</table>

*In addition to bioprocessing–liquefaction system and existing ethanol-processing operations.*
TASK 1.0 – PROJECT MANAGEMENT AND PLANNING

- Subtask 1.1 – Project Management Plan (PMP)
- Subtask 1.2 – Technology Maturation Plan (TMP)
- Subtask 1.3 – TEA and Technology EH&S Risk Assessment
  ✓ Hazardous Operations (HAZOP) Assessment
- Subtask 1.4 – State Point Data Table
- Subtask 1.5 – Life Cycle Assessment (LCA) Report
  ✓ NETL openLCA modeling
  ✓ Investigate renewable heat
    * Corn stover gasification for steam generation
  ✓ Compare to low-carbon fuel model
    * GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation)
**Initial Study**

<table>
<thead>
<tr>
<th>Option</th>
<th>Global Warming Potential, kg CO₂ eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol w/o CCS</td>
<td>-3.50E+08</td>
</tr>
<tr>
<td>Ethanol + Hybrid CCS</td>
<td>-3.00E+08</td>
</tr>
<tr>
<td>Ethanol + Alt-Hybrid CCS</td>
<td>-2.50E+08</td>
</tr>
</tbody>
</table>

**RENEWABLE HEAT STUDY**

<table>
<thead>
<tr>
<th>Option</th>
<th>Global Warming Potential, kg CO₂ eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol w/o CCS</td>
<td>-3.00E+08</td>
</tr>
<tr>
<td>Ethanol + Hybrid CCS</td>
<td>-2.50E+08</td>
</tr>
<tr>
<td>Ethanol + Alt-Hybrid CCS</td>
<td>-2.00E+08</td>
</tr>
</tbody>
</table>

*Compared to Ethanol without CCS, includes ethanol transportation to market*
**TASK 2.0 – PROJECT ENGINEERING AND DESIGN**

- **Subtask 2.1 – Design Basis**
- **Subtask 2.2 – Utility Requirements**
- **Subtask 2.3 – Flow Diagrams**
  - Existing diagrams updated
  - Major equipment list
- **Subtask 2.4 – Balance of Plant (BOP)**
  - Interconnection requirements
  - Technology island configurations
- **Subtask 2.5 – Develop Permitting Strategy**
- **Subtask 2.6 – Optimization Studies**
  - Redundancy, materials of construction
  - Scoping/optimization
## DESIGN BASIS SUMMARY

<table>
<thead>
<tr>
<th>Component</th>
<th>Bioprocessing–Liquefaction</th>
<th>Flue Gas – Chemical Absorption</th>
<th>Hybrid Capture System</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Capture Design</td>
<td>100% of CO₂ from fermentation</td>
<td>90% of CO₂ from boiler flue gas</td>
<td>&gt;90% CO₂ capture from emissions</td>
</tr>
<tr>
<td>Annual CO₂ Rate</td>
<td>~180,000 tonnes</td>
<td>~130,000 tonnes</td>
<td>~310,000 tonnes</td>
</tr>
<tr>
<td>Major Equipment</td>
<td>Blower, compression, dehydration, refrigeration, distillation</td>
<td>Boiler, blower, amine system, compression, dehydration</td>
<td>[combined equipment]</td>
</tr>
<tr>
<td>Power</td>
<td>3.8 MW</td>
<td>3.0 MW</td>
<td>6.8 MW</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>4.3 MMBtu/day</td>
<td>1300 MMBtu/day</td>
<td>1300 MMBtu/day</td>
</tr>
<tr>
<td>Water</td>
<td>82,000 gallons/day</td>
<td>420,000 gallons/day</td>
<td>500,000 gallons/day</td>
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</table>
## HYBRID–CCS SCENARIOS INVESTIGATED

<table>
<thead>
<tr>
<th>Capture Included per Scenario</th>
<th>Bioprocessing–Liquefaction</th>
<th>Flue Gas – Chemical Absorption</th>
<th>Hybrid Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max-Capture</td>
<td>100%</td>
<td>90%</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Alt-Capture*</td>
<td>100%</td>
<td>45%</td>
<td>~80%</td>
</tr>
</tbody>
</table>

*Alternative design for an amine system within existing RTE boiler and liquefaction capacities.
TASK 3.0 – DETERMINE PRE-FEED COST ESTIMATE

- **Subtask 3.1 – Develop Capture Island Cost Estimate**
  - Determine pre-FEED-level costs
  - Estimate postcombustion capture costs
  - Integrate with compression and liquefaction subsystems

- **Subtask 3.2 – Develop BOP Cost Estimate**
  - Complete integration of the hybrid capture system with the remainder of the plant

- **Subtask 3.3 – Advanced Solvent Modeling Study**
  - Model advanced solvent technologies
  - Investigate potential system sizing and cost improvements
  - Compare previous estimates
HYBRID–CCS PRELIMINARY RESULTS:
Cost Estimates*

<table>
<thead>
<tr>
<th>Item (2019$)</th>
<th>Bioprocessing – Liquefaction</th>
<th>Flue Gas – Chemical Absorption</th>
<th>Hybrid Capture System</th>
<th>Alternative Amine Scenario</th>
<th>Alternative Hybrid Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Investment</td>
<td>$32MM</td>
<td>$59MM</td>
<td>$91MM</td>
<td>$25MM</td>
<td>$57MM</td>
</tr>
<tr>
<td>Cost of CO₂ Captured</td>
<td>$35/tonne</td>
<td>$96/tonne</td>
<td>$55/tonne</td>
<td>$80/tonne</td>
<td>$45/tonne</td>
</tr>
</tbody>
</table>

*Additional Notes
- Installed equipment cost estimates (i.e., do not include civil engineering).
- Estimate accuracy is about ±30% based on DOE modeling and limited vendor quotes.
HYBRID–CCS PRELIMINARY RESULTS:
Advanced Solvent Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flue Gas – Chemical Absorption</th>
<th>Hybrid Capture System</th>
<th>Advanced Solvent</th>
<th>Advanced Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>1300 MMBtu/day</td>
<td>1300 MMBtu/day</td>
<td>950 MMBtu/day</td>
<td>950 MMBtu/day</td>
</tr>
<tr>
<td>Cost of CO₂ Captured</td>
<td>$96/tonne</td>
<td>$55/tonne</td>
<td>$93/tonne</td>
<td>$54/tonne</td>
</tr>
</tbody>
</table>

*Additional Notes
- Only natural gas showed significant variation between solvents.
- Estimate accuracy is about ±30% based on DOE modeling and limited vendor quotes.
FUTURE HYBRID CCS PLANS

- Combined heat and power (CHP) investigations
  - Fossil and renewable
  - Renewable feedstock logistics
  - Implementation cost estimates
  - State Energy Research Center of North Dakota (SERC)

- FEED investigations
  - Refined advanced solvent modeling
  - Refined cost estimates

- LCA revisions
  - Following FEED efforts
  - Following in-depth CHP investigations
  - Continued GREET comparisons
### Major Activities Conducted
- Pre-FEED
  - Design basis
  - Processing design
  - Engineered plot plan
  - HAZOP assessment
- TEA modeling
  - Advanced solvent modeling
- LCA modeling
  - Renewable heat
  - GREET comparisons

### DOE Deliverables Submitted
- PMP
- TMP
- HAZOP report
- Pre-FEED report
- State point data table
- TEA report
- LCA report
THANK YOU

Critical Challenges. Practical Solutions.
PROJECT ORGANIZATION

**Project Partners**
- DOE
- Red Trail Energy
- Energy & Environmental Research Center
- Trimeric
- KLJ

**Lead Organization**
- EERC
  - Project Manager
    - Jason Laumb

**Task 1: Project Management and Planning**
- Lead
  - J. Laumb
- Task Assist
  - J. Kay

**Task 2: Project Engineering and Design**
- Lead
  - K. Leroux
- Task Assist
  - Trimeric
  - KLJ
- Red Trail Energy

**Task 3: Determine Pre-FEED Cost Estimate**
- Lead
  - J. Kay
- Task Assist
  - Trimeric
  - KLJ
- Red Trail Energy
## PROJECT TIMELINE

### Task 1.0 – Project Management and Planning
- **Subtask 1.1 – Project Management Plan**
- **Subtask 1.2 – Technology Maturation Plan**
- **Subtask 1.3 – Techno-Economic Analysis (TEA) and Technology EH&S Risk Assessment**
- **Subtask 1.4 – State Point Data Table**
- **Subtask 1.5 – Life-Cycle Assessment (LCA) Report**

### Task 2.0 – Project Engineering and Design
- **Subtask 2.1 – Design Basis**
- **Subtask 2.2 – Utility Requirements**
- **Subtask 2.3 – Flow Diagrams**
- **Subtask 2.4 – Balance of Plant**
- **Subtask 2.5 – Develop Permitting Strategy**
- **Subtask 2.6 – Optimization Studies**

### Task 3.0 – Determine Pre-FEED Cost Estimate
- **Subtask 3.1 – Develop Capture Island Cost Estimate**
- **Subtask 3.2 – Develop BOP Cost Estimate**
- **Subtask 3.3 – Advanced Solvent Modeling (ASM)**

<table>
<thead>
<tr>
<th>Milestone (M)</th>
<th>Deliverables (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 – Design basis determined</td>
<td>D1 – Updated Project Management Plan</td>
</tr>
<tr>
<td>M2 – Complete pre-FEED analysis</td>
<td>D2a – Technology Maturation Plan (TMP)</td>
</tr>
<tr>
<td>M3 – Complete design</td>
<td>D3 – TEA and Technology EH&amp;S Risk Assessment</td>
</tr>
<tr>
<td>M4 – Complete TEA</td>
<td>D4 – State Point Data Table</td>
</tr>
<tr>
<td></td>
<td>D5 – HAZOP Review</td>
</tr>
<tr>
<td></td>
<td>D6 – Pre-FEED Report</td>
</tr>
<tr>
<td></td>
<td>D7a – LCA Report</td>
</tr>
<tr>
<td></td>
<td>D7b – LCA Addendum</td>
</tr>
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<td>D8 – Advanced Solvent Modeling Addendum</td>
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