

Initial Engineering and Design for CO₂ Capture from Ethanol Facilities

primary project goal

The University of North Dakota Energy and Environmental Research Center (UNDEERC) and project partners Red Trail Energy LLC (RTE), Trimeric Corporation, and KLJ are completing an initial engineering design and cost estimate for the installation of a hybrid system for the capture and compression of carbon dioxide (CO₂) generated from an ethanol production facility near Richardton, North Dakota. The hybrid capture system combines commercially available technologies of chemical absorption to process the CO₂ emissions associated with heat production (i.e., steam generated by firing a natural gas boiler) and liquefaction to process the CO₂ emissions associated with bioprocessing at RTE's ethanol plant. The project team will complete a pre-front-end engineering and design (pre-FEED) analysis of the hybrid capture system, which includes an environmental health and safety (EH&S) risk assessment, a constructability review, identification of permits, and corporate approvals. A techno-economic assessment (TEA) and pre-FEED-level cost estimate will also be completed.

technical goals

- Design a hybrid capture system using CO₂ emissions from both bioprocessing and heat production at the host site facility.
- Complete a pre-FEED analysis of the hybrid capture system to include EH&S, a constructability report, identification of permits, and corporate approvals.
- Evaluation of performance and TEA in accordance with the U.S. Department of Energy's (DOE) methodology, as demonstrated by the bituminous baseline study.

technical content

The RTE carbon capture and storage (CCS) project is constructing a CO₂ capture facility adjacent to the RTE ethanol plant near Richardton (Figure 1), to ultimately inject about 180,000 tonnes of CO₂ annually more than a mile below RTE property for permanent storage. The hybrid capture system combines chemical absorption to capture and compress CO₂ emissions associated with heat production (i.e., natural gas steam boilers, ~130,000 tonnes/yr CO₂) and liquefaction to capture and compress CO₂ emissions associated with bioprocessing at the RTE operating ethanol facility (~180,000 tonnes/yr CO₂). The resulting 310,000 tonnes/yr CO₂ could then be destined for geologic injection and storage (Figure 2), or could be available for enhanced oil recovery (EOR) in the future because of the low oxygen (O₂) content of the CO₂ final product. This system was designed to use existing utilities to provide the required energy for potential hybrid capture operations. A conventional 30 wt.% monoethanolamine (MEA) absorber–stripper process was designed to capture the CO₂ from the boiler burner exhaust streams and to recover it as an essentially pure gas.

The liquefaction process was designed during the 2016–2017 study funded by DOE and the North Dakota Industrial Commission (NDIC) and conducted by the

program area:

Point Source Carbon Capture

ending scale:

Pre-FEED

application:

Post-Combustion Industrial PSC

key technology:

Solvents

project focus:

Hybrid Absorption-Liquefaction CO₂ Capture System for Ethanol Production Plants

participant:

University of North Dakota Energy and Environmental Research Center (UNDEERC)

project number:

FE0031938

predecessor projects:

N/A

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partners:

Red Trail Energy LLC; Trimeric Corporation

start date:

10.01.2020

percent complete:

89%

EERC and RTE to assess the overall technical feasibility to remove CO₂ and perform subsurface injection onsite. A more rigorous design was conducted by Trimeric Corporation in 2019.

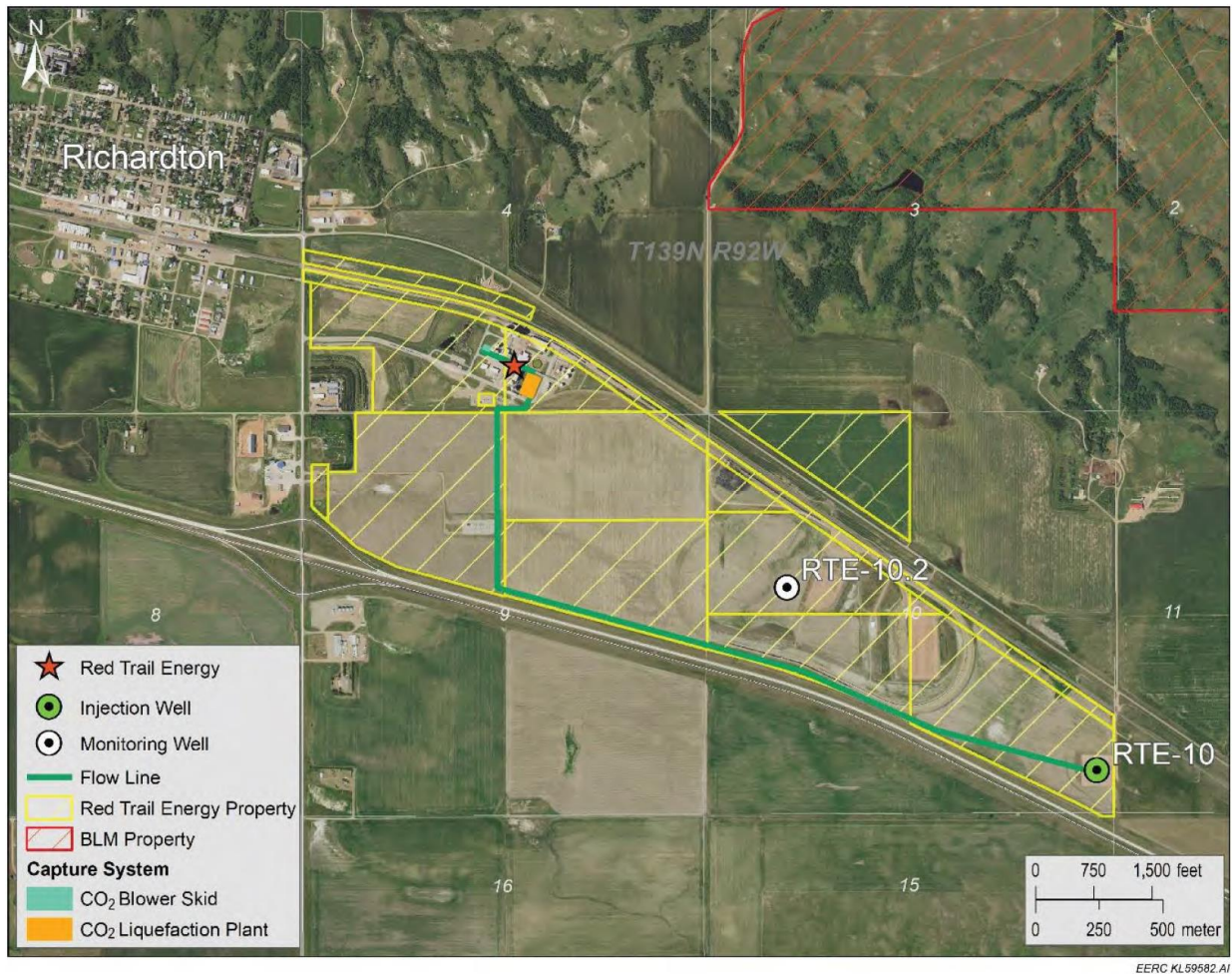


Figure 1: RTE ethanol facility and CCS site.

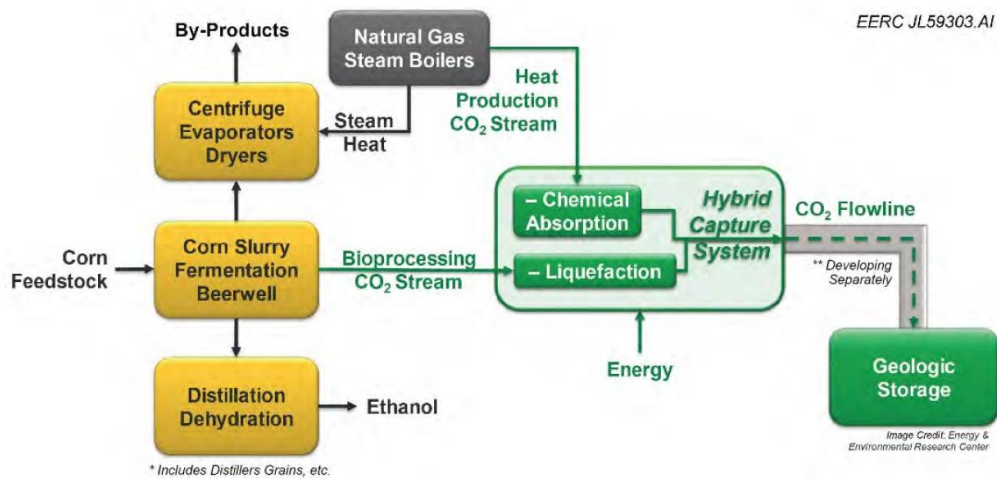


Figure 2: Block diagram of project process (*includes distillers' grains, etc.) at the RTE ethanol-CCS site; the hybrid capture system includes the required compression for geologic injection.

The hybrid capture system was designed to use RTE existing utilities to provide the required energy for potential operations. The liquefaction process captures the entirety of the nearly pure CO₂ (>99% dry) produced from RTE's fermentation process, compresses the CO₂ up to approximately 350 pounds per square inch gauge (psig), dehydrates

the gas, and then liquefies it using a closed-loop ammonia refrigeration process. A conventional distillation column distills the liquid CO₂ to remove oxygen, in addition to other noncondensable gases. The chemical absorption process assumes 90% capture of the CO₂ from flue gas emitted by the two existing natural gas-fired boilers at the RTE facility, along with a potential new boiler, to provide the necessary steam for this portion of the hybrid capture process. The flue gas from the three boilers would contain a fraction of CO₂ (~4%) sufficient for capture and be fed to the absorption process, where CO₂ would be removed by employing MEA as a chemical solvent. The product CO₂ would be compressed and dehydrated, then combined with the CO₂ from the liquefaction process. The combined final CO₂ product stream could be then transported for geologic storage.

TABLE 1: SOLVENT PROCESS PARAMETERS*

Pure Solvent	Units	Current R&D Value	Target R&D Value
Molecular Weight	mol ⁻¹	68.0831	68.0831
Normal Boiling Point	°C	170.6	170.6
Normal Freezing Point	°C	10.4	10.4
Vapor Pressure @ 15°C	bar	<.001	<.001
Manufacturing Cost for Solvent	\$/kg	—	—
Working Solution			
Concentration	kg/kg	0.3	0.3
Specific Gravity (15°C/15°C)	-	1.02	1.02
Specific Heat Capacity @ STP	kJ/kg-K	3.7	3.7
Viscosity @ STP	cP	2.5	2.5
Surface Tension @STP	dyn/cm	0.06	0.06
CO ₂ Mass Transfer Rate [K _L]	m/s	—	—
CO ₂ Reaction Rate	-	—	—
Thermal Conductivity	W/(m-K)	—	—
Absorption			
Pressure	bar	0	0
Temperature	°C	43	43
Equilibrium CO ₂ Loading	mol/mol	2.1	2.1
Heat of Absorption	kJ/mol CO ₂	1930	1930
Solution Viscosity	cP	1.8	1.8
Desorption			
Pressure	bar	0.7	0.7
Temperature	°C	115	115
Equilibrium CO ₂ Loading	mol/mol	5.1	5.1
Heat of Desorption	kJ/mol CO ₂	1930	1930

*Based on published commercial MEA data where available.

Definitions:

STP – Standard Temperature and Pressure (15°C, 1 atm).

Pure Solvent – Chemical agent(s), working alone or as a component of a working solution, responsible for enhanced CO₂ absorption (e.g., the amine MEA in an aqueous solution).

Manufacturing Cost for Solvent – “Current” is market price of chemical, if applicable; “Target” is estimated manufacturing cost for new solvents, or the estimated cost of bulk manufacturing for existing solvents.

Working Solution – The solute-free (i.e., CO₂-free) liquid solution used as the working solvent in the absorption/desorption process (e.g., the liquid mixture of MEA and water).

CO₂ Mass Transfer Rate – Overall liquid phase mass transfer coefficient.

CO₂ Reaction Rate – A characterization of the CO₂ absorption trend with respect to time, as complete in the range of time as possible.

Absorption – The conditions of interest for absorption are those that prevail at maximum solvent loading, which typically occurs at the bottom of the absorption column. Measured data are preferable to estimated data.

Desorption – The conditions of interest for desorption are those that prevail at minimum solvent loading, which typically occurs at the bottom of the desorption column. Operating pressure and temperature for the desorber/stripper are process dependent. Measured data are preferable to estimated data.

Pressure – The pressure of CO₂ in equilibrium with the solution. If the vapor phase is pure CO₂, this is the total pressure; if it is a mixture of gases, this is the partial pressure of CO₂.

Concentration – Mass fraction of pure solvent in working solution.

Loading – The basis for CO₂ loadings is moles of pure solvent.

Estimated Cost – Basis is kg/hr of CO₂ in CO₂-rich product gas; assuming targets are met.

Chemical/Physical Solvent Mechanism – Absorption/desorption process as expected for 30 wt.% MEA.

Solvent Contaminant Resistance – Solvent is sensitive to exposure to sulfur dioxide (SO₂), halogen, nitrogen oxide (NO_x), and trace metals.

Solvent Foaming Tendency – Foaming tendency considered low for this application.

Air Feed-Gas Pretreatment Requirements – Pretreatment is not required.

Solvent Make-Up Requirements – Process preliminary design includes “bleed and feed” process for solvent makeup/reclaiming at a projected rate of 0.44 tonnes/day. Reclaiming will be conducted offsite.

Waste Streams Generated – 30 wt.% MEA to be taken offsite for reclaiming.

Process Design Concept – See description above.

Proposed Module Design – Amine-based system is typical absorption/desorption system.

TABLE 2: HYBRID PROCESS CARBON CAPTURE ECONOMICS

Economic Values	Units	Current R&D Value	Target R&D Value
Cost of Carbon Captured	\$/tonne CO ₂	55	55
Capital Expenditures	\$/tonne CO ₂	30	30
Operating Expenditures	\$/tonne CO ₂	25	25

Definitions:

Cost of Carbon Captured – Projected cost of capture per mass of CO₂ captured under expected operating conditions.

Capital Expenditures – Projected capital expenditures in dollars per unit of CO₂ captured.

Operating Expenditures – Projected operating expenditures in dollars per unit of CO₂ captured.

Calculations Basis – Calculations taken from fundamental quotes for standard commercially available items. Capital cost levels utilized from the National Energy Technology Laboratory (NETL) quality guidelines for cost estimation methodology.

Scale of Validation of Technology Used in TEA – This technology is based on existing equipment and processes. Novel techniques are not being employed.

Qualifying Information or Assumptions – Assumes 97% online factor, which matches operation time of the ethanol plant. Water, natural gas, and electricity costs based on current rates at the ethanol facility.

technology advantages

The 310,000 tonnes/yr CO₂ from the fermentation process and steam boilers within the RTE ethanol facility can be stored using this technology.

R&D challenges

Scale-up and variability of vendor estimates for operating costs of the supercritical carbon dioxide (sCO₂) loop process.

status

UNDEERC completed the pre-FEED design of a commercial-scale hybrid capture system. The TEA for the commercial-scale facility was also completed. Final reporting is currently being completed.

available reports/technical papers/presentations

Jason Laumb, "Initial Engineering and Design for CO₂ Capture from Ethanol Facilities," Project kickoff meeting presentation, Pittsburgh, PA, November 3, 2020. <http://www.netl.doe.gov/projects/plp-download.aspx?id=11016&filename=Initial+Engineering+and+Design+for+CO2+Capture+from+Ethanol+Facilities.pdf>.

Jason Laumb, "Initial Engineering and Design for CO₂ Capture from Ethanol Facilities," NETL Carbon Management Research Project Review Meeting, Pittsburgh, PA, August 3, 2021. https://netl.doe.gov/sites/default/files/netl-file/21CMOG_CCUS_Laumb.pdf