Contract No. R-028-039
"Integrated Carbon Capture and Storage for North Dakota Ethanol Production"
Submitted by Energy & Environmental Research Center
Principal Investigator: Kerryanne Leroux

PARTICIPANTS

Sponsor	**Cost Share**	
Red Trail Energy	$ 90,000	
Department of Energy	$200,000	
Subtotal Cash Cost Share		$290,000
Red Trail Energy	$200,000	
Subtotal In-kind Cost Share		$200,000
North Dakota Industrial Commission	$490,000	
Total Project Cost		$980,000

Project Schedule – 6 months
Contract Date – August 29, 2016
Start Date – November 1, 2016
Completion Date – May 31, 2017

Project Deliverables:
Progress Report: January 31, 2017 ✓
Progress Report: April 30, 2017 ✓
Final Report: May 31, 2017 ✓

OBJECTIVE/STATEMENT OF WORK:
The purpose of this project is to conduct a feasibility study for integrating carbon capture and storage (CCS) of CO_2 emissions from Red Trail Energy (RTE) to reduce net CO_2 emissions associated with ethanol production. Specifically, the project will:

- Assess the technical feasibility of carbon capture at Red Trail and subsequent geologic CO_2 storage.
- Develop a field implementation plan (FIP) determining the design and implementation steps needed to install a CCS system.
- Evaluate the economic feasibly of CCS deployment, including installation and operating costs as well as potential revenue from low-carbon fuel markets and/or tax incentives to assess the benefits to ND ethanol producers.

STATUS:

The contract has been executed.

Status Report received 1/30/2017 and is available on the Renewable Energy Program website. The status report provides information on the work that has been undertaken during the reporting period for each of the objectives. Some highlights of the work are as follows:

Feasibility Study - The RTE CO_2 emissions stream was evaluated and three options for CO_2 capture at the RTE site were investigated to generate an injection-grade CO_2, an enhanced oil recovery (EOR), or a food-grade product. Each of the potential CO_2 products investigated has different purity requirements. Each potential CO_2 product requires an independent approach to processing and is discussed in the status report. Existing site characterization data for both the surface and subsurface environment in the vicinity of the RTE ethanol facility were collected and evaluated for

use in subsequent geologic modeling for CO_2 storage design. The geologic model integrates the derived geologic site characterization data to account for the properties specific to the storage complex at the RTE site. Efforts during this reporting period focused on creating the structure of the geologic model, such that as site characterization data becomes available, inputs can be made directly. Once completed, the geologic model provides the foundation for dynamic simulations of potential injection scenarios. Life cycle analysis (LCA) efforts within the reporting period centered on the team learning the intricacies of the model used by the California Low-Carbon Fuel Standards (LCFS) Program. The efforts of this activity will thus estimate a carbon intensity (CI) value for RTE's ethanol should the approximate 163,000 tonnes CO_2 emitted annually from the fermentation process be captured and geologically stored, theoretically lowering the CI value significantly.

Field Implementation Plan - Draft conceptual designs for each of the three CO_2 capture options (injection-, EOR-, and food-grade) at the RTE site were generated. A draft list of monitoring technologies for the monitoring, verification and accounting (MVA) plan was completed to include potential near-surface and deep subsurface monitoring as well as potential monitoring of surface infrastructure. Draft preliminary well designs were started for potential installation of up to three wells at the RTE site: the main CO_2 injection well, a characterization/monitoring well, and a shallow geophone well for monitoring seismicity.

Economic Analysis - the preliminary economic assessment will quantify the costs and benefits of combining commercial CCS with ethanol production at the RTE site. Initial rough capital costs for installation of a CO_2 capture facility at the RTE site were estimated for the three design options investigated. Preliminary estimates suggest a potential increase in annual revenue of about $8,830,000 may be possible from implementing CCS at the RTE facility, assuming pathways to market such as the existing California LCFS Program and the emerging Oregon Clean Fuels Program (CFP) are granted.

Status Report received 4/30/2017 and is available on the Renewable Energy Program website. The status report provides information on the work that has been undertaken during the reporting period for each of the objectives. Some highlights of the work are as follows:

Feasibility Study - Sampling of the generated CO_2 stream at the RTE facility was conducted to determine design requirements for capture or infrastructure systems, specifically for potential O_2 removal. The existing site characterization data for both the surface and subsurface environment in the vicinity of the RTE ethanol facility was evaluated for use in subsequent geologic modeling. The surface environment was assessed to identify land use, sensitive areas, and local population characteristics. The number of and type of existing groundwater wells and other non-oil and gas wells was evaluated.

Twenty-seven static model scenarios were created to address the ranges for thickness, porosity, and permeability identified in the site characterization activity. From the 27 static models, 18 simulation models were created. A sensitivity analysis on estimated wellhead pressures required for CO_2 injection to calculate compression output requirements for capture facility design was created.

A screening-level risk assessment (SLRA) was conducted. The assessment evaluated 34 technical risks associated with CO_2 supply, injectivity, storage capacity, containment, and induced seismicity. It also assessed 17 external or commercials risks associated with ethanol and CCS policy, the uncertainty surrounding policies that are under development, and a recent change in federal administration.

A detailed life cycle analysis (LCA) was completed to derive carbon intensity (CI) values for CCS implementation at the RTE facility, which are used to estimate carbon credits and CO_2 market value through the California Low-Carbon Fuel Standards (LCFS) Program and thus estimate potential revenue. CI values were derived for RTE's existing ethanol production using the California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (CA-GREET) model employed by the LCFS Program. Based on the LCFS methodology, the EERC used the CA-GREET model to derive CI values for a CCS operating scenario at RTE.

Field Implementation Plan – Conceptual infrastructure designs for capture, dehydration, compression, and transport of CO_2 based on the findings from the assessment of the CO_2 stream at the RTE facility and estimated pressure requirements for CO_2 injection into the Broom Creek Formation were completed. Pipeline requirements were determined based on the composition and flow rates of the CO_2 generated at RTE, as well as estimated distance to a potential injection sites. Permitting requirements were investigated for a North Dakota Class VI CO_2 injection well, assuming North Dakota regulatory primacy is granted. Potential pathways were explored for CCS within low-carbon fuel programs.

The preliminary monitoring, verification and accounting (MVA) plan is nearing completion by incorporating derived data and information generated during the permitting plan and well design activities to include testing and monitoring requirements as outlined in the North Dakota Administrative Code. Surface, near-surface, and deep subsurface monitoring approaches and techniques were considered.

A site characterization plan was developed that includes discussion of well logging, core acquisition and testing, and downhole testing for both the prospective monitoring and injection wells.

Economic Analysis – The potential revenue was estimated based on the CI values calculated during LCA activities and the LCFS Program market for CO_2 credits. Alternative markets for a CO_2 product generated at the RTE facility were investigated, such as enhanced oil recovery (EOR) or as a food-/chemical-grade source. Capital expenses (CAPEX) and annual operating expenses (OPEX) to implement CCS at the RTE facility were estimated based on Field Implementation Plan (FIP) designs of major components. Estimated costs and revenue for the injection, EOR, and food-grade systems to evaluate economic benefit were compared.

Final Report received 5/31/2017 and is available on the Renewable Energy Program website. The final report provides information on the work that has been undertaken during the project. The conclusions of the Project state:

- The CO_2 generated at the RTE facility contains minimal impurities (>99% CO_2), requiring nominal processing for injection, such as dehydration of the CO_2 stream and compression

up to 1500 psi. A 4-inch pipeline is recommended to transport CO_2 to the injection site within 1 mile of the RTE facility. Specific flow rates and composition of the CO_2 stream at the RTE facility will be needed to refine engineering designs.

- Site-specific geologic characterization data are imperative for the successful deployment of CCS at the RTE site. Geologic modeling and subsequent simulation estimated the average lateral extent of potential CO_2 storage to be about 1.8 miles in diameter after a 20-year injection period and 10-year post-injection monitoring period. Well logging, core acquisition and testing, and downhole testing at the RTE site are recommended for improved modeling and simulation estimates, as well as acquiring pertinent pre-injection data.
- A programmatic risk analysis of CCS implementation at the RTE site determined the highest-ranking potential risks are external or commercial (i.e., not technical risks) due to uncertainty surrounding carbon storage policies currently under development. The North Dakota Class VI permitting process for a CO_2 storage facility is time- and data intensive and will require coordination with regulators to ensure all designs and plans are compliant prior to submittal. Approval pathways for low-carbon fuel programs to include CCS are still in the development stages and will also require coordination with officials to ensure compliance for acquiring credits.
- A provisional monitoring, verification, and accounting (MVA) program and preliminary designs for monitoring and injection wells were derived based on permitting requirements to demonstrate secure CO_2 injection and long-term stability of potentially stored CO_2 at the RTE site. Refinement of the MVA program and well designs will depend greatly on data attained to meet permitting regulations (e.g., geologic core analysis) and pathway requirements for obtaining carbon credits.
- A life cycle analysis showed >40% potential net reduction of CO_2 emissions for ethanol-CCS at RTE. A significant reduction in CI value may thus be achieved for ethanol production with CCS implementation, a required pathway parameter for designating carbon credits through low-carbon fuel programs.
- Average estimated capital costs were $29.0 million for installed infrastructure and implementing pre-injection plans. Annual expenses for energy requirements and continued execution of operational plans were estimated to be about $1.9 million on average. These preliminary values contain many site-specific uncertainties, such as permitting and pathway requirements (including related data needs), investment interest rates, escalation in construction or energy prices, land or pore space purchase, etc. Estimates for potential revenue that could be generated from low-carbon fuel programs suggest a considerable economic benefit from ethanol-CCS; however, results are proprietary because of the business-sensitive nature of the assessment, including additional uncertainties such as market stability. Alternate markets such as enhanced oil recovery and food/chemical-grade CO_2 may also be viable but require more detailed investigation. Therefore, RTE intends to move forward to the next phase of assessment for CCS implementation.

With the filing of the final report this contract has been closed.

Updated 9/14/2017