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January 30, 2017

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol, 10th Floor
600 East Boulevard Avenue
Bismarck, ND 58505-0310

Dear Ms. Fine:

Subject: Quarterly Progress Report Entitled "Integrated Carbon Capture and Storage for North Dakota Ethanol Production"; Contract No. R028-039; EERC Fund 21525

Attached is the subject report for the period of November 1, 2016, through December 31, 2016, that shows the progress that has been made with partners of this project.

Thank you for funding this work. If you have any questions, please contact me by phone at (701) 777-5013 or by e-mail at kleroux@undeerc.org.

Sincerely,

for Kerryanne Leroux

Kerryanne M. Leroux
Senior Chemical Engineer, Oilfield Operations
Team Lead

KML/kal

Attachment

INTEGRATED CARBON CAPTURE AND STORAGE FOR NORTH DAKOTA ETHANOL PRODUCTION

Quarterly Progress Report

(for the period of November 1, 2016, through December 31, 2016)

Prepared for:

Karlene Fine

North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Project Period: November 1, 2016 – May 31, 2020
Contract No. R028-039

Prepared by:

Kerryanne M. Leroux

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January 2017

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TABLE OF CONTENTS

LIST OF FIGURES ii

LIST OF TABLES ii

ACCOMPLISHMENTS 1
- Major Goals of the Project 1
- Accomplishments under These Goals (for the reporting period) 1
  - Feasibility Study 1
  - Field Implementation Plan 4
  - Economic Analysis 4
- Plan for the Next Reporting Period to Accomplish the Goals 8

PARTNERS AND FINANCIAL INFORMATION 8

PRODUCTS 9
- Publications, Conference Papers, and Presentations 9
- Web or other Internet Site(s), Technologies or Techniques, Inventions, Patent Applications, and/or Licenses 9

CHANGES/PROBLEMS 9

LIST OF FIGURES

1 Surface features at the RTE site 3

2. Draft conceptual design for an injection-grade CO_2 product at the RTE site 5

3 Draft conceptual design for an EOR-grade CO_2 product at the RTE site 5

4 Draft conceptual design for a food-grade CO_2 product at the RTE site 6

LIST OF TABLES

1 CO_2 Stream Compositional Requirements for Various End Uses 2

2 Preliminary List of Potential MVA Technologies for CCS Implementation at RTE 7

3 First Draft Capital Cost Estimations for RTE CO_2 Capture Facility Options..... 7

4 Budget and Expenses Through the Reporting Period 8

INTEGRATED CARBON CAPTURE AND STORAGE FOR NORTH DAKOTA ETHANOL PRODUCTION

ACCOMPLISHMENTS

Major Goals of the Project

The ultimate goal of this effort is implementation of a small-scale (<200,000 metric tons, or tonnes, CO_2 per year) commercial carbon capture and storage (CCS) system at an industrial fuel production facility to generate a reduced-carbon ethanol fuel applicable for low-carbon fuel programs. To achieve that goal, the Energy & Environmental Research Center (EERC), in partnership with the U.S. Department of Energy (DOE); North Dakota ethanol producer, Red Trail Energy (RTE); and the North Dakota Industrial Commission (NDIC), is conducting a study to determine the technical and economic feasibility of implementing commercial CCS at a North Dakota ethanol production facility and proximate geologic injection site.

Accomplishments under These Goals (for the reporting period)

Specific objectives are to 1) assess the technical feasibility of carbon capture at a North Dakota ethanol facility and subsequent geologic CO_2 storage at a proximate site; 2) develop a field implementation plan (FIP) determining the design and implementation steps needed to install a CCS system; and 3) evaluate the economic feasibility 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 North Dakota ethanol producers.

Feasibility Study

This feasibility study evaluates the potential for commercial CO_2 storage at the site of the RTE ethanol production facility. Activities include preliminary evaluations for a CO_2 capture system, site characterization, geologic modeling and simulation, risk assessment, and a life cycle analysis (LCA). The following describes the progress thus far on these activities; it should be noted that simulation and risk assessment activities will begin in the next quarter.

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. The CO_2 stream contains approximately 99.8% (dry) CO_2, 0.78% H_2O, and 0.03% (dry) O_2 based on 2013 scrubber tests. Each of the potential CO_2 products investigated has different purity requirements, as shown in Table 1. Injection-grade quality is based on the specifications for saline injection specific to the geology of the site and installation of a carbon steel pipeline, meaning a restriction on water content of ≤0.05% by weight and O_2 ≤0.05% by volume. It should be noted that the range in literature for O_2 is 0.001%–4%, requiring further investigation and site-specific data to be conducted during the next reporting period to determine design impacts. Commercial CO_2 pipeline specifications are the determining factor for EOR-grade CO_2, requiring ≥95 mol % CO_2, ≤0.05% H_2O, and ≤0.001% O_2, according to Kinder-

Table 1. CO_2 Stream Compositional Requirements for Various End Uses

Component (max., unless noted)	Unit (unless noted)	Saline Reservoir/ Carbon Steel Pipeline[1]	EOR/ Commercial Pipeline[1]	Food/Beverage Grade[2,3]
CO_2 (min.)	vol%	95	95	≥99.9
H_2O	ppmw	500	500	≤20 ppmv
N_2	vol%	4	1	NRL†
O_2	vol%	0.05	0.001	≤30 ppmv (total O_2 and Ar)
Ar	vol%	4	1	
CH_4	vol%	4	1	≤50 ppmv‡
H_2	vol%	4	1	NRL
CO	ppmv	35	35	≤10
H_2S	vol%	0.01	0.01	≤0.1 ppmv
SO_2	ppmv	100	100	≤1 ppmv
NO_x	ppmv	100	100	≤2.5 each for NO and NO_2
Dissolved O_2	ppmv	NRL	NRL	<5

† No requirement listed.
‡ Part of "Total Volatile Hydrocarbons."

Morgan pipeline specifications. As expected, food-grade CO_2 is the most stringent, with ≥99.9 vol% CO_2, ≤20 ppm H_2O, and <30 ppm O_2 specifications. Therefore, each potential CO_2 product requires an independent approach to processing, discussed further in the following section.

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. Surface structures and features were identified, such as existing wells, land ownership, and water resources, within a 2-mile radius of the RTE facility (Figure 1). Types of subsurface data included geologic formation tops, lithologies, and facies specific to the Broom Creek and Amsden Formations. Broom Creek petrophysics for porosity and permeability distributions were also identified. Previous modeling efforts for these formations were also investigated for site characterization data.

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 this reporting period focused on creating the structure of the geologic model, such that as site characterization data become available, inputs can be made directly. Once completed, the geologic model provides the foundation for dynamic simulations of potential injection scenarios.

[1] Herron, S.; Myles, P. *CO_2 Impurity Design Parameters;* Quality Guidelines for Energy System Studies; Report DOE/NETL-341/011212; Aug 2013.
[2] Logichem Process Engineering. CO_2 Food Grade Specifications, 2011.
[3] Technical Committee of the Brewers Association. *Draught Quality Manual*, 2nd Ed.; Appendix A; 2011.

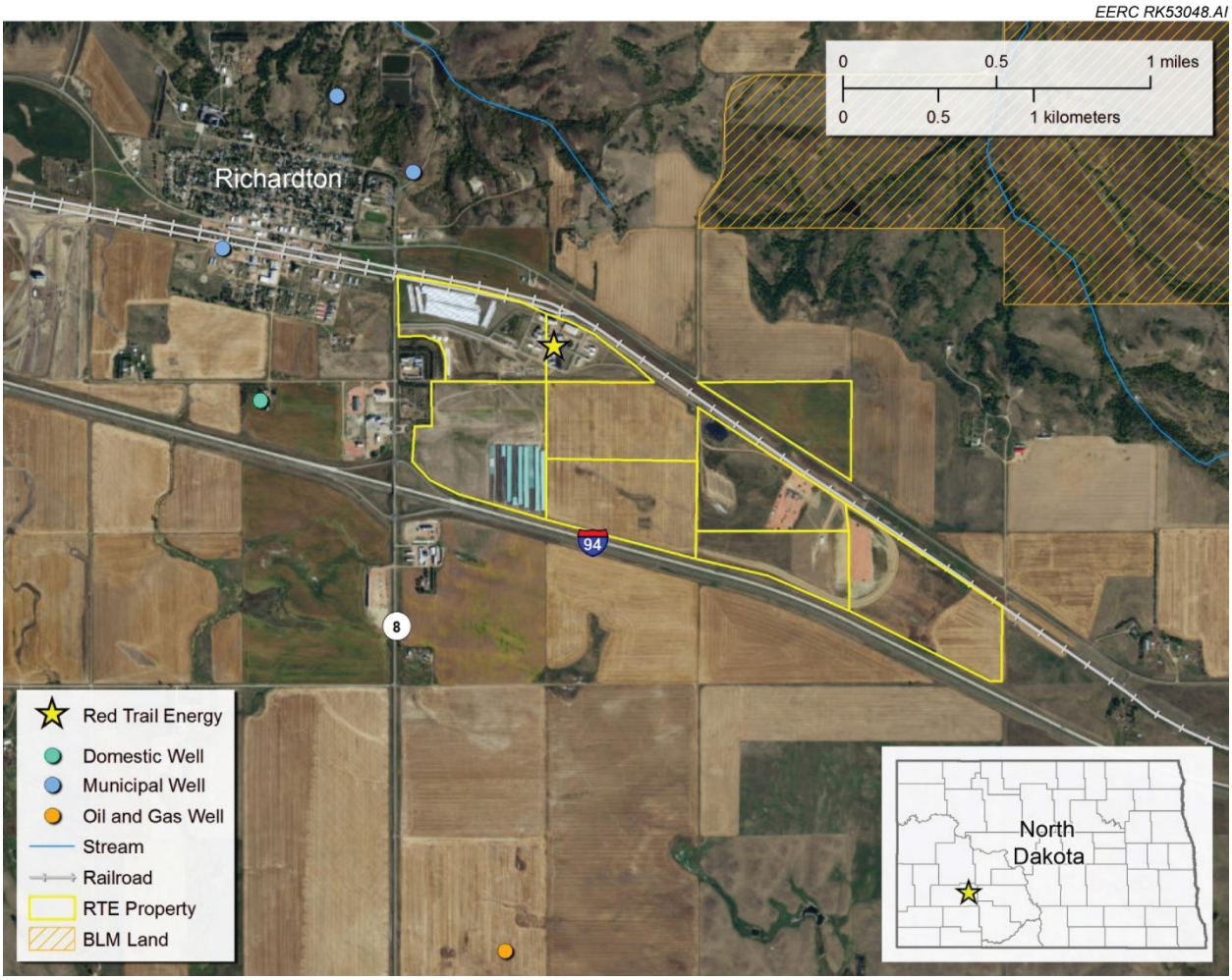

Figure 1. Surface features at the RTE site.

LCA efforts within the reporting period of this document centered on the team learning the intricacies of the model used by the California Low-Carbon Fuel Standards (LCFS) Program, referred to as CA-GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation). The California LCFS Program targets fuels such as ethanol that demonstrate a lower carbon intensity (CI) value than standard fuels such as gasoline, with incentives through the program's CO_2 credit market. The GREET model was created by Argonne National Laboratory using the LCA approach to determine the net carbon emissions from producing a particular fuel. The model was modified by the California LCFS Program to generate a CI value for fuels based on this approach for direct comparison. Credits are then issued based on the difference in CI value between the producer's fuel and the conventional fuel displaced. For example, conventional gasoline currently has a CI value of 96.5 gCO_2e/MJ (CO_2 equivalents per megajoule). RTE's ethanol has two approved CI values: 82.5 gCO_2e/MJ when generating a dried distiller's grain with solubles (DDGS) coproduct and 76.5 gCO_2e/MJ when generating a modified distiller's grain with solubles (MDGS) coproduct. It should be noted that the higher CI value is generated from using the additional energy required to completely dry the coproduct for DDGS compared to MDGS production. The efforts of this activity will thus estimate a 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

The FIP describes the steps necessary to design and install infrastructure for the capture and secure storage of CO_2 at the RTE site. Activities include conceptual plant infrastructure design; a permitting plan; a monitoring, verification, and accounting (MVA) plan; well design; and well characterization and testing design. The following describes the progress thus far on these activities; it should be noted that the permitting plan and well characterization and testing design will begin in the next quarter.

Draft conceptual designs for each of the three CO_2 capture options (injection-, EOR-, and food-grade) at the RTE site were generated, shown in Figures 2–4. Injection-grade CO_2 will require at minimum water removal (Figure 2), as shown in Table 1. EOR-grade CO_2 mostly requires water removal and possibly some O_2 removal (Figure 3) to meet standard pipeline specifications. As food-grade CO_2 has the most stringent purity requirements, its process design is thus the most complex (Figure 4), particularly to remove water and O_2 to the required specifications.

A draft list of monitoring technologies for the MVA plan was completed to include potential near-surface and deep subsurface monitoring as well as potential monitoring of surface infrastructure (Table 2). In general, the MVA plan delineates the steps necessary to monitor, verify, and account for the secure injection and long-term containment of CO_2 in accordance with the requirements of appropriate North Dakota and federal regulatory bodies, including U.S. Environmental Protection Agency (EPA) Class VI underground injection control (UIC) regulations. Therefore, this list will continue to be modified as more information about the site and permitting requirements becomes available.

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. The conceptual design will include the drilling and completion of the injection well at the RTE location that meets all relevant regulations and provides sufficient capacity for estimated CO_2 injection volumes and, thus, will incorporate findings from permitting, modeling, and simulation activities. Conceptual designs and costs for potential monitoring wells will also be considered to fulfill the developed MVA plan.

Economic Analysis

The preliminary economic assessment will quantify the costs and benefits of combining commercial CCS with ethanol production at the RTE site. Activities include estimating capital and operating expenses for CCS implementation and potential revenue through low-carbon fuel programs or other CO_2 markets. The following describes the progress thus far on these activities; it should be noted that capital costs for injection, all operating costs, and revenue for other CO_2 markets will begin in the next quarter.

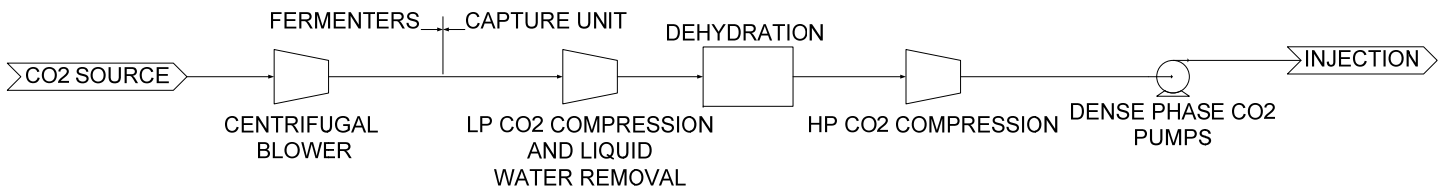

Figure 2. Draft conceptual design for an injection-grade CO_2 product at the RTE site (image courtesy of Trimeric Corporation).

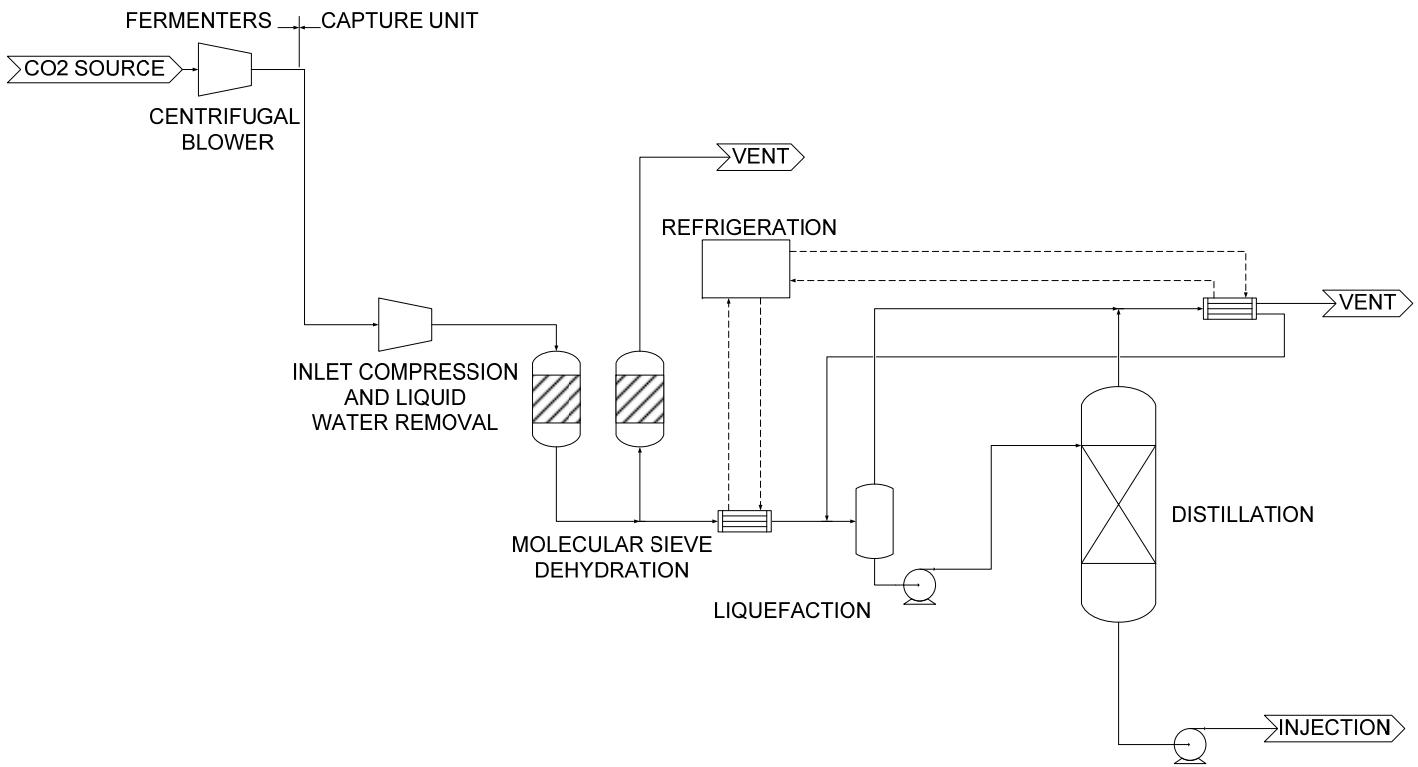

Figure 3. Draft conceptual design for an EOR-grade CO_2 product at the RTE site (image courtesy of Trimeric Corporation).

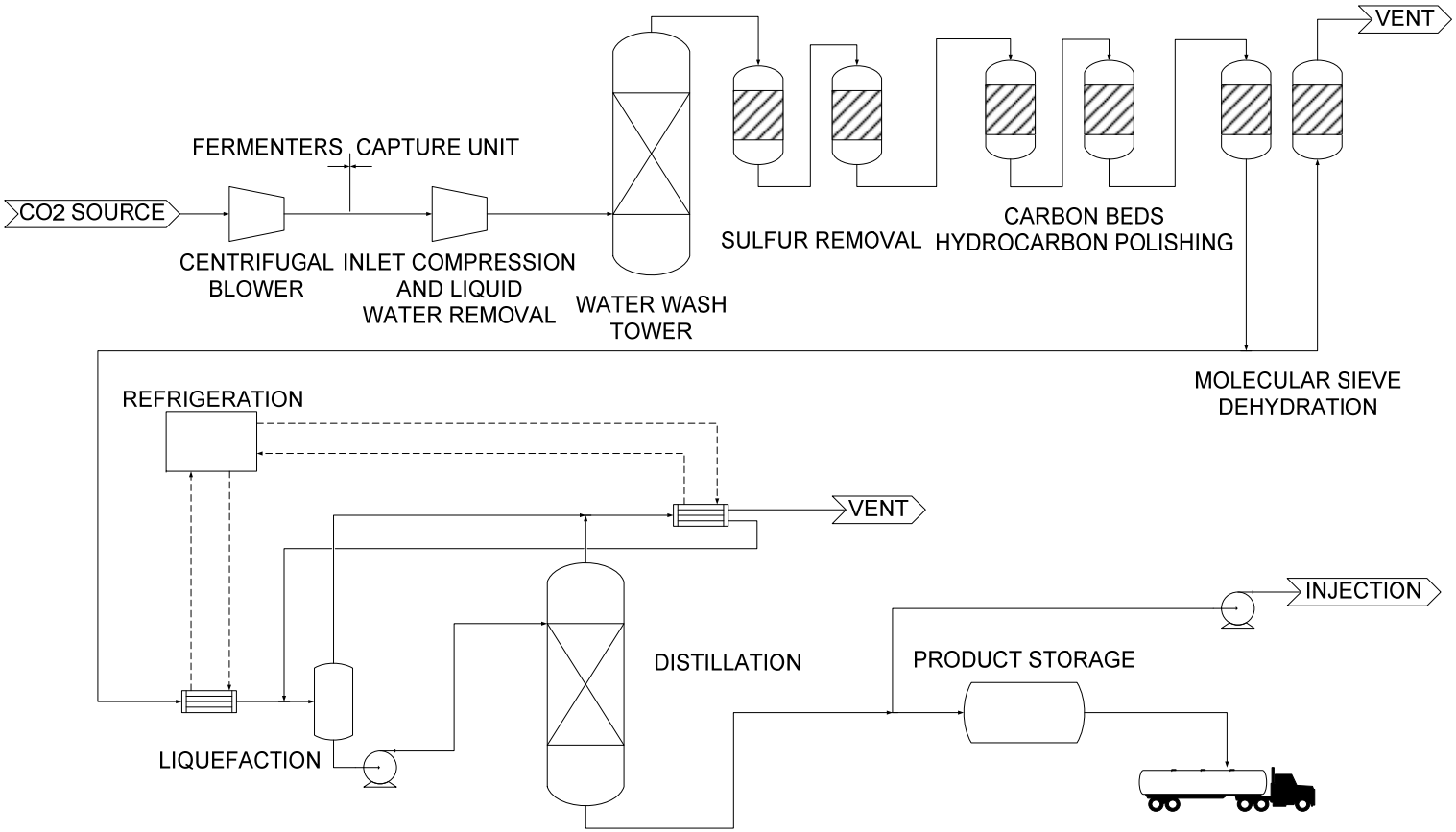

Figure 4. Draft conceptual design for a food-grade CO_2 product at the RTE site (image courtesy of Trimeric Corporation).

Table 2. Preliminary List of Potential MVA Technologies for CCS Implementation at RTE

Category	Type of Monitoring	Monitoring Technique	Area of Monitoring
Surface Infrastructure	CO_2 composition	Sampling, analyses	Pipeline
	CO_2 flow rate	Flowmeters	Pipeline, injection well
	CO_2 parameters	Pressure/temperature gauges	Pipeline, injection well
Near-Surface	Surface water quality	Sampling, analyses	RTE-owned holding pond
	Soil gas composition	Soil gas profile station; sampling, analyses	Injection site
	Groundwater quality	Water-monitoring well; sampling, analyses	Shallow aquifers, lowest USDW*
Deep Subsurface	Deep aquifer water quality	Monitoring well, pressure/temperature gauges; sampling, analyses	Aquifers above storage reservoir
	Storage reservoir conditions	Monitoring well, pressure/temperature gauges	Storage reservoir and seal
	CO_2 plume location	Cross well seismic land survey, modeling and simulation	Storage reservoir and seal
	CO_2 plume location	4-D time-lapse seismic land surveys	Entire storage complex
	Microseismicity	Passive seismic well	Entire storage complex

*Underground source drinking water.

Initial rough capital costs for installation of a CO_2 capture facility at the RTE site were estimated for the three design options investigated: injection-grade, EOR-grade, and food-grade. These initial costs are for comparison purposes only and are summarized in Table 3. The costs are based on the designs provided in Figures 2–4 and a maximum RTE CO_2 stream flow rate of about 24 tonnes/hr. The facility designed for strictly CO_2 injection into a saline formation is considered the "base case," as it requires the least amount of processing, e.g., water removal and pressurization. As mentioned previously, EOR-grade CO_2 may also require O_2 removal,

Table 3. First Draft Capital Cost Estimations for RTE CO_2 Capture Facility Options

Capture Design Option	Estimated Cost
Injection-Grade Facility	$13,100,000
EOR-Grade Facility	$14,700,000
Food-Grade Facility	$15,700,000

potentially adding about $1.6 million to the estimated capital expanses of a capture facility at RTE. Food-grade CO_2 is the most complex option investigated, potentially adding about $2.6 million to a base capture facility for the RTE site.

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. This estimate includes a market value of $60/tonne CO_2 reduced, based on the average from the California LCFS Program[4], and assumes 90% capture and injection of the 163,000 tonnes CO_2 emitted annually at RTE. Although CCS is not yet included in the California LCFS Program or the Oregon CFP, efforts are being made to incorporate a pathway plan to account for carbon storage, particularly via saline formation injection.[5]

Plan for the Next Reporting Period to Accomplish the Goals

Complete all technical work or near completion to begin conclusive assessment of technical and economic viability, as well as compiling results for the FIP. Specifically, the risk assessment, simulation, permitting and well characterization and testing design activities will be conducted. In addition, costs for permitting, equipment and infrastructure, installation, well characterization and testing, and operations (including MVA activities) will be estimated based on the FIP conceptual designs, and potential revenue from applying CCS to RTE ethanol production will be estimated. Refinement of results generated thus far may also be performed as more information becomes available from these activities.

PARTNERS AND FINANCIAL INFORMATION

This project is sponsored by the NDIC Renewable Energy Program, DOE, and RTE. Table 3 shows the budget of $1,005,000 for this project and expenses through the reporting period.

Table 4. Budget and Expenses Through the Reporting Period

Sponsor	Budget	Expenses	Remaining
NDIC Cash	$490,000	$48,578	$441,422
DOE Cash	$225,000	$17,904	$207,096
RTE Cash	$90,000	$3,967	$86,033
RTE In-Kind	$200,000	$–	$200,000
Total Project	**$1,005,000**	**$70,449**	**$934,551**

[4] California Air Resources Board. Data Dashboard Jan 4, 2017, www.arb.ca.gov/fuels/lcfs/credit/lrtcreditreports.htm (accessed Jan 2017).
[5] Peters, B. Oregon Department of Environmental Quality, personal communication, Dec 2016.

PRODUCTS

Publications, Conference Papers, and Presentations

An overview of the project effort was presented to the Oregon Department of Environmental Quality in relation to the emerging Oregon CFP.

Web or other Internet Site(s), Technologies or Techniques, Inventions, Patent Applications, and/or Licenses

None.

CHANGES/PROBLEMS

None.