Carbon Capture and Geological Storage at an Ethanol Facility

Red Trail Energy

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1.0 Overview

1.1 Project Description

Red Trail Energy LLC (RTE) owns and operates an ethanol production plant near Richardton, North Dakota. The plant complex is situated inside a footprint of approximately 25 acres of land which is part of an approximately 135-acre parcel. RTE acquired ownership of the land in 2004 and 2005. Included in the immediate campus area of the plant are perimeter roads, buildings, tanks, and equipment. An administrative building and parking area are located approximately 400 feet from the plant complex. The plant was placed into service in January 2007 and is capable of producing in excess of its name-plate production capacity of 50 million gallons of ethanol per year. RTE uses corn as feedstock to produce ethanol at the plant.

The project captures carbon dioxide (CO2) generated by the fermentation process during ethanol production. Fermentation exhaust is cleaned using a water scrubber which separates any remaining ethanol and other impurities to produce a purity stream of CO2. From the scrubber CO2 exhaust is sent to compressors to raise its pressure to 325 psi. Upon compression, the CO2 is dehydrated to remove any remaining water and is then sent to a refrigeration unit where it is subcooled to a liquid at -10°F. The condensed CO2 is then lightly distilled and pumped through a flowline to an injection well onsite where it is sequestered permanently in the Broom Creek formation. The injected gas has high CO2 purity (greater than 99.9%) with only trace quantities of nitrogen and oxygen.

1.2 Project Boundaries

Company Name	Red Trail Energy
Project Name	Carbon Capture and Geological Storage at an Ethanol Facility
Reporting Period	06/16/2022 – 06/15/2023
GHGs Removals	Biogenic CO2
Project Criteria	• Puro Standard General Rules (Version 3.0) • Puro Standard Geologically Stored Carbon Methodology (Edition 2021) • ISO 14040:2006 LCA Principles and Framework • ISO 14044:2006 LCA Requirements and Guidelines

1.3 Project Timeline

Date	Activity

06/16/2022	Start of capture of CO2 at the plant and injection of CO2 into storage
07/31/2023	End of first reporting period
06/16/2027	Expiration of Production Facility Registration

The project activity began at the facility on 06/16/2022 as evidenced by the well data record for RTE 10 in North Star, North Dakota Oil and Gas statewide tracking and reporting system. The activity will be eligible for crediting for a period of 5 years until 06/16/2027.

1.4 Contact Information

Red Trail Energy

Name	Role	Contact
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EcoEngineers

Name	Role	Contact
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2.0 Project Eligibility

2.1 Activity Eligibility

2.1.1 Source of CO2

In the context of ethanol production, the fermentation process generates biogenic CO2 when yeast consumes sugars and produces ethanol. To ensure the biogenic origin of the CO2 captured, Red Trail ran C14 isotope test by following the ISO 13833 that is a standardized method designed to determine the biogenic fraction of mixed CO2 samples.

2.1.2 Storage Durability

The project activity increases geologically stored carbon permanently with respect to the appropriate time scale. The captured CO2 stream is directly injected into the Broom Creek Formation below the project site via the onsite permitted Class VI well (RTE-10). RTE received formal approval of its North Dakota CO2 storage facility permit (SFP) on October 19, 2021. This approval by the North Dakota Industrial Commission (NDIC) authorizes the geologic storage of CO2 from the RTE ethanol facility in the amalgamated storage reservoir pore space of the Broom Creek Formation (NDIC Order Nos. 31453 and 31454). North Dakota has the authority to regulate the geologic storage of CO2 and primacy to administer the North Dakota Underground Injection Control (UIC) Class VI Program (83 Federal Register 17758, 40 Code of Federal Regulations [CFR] 147). No other geologic storage project exists or is planned at or near the RTE CCS project.

2.1.3 Biomass Sustainability

The land adjacent to RTE is agricultural land that has been farmed since at least 1972 based on direct aerial photography as noted in the Phase I Environmental Site Assessment report completed by Environmental Resource Group. Historically the land has been used for wheat and corn production. Corn production has become predominate since 2007 for ethanol production.

Historical records confirm that the adjacent agricultural land was never previously an area of high biodiversity value, nor did it transition from regions with high carbon stock after January 2008. This distinction is crucial per the EU Renewable Energy Directive (RED II). The directive stipulates that biomass should not originate from lands possessing these characteristics in January 2008 and subsequently converted for biomass production. Thus, the biomass derived from this land aligns with the sustainability standards set forth by the EU directive on land-use changes.

2.1.4 Environmental and Social Safeguards

As part of the permitting processes for the geological storage site, a screening level risk assessment (SLRA) of the geologic storage project was performed in accordance with the international standard, ISO 31000 (Leroux and others, 2017). The SLRA was conducted through a series of work group sessions involving subject matter experts (SMEs) who were asked to review 26 individual technical project risks and assign them a probability of occurrence and assess their potential impacts on cost, schedule, health and safety, legal/regulatory compliance, permitting compliance, and corporate image/public relations. These technical risks were grouped into the following five risk categories:

1. carbon dioxide (CO_2) supply, injectivity, and storage capacity (seven risks);
2. subsurface containment – lateral migration of CO_2 or formation water brine (three risks);
3. subsurface containment – propagation of subsurface pressure plume (three risks);
4. subsurface containment – vertical migration of CO_2 or formation water brine via injection wells, plugged and abandoned wells, monitoring wells, or faults/fractures (12 risks);
5. induced seismicity (one risk).

The risk assessment results indicated that all of the technical risks were ranked low, i.e., represented low-probability and low- to moderate-impact events. While the results of the SLRA indicated that there are no risks that would preclude the commercial deployment of the project, it did identify a set of operational events with the potential for endangering underground sources of drinking water (USDWs) for future monitoring and provided the basis for the identification and costing of potential emergency response actions during the geologic storage operations. RTE developed 10 supporting plans to address the identified risks.

Supporting Plans
Emergency and Remedial Response Plan
Financial Assurance Demonstration Plan
Worker Safety Plan
Testing and Monitoring Plan
Corrosion Monitoring and Prevention Plan
Surface Leak Detection and Monitoring Plan
Subsurface Leak Detection and Monitoring Plan

Well Casing and Cementing Plan
Plugging Plan
Postinjection Site Care and Facility Closure Plan

2.2 Additionality

2.2.1 Carbon Finance

Red Trail establishes its additionality by providing a comprehensive breakdown of all costs linked to the Project. This encompasses the initial capital expenditure for the CCS infrastructure, along with operational, maintenance, and any additional related expenses. Both the Validation and Verification Body and Puro.Earth will have access to the details of this capital and operational investment upon request.

2.2.2 Legal Requirement

Red Trail has a Title V Permit to Operate (Permit Number T5-X12002), issued by the State of North Dakota Division of Air Quality, to vent all CO2 produced to the atmosphere. There are no current state or federal requirements to reduce our CO2 emissions.

3.0 Monitoring Plan

3.1 Monitoring Overview

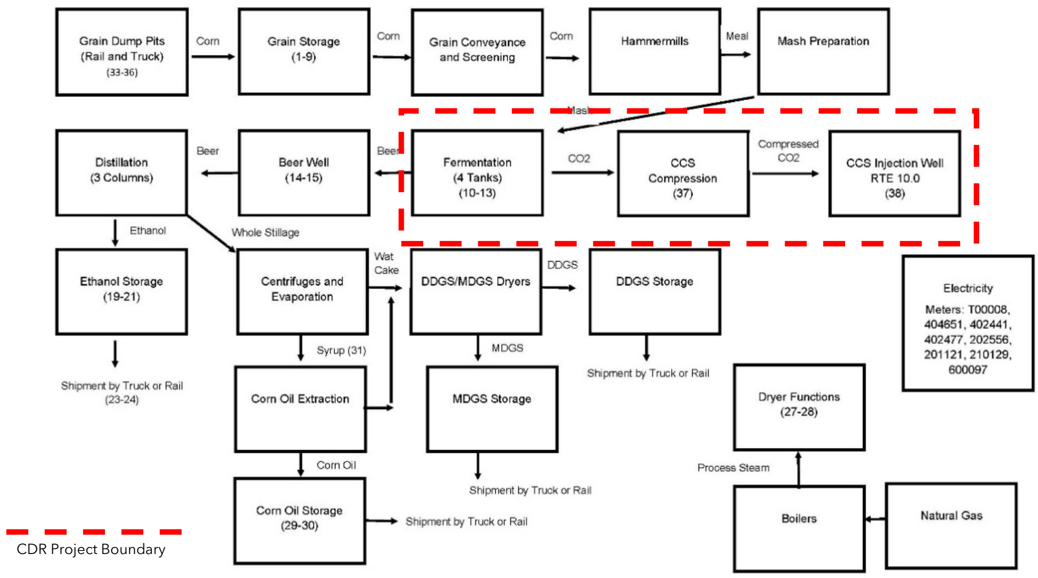

Figure 1. Red Trail Energy's ethanol production facility process flow diagram. The boundaries that are directly related to the CO2 generation, capture and storage are indicated within the red intertwined rectangle.

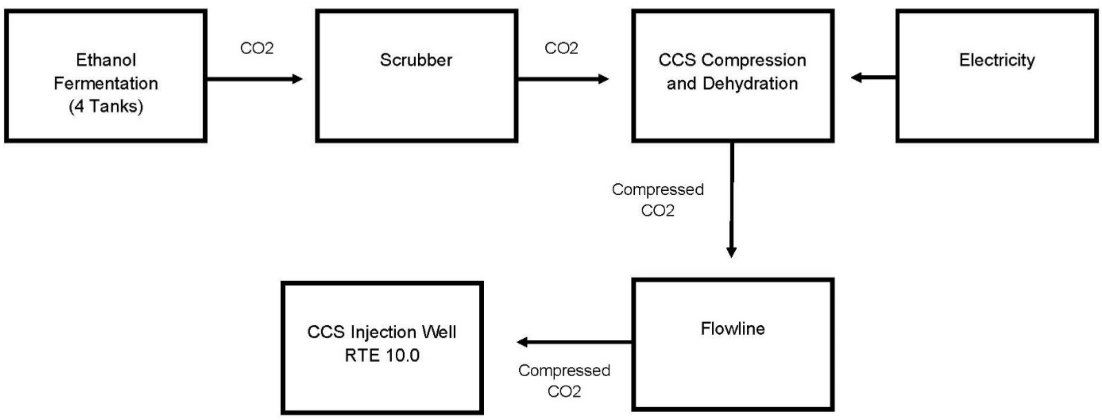

Figure 2. Red Trail's CCS system in which the CO2 is absorbed and purified in the scrubber, where it is sent to the compression and dehydration, and then injected in the underground reservoir to be stored permanently.

3.2 Data Management

3.2.1 Reporting

Red Trail Energy Monitoring Team

Name	Role	Contact
Dave Burns	Quarterly reporting	daveb@redtrailenergy.com
Ray Dobitz	Oversee data collection and entry	ray@redtrailenergy.com
Joni Entze	Recordkeeping and reporting	jonif@redtrailenergy.com
Kent Glasser	Oversee data collection and preventative/routine maintenance	Kentg@redtrailenergy.com
Jodi Johnson	Oversee recordkeeping and reporting	jodi@redtrailenergy.com

CO_2 captured is measured daily in pounds per hour first with a coriolis meter after dehydration and compression and then measured again at the well head after it passes through the flowline. Siemens PCS 7 (DCS) is the software used to read the meter and readings are recorded in the production report. A data log report is run at month end to reconcile total daily pounds recorded. Readings taken at the well head are used for state and federal reporting purposes.

3.2.2 Record Keeping

"The Issuing Body is responsible for retention of all records for a minimum of 5 years in the past"

RTE will follow the record retention requirements specified by 40 CFR § 98.3(g). In addition, it will follow the requirements in Subpart RR 40 CFR § 98.447-Subpart RR by maintaining the following records for at least 3 years (according to RTE information retention policies, the data is kept and stored inside its servers for 5 years):

- Quarterly records of CO_2 received at standard conditions and operating conditions, operating temperature and pressure, and concentration of the streams.
- Quarterly records of injected CO_2, including volumetric flow at standard conditions and operating conditions, operating temperature and pressure, and concentration of the streams.
- Annual records of information used to calculate the CO_2 emitted by storage reversals from reversal pathways.

- Annual records of information used to calculate the CO_2 emitted from potential equipment releases and vented emissions of CO_2 from equipment located on the surface between the flowmeter used to measure injection quantity and the injection wellhead.

This data will be collected, generated, and aggregated as required for reporting purposes.

3.3 Risk Monitoring

3.3.1 Economic Leakage

The installation and operation of the capture equipment and injection well onsite does not displace any activities and associated GHG emissions from the ethanol production plant to another location. As such, the project has no economic leakage.

3.3.2 CO_2 Reversals from Storage

An evaluation of potential subsurface leakage pathways and surface equipment failures during implementation of the project was informed by a screening level risk assessment (SLRA), which was performed in accordance with the International Organization for Standardization's (ISO's) risk management standard ISO 31000 (Leroux and others, 2017). The SLRA was conducted through a series of work group sessions involving Energy & Environmental Research Center subject matter experts. During these meetings, factors and equipment that could lead to potential CO_2 reversal from storage pathways were identified and evaluated for the following:

1. Surface components (flowline and wellhead)
2. Abandoned oil and gas wells
3. Faults, fractures, bedding plane partings, and seismicity
4. Injection well or monitoring well
5. Confining zone limitations

This leakage assessment determined none of the pathways required corrective action and the probability of storage reversals are unlikely.

3.3.3 Environmental Risks

In Red Trail Energy's North Dakota CO_2 Storage Facility Permit Application approved by the NDIC on October 19, 2021, RTE identified owners (surface and mineral) within the storage reservoir boundary plus 0.5 miles outside of the storage reservoir boundary. North Dakota law explicitly grants title of the pore space in all strata underlying the surface of lands and waters to the overlying surface estate (North Dakota Century Code [NDCC] Chapter 47-31-Subsurface

Pore Space Policy). All owners were notified of the permit application per NDCC policy and more than 60% of landowners consented to the pore space agreement per ND law.

The Financial Assurance Demonstration Plan in the North Dakota CO2 Storage Facility Permit Application outlines RTE's financial instruments in place to meet the regulatory requirements for the geological storage of CO2 prescribed by the state of North Dakota. The financial instruments in place are sufficient to cover costs associated with the following actions:

1. Corrective action on all active and abandoned wells which are within the area of review (AOR) and penetrate the confining zone, that have the potential to endanger underground sources of drinking water through the subsurface movement of the injected carbon dioxide or other fluids.
2. Plugging of injection wells.
3. Implementation of postinjection site care and facility closure activities.
4. Implementation of emergency and remedial response actions.

The Testing and Monitoring Plan in the North Dakota CO2 Storage Facility Permit Application outlines the types of monitoring programs in place to verify that the geologic storage project is operating as permitted and is protecting underground sources of drinking water. Monitoring is broken down into the following types:

1. Analysis of Injected CO2
2. CO2 Flow Line
3. Continuous Recording of Injection Pressure, Rate, and Volume
4. Well Annulus Pressure Between Tubing and Casing
5. Near-Surface Monitoring
6. Direct Reservoir Monitoring
7. Indirect Reservoir Monitoring
8. Internal and External Mechanical Integrity
9. Corrosion Monitoring

4.0 GHG Removal Statement

4.1 Summary of Project Removals

Ex-ante CDR quantification (tCO2e)

Year	Baseline Emissions	Project Emissions	Net CDR	Storage Reversals
2022	182,005	24,415	157,590	0

Life cycle assessment of Red Trail Energy geologically stored carbon for CORC calculation

Report prepared by EcoEngineers

Report prepared for Red Trail Energy ("Client")

Revision Date: 11/16/2023

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	10/31/2023	11/16/2023							
EXECUTION	ECO	ECO							
APPROVAL	RTE	RTE							

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Abstract

This Life-cycle Assessment (LCA) report deals with accounting carbon intensity (CI) of a carbon capture and storage (CCS) project using the operational data of the Red Trail Energy LLC (RTE) CCS-facility located at Richardton, North Dakota. The scope of the RTE-CCS facility is to capture and inject the CO_2 generated from the fermentation process of its ethanol facility. The system boundary for the LCA modelling starts at tapping the exhaust gas from the ethanol plant in a CCS-facility and ends at the injection. Injection is made into the Bloom Creek formation located at the facility site. At the CCS-facility, first, exhaust gas is sent to a water scrubber to enhance purity of the CO_2, and then follows the other subsequent stages such as compression, condensation and finally injection. The functional unit for LCA modelling is 1 kg CO_2 injected. The purity of CO_2 is greater than 99.9% and contains some trace quantities of nitrogen and oxygen. CI modelling was carried out considering both the use of capital goods (infrastructure and equipment) and operational data (generation and injection of CO_2 produced from the ethanol facility), and the associated energy consumption in the throughput. Emission factors (EFs) for different raw materials consumed in the CCS processes are based on ecoinvent v3.3.1. The study has also used EFs from GREET model, mainly to utilize related regional eGrid-mix that best represents the electricity mix available in the RTE-CCS facility. The net CI is -0.866 kg CO_2e/kg CO_2 injected. While injecting 1 kg CO_2, carbon emissions to the atmosphere was mostly from the production and supply of electricity. For instance, about 93% of the emitted CO_2 was due to electricity used at the capture-phase. In the case of unavailability of EFs of specific infrastructure and equipment types, the evaluation has assumed and used the best available representative LCI model. Future prospects can be pursuing a detailed LCA modelling using more granular LCI data related to the capital goods so that EFs for producing them can be more representative. Other prospects can be investigating the prudent use of electricity that can be co-produced from potential cogeneration units of the ethanol facility thereby reducing the impact of capturing and injecting CO_2 at the site.

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Glossary

RTE Red Trail Energy LLC

CI Carbon intensity

CO_2 Carbon Dioxide

CO_2e Carbon Dioxide-equivalent

CORC CO_2 Removal Certificate

CCS Carbon Capture and Storage

EF Emission Factors

GHG Greenhouse Gas

GWP Global Warming Potential

LCA Life-Cycle Assessment

MCC Motor Control Center

1. Introduction

Red Trail Energy LLC (RTE) owns and operates an ethanol production plant near Richardton, North Dakota. RTE captures carbon dioxide (CO2) generated by the fermentation process during ethanol production. A water scrubber technology is used to clean the fermentation exhaust, which separates residual ethanol and other impurities. From the scrubber CO2 exhaust is sent to compressors, and then it is processed in a dehydrator to remove remaining water. The compressed CO2 is then sent to a refrigeration unit, from which the condensed CO2 is then lightly distilled and pumped through a flowline to an injection well onsite where it is sequestered permanently in the Broom Creek formation. The injected gas has high CO2 purity (greater than 99.9%) with only trace quantities of nitrogen and oxygen. The stages of CCS accompanied with processing fermentation exhaust until underground storage of CO2 is described in a greater detail in section 3.3.

Red Trail Energy has aimed at the forefront of integrating CCS technology to decarbonize its ethanol production process. This project hence evaluates the environmental benefits of CO2 capture and securely storing in a permanent geological formation. This LCA report estimates the net reduction of greenhouse gas (GHG) emission of the proposed project. Aligning with the Puro Earth's guideline, this report includes emission from the energy demand for the CCS process as well as one-time emissions from the infrastructure development, which includes electrical and mechanical process equipment, pipeline construction, wellbore construction, and other supporting building structure, etc. A life-cycle assessment (LCA) methodology is adopted to calculate the net GHG emissions.

2. Goal and scope definition

2.1. Goal of the study

EcoEngineers has been contracted to complete an LCA model to determine the effects of removal of CO2 by RTE's project activity for compliance with the Puro Standard and the Geologically Stored Carbon Methodology (2021) published by Puro.earth. Modelling was completed for the initial reporting period of 6/16/2022 through 6/15/2023. Results of the study shall be used by RTE to complete their registration package for verification to receive CO2 Removal Certificates (CORCs) from Puro.earth.

2.2. Scope of the study

2.2.1. Product-systems considered

The evaluation deals with the processing of fermented CO2 that is produced in an ethanol production unit and eventually captured and stored in a compliant storage site.

2.2.2. Impact categories and impact assessment methods

The impact category selected for this evaluation is carbon intensity (CI), expressed in kg CO2e. In other words, the CI for this evaluation is defined as-how many grams of carbon dioxide (CO2) are released in the entire process of capturing and storing 1 kg of CO2. The impact was calculated using TRACI v2.1 method. The global warming potential (GWP) factors for the related greenhouse gases (GHGs) are in accordance with IPCC AR4 report (IPCC, 2007). The impact was evaluated in a 100-years-time perspective.

2.2.3. System boundary

For geologically stored carbon CORCs, the functional unit is 1 kg of CO2 captured and stored in a compliant storage site. The injected CO2 is greater than 99.9% purity and contain some trace quantities of nitrogen and oxygen. The reference flow is 1 kg of CO2. The system boundary starts at the gate of the CO2 processing facility, first treating the exhaust gas received from the ethanol plant. Ethanol production facility is outside of the system boundary considered for the current evaluation. Furthermore, the life-cycle impact evaluation is carried out considering both (a) Upstream or Background systems, which are responsible for producing and supplying raw materials (e.g., equipment, infrastructures, fuels) to the CCS-facility, and (b) Facility or Foreground system, where actual processing of fermented CO2 takes place and of which this evaluation is carried upon (see Figure 1).

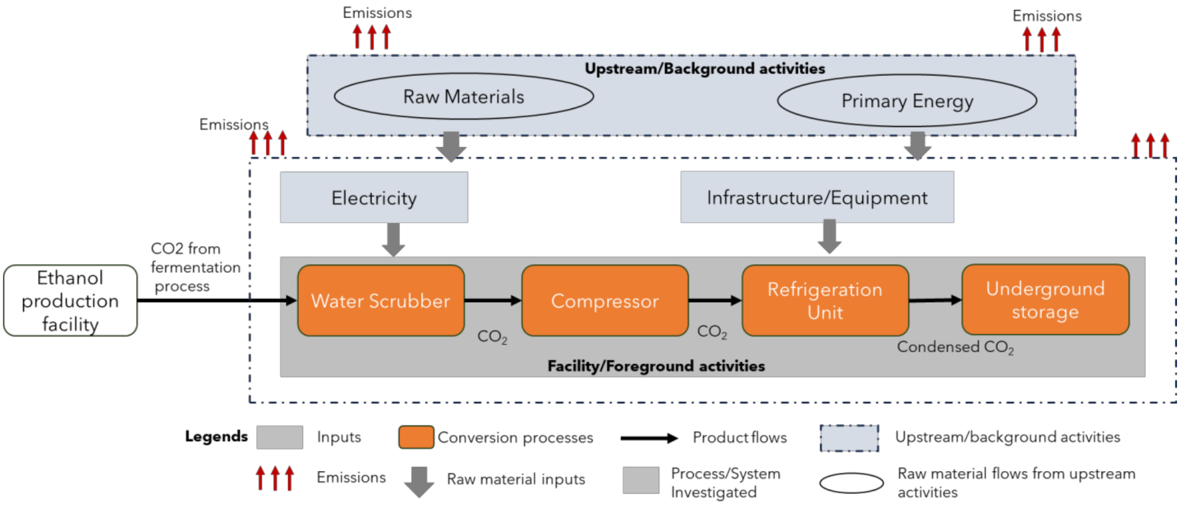


Figure 1. Schematic System Boundary Diagram for the processing and storage of CO_2.

Electricity is the sole energy input for the project. Roughrider Electric Cooperative is the electricity supplier. Please, see Roughrider Electric 07.31.23.pdf invoice for reference. The Ethanol Plant (meter T00008) and Coal Unloading (meter 404651) meters are related to ethanol production and equal the 3,691,240 KWh for July-23 from column AJ in the supporting document RTE Information Update 11132023.xlsx. The RTE 10.2 (meter 202556), RTE 10.0 (meter 201121), 139-92-13 NW (meter 210129), and Carbon Capture (meter 600097) meters are all related to carbon capture and storage so adding those to the other meters gets the total of 6,406,322 KWh from column AI in the same supporting document above.

Following agreement with the Oregon's Department of Environmental Quality (DEQ), the Admin Bldg (meter 110267) and East Shop (meter 402184) meters are not included since they do not relate to the production of ethanol and CCS. The East Shop is cold storage for the equipment during the winter months.

The electricity usage is divided into each project's emissions stages by the power requirements ratios provided in the RTE Information Update 11132023.xlsx supporting documentation.

2.2.4. Multi-functionality and allocation procedures

In the evaluated system there is no co-product produced, hence multi-functionality issue or applying any allocation procedure is not relevant. All the raw materials that are consumed in the actual operations of the CCS facility are primarily derived from the facility operation data and are used with respect to the functional unit defined in the evaluation. The multi-functionality issues related to the background system were dealt by selecting "cut-off unit process" of the selected LCI data for the selected infrastructures and raw materials.

2.2.5. Assumptions and limitations

The CI modelling has followed various assumptions, such as choosing emission factors (EF) for different inputs, primarily of the infrastructures. In the case of unavailability of specific EF of certain equipment, such as of the tanks and vessels, EFs are calculated based on the net steel weight. These are explained in greater detail in the following sections. In the case of unavailability of US-specific EF, we have assumed the EF of the raw materials that are originated at Rest-of-the World (ROW) and Global (GLO) geography as defined in ecoinvent v3.

3. Life cycle inventory analysis

3.1. Software, databases, and other data sources

To calculate the EFs of major mechanical and electrical equipment the specification provided by RTE has been used. In some cases (such as electric motor), data is obtained from the equipment manufacturers' website. Based on the specifications, EFs are calculated by calculating the materials requirement and their corresponding EFs from both GREET 2022 and ecoinvent v3.3.1. EFs of most mechanical and electrical equipment are from econinvent 3.3.1 database. Ecoinvent 3.3.1 has a long list of EFs for different equipment based on various geographic locations. For this study, the equipment types have been matched and the EFs are calculated by adjusting their sizes/capacities, as relevant. For each infrastructure, whenever LCA database was adopted from ecoinvent v3.3.1, the EFs are simulated using a PC tool (SimaPro).

Likewise, EFs derived from the CA-GREET 3.0 model is primarily used for electricity usage. The EFs for the major infrastructure construction such as pipelines, wellbore, and skids are quantified based on the amount of materials requirements. The emission factors of some construction materials (e.g., steel, cast iron, polymer materials, aluminium alloys, and copper) are from Argonne GREET 2022 database, however, a few emission factors (e.g., Portland cement) are from ecoinvent 3.3.1 database based on U.S. geographic location.

3.2. Missing data disclosure

The materials required for the wellbore construction is estimated based on the wellbore design. For the wellbore construction, carbon resistant cement is assumed as raw materials being used. As the EFs of such materials are not available, the EF of the Portland cement is assumed as a substitute data. Due to the lack of EF data for specific steel grades, generic steel production data for the U.S. is used for pipeline construction and skid production. For the wellbore tubing chromium steel 18-8 data is used in place of 13 Cr.80.

As stated above, for the infrastructure and equipment, it was hard to get exact EFs per listed equipment. However, the EFs are derived from the best representative infrastructures that are available in ecoinvent v3.3.1. Furthermore, for equipment such as tanks, vessels, EFs are calculated considering the calculated weight of steel to be required. Energy inputs that would be required for fabricating tanks and vessels were not included in the calculation. Weight of steel was calculated following the dimensions of each vessel, as reported in the supplementary documents (supporting documents: "rte-capture-design-package - pipeline length.pdf").

3.3. Inventory data

3.3.1. Background information on the CCS-facility and feedstock supply

RTE owned ethanol plant is located near Richardton, North Dakota, USA. The plant complex is situated inside a footprint of approximately 25 acres of land which is part of an approximately 135-acre parcel. The plant was placed into service in January 2007 and can produce more than its name-plate production capacity of 50 million gallons of ethanol per year. RTE uses corn as feedstock to produce ethanol at the plant. RTE captures CO2 generated by the fermentation process during ethanol production.

3.3.2. Processing and Carbon Dioxide capture

Regarding the processes involved in the CO2 capture, it initiates with the cleaning of fermentation exhaust in a water scrubber. This step separates any remaining ethanol and other impurities, thereby producing a purity stream of CO2. From the scrubber, CO2 exhaust is sent to compressors to raise its pressure to 325 psi. Upon compression, the CO2 is dehydrated to remove any remaining water and is then sent to a refrigeration unit where it is subcooled to a liquid at –10°F. The condensed CO2 is then lightly distilled and pumped through a flowline to an injection well onsite where it is permanently sequestered in the Broom Creek formation. The injected gas has a high CO2 purity (greater than 99.9%) with only trace quantities of nitrogen and oxygen.

The project activity increases geologically stored carbon permanently with respect to the appropriate time scale. The captured CO2 stream is directly injected into the Broom Creek Formation below the project site via the onsite permitted Class VI well (RTE-10). RTE received formal approval of its North Dakota CO2 storage facility permit (SFP) on October 19, 2021. This approval by the North Dakota Industrial Commission (NDIC) authorizes the geologic storage of CO2 from the RTE ethanol facility in the amalgamated storage reservoir pore space of the Broom Creek Formation (NDIC Order Nos. 31453 and 31454). North Dakota has the authority to regulate the geologic storage of CO2 and primacy to administer the North Dakota Underground Injection Control (UIC) Class VI Program (83 Federal Register 17758, 40 Code of Federal Regulations [CFR] 147). No other geologic storage project exists or is planned at or near the RTE CCS project.

The CO2 flow readings are taken at two different points, at the outlet of the compression equipment and at the well head (Appendix 7.3). Per Equations provided in Puro earth (2021) methodology, section 4.4, the CO2 losses could be derived from the difference between these two readings mentioned above.

- CO2 Losses (in Kg CO2e):

$$C_{Loss} = C_{Captured} - C_{Injected}$$

- Project Emissions (in Kg CO2e):

$$E_{Project} = E_{Capture} + E_{Transport} + E_{Injection} + E_{Equipment}$$

- Carbon Balance (in Kg CO2e):

$$C_{Captured} - E_{Project} - C_{Loss} = CO_2\ Removal\ (Kg)$$

However, due to meter reading inaccuracies (refer to supplementary document Enetek explanation of issue with Corolis meter.pdf) at the compression point, that reading is disregarded and injected numbers are used instead. Hence, the Carbon Balance equation for RTE is calculated as follows:

- RTE's Carbon Balance (in Kg CO2e):

$$C_{Injected} - E_{Project} = CO_2\ Removal\ (Kg)$$

The life cycle inventory (LCI) of the RTE-CCS facility is shown in Table 1. Detail on the processing capacity of CO2 is shown in Appendix 7.3.

Table 1. Life Cycle Inventory of RTE-CCS facility (values are rounded).

Stage / Description	Unit	Amount
$E_{capture}$		
Electricity	*MWh*	*33,256*
$E_{transport}$		
Electricity	*MWh*	*30*
$E_{injection}$		
Electricity	*MWh*	*101*
$E_{equipment}$		
Main Building	*sq. m*	*1189*
MCC Building	*sq. m*	*46*
Pipeline (Onsite CO2 pipeline)	*ft*	*400*
Pipeline (CO2 transport pipeline from storage to well)	*ft*	*2640*
Skids Construction	*numbers*	*13*
Electrical equipment	*numbers*	*See "RTE - puro_LCA Model - GCS_G.xlsx"*
Mechanical equipment	*numbers*	*See "RTE - puro_LCA Model - GCS_G.xlsx"*
C_{loss}		
CO_2 loss	*tonne*	*Not Applicable*
$C_{injected}$		
CO_2 injected	*tonne*	*182,005*
$C_{captured}$		
CO2 captured	*tonne*	*Not Applicable*

4. Life cycle impact assessment and interpretation

The calculated net CI is -0.866 kg CO_{2e}/ kg CO_2 injected. To inject 1 kg CO_2, the GHG contributions due to capturing-stage was 0.125 kg CO_{2e}, transport (0.0001 kg CO_2e), injection process (0.0004 kg CO_2e), and the infrastructure/equipment productions contributed 0.0086 kg CO_2e. Emissions related to the capture-phase is associated with the electricity consumption, mainly executing the processes: tapping exhaust gas from ethanol plant to the CCS-facility, processing in a scrubber and followed by compression and condensation. The EF for the electricity consumption is based on the average grid-mix in MROW (eGRID subregion), which was adopted from the GREET model. It is to be noted that of the related eGRID-mix of net-generation capacity in MROW, 60% is from the fossil-fuel based power plants (mostly from coal), and only about 29% is from renewable sources, including hydropower, nuclear (11%) and the rest from other sources.

The transportation phase included the emissions due to pipeline transport, primarily for electricity consumed to pump CO_2 from the compression equipment to the injection well. Like other stages, emissions related to injection-phase is also associated with the consumption of electricity. Emissions related to the infrastructure comprised of (a) construction of main building (b) construction of MCC building (c) wellbore construction (d) construction of skids (e) production of electric equipment and (f) production of mechanical equipment (such as compressors, tanks, blowers, motors, pumps, motor control units etc.). The detail list of equipment is reported in see Table 1 for reference.

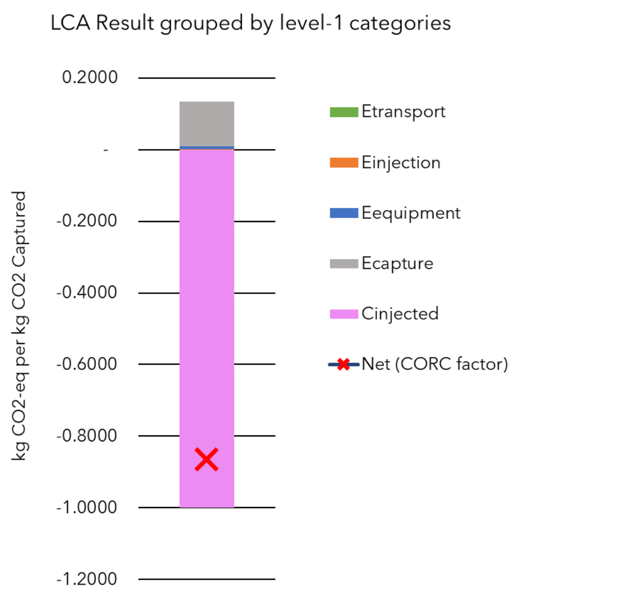


Figure 2. CI (kg CO_2e/ kg CO_2 injected) of RTE-CCS system, including contributions from each stage in the injection process.

Table 2- Emissions at different stages of CCS-process

CCS-Stages	**Climate impact in kg CO2-eq/kg CO2 injected**
Ecapture	0.125
Etransport	0.000
Einjection	0.000
Eequipment	0.009
Cinjected	-1.000
Net (CORC factor)	-0.866

5. Discussion, conclusions, and recommendations

This study deals with Carbon Intensity (CI) modelling of carbon dioxide (CO_2) capture in the RTE facility. The evaluation is carried out for injecting CO_2 generated from the fermentation process of an ethanol production facility at RTE. The functional unit for the evaluation is 1 kg CO_2 injected in the geological storage at the RTE site. System boundary for the evaluation starts from receiving exhaust gas from the ethanol facility and ends at the injection site. Life cycle inventory analysis was carried out considering the on-site operational data, including metered data on injected CO_2 and energy input required to operate the CCS facility. The net CI is -0.866 kg CO_{2e}/ kg CO_2 injected. Regarding the contribution from the different stages of the RTE-CCS facility, about 93% of the emissions were due to electricity consumed at capture-phase, followed by 6% from the production of the mechanical and electrical equipment that are used in the facility. Rest of the impact are related to pipeline transport and the injection phase, which are again related to the consumed electricity.

The overall CI modelling is largely based on the emission factors adopted from various LCA databases (GREET and ecoinvent). Reasons for depending on different databases was primarily due to the unavailability of specific EFs that could best match with the specific types of infrastructures. Prospects of pursuing industrial-LCA thus could be using more granular data on the production of accessories and equipment so that for each specific infrastructure better EF can be established. Furthermore, since electricity consumption at the capture-phase had the major contribution to the overall CI, potential mitigation measures thus are adhered with using more renewable sources, and/or lies with prospects of using co-generated energy from the ethanol facility. Likewise, identifying potential measures to increase the efficiency of the CCS plant and reducing the energy consumption could also be viable interventions that can be made at the project site.

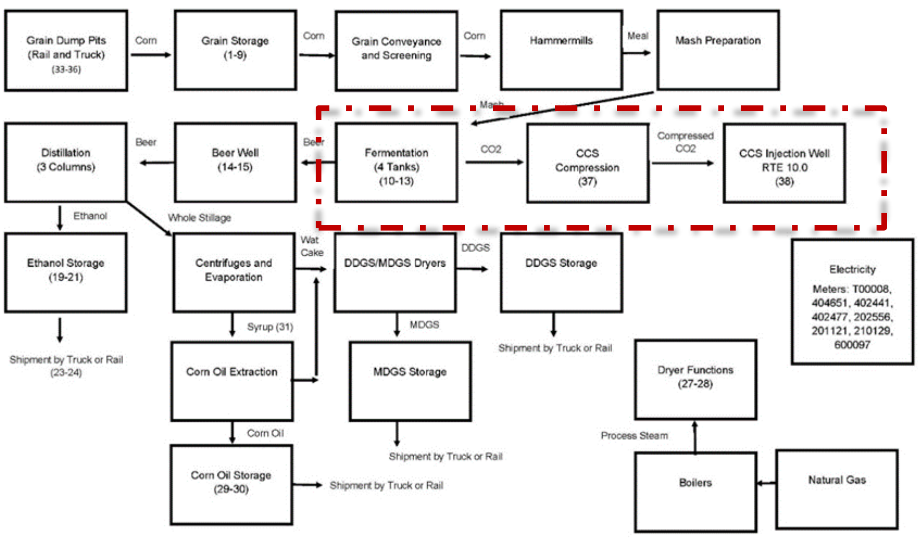
6. References

- Bare, J. C. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), Version 2.1 - User's Manual. EPA/600/R-12/554 2012.
- eGRID. Emissions & Generation Resource Integrated Database (eGRID). https://19january2021snapshot.epa.gov/egrid_.html
- GREET. https://greet.anl.gov/
- IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
- Puro earth, 2021. Puro Standard and the Geologically Stored Carbon Methodology (2021). https://puro.earth/carbon-removal-methods/
- Wernet, Gregor, et al. "The ecoinvent database version 3 (part I): overview and methodology." The International Journal of Life Cycle Assessment 21 (2016): 1218-1230.

7. Appendix

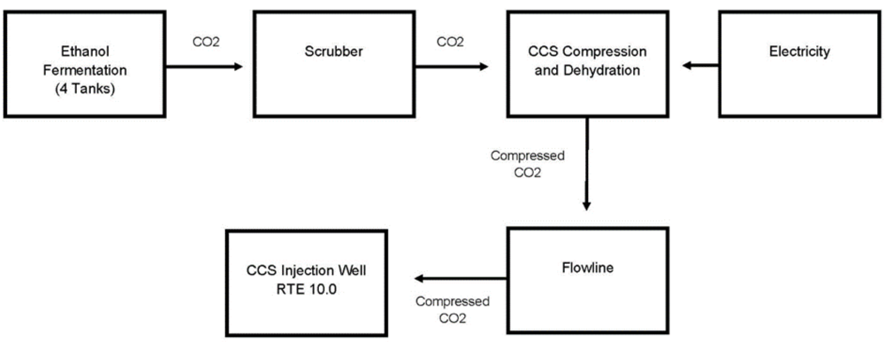
7.1. Appendix 7.1. Red Trail Energy's ethanol production facility process flow diagram

The boundaries that are directly related to the CO_2 generation, capture and storage are indicated within the red intertwined rectangle.



7.2. Appendix 7.2. Red Trail's CCS system process flow diagram

The CO_2 is absorbed and purified in the scrubber, where it is then sent to the compression and dehydration, and then injected in the underground reservoir to be stored permanently.



7.3. Appendix 7.3. Inventory for CO2 at compression and at well head in different months.

Operation months	**CO2 at Compression Equipment (in Pound)**	**CO2 at Well head (in Pound)**
June-22	12,801,650	12,801,650
July-22	26,910,047	27,044,618
August-22	28,292,944	28,613,908
September-22	29,672,752	30,493,882
October-22	23,059,688	23,858,936
November-22	26,171,368	26,249,344
December-22	31,739,648	31,749,648
January-23	31,532,832	31,469,248
February-23	30,913,872	30,932,112
March-23	33,562,320	33,587,504
April-23	32,148,992	32,167,872
May-23	35,523,936	35,628,320
June-23	24,272,928	24,350,656
July-23	32,222,464	32,304,576
Total	**398,825,441**	**401,252,274**
Notes: 1 lb = 0.454 kg		

8. Supplementary documents

- RTE - puro_LCA Model – GCS_G.xlsm
- RTE - puro_LCA Result reporting – GSC_B.xlsx
- RTE Information Update 11132023.xlsm
- 1.2 GENERAL ARRANGEMENT DRAWINGS Salof - Buildings square footage.pdf
- rte-capture-design-package - pipeline length.pdf
- S20007 Red Trail Tagged Equipment 2021.11.10 - Eco.xlsx
- Table 15 - S20007-RTE-Electrical Equipment Information – Eco.xlsx
- RTE Equipment and Infrastructure EFs - Part 1.xlsx
- RTE Equipment and Infrastructure EFs - Part 2.xlsx
- Roughrider Electric 07.31.23.pdf
- Enetek explanation of issue with Corolis meter.pdf

puro · earth

Stakeholder Engagement Report

PURO.EARTH Puro.earth Oy, Lapinlahdenkatu 16, 00180 Helsinki, Finland

The purpose of this document is to gather results of the Stakeholder Engagement that has been conducted by potential CO2 Removal Suppliers of Puro.earth. It is subdivided into the three following sections:

- 1 – Stakeholder invitations
- 2 – Verbal consultation
- 3 – Text-based consultation

Please fill in section one in any case, and, depending on your selected means of Stakeholder Engagement, either section two or section three.

Note: File 01_Stakeholder Engagement EERC Outreach Toolkit Nov 21 has also been provided to show outreach engagement efforts in 2020-2021. This is sample of the outreach efforts that took place during each phase of the project.

contact@puro.earth Puro.earth Oy, Lapinlahdenkatu 16, 00180 Helsinki, Finland https://puro.earth

1 – Stakeholder invitations

1.1. Invitation table

Name of invitee	Organization / Stakeholder type	Gender (m/f/d/no information)	Date of invitation	Method of invitation
See attached file: 01_Stakeholder Invitation				

(To add rows, right-click the lowest click "insert" and click "insert below")

1.2. Sample invitation (may also be inserted as a screenshot):

See attached file: 01_Stakeholder Sample Invitation

Multiple outreach events were held for residents of Richardton, ND. Individual meetings with landowners to discuss the pore space agreement and access to land for geophysical survey. Presentation and discussion at RTE investor annual meetings.

1.3. Were any stakeholders not invited although they are listed in para 3.1 of the Stakeholder Engagement Requirements and so relevant that they should clearly have been invited? If so, please provide justification:

All stakeholders were invited.

2 – Verbal consultation

Please fill in this template if your Stakeholder Engagement was based on verbal feedback (e.g., webinar or physical meeting)

2.1 Date or period of consultation: 2017 - 2022

2.2. Table of hosts:

Name of host	Organization	E-mail address
Red Trail Energy		
Energy & Environmental Research Center (EERC)		

2.3. Table of participants:

Name of participant	Organization / Stakeholder type	Gender (m/f/d/prefer not to say)	E-mail address
See attached file: 01_Stakeholder Engagement Table of Participants	This is only a sample of participants. It shows participation at 2 investor annual meetings.		

2.4. Duration of webinar (in minutes): average of 120 minutes

2.5. List of received live-feedback and live-answers during webinar (bullet points are sufficient if they accurately reflect true content):

Comment (stakeholder)	Gender of stakeholder	Answer (CO_2 removal supplier)
See attached file: 01_List of Feedback		

2.6. In case the feedback indicates that alterations must be made to the project's design, please summarize the content of those comments and how you will address them. If you decide not to alter project design despite the feedback, please provide a justification:

Did not recieve feedback on alterations.

2.7. In case any relevant stakeholders could not take part in the public comment period due to reasons such as lack of mobile access or physical disability, please describe and summarize how you engaged with them, what their feedback was, and how you will react to it. If you decide to not alter project design although the comments indicate so, please provide a justification:

Seperate meetings were held with landowners that could not attend the Open House events. Questions were answered on how payments will be calculated for pore space owners, how the number of needed permit acres were calculated, the price per acre and ton of CO2 that will be paid, safety questions on the project. No feedback for alterations were recieved.

3 – Text-based consultation

Please fill in this template if your Stakeholder Engagement was based on written feedback (e.g., comments on a website or emails).

3.1. Date or period of consultation:

3.2. Number of comments submitted:

3.3. Table of addressed public comments

Comment of stakeholder	Answer from CO_2 removal supplier	Name of stakeholder	Organization	E-mail address

3.4. In case the feedback indicates that alterations must be made to the project's design, please summarize the content of those comments and how you will address them. If you decide not to alter project design despite the feedback, please provide a justification:

Your answer here

3.5. In case any relevant stakeholders could not take part in the public comment period due to reasons such as lack of mobile access or physical disability, please describe and summarize how you engaged with them, what their feedback was, and how you will react to it. If you decide to not alter project design although the comments indicate so, please provide a justification:

Your answer here