NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Saline Aquifer CO2 Injection Site, Operations

Reference Flow: 1 kg of sequestered CO2

Brief Description: This unit process models the injection operations and sequestration of CO2 in a saline aquifer formation.

Section I: Meta Data

Geographical Coverage: United States **Region:** United States

Year Data Best Represents: 2006

Process Type: Waste Treatment Process (WT)

Process Scope: Gate-to-Gate Process (GG)

Allocation Applied: None

Completeness: Individual Relevant Flows Captured

Flows Aggregated in Data Set:

☑ Process ☑ Energy Use ☐ Energy P&D ☐ Material P&D

Relevant Output Flows Included in Data Set:

Releases to Air:	☑ Greenhouse Gases	☐ Criteria Air	☐ Other
Releases to Water:	☐ Inorganic	☐ Organic Emissions	☐ Other
Water Usage:	☐ Water Consumption	☐ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

CO2_flow	*[tonne/day] Flow rate of CO_2 through compressor*
EF_CO2	*[kg/day] Emission factor for CO_2 released to air from injection pump*
Motor_eff	*[dimensionless] Efficiency of electric motors used by CO_2 compressors*
Electricity	*[MWh/kg] Electricity required for CO_2 compression*

Brine_Prod	*[kg/kg CO_2 injected] Amount of brine produced from saline aquifer per kg of CO_2 injected*
Plume_Area	*[square km] area of CO_2 plume in saline aquifer*
CO2_leakage	*[kg/kg CO_2 injected] Amount of sequestered CO_2 that leaks from the saline aquifer*
Injection_yrs	*[years] Number of years of CO_2 injection into the saline aquifer sequestration site*

Tracked Input Flows:

Carbon Dioxide [Intermediate Flow]	*[Technosphere] Captured CO_2 for sequestration in a saline aquifer*
Seismic Truck Survey [Other]	*[Technosphere] Seismic survey for saline aquifer site preparation*
Saline Aquifer Well Const. and Install. [Construction]	*[Technosphere] Well construction and installation for sequestration operations*
Power [Electric Power]	*[Technosphere] Electricity for CO_2 injection pumps*

Tracked Output Flows:

Brine Water [Water]	*Reference flow*
Carbon dioxide [Inorganic emissions to air]	*Emission to air*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_Saline_Aquifer_CO2_Injection_Site_Operations_2012.01.xls*, which provides additional details regarding relevant calculations, data quality, and references.

Goal and Scope

This unit process provides a summary of relevant input and output flows associated with the injection operations associated with CO_2 sequestration in a saline aquifer. The inputs to this unit process include CO_2 from a pipeline, site preparation and construction activities associated with the sequestration site and electricity used to power the injection pumps. Outputs include produced brine from the saline aquifer and CO_2 emissions resulting from injection pump seal leakage and saline aquifer formation leakage. The reference flow of this unit process is: 1 kg of sequestered CO_2.

Boundary and Description

This unit process provides a summary of relevant input and output flows associated with the injection site operations for CO_2 sequestration in a saline aquifer. The tracked inputs are electricity, CO_2, well construction/installation, and site preparation. The key outputs are sequestered CO_2 and CO_2 emissions to air. The reference flow of this unit process is the sequestration of one kilogram of CO_2.

The NETL saline aquifer storage cost model (internal) contains a representative list of possible storage formations in the United States. For each formation, the cost model calculates the required number of injection wells, maximum CO_2 plume area, and formation injection pressure based on the individual geologic formation characteristics. The maximum plume area is used to determine the area of the site that must be surveyed, by utilizing seismic technology, as one of the site preparation requirements prior to any injection of CO_2. For the formations investigated, the median plume area was approximately 75 square kilometers. Details on the inputs and emissions associated with seismic monitoring area provided in a separate unit process.

The injection pressure calculated from the model is used to determine the pumping requirements. The average injection pressure based on the midpoint of the geologic formation was 3,780 psia. At pipeline conditions, liquid carbon dioxide forms at a pressure of 1,070 psia (7.38 MPa). The pipeline pressure is maintained above this critical point to ensure that all CO_2 remains in the liquid state. For the calculation of the injection pumping power requirements, it was assumed that the pipeline pressure at the injection site is at the critical pressure. The power to pressurize supercritical CO_2 from its critical point (1070 psia or 7.38 MPa) to the required injection pressure (3,780 psia or 26.1 MPa) is described by **Equation 1**. This equation is based on a performance curve for CO_2 pumping and is a function of CO_2 flow rate based on a supercritical CO_2 pump and accounts for pressure drop in the injection pipe from the surface to aquifer (McCollum & Ogden, 2006).

$$\text{Power (MW)} = 0.0005331 * x, \text{ where } x = CO_2 \text{ flow rate (tonnes/day)} \quad \textbf{(Equation 1)}$$

This unit process models all CO_2 pumping using electric power. The power requirements calculated by **Equation 1** represent pump output, not pump input. The power inputs for CO_2 injection pumping are calculated by dividing the outputs of the above equations by the efficiency of electric motors.

To convert to a basis of CO_2 injected, the power input (MW) is multiplied by the operating time at full capacity (24 hours/day) and divided by CO_2 throughput at full capacity (in tonnes/day). At a CO_2 flow rate of 10,000 tonnes/day, the electricity requirements for injection pumping are 1.279E-05 MWh/kg of CO_2.

The operation of CO_2 compressors and pumps results in fugitive emissions of CO_2. The low, mid-range, and high emission factors for CO_2 from compressors are 6,972, 23,240, and 116,200 kg of CO_2 per megawatt-year (MW-yr). These factors are based on natural gas pipeline data that the Intergovernmental Panel on Climate Change (IPCC) collected and adapted to CO_2 pipelines using the relative densities of natural gas and CO_2 (Holloway, Karmijee, Akai, Pipatti, & Rypdal, 2006). On a daily basis, this is equivalent to 19.1, 64.0, and 318 kg CO_2/MW-day. This unit process applies these emission factors to the calculated pump power output to determine the fugitive CO_2 emissions from CO_2 pumps at the injection site.

In addition to the fugitive CO_2 emissions from the injection pump, the unit process also assumes some leakage of CO_2 to the atmosphere from the underground storage formation. It is assumed that one percent of the stored CO_2 eventually migrates to the surface over a 100-year monitoring period.

Brine water production from the saline aquifer is one method to control the pressure in the underground formation; however, it is not always required (ANL, 2011). Extraction of water from the aquifer storage formation would occur away from the injection wells to prevent any undesired migration of the stored CO_2 to the surface along with the produced brine. Assuming that an equal volume of brine is displaced to store CO_2 in the aquifer, 1,300 to 1,500 L of water could be produced per metric tonne of CO_2 sequestered in the formation (ANL, 2011). The inputs and emissions associated with brine management are provided in a separate unit process.

Figure 1 provides an overview of the boundary of this unit process. There are four inputs to this unit process: electricity used for powering the injection pumps, pipeline CO_2, site preparation seismic monitoring, and well construction/installation. The fugitive emission of CO_2 is accounted for in this unit process. The tracked output from the process is produced brine water that is treated in a separate unit process.

Table 1 summarizes emission factors and other parameters that are relevant to this unit process. **Table 2** provides a summary of modeled input and output flows and shows all inputs and outputs on the basis of the reference flow (the sequestration of one kilogram of CO_2). Additional detail regarding input and output flows, including calculation methods, is contained in the associated DS.

Figure 1: Unit Process Scope and Boundary

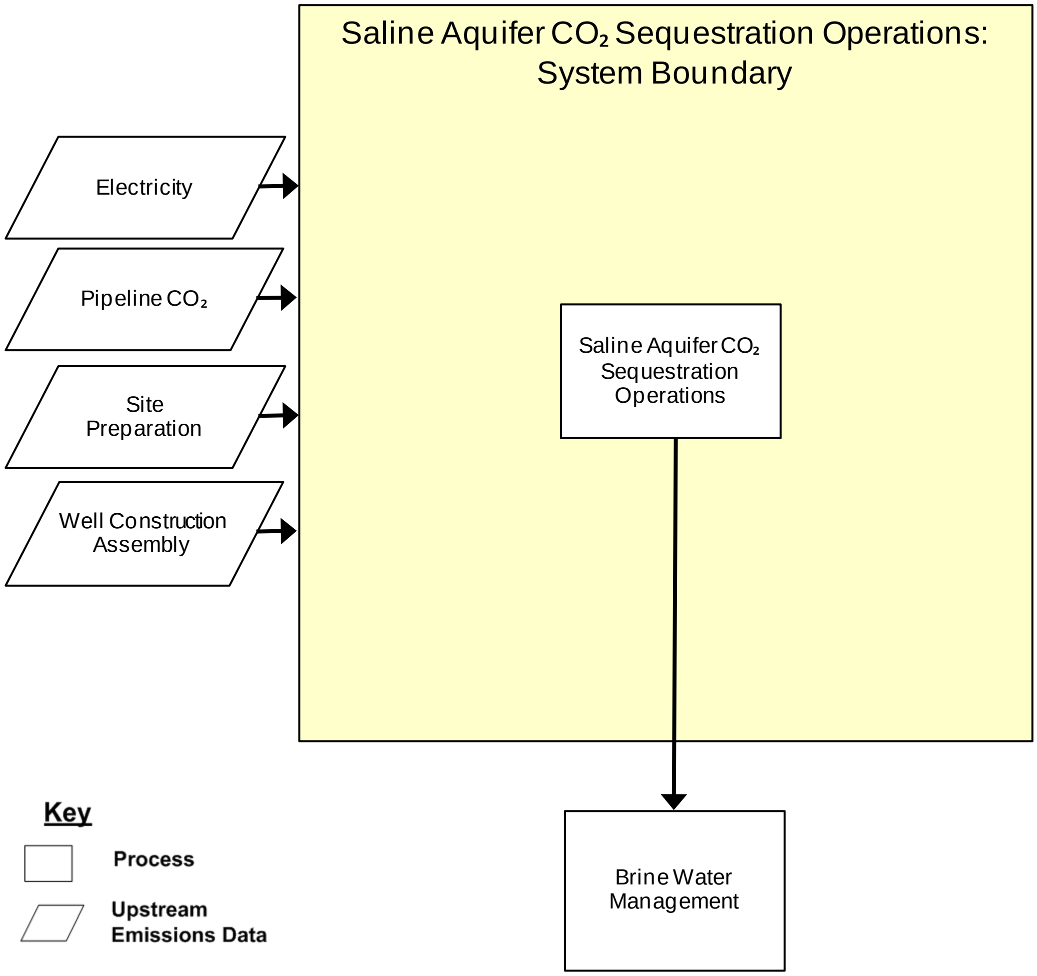

Table 1: Parameters CO_2 Injection Operations

Parameter	Value	Units	Reference
Plume Area	75	square-km	NETL – Saline Storage Cost Model
Injection Pressure	3,780	psia	NETL – Saline Storage Cost Model
Brine Production	1,400	l/tonne CO_2 injected	ANL, 2011
Operation Lifetime	30	years	NETL – Saline Storage Cost Model
CO_2 Flow	10,000	tonne/day	NETL Engineering Assumption
Injection Pump CO_2 Emissions	64	kg/(MW-day)	Holloway et al., 2006
CO_2 Leakage from Aquifer	1.00	percent (over 100 year monitoring basis)	NETL Engineering Assumption

Table 2: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Carbon Dioxide [Intermediate Flow]	1.01	kg
Seismic Truck Survey [Other]	6.85E-10	square-km
Saline Aquifer Well Construction and Installation [Construction]	9.13E-12	pieces
Power [Electric Power]	1.28E-05	MWh
Outputs		
Sequestered CO2	1	kg
Brine Water [Water]	1.40	kg
Carbon dioxide [Inorganic emissions to air]	1.01E-02	kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows.

Embedded Unit Processes

None.

References

ANL. (2011). *Management of Water Extracted from Carbon Sequestration Projects*. (ANL/EVS/R-11/1). Chicago, Illinois: Argonne National Laboratory Retrieved July 25, 2012, from http://www.ipd.anl.gov/anlpubs/2011/03/69386.pdf

Holloway, S., Karmijee, A., Akai, M., Pipatti, R., & Rypdal, K. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Chapter 5: Carbon Dioxide Transport, Injection, and Geological Storage*. Intergovernmental Panel on Climate Change Retrieved September 10, 2012, from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_5_Ch5_CCS.pdf

McCollum, D. L., & Ogden, J. M. (2006). *Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage & Correlations for Estimating Carbon Dioxide Density and Viscosity*. (UCD—ITS—RR—06-14). Davis, California: Institute of Transportation Studies University of California Davis Retrieved September 10, 2012, from http://pubs.its.ucdavis.edu/publication_detail.php?id=1047

Section III: Document Control Information

Date Created: September 10, 2012

Point of Contact: Timothy Skone (NETL), Timothy.Skone@NETL.DOE.GOV

Revision History:

Original/no revisions

How to Cite This Document: This document should be cited as:

NETL (2012). NETL Life Cycle Inventory Data – Unit Process: Saline Aquifer CO2 Injection Site Operations. U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: September 2012 (version 01). www.netl.doe.gov/energy-analyses (http://www.netl.doe.gov/energy-analyses)

Section IV: Disclaimer

Neither the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) nor any person acting on behalf of these organizations:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe on privately owned rights; or

B. Assumes any liability with this report as to its use, or damages resulting from the use of any information, apparatus, method, or process disclosed in this document.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by NETL. The views and opinions of the authors expressed herein do not necessarily state or reflect those of NETL.