Process Name: Dry Mill Ethanol Plant w/ Corn Oil and CCS

Reference Flow: 1 kg of Ethanol (E95)

Brief Description: Inputs and outputs for ethanol production by a dry mill ethanol plant using corn grain feed and natural gas fuel. DDGS and corn oil are co-products. CO_2 is captured. Includes addition of denaturant (gasoline) as 5 percent volume of final product.

Section I: Meta Data

Geographical Coverage: US **Region:** Midwest

Year Data Best Represents: 2009

Process Type: Energy Conversion (EC)

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

Allocation Applied: Yes

Completeness: All Relevant Flows Recorded

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 Pollutants	☐ Other
Releases to Water:	☒ Inorganic Emissions	☐ Organic Emissions	☐ Other
Water Usage:	☒ Water Consumption	☒ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

DISPLACED_FEED — *Mass of corn feed displaced by DDGS (kg/kg of pure ethanol)*

Tracked Input Flows:

Corn grain — *Corn grain input to dry mill ethanol plant*

Power — *Electricity input to dry mill ethanol plant*

Natural gas USA — *Natural gas input to dry mill ethanol plant*

Tracked Output Flows:

Ethanol (E95)	*1 kg of ethanol (E95) production (the reference flow of this unit process)*
Corn oil	*Corn oil extracted from DDGS (a co-product of this unit process)*
Carbon dioxide	*Carbon dioxide captured for sequestration*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_EthanolDryMill_CornOilandCCS_2010.01.xls*, which provides additional details regarding calculations, data quality, and references as relevant.

Goal and Scope

This unit process accounts for the operating activities for a dry mill ethanol plant that uses corn grain as a feedstock and includes a corn oil extraction process. All flows of this unit process are normalized to a reference flow for the production of 1 kg of ethanol that is denatured with gasoline at a concentration of 5 percent by volume (E95). The inputs to the process include water, corn grain, natural gas, electricity, and gasoline. Water is used for cooling and other process-related utilities; water is assumed to enter the boundaries of this unit process having no upstream resource consumption or environmental emissions. Corn grain is a biomass feedstock that is converted to ethanol via fermentation; the resource consumption and emissions associated with the upstream production and delivery of corn grain to the ethanol plant are not included in the boundaries of this unit process but are accounted for by upstream unit processes.

Natural gas is used for on-site energy generation, and electricity is used to power pumps and a carbon dioxide compressor; these two energy sources have upstream resources and emissions that are not included in this unit process. Gasoline is used as a denaturant, making the product ethanol unfit for human consumption; the upstream resources and emissions associated with gasoline are not included in this unit process. The outputs of this unit process are E95 (a mixture that is 95 percent ethanol and 5 percent gasoline by volume), corn oil, carbon dioxide (CO_2) (for sequestration), wastewater, air emissions, and water emissions.

Boundary and Description

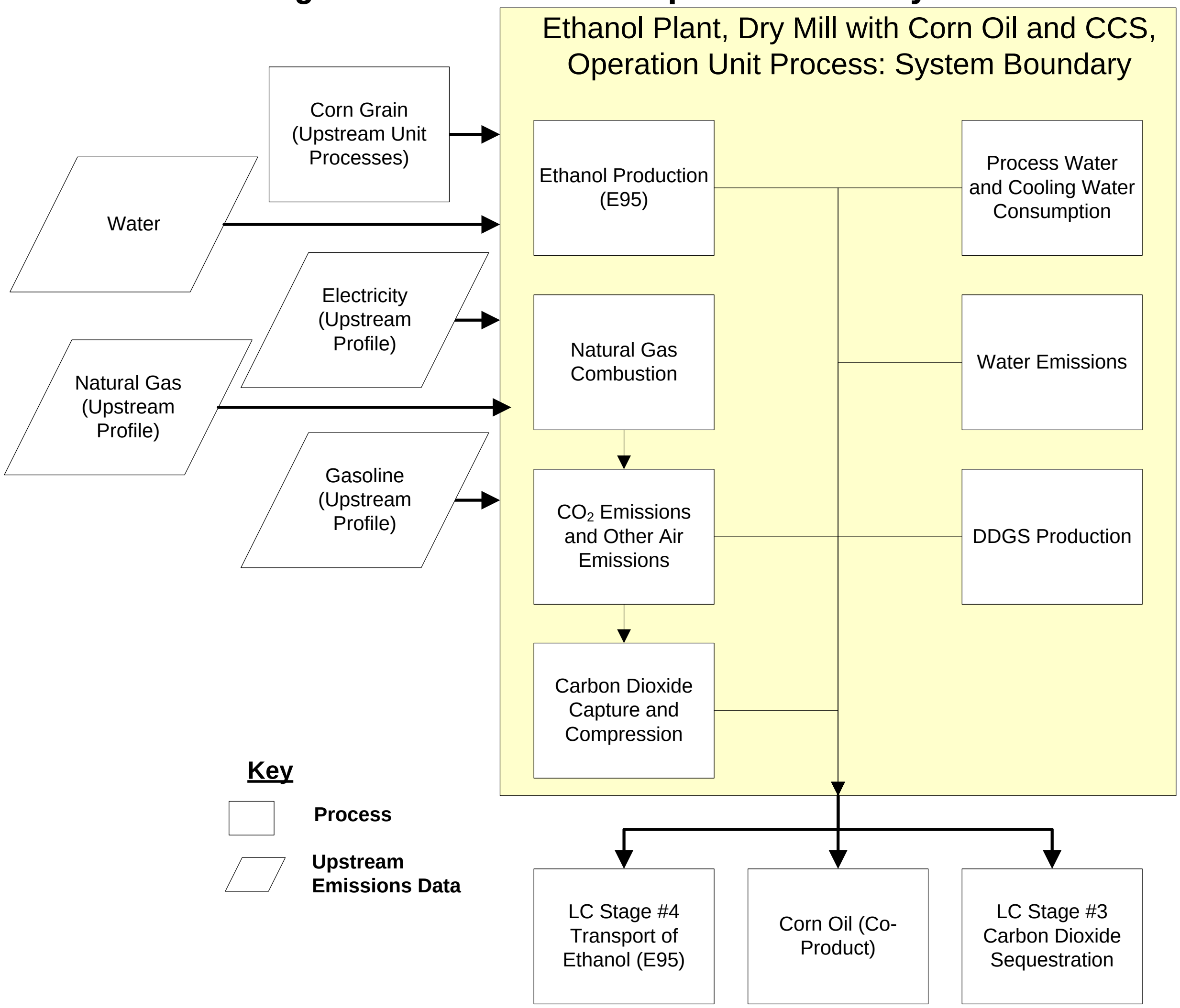
This unit process models the production of ethanol via a conventional dry mill technology that ferments corn starch to ethanol, followed by extraction of corn oil from DDGS and capture of CO_2 for sequestration. The energy inputs and outputs of this process are provided in the EPA documentation of the RFS2 (Renewable Fuel Standards, Version 2) program (EPA 2009a). This unit process describes activities that occur within Life Cycle (LC) Stage #3 of dry mill ethanol production. The steps that precede this unit process include the production of corn grain in LC Stage #1, and the transport of corn grain in LC Stage #2. The step that immediately follows this unit process is the pipeline transport of ethanol in LC Stage #4. **Figure 1** provides an overview of the boundary of this unit process. Rectangular boxes represent relevant sub-processes, while trapezoidal boxes indicate upstream data that are outside of the boundary of this unit process. As shown, upstream resources and emissions associated with the production and delivery of biomass are accounted for outside of the boundary of this unit process, while water is assumed to enter the boundary of the unit process with no upstream resources or emissions. The methods for calculating these operating activities are described below.

This unit process has one adjustable parameter: “DISPLACED_FEED”. “DISPLACED_FEED” represents the amount of corn-based animal feed that is displaced by DDGS (distillers dried grains with solubles). DDGS is a co-product of dry mill ethanol production and is comprised of spent grains that have a fat and protein content that make it a suitable material for animal feed. The default value for “DISPLACED_FEED” is 1, which models the displacement of 1 kg of conventional corn-based animal feed per 1 kg of DDGS production. A reasonable range of values for “DISPLACED_FEED” is 0.8 to 1.2.

The basis document for this unit process is the EPA DRIA (Draft Regulatory Impact Analysis) (EPA 2009a), which presents the policy implications of the Renewable Fuel Standards. Another key data sources for this unit process is a USDA model of dry mill ethanol production (McAloon 2008), which includes the raw material inputs, purchased fuels, and flow rates of key process streams. The EPA DRIA (EPA 2009a) uses the USDA dry mill ethanol model as a basis for the energy and material flows of conventional dry mill ethanol production. These two sources were used for determining the raw material inputs, co-products, and purchased energy necessary for the production of a given quantity of ethanol.

The dry mill ethanol plant of this unit process includes a corn oil extraction process, a post-fermentation process that recovers corn oil from DDGS. The corn oil extraction process increases the electricity requirements of the plant, but also reduces the drying requirements of the DDGS and thus reduces the thermal energy (from natural gas) requirements of the plant. The corn oil extraction process increases the electricity requirements by 9 percent and reduces the natural gas requirements by 4 percent (EPA 2009a).

Figure 1: Unit Process Scope and Boundary



The vent stream from the fermentation process of the ethanol dry mill is greater than 98 percent CO_2 by mass, with water vapor accounting for the balance of the stream composition. This unit process assumes that the electricity requirements of a compressor account for the majority of energy requirements for the capture of CO_2 at the dry mill ethanol plant. The compressor captures CO_2 from the vent stream and compresses it from atmospheric pressure to 2,200 psi (15.2 MPa). The electricity required by the compressor was calculated by assuming a four-stage compressor and the work required to achieve the compression ratio of each stage. The power requirements of the compressor are estimated at 3.24 MW.

This unit process assumes that 100 percent of the CO_2 in the vent stream is captured. The dry mill ethanol plant of this unit process has an operating capacity of 40 MGY (million gallons per year). This operating capacity is two-thirds of the ethanol throughput modeled for this LCA (approximately 60 MGY). However, the operating requirements described by this unit process are normalized to 1 kg of production and it is assumed that negligible efficiencies of scale are gained when a 40 MGY dry mill ethanol plant is scaled up to a 60 MGY ethanol plant.

The CO_2 emissions from the dry mill ethanol plant include biogenic CO_2 vented from the fermentation processes (EPA 2009a) and CO_2 from the combustion of natural gas used for steam generation (McAloon 2008). The CO_2 from natural gas combustion was calculated using AP-42 emission factors (EPA 2009b). No data are available for the emission of methane, nitrous oxide, or other greenhouse gases.

The EPA Draft Regulatory Impact Analysis (2009) includes non-greenhouse gas emissions (including carbon monoxide, nitrogen oxides, particulate matter, and sulfur oxides) from dry mill ethanol production facilities that use natural gas as a fuel. This unit process converts these emissions from a basis of grams per gallon of ethanol to kilograms per kg of ethanol using standard unit conversion factors and the volumetric density of pure ethanol (0.789 kg/L).

Heavy metals such as lead and mercury are not present in the raw materials used by the ethanol dry mill, and thus it is unlikely that significant levels of lead or mercury are released from this unit process. The EPA Draft Regulatory Impact Analysis reports zero ammonia emissions from the dry mill plants that use natural gas as a fuel; it is thus assumed that dry mill ethanol facilities have negligible ammonia emissions.

The ethanol plant uses water sourced from a well. Water is used for steam generation and cooling towers and is discharged as vapor and wastewater. The use rates of water are reported in the USDA dry mill ethanol model (USDA 2009); to translate water use rates to water consumption rates, this unit process assumes that water for the steam system requires a 3 percent makeup rate and water used for cooling towers requires a 5 percent makeup rate (McAloon 2010) .

The volume and quality of discharged wastewater is based on the average wastewater emissions of 13 dry mill ethanol facilities in the Midwest U.S. as reported by the NPDES (National Pollutant Discharge Elimination System) for 13 dry mill ethanol facilities in the Midwest United States (EPA 2008). The discharged wastewater includes nonmetals (chloride, nitrogen, phosphorus, sulfate, total dissolved solids, and total suspended solids) and metals (arsenic, chromium, copper, iron, lead, manganese, nickel, selenium, and zinc).

DDGS (distillers dried grains with solubles) is a co-product of dry mill ethanol production and is a viable replacement for conventional materials used for animal feed. To manage the DDGS co-product of the dry mill ethanol plant, this unit process assumes that DDGS displaces corn used for animal feed. (In other words, system expansion with credit for displacement has been chosen as the method for avoiding co-product allocation between DDGS and ethanol.) Instead of showing DDGS as an output of this unit process, this unit process reduces the input of corn used for ethanol production, which is equivalent to modeling a parallel system for corn production that is displaced by DDGS. This method is feasible only because the co-product (DDGS) of this unit process happens to displace another product (corn for animal feed) that is identical to the input of this unit process (corn for ethanol production).

Corn oil is also a co-product of this unit process, and is produced at a rate of 0.9 kg per bushel of corn grain input (Watkins 2007). NETL recommends system expansion for managing the co-production of corn oil. The corn oil from the dry mill ethanol plant of this unit process is of adequate quality for conversion to biodiesel and, in turn, can displace soybean oil, the conventional feedstock for biodiesel. The displacement of soybean oil by corn oil is not modeled within the boundaries of this unit process.

Properties of dry mill ethanol plants that use corn grain as a feedstock are shown in **Table 1**. **Table 2** provides a summary of modeled input and output flows. Additional details regarding input and output flows, including calculation methods, are contained in the associated DS sheet.

Table 1: Properties of Dry Mill Ethanol Plant with Corn Oil Extraction and Carbon Capture (EPA 2009a)

Property (at 100% capacity)	Dry Mill Ethanol Plant
Raw Material Feedstock	Corn Grain
Co-products	DDGS; Corn Oil
Ethanol Output, MGY (million L/yr)	40 (151)
Geography	U.S. Midwest
Process Fuel	Natural Gas

Table 2: Unit Process Input and Output Flows

Flow Name*	Dry Mill Ethanol Plant	Units (Per Reference Flow)
Inputs		
Corn grain	**2.03**	**kg**
Water (unspecified) [Water]	8.40	Kg
Power [Electric power]	**2.015**	**MJ**
Natural gas USA [Natural gas (resource)]	**0.215**	**Kg**
Gasoline (NETL) [Crude oil products]	**0.0469**	**Kg**
Outputs		
Ethanol (E95)	1	Kg
Corn oil	1.06E-01	Kg
Carbon dioxide [Inorganic emissions to air]	6.15E-01	Kg
Carbon dioxide [Inorganic intermediate products]	8.96E-01	Kg
VOC (unspecified) [Organic emissions to air (group VOC)]	1.28E-03	Kg
Carbon monoxide [inorganic emissions to air]	6.06E-04	Kg
Nitrogen dioxide [Inorganic emissions to air]	1.76E-03	Kg
Particulate Matter, unspecified [Other emissions to air]	7.02E-04	Kg
Sulphur dioxide [Inorganic emissions to air]	2.23E-03	Kg
Chloride [Inorganic emissions to fresh water]	2.00E-04	Kg
Nitrogen [Inorganic emissions to fresh water]	4.83E-06	Kg
Phosphorus [Inorganic emissions to fresh water]	2.81E-06	Kg
Sulphate [Inorganic emissions to fresh water]	9.50E-04	Kg
Solids (dissolved) [Analytical measures to fresh water]	7.08E-04	Kg
Solids (suspended) [Particles to fresh water]	4.54E-04	Kg
Arsenic (+V) [Heavy metals to fresh water]	3.37E-08	Kg
Chromium (unspecified) [Heavy metals to fresh water]	3.13E-09	kg
Copper (+II) [Heavy metals to fresh water]	1.43E-08	kg
Iron [Heavy metals to fresh water]	2.46E-06	kg
Lead (+II) [Heavy metals to fresh water]	1.64E-11	kg
Manganese (+II) [Heavy metals to fresh water]	1.53E-08	kg
Nickel (+II) [Heavy metals to fresh water]	9.77E-09	kg
Selenium [Heavy metals to fresh water]	4.61E-09	kg
Zinc (+II) [Heavy metals to fresh water]	1.44E-07	kg
Water (returned to receiving body) [Water]	1.13E-01	kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows. Upstream environmental flows were added during the modeling process using GaBi modeling software, as shown in Figure 1.

Embedded Unit Processes

None.

References

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EPA 2009a	EPA, 2009. *Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program.* U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division. 2009.
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Watkins 2007	Watkins, C. Two Fuels from One Kernel. International News on Fats, Oils and Related Materials (INFORM). AOCS Press. November 1, 2007. http://www.greenshift.com/pdf/EPM_One_Kernel_Two_Fuels.pdf (Accessed September 28, 2009).

Section III: Document Control Information

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