NETL Life Cycle Inventory Data
Process Documentation File

Process Name:	Biochemical Ethanol Plant with Boiler Cogen
Reference Flow:	1 kg of Ethanol (E95)
Brief Description:	Inputs and outputs for ethanol production by a biochemical ethanol plant using cellulosic feedstocks. Electricity is cogenerated with a recovery boiler. 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:	No		
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:

CASE_CS	*Allows the selection of corn stover feedstock (binary)*
CASE_SG	*Allows the selection of switchgrass feedstock (binary)*
FEED_CS_E100	*Feed rate of corn stover per unit production of pure ethanol (kg corn stover/kg ethanol)*

FEED_SG_E100	*Feed rate of switchgrass per unit production of pure ethanol (kg corn stover/kg ethanol)*

Tracked Input Flows:

Corn Stover	*Corn stover input to biochemical ethanol plant*
Switchgrass	*Switchgrass input to biochemical ethanol plant*
Lime (calcium hydroxide) [Non renewable resources]	*Lime input to biochemical conversion process*
Sulfuric acid	*Sulfuric acid input to biochemical conversion process*
Gasoline (NETL) [Crude oil products]	*Gasoline input used as a denaturant in ethanol.*

Tracked Output Flows:

Ethanol (E95)	*1 kg of ethanol (E95) production (the reference flow of this unit process)*
Power [Electric power]	*Cogenerated electricity sold to the grid (a co-product)*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_Biochem_Ethanol_BoilerCogen_2010.01.xls*, which provides additional details regarding calculations, data quality, and references as relevant.

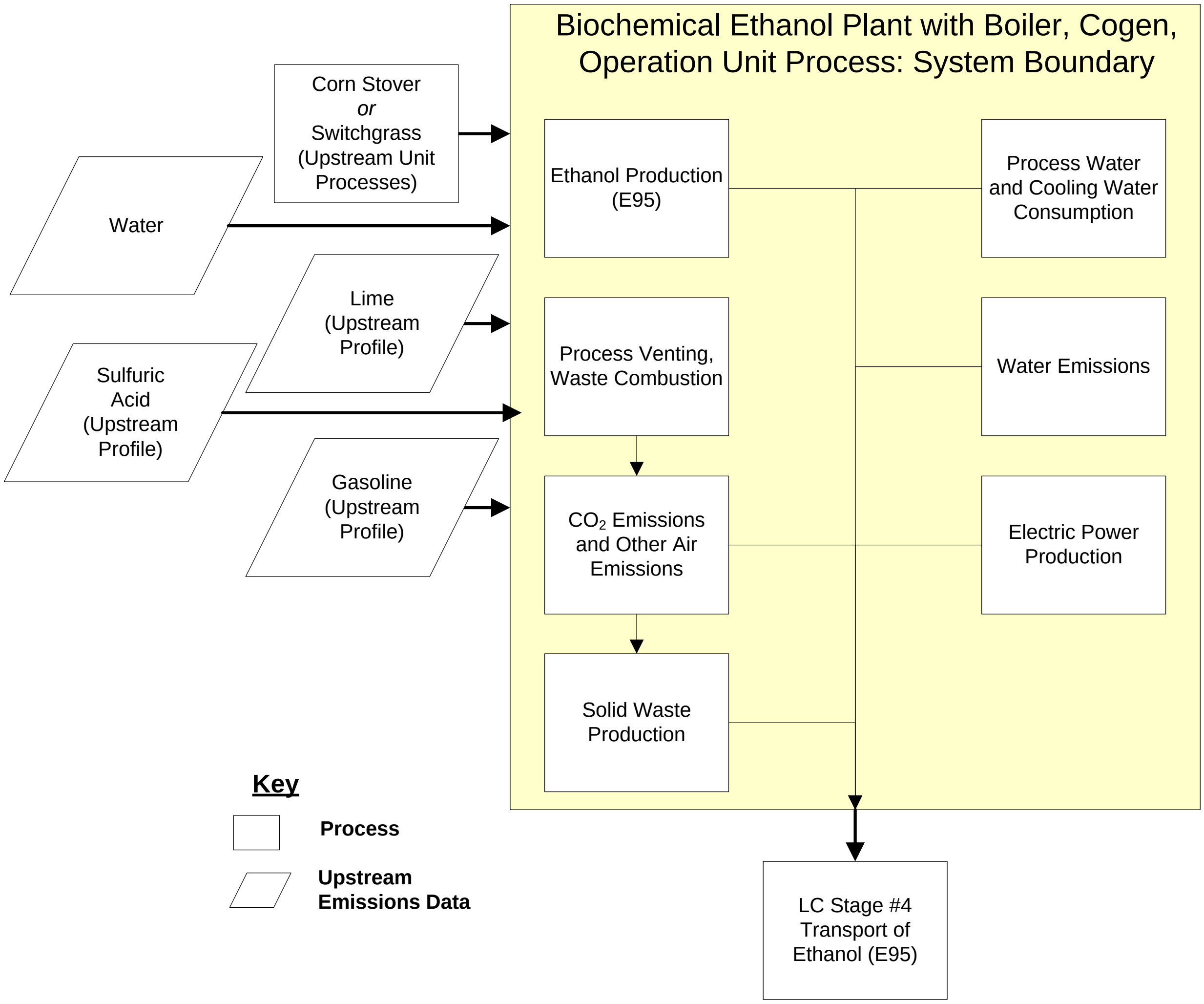
Goal and Scope

This unit process accounts for the operating activities for a biochemical ethanol plant that uses cellulosic feedstock. 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 stover or switchgrass, sulfuric acid, lime, 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 stover or switchgrass are two types of cellulosic feedstock that can be converted to ethanol via dilute acid treatment followed by fermentation; the resource consumption and emissions associated with the upstream production and delivery of corn stover and switchgrass to the ethanol plant are not included in the boundaries of this unit process but are accounted for by upstream unit processes. Sulfuric acid and lime are agents used in the preparation of cellulosic feedstock for fermentation. 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 output of this unit process is E95 (a mixture that is 95 percent ethanol and 5 percent gasoline by volume), wastewater, and air emissions.

Boundary and Description

This unit process models the production of ethanol via a biochemical ethanol plant that treats cellulosic feedstock in a dilute acid solution and then ferments the cellulose to produce ethanol. The energy inputs and outputs of this process are provided in an NREL technoeconomic analysis of biochemical ethanol production (Aden et al 2002). This unit process describes activities that occur within Life Cycle (LC) Stage #3 of ethanol production. The steps that precede this unit process include the production of corn stover or switchgrass in LC Stage #1, and the transport of corn stover or switchgrass 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.

Figure 1: Unit Process Scope and Boundary



This unit process has four adjustable parameters which allow the modeling of two types of cellulosic feedstocks used for bioochemical ethanol production. “CASE_CS” is an adjustable parameter that allows the selection of corn stover as the cellulosic feedstock to the biochemical ethanol plant; the value of this parameter is “1” or “0”. “CASE_SG” is an adjustable parameter that allows the selection of switchgrass as the cellulosic feedstock to the biochemical ethanol plant; the value of this parameter is “1” or “0”. Only one type of cellulosic feedstock can be modeled at a time, so “CASE_CS” and “CASE_SG” are mutually exclusive. “FEED_CS_E100” is an adjustable parameter that specifies the amount of corn stover per production of one kg of pure ethanol; the default value for this parameter is 3.75. “FEED_SG_E100” is an adjustable parameter that specifies the amount of switchgrass per production of one kg of pure ethanol; the default value for this parameter is 3.64.

The basis document for this unit process is a 2002 study conducted by NREL (National Renewable Energy Laboratory) that models the biochemical conversion of biomass to ethanol. Corn stover is the type of cellulosic feedstock used in the basis document (Aden et al 2002); this unit process assumes that the operating characteristics of the biochemical ethanol plant do not change significantly with changes in the type of cellulosic feedstock. However, one adjustment made for the switchgrass scenario is the amount of feedstock per unit of ethanol production. The input of switchgrass was estimated by scaling the corn stover feed rate by the relative heating values (lower heating value) of corn stover and switchgrass.

The physical flows of the biochemical ethanol plant are based on an ASPEN model that accounts for all process streams starting with the receipt of biomass feedstock and ending with production of ethanol (Aden et al 2002). The properties of these streams were used to calculate the raw materials, utilities, and air emissions associated with the biochemical production of ethanol.

The biochemical ethanol plant of this unit process has an operating capacity of 69 MGY (million gallons per year). The process begins when feedstock is shredded and then exposed to a dilute sulfuric acid catalyst at high temperatures for a short time, which liberates the hemicellulose sugars and other compounds (Aden et al 2002). During separation, washing removes the acid from the solids for neutralization; overliming (or over neutralizing) is required to insure all compounds toxic to fermentation (that were liberated during pretreatment) are removed. Enzymatic hydrolysis (or saccharification) is then coupled with co-fermentation through a series of tanks, and most of the cellulose and xylose are converted to ethanol after several days (this process is called SSCF, which stands for simultaneous saccharification with co-fermentation).

Supporting processes to the biochemical conversion of cellulose include wastewater treatment, which is necessary to digest the organics that result from fermentation. The methane generated from wastewater treatment is combusted for energy recovery. A fluidized bed combustor capable of handling inputs with a wide array of characteristics (i.e., varying moistures and heating values) is used for the combustion of the methane, residual biomass, and other waste materials from the process. The fluidized bed combustor has 68 percent boiler efficiency and is followed by a multistage steam turbine that generates electricity. Excess electricity is the only co-product of this technology that exits system boundaries.

The basis document for this unit process (Aden et al 2002) provides a description of a wastewater treatment system, but it does not provide data on the characteristics of discharged wastewater. Furthermore, since this type of technology has not yet been employed on a commercial scale, no primary data are available on the quality of wastewater discharges from ethanol plants that use biochemical conversion of cellulosic feedstocks. Due to this data limitation, the waterborne emissions from biochemical ethanol plants are not included in this unit process.

The carbon dioxide (CO_2) emissions from the biochemical ethanol plant include CO_2 from the scrubber vent stream (which is downstream of the fermentation process) and the combustion exhaust of the boiler. Since the biochemical ethanol plant of this unit process does not use fossil fuels, it is assumed that all CO_2 emissions from the unit process are biogenic. No data are available for the emission of methane, nitrous oxide, or other greenhouse gases.

Other air emissions included in this unit process are particulate matter (PM10), sulfur oxides (SOx), carbon monoxide (CO), and nitrogen oxides (NOx). The exhaust gas from waste-to-energy combustion accounts for the majority of these emissions. The emissions rates of these pollutants are provided in the basis document (Aden 2002), and are based on specifications provided by a combustion equipment vendor. PM10 is controlled with a baghouse with a 98.8 percent efficiency; no other environmental controls are used by the combustion processes.

Heavy metals such as lead and mercury are not present in the raw materials used by the biochemical ethanol plant, and thus it is unlikely that significant levels of lead or mercury are released from this unit process.

The biochemical ethanol plant uses water for steam generation and cooling towers. Water is lost through cooling tower evaporation and is also discharged as wastewater. A water balance is included in the basis document (Aden et al. 2002), which gives the hourly flow rates of makeup water streams. When expressed on the basis of ethanol production, the water use rate is 7.7 kg per kg of pure ethanol production. The rates of wastewater discharge were estimated from output streams of the wastewater treatment system, as shown in the ASPEN modeling diagrams provided in the basis document (Aden et al. 2002). The wastewater discharge rate is 4.0 kg per kg of pure ethanol production. The rate of wastewater discharge is less than the rate of water input because of water lost to evaporation.

The basis document (Aden et al 2002) does not provide any data on the on the quality of wastewater from biochemical ethanol plants. Furthermore, since biochemical ethanol plants have not been commercialized, no primary data are available on the quality of wastewater discharges from such plants.

The properties of the biochemical ethanol plant of this unit process 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 Biochemical Ethanol Plant (Aden 2002)

Property	Biochemical Ethanol Plant
Raw Material Feedstock(s)	Corn Stover or Switchgrass
Ethanol output at 100% capacity, MGY (million L/yr)	69.3 (262)
Electricity output at 100% capacity, kWh/gal (MJ/L)	2.28 (2.17)
Geography	U.S. Midwest
Overall Plant Efficiency (% HHV)	53.1%

Table 2: Unit Process Input and Output Flows

Flow Name*	Biochemical Ethanol Plant w/ Boiler Cogen and Corn Stover Feedstock	Biochemical Ethanol Plant w/ Boiler Cogen and Switchgrass Feedstock	Units (Per Reference Flow)
Inputs			
Water (unspecified) [Water]	7.30	7.30	kg
Corn Stover	**3.58**	**0.00**	**kg**
Switchgrass	**0.00**	**3.47**	**kg**
Gasoline (NETL) [Crude oil products]	**3.69E-02**	**3.69E-02**	**kg**
Lime (calcium hydroxide) [Non renewable resources]	**9.37E-02**	**9.37E-02**	**kg**
Sulfuric acid	**1.29E-01**	**1.29E-01**	**kg**
Outputs			
Ethanol (E95)	1.00	1.00	kg
Carbon dioxide (biotic) [Inorganic emissions to air]	2.62	2.62	kg
Ammonia [Inorganic emissions to air]	3.47	3.47	kg
Hydrogen sulphide [Inorganic emissions to air]	2.26E-04	2.26E-04	kg
Water (returned to receiving body) [Water]	2.26E-04	2.26E-04	kg
Solid Waste (unspecified) [Solid Waste]	3.60E-05	3.60E-05	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

Aden et al 2002. Aden, A. *et al. Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover.* NREL. 2002.

Section III: Document Control Information

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Original/no revisions

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Section IV: Disclaimer