NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Corn Stover Cultivation, Operation

Reference Flow: 1 kg Biomass Operation

Brief Description: This unit process includes operation of farming activities for cultivation of corn stover, including diesel, fertilizers, herbicides and water use, as well as emissions from diesel combustion, criteria air pollutants, and water emissions.

Section I: Meta Data

Geographical Coverage: US **Region:** Midwest

Year Data Best Represents: 2008

Process Type: Extraction Process (EP)

Process Scope: Cradle-to-Gate Process (CG)

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:

Stover yield (STOVER_YIELD_Y)	*The yield of corn stover, in kg/acre-yr*
Corn yield (CORN_YIELD_Y)	*The yield of corn grain, in kg/acre-yr*
Allocation (ALLOCATE_ENERGY)	*If using energy allocation, use value = 1 else use value = 0.*

Tracked Input Flows:

Diesel [Crude oil products]	*Diesel (from crude oil) usage for biomass cultivation operations*

N Fertilizers [Inorganic intermediate products]	*Nitrogen fertilizer used in biomass cultivation operations*
P Fertilizers [Inorganic intermediate products]	*Phosphorus fertilizer used in biomass cultivation operations*
K Fertilizers [Inorganic intermediate products]	*Potassium fertilizer used in biomass cultivation operations*

Tracked Output Flows:

Biomass Operation [Installation]	*This unit process is assembled with the biomass harvesting operation unit process; therefore, the reference flow is assumed to be 1 kg biomass, operation*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage1_O_CS_Cultivation_2010.02.xls*, which provides additional details regarding relevant calculations, data quality, and references.

Goal and Scope

The scope of this unit process covers the operation of farming activities used for cultivation for corn stover biomass in Life Cycle (LC) Stage #1. This unit process is based on the reference flow of 1 kg of biomass, operation, as described below and in **Figure 1.** The mass of diesel to power seeding equipment, mass of fertilizer and herbicides, and related emissions are calculated based on the reference flow. Considered are the mass consumption of diesel, consumption of nitrogen, phosphorus and potassium (NPK) fertilizer, consumption of herbicides, emissions from the combustion of diesel used in cultivation equipment, particulate matter emissions associated with fugitive dust, water input flows required for biomass cultivation, wastewater flows including stormwater and runoff water, emissions of criteria air pollutants, and air emissions of mercury and ammonia.

Boundary and Description

The LC boundary of this unit process starts with the seeding of biomass and ends with corn stover ready for harvest. Operations of farming activities used for cultivation for corn stover are based on the production of 1 kg of corn stover biomass. Diesel is consumed by the tractor as it pulls the disc tiller and the seeding equipment. The diesel consumption rate for equipment used in farming cultivation activities was calculated based on specifications of a 1,953-rpm tractor consuming 10.26 gal/hour of diesel fuel, and a disc tiller 188 inches wide (John 2009a, John 2009b), and an assumption that the tractor operates at an average speed of 5.8 miles per hour (mph; Caterpillar 2010).

By multiplying the width of the disk tiller, which is assumed to 15.7 feet, by the operating speed of the tractor, the land coverage rate is estimated at 11 acres/hour. Multiplying this land coverage rate by the fuel consumption rate, the estimated diesel consumption is 0.93 gal/acre cultivated. This calculation assumes that the tractor makes a single pass over the site.

Diesel emission factors, per gallon of diesel consumed, are based on nonroad diesel engine data (DOE 2007, Federal Register 2004, SCAQMD 2005). The combustion of diesel results in the direct emission of greenhouse gases (GHGs) and criteria air pollutants (CAPs) . The emission factors for GHGs are based on U.S. Department of Energy (DOE) instructions for the voluntary reporting of GHGs (DOE 2007). Emission factors for particulate matter (PM), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) are based on U.S. Environmental Protection Agency (EPA) documentation on air emissions from nonroad diesel engines (NARA 2004). These emission factors are expressed in terms of the mass of emission per brake horsepower (bhp)-hour, which requires a determination of the bhp of the tractor. This unit process uses a conversion factor of 0.066 gal/bhp-hr (SCAQMD 2005) to apply the emission factors for PM, NO_x, and VOC to a basis of gallons of diesel combusted in nonroad heavy equipment.

Emissions of sulfur dioxide (SO_2) are calculated stoichiometrically by assuming that diesel has a sulfur content of 15 ppm (DieselNet 2009a, DieselNet 2009b) and that all sulfur in diesel is converted to SO_2 upon combustion. The calculated emission factor for diesel is 2.52677×10^{-5} kg SO_2/L.

The emission factors for carbon monoxide (CO) are based on Tier 4 emission standards, which specify an array of CO emission factors across a range of engine sizes (DieselNet 2009). This unit process assumes that the engine of the tractor is greater than 175 horsepower, and the calculated emission factor for diesel is 0.0104067 kg CO/L.

Fugitive dust emissions are generated by the disturbance of surface soil during the use of farm equipment. Fugitive dust emissions from cultivation are estimated using an emission factor specified by the Western Regional Air Program (WRAP. Countess Environmental 2004), which conducted air sampling studies on ripping and sub-soiling practices used for breaking up soil compaction. The emission factor for fugitive dust is 1.2 lb PM/acre-pass. The tractor makes two passes of the site and thus has a fugitive dust emission factor of 2.4 lbs PM/acre. The total emissions of fugitive dust are 1.088 lbs PM/acre (0.2875 kg/kg biomass).

Fertilizer use quantifies the amounts of nitrogen, phosphorous, and potassium required, while herbicide use is quantified in support of weed control. The mass of fertilizer was calculated, but upstream emissions were not included in this unit process; they were included during the GaBi modeling phase of the LCA instead (RAND 2009). It is assumed that 10 percent (by weight) of applied nitrogen fertilizer volatilizes. Of that volatized nitrogen fertilizer, it is further assumed that 1 percent reacts to form N_2O. Of the 90 percent of nitrogen fertilizer that does not volatize, soil processes release 0.0125 tons of N_2O per ton of nitrogen. An estimated 30 percent of non-volatized nitrogen is assumed to leach or run off, forming 0.025 tons of N_2O per ton of nitrogen in leachate or runoff (Ney *et al*. 2002).

Biomass production for this study is assumed to occur in the Midwestern United States, where rain during the growing season contributes substantially to the water requirements of crops (DOC 2009). However, in many cases, supplemental irrigation water is also used to support increased yield and to relieve crop water stress during dry periods. As a result, quantifying water use and consumption for biomass crops grown in the Midwest is relatively complicated as compared to, for instance, biomass crops grown in the West, where growing season irrigation is the only significant source of water (SFP 2007). Water is applied as rainfall or as irrigation water from a combination of surface water and groundwater sources. Runoff water occurs as a result of excess rainfall, and agricultural pollutants, including nitrogen and phosphorous emissions, associated with stormwater runoff are quantified (USDA 2009).

CO_2 uptake is quantified based on available carbon content data for corn stover, where CO_2 uptake is calculated stoichiometrically from the amount of carbon contained in the stover, assuming that all carbon was originally taken up as CO_2. The average carbon fraction of dry stover is assumed to be 46 percent, while the average carbon fraction of dry kernel is assumed to be 45 percent (DOE 2009, Wallace 1937).

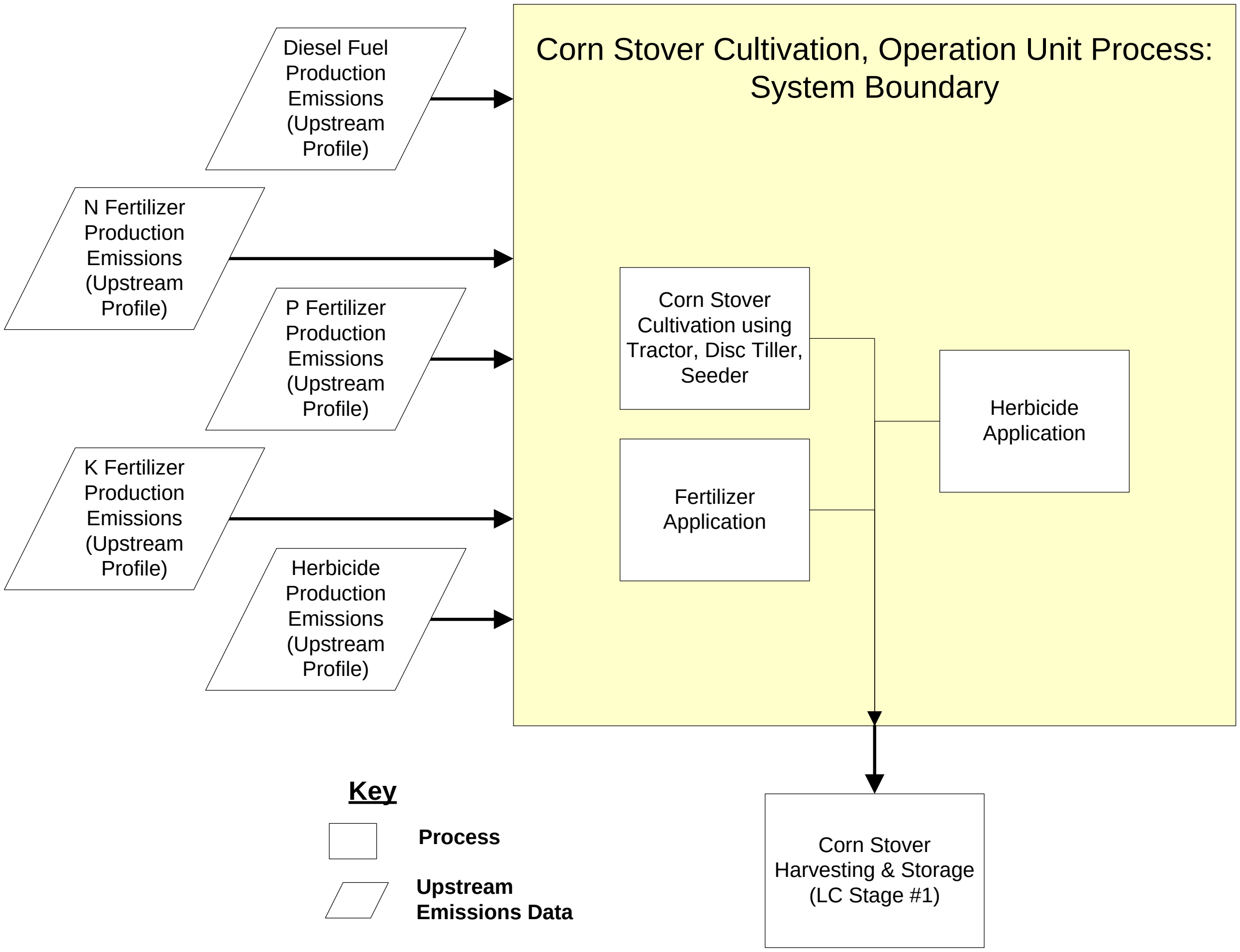
There are three adjustable parameters in this unit process: the annual yield of corn stover (“STOVER_YIELD_Y”), the annual yield of corn grain (“CORN_YIELD_Y”),and the calculation of co-product allocation based on energy (“ALLOCATE_ENERGY”) basis. The annual yields of corn grain and stover(kg/acre-year) are used to translate the values for diesel consumption, diesel combustion and fugitive dust emissions from a basis of quantity per acre to a basis of quantity per kg of biomass production. NETL currently recommends a default value of 3,829 kg/acre-yr for corn yield based on a survey of national data from 2004 to 2009 (Iowa State 2009, USDA 2010). The recommendation for stover yield is 1,001 kg/acre year (NETL 2011, Petrolia 2009).

The parameter for energy-based co-product allocation allows the unit process to allocate inputs and outputs between co-products on an energy or mass basis. If the value for “ALLOCATE_ENERGY” is 1, then energy-based co-product allocation is used; if the value for “ALLOCATE_ENERGY” is 0, then mass-based co-product allocation is used and a ratio of the yield rates is used to apportion emissions.

The HHVs of corn stover and kernel are assumed to be 6,399 Btu/lb and 6,970 Btu/lb, respectively at 15 percent moisture (NETL 2007, PSU 2009).

Figure 1 shows the boundaries of this unit process, including a schematic of operations considered within it. The figure includes operations directly related to the growing of corn stover that account for fertilizer production, diesel production, water, and other agricultural inputs. Upstream processes may require energy or other ancillary substances, which are not shown here. Rectangular boxes represent relevant upstream processes, while trapezoidal boxes indicate upstream data that are outside of the boundary of this unit process. As shown, upstream emissions associated with the production and delivery of nitrogen, phosphorus and potassium (NPK) fertilizers and diesel fuel are accounted for outside of the boundary of this unit process.

Figure 1: Unit Process Scope and Boundary



Properties of corn stover and corn grain biomass cultivation operation activities relevant to this unit process are illustrated 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.

Table 1: Properties of Biomass Cultivation Operation Activities

Property	Value	Units
Corn stover yield	1001	kg/acre-year
Corn grain yield	3829	kg/acre-year
HHV corn stover at 15% moisture	14.88	MJ/kg
HHV corn stover at 15% moisture	6399	Btu/lb
HHV corn grain at 15% moisture	16.21	MJ/kg
HHV corn grain at 15% moisture	6970	Btu/lb

Table 2: Unit Process Input and Output Flows

Flow Name*	Value	Units (Per Reference Flow)
Inputs		
Biomass Operation [Installation]	**1**	**kg**
Diesel [Crude oil products]	**2.27E-04**	**kg**
N Fertilizer [Inorganic intermediate products]	**3.01E-03**	**kg**
P Fertilizer [Inorganic intermediate products]	**4.65E-04**	**kg**
K Fertilizer [Inorganic intermediate products]	**1.10E-03**	**kg**
Herbicide Use (Atrazine) [Inorganic intermediate products]	**1.50E-05**	**kg**
Water (ground water) [Water]	2.04E+00	L
Water (surface water) [Water]	2.04E+00	L
Water (storm) [Water]	8.86E+01	L
Outputs		
Biomass Operation [Installation]	1.00	kg
Carbon dioxide [Inorganic emissions to air]	7.16E-04	kg
Carbon monoxide [Inorganic emissions to air]	3.99E-06	kg
Methane [Organic emissions to air (group VOC)]	1.03E-07	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	4.33E-05	kg
Nitrogen dioxide [Inorganic emissions to air]	3.24E-07	kg
Carbon dioxide (biotic) [Inorganic emissions to air]	2.73E-01	kg
Sulphur dioxide [Inorganic emissions to air]	6.81E-09	kg
Particulate Matter, unspecified [Other emissions to air]	4.36E-05	kg
Volatile Organic Carbons [Organic emissions to air]	1.51E-07	kg
Nitrogen [Inorganic emissions to fresh water]	1.03E-05	kg
Phosphorus [Inorganic emissions to fresh water]	3.84E-08	kg
Water (storm runoff) [Water]	2.82E+00	L

* **Bold face** clarifies that the input is from the technosphere and *does not* include upstream environmental flows.

Embedded Unit Processes

None.

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Section III: Document Control Information

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Section IV: Disclaimer