NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Corn Grain, Cultivation, Operation

Reference Flow: 1 kg of Biomass Operation

Brief Description: This unit process includes operation of farming activities for cultivation of corn grain 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: 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:

Corn yield (yield_ratio_y)	*Represents the weight of corn grain acre year.*

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 comprised of this document, as well as the data sheet (DS) *DS_Stage1_O_CG_Cultivation_2011.02.xls*, which provides additional details regarding calculations, data quality, and references as relevant.

Goal and Scope

The scope of this unit process covers the operation of farming activities used for cultivation for corn grain biomass in life cycle (LC) Stage #1. This unit process is based on the reference flow of 1 kg of biomass. The cultivation activities are described below and shown 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. Impacts considered include 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 grain ready for harvest. Operations of farming activities used for cultivation for corn grain are based on 1 kg of biomass operation of cultivation activities. 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 1953 rpm tractor consuming 10.26 gal/hour of diesel fuel and a disc tiller of 188 inches width (John 2009a, John 2009b), and assuming that the tractor operates at 5.8 miles per hour (mph), an average operating speed (Tillage 2009).

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 per 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 two passes over the site and the total diesel consumption is 1.86 gal/acre.

Similarly, the tractor seeder consumes an average of 10.26 gallons per hour (John 2009a). The seeder width is 12.19 m (40 ft) wide (John 2009c). It is assumed that tractor operates at 5 miles per hour (mph), an average operating speed, in seeding operations. The width of seeder and speed of the tractor translate to a land coverage rate of 24.24 acres per hour. The tractor seeder makes single pass of the land site. Multiplying the land coverage rate by the fuel consumption rate, the estimated diesel consumption is 0.42 gal/acre-pass.

The combined diesel consumption of the tractor disk tiller and tractor seeder is the sum of 1.86 gal/acre and 0.42 gal/acre, which equals 2.28 gal/acre-year.

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 DOE instructions for the voluntary reporting of GHGs (DOE 2007). Emission factors for particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs) are based on 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-hour (bhp), 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, NOx, 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 emissions 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 0.0104 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 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 pass 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 (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 one percent reacts to form nitrous oxide (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 runoff, 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, a region 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).

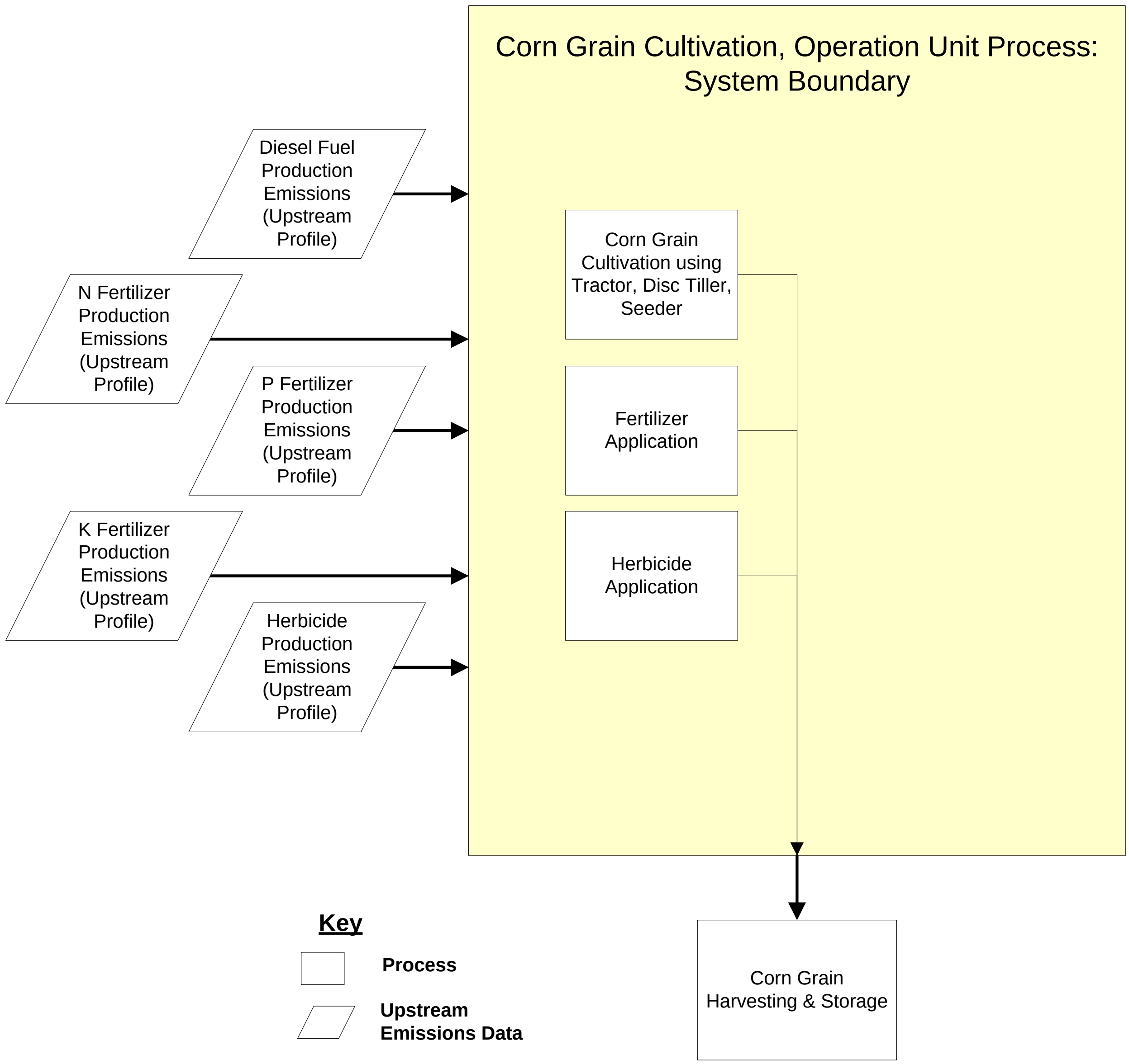
Carbon dioxide (CO_2) uptake is quantified based on available carbon content data for corn stover, where CO_2 uptake is calculated stoichiometrically from the amount of carbon contained in the stover, assuming that all carbon was originally taken up as CO_2. The average carbon fraction of dry stover is assumed to be 46 percent, while the average carbon fraction of dry kernel is assumed to be 45 percent (DOE 2009, Wallace 1937). The low and high heating values of the kernel are assumed to be 6,643 and 6,970 Btu/lb, respectively (Pimentel *et al*. 2005, PSU 2009).

There is one major adjustable parameter in this unit process: the annual yield of corn grain. This adjustable parameter is designed to allow modeling flexibility, enabling the modeler to update the unit process to meet specific assumptions and study criteria, as relevant. Additionally, adjustable values may be updated as needed to incorporate newer or revised data sources. Corn grain yield per year indicates the annual yield of corn grain per acre and it is 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 kilogram of biomass production. NETL currently recommends a default value of 3,829 kg/acre-yr for this parameter based on a survey of national data from 2004 to 2009 (Iowa State 2009, USDA 2010).

Figure 1 shows the boundaries of this unit process, including a schematic of operations considered within the boundary of this unit process. The figure includes operations directly related to the growing of corn grain 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 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 sheet.

Table 1: Properties of Biomass Cultivation Operation Activities

Property	Value	Units
Corn grain yield	3829	kg/acre-year
HHV corn grain	6970	MJ/kg
HHV corn grain	14.6	Btu/lb
LHV corn grain	15.5	MJ/kg
LHV corn grain	6545	Btu/lb

Table 2: Unit Process Input and Output Flows

Flow Name*	Value	Units (Per Reference Flow)
Inputs		
Biomass Operation [Installation]	**1.00E+00**	**kg**
Diesel [Crude oil products]	**1.91E-03**	**kg**
N Fertilizer [Inorganic intermediate products]	**1.96E-02**	**kg**
P Fertilizer [Inorganic intermediate products]	**3.03E-03**	**kg**
K Fertilizer [Inorganic intermediate products]	**6.77E-03**	**kg**
Herbicide Use (Atrazine) [Inorganic intermediate products]	3.75E-04	kg
Water (ground water) [Water]	1.33E+01	L
Water (surface water) [Water]	1.33E+01	L
Water (storm) [Water]	5.77E+02	L
Outputs		
Biomass Operation [Installation]	1.00E+00	kg
Carbon dioxide [Inorganic emissions to air]	6.00E-03	kg
Carbon monoxide [Inorganic emissions to air]	2.35E-05	kg
Methane [Organic emissions to air (group VOC)]	8.60E-07	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	2.83E-04	kg
Nitrogen dioxide [Inorganic emissions to air]	2.71E-06	kg
Carbon dioxide (biotic) [Inorganic emissions to air]	1.49E+00	kg
Sulphur dioxide [Inorganic emissions to air]	5.71E-08	kg
Particulate Matter, unspecified [Other emissions to air]	2.84E-04	kg
Volatile Organic Carbons [Organic emissions to air]	1.27E-06	kg
Nitrogen [Inorganic emissions to fresh water]	6.71E-05	kg
Phosphorus [Inorganic emissions to fresh water]	2.50E-07	kg
Water (storm runoff) [Water]	1.84E+01	L

* **Bold face** clarifies 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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