# NETL Life Cycle Inventory Data
# Process Documentation File

**Process Name:** Switchgrass Cultivation, Operation

**Reference Flow:** 1 kg of Biomass Operation

**Brief Description:** This unit process includes operation of farming activities for cultivation of switchgrass 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:**

| | |
|---|---|
| Switchgrass yield (Biomass_yield_y) | *The annual yield rate of switchgrass production.* |
| Nitrogen Fertilizer (Fertilizer_N) | *Amount of nitrogen applied via fertilizer annually, per acre.* |
| Phosphorus Fertilizer (Fertilizer_P) | *Amount of phosphorus applied via fertilizer annually, per acre.* |
| Potassium Fertilizer (Fertilizer_K) | *Amount of potassium applied via fertilizer annually, per acre.* |

**Tracked Input Flows:**

| | |
|---|---|
| Biomass Operation [Installation] | *This unit process is assembled with Land Preparation process in series.* |
| 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_SG_Cultivation_2010.02.xls*, which provides additional details regarding calculations, data quality, and references as relevant.

### Goal and Scope

The scope of this unit process covers the operations of farming activities used for cultivation of switchgrass 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 farming (a tractor using a pull disk tiller and seeder) equipment, mass of fertilizers 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 herbicide, emissions from the combustion of diesel (in tractor engine), 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 the switchgrass plants ready for harvest. Operations of farming activities used for cultivation of switchgrass are based on based on the production of 1 kg of switchgrass biomass. Assuming switchgrass crop rotation is every 10 years and the study period is 30 years, replanting of switchgrass biomass is estimated 3 times (McLaughlin et al 1999, Parrish et al 2005). Diesel is consumed by the tractor as it pulls the disk tiller and seeder equipment. The diesel consumption in equipment used in farming cultivation activities was calculated based on specifications of a 1,953 rpm tractor consuming 10.26 gal/hour diesel fuel to pull a disk tiller of 4.77 m (188 inches) width (John 2009b) and assuming that tractor operates at 5.8 miles per hour (mph), an average operating speed (Tillage 2009).

By multiplying the width of the disk tiller 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-pass cultivated. This unit process assumes that the tractor disk tiller will make two passes of the land site, which doubles the total fuel consumption of the tractor disk tiller to 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 a single pass of the land site. Multiplying the land coverage rate by the fuel consumption rate, the estimated diesel consumption is calculated to be 0.42 gal/acre-pass.

The combined diesel consumption of the tractor disk tiller and tractor seeder is the sum of 1.83 gal/acre and 0.42 gal/acre, which equals 2.28 gal/acre-planting. Replanting of switchgrass is calculated 3 times, resulting in a diesel consumption rate of 0.865 L diesel/acre-year.

Diesel emission factors, per gallon of diesel consumed, are based on non-road 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 emissions factors for GHGs are based on DOE instructions for the voluntary reporting of GHGs (DOE 2007). Emissions factors for particulate matter (PM), nitrogen oxides ($NO_x$), and volatile organic compounds (VOCs) are based on EPA documentation on air emissions from non-road diesel engines. These emissions factors are expressed in terms the mass of emissions 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 emissions factors for PM, $NO_x$, and VOC to a basis of gallons of diesel combusted in non-road heavy equipment.

Emissions of sulfur dioxide ($SO_2$) are calculated stoichiometrically by assuming that diesel has a sulfur content of 15 ppm (DieselNet 2009a) and that all sulfur in diesel is converted to $SO_2$ upon combustion. The calculated emissions factor for diesel is $2.526 \times 10^{-5}$ kg $SO_2$/L.

The emissions factors for carbon monoxide (CO) are based on Tier 4 emissions standards, which specify an array of CO emissions factors across a range of engine sizes (DieselNet 2009b). The engine of the tractor to pull the disk tiller and seeder is greater than 175 horsepower, and the calculated emissions factor for diesel is 0.0104 kg CO/L.

Fugitive dust emissions are generated by the disturbance of surface soil in cultivation operations. Fugitive dust emissions from cultivation activities are estimated using an emissions factor specified by Western Regional Air Program (WRAP) (WRAP. 2004), which conducted air sampling studies on ripping and sub-soiling practices used for breaking up soil compaction. The emissions factor for fugitive dust using heavy equipment is 0.54 kg PM/acre-pass (1.2 lb PM/acre-pass) (WRAP 2004). Assuming replanting times 10 years and 30 years horizon time of the study, the tractor – tiller makes two passes of the site every 10 years and thus has a fugitive dust emissions factor of 0.1088 kg PM/acre-year, and tractor-seeder makes one pass of the site every 10 year and thus has a fugitive dust emissions factor of 0.0544 kg PM/acre. The total emissions of fugitive dust are 0.1632 kg PM/acre-year.

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 based on several independent studies performed in United States (Parrish et al 2005), but upstream emissions were not included in this unit process. 10 percent (by weight) of the applied nitrogen fertilizer is assumed to be volatilized. 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 runoff, forming 0.025 tons of $N_2O$ per ton of nitrogen in leachate or runoff (Ney et al 2002).

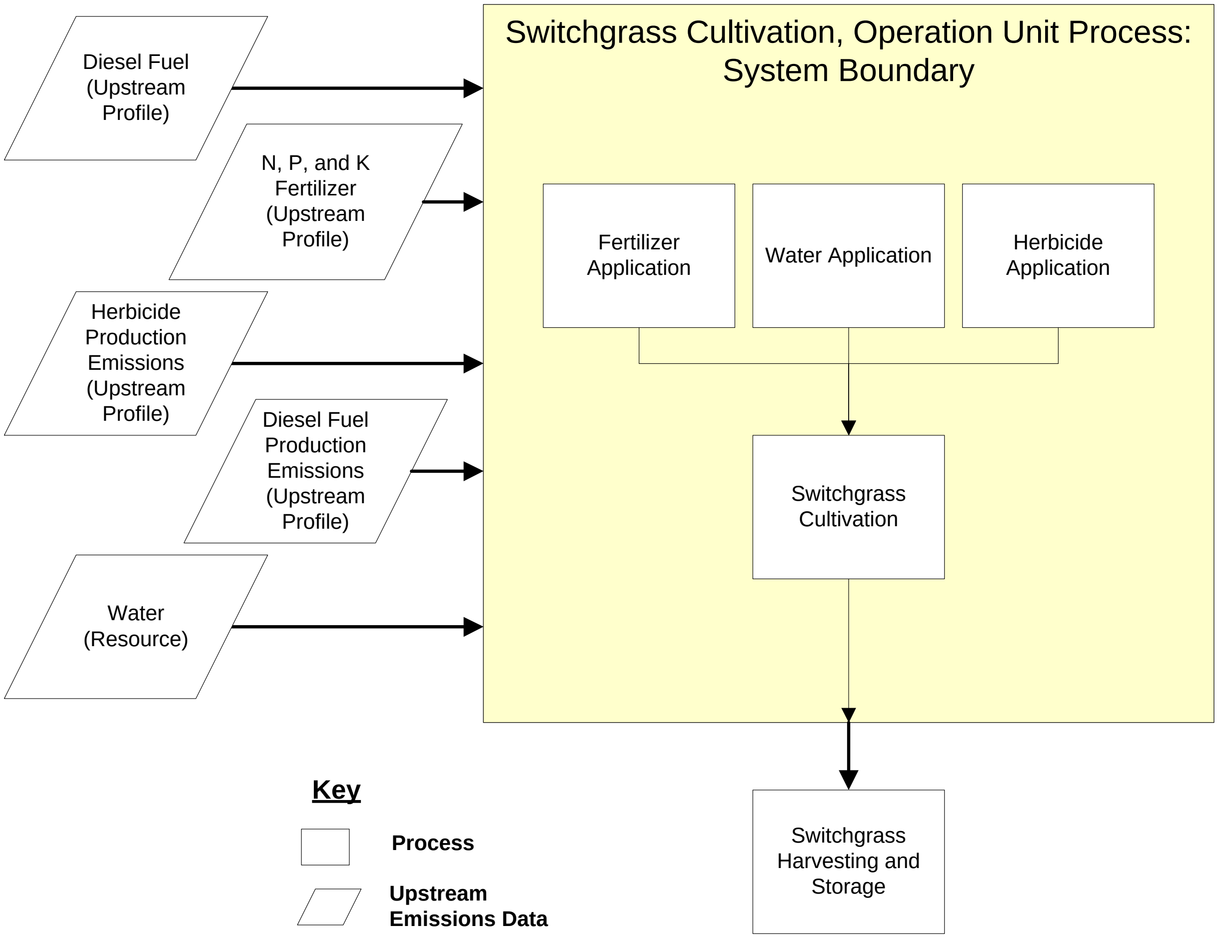
Biomass production for this study is assumed to occur in the Midwestern United States, a region where rain during the growing season contributes substantially to the water requirements of crops (DOC 2009). However, in many cases, supplemental irrigation water is also used to support increased yield and 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). Based on Midwest rainfall average data, 2755 $m^3$/acre water, required for cultivation of switchgrass biomass, is estimated. 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). Total irrigation water is assumed to be 135 mm/year, whereas total surface runoff water is assumed to be 17 mm/year (Brown et al 2000). Total 545121 L/acre –year irrigation is estimated, 50 percent is assumed to be groundwater and surface water. Total runoff water is 70,314 liters per acre year is estimated.

Carbon dioxide ($CO_2$) uptake is quantified based on available carbon content data for SRWC. $CO_2$ uptake is calculated stoichiometrically from the amount of carbon contained in SRWC, assuming that all carbon was originally taken up as $CO_2$. The average carbon fraction of SRWC is assumed to be 42.6 percent on a dry basis (NETL 2012).

Four adjustable process parameters are included in this unit process. These are designed to allow modeling flexibility to enable the modeler to update the unit process to meet specific assumptions and study criteria, as relevant. Additionally, these values may be updated as needed to incorporate newer or revised data sources. The annual yield rate represents the annual yield of switchgrass per acre area in a year. NETL currently recommends a default value of 3,569 kg/acre–year for this parameter based on the Calculating Uncertainty in Biomass Emissions (CUBE) model (NETL 2011). N, P and K fertilizers indicate the amount of use per acre. NETL currently recommends a default value for nitrogen of 62 kg/acre, for phosphorus of 4.3 kg/acre and for potassium of 0 kg/acre.

**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 operation directly related to the growing of switchgrass, as well as upstream processes 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 switchgrass 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**

| | Value |
|---|---|
| Biomass Yield, kg/acre-yr | 3,569 |
| $CO_2$ Uptake per kg of Biomass, kg | -1.3277 |
| Diesel per kg of Biomass, kg | 2.04E-04 |
| Herbicide per kg of Biomass, kg | 2.97E-04 |
| Nitrogen Fertilizer per kg of Biomass, kg | 1.74E-02 |
| Phosphorous Fertilizer per kg of Biomass, kg | 1.21E-03 |
| Potassium Fertilizer per kg of Biomass, kg | 0 |

**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]** | **2.04E-04** | **kg** |
| **N Fertilizer [Inorganic intermediate products]** | **1.74E-02** | **kg** |
| **P Fertilizer [Inorganic intermediate products]** | **1.21E-03** | **kg** |
| **K Fertilizer [Inorganic intermediate products]** | **0.00E+00** | **kg** |
| Herbicide Use (Atrazine) [Inorganic intermediate products] | 2.97E-04 | kg |
| Water (ground water) [Water] | 7.64E+01 | L |
| Water (surface water) [Water] | 7.64E+01 | L |
| Water (storm) [Water] | 6.19E+02 | L |
| **Outputs** | | |
| Biomass Operation [Installation] | 1 | kg |
| Carbon dioxide [Inorganic emissions to air] | 6.44E-04 | kg |
| Carbon dioxide (biological) [Inorganic emissions to air] | -1.33E+00 | kg |
| Carbon monoxide [Inorganic emissions to air] | 2.52E-06 | kg |
| Methane [Organic emissions to air (group VOC)] | 9.22E-08 | kg |
| Nitrous oxide (laughing gas) [Inorganic emissions to air] | 2.50E-04 | kg |
| Nitrogen dioxide [Inorganic emissions to air] | 2.91E-07 | kg |
| Sulphur dioxide [Inorganic emissions to air] | 6.13E-09 | kg |
| Particulate Matter, unspecified [Other emissions to air] | 4.58E-05 | kg |
| Volatile Organic Carbons [Organic emissions to air] | 1.36E-07 | kg |
| Nitrogen [Inorganic emissions to fresh water] | 1.40E-05 | kg |
| Phosphorus [Inorganic emissions to fresh water] | 6.59E-08 | kg |
| Water (storm runoff) [Water] | 1.97E+01 | L |

* **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.

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## Section III: Document Control Information

**Date Created:** February 09, 2010

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

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