NETL Life Cycle Inventory Data
Process Documentation File

Process Name:	Southern Pine Biomass Cultivation, Operation
Reference Flow:	1 kg of Biomass, Operation
Brief Description:	This unit process includes operation period farming activities for cultivation of SRWC (from Southern Pine), 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:	2011		
Process Type:	Extraction Process (EP)		
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:

Rotation period (Biomass_Rot)	*Represents the rotation for Southern pine biomass.*
Corn stover yield (Biomass_yield_y)	*Represents the annual yield rate of the corn stover*
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 SRWC land preparation operations process in series.*
Electricity [Electricity]	*Amount of electricity required for the production of 1 kg of biomass ready for harvest*
Diesel [Crude oil products]	*Amount of diesel (from crude oil) required for the production of 1 kg of biomass ready for harvest.*
N Fertilizers [Inorganic intermediate products]	*Amount of nitrogen fertilizer used in production of 1 kg of biomass ready for harvest.*
P Fertilizers [Inorganic intermediate products]	*Amount of phosphorus fertilizer used in production of 1 kg of biomass ready for harvest.*
K Fertilizers [Inorganic intermediate products]	*Amount of potassium fertilizer used in production of 1 kg of biomass ready for harvest.*
Herbicide Use (Diuron) [Inorganic intermediate products]	*Amount of herbicide required in the production of 1 kg of biomass ready for harvest.*

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_SouthernPine_Cultivation_2012.01.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 for short rotation woody crop (SRWC) 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 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 herbicide, emissions from the combustion of diesel used in cultivation equipment, particulate matter emissions associated with fugitive dust, water input flows required for biomass cultivation, runoff water, and emissions of criteria air pollutants.

Boundary and Description

The LC boundary of this unit process starts with the seeding of biomass and ends with SRWC ready for harvest. Operating activities for the cultivation of SRWC are based on the production of 1 kg of SRWC biomass operation activities. The replanting cycle is assumed to be every 5 years.

SRWC is planted once every 5 years and harvested at the end of the fifth year. For planting, three passes are made across the field: 2 passes for tilling and 1 pass for planting. The SRWC is fertilized each year using N, P, and K fertilizers, and is sprayed with an herbicide each year. Water is supplied to the SRWC via a combination of rainfall and irrigation water, with the irrigation water being a 50%-50% mix of surface water and groundwater. Energy required for the application of fertilizers, herbicides, and application of water is assumed to be negligible.

Diesel is consumed by the tractor as it pulls the disc tiller and the planter equipment. A tractor consumes diesel an average of 10.26 gallons per hour (John Deere 2009a). The diesel consumption of equipment used in farming cultivation activities was calculated based on specifications of a 1,953 rpm tractor.

The width of a disk tiller is 4.77 m (15.7 ft) (John Deere 2009b). The tractor with a tiller implement has an average operating speed of 5.8 miles per hour (mph) (Tillage 2009). By multiplying the width of the disk tiller by the speed of the tractor, a land coverage rate of 11 acres per hour is calculated. The tractor makes two passes over the site, requiring 1.86 gal/acre of diesel.

The width of a planter is 2.39 m (7.83 ft) (C&G 2004). The tractor with a planter has an average operating speed of 4 miles per hour (mph) (Tillage 2009). By multiplying the width of the planter and speed of the tractor, a land coverage rate of 3.8 acres per hour is estimated. The tractor planter makes a single pass of the land site. The ratio of the fuel consumption rate and land coverage rate is a diesel consumption rate of 2.7 gal/acre.

Diesel emissions 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 GHGs (greenhouse gases) and CAPs (criteria air pollutants). The emissions factors for GHGs are based on DOE instructions for the voluntary reporting of GHGs (DOE 2007). Emissions factors for PM (particulate matter),

NO_x (nitrogen oxides), and VOCs (volatile organic compounds) are based on EPA documentation on air emissions from non-road diesel engines. These emissions factors are expressed in terms of the mass of emissions per bhp-hr (brake horsepower-hour), which requires a determination of the bhp-hr 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 SO_2 (sulphur dioxide) are calculated stoichiometrically by assuming that diesel has a sulphur content of 15 ppm (DieselNet 2009a, DieselNet 2009b) and that all sulphur in diesel is converted to SO_2 upon combustion. The calculated emissions factor for diesel is 2.53 x 10^{-5} kg SO_2/L.

The emissions factors for CO (carbon monoxide) are based on Tier 4 emission standards, which specify an array of CO emissions 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 calculated emissions factor for diesel is 0.0104 kg CO/L.

Fugitive dust emissions are generated by the disturbance of surface soil during tilling . Planting and other activities involving farm equipment (such as applying fertilizers and herbicides) are assumed to generate insignificant levels of fugitive dust compared to tilling. Fugitive dust emissions from tilling are estimated using an emissions factor specified by WRAP (Western Regional Air Program) (Countess Environmental 2004), which conducted air sampling studies on ripping and sub-soiling practices used for breaking up soil compaction. The emissions factor for fugitive dust is 1.2 lb PM/acre-pass. The tractor makes two passes of the site during tilling and thus has a fugitive dust emissions factor of 2.4 lbs PM/acre. Replanting is assumed to take place every 5 years and horizon time of the study is assumed to be 30 years. Multiplying the replanting time and dividing by the horizon time, the total emissions of fugitive dust are 0.2177 kg PM/acre calculated.

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 (RAND 2009), but upstream emissions for fertilizer production and delivery are not included in the boundary of this unit process. 10 percent (by weight) of the nitrogen that is applied as 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.

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. Based on Midwest rainfall average data, 17,300 m^3/acre is estimated. Water is applied as rainfall or as irrigation water from a combination of surface water and groundwater sources. Total irrigation water is estimated to be 135 mm/year (Brown, R. *et al*. 2000) based on the difference between the total evapo-transpiration demand for the crop and the amount of rainfall. Total runoff water is assumed to be 17 mm/year based on data from Brown et al. (2000) and is calculated to be 70,314 liters per acre per year.

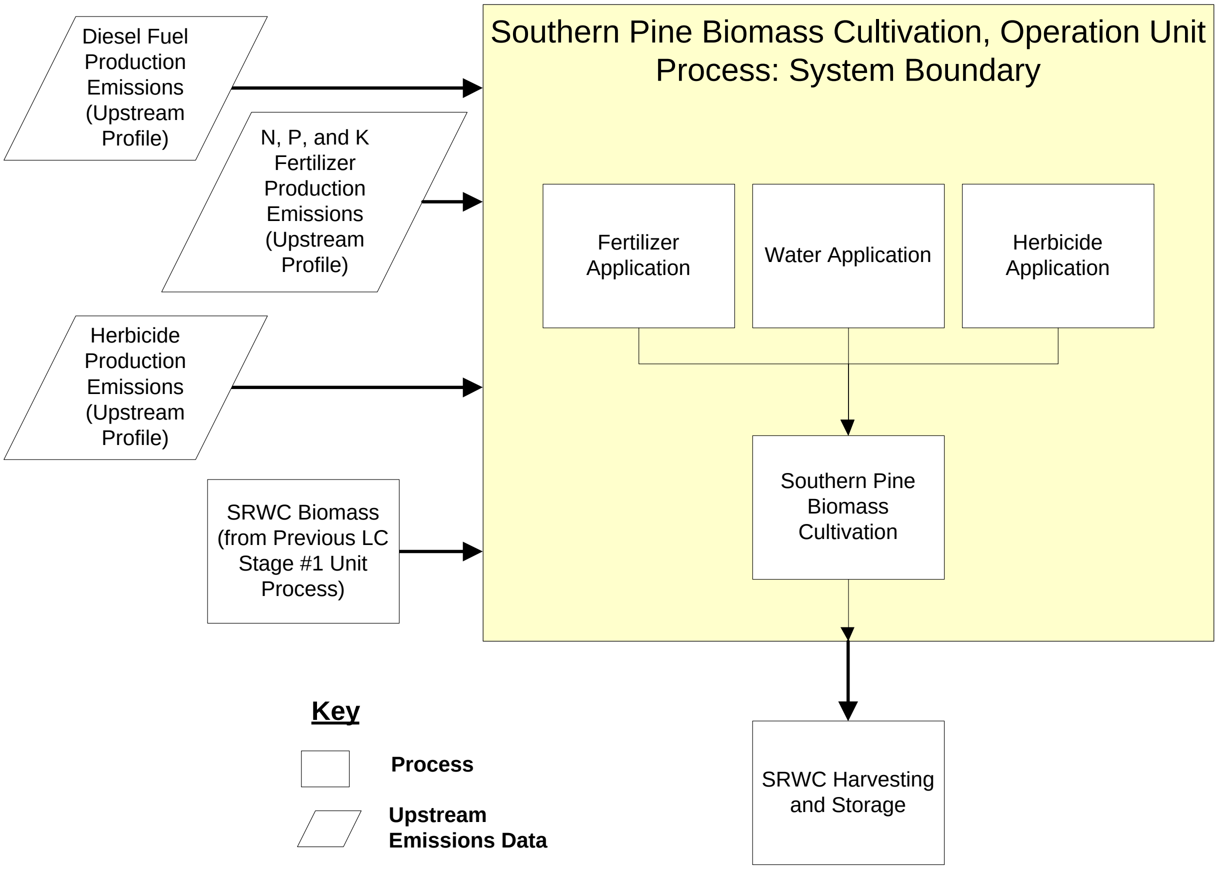
Loss of nitrogen and phosphorous via runoff water is also accounted for within the unit process. Waterborne nitrogen and phosphorous emissions are based on a study completed by Mallarino et al (2009), which provides survey data for agricultural runoff water, in order to quantify nutrient loss from fields. Anticipated nutrient loading rates were calculated by averaging data provided for a conventional nutrient management scheme.

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 49.63 percent (Stolarski 2008).

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 SWRC per acre in a year. NETL currently recommends a default value of 6,350 kg/acre-year for this parameter. N, P and K fertilizers indicate the amount of these fertilizers used per acre. NETL currently recommends default values of 232.5 kg-N/acre, 75 kg-P/acre and 130 kg-K/acre for nitrogen, phosphorous and potassium per rotation, respectively.

Figure 1 shows the boundaries of this unit process and sub-processes, and the flows of sub-processes. The figure includes processes directly related to the growing of SRWC, 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, but for the purposes of this discussion the figure does not show other flows. 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 technosphere inputs (nitrogen, phosphorus, potassium (NPK) fertilizer & diesel profiles) fuel are accounted for outside of the boundary of this unit process.

Figure 1: Unit Process Scope and Boundary



Properties of SRWC biomass cultivation operation activities relevant to this unit process are illustrated in **Table 1**. Heating values for SRWC are provided as a reference point to document assumptions and for comparison with other biomass types applied outside of this unit process, as relevant. **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	Reference
SRWC yield	6,350	kg/acre-year	DOE 2011; Kline and Coleman 2010
Harvest Frequency	13	Years	Study Value

Table 2: Unit Process Input and Output Flows

Flow Name*	**Value**	**Units (Per Reference Flow)**
Inputs		
Biomass Operation [Installation]	**1.00E+00**	**kg**
Electricity [Electricity]	**3.03E-03**	**kWh**
Diesel [Crude oil products]	**4.15E-03**	**kg**
N Fertilizer [Inorganic intermediate products]	**2.82E-03**	**kg**
P Fertilizer [Inorganic intermediate products]	**9.08E-04**	**kg**
K Fertilizer [Inorganic intermediate products]	**1.57E-03**	**kg**
Herbicide Use (Diuron) [Inorganic intermediate products]	2.14E-04	L
Water (ground water) [Water]	4.29E+01	L
Water (surface water) [Water]	4.29E+01	L
Water (storm) [Water]	3.48E+02	L
Outputs		
Biomass Operation [Installation]	1	kg
Carbon dioxide [Inorganic emissions to air]	1.31E-02	kg
Carbon dioxide (biological) [Inorganic emissions to air]	-9.87E-01	kg
Carbon monoxide [Inorganic emissions to air]	5.13E-05	kg
Methane [Organic emissions to air (group VOC)]	1.87E-06	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	3.76E-05	kg
Nitrogen oxides [Inorganic emissions to air]	5.91E-06	kg
Sulphur dioxide [Inorganic emissions to air]	1.24E-07	kg
Particulate Matter, unspecified [Other emissions to air]	3.45E-05	kg
Volatile Organic Carbons [Organic emissions to air]	2.76E-06	kg
Mercury (+II) [Heavy metals to air]	6.49E-19	kg
Ammonia [Inorganic emissions to air]	5.42E-07	kg
Nitrogen [Inorganic emissions to fresh water]	3.49E-05	kg
Phosphorus [Inorganic emissions to fresh water]	3.70E-08	kg
Water (storm runoff) [Water]	1.11E+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

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