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 inputs of combusted diesel, fertilizers, herbicides and water use, as well as 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: 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:

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 [Electric Power]	*Amount of electricity required for the production of 1 kg of biomass ready for harvest*
Diesel Combustion, Mobile Sources, Truck [Refinery products]	*Amount of diesel combusted within the mobile source.*
Equipment Assembly per kg Biomass [Valuable substances]	*Amount of farm equipment required for 1 kg of biomass.*
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_2012.02.xlsx*, 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 combusted 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, particulate matter emissions associated with fugitive dust, water input flows required for biomass cultivation, runoff water, and emissions of criteria air pollutants. The energy and material flows for the upstream production and delivery of diesel as well as LC emissions of diesel production and combustion are not included in the boundary of this process.

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 emissions for the required amount of diesel combusted for this process are accounted for in an upstream diesel combustion process. That process is pulled as an input to this process.

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. This unit process assumes that the engine of the tractor is greater than 175 horsepower.

The impacts associated with the manufacturing of the tractor, disk tiller, and planter are accounted for in a separate unit process. This process scales the manufacturing processes based on the amount of biomass demanded.

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 PM10/acre-pass. The tractor makes two passes of the site during tilling and thus has a fugitive dust emissions factor of 2.4 lbs PM10/acre. Replanting is assumed to take place every 13 years and horizon time of the study is assumed to be 30 years. Multiplying the replanting frequency and dividing by the horizon time, the total emissions of fugitive dust are 0.0837 kg PM10/acre/year calculated. The ratio of PM2.5 to PM10 utilized for this study is 0.15 kg PM2.5/kg PM10.

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. Approximately, 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 while five percent forms NH_3 and NO_X respectively. 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.

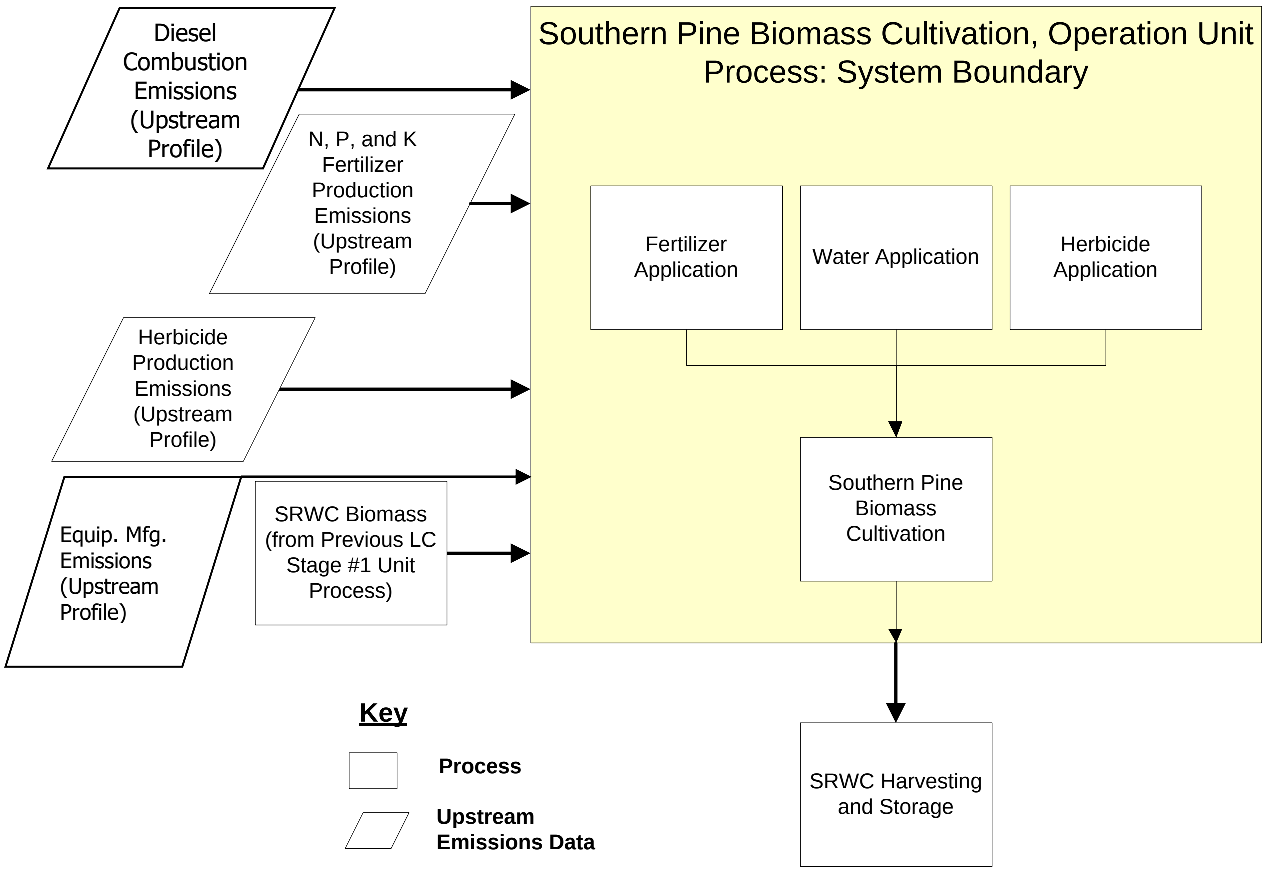
Loss of nitrogen and phosphorous via runoff water is also accounted for within the unit process. Waterborne nitrogen and phosphorous emissions are based on a study completed by Mallarino et al (2009), which provides survey data for agricultural runoff water, in order to quantify nutrient loss from fields. 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 combustion 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)	DQI
Inputs			
Biomass Operation [Installation]	**1.00E+00**	**kg**	**2,2**
Electricity [Electricity]	**3.03E-03**	**kWh**	**2,2**
Diesel Combustion, Mobile Sources, Truck [Refinery products]	**4.15E-03**	**kg**	**2,2**
Equipment Assembly per kg Biomass [Valuable substances]	**1.00E+00**	**Pieces**	**2,2**
N Fertilizer [Inorganic intermediate products]	**2.82E-03**	**kg**	**2,2**
P Fertilizer [Inorganic intermediate products]	**9.08E-04**	**kg**	**2,2**
K Fertilizer [Inorganic intermediate products]	**1.57E-03**	**kg**	**2,2**
Herbicide Use (Diuron) [Inorganic intermediate products]	**2.14E-04**	**L**	**2,2**
Water (ground water) [Water]	4.29E+01	L	2,2
Water (surface water) [Water]	4.29E+01	L	2,2
Water (storm) [Water]	3.48E+02	L	2,2
Outputs			
Biomass Operation [Installation]	1	kg	2,2
Carbon dioxide (biological) [Inorganic emissions to air]	-9.87E-01	kg	2,2
Nitrous oxide (laughing gas) [Inorganic emissions to air]	3.73E-05	kg	2,2
Ammonia [Inorganic emissions to air]	1.41E-04	kg	2,2
Nitrogen oxides [Inorganic emissions to air]	1.41E-04	kg	2,2
Dust (PM10) [Particles to air]	1.32E-05	kg	1,2
Dust (PM2.5) [Particles to air]	1.98E-06	kg	1,2
Nitrogen [Inorganic emissions to fresh water]	3.49E-05	kg	2,2
Phosphorus [Inorganic emissions to fresh water]	3.70E-08	kg	2,2
Water (storm runoff) [Water]	1.11E+01	kg	2,2

* **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.

Inventory items not included are assumed to be zero based on best engineering judgment or assumed to be zero because no data was available to categorize them for this unit process at the time of its creation.

Embedded Unit Processes

None.

References

Battye et al. 1994 — Battye R., Battye, W., Overcash, C., Fudge, S. 1994. Development and Selection of Ammonia Emissions Factors, Final Report. US Environmental Protection

	Agency, Washington, D.C. http://www.epa.gov/ttn/chief/old/efdocs/ammonia.pdf (Accessed December 16, 2009
Brown *et al*. 2000	Brown, R. *et al*. 2000. "Potential production and environmental effects of switchgrass and traditional crops under current and greenhouse-altered climate in the central United States: a simulation study." *Agriculture, Ecosystems, and Environment* 78:31-47.
C&G 2004	C&G. 2004. Tree Planting from C&G. Manufacturer Specifications.
Conaway et al. 2005	Conaway, C.H., Mason, R.P., Steding, D.J., Flegal, A.R. 2005. "Estimate of mercury emission from gasoline and diesel consumption, San Francisco Bay area, California." Atmospheric Environment 39:101-105. http://www.sciencedirect.com/science?_ob=MImg&_imag
DOC 2009	Department of Conservation. 2009. *U.S. Midwest Average Rainfall, 1971-2000*. U.S. Department of Conservation. www.ncdc.noaa.gov/oa/climate/online/ccd/nrmpcp.txt (Accessed April 2, 2012).
EPA 2007	EPA. 2007. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005 -Annex 6 Additional Information. U.S. Environmental Protection Agency.
Federal Register 2004	Federal Register. 2004. *Part II: Environmental Protection Agency: 40 CFR Parts 9, 69, et al. Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel; Final Rule*. National Archives and Records Administration.
John Deere 2009a	John Deere. 2009. *John Deere Model 7830 165 PTO hp (Manufacturer Specifications)*. Deere & Company.
John Deere 2009b	John Deere. 2009. *John Deere Model 425 Disk Harrow Wheel Type Offset (Manufacturer Specifications)*. Deere & Company.
Kline and Coleman 2010	Kline, K., and Coleman, M. 2010. Woody Energy Crops in the Doutheastern United States: Two Centuries of Practitioner Experience. Biomass and Bioenergy 34:1655-1666.

Mallarino *et al*. 2009	Mallarino, A. et al. 2009*. Biomass Harvest and Nutrient N-P Management Impacts on Nutrient Loss From Fields.* Department of Agronomy and Agricultural and Biosystems Engineering, Iowa State University. Presentation*.*
McLaughlin et al. 1999	McLaughlin, S. et al. 1999. Developing Switchgrass as a Bioenergy Crop. InPerspectives in New Crops and New Uses. J. Janick (ed), ASHS Press, Alexandria, Virginia.
Miller and Bender 2008	Miller, R. and B. Bender. 2008. Growth and Yield of Willow and Poplar Hybrids in the Central Upper Peninsula of Michigan. Michigan State University. August, 2008.
Ney and Schnoor 2002	Ney, R., and Schnoor, J. 2002. Greenhouse gas emission impacts of substituting switchgrass for coal in electric generation: the Chariton Valley Biomass Project. Center for Global and Regional Environmental Research. May 20, 2002.
Pimentel and Patzek 2005	Pimentel, D. and Patzek, W. 2005. "Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower." Natural Resources Research 14(1): 65-76.
PAMI 1986	Prairie Agricultural Machine Institute. 1986. Evaluation Report 504: Versatile (1985 Model) 2200 Seed Drill. Prairie Agricultural Machine Institute.
Stanturf et al. 2001	Stanturf, J. et al. 2001. Chapter 5: Ecology and Silviculture of Poplar Plantations. In Poplar Culture in North America. Dickmann D., Isebrands J., Eckenwalder J., Richardson J., eds. NRC Research Press, pp. 153-206.
Stolarski 2008	Stolarski, M. 2008. "Content of Carbon, Hydrogen, and Sulphur in Biomass of Some Shrub Willow Species." *Journal of Elementology* 13(4):655-663.
Tillage 2009	Tillage Answers. 2009. *Tillage Calculators*.www.tillageanswers.com/tandem_calculator.cfm (Accessed February 2, 2010).
WRAP 2004	Western Regional Air Partnership. 2004. WRAP Fugitive Dust Handbook. WGA Contract No. 30204-83. Western Governors' Association.

U.S. DOE 2011	U.S. DOE. 2011. U.S. Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. Available at: http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf Accessed May 4, 2012.

Section III: Document Control Information

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Revision History:

29DECEMBER2014 Updated to reflect combustion removal. Diesel combustion is now an input.

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