NETL Life Cycle Inventory Data
Process Documentation File

Process Name: NPK Nutrients Replacement, Operation

Reference Flow: 1 kg of Corn Stover Biomass Collection

Brief Description: This unit process includes the amount of NPK fertilizer replaced due to the collection of corn stover from the ground as well as diesel use, air emissions from direct N2O volatilization, diesel combustion, and criteria air pollutants.

Section I: Meta Data

Geographical Coverage: US **Region:** Midwest

Year Data Best Represents: 2005

Process Type: Basic Process (BP)

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:

Corn Stover yield (yield_CS)	*The annual yield rate of corn stover biomass production.*

Tracked Input Flows:

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

Tracked Output Flows:

CS Biomass Collection	*This unit process is assembled with the corn stover biomass collection operation unit process; therefore the reference flow is assumed to be 1 kg CS biomass collection.*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage1_O_NPK_Nutrient_Replacement_2010.01.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 for nitrogen, phosphorus, and potassium (NPK) nutrients replacement in Life Cycle (LC) Stage #1. The unit process is based on the reference flow of 1 kg of corn stover (CS) biomass collection, as described below, and as shown in **Figure 1.** The inputs to the unit process include diesel use, and nitrogen, phosphorus and potassium (NPK) fertilizer use. Diesel is used as fuel power equipment to apply NPK fertilizers on the ground; the energy and material flows for the upstream production and delivery of diesel as well as life cycle emissions of diesel production are not included in the boundary of this process.

NPK is applied to the site to replace the nutrients that would return to the site had corn stover not been collected; the energy and material for the upstream production and delivery of NPK fertilizers as well as life cycle emissions of NPK fertilizers production are not included in the boundary of this process. The air emissions from diesel combustion and fugitive dust from spreading equipment are included within the boundary. Fugitive dust is categorized as particulate matter (PM) emissions to air. Water use and emissions to water are not characterized in this process, because they are assumed to comprise a negligible contribution to the direct operations of NPK replacement activities, and are otherwise considered in Stage #1 biomass cultivation unit processes.

Boundary and Description

The LC boundary of this unit process covers only the operations to apply NPK nutrients (fertilizers) to the site. When corn stover is collected after corn is harvested, it is necessary to apply fertilizer to the site to replace the nutrients that would return to the site had the stover not been collected. This unit process accounts for the NPK fertilizer used to restore soil nutrients when corn stover is collected. The operations for NPK nutrient replacement are based on the estimated diesel consumption of tractor-spreader equipment, the direct emissions from diesel combustion and fugitive dust emissions caused by surface dust. **Figure 1** provides an overview of the boundary of this unit process. Rectangular boxes represent relevant sub-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 diesel fuel, nitrogen, phosphorus, and potassium fertilizers are accounted for outside of the boundary of this unit process. The methods for calculating these operating activities are described below.

NPK nutrient replacement data is based on an independent study by ARS (Agricultural Research Service) National Soil Tilth Laboratory (Perry. 2008). The researchers studied the relationship between stover removal rates and soil quality. The research involved a sampling of four cornfields in Iowa and concluded that the per-acre losses were up to 20.41 kg/acre (45 lbs) for nitrogen, 0.9 – 1.8 kg/acre (2 to 4 lbs) for phosphorus, and 10 – 18 kg/acre (22 to 38 pounds) for potassium. The calculations in this unit process assume the high end of the replacement rates of NPK because the fuels LCA assumes a high collection rate of stover.

It is assumed that 10 percent (by weight) of applied nitrogen fertilizer volatilizes, and 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).

The yield rate of corn stover is based on independent studies by USDA (USDA. 2009, Brechbill. 2008) and South Dakota State University (SunGrant Initiative. 2007). The USDA data is representative of 10 sites and the average of the data points for corn stover yield was 4.25 tons/acre (3,856 kg/acre) used for this study. The per-acre replacement rate of fertilizer was converted to a basis of corn stover yield by using a yield of 3,856 kg of stover per acre.

The diesel consumption rate for equipment used as its applies to NPK nutrients was calculated based on specifications of a 1,953 rpm tractor consuming 10.26 gal/hour diesel fuel and a spreader 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).

The tractor makes a single pass over the site. By multiplying the width of the spreader, 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-pass cultivated. Dividing the fuel consumption by the corn stover yield rate, which is 3,856 kg/acre estimated, the estimated diesel consumption is 0.00077 kg diesel per kg biomass cultivated.

Diesel emission factors, per gallon of diesel consumed, are based on non-road diesel engine data (DOE. 2007, NARA. 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). Emission 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 (NARA. 2004). These emissions factors are expressed in terms of the mass of emissions per bhp (brake horsepower-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 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, 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 emissions standards, which specify an array of CO emissions factors across a range of engine sizes (DieselNet. 2009b). This unit process assumes that the engine of the tractor is greater than 175 horsepower, and the calculated emissions factor for diesel is 0.0104067 kg CO/L.

Fugitive dust emissions from NPK replacement activities 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 0.54 kg/acre-pass (1.2 lb PM/acre-pass). The tractor-spreader makes one pass of the site and total emissions of fugitive dust are 0.54 kg/acre-pass (0.1437 kg/kg biomass).

There is one adjustable process parameter included in this unit process: the annual yield rate of the corn stover. It allows modeling flexibility to enable the modeler to update the unit process to meet specific assumptions and study criteria, as relevant. The annual yield rate represents the mass ratio of corn stover per acre. NETL currently recommends a default value of 3,855 kg/acre-yr for this parameter. It is used to translate the values for NPK fertilizer, diesel consumption, diesel combustion emissions and fugitive dust emissions from a basis of quantity per acre to a basis of quantity per kg of biomass.

Table 1 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.

Figure 1: Unit Process Scope and Boundary

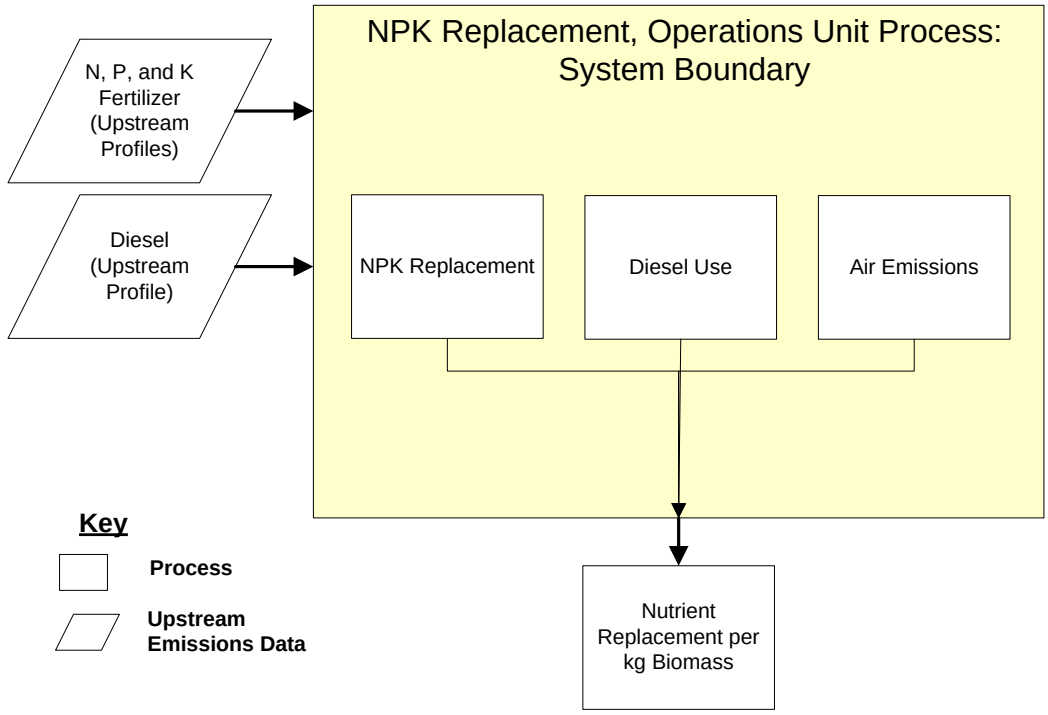

Table 1: Unit Process Input and Output Flows

Flow Name*	Value	Units (Per Reference Flow)
Inputs		
Diesel [Crude oil products]	**7.75E-04**	**kg /kg biomass**
N Fertilizer [Agro chemicals]	**5.29E-03**	**kg/kg biomass**
P Fertilizer [Agro chemicals]	**4.71E-04**	**kg/kg biomass**
K Fertilizer [Agro chemicals]	**4.47E-03**	**kg/kg biomass**
Outputs		
NPK Nutrient Replacement [Organic intermediate products]	1	kg
Carbon dioxide [Inorganic emissions to air]	2.43E-03	kg/kg biomass
Methane [Organic emissions to air (group VOC)]	1.79E-07	kg/kg biomass
Nitrous oxide (laughing gas) [Inorganic emissions to air]	1.67E-05	kg/kg biomass
Nitrogen dioxide [Inorganic emissions to air]	5.65E-07	kg/kg biomass
Carbon monoxide (biotic) [Inorganic emissions to air]	6.97E-06	kg/kg biomass
Sulphur dioxide [Inorganic emissions to air]	1.19E-08	kg/kg biomass
Particulate Matter, unspecified [Other emissions to air]	2.82E-04	kg/kg biomass
Volatile Organic Carbons [Organic emissions to air]	2.64E-07	kg/kg biomass

* **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.

References

Brechbill 2008 — Brechbill, S. and Tyner, W. 2008. The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electric Utility Facilities. Working Paper #08-03. Department of Agricultural Economics, Purdue University.

Countess Environmental 2004 — Countess Environmental, 2004. *WRAP Fugitive Dust Handbook.* WGA Contract No. 30204-83. Western Regional Air Partnership.

DieselNet 2009a — DieselNet. 2009. *Emission Standards >> United States Stationary Diesel Engines*. Ecopoint Inc. http://www.dieselnet.com/standards/us/stationary.php (Accessed Feb. 12, 2010).

DieselNet 2009b — DieselNet. 2009. *Nonroad Diesel Engines*. Ecopoint Inc. www.dieselnet.com/standards/us/nonroad.php (Accessed Feb. 12, 2010).

DOE 2007	DOE. 2007. *Instructions for Form EIA-1605, Voluntary Reporting of Greenhouse Gases*. OMB No. 1905-0194. U.S. Department of Energy.
John 2009a	John Deere. 2009. *John Deere Model 7830 165 PTO hp (Manufacturer Specifications)*. Deere & Company.
John 2009b	John Deere. 2009. *John Deere Model 425 Disk Harrow Wheel Type Offset (Manufacturer Specifications)*. Deere & Company.
NARA 2004	National Archives and 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.
Perry 2008	Perry, A. 2008. Cellulosic Ethanol From Corn Stover: Calculating and Improving the Bottom Line. Agricultural Research, October 2008.
SunGrant Initiative 2007	SunGrant Initiative, 2007. *Management Guide for Biomass Feedstock Production From Switchgrass in the Northern Great Plains.* South Dakota State University.
Tillage 2009	Tillage Answers. 2009. *Tillage Calculators*.www.tillageanswers.com/tandem_calculator.cfm (Accessed January 28, 2010).
SCAQMD 2005	South Coast Air Quality Management District. 2005. *Final Environmental Assessment: Proposed Rule 1469.1 - Spraying Operations Using Coatings Containing Chromium*. SCAQMD. February, 2005.
USDA 2009	USDA. 2009. *Fact Sheet: Management and Lifecycle Assessment of Bio-energy Crop Production*. U.S. Department of Agriculture.

Section III: Document Control Information

Date Created: February 12, 2010

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

Revision History:

Original/no revisions

How to Cite This Document: This document should be cited as:

NETL (2010). *NETL Life Cycle Inventory Data – Unit Process: NPK Nutrient Replacement, operation.* U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: February 2010 (version 01). www.netl.doe.gov/energy-analyses (http://www.netl.doe.gov/energy-analyses)

Section IV: Disclaimer

Neither the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) nor any person acting on behalf of these organizations:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe on privately owned rights; or

B. Assumes any liability with this report as to its use, or damages resulting from the use of any information, apparatus, method, or process disclosed in this document.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by NETL. The views and opinions of the authors expressed herein do not necessarily state or reflect those of NETL.