Update to Soybean Farming and Biodiesel Production in GREET™

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1. Introduction

The soybean-based biodiesel pathway in the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET™) model consists of fertilizer production, soybean farming, transportation and crushing, soy oil transesterification, and biodiesel transportation and vehicle use (see Figure 1). The soybean-based biodiesel pathway estimates the farm-to-wheels (FTW) energy use and greenhouse gases (GHG) and other criteria pollutant emissions of soybean-based biodiesel. In addition, the intermediate results of the pathways (e.g., farm-to-gate energy results for soybean, soy oil and soybean meal) are employed to estimate the displacement credits for other animal feeds. The examples of animal feeds include (but are not limited to) distillers grain solubles (DGS) from corn ethanol production, other meals from oil seeds (e.g., rapeseed and palm) and algae. Therefore, the changes in soybean-based biodiesel pathways could affect many biofuel pathways directly and indirectly. In this memo, we document updates to soybean farming and biodiesel production parameters, which represent current practices more accurately. Also, we document the changes in the default allocation methods for the vegetable-oil-based biofuel pathways.

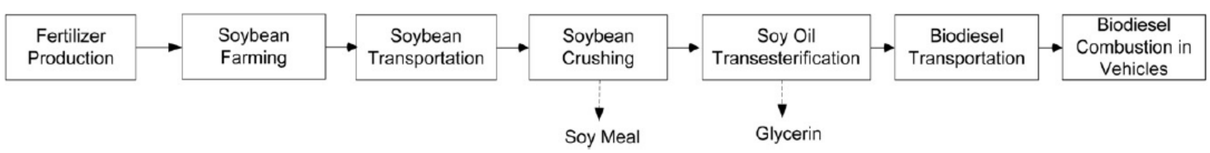


Figure 1 Soybean-based biodiesel pathway (Wang et al. 2011)

2. Data Sources and Updated Assumptions

2.1. Soybean Farming

The National Agricultural Statistics Service (NASS) in the US Department of Agriculture conducts surveys and censuses on farming practices of various agricultural products, which provides the basis of many parameters of biomass farming in GREET. The last updates on the soybean farming parameters (e.g., fertilizers, chemicals and energy inputs) in the previous GREET 2013 version were incorporated in 2010 based on Pradhan et al. (2009) using the 2002 NASS survey. Last year, NASS published the 2012 Agricultural Chemical Use Survey among soybean producers in 19 program states (Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, South Dakota, Tennessee, Virginia, and Wisconsin), which covers 96 percent of the soybean acreage planted in the US in 2012 (USDA 2013). Tables 1 and 2 present the collective soybean acreage harvested, production and yield, and the fertilizers and chemicals applied to soybean planted acres in the 19 program states in 2012, obtained from the NASS database (USDA 2014).

Table 1 Soybean acreage harvested, production and yield in 19 program states (USDA 2014)

Year	Acre Harvested (Million Acre)	Production (Billion Bushel)	Yield (Bushels/Acre)
2012	73.3	2.92	39.4
2006	71.2	3.12	42.8
2004	71.0	3.02	41.8
2002	70.0	2.70	37.8

Table 2 Fertilizers and chemicals applied to soybean planted acres in 19 program states (USDA 2014)

Year	N Fertilizer (Million Pounds)	PHOSPHATE (Million Pounds)	POTASH (Million Pounds)	Herbicide (Million Pounds)	Insecticide (Million Pounds)
2012	321	1,329	2,215	133	4,060
2006	212	772	1,455	103	2,674
2004	358	1,096	1,734	70.8	497
2002	306	907	1,829	86.7	1,077

Table 3 summarizes the fertilizer and chemical application rates for soybean farming in grams/bushel, which is incorporated in GREET1_2014.

Table 3 Fertilizers and chemicals application rates for soybean farming

Year	N Fertilizer (grams/bushel)	PHOSPHATE (grams/bushel)	POTASH (grams/bushel)	Herbicide (grams/bushel)	Insecticide (grams/bushel)
2012	49.9	206.7	344.4	20.7	0.6
2006	30.9	112.3	211.5	15.0	0.4
2004	53.9	164.9	260.9	10.7	0.1
2002	51.4	152.5	307.7	14.6	0.2

Pradhan et al. (2011) documented the 2006 survey on fuel use in soybean farming, which updated the assumptions in Pradhan et al. (2009). Table 4 presents the soybean farming energy inputs in 2002 and 2006. All of the energy inputs in Btu/bushel decreased, especially LPG. The total energy inputs from Table 4 in Btu/bushel are incorporated in GREET1_2014. The process fuel shares are calculated from the various energy inputs in Table 4, and incorporated in GREET1_2014.

Table 4 Soybean farming energy inputs in 2002 and 2006

		Energy Inputs per Acre		Energy Inputs in Btu/Bushel	
	Year	2002	2006	2002	2006
	Reference	(Pradhan et al. 2009)	(Pradhan et al. 2011)		
Diesel	gal/acre	4.06	3.56	13,724	10,684
Gasoline	gal/acre	1.26	1.37	3,849	3,712
NG	ft3/acre	58.41	58.59	1,511	1,346
LPG	gal/acre	0.73	0.21	1,632	424
Electricity	kWh/acre	6.62	6.92	594	552
Total				21,310	16,718

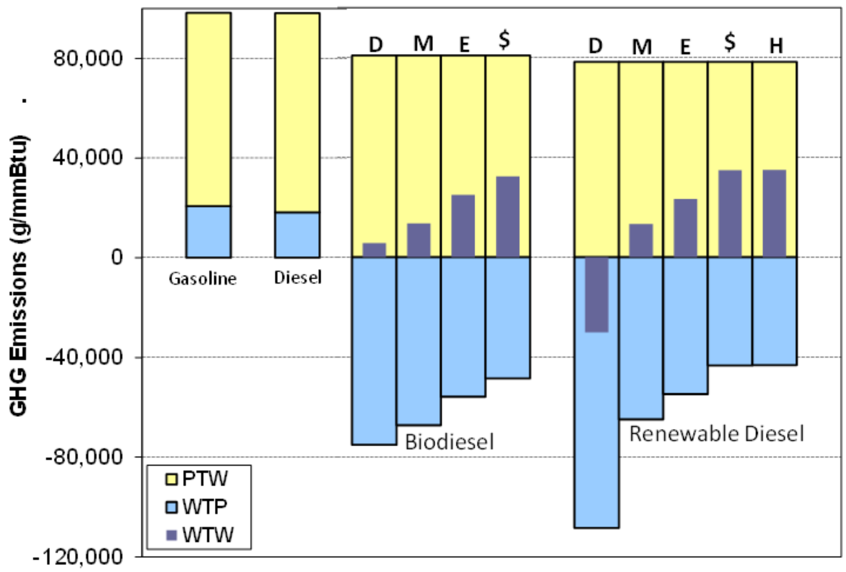
2.2. Biodiesel Production

Table 5 presents soybean crushing and soy oil transesterification assumptions from literature. The parameters from Omni Tech (2010) are based on a survey conducted by National Biodiesel Board (NBB), covering 37% of the U.S. biodiesel production while Pradhan et al. (2009) and Pradhan et al. (2011) are based on process engineering models. The previous GREET 2013 was based on Omni Tech (2010) except that #2 fuel oil, #6 fuel oil, biomass and landfill gas are excluded because they were considered not significant. Also, the glycerin yield was set to 0.214 lb/lb BD. The glycerin yield of 0.214 lb/lb BD was based on Sheehan et al. (1998), which included 20% water. Since Omni Tech (2010) data are based on a survey with good coverage, soy oil parameters are revised in GREET1_2014 to incorporate all of the parameters in Omni Tech (2010)

Table 5 Soybean crushing and soy oil transesterification assumptions

	EPA RFS2	Pradhan et al. (2009)	Pradhan et al. (2011)	Omni Tech (2010)
Soybean Crushing				
Energy Inputs (Btu/lb soy oil)				
NG	1,886	1,886	1,834	2,068
Electricity	369	355	358	447
Hexane		180	233	59
#2 fuel Oil				16
#6 fuel oil				32
Coal				1,018
Biomass				32
landfill gas				16
Total	**2,255**	**2,421**	**2,425**	**3,687**
Soy oil Transesterification				
Energy Inputs (Btu/lb BD)				
NG	591	479	141	373
Electricity	49	59	78	55
MeOH		971	941	785
Total	**640**	**1,509**	**1,160**	**1,213**
Material Inputs (g/lb BD)				
Sodium hydroxide		2.3		0.4
Sodium methoxide		5.7		10.5
Hydrochloric acid		3.2	0.3	19.7
Sodium methylate			1.4	
Phosphoric acid				0.5
Citric acid				0.3
Glycerin Yield (lb/lb BD)		**0.171**	**0.171**	**0.120**

2.3. Allocation Methods



As shown in

Figure 2, the choice of allocation methods has a significant impact on the WTW results. Especially, the WTW results of vegetable-oil-based biofuels are affected by the co-product handling method because 1) co-products are produced in two separate processes, and 2) a large amount of meals is produced during oil extraction. Figure 3 provides the mass shares of main products (e.g., soy oil and biodiesel) and co-products (e.g., meal and glycerin) from soybean crushing and soy oil transesterification processes, respectively. These co-products can be handled either on a system level where soybean crushing and soy oil transesterification processes are combined (dashed line) in a single system, or on a process level where each process is handled separately (solid line). Huo et al. (2008) suggested the use of system-level allocation because the properties (e.g., heating values and density) of soy oil (as well as other vegetable oils) were not well-defined. Thus, previous GREET versions used a system-level energy allocation as the default allocation method. However, the system level allocation allocates energy and chemical inputs for soy oil transesterification to soybean meal, although the soy meal production is independent (upstream) of soy oil transesterification. Because of the high yield of soybean meal, it is more reliable to use the process level approach as soy oil properties are now readily available. GREET1_2014 employs the process level approach.

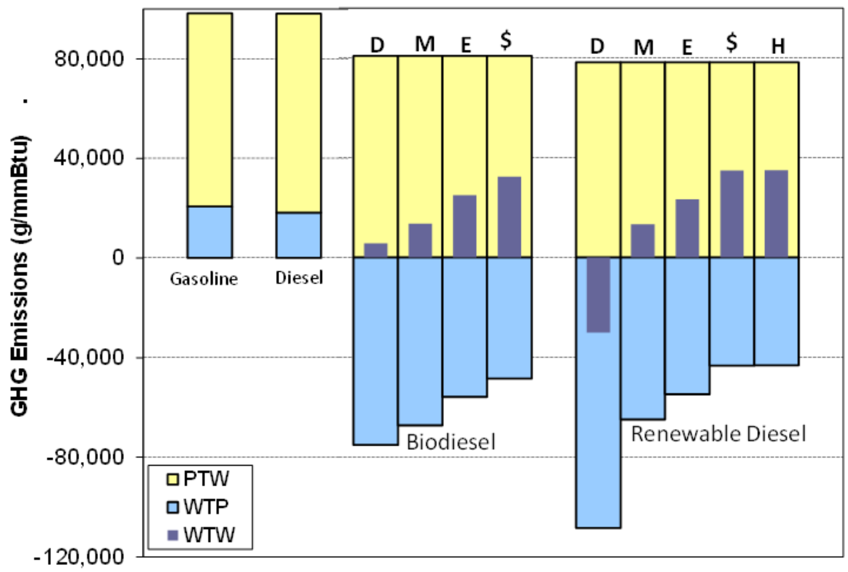


Figure 2 WTW GHG emissions of petroleum gasoline, diesel, biodiesel and renewable diesel (D: displacement, M: mass based, E: energy based, $: market value based, H: hybrid allocation)

Table 6 summarizes co-products and default co-product handling methods for vegetable-oil-based biofuel pathways in GREET. For the oil extraction process (except for jatropha oil extraction), a mass-based allocation is selected as the default co-product handling method for the following reasons: 1) the displacement ratio of the meal has yet to be defined in order for a displacement method to be applied, 2) Since the meals are not energy products, an energy-based allocation is not representative, 3) mass is not subject to fluctuations as would be the case if market value allocation is employed for vegetable oil and meals. The jatropha oil extraction co-product is unsuitable for animal feed due to its toxicity, so it is assumed to be combusted to generate electricity. Since electricity is an energy product, an energy-based allocation is applied by default.

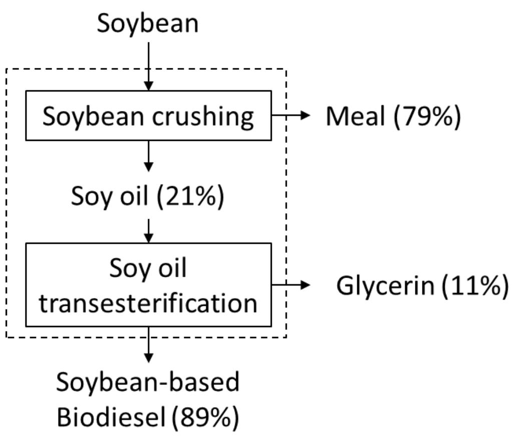


Figure 3 Mass shares of main products (e.g., soy oil and biodiesel) and co-products (e.g., meal and glycerin) from soybean crushing and soy oil transesterification

GREET has three biofuel production pathways from vegetable oil: biodiesel, renewable diesel and renewable gasoline. While biodiesel coproduces glycerin, renewable diesel and gasoline coproduce hydrocarbon fuels. Therefore, an energy-based allocation is applied for renewable diesel and gasoline production. For biodiesel production, an energy-based allocation may not be suitable since glycerin is not used as fuel in the US. A displacement method is not selected because glycerin from biodiesel production (transesterification) dominates the market. Since biodiesel and glycerin are actively traded in the market, a market-value-based allocation is selected as the default method. The default biodiesel price is set to $4.05/gal (or $0.547/lb), a 5 year average of U.S. retail biodiesel prices from July 2009 to April 2014 (U.S. Department of Energy 2014). The default glycerin price is set to $0.25/lb (Urbanchuk 2008).

Table 6 Co-products and default co-product handling methods for vegetable-oil-based biofuel pathways

Oil Extraction	**Soybean**	**Palm Oil**	**Rapeseeds**	**Jatropha**	**Camelina**
Co-products	Meal	Expeller	Meal	Electricity	Meal
Co-products Handling Methods	Mass	Mass	Mass	Energy	Mass
Biofuel Production	**Biodiesel**	**Renewable Diesel**		**Renewable Gasoline**	
Co-products	Glycerin	Fuel Gas		Fuel Gas, Light Cycle Oil, Clarified Slurry Oil	
Co-products Handling Methods	Market	Energy		Energy	

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