Updates on the Energy Consumption of the Beef Tallow Rendering Process and the Ratio of Synthetic Fertilizer Nitrogen Supplementing Removed Crop Residue Nitrogen in GREET

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1. Energy Consumption of the Beef Tallow Rendering Process

This memo documents Argonne's update on the energy inputs regarding beef tallow rendering process in GREET 2016 model. Current energy and material inputs of the rendering process in GREET were generated based on the average values from several studies and reports on biodiesel production using rendered lipids, including the analysis conducted by López et al. (2010), whose data were assembled from a survey of 25 rendering plants in the US. Figure 1 summarizes the mass balance of 1 kg tallow-based biodiesel production by López; for the tallow rendering process specifically, 3.576 kg cattle by-products from the slaughterhouse can yield 1.008 kg rendered tallow, 0.815 kg meat and bone meal (MBM), and 1.752 kg cooking vapors. Meanwhile, for each kg of total rendered products (RP), 4.144 MJ fuel and 0.573 MJ electricity are consumed. Because it was not specified in López' study what the RP consisted of, the total mass (3.576 kg/kg biodiesel) of rendered tallow, MBM and cooking vapors was used to represent the weight of RP in previous GREET simulations. However, a recent personal communication with the corresponding author confirmed that the total RP should have included rendered tallow and MBM only (1.823 kg/kg biodiesel). In other words, previous energy inputs were overestimated by 96.2% (3.576/1.823 = 1.962). In this memo, all values were corrected to take into account for the updated information as shown in Table 1. The boiler efficiency for the thermal energy is 85%, and the percentage of each fuel type (LHV) of the total energy in the rendering process remain the same as previously reported in GREET 2016: 40.8% natural gas, 26.8% residual oil, and 21.1% fat and grease, and 11.3% electricity.

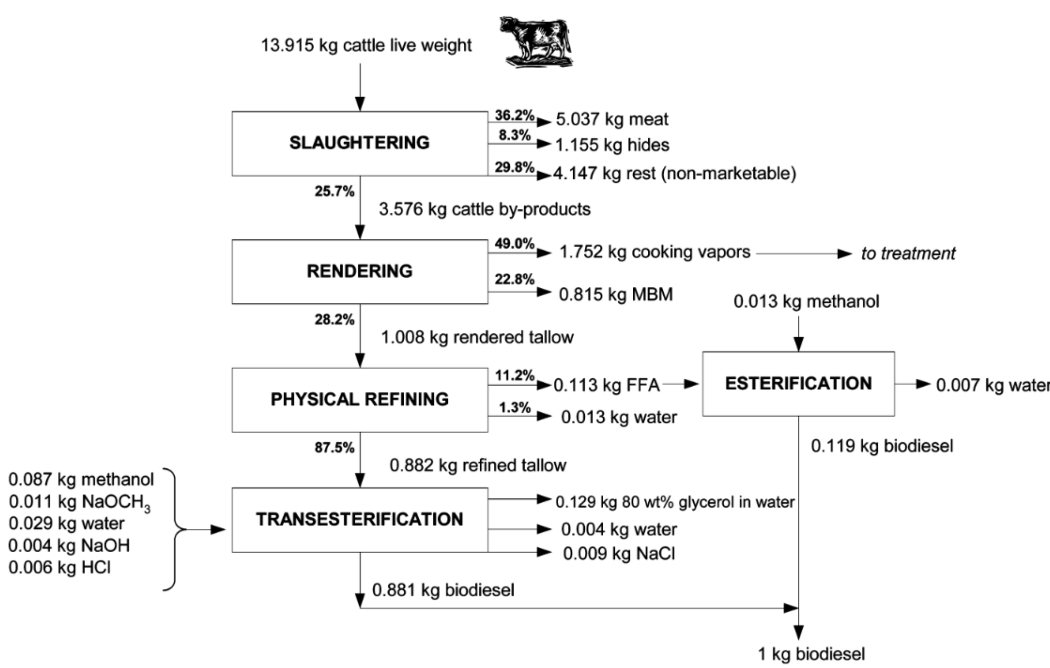

Figure 1: Mass balance for the production of 1 kg of biodiesel from beef tallow (López et al., 2010).

Table 1: Energy consumption, fat and MBM yields of beef tallow rendering process. Numbers marked with strikethrough indicate previously reported values; updated values are listed right below in the same row.

	NG	**Fuel oil**	**Diesel**	**Fat & grease**	**Total thermal energy**	**Electricity**	**Total rendered products**	**MBM yield**
Unit	**Btu/lb fat**	**Btu/lb fat**	**Btu/lb fat**	**Btu/lb fat**	**Btu/lb fat**	**Btu/lb fat**	**lb/lb fat**	**lb /lb fat**
Dufour and Iribarren, 2012	3,231				2,747	450	1.80	0.81
Gooding, 2012	2,405	1,421			3,252	518	2.08	1.08
López et al., 2010	~~2,913~~ **1,485**	~~1,862~~ **949**	~~14~~ **7**	~~1,531~~ **780**	~~5,372~~ **2,739**	~~874~~ **446**	~~3.55~~ **1.81**	0.81
Nelson and Schrock, 1993	5,732				4,872	418		
(S&T)[2], 2011					12,974	1,900		
(S&T)[2], 2011					2,016	593		
CARB, 2009					5,950	671		
CARB, 2009					5,816	698		
CARB, 2009					6,084	643		
FPRF, 2005					3,452	379	2.0	1.0
GREET Selected Values	~~2,900~~ **1,700**	~~1,900~~ **1,000**	~~0~~ **0**	~~1,500~~ **780**	~~5,355~~ **2,958**	~~800~~ **500**	~~3.5~~ **2.0**	0.8

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2. Ratio of Synthetic Fertilizer Nitrogen Supplementing Removed Crop Residue Nitrogen

The organic nitrogen (N) in crop residue can become available to plants via mineralization in a long-term, even though N immobilization can occur during the early stages of residue return (Hoorman & Islam, 2010; Reis *et al.*, 2011). With crop residue removed from the field, N bounded in the residue has also been removed which could potentially reduce soil N availability (Sindelar *et al.*, 2013; Wortmann *et al.*, 2016). To account for this impact in corn residue biofuel life cycle analysis, GREET originally supplemented removed residue N by synthetic fertilizer N at 1:1 ratio. It suggested that for each unit of N removed with residue, a unit of fertilizer N will be added into corn field to maintain soil N level. Therefore the corn residue biofuel would be burdened with this additional fertilizer use, in terms of energy use and greenhouse gas emissions associated with fertilizer production. However, N availability in crop residue is different from fertilizer. Plant available N (PAN) in residue is released gradually in a few years, especially for corn residue with high C/N, while conventional synthetic fertilizer N can become available immediately. Lignin content also affects residue decomposition which could further limit residue N availability (Stewart *et al.*, 2015). Therefore the supplement ratio of 1:1 used in GREET needs to be revisited.

Few studies report quantitative relationship between residue N and fertilizer N or supplement ratio. However, there were studies reporting soil N level after residue removal (e.g., Sindelar *et al.*, 2013; Schmer *et al.*, 2014; Wortmann *et al.*, 2016) and some estimating recommended N use based on N balance and N efficiency (e.g., Ristow *et al.*, 2007; Tan & Liu, 2015). According to literature review, the supplement ratio could be as low as zero suggesting no supplemental N needed, to as high as 1. In an estimation made by Cornell University Cooperative Extension, available N from residue (i.e. SOD) was calculated on the basis of N release rate (Ristow *et al.*, 2007). It was estimated that, about 72% of total SOD N becomes available within three years. Considering that 19% of lignin in corn residue is regarded immobile, 58% of corn residue N could be available. To account for uncertainties existed in current literature, we suggest the following revised supplemental ratio to be used in GREET henceforward (see Figure 1):

- A triangular distribution is assumed due to lack of data points;
- The minimum, likeliest and maximum values are set at 0%, 58% and 58%, respectively;
- The nominal value for point-value evaluations is set at 40%.

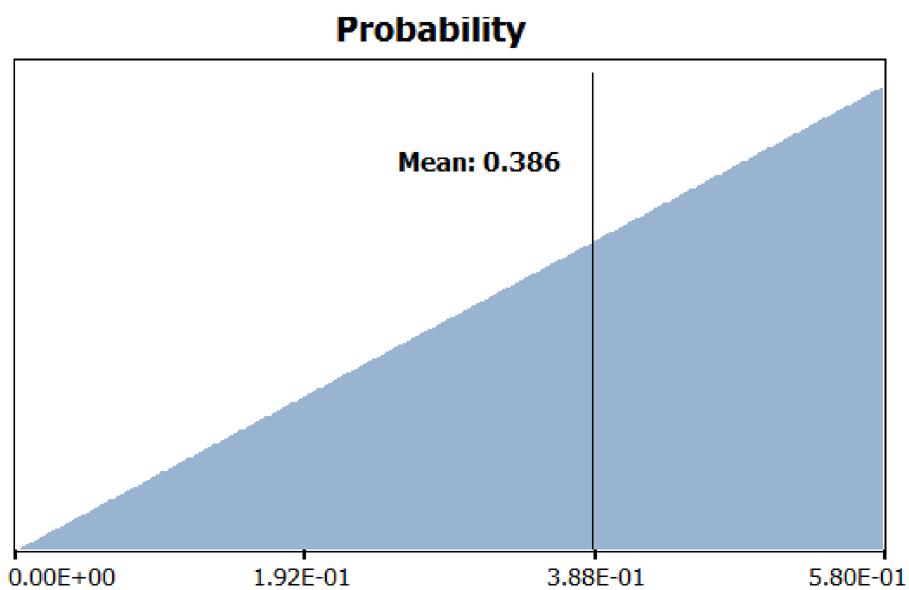

Figure 1 Distribution function of the ratio of supplemental N

It should be noted, however, this ratio needs to be further revised when relevant studies become available to reflect specific supplemental ratio or even PAN release rate for various crop residues, residues with different C/N ratios, different rotation systems, and different management systems.

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