RENEWABLE FUELS ASSOCIATION

March 2016

RE-EXAMINING CORN ETHANOL'S ENERGY BALANCE RATIO

The U.S. Department of Agriculture (USDA) recently published an analysis of the energy balance of corn ethanol produced at dry mill biorefineries (Gallagher et al., 2016).[1] The report concludes that corn ethanol's energy balance ratio today is "between 2.1 and 2.3," describing the result as "…a small but positive improvement since 2008." The new USDA report also analyzed a model dry mill in Iowa that markets wet distillers grains and is more closely situated to feedstock supplies and ethanol markets, thus reducing energy use versus the reference case. Ethanol from the model Iowa biorefinery configuration was found to have an energy balance of 4.0.

USDA's previous report on corn ethanol's energy balance (Shapouri et al., 2010), which was based on 2008-era data, concluded that the energy balance ratio at that time was between 1.9 and 2.3. Thus, the new USDA report suggests the average energy balance of corn ethanol is essentially the same today as it was in 2008. This result seems at odds with observed reductions in energy use by dry mill biorefineries since 2008 (Wang et al., 2012; Mueller & Kwik, 2013; Christianson & Associates, 2016). A number of dry mills using more efficient energy systems completed construction after 2008, and many older facilities have undertaken retrofits and adopted new technologies. These developments have resulted in significantly lower average energy use at dry mills today than in 2008.

This brief analysis was undertaken by RFA for two reasons: 1) to understand the apparent lack of improvement in corn ethanol's energy balance since 2008 suggested by USDA's latest analysis; and 2) to examine the impact of using more current biorefinery energy use data on the energy balance ratio. In summary, we find two primary explanations for the lower-than-expected energy balance ratio reported in USDA's latest analysis:

- The new USDA analysis relies on the same 2008 survey of dry mill energy use that was used for the previous analysis published in 2010.
- The new USDA analysis assumes for its reference case that all distillers grains require drying, which increases energy use. Further, impacts of corn distillers oil removal are not considered.

When more current and robust data regarding dry mill biorefinery energy use are considered, we conservatively find the average energy balance of corn ethanol is more likely in the range of **2.6 to 2.8**, with the top quartile of dry mill biorefineries averaging **3.2 to 3.4** and some plants very likely achieving the **4.0** energy balance in USDA's "Iowa Wet DG" case.

Energy Use for Ethanol Processing

The new USDA report's estimate of thermal and electrical energy use by dry mills comes from a 2008 survey of 18 dry mill biorefineries conducted by the National Agricultural Marketing Association. It is the same survey data that was used in USDA's previous report (Shapouri et al., 2010) on corn ethanol's

[1] "Energy balance" refers to the ratio of the amount of usable energy delivered by a fuel to the total amount of energy invested in producing the fuel. This measure is sometimes referred to as "energy return on energy investment."

energy balance. The 2008 survey found average thermal energy use of 29,421 BTU/gallon (LHV) and average electricity use of 0.757 kWh/gallon at facilities drying their distillers grains co-product. USDA applies an energy loss factor of 0.2963 to the electricity to account for the fact that roughly three units of energy are required upstream of the ethanol biorefinery to generate one unit of usable energy in the form of electricity. Thus, when converted to BTUs, USDA's 2008 survey found average dry mill energy use related to electricity was 8,720 BTU/gallon. Accordingly, total energy use at the average dry mill biorefinery was estimated at 38,141 BTU/gallon based on the 2008 survey results.

In April 2013, Mueller & Kwik published the results of a survey of 84 dry mill biorefineries, representing more than half of the installed capacity at the time. The survey results, which are based on 2012 operating data, showed average thermal energy use of 23,862 BTU/gallon (LHV) and average electricity use of 0.75 kWh/gallon. When USDA's energy loss factor is applied to the electricity use estimate, total energy use averaged 32,501 BTU/gallon in this survey. Data from the Mueller & Kwik report have served as the basis for recent updates to the Department of Energy's GREET model.

In February 2016, Christianson & Associates PLLP (a Minnesota-based accounting and consulting firm) presented dry mill thermal energy and electricity use averages from the firm's benchmarking program.[2] Through this program, the firm collects quarterly data regarding more than 90 operational and financial factors from approximately 60 dry mill biorefineries.[3] Average thermal energy use was 27,043 BTU/gallon (HHV) in 2015, according to the benchmarking data. To provide an appropriate comparison to the figures from USDA and Mueller & Kwik, we converted this value to its lower heating value of 24,409 BTU/gallon (LHV).[4] Average electricity use was reported at 0.67 kWh/gallon, or 7,718 BTU/gallon after considering energy loss. Thus, average total energy use was 32,217 BTU/gallon in the Christianson & Associates benchmarking service—nearly identical to the Mueller & Kwik survey results. Table 1 compares key variables from the dry mill energy use surveys conducted by USDA, Mueller & Kwik, and Christianson & Associates.

Table 1. Comparison of Dry Mill Energy Use Surveys

	USDA Reference Case (Gallagher et al., 2016)	Mueller & Kwik (2013)	Christianson & Associates (2016)
Dry Mills Included in Survey	18	84	~60
Year of Operational Data Surveyed	2008	2012	2015
Average Thermal Energy (BTU/gal.) (LHV)	29,421	23,862	24,409
Average Electricity (kWh/gal.)	0.757	0.750	0.670

The top quartile of dry mills participating in the Christianson & Associates benchmarking service achieved average thermal energy use of 20,405 BTU/gallon (LHV) and average electricity use of 0.56 kWh/gallon (6,450 BTU/gallon after energy loss). Accordingly, total energy use by biorefineries in the leading quartile was just 26,856 BTU/gallon.

[2] Presentation to the Renewable Fuels Association National Ethanol Conference. Feb. 17, 2016. New Orleans, LA.
[3] Personal communication with Christianson & Associates. More information on the service is available at www.christiansoncpa.com.
[4] Ethanol's high heat value (HHV) is 84,530 BTU/gal. and its low heat value (LHV) is 76,330 BTU/gal. (U.S. Department of Energy). Thus, HHV can be converted to LHV by multiplying 0.903.

Notably, the average energy use values from Mueller & Kwik and Christianson & Associates include data from both biorefineries that dry distillers grains and biorefineries that sell distillers grains in wet form (i.e., avoiding energy use for drying). This is in contrast to the USDA reference case, which appears to assume all distillers grains are dried. Monthly data from USDA's National Agricultural Statistics Service (NASS) indicate that 56% of the distillers grains produced in 2015 were dried, while 34% were sold wet and 10% were partially dried.[5] Thus, roughly half of distillers grains are being fully dried.

Re-estimating Corn Ethanol's Energy Balance

When energy use data from Mueller & Kwik and Christianson & Associates are used in lieu of the 2008 USDA survey data, the average energy balance for corn ethanol is in the range of **2.6 to 2.8**, compared to the range of 2.1 to 2.3 suggested in the new USDA paper (Table 2). The energy balance of the top-performing quartile of biorefineries is in the range of **3.2 to 3.4**, which approaches the USDA estimate of 4.0 for an ideally situated dry mill producing wet distillers grains. To ensure a consistent comparison, we adopted USDA energy use estimates for all other segments of the corn ethanol production lifecycle. We also provide energy balance estimates based on both co-product credit values included in USDA's analysis (i.e., a model-based credit and a survey-based credit).

Table 2. Corn Ethanol Energy Balance Ratio Based on USDA Survey and Newer Data

Note: All figures in BTU/gal. (LHV) with exception of electricity (kWh/gal.)	**USDA (Gallagher et al. 2016)**		**Christianson & Assoc. (2016)**		**Mueller & Kwik (2013)**
	Ref. Case (Dry DG)	**Iowa WDG**	**Average**	**Top Quartile**	**Average**
Corn Production	9,007	7,724	9,007	9,007	9,007
Corn Transport	701	557	701	701	701
Total Ethanol Conversion:	38,141	23,424	32,127	26,856	32,501
Thermal (Natural Gas)	*29,421*	*16,485*	*24,409*	*20,405*	*23,862*
Electricity (kWh)	*0.757*	*0.602*	*0.670*	*0.560*	*0.750*
Electricity Adjusted for Loss	*8,720*	*6,939*	*7,718*	*6,450*	*8,639*
Ethanol Transportation	993	600	993	993	993
Farm Machinery	1,330	1,330	1,330	1,330	1,330
Total Energy Used	50,172	33,635	44,158	38,887	44,532
Co-product Credit (CPC)-Survey	(14,717)	(14,717)	(14,717)	(14,717)	(14,717)
Energy Use Net of CPC-Survey	35,455	18,918	29,441	24,170	29,815
Co-product Credit (CPC)-Model	(16,591)	(16,591)	(16,591)	(16,591)	(16,591)
Energy Use Net of CPC-Model	33,581	17,044	27,567	22,296	27,941
Ethanol Energy Output	76,300	76,300	76,300	76,300	76,300
Energy Ratio, w/o CPC	1.52	2.27	1.73	1.96	1.71
Energy Ratio, w/ CPC--Survey	**2.15**	**4.03**	**2.59**	**3.16**	**2.56**
Energy Ratio, w/ CPC--Model	**2.27**	**4.48**	**2.77**	**3.42**	**2.73**

[5] USDA National Agricultural Statistics Service. "Grain Crushings and Co-products Production." Published Monthly.

Notably, the average energy balance ratio resulting from the use of the Mueller & Kwik energy use data is nearly identical to the ratio resulting from the use of the Christianson & Associates data. The general agreement of data from two independent sources suggests that the data is robust and reliable.

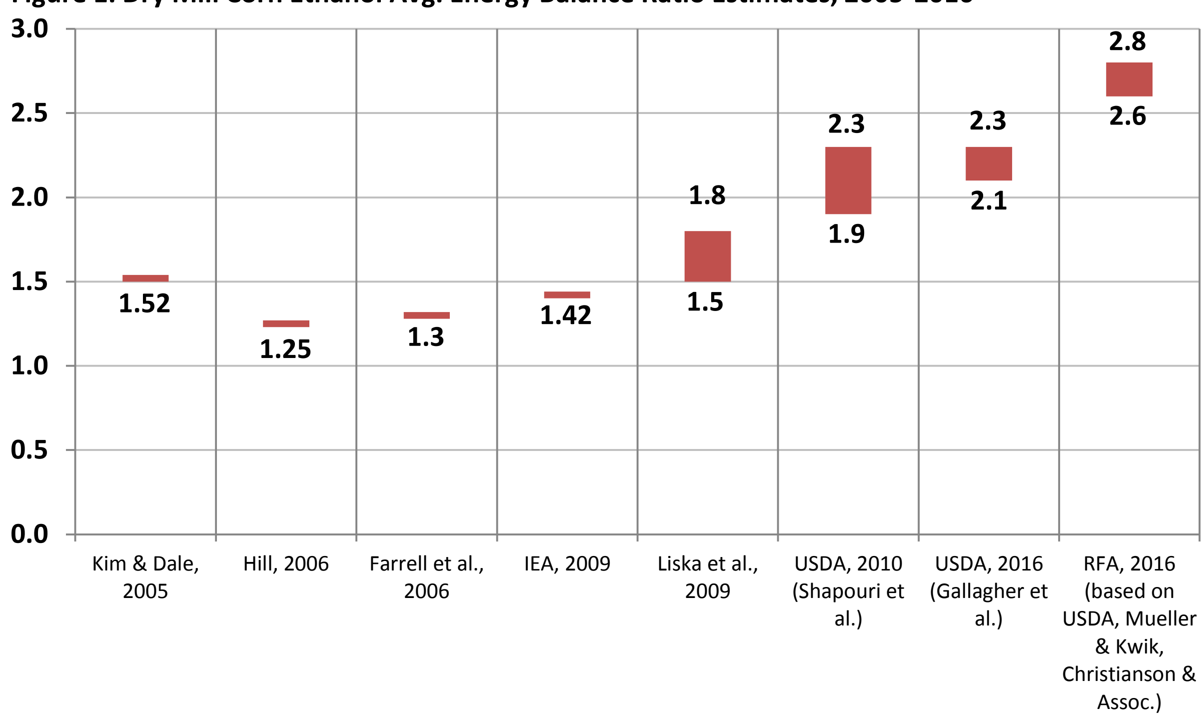
Impact of Corn Distillers Oil (CDO) Removal on Energy Balance

It is important to recognize that none of the energy balance ratios in Table 2 fully account for the impact of corn distillers oil (CDO) removal on ethanol's energy efficiency. CDO has its own distinct energy value as a feedstock for biodiesel or renewable diesel production. Today, more than 85% of dry mills extract CDO from distillers grains. The energy input (mostly electricity) required to remove CDO is modest and is likely already included in the energy use data in Table 2 from Christianson & Associates and Mueller & Kwik.[6] However, the energy output from CDO extraction is not reflected in Table 2. That is, depending on the accounting method used, CDO extraction likely results in either a larger co-product credit *or* more BTUs of energy output than is reflected in Table 2.[7] Proper accounting of CDO would likely boost the *average* energy balance ratio to approximately **2.9 to 3.0**. This is an area for further study.

Improvement in Corn Ethanol's Energy Balance

When more recent data is used regarding thermal and electrical energy use at dry mills, the current average energy balance ratio for corn ethanol is conservatively found to be in the range of **2.6 to 2.8**, roughly 25-35% higher than the 2008 estimate from Shapouri et al. (2010). This demonstrates continued progress in the energy efficiency of corn ethanol production over the past decade (Figure 1).

Figure 1. Dry Mill Corn Ethanol Avg. Energy Balance Ratio Estimates, 2005-2016



[6] Back-end CDO extraction technologies significantly penetrated the dry mill market between roughly 2009-2013.

[7] Approximately 0.2-0.3 pounds of CDO are produced per gallon of ethanol produced. This results in an additional 3,100-4,650 BTU of energy output per gallon, but also results in slightly reduced mass of distillers grains.

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