California Air Resources Board –

Memo on the Life-Cycle GHG Emissions Intensity of Corn-Ethanol As Calculated by the BESS and GREET Life-Cycle Models: Suggestions for the Low Carbon Fuel Standard

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1. A recommendation for the implementation of the Low Carbon Fuel Standard (LCFS) suggests: "*RECOMMENDATION 6*: To the degree possible, values used to certify the carbon intensity (i.e., GWI) of different fuels should be based upon empirical data representative of the specific inputs and processes in each fuel's life cycle. Pessimistic default values should be determined by state agencies for each of these inputs and processes. Fuel providers will face the option of either adopting these pessimistic values (with GWI values higher than average values) or opting in by providing sufficient data to certify a lower life cycle GWI value for a particular fuel." (http://www.arb.ca.gov/fuels/lcfs/lcfs_uc_p2.pdf)

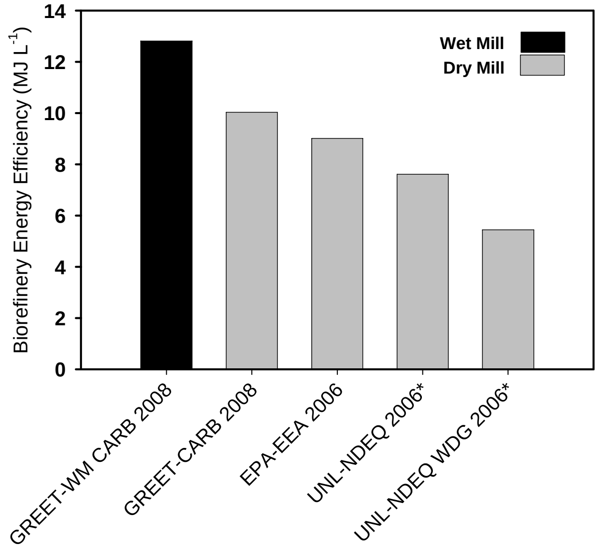
Corn-ethanol will be the largest source of renewable fuel available for California markets, outside of ethanol produced from sugarcane imported from Brazil, for the foreseeable future. However, there is substantial variation in the GHG emissions intensity of corn-ethanol due to biorefinery design and location. The potential volume of ethanol imported into California requires that this variability in carbon intensity be more fully considered when implementing the LCFS. Because large-scale commercialization of second-generation biofuels is at minimum 7-10 years in the future, we believe that methods developed to estimate the carbon intensity of corn-ethanol will serve as the standard for implementing a LCFS for all future biofuels.

The variability of corn-ethanol primarily arises from two sources: 1) the yield and input use efficiency of crop production, and 2) biorefinery energy efficiency and co-product use. Crop production requires appropriate state-level default values due to the significant variability in crop yields, energy use (primarily for irrigation), and nitrogen fertilizer application rates (see CARB presentation of BESS model; http://www.arb.ca.gov/fuels/lcfs/011708lcfs_unebraska.pdf). Based on state averages for crop yields and management, crop production represents 37 to 65% of total life-cycle GHG emissions, and this variation needs to be accounted for when estimating the carbon intensity of corn-ethanol from different biorefineries.

Likewise, energy efficiency and source of energy at the biorefinery can determine if the corn-ethanol production life-cycle is a net emitter of GHGs relative of gasoline, or provide GHG savings of up to 50%, according to recent GREET model calculations (Wang et al. 2007). Previous studies indicate that wet mills require more thermal energy on average than dry mills per unit of ethanol produced (Shapouri et al. 2004). Coal powered facilities have also been identified as class of ethanol plants deserving special attention due to higher emissions compared to natural gas powered facilities (Wang et al. 2007).

To better assess the fossil fuel efficiency of biorefineries in Nebraska and Iowa, we surveyed information from state regulatory agencies for natural gas powered dry mills. Current industry performance is significantly better than suggested by the baseline employed by CA-GREET at 36,000 Btu gal^{-1} (10.03 MJ L^{-1}) (http://www.arb.ca.gov/fuels/lcfs/greet_input.pdf) (Figure 1 and Table 1). Data from the Nebraska Department of Environmental Quality (NDEQ) shows that the industry also performed better than a recent EPA estimate of the efficiency of state-of-the-art systems (EPA-EEA 2006). Biorefineries not drying distillers grains (producing wet distillers grains) were most energy efficient (UNL-NDEQ WDG 2006 in Figure 1). Nine facilities in Iowa on average had a similar efficiency as facilities in Nebraska (see the BESS model, version 2008.3.0 at www.bess.unl.edu for further details).

Figure 1. Biorefinery Thermal Energy Efficiency:
Previous Estimates vs. Nebraska Survey (NDEQ)



Therefore, we suggest at least three categories for the assessment of fuel ethanol production in the LCFS protocol as described below and as summarized in Table 1:

1) Title V permitted facilities that are major pollution sources (e.g. 100 tons VOC/yr). This category will likely include all wet mills and coal powered facilities. In Nebraska and Iowa, all wet mills and coal facilities (totaling 3 out 12 in Nebraska, and 6 out of 19 in Iowa in 2006) are Title V permitted due to their high emissions levels.
2) Dry mills powered by natural gas are the largest class of existing ethanol plants, and the majority of industry expansion will occur in this class. In Nebraska and Iowa, 23 plants were in this class in 2006, representing 17% of US total production capacity in 2006.
3) Dry mills powered by natural gas, w/out dryers for DG (or biomass powered). This class represents the highest efficiency ethanol plants that are currently operating, and represents the vanguard of the industry. Biorefineries can feed wet co-products to cattle in high density areas, and do not need to dry distillers grains. Closed-loop facilities (e.g. Mead, Nebraska) use cattle manure to substitute purchased natural gas. Other ethanol plants also use co-products as an energy source to power the biorefinery (e.g. Corn Plus), or will use waste biomass (RFA 2008; Wang et al. 2007). Class III biorefineries are a small but growing group.

Table I. Suggested Classes of Corn-Ethanol Production Systems in the LCFS.

Class	I	II	III
Description	Title V (coal Dry Mill w/ dry DG)	Nebraska Avg. Natural Gas Dry Mills	Nebraska Avg. N.G. Dry Mills w/ Wet DG
Thermal Energy[†], MJ L-1	10.1	7.61	5.44
GWI[††], gCO2e/MJ	73.5	45.6	34.9
BESS Life-cycle GHG reduction compared to gasoline	20%	50%	62%

[†]Thermal energy efficiency for a coal powered dry mill (Class I) is from a recent estimate (EPA-EEA 2006). Efficiency for natural gas powered dry mills in Nebraska is a weighted-average (based on production) for nine ethanol plants, data derived from 2006 Annual Emissions Inventories from the Nebraska Department of Environmental Quality (NDEQ); four plants not drying distillers grains are included in a weighted-average for the Class III value.

[††]The Biofuel Energy Systems Simulator was used to calculate the emissions intensity of the fuel and the reduction relative to gasoline (BESS model, version 2008.3.0, available for download at www.bess.unl.edu; the above results in the three categories are from BESS scenarios #7, #4, and #5, respectively; other statistics are in the model for comparison).

2. The baseline year for the LCFS evaluation of corn-ethanol should be 2007 or later, because biofuel production capacity is increasing rapidly, and more efficient facilities are coming on line (2006 has been suggested as the baseline year). From 2006 to 2007, industry capacity increased from 4.9 to 6.5 billion gallons per year (BGY), and in January 2008, operational capacity was 7.9 BGY. Capacity under construction totals 5.5 BGY adding to a total industry capacity of 13.4 BGY over the next two years, which is nearly three times the 2006 capacity (RFA 2008). Before 2006, publicly available surveys of industry efficiency are derived from a 2001 survey (Shapouri 2004) and the 2002 cost-of-production survey for natural-gas powered dry mills conducted by the USDA (Shapouri and Gallagher 2005). With the dramatic increase in state-of-the-art refinery capacity soon to be on line, average industry energy efficiency will improve substantially, and a later baseline year will more accurately represent the industry; earlier years give a large bias towards much higher carbon intensity for corn-ethanol.

3. Default parameters in the GREET model or related models to evaluate the life-cycle GHG emissions from corn-ethanol require complete documentation and supporting references. Hundreds of parameters and supporting references are required to accurately evaluate corn-ethanol. The GREET model has undergone many revisions, and its supporting documentation that provides the source of all parameters is not yet available from a review of associated documentation on the GREET website from Argonne National Laboratory (http://www.transportation.anl.gov/software/GREET/). Furthermore, the current default values for GREET as posted on the CARB website lack appropriate references for identifying the sources and justifications for the suggested default parameters that are used (http://www.arb.ca.gov/fuels/lcfs/greet_input.pdf),

   Alternatively, the BESS model was developed for the accurate life cycle assessment of individual corn-ethanol production systems. The model was developed from a generic assessment framework reported in the journal *Science* (Farrell et al. 2006). The BESS model development was supported by a grant from the Western Governors' Association with funds from the U.S. Department of Energy, and administered by the Nebraska Energy Office. Detailed documentation of default input parameters and conversion efficiencies are given in the User' Guide for the BESS model; a summary report lists all input parameters and output metrics, and a complete emissions inventory is produced for assessment of the specified corn-ethanol life cycle (www.bess.unl.edu). We strongly believe that any model used as the basis for establishing a LCFS must have a similar degree of transparency and documentation as found in the BESS model.

4. Co-product credits have been shown to be important for accurately evaluating life-cycle GHG emissions from corn-ethanol (Farrell et al. 2006). Co-product distillers grains now make up a larger portion of cattle diets due to recent changes in feeding practices, displacing corn and urea in the diet (Klopfenstein, *in press*). Soybean meal has been priced out of the ruminant diet, and now largely goes to the swine, poultry, and dairy industries. In the BESS model, we have developed an accurate GHG crediting scheme for co-products based on these changes in feeding practices. Furthermore, the credit calculated by BESS is nearly four times larger than the credit given to co-products based on the GREET calculation (Table 2). A manuscript description of the co-product model in BESS is in preparation.

   We compared the available life-cycle models (GREET, EBAMM, BEACCON, and BESS) to determine why their results differ. Two parameters were most influential for determining the life-cycle GHG emissions intensity: 1) biorefinery energy efficiency, and 2) co-product GHG credits. By employing the most accurate industry statistics for biorefinery thermal energy efficiency and a more accurate co-product crediting scheme, natural gas powered dry mills were found to reduce GHG emissions compared to gasoline by 50-62% (BESS model), which is about two-fold greater than 24% reduction estimated by the GREET model (Table 2).

Table 2. Comparing Results from Different Life-Cycle GHG Emissions Models for Dry-Mill Corn-Ethanol Systems (gCO2e MJ^{-1})

Emissions	GREET	EBAMM	BEACCON	BESS (2)	BESS (4)	BESS (5)
Crop Production	32	37	32	29	35	34
Biorefinery	43	64	37	29	31	25
Co-Product Credit	-5	-25	-5	-19	-21	-24
Denaturant	-	-	6	-	-	-
Land Use Change	-	-	1	-	-	-
GWI	70	76	71	40	46	35
Gasoline	92	92	92	92	92	92
GHG reduction, %	24	17	23	56	50	62

GREET vs. 1.8: available from http://www.transportation.anl.gov/software/GREET/
EBAMM: vs.1.1-1: Farrell et al. 2006, Science, "Ethanol Today" avg. ethanol plant in 2001
BEACCON vs.1.1: available from www.lifecycleassociates.com; largely based on GREET
BESS (2): vs.2008.3.0: (Scenario #2) natural gas powered dry-mill (UNL Corn-Belt survey of new plants), Midwest avg. cropping; BESS (4): Nebraska Department of Environmental Quality survey data representing the average of nine natural gas powered dry-mills in Nebraska. BESS (5): NDEQ survey data representing the average of four natural gas powered dry-mills with wet DG. BESS has a variable co-product credit which is dependent on the emissions intensity of crop production and the composition of co-product types.

5. More thorough quantification of life-cycle GHG emissions associated with gasoline is needed to more accurately compared fossil fuels and biofuels. At least two sources deserve more attention: (1) the life-cycle GHG emissions associated with the implementation and operation of military security needed to protect shipping routes and infrastructure for Middle Eastern oil. Military costs associated with imported oil were estimated at $49 billion annually in the 1990s (Copulos 2003; Lugar 2006), and have since been revised upward to $138 billion annually (Copulos 2007); and (2) more thorough quantification of the GHG emissions associated with losses from extraction, transportation, and refining of petroleum (O'Rourke and Connolly 2003). In addition, since the vast majority of new petroleum currently under development comes from deep-water reserves and tar sands and oil shale, the carbon intensity of these fuels should be more heavily weighted in the LCFS for gasoline.

In summary, while biofuels are clearly not a silver bullet to replace liquid motor fuels, they can become a significant component of a comprehensive strategy for reducing reliance on high carbon-intensity fossil fuels. To fully exploit the potential of biofuels, we must ensure that the biofuel systems to be developed also contribute to mitigation of GHG emissions. An accurate and robust LCFS assessment method is critical to this goal.

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