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Response to Plevin: Implications for Life Cycle Emissions Regulations

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Response to Plevin: Implications for Life Cycle Emissions Regulations

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A robust dialogue concerning appropriate parameter values for life cycle assessment (LCA) models is necessary because regulation of life cycle greenhouse gas (GHG) emissions from biofuel systems will determine market access and government subsidies for biofuel producers.[1] Such a dialogue is also critical for creating more accurate LCA methods that will be accepted by scientists, industry, and the public. Plevin (2009) has identified multiple concerns with the life cycle emissions methodology employed in our previous analysis using the Biofuel Energy Systems Simulator (BESS) model (Liska et al. 2009), but only four alter our estimates substantially: (1) denaturant addition (+6.5 gCO_2e MJ^{-1}), (2) lime application rate and emission factor (+3.8), (3) upstream fossil fuel emissions (+2.3), and (4) electricity emission factor (+1.5), which sum to a +14.1 gCO_2e MJ^{-1} upward adjustment to our original estimate of 45.1 gCO_2e MJ^{-1} (Plevin 2009, Table 1). Plevin's other concerns total 1.5 gCO_2e MJ^{-1} in additional emissions, which does not substantially alter the GHG reduction estimates in BESS. Therefore, we address these four key issues [2] and show that, after correction for the relevant errors, life cycle GHG emissions from Midwest corn-ethanol are 47% less compared to gasoline, which is similar to the original BESS estimate of a 51% reduction (these estimates do not include indirect emissions, e.g., from land use change [Liska and Perrin 20091). This small reduction in the BESS estimate does not change the findings reported in our article (Liska et al. 2009).

Although Plevin (2009) used the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET)-BESS analysis metamodel (GBAMM), the Energy Resources Group (ERG) biofuel analysis metamodel (EBAMM) was the first to provide a consistent framework for LCA of GHG emissions from corn-ethanol by directly addressing the lack of standardization in previous studies (Farrell et al. 2006). As such, the EBAMM model reconciles differences among previous LCAs for corn-ethanol and provides a transparent framework and strong conceptual foundation for subsequent LCAs. The BESS model was built on the EBAMM framework, with the following modifications: (1)

more detailed calculations for emissions from corn production (updated yield and input data, including emissions of nitrous oxide [N_2O] from fertilizer, as defined by the IPCC [2006]), (2) more recent and comprehensive biorefinery data based on new surveys, (3) a more detailed coproduct credit calculation based on updated data and understanding of distiller's grains use in livestock feed, (4) IPCC emission factors, and (5) a user-friendly graphic interface. These changes were intended to improve the accuracy of estimated life cycle emissions from corn-ethanol.

The corn-ethanol industry has rapidly grown over the past decade, and one of the goals of our analysis was to document improvements in life cycle efficiency due to new infrastructure. In 2009, the U.S. ethanol industry has 12.5 billion gallons (47.3 billion liters) of installed annual production capacity, up from 1.8 billion gallons in 2001 (RFA 2009). Currently, 90% of installed biorefinery capacity is dry mills, and 89% of capacity is powered by natural gas (Cooper 2009). If one wants to determine the impact of infrastructure developments on life cycle emissions, the EBAMM model can provide an established independent assessment method relative to GREET, BESS, and GBAMM calculations. By applying industry survey data from Liska and colleagues (2009) to the EBAMM model, we obtain GHG emission values similar to those given by BESS. For example, when we replace the EBAMM biorefinery thermal energy input values for natural gas and coal (at 13.9 MJ per liter of ethanol in total, on the basis of data from a 2001 survey of wet and dry mills) with the natural gas efficiency values in BESS (at 7.7 MJ L^{-1}, on the basis of multiple independent surveys from 2006 [Liska et al. 2009]), the life cycle GHG emissions reduction from corn-ethanol in EBAMM rises from 18% to 55% compared to gasoline, for a net emissions intensity of 42 gCO_2e MJ^{-1}. This compares favorably with the BESS estimate of 45 gCO_2e MJ^{-1}, yet many other parameter changes were included in our estimate.

In the GBAMM comparison of the GREET and BESS models, the inclusion of gasoline denaturant at 4.7% of ethanol volume has the greatest impact on GHG emissions estimates in BESS. Plevin (2009) assumes the 4.7% inclusion rate is the industry average in 2006, In fact, this denaturant level was not reported in the RFA-Argonne survey (Wu 2008), and it therefore appears to be a speculative estimate. Federal law allowed this fraction to vary between 2% and 5%, but recent legislation now restricts denaturant to a maximum of 2% of ethanol volume for shipping to blenders (U.S. Congress 2008). After transport, ethanol is blended with more gasoline to reach the desired ethanol blend concentration, roughly 10% (E10) or 85% (E85) for use in vehicles.

Denaturant is added in accordance with federal regulations for beverage alcohol and is not an essential component of biofuel. For example, the Brazilian ethanol industry widely uses the anhydrous form. For Midwest average corn-ethanol in our previous BESS analysis (Liska et al. 2009), we did not include denaturant for three reasons: (1) Denaturant was not within the life cycle boundaries of corn-ethanol in the EBAMM model (Farrell et al. 2006), (2) survey data from biorefineries in Iowa and Nebraska for anhydrous ethanol yields and efficiencies were very similar to Midwest efficiencies for denatured ethanol production, and (3) the exact blending ratio was unknown and varies substantially. Furthermore, if one were to compare blended fuels (ethanol containing gasoline versus gasoline containing ethanol), as is done in the GBAMM model, the difference between the life cycle emissions from blended fuels would be less than for pure fuels. This is because the inclusion of denaturant in the life cycle of ethanol results in a higher GHG intensity (as Plevin [2009] has shown), whereas inclusion of ethanol in gasoline blends results in a lower GHG intensity (CARB 2009a; see the Version 2.0 and 2.1 updates for California Gasoline Blendstock, January 12, 2009, and February 27, 2009, respectively).

But the critical issue for tracking GHG emissions is the *inherent* GHG contribution of the life cycle of biofuel production versus that of gasoline. We argue that the LCAs of different transportation fuels should directly analyze the GHG emissions intensity of pure products on the basis of their sources: 100% petroleum-based gasoline in the form of reformulated blendstock versus 100% ethanol in anhydrous form. Conversely, Plevin (2009) and the California

Air Resources Board (CARB) are concerned with the composition of fuels imported into California.

When denaturant is removed from the life cycle of ethanol, some adjustment of biorefinery efficiencies for yield loss is necessary in the Midwest average scenario in the BESS model for the data we used. Because the RFA-Argonne survey was for denatured ethanol (Wu 2008), removal of this additional volume would reduce the yield of ethanol per unit of grain, increase the yield of coproduct per unit of ethanol, and increase the natural gas and electricity consumption per unit of ethanol. Whereas Plevin (2009) identified these parameter changes to result in a +3.1 $gCO_2e\ MJ^{-1}$ adjustment in GBAMM, calculated using the spreadsheet available as Supplementary Materials on the *JIE* Web site for the article by Liska and colleagues (2009), this adjustment (if for consistency we assume ethanol to be 4.7% by volume denaturant) is found to be +2.0 $gCO_2e\ MJ^{-1}$. The difference is due to the fact that the GBAMM model does not accurately represent the equations found in the BESS model concerning the coproduct credit.[3]

Plevin (2009) correctly identifies higher lime applications as a major GHG emission from corn-ethanol production that was underreported in our analysis. Updated Agricultural Resource Management Survey (ARMS) data from the U.S. Department of Agriculture for the Midwest show that the lime application rate was 477 kg $ha^{-1}\ yr^{-1}$ in 2005 (Beckman 2009); the rate used by Liska and colleagues (2009; 212 kg $ha^{-1}\ yr^{-1}$) was too low. Also, the IPCC emission factor for CO_2 from lime application was previously neglected, and we thank Plevin for pointing out this omission. Emissions from lime applications are a significant contribution to corn production GHG intensity, and Plevin's correction emphasizes the need for corn producers to minimize such applications when possible.

Plevin (2009) also suggests that the adjusted upstream fossil fuel emission factors used in BESS were conservative relative to those used in the GREET model. In BESS, life cycle GHG emissions from fossil fuels are based on direct GHG emission values from the IPCC, corrected for upstream energy use on the basis of GREET fossil fuel production efficiencies. We agree with Plevin that the IPCC should further research its emission factors to increase the accuracy of the estimates for the LCA of biofuel systems, and LCA in general. As we state below, the adjusted IPCC values we use are still less than GREET emission factors, with a difference of 2.3 $gCO_2e\ MJ^{-1}$ (as calculated by Plevin), because our adjustments do not account for other upstream emissions included in GREET. But an advantage to using the IPCC emission factors is that they are likely to be more consistent with international efforts to standardize biofuel LCA GHG emissions accounting (e.g., Roundtable on Sustainable Biofuels and the British Standards Institute [RSI 2008]). We use the IPCC emission factors in BESS because they have recently been reviewed and revised by a number of independent experts, and they can be straightforwardly applied (IPCC 2006). We are less confident about and familiar with the data-vetting process employed in the updating of GREET parameter values. In fact, the current version of GREET (Version 1.8b) represents an accumulation of numerous modifications that, in sum, have not undergone an explicit review by experts for each individual fuel pathway.

Plevin (2009) also identifies emissions from electricity as too low in BESS. We had calculated the GHG intensity for U.S. average electricity using data from the Environmental Protection Agency (EPA). Plevin used the same EPA data and the GREET model, which includes more parameters for upstream emissions, and his corrected value for the GHG intensity of electricity appears to be more accurate than the value we used.

We can now estimate the corrected GHG emissions intensity of corn-ethanol on the basis of the major relevant revisions suggested by Plevin (2009) using the Supplementary Materials spreadsheet from Liska and colleagues (2009). If we exclude emissions from 4.7% denaturant and keep IPCC upstream emission factors, the parameters changed in the BESS Midwest scenario include (1) adjustment of biorefinery yields and efficiencies for inclusion of denaturant; (2) lime application rate at 477 kg $ha^{-1}\ yr^{-1}$ and application emission factor for lime (12% of lime carbon [C] applied is lost as CO_2, as per the IPCC [2006]); and (3) an electricity emission factor that is representative of the Midwest life

cycle average (910 $gCO_2e\ MWh^{-1}$), as opposed to the nonlife cycle U.S. average (623 $gCO_2e\ MWh^{-1}$). Changing these factors raises the GHG intensity of Midwest corn-ethanol from 45.1 to 51.8 $gCO_2e\ MJ^{-1}$. (When we use GBAMM, include *all* of Plevin's adjustments except denaturant addition, and use an adjusted coproduct credit based on the three changes above, the recalculated value is 51.5 $gCO_2e\ MJ^{-1}$).[4] If one were to add emissions from denaturant (+4.5, i.e., 6.5 – 2.0), use GREET upstream fossil fuel emissions (+2.3), and add other minor additions raised by Plevin but not considered here (+1.5), this intensity would increase to 60.1 $gCO_2e\ MJ^{-1}$, which is essentially Plevin's adjusted value.

On the basis of the above analysis, we plan to release an updated version of the BESS model. In addition to changes for anhydrous ethanol, lime rate, and the electricity emission factor, we will increase the estimated average GHG intensity of 100% petroleum-based gasoline from 92 to 97.7 $gCO_2e\ MJ^{-1}$. This change reflects the inclusion of tar sands at 7% of U.S. average gasoline in 2007, on the basis of new petroleum statistics and new research into GHG emissions from tar-sands-derived gasoline (Liska and Perrin 2009). When we use this updated value for gasoline emissions and include the three changes in BESS on the basis of Plevin's (2009) suggestions as given above, life cycle emissions reductions for Midwest corn-ethanol decrease from 51%, as reported in our previous analysis (Liska et al. 2009), to 47%.

One of our goals in developing the BESS model for corn-ethanol LCA was to ensure that all parameters used had well-documented sources and that the underpinning assumptions were clearly stated. The fact that Plevin (2009) could critique the BESS model parameters and assumptions in such detail indicates that we achieved a degree of success in creating the desired transparency. It is now critical that LCA models used to regulate transportation fuels achieve a similar degree of transparency with regard to input parameters and assumptions and that the values employed accurately represent the industry as it functions today. In fact, both CARB and EPA plan to use the GREET model with extensive modification as the basis for regulating biofuels (CARB 2009b; U.S. EPA 2009). Unfortunately, the current LCA methodologies employed by both CARB and EPA do not state all primary assumptions and data sources used, and thus it would be impossible to rigorously evaluate and critique their GHG estimates with the same degree of rigor given to the BESS model by Plevin. A detailed critique of the lack of transparency in the use of the GREET model by CARB is provided elsewhere (Cassman and Liska 2009), and similar arguments can be made against the EPA's use of GREET in proposed LCA regulations. Therefore, in our view, the documentation of parameter values and data sources used in GREET by CARB and EPA does not meet ISO or EPA standards or U.S. federal law with regard to transparency and sufficient detail (ISO 1997; OMB 2002; U.S. EPA 2002).

Incomplete documentation of assumptions and data sources for the approximately 300 underlying parameters in corn-ethanol LCA of GHG emissions is not an acceptable standard to facilitate disclosure and clarity for regulatory purposes. In fact, the BESS model was specifically developed to encourage transparency and to support an open dialogue about the accuracy of parameter values used. It is essential that all values for primary data inputs used in state and federal LCA GHG regulations for both biofuels and gasoline are equally well documented and accessible and are representative of the systems evaluated.

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Notes

1. Life cycle GHG emissions regulations were implemented under the Energy Independence and Security Act of 2007 (U.S. EPA 2009) and the Low Carbon Fuel Standard of California 2007 (CARB 2009b).
2. This contribution was not formally peer-reviewed by *Journal of Industrial Ecology*.

3. The Supplementary Materials from Liska and colleagues (2009) must be used to accurately evaluate the impact of these parameter changes on GHG emissions due to linked equations in the coproduct model in BESS. Plevin (2009) also made an error in calculating the adjusted coproduct yield per unit of ethanol (see cell F44 in the Supplementary Materials on the Web; this cell is not included in Plevin's [2009] calculations).
4. To recalculate using GBAMM (on the basis of the spreadsheet provided as Supplementary Material on the Web for Plevin's [2009] article), remove denaturant (cell F61), increase the coproduct credit to –20 gCO_2e MJ^{-1} (cell F55; we determined this value from Liska et al.'s [2009] Supplementary Material by adjusting the parameters described in the text preceding this note), and increase lime to 477 kg ha^{-1} (cell F23).

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