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Greenhouse Gas Emissions from Biofuels

With the Congress considering an increase in the national mandate for ethanol in the nation's gasoline supply and presidential candidates touring Iowa and paying homage to the continued subsidization to turn corn into fuel, the United States is unlikely to turn away from policies and programs designed to exploit agriculture for energy generation.

Energy legislation would substantially increase the ethanol mandate and enact a host of other credits and incentives designed to expand production and use of biofuels. A principal justification offered for increasing the use of ethanol is that it results in less greenhouse gas emissions than petroleum-based fuels.

In our 2006 report, *Transportation Fuels from Biomass: An Interesting, But Limited Option*,[1] the George C. Marshall Institute concluded that conventional and unconventional oil reserves were adequate for many decades to come. Using the best available agricultural and processing technology, ethanol produced from corn fermentation contains about 36% more energy than the fossil fuel used to produce it. Since it is currently produced from corn, U.S. ethanol supply is limited to a few percent of the demand for gasoline. Ethanol currently enjoys a $0.51/gallon subsidy, but even with this subsidy, and current high oil prices, it is more expensive than gasoline.

Two different approaches, the Lifecycle Emission Model, a bottom-up approach developed by Delucchi and co-workers at the Institute of Transportation Studies at University of California, Davis;[2] and the inverse approach used by Crutzen, *et al*. (2007),[3] indicate that for U.S. corn cultivation, at least 3% of the nitrogen in fertilizer is converted to nitrous oxide (N_2O). Because a pound of N_2O has 296 times the greenhouse gas impacts of a pound of carbon dioxide (CO_2), N_2O emissions from corn cultivation are sufficient to eliminate the greenhouse gas benefit of using corn-derived ethanol as a transportation fuel.

Growing crops, processing them into biofuels, and using the biofuels for transportation involves a number of steps, each with a different greenhouse gas emission profile. Life cycle analysis (LCA) offers a comprehensive way of evaluating the emission from each of these steps and summing them into a total, and comparing that total with the total emission from other fuels options. A comprehensive LCA would consider the emissions associated with:

1. preparing land for growing crops,
2. growing and harvesting crops,
3. transporting the harvested crops to a processing plant,
4. converting the crops into biofuels,
5. transporting and distributing the biofuels,
6. using the biofuels, and
7. manufacturing and disposing of the vehicles that use the biofuels.

Completing a comprehensive LCA is a major undertaking, but two assumptions help to simplify the task.

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- Assume that land prepared for growing crops will be used for many decades. Therefore, on a unit of biomass basis, the emissions from this step will be small.
- Assume that biofuels will be used either in small amounts in blends with conventional fossil fuel-derived transportation fuels, or in flexible fuel vehicles. Therefore, there are essentially no differences in the emissions associated with vehicle manufacture and disposal across the different fuel options, and this source of emissions can be ignored when making comparisons.

If these simplifying assumptions are made, the following sources of emissions remain:

1. growing and harvesting crops,
2. transporting the harvested crops to a processing plant,
3. converting the crops into biofuels,
4. transporting and distributing the biofuels, and
5. using the biofuels.

The analogous emission sources for transportation fuels derived from crude oil are:

1. producing crude oil,
2. transporting the crude oil to a refinery,
3. refining crude oil into transportation fuels,
4. transporting and distributing the conventional transportation fuels, and
5. using conventional transportation fuels in vehicles.

This simplified comparison is often referred to as a well-to-wheels study.

For biofuels, well-to-wheel studies are complicated by significant, but poorly defined nitrous oxide (N_2O) and methane (CH_4) emissions from growing and harvesting crops. N_2O and CH_4 are powerful greenhouse gases. A pound of N_2O has 296 times the greenhouse gas impact of a pound of carbon dioxide (CO_2), and a pound CH_4 has 23 times the greenhouse gas impact of a pound of CO_2.[4] The ratio of the greenhouse gas impact of a pound of a greenhouse gas to that of CO_2 is known as its Global Warming Potential (GWP).

In evaluating the impact that the use of biofuels would have on U.S. greenhouse gas emissions, it is important to use only recent studies because both agricultural and biofuel technologies are changing rapidly. In particular, improvement in application of fertilizer, the major source of N_2O emissions, has significantly reduced the amount of fertilizer needed to produce a bushel of corn. Also, it is important to focus on U.S. studies. Biofuels are produced in other countries, but the agricultural resources and technologies used are different. Results from well-to-wheels studies in these countries can be used only if care is taken to adjust for the differences in agricultural practices.

Recent U.S. Well-to-Wheels Results for Ethanol from Corn

Two major U.S. efforts are underway to quantify well-to-wheels emissions from transportation fuel options:

1. the **G**reenhouse Gas, **R**egulated **E**missions and **E**nergy Use in **T**ransportation (GREET) Model developed by M. Wang and co-workers at Argonne National Laboratory, and
2. the **L**ifecycle **E**missions **M**odel (LEM) developed by M.A. Delucchi and co-workers at the Institute of Transportation Studies at University of California, Davis.

The GREET model has far more detail about vehicle manufacture and use than about fuel manufacture. It was designed to evaluate energy use differences between alternate vehicle and fuel combinations. Its application to biofuels GHG emissions issues seems to be an afterthought, and it is difficult to find detailed emissions data in either the model documentation or the various publications presenting GREET results. EPA recognizes these limitations and is in the process of updating GREET so that it will be more applicable to the evaluation of biofuels.

LEM is more focused on fuel and emission questions, but is still under development. Several appendices to the report documenting the model are still not available. Neither the model nor its results have been published in the scientific literature. The report presenting well-to-wheels information for biofuels is still a draft, but is available on Delucchi's website: ***www.its.ucdavis.edu/people/faculty/delucchi/index.php***

Wu, Wang and Huo (2006) used GREET to evaluate well-to-wheels greenhouse gas emissions for ethanol from corn fermentation.[5] These results are summarized below.

Fuel	2030 kg CO_2-eq Emissions/ MBTU (million BTU) of Transport Fuel
Reformulated Gasoline	98
E100 from Corn Fermentation	74 (-24%)

Delucchi provides the following well-to-wheels greenhouse gas emissions results from LEM:[6]

Fuel	CO_2-eq Emission kg/mi
Gasoline in a 26 mpg light-duty vehicle	0.48
E90 from Corn Fermentation	- 2%

A recent paper by Crutzen, *et al.* (2007) finds that 4 ± 1% of fixed nitrogen from agriculture is emitted as N_2O.[7] (Note: Crutzen is a Nobel Prize Laureate for his work on mechanism of stratospheric ozone depletion.) Crutzen, *et al.*, did not conduct a well-to-wheels analysis, but concluded that N_2O emissions from corn cultivation would negate any CO_2 savings from reduced fossil fuel use.

Why Do the Studies Get Different Results?

The major difference between the three studies is their estimate of the amount of nitrogen in fertilizer that is converted to N_2O. Based on expert judgment, GREET assumes that 2% of the nitrogen applied as fertilizer will be emitted as N_2O. While there is some year-to year variation, nitrogen fertilizer rates for corn production have been dropping steadily, from 612 grams/bushel in 1990 to 441 grams/bushel in 2005.[8] One gram of nitrogen generates 1.57 grams of N_2O. Applying a GWP of 296 to the 2005 values for nitrogen fertilizer use results in N_2O emissions of approximately 4100 g CO_2-eq/bushel.

$$CO_2\text{-eq} = 441 \text{ g N/bu x } 0.02 \text{ x } 1.57 \text{ g } N_2O\text{/g N x } 296 = 4099 \text{ g } CO_2\text{-eq/bu}$$

By comparison, LEM uses total N_2O emissions of approximately 6400 g CO_2-eq/bushel for corn production, and total land-use emissions from corn cultivation of 6725 g CO_2-eq/bushel.[9]

The difference between the GREET and LEM estimates of N_2O emission rates appears to result from the number of pathways considered for N_2O emission generation. The major pathways, which both models focus on, are:

- the conversion of the nitrogen in synthetic fertilizer to N_2O by microbial action,
- volatilization as NH_3 (ammonia), which can subsequently be oxidized to N_2O, and
- leaching as nitrate, which also can be oxidized to N_2O, via surface and groundwater.

Both models estimate roughly the same N_2O emission rate from these processes: GREET's value is the about 4100 g CO_2-eq/bushel calculated above, while LEM's value is 4260 g CO_2-eq/bushel.[10]

While N_2O emissions from synthetic nitrogen fertilizer appear to be the only pathway considered in GREET,[11,12] LEM considers eight additional pathways for N_2O emissions, which bring total N_2O emissions to about 6400 g CO_2-eq/bushel. This translates to the conversion of more than 3% of the nitrogen in fertilizer to N_2O.

LEM also considers seven additional pathways for land-use GHG emissions from corn cultivation, including CO_2 sequestration and release from soil. While the emission or sequestration rates from some of these pathways are about as large as the primary N_2O emission pathway, sequestration cancels most of the emissions, leaving a net effect of only 340 g CO_2-eq/bushel. LEM's total land-use emission rate from corn cultivation is 6725 g CO_2-eq/bushel.[13]

Crutzen, *et al*. (2006) used an inverse approach, apportioning the increase in atmosphere N_2O concentration to the various sources of N_2O emissions, and then evaluating the amount apportioned to agriculture as a fraction of the fixed nitrogen either applied as fertilizer or generated naturally by legumes.[14] The uncertainties in this approach ($\underline{+}$ 25%) are probably no greater than those in LEM.

N_2O Emissions From Biomass Fuels

Two different approaches, LEM's bottom-up approach and Crutzen, *et al*.'s inverse approach, indicate that for U.S. corn cultivation at least 3% of the nitrogen in fertilizer is converted to N_2O. These emissions are sufficient to eliminate the greenhouse gas benefit of using corn-derived ethanol as a transportation fuel. GREET's lower estimate of conversion of nitrogen to N_2O can be ignored because it is based on a simplistic assumption that does not consider all of the pathways by which nitrogen can be converted into N_2O.

GREET, LEM and Crutzen *et al*. consider greenhouse gas emissions from other processes for manufacturing biofuels. GREET is the most optimistic, showing an 85-89% reduction in greenhouse gas emissions for ethanol from cellulose.[15] These values are suspect because they are based on the same simplistic assumptions that were used for GREET's estimate of N_2O emissions from corn cultivation. LEM's estimate is lower than GREET's, but still shows about a 60% reduction in greenhouse gas emissions for use of ethanol from cellulose fermentation.[16] Crutzen, *et al*. show a net increase in greenhouse gas emissions for ethanol produced by the fermentation of cellulose from grass or crop residues, but the results are based on European conditions and may not be directly applicable to U.S. conditions.[17] The wide range of results presented in the three publications, and the fact that cellulose fermentation is still under development, make it difficult to draw any conclusion about these results. However, it is clear that further work is needed to define the greenhouse gas emissions from biofuels production.

Notes

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