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Comments On:
Richardson, M., and P. Kumar (2017), Critical Zone services as environmental assessment criteria in intensively managed landscapes, Earth's Future, 4, oi:10.1002/2016EF000517.

I reviewed the above referenced paper by Richardson and Kumar. The study sets out to conduct a comparative life cycle assessment (LCA) between two crop uses, corn food/feed and corn-based ethanol. I conclude that the paper is not written consistent with established life cycle methodology. Specifically, the paper does not follow guidelines set early on by ISO Standards including ISO 14044 on Life Cycle Assessment.

Section 4.2.3.7 and 4.5.3.4 of ISO 14044 provides direct references to data quality in comparative studies:

> Section 4.2.3.7: "In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results. Consequently, the scope of the study shall be defined in such a way that the systems can be compared. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundary, <u>data quality</u>, allocation procedures, decision rules on evaluating inputs, and outputs and impact assessment."

> Section 4.5.3.4: "If relevant to the LCA or LCI study the following questions shall be addressed. Are differences in <u>data quality along a product system life cycle</u> and between different product systems consistent with the goal and scope of the study?"

I offer the following explanation.

<u>Corn Ethanol LCA Inputs</u>

Richardson and Kumar utilize one key input data source to their ethanol LCA (page 3):

> "We base the U.S. LCA on *Ethanol Today*, a comprehensive dataset available for corn-based ethanol production, which synthesizes and consolidates six different corn-based ethanol LCA studies into one data set simulating today's production system and GHG emissions."

That paper by paper by Farrell et al. was written in 2006 before the build-up of the modern dry grind ethanol industry.[1] Since that paper is in itself a synthesis of datasets the underlying references are even older. Below, we have reproduced the energy balances from the Farrell paper.

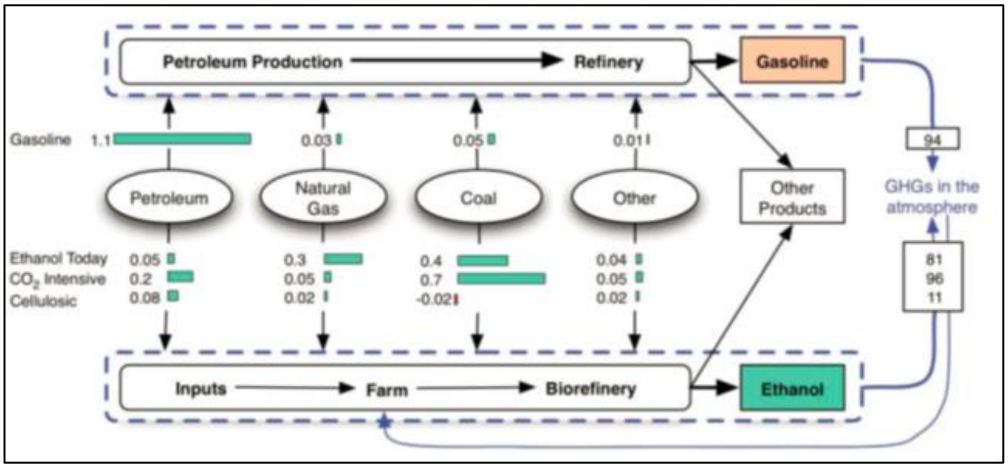

Figure reproduced from Farrell (2006) paper

Back in 2006 the Ferrell paper concluded that ethanol produced during that time frame would produce greenhouse gas emissions of 81 gCO_2/MJ compared to gasoline of 96 gCO_2/MJ, a 16% reduction. This analysis did not take into account indirect land use change (as that paper even predates the land use change discussion).

In fact, the following citations from the original Farrell paper illustrate the state of the data quality at the time:

> Farrell Page 507:" Moreover, despite large differences in net energy, all studies show similar results in terms of more policy-relevant metrics: GHG emissions from ethanol made from conventionally grown corn can be slightly more or slightly less than from gasoline per unit of energy"
>
> Farrell Page 507: "Relative to gasoline, ethanol produced today is much less petroleum intensive but much more natural gas– and coal-intensive. Production of ethanol from lignite fired biorefineries located far from where the corn is grown results in ethanol with a high coal intensity and a moderate petroleum intensity.

Because of the high coal share assumptions and low energy conversion assumption of biorefineries from the 2006 input data set it follows that Richardson and Kumar return the following results (Page 10):

> "Although it does not lose energy, the refinery barely yields positive total net energy. At around 3 MJ/m^2,the total net energy for ethanol production demonstrates how this process is merely a transfer of mechanical and chemical energy associated with the refinery inputs, mainly natural gas and coal, to potential chemical energy stored in ethanol"

[1] Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammenn (2006), Ethanol can contribute to energy and environmental goals, Science, 311(5760), 506–508. https://doi.org/10.1126/science.1121416.

We have published widely on efficiency improvements at corn ethanol plants since the data cited by Richardson and Kumar. Our publications are based on comprehensive and much more recent industry surveys published in 2010 and 2013 (after the build-out of the modern dry grind industry).[2,3,4] The industry's average performance (including plants selling dried and wet distillers grains) form those publications are summarized in the graph below. As can be seen while the average US gallon of ethanol required over 35,000 BTU the current average gallon (combination of all plants producing wet and dried distillers grains at different shares) utilizes much less energy.

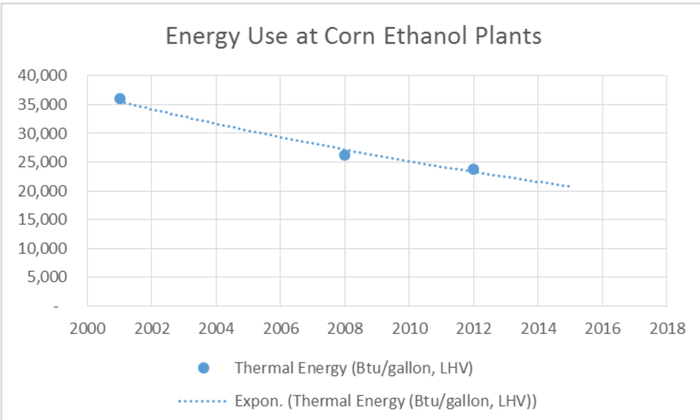

Figure showing energy utilization at ethanol plants

Soil Carbon LCA Inputs

Richardson and Kumar assess soil carbon according to the following (page 6 of the publication):

> "To avoid double-counting carbon that would already be stored in the soil in a natural system, the load for the soil carbon storage in kg/m^2 (*CCS*)was taken as the change of the measured daily average of organic carbon stored in the soil from that of the neighboring natural prairie parcel at the EBI site during the 2008 growing season [*Smith et al*., 2013]."

For years researchers have used well calibrated, spatially explicit biophysical soil carbon models to assess differences in soil carbon storage between different ethanol feedstocks and native landscapes. Importantly, carbon stock adjustments vary widely by geographic region, crop yields, climatic conditions, and soil textures.

The GREET model developed by Argonne National Laboratory, for example, maintains a continuously updated database of soil carbon adjustments from land use change resulting from biofuels production that has a county by county resolution for all major crop growing regions across the US. The latest

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[2] Mueller, Steffen. "US Corn Ethanol: Emerging Technologies at the Biorefinery and Field Level"; EESI Congressional Briefing. September 18, 2014. Washington, DC.

[3] Mueller, Steffen and Kwik, John. (2013). 2012 Corn Ethanol: Emerging Plant Energy and Environmental Technologies. University of Illinois – Chicago Energy Resources Center. Available online: http://www.erc.uic.edu/PDF/mueller/2012_corn_ethanol_draft4_10_2013.pdf.

[4] Mueller, S. "2008 National dry mill corn ethanol survey"; Biotechnol Lett DOI 10.1007/s10529-010-0296-7, May 15, 2010.

iteration of that database was released in 2016. Many peer reviewed publications support this approach.[5]

To base soil carbon comparisons on one parcel (from 2008 data) as done in Richardson and Kumar is highly simplified and ignores the current state of the science.

<u>Conclusion</u>

In summary, the Richardson and Kumar paper's outdated energy and soil carbon data use does not meet the data quality requirements set by ISO standards on Life Cycle Assessments. The paper's conclusion that their LCA results reflect a consistent comparison between corn feed/food and ethanol production "as technology stands now" is simply not supported.

The recently released USDA (2017) report states that corn ethanol shows greenhouse gas savings over gasoline of 43 percent including international land use change.[6] Excluding international land use change modeling by this author has shown that ethanol on average achieves a 50% reduction over gasoline.

These latest LCA findings reflect the current state of the ethanol industry with modern, natural gas fired plants which render the coal shares as well as the wet to dry grind shares cited Richardson and Kumar based on Farrell outdated. These latest USDA LCA findings also include the use of updated, spatially explicit biophysical soil carbon models.

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[5] Qin, Z., Dunn, J. B., Kwon, H., Mueller, S. and Wander, M. M. (2016), Influence of spatially-dependent, modeled soil carbon emission factors on life-cycle greenhouse gas emissions of corn and cellulosic ethanol. GCB Bioenergy. doi:10.1111/gcbb.12333

Qin, Z., Dunn, J. B., Kwon, H., Mueller, S. and Wander, M. M. (2015), Soil carbon sequestration and land use change associated with biofuel production: empirical evidence. GCB Bioenergy. doi: 10.1111/gcbb.12237

J. B. Dunn, S. Mueller, H. Kwon Land-use change and greenhouse gas emissions from corn and cellulosic, M. Wander, M. Wang. Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) Manual, ANL/ESD/12-5, Rev. 2, May 2014.

Ho-Young Kwon, Steffen Mueller, Jennifer B. Dunn, Michelle M. Wander; Modeling state-level soil carbon emission factors under various scenarios for direct land use change associated with United States biofuel feedstock production; Biomass and Bioenergy (2013), http://dx.doi.org/10.1016/j.biombioe.2013.02.021

Jennifer B Dunn, Steffen Mueller, Ho-young Kwon and Michael Q Wang; Land-use change and greenhouse gas emissions from corn and cellulosic ethanol; Biotechnology for Biofuels 2013, 6:51 doi:10.1186/1754-6834-6-51; Published: 10 April 2013

[6] United States Department of Agriculture; "A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol"; https://www.usda.gov/media/press-releases/2017/01/12/usda-releases-new-report-lifecycle-greenhouse-gas-balance-ethanol