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RE: Response to Proposed Renewable Fuel Standard (RFS) Program Standards for 2023–2025

INTRODUCTION

We at Environmental Health & Engineering (EH&E) are a multi-disciplinary team of environmental health scientists and engineers with expertise in measurements, models, data science, lifecycle analyses (LCA), and public health. Members of our team conducted a state of the science review of the carbon intensity (CI) for corn ethanol in the United States (U.S.), as well as a reply supporting our work[1,2] and a comprehensive assessment of the impacts of corn ethanol fuel blends on tailpipe emissions.[3,4] A primary conclusion from our past and present work is that the best available science suggests a well-to-wheel corn starch ethanol CI of 51 gCO_2e/MJ, representing an approximately 46% reduction in GHG emissions relative to the petroleum gasoline baseline.[5] Over the past several months, we have submitted public comments

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[1] Scully, M.J., Norris, G.A., Alarcon Falconi, T.M., and MacIntosh, D.L. 2021a. Carbon intensity of corn ethanol in the United States: state of the science. Environmental Research Letters, 16(4), pp.043001.

[2] Scully, M.J., Norris, G.A., Alarcon Falconi, TM., and MacIntosh, D.L., 2021. Reply to Comment on ‘Carbon intensity of corn ethanol in the United States: state of the science’. Environmental Research Letters, 16(11), p.118002.

[3] Kazemiparkouhi, F., Alarcon Falconi, T.M., Macintosh, D.L., and Clark, N. 2022a. Comprehensive US database and model for ethanol blend effects on regulated tailpipe emissions. Sci Total Environ, 812, pp.151426.

[4] Kazemiparkouhi, F., Karavalakis, G., Alarcon Falconi, T.M., Macintosh, D.L., and Clark, N. 2022b. Comprehensive US database and model for ethanol blend effects on air toxics, particle number, and black carbon tailpipe emissions. Atmospheric Environment: X, 16, 100185.

[5] Scully et al. 2021a.

to governmental agencies including EPA and the State of Washington.[6,7,8,9,10] We have also recently published a reply that shares feedback on a recent but questionable study of domestic land use change.[11] A theme present across all of our analyses is that, overall, the CI estimates for the indirect land use change (iLUC) associated with corn starch ethanol have been converging on lower values when considering the best available science and improved models. The latest analyses of the four commonly relied upon models—GTAP-BIO, FAPRI-CARD, MIRAGE, and GLOBIOM—show results that are 2-fold to 4-fold lower than the results from studies that use outdated models. Studies that do not incorporate the best available science suggest a strong link between biofuel expansion and iLUC; as we will discuss, recent empirical research does not support that relationship.

While we can gain preliminary insight from the convergent downward trend of recent studies with updated models, this is not to say that the estimates from all updated models and analyses should be weighted equally. In this letter, we provide an example of a process that EPA may consider to evaluate studies against a set of criteria and assign more weight to studies that reflect the best available science. In our Scully et al. 2021 analysis, we critically evaluated models and input data used in 26 CI land use change (LUC) values published from 2008 to 2020.[12] Our evaluation process is outlined in detail in the paper and within a supplemental table. Based on the best available science, we determined a credible range for LUC of -1.0 to 8.7 gCO2e/MJ with a central best estimate of 3.9 gCO2e/MJ. We continue to view that range and the central best estimate as credible based on best available science.

We submit this letter to EPA in response to the proposed Renewable Fuel Standard (RFS) Program: Standards for 2023–2025 and Other Changes (hereafter, "the Set Proposal")[13] and the associated Draft Regulatory Impact Analysis (DRIA)[14].

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[6] EH&E. 2022a. Comments on the 2022 Workshop on Biofuel Greenhouse Gas Modeling. 1 April 2022. Available within POET's comment at: https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0921-0047

[7] EH&E. 2022b. Climate Response to 2020, 2021, and 2022 Renewable Fuel Standard (RFS) Proposed Volume Standards. 3 February 2022.

[8] EH&E. 2022c. Comments on the New York State Climate Action Council Draft Scoping Plan. 1 July 2022.

[9] EH&E. 2022d. Comments on the draft Washington Clean Fuels Program Rule (Chapter 173-424 WAC). 25 April 2022.

[10] EH&E. 2022e. Comments on the Washington Clean Fuels Program Rule (Chapter 173-424 WAC). 31 August 2022.

[11] Alarcon Falconi, T.M., Kazemiparkouhi, F., Schwartz, B., and MacIntosh, D.L. 2022. Inconsistencies in domestic land use change study. Proceedings of the National Academy of Sciences, 119(51), p.e2213961119.

[12] Scully et al. 2021a.

[13] EPA. 2022a. Proposed Renewable Fuel Standard (RFS) Program: Standards for 2023–2025 and Other Changes. December 2022. EPA-HQ-OAR-2021-0427.

[14] EPA. 2022b. Draft Regulatory Impact Analysis (DRIA): RFS Standards for 2023-2025 and Other Changes. November 2022. EPA-420-D-22-003.

We write these comments in reply to EPA's invitation for comment at the end of section IV A of the Set Proposal (Federal Register page 80611). In addition to responding directly to the topics outlined by EPA, we present our perspectives on the downward trend of iLUC estimates as models have evolved to incorporate updated data and also look toward future implications. In looking forward, we summarize potential air quality and public health benefits associated with increased ethanol volumes.

To present these layers, we organize our report into three parts:

Part I: Discussion of iLUC Model Agreement for Corn Starch Ethanol

In the first section of this letter, we use our familiarity with LCA literature to further review and comment on the downward trend observed within estimates of the iLUC of corn starch ethanol. We begin with this theme because of the focus on iLUC during the Biofuel Workshop[15] and within the DRIA, plus the analysis we present provides background information useful to our responses to EPA. The trends observed in our investigation here are consistent with our past findings.

First, we provide a brief introduction to how researchers estimate the carbon intensity of biofuels, noting that iLUC is a large proportion of many older estimates. We then frame the basics of iLUC modeling and mention some of the assumptions and inputs that can be adjusted or selected by modelers.

We next demonstrate that refined iLUC modeling estimates are reliably producing results of similar magnitude, which are materially lower than the results of older, unrefined models. We share five examples that follow the trend of low iLUC estimates after adjustments to models. The results from these studies are of similar size despite being the product of models with different methods, designs, data, parameter values, and adjustments.

After confirming that recent models are reliably generating similar results, we address the uncertainty that surrounds iLUC estimates. We also review empirical observations to reveal that real-world data may not link biofuel production and LUC, supporting the lower iLUC estimates generated by refined and current models. Both of these considerations encourage the use of improved models to reduce uncertainty and tune results to observed land use statistics and trends.

Our findings further make the case that, across the board, corn starch ethanol iLUC estimates that rely on improved models of the four commonly relied upon models—GTAP-BIO, FAPRI-

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[15] EPA. 2022c. Workshop on Biofuel Greenhouse Gas Modeling. https://www.epa.gov/renewable-fuel-standard-program/workshop-biofuel-greenhouse-gas-modeling

CARD, MIRAGE, and GLOBIOM— are trending downward and are 2-fold to 4-fold lower than older results from EPA 2010 and California Air Resources Board (CARB) in 2015/2018. Model adjustments and data improvements, which tune results closer to reality, are responsible for the downward trend, which is observed even when different models and different adjustments are studied.

Part II: Response to EPA's Invitation for Comment

Our letter then directly replies to EPA's invitation for comment. We first commend EPA for using the approach of a literature review in order to make decisions without delay, based on the current state of the science. We also compare the range of results with the ranges identified in our Scully et al. 2021 paper.

We then look closely at the studies included in EPA's literature review. As the studies vary in quality, we recommend EPA define and apply criteria to assess the quality of each study and down-weight studies that are not as reliable. We propose an example of conditions EPA can use to determine which studies are most suitable for producing results that inform policy.

We then comment on how EPA should consider impacts over time, in terms of both adjustments of model results and looking toward the future. We also provide considerations for EPA around new research that is now available.

Part III: Additional Air Quality Benefits of Corn Starch Ethanol

To close the letter, we shift our discussion from carbon to other emissions and discuss ethanol's role in mitigating health effects from vehicle fuel use. In doing so, we review the best available science on the connection between ethanol, emissions, air quality, and health.

Our review of the literature and results from our emission studies demonstrate benefits of higher ethanol fuel blends. We first show that as the percentage of ethanol blended with gasoline increases, the content of aromatics (hazardous air pollutants) in the fuel decrease. Next, we explain that, to the extent that ethanol is a substitute for aromatics in fuel, higher ethanol fuel blends reduce particle matter (PM), benzene, toluene, ethylbenzene, m/p-xylene and o-xylene (BTEX), 1-3 butadiene, black carbon (BC), and particle number (PN) emissions with no concomitant increase in carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NOx), or acrolein emissions. Although ethanol fuel blends have higher acetaldehyde and potentially formaldehyde emissions than non-ethanol fuels, atmospheric measurements indicate that use of ethanol blends do not increase concentrations of acetaldehyde and formaldehyde above background levels in ambient air, indicating that emissions from other sources are larger than from light-duty vehicles.

We then summarize the findings of numerous studies that have shown that lower PM emissions result in lower ambient PM concentrations and exposures, which in turn are causally associated with lower risks of total mortality and cardiovascular effects. As cardiovascular disease is a leading mortality cause in the U.S., higher ethanol fuel blends offer a valuable opportunity to reduce PM concentrations and risk of adverse cardiovascular and respiratory outcomes (section 5). Higher ethanol fuel blends would also likely reduce benzene concentrations (an aromatic) and the associated cancer risk, since 40% of benzene emissions are attributed to the transportation sector and higher ethanol fuel content has lower aromatic emissions.

We also consider the disproportionate impact of air pollution on environmental justice communities (EJCs). EJCs are more likely to be situated near dense traffic corridors and may be exposed to higher concentrations of pollutants, in particular PM. An increase in the ethanol content of fuels can decrease EJCs' exposure to PM and the associated adverse health impacts. In closing this section, we present a brief case study for New York City.

PART I: DISCUSSION OF ILUC MODEL AGREEMENT FOR CORN STARCH ETHANOL

In Part I, we first share examples of refinements to modeling estimates for iLUC. These results show that studies that include model improvements tend to be 2-fold to 4-fold lower than the earlier estimates from EPA and CARB, even when studies rely on a variety of models. We then review empirical statistics that dispel the link that some older, unrefined models make between U.S. biofuel production and iLUC.

ESTIMATING THE CARBON INTENSITY OF BIOFUELS

As we discuss in Scully et al. 2021, the components of greenhouse gas (GHG) LCA for corn starch ethanol can be consolidated into emissions categories that include farming, fuel production, LUC, and tailpipe.[16] The carbon emissions contribution of each component is projected through the modeling of both measured and estimated data.[17] When the carbon intensity of each category is summed to reflect the total impact of corn starch ethanol, LUC emissions – in particular iLUC – can sometimes account for a large percentage of the total, or most of the total depending on the approach, especially for unrefined models.[18,19]

Policy decisions related to biofuel use are shaped by estimates for the CI value of corn ethanol. With iLUC representing a potentially large component of the CI of corn ethanol, it is important that iLUC estimates are credible and reflect the best available science. Agencies making policy decisions based on a review of multiple iLUC estimates should carefully investigate the credibility of each estimate and not apply equal consideration to estimates that fail to incorporate the best available science.

ILUC MODEL CHARACTERISTICS AND PARAMETERS

Agroeconomic modeling is often used to estimate the GHG emissions from iLUC caused by a given scenario.[20] This practice involves a range of assumptions and uncertainty, particularly given that some empirical data does not even support the notion that biofuel production is linked

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[16] Scully et al. 2021a.

[17] https://www.epa.gov/renewable-fuel-standard-program/lifecycle-analysis-greenhouse-gas-emissions-under-renewable-fuel

[18] Brandão, M., Azzi, E., Novaes, R.M., and Cowie, A., 2021. The modelling approach determines the carbon footprint of biofuels: the role of LCA in informing decision makers in government and industry. Cleaner Environmental Systems, 2, p.100027.

[19] Wicke, B., Verweij, P., Van Meijl, H., Van Vuuren, D.P., and Faaij, A.P., 2012. Indirect land use change: review of existing models and strategies for mitigation. Biofuels, 3(1), pp.87-100.

[20] Coordinating Research Council. 2012. Transportation Fuel Life Cycle Analysis: A Review of Indirect Land Use Change and Agricultural N2O Emissions. CRC Project. No. E-88-2.

with iLUC,[21] as we will discuss later in this letter. Models are presented with an assessment question: for a specified number of additional gallons of corn ethanol production (the ethanol shock) over a certain set of years (the amortization period), how much carbon is released due to indirect land conversion over the years that follow?

We understand that not all model runs address the same question, as the quantity of the ethanol shock, the time period studied, and the amortization period can change. But even when responding to the same question, models rely on different data sources and assumptions.

Answering this type of question requires the model to predict economic outcomes and their impact on land cover change, then incorporate a chosen emissions factor database which assigns carbon stock to various land. Each step requires assumptions that can impact the total output.[22]

Models capable of these simulations include computational general equilibrium (CGE) models, which include all economic markets, and partial equilibrium (PE) models, which consider the impact on only a subset of economic sectors.[23] Simulations can also be performed by integrated assessment models (IAMs) such as GCAM, though this model type is not discussed in this letter as studies we have identified that use GCAM aim to understand the causes of uncertainty instead of refining the values of CI estimates.[24,25] In addition to the scope of markets considered, models can vary by the number of regions used to divide the world map and the model's categorization of land cover type, as well as other characteristics.[26]

In the DRIA, EPA notes three primary categories that contribute to LUC: "1) acres of cropland expansion, 2) types of land displaced by cropland expansion, and 3) GHG emissions per acre of land use change."[27] Therefore, assumptions about inputs related to these elements, such as land cover data, land use data, carbon stocks, and emissions factors, can drive the outcome of models

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[21] IEA Bioenergy. 2022. Towards an improved assessment of indirect land-use change. Task 43 – Task 38. Report, October 2022.

[22] Khanna, M. and Crago, C.L., 2012. Measuring indirect land use change with biofuels: implications for policy. Annu. Rev. Resour. Econ., 4(1), pp.161-184.

[23] Earles, J.M. and Halog, A., 2011. Consequential life cycle assessment: a review. The International Journal of Life Cycle Assessment, 16(5), pp.445-453.

[24] Plevin, R.J., Beckman, J., Golub, A.A., Witcover, J., and O'Hare, M., 2015. Carbon accounting and economic model uncertainty of emissions from biofuels-induced land use change. Environmental science & technology, 49(5), pp.2656-2664.

[25] Mignone, B.K., Huster, J.E., Torkamani, S., O'ROURKE, P.A.T.R.I.C.K. and Wise, M., 2022. Changes in Global Land Use and CO2 Emissions from US Bioethanol Production: What Drives Differences in Estimates between Corn and Cellulosic Ethanol?. Climate Change Economics, 13(04), p.2250008.

[26] Unnasch, S., T. Darlington, J. Dumortier, W. Tyner, J. Pont and A. Broch (2014) CRC Report No. E-88-3. Study of Transportation Fuel Life Cycle Analysis: Review of Economic Models Used to Assess Land Use Effects. Prepared for Coordinating Research Council Project E-88-3.

[27] EPA. 2022b. DRIA.

that answer the same question, resulting in varying iLUC estimates. Other assumptions, such as price elasticity of demand, can also influence model results.[28]

MODEL RELIABILITY

Knowing that the selected parameters can influence the output, we next investigate the reliability of models, which here is defined as whether models reach similar results when offered the same assessment question. Most current iLUC estimates for corn starch ethanol, including models developed in the U.S. and Europe, fall within a relatively narrow range. As shown in Figure 1, these current estimates are considerably lower than findings published by EPA in 2010 and CARB in 2015/2018. The figure, which is based on updates to Figure 2 in Scully et al. 2021, includes iLUC estimates from the most current relevant and applicable modeling efforts in the U.S. (shown in blue) and in Europe (shown in red).[29] The four commonly relied upon models shown—GTAP-BIO, FAPRI-CARD, MIRAGE, and GLOBIOM—provide estimates that are lower than older modeling results. For reference, we also include USDA, Washington State, and Oregon State studies, which are based on review of primary LUC analyses. Results for GCAM are not included in Figure 1 because in Plevin et al. 2015, the prominent application of this model for corn starch ethanol iLUC, the authors report ranges of iLUC values and later explain that the ranges are not predictions but instead were generated to understand model sensitivity to selected parameters.[30] In that paper, the uncertainty analysis aims to determine the relative influence of individual parameter uncertainty on overall uncertainty, not reduce uncertainty.

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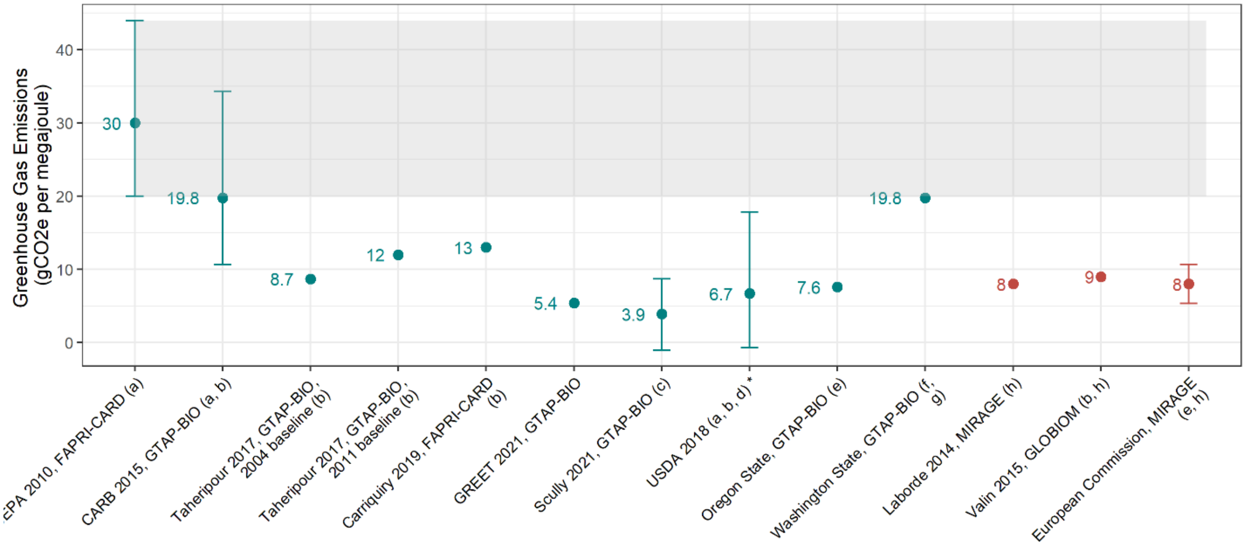
[28] California Air Resources Board (CARB). 2015 Appendix I: detailed analysis for indirect land use change

[29] Scully et al. 2021a.

[30] Plevin et al. 2015.



a Uses older versions of the model
b Indirect and direct land use change
c Partially based on a review of primary land use change analyses
d Based on a review of primary land use change analyses using multiple models
e Policy based on primary land use change analyses
f Proposed policy based on primary land use change analyses
g Based on CARB 2015 analysis
h Adjusted to a 30-year, amortization period
* Includes CARB 2015 LUC as the upper range

Figure 1 Comparison of EPA's iLUC estimates with relevant most recent studies from the U.S. (teal) and Europe (red)

Several publications also recognize this downward trend in iLUC estimates for corn starch ethanol over the last decade.[31,32,33,34] As we explore in the next section, this agreement can be attributed to model adjustments and data improvements, even when different models and different adjustments are studied.

MODEL AGREEMENT THROUGH MODEL ADJUSTMENTS AND DATA IMPROVEMENTS

Over time, models and their input data are updated to reflect the best available science, more granular regionalization, or a better understanding of economic relationships. Adjustments to

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[31] Lee U, Hoyoung K, Wu M, Wang M. 2021. Retrospective analysis of the U.S. corn ethanol industry for 2005-2019: implications for greenhouse gas emission reductions. Biofuels, Bioproducts & Biorefining, 15(5), pp.1318-1331.

[32] Dunn JB, Mueller S, Kwon H-Y and Wang MQ. 2013. Land-use change and greenhouse gas emissions from corn and cellulosic ethanol. Biotechnology for Biofuels, 6(1), pp.1-3.

[33] Taheripour F, Mueller S and Kwon H. 2021a. Appendix A: supplementary information to response to 'How robust are reductions in modeled estimates from GTAP-BIO of the indirect land use change induced by conventional biofuels?' Journal of Cleaner Production., 310, pp.127431.

[34] Carriquiry M, Elobeid A, Dumortier J and Goodrich R. 2019. Incorporating sub-national Brazilian agricultural production and land-use into U.S. biofuel policy evaluation. Applied Economic Perspectives and Policy, 42, pp.497-523.

models or their inputs impact iLUC estimates, and as discussed, current iLUC estimates are converging downward.

To show the effects of these improvements, we examine five studies where authors update their previous modeling of iLUC estimates for corn starch ethanol. For each scenario, we highlight the changes made and use a subsection to describe the reasoning for each adjustment. We then look at the result of the improvement to gauge how sensitive models are to various changes.

Example 1: EPA 2009/2010 (FAPRI and FAPRI-CARD)

Our first example considers updates EPA made to their modeling during the rulemaking process for the 2010 Renewable Fuel Standard (RFS2). EPA initially developed iLUC estimates for corn starch ethanol in the proposed RFS2 rule published in 2009. After review of public comments on the initial proposed rule, EPA updated its iLUC estimates for corn ethanol in the 2010 RFS2 final rule.[35] These changes were made possible by the availability of updated studies, including numerous improvements to the Food and Agricultural Policy Research Institute-Center for Agricultural and Rural Development (FAPRI-CARD) model that are detailed in the 2010 RFS2 final rule.[36]

Price-induced Crop Yields, Animal Feed Replacements, and Improved Land Use Data

Multiple updates were applied at once for the corn starch ethanol iLUC estimate EPA developed for their final RFS2 rule. These include, but are not limited to, the addition of price-induced crop yields, refined animal feed replacement ratios, and improved satellite data.

EPA first modeled with an early FAPRI edition, then used FAPRI-CARD when it became available in early 2010. The FAPRI-CARD model introduces yield price elasticity (YDEL) factors that allow crop yields to respond to changes in price, reflecting studies of this relationship.[37,38] These price-induced crop yield elasticities were not incorporated into the early FAPRI version.[39]

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[35] EPA. 2010. RFS2 RIA.

[36] EPA Federal Register 40 CFR Part 80 Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Final Rule. March 26, 2010.

[37] Miao, R., Khanna, M. and Huang, H., 2016. Responsiveness of crop yield and acreage to prices and climate. American Journal of Agricultural Economics, 98(1), pp.191-211.

[38] Taheripour, F., Zhao, X. and Tyner, W.E., 2017a. The impact of considering land intensification and updated data on biofuels land use change and emissions estimates. Biotechnology for biofuels, 10(1), pp.1-16.

[39] EPA. 2009. RFS2 DRIA.

The updated modeling also integrates research by Argonne National Laboratory which found that a pound of distillers grains with solubles (DGS) can replace 1.196 pounds of corn and soybean meal used for beef cattle and dairy cows, as DGS is more nutritious for these animals.[40] The new EPA analysis gradually increases the replacement rate for these specific animal feeds to reflect the improved understanding.

Additionally, multiple improvements were made to the land use data for EPA's 2010 analysis.[41] The updated EPA model relies on a newer version of the MODIS database containing more recent satellite data. Along with expanding the dataset from just 2001-2004 to now 2001-2007, the quality of the data improved from 1-kilometer resolution to 500-meter resolution. The FASOM model EPA used to determine domestic iLUC updated its list of land type categories to match the land types defined in the USDA National Agriculture Statistics Service (NASS) database, providing a more specific classification of land. Finally, FAPRI-CARD incorporated a module that divides Brazil into six regions to allow for more granular detail on the agricultural practices of each region, a feature not included in the old FAPRI model.

Table 1 shows that applying these changes reduced the iLUC estimate for corn ethanol by 50%, a difference of 30.24 gCO_2e/MJ. This comparison involves several adjustments at once, so individual components cannot be isolated to gauge their influence on the model. However, in general, refining the model to incorporate better data and better economic understanding significantly reduced the iLUC estimate.

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[40] Arora, S., Wu, M. and Wang, M., 2011. Update of distillers grains displacement ratios for corn ethanol life-cycle analysis (No. ANL/ESD/11-1). Argonne National Lab.(ANL), Argonne, IL (United States).

[41] EPA. 2010. RFS2 RIA.

Table 1 EPA's Central Estimates of International Land Use Change Associated with Corn Ethanol for Biofuel Over 30 Years, 2022[a]

Author	Study Year	Land Use Change Model	Model Adjustments	Central Estimate of International LUC Emissions (g CO_2e per MJ)
EPA	2009 (original RFS2 analysis)	FAPRI	NA	60.37[a]
	2010 (revised RFS2 analysis)	Updated FAPRI-CARD, including Brazil module[c]	- Price-induced crop yields - Animal feed replacements - Improved land use data	30.13[b]

EPA	U.S. Environmental Protection Agency
g CO2e per MJ	gram carbon dioxide equivalent emissions per megajoule
RFS	Renewable Fuel Standard
FAPRI	Food and Agricultural Policy Research Institute
NA	not applicable
FAPRI-CARD	Food and Agricultural Policy Research Institute-Center for Agricultural and Rural Development

a U.S. Environmental Protection Agency (EPA). Lifecycle Greenhouse Gas (GHG) Emissions Results Spreadsheets (30 October 2008). Docket: EPA-HQ-OAR-2005-0161.

b EPA 2010 Renewable Fuel Standard program (RFS2) regulatory impact analysis (RIA) Report No.: EPA-420-R–10–006 (Washington, DC: United States Environmental Protection Agency, Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency).

c Per RFS2 RIA (February 2010), Section 5.1.2.6.

Example 2: Carriquiry et al. 2019 (FAPRI-CARD)

Carriquiry et al.[42] present another example using FAPRI. The authors use a 2016 version of FAPRI-CARD that includes effects of demand for ethanol on the price and supply of corn and other agricultural products, multiple cropping, and conversion of pasture area in Brazil to cropland. Improvements in data made between the 2008 GHG Model and the 2016 GHG Model used to determine emissions factors include enhanced quality of spatial data and a refined relationship between crop yield.

Emissions Factors and Regionalization for Brazil

Carriquiry et al. present multiple iterations of model runs to allow for a helpful comparison. The authors start with a 2016 version of FAPRI-CARD that relies on a 2008 GHG model to determine emissions factors. Another model run is then completed with a 2016 GHG model instead of the 2008 GHG model; the updated model considers more crops and soil data with

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[42] Carriquiry et al. 2019.

greater spatial resolution.[43] In an additional iteration, the 2018 GHG model is used in conjunction with the Brazil module, mentioned during the discussion of EPA's model improvements, to present more granular information for six regions of the country.

As shown in Table 2, updating only the emissions factor data yielded a 22% decrease in an iLUC estimate, a difference of 5 gCO_2e/MJ. Combining the enhanced emissions factor data and additional detail for Brazil doubled this impact: the estimate reduced by 44%, or 10 gCO2e/MJ.

Table 2 CARD/FAPRI Central Estimates of Total Land Use Change Associated with Corn Ethanol for Biofuel Over 30 Years, ending in 2021/2022[a]

Author	Land Use Change Model	Emissions Factors	Central Estimate of LUC Emissions (g CO_2e per MJ)
Carriquiry et al.	FAPRI-CARD	2008 model	23.2
		2016 model without sub-national land use data and inputs for Brazil	18.2
		2016 model with sub-national land use data and inputs for Brazil	13.1

FAPRI-CARD	Food and Agricultural Policy Research Institute-Center for Agricultural and Rural Development
LUC	land use change
g CO2e per MJ	gram carbon dioxide equivalent emissions per megajoule

[a] Carriquiry, M., Elobeid, A., Dumortier, J. and Goodrich, R., 2019. Incorporating sub-national Brazilian agricultural production and land-use into U.S. biofuel policy evaluation. *Applied Economic Perspectives and Policy*, 42(3), pp.497-523.

Example 3: Taheripour & Tyner 2016 and Taheripour et al. 2017 (GTAP-BIO)

Taheripour et al.[44] describe updates to the land use module of GTAP-BIO and compare the results of multiple model runs by Taheripour and Tyner.[45] The various scenarios studied set two different years as the baseline year (2004 or 2011) and assigned two different volumes of ethanol shock. For a baseline year of 2004, the model reflects the introduction of 11.59 billion gallons (BG) of ethanol, starting with 3.41 BG and growing to 15 BG. The 2011 baseline scenario is assigned a 1.07 BG ethanol shock, growing from 13.93 BG to 15 BG. These two situations, therefore, ask different questions of the model. Below, we review how model adjustments impact the results for each of these two scenarios.

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[43] Dumortier, J., Hayes, D.J., Carriquiry, M., Dong, F., Du, X., Elobeid, A., Fabiosa, J.F. and Tokgoz, S., 2011. Sensitivity of carbon emission estimates from indirect land-use change. Applied Economic Perspectives and Policy, 33(3), pp.428-448.

[44] Taheripour et al. 2017.

[45] Taheripour F, Cui H, Tyner WE. 2016. An exploration of agricultural land use change at the intensive and extensive margins: implications for biofuels induced land use change. In: Qin Z, Mishra U, Hastings A, editors. Bioenergy and land use change, pp.19-37. American Geophysical Union (Wiley).

Regional Land Transformation Elasticities and Regional Land Intensification

Before model refinement, the 2004 and 2011 scenarios estimated iLUC due to corn ethanol at 13.4 gCO2e/MJ and 23.3 gCO2e/MJ, respectively.[46] Updates to the model included regional assignments of YDEL, which range from 0.175 to 0.325, instead of the 0.25 previously used by GTAP for all regions. This change was made to support regional observations in Food and Agriculture Organization (FAO) data from the United Nations. Data from FAO also revealed that land intensification allows for more efficient use of cropland; updates to the model are tuned to better consider land intensification. As displayed in Table 3, after incorporating the adjustments, the result for the 2004 scenario reduced by nearly half (a reduction of 48%), dropping by 11.3 gCO2e/MJ to 12 gCO2e/MJ. The 2011 scenario reduced by 35%, brought down by 4.7 gCO2e/MJ to 8.7 gCO2e/MJ.

Table 3 GTAP-BIO Central Estimates of Total Land Use Change Associated with Corn Ethanol Biofuel Over 30 Years. [a] Modeled greenhouse gas emissions were estimated with an older version of GTAP-BIO ("Untuned land use module") and a newer version ("Updated land use module") that has parameters tuned to observed changes in cropland and harvested area in the U.S., Brazil, and other regions of the world.

GTAP-BIO Model Version	GTAP-BIO Economic Database (Baseline Year)	Ethanol Expansion (billion gallons)	Land Use Change Emissions (g CO_2e per MJ)
Untuned land use module	Version 7 (2004)	11.59 BG (3.41 to 15 BG)	13.4
Updated land use module			8.7
Untuned land use module	Version 9 (2011)	1.07 BG (13.93 to 15 BG)	23.3
Updated land use module			12.0

GTAP-BIO	Global Trade Analysis Project-biofuel model
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies model
g CO2e per MJ	gram carbon dioxide equivalent emissions per megajoule
BG	billion gallons

[a] Taheripour F, Zhao X, Tyner WE. 2017. The impact of considering land intensification and updated data on biofuels land use change and emissions estimates. *Biotechnology for Biofuels* 10(1), pp.1-16.

Example 4: Laborde 2011 and Laborde 2014 (MIRAGE)

We next turn to an example from a European model, MIRAGE, which is studied by Laborde et al.[47] in a 2014 report for the European Commission (EC). The authors start with a model

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[46] Taheripour et al. 2017.

[47] Laborde, D., Padella, M., Edwards, R. and Marelli, L., 2014. Progress in Estimates of ILUC with MIRAGE Model. Publications Office of the European Union.

previously run by Laborde[48] for the International Food Policy Institute (IFPRI) in 2011, which estimates 10 gCO2e/MJ from iLUC associated with corn ethanol. Laborde et al. then incorporate various updates to the modeling via a piecemeal approach that allows us to review the relative impact of each adjustment.

Wheat Yield Adjustments

One change made between the models was to adjust wheat yield data to better align with projections generated by a collaboration between the Organization for Economic Co-operation and Development (OECD) and the FAO.[49] This modification resulted in no change to the iLUC estimate for corn ethanol.

Certain Crop Replacements Unavailable

Laborde et al. also considered an adjustment to crop displacement. The authors noticed that the 2011 study included significant expansion into land previously used for "other oilseeds." Laborde et al.[50] questioned how realistic it would be for cereal grains to replace "other oilseeds" such as olives. When preventing the model from displacing "other oilseeds," the corn ethanol iLUC estimate increased by only 1 gCO2e/MJ.

Food Production is Constant

Finally, Laborde et al. analyze the relationship between biofuel production and food consumption.[51] The authors note that agroeconomic models assume that additional biofuel demand simultaneously raises corn prices, increases the supply of corn, and lowers the demand of corn for other purposes, including food for humans and animals. With lower consumption of corn as food, the iLUC impacts of corn are reduced.

Laborde et al. were encouraged by the EC to add in an assumption that there is no reduction in food consumption due to crop price increase. When holding food consumption constant, the iLUC estimate for corn increased by 2 gCO2e/MJ to 12 gCO2e/MJ.

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[48] Laborde, D., 2011. Assessing the land use change consequences of European biofuel policies (pp. 1-111). ATLASS Consortium.

[49] Laborde et al. 2014 and Laborde 2011.

[50] Laborde et al. 2014 and Laborde 2011.

[51] Laborde et al. 2014 and Laborde 2011.

Combined Updates

Combining all three potential updates, the total corn ethanol iLUC impact is 13 gCO2e/MJ.[52] When the total is amortized to 30 years instead of 20 years, the estimated iLUC of 8 gCO2e/MJ fits well with the range of improved estimates shown in Figure 1.

Table 4 MIRAGE Central Estimates of Total Land Use Change Associated with Corn Ethanol for Biofuel Over 20 Years, ending in 2020[a,b]

Land Use Change Model	Author	Study Year	Data and Model Adjustments	Central Estimate of LUC Emissions (g CO_2e per MJ)
MIRAGE	Laborde	2011	No model/data adjustments	10
	Laborde et al.	2014	EU2020 wheat yields adjusted to OEC-FAO projections	10
			“Other oilseeds” no longer available as a crop replacement	11
			Food production is constant	12
			All adjustments combined	13

MIRAGE	Modeling International Relationships in Applied General Equilibrium
LUC	land use change
g CO2e per MJ	gram carbon dioxide equivalent emissions per megajoule

[a] Laborde, D., 2011. Assessing the land use change consequences of European biofuel policies. ATLASS Consortium. pp.1-111.

[b] Laborde, D., Padella, M., Edwards, R. and Marelli, L., 2014. Progress in Estimates of ILUC with MIRAGE Model. Publications Office of the European Union.

Example 5: Taheripour et al. 2022 (GTAP-BIO for ETJ SAF)

Our final example focuses on sustainable aviation fuel (SAF), which is an emerging opportunity for corn ethanol. Ethanol-to-jet (ETJ) fuel is an important area of study because of limits to using battery-electric or hydrogen solutions in aircraft.[53] The value of iLUC associated with SAF differs from ethanol used in road-based vehicles as the SAF value includes production-specific technology and variations in co-production options.[54]

In a 2022 presentation at the GTAP 25th Annual Conference on Global Economic Analysis, Taheripour et al. compiled iLUC values for multiple SAF pathways.[55] Slides from the presentation show results using two different emissions factors: AEZ-F and CCLUB. Within the

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[52] Laborde et al. 2014 and Laborde 2011.

[53] Zhao, X., Taheripour, F., Malina, R., Staples, M.D. and Tyner, W.E., 2021. Estimating induced land use change emissions for sustainable aviation biofuel pathways. Science of the Total Environment, 779, p.146238.

[54] Zhao et al. 2021.

[55] Taheripour, F., Steffen, M., Karami, O., Sajedinia, E., Emery, I. and Kwon, H., 2022a. Biofuels induced land use change emissions: The role of implemented emissions factors in assessing terrestrial carbon fluxes. 25th Annual Conference on Global Economic Analysis: Accelerating Economic Transformation, Diversification and Job Creation. June 8-10, 2022: Virtual.

emissions factors options, the presenters also compared results based on amortization period. This example further shows how model and data refinements can produce lower iLUC estimates, even for ETJ fuel.

Emissions Factors

In a reply to comments on our Scully et al. 2021 paper, we describe the reasons for utilizing emissions factors from CCLUB over AEZ-EF.[56] This includes that the CENTURY emissions factors informing the CCLUB model use USDA data to estimate the emissions factors for cropland pasture converted to cropland. In comparison, the AEZ-EF emissions factors make a simple, blanket assumption to set cropland-pasture-to-cropland emissions factors to one half the value of emissions factors for pasture-to-cropland.[57]

When looking at a 25-year amortization period for grain-based ETJ fuel, Taheripour et al. report iLUC of 24.9 gCO2e/MJ when using AEZ-EF emissions factors and 15.6 gCO2e/MJ when using CCLUB emissions factors.[58] This a reduction of 37%, or 9.3 gCO2e/MJ, from choosing the scientifically defensible emissions factors. Results are similar when reviewing the outcomes for the 30-year amortization period. The ETJ fuel iLUC estimate using AEZ-EF yields 20.8 gCO$_2$e/MJ, while the estimate relying on CCLUB is 38% lower (7.8 gCO$_2$e/MJ lower) at 13 gCO$_2$e/MJ.

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[56] Scully et al. 2021b.

[57] Taheripour, F., Mueller, S. and Kwon, H., 2021b. Response to “how robust are reductions in modeled estimates from GTAP-BIO of the indirect land use change induced by conventional biofuels?”. Journal of Cleaner Production, 310, p.127431.

[58] Taheripour et al. 2022a.

Table 5 GTAP-BIO Central Estimates of Total Land Use Change Associated with Corn Ethanol for Jet Fuel Over 25 or 30 Years, ending in 2020[a]

Author	Land Use Change Model	Emissions Factors and Amortization Period	Central Estimate of LUC Emissions (g CO_2e per MJ)[b]
Taheripour et al.	GTAP-BIO	AEZ-EF with 25-year amortization period	24.9
		CCLUB with 25-year amortization period	15.6
		AEZ-EF with 30-year amortization period	20.8
		CCLUB with 30-year amortization period	13

GTAP-BIO	Global Trade Analysis Project Biofuels Model
LUC	land use change
g CO2e per MJ	gram carbon dioxide equivalent emissions per megajoule

a Taheripour, F., Steffen, M., Karami, O., Sajedinia, E., Emery, I. and Kwon, H., 2022. Biofuels induced land use change emissions: The role of implemented emissions factors in assessing terrestrial carbon fluxes. 25th Annual Conference on Global Economic Analysis: Accelerating Economic Transformation, Diversification and Job Creation. June 8-10, 2022: Virtual.

B Grain ETJ SAF iLUC values

CONSIDERATIONS FOR ILUC MODELING

Though iLUC represents a significant component of many estimates for the carbon intensity of corn ethanol, this contribution is difficult to estimate and verify. Uncertainty surrounds the assumptions used in iLUC modeling, though empirical observations can be used to assess how well components of iLUC modeling results reflect reality. The two subsections that follow give recommendations for dealing with uncertainty and considering empirical observations.

Uncertainty

iLUC is particularly challenging to model because it is not possible to directly measure indirect land use change.[59] In addition, the models assume direct relationships exist between iLUC, economics, and human behavior, when in fact, national and international policy, immigration and emigration, prices of influential commodities such as oil and natural gas, severe weather events,

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[59] Woltjer, G., Daioglou, V., Elbersen, B., Ibañez, G.B., Smeets, E.M.W., González, D.S. and Barnó, J.G., 2017. Study report on reporting requirements on biofuels and bioliquids stemming from the directive (EU) 2015/1513.

climate change, and other factors have large influences on the value and use of land.[60,61,62,63,64] Within the domain of the iLUC models alone, researchers hold conflicting opinions on which factors are the most influential,[65,66,67,68,69] though these variable assumptions include yield responsiveness, ease of land conversion, crop substitution, and consumption elasticity.[70,71]

Given the unknown value of iLUC caused by corn ethanol, it is best practice to try to control this uncertainty by using estimates based on recent, updated models that rely on recent, adjusted inputs. Our April 2022 "Comments on the 2022 Workshop on Biofuel Greenhouse Gas Modeling," which were delivered to EPA, detail a strategy for moving forward with policy decisions despite uncertainty in iLUC estimates. We recommend following the example employed by existing literature reviews[72,73] to conduct a systematic review of existing estimates that carefully filters for credible results. This can be in concert with efforts to further refine iLUC model parameters. Our proposed approach for a literature review does differ from EPA's literature review in a critical way: we encourage the use of a filter or weighting scheme to prioritize the most reliable results, while EPA's range in DRIA Table 4.2.3.13-1 currently presents all well-to-wheel CI results without removing or downweighing inferior studies. The text of the DRIA does, however, address the variation in study quality by noting on page 145 that "We sometimes bring other models and empirical studies into the discussion as comparison points, but we otherwise set them aside to focus on models that are designed to evaluate

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[60] Shams Esfandabadi, Z., Ranjbari, M. and Scagnelli, S.D., 2022. The imbalance of food and biofuel markets amid Ukraine-Russia crisis: A systems thinking perspective. Biofuel Research Journal, 9(2), pp.1640-1647.

[61] Olesen, J.E. and Bindi, M., 2002. Consequences of climate change for European agricultural productivity, land use and policy. European journal of agronomy, 16(4), pp.239-262.

[62] Shrestha, D.S., Staab, B.D. and Duffield, J.A., 2019. Biofuel impact on food prices index and land use change. Biomass and Bioenergy, 124, pp.43-53.

[63] Park, S., Chapman, R. and Munroe, D.K., 2022. Examining the relationship between migration and land cover change in rural US: evidence from Ohio, United States, between 2008 and 2016. Journal of Land Use Science, 17(1), pp.60-78.

[64] McKay, D., 2003. Cultivating new local futures: Remittance economies and land-use patterns in Ifugao, Philippines. Journal of Southeast Asian Studies, 34(2), pp.285-306.

[65] Plevin et al. 2015.

[66] Taheripour et al. 2017a.

[67] Plevin, R.J., Jones, J., Kyle, P., Levy, A.W., Shell, M.J. and Tanner, D.J., 2022. Choices in land representation materially affect modeled biofuel carbon intensity estimates. Journal of cleaner production, 349, p.131477.

[68] ICAO. 2019. CORSIA Supporting Document: CORSIA Eligible Fuels – Life Cycle Assessment Methodology. June 2019.

[69] Transport Energy Strategies. 2021. Well-to-Wheels Carbon Intensity for Ethanol Blended Fuels. Report, September 2021.

[70] Khanna et al. 2012.

[71] Woltjer et al. 2017.

[72] Scully et al. 2021a.

[73] Lewandrowski J, Rosenfeld J, Pape D, Hendrickson T, Jaglo K, Moffroid K. 2019. The greenhouse gas benefits of corn ethanol – assessing recent evidence. Biofuels 11(3), pp. 361-375.

hypothetical scenarios and project future effects."[74] This statement by EPA should be incorporated into the CI results they present.

If we apply this logic to the studies captured in Figure 1 above, we see that improved models and adjusted data work to reduce uncertainty. Even when considering different models (GTAP-BIO, FAPRI-CARD, MIRAGE, and GLOBIOM), different parameter values, and different adjustments, the results from these studies converge downward. Eight of the eleven results range from 3.9 to 9 gCO_2e/MJ, with two at 12 and 13 gCO_2e/MJ and one at the CARB 2016 value of 19.8 gCO_2e/MJ. This is not to say that all models and analyses should be weighted equally; in Scully et al. 2021 we conducted a more in-depth evaluation of LUC studies.[75] We considered 26 CI LUC studies (including the U.S. based analyses shown in Figure 1) published from 2008 to 2020 and filtered those studies based on a critical evaluation of the underlying agroeconomic model, economic data year, YDEL, and incorporation of land intensification. We determined a credible range for LUC of -1.0 to 8.7 gCO2e/MJ with a central best estimate of 3.9 gCO2e/MJ. European studies were outside the scope of Scully et al. 2021, but Figure 1 shows that iLUC central estimates from these studies (8 and 9 gCO2e/MJ) fall within or very close to our identified range, which we still consider credible based on best available science. In Part II, we provide an example of a process that EPA may consider to evaluate studies against a set of criteria and assign greater weight to studies that reflect the best available science.

Empirical Observations

The case for using updated iLUC values is further supported when reviewing empirical data. An October 2022 report by the International Energy Agency Bioenergy Technology Collaboration Program (IEA Bioenergy) compares predicted trends from iLUC modeling with observed data.[76]

When looking at the empirical information in the IEA study, there is no indication of iLUC associated with biofuel demand that is suggested by the agroeconomic models. Specifically, the IEA report concludes that "Contrary to modelled relationships, statistics showed **no link** between expansion of U.S. biofuel production between 2005 and 2015 and corn production, corn export, or deforestation in Brazil."[77] These observations conflict with older, unrefined iLUC analyses that link increased biofuel demand with high iLUC estimates; the empirical data instead supports the lower iLUC results produced from updated models. Below, we highlight some of the evidence IEA finds in contradiction to the assumptions about biofuel demand.

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[74] EPA. 2022b. DRIA.

[75] Scully et al. 2021.

[76] IEA Bioenergy. 2022. (emphasis added).

[77] IEA Bioenergy. 2022.

First, we look at IEA's assessment of trends in animal production. IEA dispelled predictions that the U.S. livestock sector would be harmed by the increased designation of corn for ethanol. Data from FAO actually shows that U.S. meat production increased between 2005 and 2015. Though use of corn for animal feed did decline, DGS was made more available and was used as feed instead. DGS allowed for more efficient animal production, as it contains more proteins and key nutrients.

Next, IEA doubts a relationship between ethanol and corn price, which we have also questioned in prior letters. IEA calls attention to fluctuations in the price of corn, showing that the high corn prices in 2012 were likely associated with drought and that 2017 corn prices are close to the prices from 1996. In disconnecting ethanol production and corn price, IEA also reminds readers that simultaneous observations do not indicate causality.

This comparison with statistics shows that biofuel demand and iLUC are not necessarily linked as previously indicated by early modeling. In the future, carefully-constructed empirical analyses have the potential to further support improved estimates.

PART II: RESPONSE TO EPA'S INVITATION FOR COMMENT

On Federal Register page 80611 of the Set Proposal, EPA directly lists a handful of topics for comment. We address each in the sections that follow.

RANGE AND APPROACH

We begin with EPA's first call for input from the Set Proposal:

> EPA: We invite comment on the range of lifecycle GHG emissions impacts of the biofuels considered as part of this proposed rulemaking, and input on the proposed approach, or other potential approaches, for conducting a model comparison exercise for the final rule.[78]

We are pleased to see EPA has taken the approach of a literature review. With the breadth of existing literature available, we have previously recommended this type of method to EPA as it provides timely information needed for policy decisions.

While we applaud EPA's efforts to further understand the models and conduct their own new analysis using combined models, for the purposes of the current rule, there is enough information in the literature as it exists to support EPA's conclusion that corn starch ethanol offers significant GHG reductions. The current rule need not be delayed by the additional time needed to complete a comprehensive new modeling exercise.

That said, we do agree this new analysis is worthwhile, particularly to refresh the values for components such as farming and co-products that have become more efficient over time.

EPA should offer for public review and comment on the iLUC and CI numbers it intends to generate from its new modeling exercise before the values are finalized. This step of allowing scientific scrutiny keeps with the processes employed for the RFS2, where comments on the draft impact analysis were reviewed to allow adjustments to the analysis before the estimates became part of the final record used to make policy decisions.

Well-to-Wheel Emissions

Based on our 2021 systematic review, the best available science suggests that corn starch ethanol has a CI of 51 gCO_2e/MJ, representing an approximately 46% reduction in GHG emissions

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[78] EPA. 2022a.

relative to fossil fuels.[79] Our analysis identified a credible range for well-to-wheel emissions of 37.6 to 65.1 gCO2e/MJ. EPA's literature review, which used a broad lens to include a wider range of studies, found CI values ranging from 38 to 116 gCO2e/MJ. As we will discuss in the sections that follow, there is variation in the quality of the studies included in EPA's list we recommend EPA address this variation by assigning more weight to high-quality studies and down-weighting studies that do not meet a prescribed standard.

Upstream Emissions

When focusing only on upstream emissions, the studies included in the DRIA report a range of 9 to 51 gCO2e/MJ. Our Scully et al. 2021 study sits at the lowest end of this range. EPA notes on page 174 of the DRIA that our estimate includes a "relatively large" co-product credit for DGS. However, our co-product credit estimates are based on analyses that follow the ISO 14044 standard for LCAs and that consider that DGS sold as animal feed can displace urea, corn, and soybean meal in different quantities depending on which type of livestock is being fed.[80,81,82,83,84,85] We considered the emission co-product credit from DGS in our analysis and generated a central estimate of -12.8 gCO_2e/MJ with range of -13.5 to -12.1 gCO_2e/MJ based on analyses from ANL, CARB, and USDA using GREET that conform with the ISO 14044 standard for addressing co-product credits in LCAs.[86,87,88,89,90,91] GREET (the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model) is the most widely used tool and database over the prior 10 years for assessing GHG emissions from corn ethanol in the U.S.[92]

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[79] Scully et al. 2021.

[80] ANSI. Environmental Management - Life Cycle Assessment - Requirements And Guidelines ISO 14044:2006 specifies requirements and provides guidelines for 2020 [Available from: https://webstore.ansi.org/Standards/ISO/ISO140442006?gclid=Cj0KCQjwoJX8BRCZARIsAEWBFMJ8CasSwv-htj7sk3pm674E6GMXi4-kqpIIJ4duY2kWkJ-Wx-Dz1gsaAtBJEALw_wcB

[81] CARB. CA-GREET 2.0 Model 2015 [updated May 6. Available from: https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

[82] CARB. CA-GREET 3.0 Model 2019 [updated January 4, 2019. Available from: https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

[83] Argonne National Laboratory (ANL). GREET 1 2016. GREET 1 Series (Fuel-Cycle Model): Argonne National Library; 2016.

[84] ANL. GREET 1 2019. GREET 1 Series (Fuel-Cycle Model): Argonne National Laboratory; 2019.

[85] ANL. GREET 2020. GREET 1 Series (Fuel-Cycle Model): Argonne National Laboratory; 2020.

[86] ANSI. Environmental Management - Life Cycle Assessment - Requirements And Guidelines ISO 14044:2006 specifies requirements and provides guidelines for 2020 Available from: https://webstore.ansi.org/Standards/ISO/ISO140442006?gclid=Cj0KCQjwoJX8BRCZARIsAEWBFMJ8CasSwv-htj7sk3pm674E6GMXi4-kqpIIJ4duY2kWkJ-Wx-Dz1gsaAtBJEALw_wcB

[87] CARB. CA-GREET 2.0.

[88] CARB. CA-GREET 3.0.

[89] ANL. GREET 1 2016.

[90] ANL. GREET 1 2019.

[91] ANL. GREET 2020.

[92] ANL. GREET Model Platforms. Argonne National Laboratory (ANL); 2020 October 9, 2020.

Land Use Change

As reinforced in Scully et al. 2021 and Part I above, refined models and updated data that reflect the best available science report smaller CI contributions from LUC than the results of the initial LUC research. In Scully et al. 2021, we critically reviewed 26 LUC CI values published from 2008 to 2020 and evaluated the underlying agroeconomic model, economic data year, YDEL, and incorporation of land intensification. We also calculated an updated dLUC emission value using the 2020 ANL CCLUB model with CENTURY-based emission factors for characterizing soil organic carbon (SOC). In a reply to comments on our Scully et al. 2021 paper, we describe the reasons for utilizing emissions factors from CCLUB over AEZ-EF.[93] This includes that the CENTURY emissions factors informing the CCLUB model use detailed USDA data to estimate the emissions factors for cropland pasture converted to cropland. In comparison, the AEZ-EF emissions factors make a simple, blanket assumption that cropland-pasture-to-cropland emissions factors are one half the value of emissions factors for pasture-to-cropland.[94] Our calculations result in net sequestration of soil carbon when planting on land that is categorized as cropland pasture, a land type that is often rotated. We discuss this concept in our 2021 response to Spawn-Lee et al., and papers by Taheripour et al. and Claassen et al. further detail these observations and how models account for this sequestration.[95,96]

EVALUATING AND WEIGHTING STUDY RESLTS

This next section reflects the intersection of two prompts from EPA:

> EPA: We invite comment on the scope of this review as well as comment on the specific studies included in the review.
>
> EPA: Given the different types of modeling frameworks currently available, we also invite comments on the appropriateness of these different approaches for conducting lifecycle GHG emissions analysis and whether model results can or should be weighted if we choose a multi-model approach to assessing GHG emissions for purposes of RFS volumes assessment.[97]

The results of EPA's literature review include twenty results from nine studies, as summarized in Table 6 below. The list contains studies relying on both established models and other approaches. Even within these approaches, there is variation in the quality of studies. We

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[93] Scully et al. 2021b.
[94] Taheripour et al. 2021b.
[95] Taheripour et al. 2021b.
[96] Claassen, R., Carriazo, F., Cooper, J.C., Hellerstein, D. and Ueda, K., 2011. Grassland to cropland conversion in the Northern Plains: the role of crop insurance, commodity, and disaster programs (No. 1477-2017-4005).
[97] EPA. 2022a.

appreciate the scientific integrity of including a broad range of research, but when all studies are not of the same quality, they cannot be considered equally. For that reason, we recommend evaluating studies against a set of criteria and assigning more weight to studies that reflect the best available science. We provide a set of example criteria that EPA can consider incorporating into a study evaluation process based on the criteria discussed below. Our evaluation process outlined below is not intended to be definitive but rather provides an example EPA may consider for the construction of their own weighting system.

Table 6 Studies Considered in the Range of Well-to-Wheel CI Results for Corn Starch Ethanol from EPA's 2022 DRIA

Study	Agroeconomic Model	Result Considered
BEIOM (Avelino et al 2021)	BEIOM	BEIOM (2021)/Avg. Dry Mill
Brandão 2022	None	Brandão (2022)
CARB 2018	GTAP-BIO	CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/High LUC
		CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/Mean LUC
		CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/Low LUC
EPA 2010	FASOM-FAPRI	RFS2 rule (2010)/FASOM-FAPRI/NG Dry DDGS/High LUC
		RFS2 rule (2010)/FASOM-FAPRI/2022 Avg NG Dry Mill/Mean LUC
		RFS2 rule (2010)/FASOM-FAPRI/Adv. NG Dry Mill/Low LUC
GREET 2021	GTAP-BIO	GREET (2021)/GTAP-BIO+CCLUB/NG Dry Mill DDGS
		GREET (2021)/GTAP-BIO+CCLUB/Avg Plant
		GREET (2021)/GTAP-BIO+CCLUB/Gen 1.5 w/ DCO
		GREET (2021)/GTAP-BIO+CCLUB/NG Dry Mill WDGS
Lark et al 2022	None	Lark et al. (2022)/Other/RFS2 RIA
		Lark et al. (2022)/Other/CA-LCFS
		Lark et al. (2022)/Other/GREET
Lee et al 2021	GTAP-BIO	Lee et al. (2021)/GTAP-BIO+CCLUB/2019
Lewandrowski et al 2019	FASOM + GTAP-BIO	Lewandrowski et al. (2019)/FASOM+GTAP-BIO/2022 BAU
Scully et al 2021	GTAP-BIO	Scully et al. (2021)/GTAP-BIO+CCLUB/High LUC
		Scully et al. (2021)/GTAP-BIO+CCLUB/Central LUC
		Scully et al. (2021)/GTAP-BIO+CCLUB/Low LUC

Data adapted from: EPA. 2022d. Rulemaking Docket: Set Rule for the Renewable Fuel Standard Program, Supporting and Related Material. LCA Table.

Scope

In terms of the scope of studies, we appreciate the focus on recent research published after EPA's 2010 RFS2 analysis. Later in this section, we will encourage the inclusion of additional studies published since the RFS2. As mentioned, we do support EPA's investigation of new approaches in efforts to dial in estimates, but we again caution against relying heavily on untested methods.

Criteria for Evaluating Studies and Models

In order to include all studies without assigning equal weight to each, we recommend using criteria to evaluate the strengths and weaknesses of each study, similar to systematic reviews and meta-analyses where attributes are preidentified and works are rated by those attributes. Assessing each study against a standard will indicate which studies score higher or lower, thus providing a framework that allows the up-weighting of studies that are more reliable and/or down-weighting of studies that are less reliable.

In our April 2022 comments to EPA after the Biofuels Workshop, we defined "best available science" as research and tools that are "current, credible, transparent, complete, and capable of being reproduced." With these adjectives in mind, below we present some potential evaluation criteria for EPA's consideration. These criteria consider whether each study follows a generally **accepted approach**, utilizes **refined modeling tools**, uses **complete data**, and documents a **transparent process.** Our assessment method and the elements of our evaluation process outlined in the subsections that follow are not necessarily definitive but instead provide examples EPA may consider for the construction of their own weighting system.

Note that the assessment that follows is for example purposes only. The ratings shown are not necessarily a definitive indicator of quality or reliability but serve to highlight strengths and weaknesses of the studies presented. For simplicity, we assign a binary Yes/No in our evaluation. The allocation of a "No" does not indicate an absolute nonexistence of a trait but instead grades the study relative to the full set of studies under consideration. Likewise, a "Yes" does not indicate absolute existence of a trait and, again, reflects the study relative to the full set of studies considered. There are multiple potential approaches one could take to expand on this concept. For example, one could weight criteria differentially rather than equally as we have done. For instance, the refined modeling tools criterion could be given a relatively large weight to ensure prioritization of results from studies based upon the best available science.

Accepted Approach

Our first criterion considers whether the study uses a generally accepted approach. We start sorting studies using a line drawn by EPA in the current DRIA, which sets five models (GREET, GLOBIOM, GTAP-BIO, ADAGE, GCAM) apart from other modeling approaches. On page 119 of the DRIA, in Section 4.2.2, EPA explains that the five listed models, which were discussed at last year's Biofuels Workshop, can be relied on to "evaluate significant indirect emissions, including indirect land use change emissions."[98] Accepted models have been subject to replication and scrutiny that bolster their reliability. Other models and approaches, however, are mentioned in the DRIA "for informational purposes, but we do not think they meet our statutory requirements under the CAA to evaluate all significant direct and indirect emissions," as EPA notes on page 145.[99]

Studies relying on the models listed by EPA meet the criteria. Studies using FASOM/FAPRI or MIRAGE also meet the criteria, given that EPA and the European Commission have relied on results from these models to inform energy policy. Models using other approaches will currently not meet the criteria. While the models introduced above are those that are generally accepted today, other models may receive enough replication and scrutiny in the future to later enter this "accepted" category. Inversely, models which fall out of usage in the scientific literature may eventually be removed from this "accepted" category.

Refined Modeling Tools

A reliable agroeconomic model is necessary to incorporate market responses to changes in demand. The recent *Current Methods for Life Cycle Analyses of Low-Carbon Transportation Fuels in the United States* report by the National Academies of Science (NAS) explains that "As models used to assess induced LUC have been updated over the last decade, they have incorporated new elements to reflect agricultural practices in finer detail, including multi-cropping, new land categories such as idled or marginal cropland, and new forms of market mediated responses to biofuel demand."[100] As discussed in Part I, well-developed agroeconomic models will have been tested and refined to improve the accuracy of results and, thus, meet our evaluation criteria. Studies that use versions of models that have been superseded by more complete, better tuned models are no longer reflective of the best available science and do not meet our assessment criteria. In an effort to better evaluate newer models/approaches that have not had time to evolve, in this category we may also consider whether the study produces results that align with empirical data, as a rough strategy to assess tool performance.

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[98] EPA. 2022b. DRIA.

[99] EPA. 2022b. DRIA. Page 143

[100] National Academies of Sciences, Engineering, and Medicine, 2022. Current Methods for Life Cycle Analyses of Low-Carbon Transportation Fuels in the United States.

To highlight the utility of calibrating model results to real-world observations and data, we turn to other areas of research where this practice is employed. Keeping a focus on EPA, we will look at an air quality modeling tool the Agency developed called The Community Multiscale Air Quality Modeling System (CMAQ). Ren et al. 2022 describe how estimates for ozone concentrations modeled by CMAQ often differ from observed concentrations.[101] The authors, which include an EPA scientist, explain that "data fusion" can be used to improve model results by making adjustments based on observed data. This process is employed in von Stackelberg et al. 2013, where model outputs are scaled based on measured data; the team includes a researcher from EPA's National Exposure Research Laboratory (NREL).[102] EPA also used this process in the May 2020 Anti-backsliding Study to create "fused fields" for ozone and $PM_{2.5}$ CMAQ estimates "where the model output has been adjusted using monitored data."[103] The application of this process by EPA itself reinforces the merit of tuning models to empirical data.

Complete Data

The next criterion considers whether the study is missing the consideration of key data or if the research is otherwise incomplete. Studies with significant gaps in economic or geographic scope will not meet the criteria.

Transparent Process

Our final test asks if the study employs a transparent process. This criterion accounts for whether information needed to understand the methodology and reproduce the study is available. As noted in recommendations by NAS, "reporting one's data sources transparently can increase confidence in LCA results and enable reproducibility."[104] Not meeting the transparency criterion means that a paper has less publicly available backup information relative to the other studies in the set and likely cannot be reproduced from the information available to the public.

Assessing Included Studies

Below, we assess each study used in Figure 4.2.3.3-1 of EPA's DRIA using the four criteria. We first provide a chart summarizing whether studies meet each condition by indicating "Yes" or

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[101] Ren, X., Mi, Z., Cai, T., Nolte, C.G. and Georgopoulos, P.G., 2022. Flexible Bayesian ensemble machine learning framework for predicting local ozone concentrations. Environmental Science & Technology, 56(7), pp.3871-3883.

[102] von Stackelberg, K., Buonocore, J., Bhave, P.V. and Schwartz, J.A., 2013. Public health impacts of secondary particulate formation from aromatic hydrocarbons in gasoline. Environmental Health, 12(1), pp.1-13.

[103] EPA. 2020. Clean Air Action 211(v)(1) Anti-backsliding Study. EPA-420-R-20-008.

[104] NAS. 2022.

"No." The number of "Yes" responses are tallied to assign a score to each study, where a study receiving a higher score meets more criteria. We then provide additional explanation for each score, along with further commentary on the studies. Studies are introduced in alphabetical order.

BEIOM (Avelino et al. 2021)

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	No	Other approach
Refined Modeling Tools	No	Refinements are needed and authors note inconsistencies with observed data
Complete Data	No	Only considers the U.S. and does not include LUC
Transparent Process	Yes	Model is well documented and available for public use
Score:	1/4	

EPA includes results from the Bio-based circular carbon economy Environmentally extended Input−Output Model (BEIOM) reported by Avelino et al. 2021.[105] The BEIOM is based on an Environmentally-Extended Input-Output (EEIO) model called USEEIO, originally developed by EPA's NREL.[106] Substantial documentation and modeling files for the base USEEIO are available for public review and trial.[107] Avelino et al. complement this with extensive documentation detailing their process and the steps used to adapt the USEEIO model.

The BEIOM model is described in Lamers et al. 2021, to which all authors from Avelino et al. 2021 contribute, where it is noted that the BEIOM model only studies the economy and emissions of the U.S. and does not capture international interactions, rendering the data incomplete.[108] In closing their paper, Avelino et al. note refinements that are still needed, such as breaking down the U.S. into regions and addressing the conflicting environmental and economic assignment of impacts by international companies operating in the U.S., an issue intrinsic to EEIO databases.[109] Additionally, Lamers et al. 2021 note that the constant crop prices assigned by the BEIOM model do not match the elastic crop prices observed in the real world.[110] While

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[105] Avelino, A.F., Lamers, P., Zhang, Y. and Chum, H., 2021. Creating a harmonized time series of environmentally-extended input-output tables to assess the evolution of the US bioeconomy-A retrospective analysis of corn ethanol and soybean biodiesel. Journal of Cleaner Production, 321, p.128890.

[106] NERL. Bioenergy Models. BEIOM. https://bioenergymodels.nrel.gov/models/42/

[107] EPA. US Environmentally-Extended Input-Output (USEEIO) Technical Content. https://www.epa.gov/land-research/us-environmentally-extended-input-output-useeio-technical-content [Accessed 3 Feb 2023]

[108] Lamers, P., T. Avelino, A.F., Zhang, Y., D. Tan, E.C., Young, B., Vendries, J. and Chum, H., 2021. Potential socioeconomic and environmental effects of an expanding US bioeconomy: an assessment of near-commercial cellulosic biofuel pathways. Environmental Science & Technology, 55(8), pp.5496-5505.

[109] Avelino et al. 2021

[110] Lamers et al. 2021

the BEIOM model does build on the existing work of the USEEIO, further refinements are needed to improve this tool.

Brandão 2022

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	No	Other approach
Refined Modeling Tools	No	Inconsistencies with empirical data noted by IEA; no agroeconomic model; iLUC model still needs improvements
Complete Data	No	No economic model; key parameters not captured
Transparent Process	No	Model documentation is behind a paywall
Score:	0/4	

As described in EPA's DRIA, Brandão 2022 does not utilize an economic model.[111] This prevents the study from incorporating market effects and efficiencies stemming from demand-induced intensification. Instead, the researcher uses an alternate approach of making estimates based on differences in corn production for ethanol over production from 1999 to 2018.[112] This framework essentially ignores the intricacies and relationships of the demand for products and models only the estimated demand for land.[113]

To estimate iLUC, Brandão utilizes a modified version of the iLUC Club 2.-0 model developed by Schmidt et al. 2015.[114,115] Access to the model and its documentation lie behind a membership paywall of 3,500 EUR (approximately $3,756 USD),[116] hindering transparency and review by others. While we recognize that scientific papers often do require purchase to review, extensive documentation for the other models considered by EPA is available to the public at no charge. Di Lucia et al. 2019 provide a review of the iLUC Club model, in which the authors comment that while this model does incorporate increased yields, the intensification is "based on global past trends even though global past trends might not be fully representative of the specific conditions in the case study area."[117] This can be contrasted with updates to FAPRI/FASOM and GTAP-BIO that assign regional intensification factors to Brazil. Further, Schmidt et al. note in their

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[111] DRIA 2022

[112] Brandão, M., 2022. Indirect Effects Negate Global Climate Change Mitigation Potential of Substituting Gasoline With Corn Ethanol as a Transportation Fuel in the USA. Frontiers in Climate, 4, p.33.

[113] Brandão, M., 2022.

[114] Brandão, M., 2022.

[115] Schmidt, J.H., Weidema, B.P. and Brandão, M., 2015. A framework for modelling indirect land use changes in life cycle assessment. Journal of Cleaner Production, 99, pp.230-238.

[116] https://lca-net.com/clubs/iluc/

[117] Di Lucia, L., Sevigné-Itoiz, E., Peterson, S., Bauen, A. and Slade, R., 2019. Project level assessment of indirect land use changes arising from biofuel production. GCB Bioenergy, 11(11), pp.1361-1375.

paper introducing the model that “price-elasticity effects are not included.”[118] As such, we consider the data incomplete.

Brandão describes that “The iLUC component of the model is based on Schmidt et al. (2015)”[119] but does not clarify modifications made to the model nor which version served as the starting point. Early updates to the model, which was first released in 2011, served to improve functionality and make corrections.[120,121] Later updates were made to incorporate additional data,[122] such as accounting for all crops,[123] but Schmidt and DeRose note that there is still “potential for improving the regionalization of the market for land in order to improve the identification of final land use impacts.”[124] Further need for refinement is signaled by conflicts with empirical data identified in the 2022 IEA report we introduced in Part I of our letter.[125] For example, page 36 of the IEA report explains that ‘Projected changes in U.S. corn area were overstated in Brandão (2022). While corn harvested area increased by 2.2 million ha, U.S. crop area did not increase. It declined by nearly 6 million ha.” Given the improvements needed to regionalize the model and the inconsistencies with empirical data, this study does not meet our criteria for utilizing refined modeling tools.

CARB 2018

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	Yes	GTAP-BIO is a generally accepted model
Refined Modeling Tools	No	Updated GTAP-BIO model available
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Model runs are downloadable and well documented
Score:	3/4	

EPA uses the three results from the CARB 2018 CA-GREET 3.0 study, which relies on the widely accepted GTAP-BIO model to estimate economy-wide impacts domestically and internationally. However, per Table 38 of its supplemental documentation, CARB’s 2018 analysis copies the same LUC value determined from their 2015 CA-GREET 2.0 assessment

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[118] Schmidt et al. 2015.
[119] Brandão, M., 2022.
[120] https://lca-net.com/projects/show/indirect-land-use-change-model-iluc/
[121] https://lca-net.com/clubs/iluc/
[122] Schmidt, J. and De Rosa, M., 2018a. Enhancing Land Use Change modelling with IO data. Slides from presentation at the SETAC Europe 28th Annual Meeting, Rome 13-17 May 2018.
[123] Schmidt, J. and De Rosa, M., 2018b. Enhancing Land Use Change modelling with IO data. Abstract of presentation at the SETAC Europe 28th Annual Meeting, Rome 13-17 May 2018.
[124] Schmidt and De Rosa. 2018b.
[125] IEA Bioenergy. 2022.

without recalculating the results.[126] That LUC value was determined with an older version of GTAP-BIO that does not incorporate updates and adjustments researchers later made to the model.[127] While GTAP-BIO itself has undergone refinements, this old iteration of the model is outdated and does not meet the criteria for a refined tool. CARB's analysis is well documented, [128] and the customized GTAP-BIO model is available for download and replication after registering for a free account.[129,]

EPA 2010

Criteria	Criteria Met	Evaluation
Accepted Approach	Yes	FASOM/FAPRI is a generally accepted model
Refined Modeling Tools	No	Updated FAPRI model available
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Model documentation is available and analysis is well documented
Score:	3/4	

EPA's range of studies includes three results from EPA's 2010 analysis for the RFS2. The analysis uses FASOM to estimate domestic LUC and FAPRI to estimate international LUC by modeling across food and agricultural sectors. Though all resources are not compiled in one location due to the model changing home universities, the FAPRI model used for international LUC has solid, publicly available historical documentation, mostly recorded in a repository managed by the University of Missouri.[130,131,132] researchers at Iowa State's Center for Agricultural and Rural Development (CARD) provided detailed documentation specific to EPA's analysis[133] The regulatory impact analysis for EPA's 2010 RS2 also provided ample description of the modeling completed using FASOM and FAPRI.[134]

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[126] CARB. 2018. CA-GREET3.0 Supplemental Document and Tables of Changes. Available from: https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation

[127] CARB. 2015. Staff report: calculating carbon intensity values from indirect land use change of crop-based biofuels. Available from: https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation

[128] CARB. 2015. Detailed Analysis for Indirect Land Use Change. Available from: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/iluc_assessment/iluc_analysis.pdf

[129] GTAP. 2014. GTAP Resources: CARB 2016 September Model. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4577

[130] University of Missouri. FAPRI-MU Reports. https://www.fapri.missouri.edu/publications/reports/

[131] Meyers, W.H., Westhoff, P., Fabiosa, J.F. and DJ, H., 2010. The FAPRI global modelling system and outlook process. Journal of international agricultural trade and development, 6(1), pp.1-19.

[132] FAPRI. 2004. Documentation of the FAPRI Modeling System. FAPRI-UMC Report # 12-04.

[133] CARD. 2009. An Analysis of EPA Renewable Fuel Scenarios with the FAPRI-CARD International Models. Available from: https://www.regulations.gov/document/EPA-HQ-OAR-2017-0655-0093

[134] EPA. 2010. Renewable Fuel Standard program (RFS2) regulatory impact analysis (RIA) Report No.: EPA-420-R–10–006

The version of FASOM/FAPRI used in the EPA's RFS2 analysis has since been refined, making EPA's analysis outdated. This is explicitly acknowledged by EPA throughout Section 4.2.1.2 of the 2022 DRIA, including an acknowledgement on page 118 that "our previously relied on biofuel GHG modeling framework is comparatively old and an updated framework is needed."[135]

Like the 2015 CARB study, the EPA 2010 result is grounded in an accepted model and good processes but falls short by not incorporating the latest updates. These studies both receive a 3/4 score under this example framework where all criteria are weighted the same. However, we must highlight that these analyses have been replaced by studies that meet the 3 criteria EPA and CARB meet but also use better refined models.

GREET 2021

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	Yes	GTAP-BIO and GREET are generally accepted approaches
Refined Modeling Tools	Yes	Utilizes updated model
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	GREET datasets are publicly available and GTAP-BIO is well documented
Score:	4/4	

EPA reports four results using ANL's GREET, which uses GTAP-BIO for LUC scenarios. GREET is a trusted tool that is updated annually to incorporate current information.[136] Updates to GTAP-BIO are chronicled in detail and available for review on the developer's website.[137,138,139,140] Members of the public are able to conduct limited replication of GTAP-BIO model runs with a free account.

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[135] EPA. 2022b. DRIA.

[136] ANL. 2021. Summary of Expansions and Updates in GREET 2021.

[137] GTAP. GTAP Research: Energy. https://www.gtap.agecon.purdue.edu/models/energy/default.asp

[138] Taheripour, F., Birur, D., Hertel, T., & Tyner, W. 2007. Introducing Liquid Biofuels into the GTAP Data Base (GTAP Research Memorandum No. 11). Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=2534

[139] Taheripour, F., & Tyner, W. 2011. Introducing First and Second Generation Biofuels into GTAP Data Base version 7 (GTAP Research Memorandum No. 21). Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3477

[140] Taheripour, F., Pena-Levano, L., & Tyner, W. 2017b. Introducing first and second generation biofuels into GTAP 9 Data Base (GTAP Research Memorandum No. 29). Purdue University, West Lafayette, IN:

As explained in the 2021 annual documentation, this recent version of GREET has been refined with "updates in both corn farming activities (e.g., corn grain yield, fertilizer/energy inputs) based on the data from the United States Department of Agriculture (USDA) and corn grain ethanol production (e.g., ethanol yield and energy inputs) based on industry biorefinery benchmarking data."[141]

Lark 2022

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	No	Other approach
Refined Modeling Tools	No	A new model that has not been tested; conflicts with empirical data
Complete Data	No	Only looks at domestic LUC; exclusion of years when corn price trend does not align with ethanol production trend; unsupported baseline
Transparent Process	No	Study is not reproducible and all information is not made available
Score:	0/4	

In their 2022 paper,[142] Lark et al. present a new approach that has not been tested. The study is not considered complete as it only looks at U.S. domestic LUC. The authors added their partial results to estimates for non-domestic-LUC components generated by EPA, CARB, and GREET.

Further, the authors provide only an incomplete repository of their data and do not provide the models for others to examine and test. As we note in our Biofuels Workshop comments, Lark 2022's characterization of corn price and demand does not match empirical data, nor does the crop rotation data used match USDA data.[143]

Global Trade Analysis Project (GTAP). Retrieved from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5172

[141] ANL. 2021. Summary of Expansions and Updates in GREET 2021.

[142] Lark, T.J., Hendricks, N.P., Smith, A., Pates, N., Spawn-Lee, S.A., Bougie, M., Booth, E.G., Kucharik, C.J. and Gibbs, H.K., 2022. Environmental outcomes of the US renewable fuel standard. Proceedings of the National Academy of Sciences, 119(9), p.e2101084119.

[143] EH&E. 2022a. Comments on the 2022 Workshop on Biofuel Greenhouse Gas Modeling. 1 April 2022. Available within POET's comment at: https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0921-0047

Aside from failing to meet the criteria above, the Lark et al. study has additional flaws, as noted in our response to the paper,[144] ANL's critiques,[145,146] and USDA's comment on the paper.[147] After extensively evaluating the details throughout a series of comments with the authors of Lark et al., researchers at ANL conclude that "we find that the Lark et al.(a) paper is more problematic than what we initially evaluated to be the case."[148]

EPA itself strongly critiqued the Lark et al. 2022 study in its June 2022 response to comments on the 2020-2022 RFS volumes.[149]

On page 208, EPA comments on a fundamental issue with the paper:

> "Notably, the study does not analyze the impacts of this rulemaking or even the use of renewable fuels during the timeframe for this rule (2020-2022). Rather the study addresses the implementation of the RFS program from 2008-2016. But even for those years, the study simply assumed that the RFS is the cause of all of the historical increases in ethanol production and thereby attributed all of the downstream environmental impacts of ethanol production to the RFS program. However, that assumption is incorrect as it ignores the other factors have contributed to the increase in corn ethanol use and production over time, of which the RFS was only one factor… Indeed, the authors of the study recognize this problem…However, the authors did not go on to assess the extent to which the RFS program as opposed to these other factors contributed to increases in ethanol production or associated environmental impacts. Thus, while the impacts from agricultural practices such as fertilizer use on water and soil quality are observable and measurable, the degree to which those impacts can be causally attributed to the RFS program or this RFS rule is unclear."

EPA's points highlight that Lark's study cannot determine impacts from the RFS, contrary to what the title of Lark et al.'s study may lead readers to believe.

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[144] Alarcon Falconi et al. 2022.

[145] Taheripour, F., Mueller, S., Kwon, H., Khanna, M., Emery, I., Copenhaver, K., Wang, M. and CropGrower, L.L.C. 2022b. Comments on "Environmental Outcomes of the US Renewable Fuel Standard".

[146] Taheripour, F., Mueller, S., Kwon, H., Khanna, M., Emery, I., Copenhaver, K., Wang, M. and CropGrower, L.L.C., 2022c. Response to comments from Lark et al. regarding Taheripour et al. March 2022 comments on Lark et. al. original PNAS paper.

[147] USDA. 2022. Technical Memorandum: Review of Recent PNAS Publication on GHG Impacts of Corn Ethanol. Available from: https://www.usda.gov/sites/default/files/documents/USDA-OCE-Review-of-Lark-2022-For-Submission.pdf

[148] Taheripour et al. 2022c.

[149] EPA. 2022e. RFS Program: RFS Annual Rules – Response to Comments. Available from: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P101562X.pdf

Lee et al. 2021

Criteria	Criteria Met	Evaluation
Accepted Approach	Yes	GREET and GTAP-BIO are generally accepted approaches
Refined Modeling Tools	Yes	Utilizes updated GTAP-BIO
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Models are well documented
Score:	4/4	

Lee et al. 2021 is another study using recent GREET, with "results from the improved GTAP versions" informing the LUC estimates.[150] As discussed, these updated versions of GREET and GTAP-BIO are key models identified by EPA and have solid documentation and scope. Lee et al.'s study advances estimates by incorporating further refinements to the corn farming and ethanol production processes by analyzing energy efficiency improvements in both sectors.

Lewandrowski et al. 2019

Criteria	Criteria Met	Evaluation
Accepted Approach	Yes	FASOM and GTAP-BIO are generally accepted approaches
Refined Modeling Tools	Yes	Purpose is to refine EPA's 2010 analysis; incorporates calibrated GTAP-BIO results
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Models are well documented
Score:	3/3	

The purpose of Lewandrowski et al.'s paper is to improve EPA's 2010 RFS2 analysis based on more recent information by using GTAP-BIO for the international LUC component.[151] Table 6 of Lewandrowski et al. 2019 shows that LUC emissions estimates are generated by averaging results from multiple runs of GTAP-BIO, including two results from a 2013 GTAP-BIO scenario that have been calibrated to observed data.

Adding Lewandrowski HEHC Case

We also encourage EPA to give consideration to the high efficiency-high conservation (HEHC) estimate by Lewandrowski et al. The HEHC estimate incorporates opportunities for emissions

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[150] Lee et al. 2021.
[151] Lewandrowski et al. 2019.

reductions in the ethanol production process, including prioritizing improved farming technology.[152] This result makes tangible the potential GHG reduction benefits of implementing technological advances and sustainable practices. EPA's Karl Simon included the result from Lewandrowski et al.'s HEHC case the Biofuels Workshop presentation titled "GHG Biofuel Modeling in the U.S.: Summary of the RFS statutory Requirements and Future Needs."[153]

Scully et al. 2021

Criteria	Criteria Met	Evaluation
Accepted Approach	Yes	GTAP-BIO is a generally accepted model
Refined Modeling Tools	Yes	Relies on updated versions of GTAP-BIO
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Study approach is reproducible and GTAP-BIO is well documented
Score:	4/4	

EPA reports the central estimate and the low and high values of the range from our Scully et al. analysis. Our paper is a limited topical review which evaluates, filters, and combines components of estimates relevant to U.S. policy to determine a credible range of CI intensity for corn starch ethanol.[154] Our process is outlined in detail within a supplemental table and our review filters for studies using updated versions of the accepted, well-documented GTAP-BIO model. Specifically, the LUC analyses we incorporate into our average, along with our own calculations using GREET, are Taheripour et al. 2017[155] and multiple configurations from USDA 2018.[156] As both of these are robust and recent analyses, we had considered encouraging EPA to include these as individual studies in their review as opposed to keeping them within the Scully et al. 2021 average. However, we recognize concerns that many new iLUC results depend on recent versions of GTAP-BIO (even though, as we show in Figure 1, the downward trend of iLUC estimates is not exclusive to GTAP-BIO). That said, we chose to keep the Taheripour et al. 2017 and USDA 2018 results packaged in the Scully et al. 2021 average, as one compiled

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[152] Lewandrowski, J. 2018. Presentation: Assessing the Carbon Footprint of Corn-Based Ethanol. Available from: https://conference.ifas.ufl.edu/ACES/prior/aces18/Presentations/Salon%20K/Thursday/0835%20Lewandrowski%20-%20Y.pdf

[153] Simon, K. 2022. GHG Biofuel Modeling in the U.S.: Summary of the RFS statutory requirements and Future Needs. Available from: https://www.epa.gov/renewable-fuel-standard-program/workshop-biofuel-greenhouse-gas-modeling

[154] Scully et al. 2021a.

[155] Taheripour et al. 2017a.

[156] Flugge, M., Lewandrowski, J., Rosenfeld, J., Boland, C., Hendrickson, T., Jaglo, K., Kolansky, S., Moffroid, K., Riley-Gilbert, M. and Pape, D., 2017. A life-cycle analysis of the greenhouse gas emissions of corn-based ethanol.

representation of recent results using GTAP-BIO, instead of adding additional GTAP-BIO studies to the list.

As we have explained above, the ratings for all studies are provided for illustrative purposes.

Incorporating Studies that Estimate LUC Only

As described above, the CI of corn ethanol can be divided into multiple categories. Instead of analyzing the full well-to-wheel value, some researchers dig into individual components of the estimate. Allowing the inclusion of studies that focus on one part of the whole is more inclusive of research that has taken a closer look at subsets of our question around the CI of corn ethanol. We propose including studies for which EPA has reviewed the LUC subcomponent, as well as another European study and an empirical study.

For consistency with the process used in Lark et al.'s composite estimates,[157] we will select a GREET value of 46.2 gCO2e/MJ (rounded to 43 gCO2e/MJ) to add to the iLUC component. This aligns well with EPA identifying a range of 40 to 50 gCO2e/MJ for the non-LUC component for the GREET 2021 results.[158] We recommend not adding iLUC values to the EPA 2010 or CARB 2015 or EPA 2010 estimates, which both rely on outdated models.

As noted in the section above, additional studies will still need to be weighted based on their quality.

Adding Studies EPA Considers for LUC Emissions

Figure 4.2.2.8-1 of EPA's DRIA plots various results for iLUC. Some of these studies would not be candidates to incorporate into the well-to-wheel review:

- CARB 2014,[159] because CARB 2018 already included
- Taheripour 2017,[160] as this value is already included within Scully et al. 2021
- Plevin et al. 2015,[161] since this study aims to estimate and comment on uncertainty, not predict an iLUC value
- ICAO 2021,[162] because the result was built specific to aviation pathways

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[157] Lark et al. 2022. Table 2.
[158] EPA. 2022b. DRIA.
[159] CARB. 2014. Detailed Analysis for Indirect Land Use Change. C. A. R. Board. Sacramento, CA: 113.
[160] Taheripour et al. 2017a.
[161] Plevin et al. 2015.
[162] ICAO. 2021. CORSIA Eligible Fuels -- Lifecycle Assessment Methodology. CORSIA Supporting Document. Version 3: 155

The remaining studies, outlined below, could be appropriate to consider in EPA's range.

Carriquiry et al. 2019

Criteria	Criteria Met	Evaluation
Accepted Approach	Yes	FAPRI-CARD is a generally accepted model
Refined Modeling Tools	Yes	Uses updated FAPRI-CARD with improved data
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Model adjustments are well documented
Score:	4/4	

As described in Part I, Carriquiry et al. 2019 uses updated version of FAPRI and calibrates the model to empirical data. The lineage of the FAPRI-CARD version used is well-documented by the papers this study builds on, such as Dumortier et al. 2011.[163]

Laborde 2014

Criteria	Criteria Met	Evaluation
Accepted Approach	Yes	MIRAGE is a generally accepted model
Refined Modeling Tools	Yes	Uses improved MIRAGE model
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Model updates are well documented
Score:	4/4	

EPA includes Laborde 2014 in Figure 4.2.2.8-3 of the 2022 DRIA when discussing estimates for cropland area change.[164] Laborde uses the MIRAGE model to estimate economy-wide global impacts.

As discussed in Part I, Laborde tunes the model based on information about yield and crop replacement. When EPA retrieved cropland area values from Laborde 2014, the Agency selected the iteration that incorporated all updates but did not freeze food consumption,[165] which we agree is an appropriate selection.

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[163] Dumortier et al. 2011.

[164] EPA. 2022b. DRIA.

[165] EPA 2022 Notes on Literature Review of Transportation Fuel Greenhouse Gas (GHG) Lifecycle Analysis (LCA)

We consider the MIRAGE model an acceptable approach as the MIRAGE results provide the scientific basis for European Commission policy on GHG emissions from iLUC associated with biofuels from corn and cereal grains.[166,167]

Developers of the MIRAGE model have recorded progress made throughout model updates.[168,169,170]

Adding Another European Study

Valin et al. 2015

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	Yes	GLOBIOM is a generally accepted model
Refined Modeling Tools	Yes	Uses improved GLOBIOM model
Complete Data	Yes	Comprehensive geographic and economic scope
Transparent Process	Yes	Model updates are well documented
Score:		

Valin et al. 2015 uses GLOBIOM to estimate global impacts on agriculture, livestock, forestry, and bioenergy sectors. GLOBIOM is one of the key models EPA identifies in Table 4.2.2.7-1 of the 2022 DRIA.[171]

Valin et al.'s paper describes updates to this edition of the model, such as how biofuel production projects are calibrated to statistics (page 18) and crop prices from GLOBIOM are calibrated to observed prices (page 26).[172]

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[166] Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Official Journal of the European Union. L 239/1.

[167] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Official Journal of the European Union. L 328/82.

[168] Decreux, Y. and Valin, H., 2007. MIRAGE, updated version of the model for trade policy analysis: focus on agriculture and dynamics (No. 1423-2016-117757).

[169] Laborde, D. and Valin, H., 2012. Modeling land-use changes in a global CGE: assessing the EU biofuel mandates with the MIRAGE-BioF model. Climate Change Economics, 3(03), p.1250017.

[170] Laborde 2011.

[171] EPA. 2022b. DRIA.

[172] Valin, H., Peters, D., Van den Berg, M., Frank, S., Havlik, P., Forsell, N., Hamelinck, C., Pirker, J., Mosnier, A., Balkovic, J. and Schmidt, E., 2015. The land use change impact of biofuels consumed in the EU: Quantification of area and greenhouse gas impacts.

Detailed updates to GLOBIOM have been documented by researchers, including a 2018 report by the International Institute for Applied Systems Analysis that summarizes the 2015 version used by Valin et al.[173,174,175]

Adding Another Empirical Study

Overmars et al. 2015

Criteria	**Criteria Met**	**Evaluation**
Accepted Approach	No	Other approach
Refined Modeling Tools	No	Uses simplified spreadsheet calculations instead of economic modeling
Complete Data	Yes	Historical data has a comprehensive geographic and economic scope, though economic tools are crude
Transparent Process	Yes	Approach emphasizes reproducibility and publicly available data
Score:	2/4	

Woltjer identifies iLUC studies that rely on various approaches for a European Commission publication.[176] This review shows not all empirical studies are showing higher results. For example, Overmars et al. 2015 use historical data to estimate iLUC impacts from corn starch ethanol and other biofuels.[177] Overmars et al. 2015 report compares results using two different emissions factor models (CSAM and IMAGE) and two different allocation methods. Results varied based on the selected emissions factors but did change when switching allocation methods.

This study does improve the work done in Overmars et al. 2011[178] but still uses an oversimplified spreadsheet approach. Even the authors note that "our method is less rigorous

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[173] Valin, H., Havlík, P., Forsell, N., Frank, S., Mosnier, A., Peters, D., Hamelinck, C., Spöttle, M. and van den Berg, M., 2013. Description of the GLOBIOM (IIASA) model and comparison with the MIRAGE-BioF (IFPRI) model. Crops, 8(3.1), p.10.

[174] Valin, H., Frank, S., Pirker, J., Mosnier, A., Forsell, N., Havlik, P., Peters, D. and Hamelinck, C., 2014. Improvements to GLOBIOM for modelling of biofuels indirect land use change. ILUC Quantification Consortium: Utrecht, The Netherland.

[175] International Institute for Applied Systems Analysis. 2018. GLOBIOM documentation.

[176] Woltjer et al. 2017..

[177] Overmars, K., Edwards, R., Padella, M., Prins, A.G., Marelli, L. and Consultancy, K.O., 2015. Estimates of indirect land use change from biofuels based on historical data. JRC Science and Policy Report, Ref. no. EUR, 26819.

[178] Overmars, K.P., Stehfest, E., Ros, J.P. and Prins, A.G., 2011. Indirect land use change emissions related to EU biofuel consumption: an analysis based on historical data. Environmental Science & Policy, 14(3), pp.248-257.

than economic models and does not pretend to replace economic models in ILUC estimates."[179] Albeit the noted shortcomings, Overmars et al. 2015 does capture economic effects across 11 global regions. Reproducibility is a tenet of this paper, which uses publicly available data and describes steps in detail.

Reviewing the Refined Range

After assigning a score to each study, we review the suite of results with a color gradient assigned to denote the reliability of the study. The lowest of our example scores are shown in yellow (0/4) and light orange (1/4), while the highest example scores are shown in dark orange (3/4) and red (4/4). Again, these scores are an example of an approach to rating studies that we encourage EPA to consider.

We first share the list with the inclusion of results from additional studies that we recommend EPA add to its literature review, where the new analyses are highlighted in blue. Our scoring scale shows that the studies meeting all criteria (receiving the highest score of 4/4) represent a range of 27 to 67 gCO2e/MJ, on the lower end of EPA's full range. The average of that range (52 gCO2e/MJ) is in line with the central estimate from our Scully et al. 2021 study (51 gCO2e/MJ).

Also, the studies meeting 3 of 4 criteria are all from the CARB 2018 and EPA 2010 analysis, which were grounded in good techniques but are now simply outdated. This reinforces our observation that as quality studies are refined and improved, the CI estimates they produce for corn ethanol converge on lower values. Note that this example assessment equally weights all evaluation criteria, which is why the CARB 2018 and EPA 2010 results score relatively well even though they have been superseded.

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[179] Overmars et al. 2015.

Table 7 Sample Evaluation of Well-to-Wheel (WTW) Corn Starch Ethanol Carbon Intensity Results for Studies in EPA's 2022 DRIA Plus Additional Recommended Studies

Analysis	WTW (gCO2e/MJ)	Score
Lark et al. (2022)/Other/RFS2 RIA	116	0/4
Brandão (2022)	105	0/4
Lark et al. (2022)/Other/CA-LCFS	105	0/4
CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/High LUC	94	3/4
RFS2 rule (2010)/FASOM-FAPRI/NG Dry DDGS/High LUC	91	3/4
Lark et al. (2022)/Other/GREET	90	0/4
CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/Mean LUC	77	3/4
RFS2 rule (2010)/FASOM-FAPRI/2022 Avg NG Dry Mill/Mean LUC	73	3/4
BEIOM (2021)/Avg. Dry Mill	69	1/4
CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/Low LUC	68	3/4
Carriquiry (2019)/FAPRI-CARD/High + GREET	67	4/4
Scully et al. (2021)/GTAP-BIO+CCLUB/High LUC	65	4/4
GREET (2021)/GTAP-BIO+CCLUB/NG Dry Mill DDGS	57	4/4
Valin (2015)/GLOBIOM + GREET	57	4/4
GREET (2021)/GTAP-BIO+CCLUB/Avg Plant	56	4/4
Carriquiry (2019)/FAPRI-CARD /Central + GREET	56	4/4
Overmars(2015)/CSAM + GREET	56	2/4
Laborde(2014)/MIRAGE + GREET	55	4/4
GREET (2021)/GTAP-BIO+CCLUB/Gen 1.5 w/ DCO	53	4/4
Carriquiry (2019)/FAPRI-CARD /Low + GREET	53	4/4
Lewandrowski et al. (2019)/FASOM+GTAP-BIO/2022 BAU	52	4/4
Scully et al. (2021)/GTAP-BIO+CCLUB/Central LUC	51	4/4
Overmars(2015)/IMAGE + GREET	49	2/4
RFS2 rule (2010)/FASOM-FAPRI/Adv. NG Dry Mill/Low LUC	49	3/4
GREET (2021)/GTAP-BIO+CCLUB/NG Dry Mill WDGS	47	4/4
Lee et al. (2021)/GTAP-BIO+CCLUB/2019	45	4/4
Scully et al. (2021)/GTAP-BIO+CCLUB/Low LUC	38	4/4
Lewandrowski et al. (2019)/FASOM+GTAP-BIO/HEHC	26	4/4

Even when we remove the additional studies our team recommends adding, the outcome presented by the chart is very clear: studies that use current and complete data are concentrated in the lower half of the range. With this narrower lens, the studies meeting all criteria (a score of 4/4) represent a range of 38 to 65 gCO2e/MJ with an average of 52 gCO2e/MJ, which aligns with our best central estimate of 51 gCO2e/MJ.

Table 8 Sample Evaluation of Well-to-Wheel (WTW) Corn Starch Ethanol Carbon Intensity Results for Studies in EPA's 2022 DRIA

Analysis	WTW (gCO2e/MJ)	Score
Lark et al. (2022)/Other/RFS2 RIA	116	0/4
Brandão (2022)	105	0/4
Lark et al. (2022)/Other/CA-LCFS	105	0/4
CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/High LUC	94	3/4
RFS2 rule (2010)/FASOM-FAPRI/NG Dry DDGS/High LUC	91	3/4
Lark et al. (2022)/Other/GREET	90	0/4
CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/Mean LUC	77	3/4
RFS2 rule (2010)/FASOM-FAPRI/2022 Avg NG Dry Mill/Mean LUC	73	3/4
BEIOM (2021)/Avg. Dry Mill	69	1/4
CARB (2018)/GTAP-BIO+AEZ-EF/Dry Mill/Low LUC	68	3/4
Scully et al. (2021)/GTAP-BIO+CCLUB/High LUC	65	4/4
GREET (2021)/GTAP-BIO+CCLUB/NG Dry Mill DDGS	57	4/4
GREET (2021)/GTAP-BIO+CCLUB/Avg Plant	56	4/4
GREET (2021)/GTAP-BIO+CCLUB/Gen 1.5 w/ DCO	53	4/4
Lewandrowski et al. (2019)/FASOM+GTAP-BIO/2022 BAU	52	4/4
Scully et al. (2021)/GTAP-BIO+CCLUB/Central LUC	51	4/4
RFS2 rule (2010)/FASOM-FAPRI/Adv. NG Dry Mill/Low LUC	49	3/4
GREET (2021)/GTAP-BIO+CCLUB/NG Dry Mill WDGS	47	4/4
Lee et al. (2021)/GTAP-BIO+CCLUB/2019	45	4/4
Scully et al. (2021)/GTAP-BIO+CCLUB/Low LUC	38	4/4

Both of these tables assert that, in general, more reliable studies present lower CI values and, therefore, should be given more consideration by EPA.

INFORMING THE FINAL RULE

We now transition to another call from EPA:

> EPA: We also invite comment on how this information [referring to EPA's review of CI estimates] may be used to inform the final rule.[180]

Given the presence of uncertainty, where values are true but unknown, EPA should use the best available science to determine an improved estimate for the CI of corn ethanol and use this updated value to inform the final rule. As our findings in the prior sections have shown, the best

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[180] EPA. 2022a.

available science produces lower CI estimates corn starch ethanol than older analyses. **This is consistent with our conclusion in Scully et al. 2021 that corn starch ethanol represents an approximately 46%reduction in GHG emissions relative to gasoline**.[181]

Reliance on the best available science for the CI of corn ethanol provides for more accurate characterization of GHG emissions for the U.S. transportation sector than continued use of EPA's 2010 estimate, as proposed by EPA in its 2022 DRIA. The best available science indicates that the 2022 DRIA overestimates the CI of corn ethanol and transportation sector GHG emissions. These same overestimates result in underestimates of U.S. progress toward decarbonization and attainment of national and international climate goals, such as the Paris Agreement. These goals have relatively near-term science-based target dates including a 43% reduction in emissions by 2030 and net zero emissions by 2050.[182] Continued reliance on an inaccurate CI for corn ethanol will likely hinder the ability of EPA and others to prioritize investment and policy into technologies that can effectively reduce GHG emissions over those timeframes. It is thus imperative that EPA incorporate the best available science on the CI of corn ethanol into its analyses.

IMPACTS OVER TIME

We continue with another prompt from EPA:

> EPA: Since models treat time differently (e.g., different time steps, static versus dynamic models), we invite comment on the most appropriate way to handle the GHG impacts of biofuels over time.[183]

We find two ways to consider this question: one option lies in the details of existing models and the other looks forward over time into the future.

For the first prompt, we agree with EPA's preference of selecting a 30-year amortization period for LUC, as reasoned in Section 4.2.3.1 of the DRIA (page 167).[184] EPA begins incorporating this consideration in DRIA Table 4.2.3.13-2 (page 194) by presenting the range of high and low values of the 30-year scenarios from the 2010 RFS2 estimates. We encourage EPA to calculate rough estimates of 30-year values for the other results included in the CI range from the literature review. To do this, EPA would multiply each estimate by its current amortization period then

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[181] Scully et al. 2021a.

[183] EPA. 2022a.
[184] EPA. 2022b. DRIA.

divide that value by 30. EPA can then use these scaled results to preliminarily present an updated range that reasonably reflects a consistent amortization period of 30 years.

The second interpretation asks what we think EPA should do now in terms of looking forward in time at future emissions. EPA's 2010 analysis included forecasting of what would be reasonably expected of industries (including farming and production processes) in the foreseeable future. EPA is repeating that process of looking ahead now by considering models that look into the future with a 20 or 30-year time horizon. We have seen, however, that much has changed since 2010 with respect to climate mitigation measures that impact the lifecycle emissions of corn ethanol. Not all technical advances in efficiency would have been predicted and captured in the 2010 estimates but, if included, these would have reduced estimates for the CI of corn ethanol. Current trends in climate law and policy indicate that decarbonization of the ethanol supply chain will only continue in the future.

In fact, there has been significant investment in GHG mitigation and emissions reduction technologies that EPA did not predict in 2010. And there have been significant advances in areas such as carbon dioxide removal technology and carbon capture utilization and geological sequestration. These improvements all further reduce the carbon emissions from corn starch ethanol and will continue being implemented and enhanced as the decades progress.

As another example of programs implemented, California's Low Carbon Fuel Standard (LCFS) employs a credit system that encourages biorefineries to reduce the CI of their plant's products and incentivizes fuel blenders to select options with a lower CI.[185,186] A 2021 review of LCFSs enacted in California, Oregon, and British Columbia concluded that each of these jurisdictions has consistently met their annual carbon intensity reduction goals for the program.[187,188]

We anticipate that between the time researchers are now making estimates and when the amortized dates arrive, technological advances will continue to bring down emissions for elements of the corn starch ethanol lifecycle. We encourage EPA to incorporate potential technology improvements into the new analysis the Agency will conduct. One such way to do so would be to adjust data inputs, either in the primary analysis or a sensitivity analysis, to consider

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[185] Liu, X., Kwon, H., Northrup, D. and Wang, M., 2020. Shifting agricultural practices to produce sustainable, low carbon intensity feedstocks for biofuel production. Environmental Research Letters, 15(8), p.084014.

[186] CARB. 2020. Slides: LCFS Basics with Notes. https://ww2.arb.ca.gov/sites/default/files/2020-09/basics-notes.pdf

[187] Mazzone, D., Witcover, J. and Murphy, C., 2021. Multijurisdictional Status Review of Low Carbon Fuel Standards, 2010–2020 Q2: California, Oregon, and British Columbia.

[188] Axsen, J. and Wolinetz, M., 2023. What does a low-carbon fuel standard contribute to a policy mix? An interdisciplinary review of evidence and research gaps. Transport Policy.

more aggressive carbon reduction strategies and technologies, such as how Lewandrowski et al. 2019 incorporate an HEHC estimate.[189]

NEW RESEARCH

We now move to the final invitation from EPA:

> EPA: We also request comment on how we can incorporate new research that examines the effectiveness of the RFS program in mitigating GHG emissions.[190]

We recommend EPA review the IEA report mentioned in Part I, which shows that empirical data does not indicate the association of iLUC with biofuel demand as suggested by older, unrefined agroeconomic models.[191] Instead, if biofuel production is not linked to iLUC and thus iLUC is not added to the overall CI value, then the resulting lower estimates for overall CI would be closer to the lower results produced from updated models.

An additional topic to address in this rulemaking or thereafter is determining an updated estimate for the carbon impact of gasoline. Though EPA does briefly review CI estimates for gasoline in section 4.2.3.2 of the DRIA, there has been, in general, less attention on the indirect impacts of gasoline production.[192,193] Better understanding the full weight of GHG implications assigned to petroleum will allow the carbon reductions offered by biofuels like corn starch ethanol to become even more apparent.

We would also like to comment on a December 2202 Reuters article that discusses the illustrative scenario presented in Section 4.2.4 of the DRIA.[194,195] The article headline and its first few paragraphs misrepresent EPA’s findings by describing the outcome of only a segment of a cumulative assessment. While the intermediate values presented by Reuters do match the numbers reported in the DRIA, it is misleading to extract a portion of a 30-year analysis. Later in

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[189] Lewandrowski et al. 2019.

[190] EPA. 2022a.

[191] IEA Bioenergy. 2022.

[192] Martin, E.W., Chester, M.V. and Vergara, S.E., 2015. Attributional and consequential life-cycle assessment in biofuels: a review of recent literature in the context of system boundaries. Current Sustainable/Renewable Energy Reports, 2(3), pp.82-89.

[193] Dale, B.E. and Kim, S., 2014. Can the Predictions of Consequential Life Cycle Assessment Be Tested in the Real World? Comment on “Using Attributional Life Cycle Assessment to Estimate Climate-Change Mitigation...”. Journal of Industrial Ecology, 18(3), pp.466-467.

[194] Reuters. 2022. U.S. biofuels proposal would lift near-term greenhouse gas emissions, EPA says. https://www.reuters.com/business/environment/us-biofuels-proposal-would-lift-near-term-greenhouse-gas-emissions-epa-says-2022-12-15/ 15 December 2022.

[195] EPA. 2022b. DRIA.

the article, Reuters quotes an email from EPA stating that it is "inappropriate to truncate the analysis after 3 years,"[196] even though this is exactly what Reuters does above.

Further, the DRIA explains on pages 193 and 194 that the illustrative scenario in the 2022 DRIA is based only on GHG impacts calculated in EPA's old 2010 RFS2 analysis. Even though EPA presents the range of their recent literature review in Table 4.2.3.13-1 and discusses some of this new science in detail, these values are not considered in the illustrative scenario. For corn starch ethanol, the range considered in the illustrative scenario is 49 to 91 gCO2e/MJ when amortized to 30 years, as shown in DRIA Table 4.2.3.13-2. This range does not incorporate new science and adjustments made over the past decade. As shown above, the best available recent science converges on a range lower than that produced by older, unrefined studies.

With that disclaimer in mind, we can look again at the DRIA's full 30-year evaluation across all biofuels. Totaling the values presented in DRIA Tables 4.1.4-9 and 4.1.4-13 results in an estimated GHG reduction of 128.2 million to 1.2 billion metric tons of CO2 over 30 years from using the proposed biofuel standards. The low estimate uses the low end of the petroleum gasoline baseline (84 gCO2e/MJ) and the high end of the CI for each biofuel, while the high estimate uses a high petroleum gasoline baseline (98 gCO2e/MJ) and the low CI for each biofuel. Both the low and high scenarios predict an GHG overall reduction over 30 years when using the proposed standards. Zooming in on just corn ethanol, EPA's estimated impacts over 30 years spread from a reduction of 99 million metric tons of CO2 to an increase of 13.8 million metric tons of CO2, with a central estimate of a reduction of 42.6 million metric tons of CO2. Using a more appropriate value for the CI of corn ethanol would better reflect its GHG reduction benefits in an illustrative scenario.

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[196] Reuters. 2022.

PART III: ADDITIONAL AIR QUALITY BENEFTS OF CORN STARCH ETHANOL

With the above sections focusing on the GHG effects of corn starch ethanol, our final section looks at the non-GHG emissions in the context of health effects and environmental justice.

In Part III, we summarize the best available science on the relationship between ethanol, tailpipe emissions, and health. Our detailed comments on those topics are presented following the summary. Our comments are largely based upon our research that has resulted in two peer-reviewed publications: a comprehensive assessment of the impacts of corn ethanol fuel blends on tailpipe emissions of regulated pollutants and of air toxics.[197,198]

CORN ETHANOL FUEL BLENDS

Most gasoline used for light-duty vehicles in the US is E10, which contains a blend of 10% (by volume) ethanol with a gasoline blend stock. Ethanol is used as a fuel additive in gasoline to boost octane without the harmful impacts posed by previous fuel additives such as methyl tert-butyl ether (MTBE) and lead. Octane rating reflects the ability of a fuel to avoid premature or auto ignition.[199] Aromatics, such as benzene, toluene, ethylbenzene, and BTEX also boost gasoline octane, but they are considered hazardous air pollutants.[200] The high-octane rating of ethanol thus also enables reduction of aromatics in the fuel.[201,202,203] In our recent study, we showed that aromatic levels decrease by approximately 7% by volume for each 10% by volume increase in ethanol content.[204] These findings are consistent with market fuel studies and with octane blending studies[205,206,207,208] and have implications for tailpipe emissions of light-duty vehicles, as will be discussed in the next section.

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[197] Kazemiparkouhi et al. 2022a.

[198] Kazemiparkouhi et al. 2022b.

[199] Anderson JE, DiCicco DM, Ginder JM, Kramer U, Leone TG, Raney-Pablo HE, Wallington TJ. 2012. High octane number ethanol–gasoline blends: Quantifying the potential benefits in the United States. Fuel, 97: 585-94.

[200] Clark, N.N., McKain Jr., D.L., Klein, T., Higgins, T.S. 2021. Quantification of gasoline-ethanol blend emissions effects. Journal of the Air & Waste Management Association, 71: 3-22.

[201] Clark et al. 2021.

[202] Kazemiparkouhi et al. 2022a.

[203] EPA. 2017. Fuel Trends Report: Gasoline 2006-2016.

[204] Kazemiparkouhi et al. 2022a.

[205] Anderson JE, Kramer U, Mueller SA, Wallington TJ. 2010. Octane Numbers of Ethanol− and Methanol−Gasoline Blends Estimated from Molar Concentrations. Energy & Fuels, 24, 6576-6585.

[206] Anderson et al. 2012.

[207] Stratiev D, Nikolaychuk E, Shishkova I, Bonchev I, Marinov I, Dinkov R, Yordanov D, Tankov I, Mitkova M. 2017. Evaluation of accuracy of literature gasoline blending models to predict octane numbers of gasoline blends. Petroleum Science and Technology, 35, 1146-1153.

[208] EPA. 2017. Fuel Trends Report: Gasoline 2006-2016.

CORN ETHANOL FUEL BLENDS AND TAILPIPE EMISSIONS

When reviewing the literature, it is important to select studies that reflect a vehicle fleet composition that is representative of current conditions. Light-duty vehicle fuel economy has increased by 32% in the US since vehicle model year 2004,[209] and emissions have decreased. For light-duty vehicles, the EPA lowered the permissible emissions of CO, NOx, non-methane organic gases (NMOG), PM, and formaldehyde from Tier 1 standards to Tier 2 standards (which took full effect in 2004), with additional reductions (Tier 3 standards) being phased in since 2017.[210] Thus, all vehicles on the road in the US prior to 2008 were held to Tier 1 (highest permissible emissions) and Tier 2 standards, while nearly all vehicles today are held to Tier 2 and Tier 3 (lowest permissible emissions) standards.

To better reflect current ethanol impacts on vehicle emissions, we reviewed over 95 studies that characterized emissions from light-duty vehicles powered by E0 and ethanol blends, focusing on Tier 2 and higher vehicles. These studies assessed pollutant emissions from a wide variety of common vehicle models, engine types, and engine operating conditions (e.g., cold start, hot running, and hot start[211]) and were conducted by both commercial and public organizations. We also draw from our own two recent studies, which are the first large-scale analyses of data from light-duty vehicle emissions studies to examine real-world impacts of ethanol-blended fuels on air pollutant emissions.[212][213] We summarized the results of those studies and discussed implications for air quality and public health in our August 2022 white paper.[214]

Emission studies of ethanol fuel blends show that tailpipe pollutant emissions vary with ethanol and aromatic content. Higher ethanol content in fuels was associated with lower emissions of key health-relevant pollutants, PM, BC, PN, and BTEX, while fuels with higher aromatic fuel

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[209] Hula A, Maguire A, Bunker A, Rojeck T, Harrison S. 2021. The 2021 EPA Automotive Trends Report: Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975. EPA-420-R-21-00. Washington (DC): United States Environmental Protection Agency.

[210] EPA. 2022f. Light Duty Vehicle Emissions.

[211] Hot start or hot running conditions occur when an engine is started or is running at regular operating temperatures (i.e., during or soon after fully warmed-up operation). Cold start conditions occur when an engine is started at temperatures below regular operating conditions. Engine operating conditions impact tailpipe emissions, with cold start emissions accounting for a substantial portion of tailpipe emissions (Reiter and Kockelman 2016).

[212] Kazemiparkouhi et al. 2022a.

[213] Kazemiparkouhi et al. 2022b.

[214] Kazemiparkouhi, F., MacIntosh, D., Suh, H., Clark, N. 2022c. Potential Air Quality and Public Health Benefits of Real-World Ethanol Fuels.

content generally showed the opposite pattern.[215,216,217,218,219,220,221,222,223,224,225,226] In our papers, we observed similar patterns of decreasing PM, BTEX, BC, and PN with increasing ethanol content.[227] Primary PM emissions, for example, decreased by 15 – 18% on average for each 10% increase in ethanol content under cold-start conditions.[228] Cold start PM emissions have consistently been shown to account for a substantial portion of all direct tailpipe PM emissions.[229,230] A 2022 CARB study that assessed the impact of E15 (splash-blended from E10) on air pollutant emissions for late model year vehicles (2016 – 2021) found that switching from E10 to E15 reduced PM emissions by 18%, with cold-start emissions being reduced by 17%.[231]

Ethanol blended fuels were also consistently shown to emit lower amounts of CO, THC, and non-methane hydrocarbons (NMHC) as compared to non-ethanol blended fuels, consistent with

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[215] Clark et al. 2021.

[216] Karavalakis G. 2018. Impacts of Aromatics and Ethanol Content on Exhaust Emissions from Gasoline Direct Injection (Gdi) Vehicles. University of California, Riverside.

[217] Karavalakis G, Short D, Vu D, Villela M, Russell R, Jung H, Asa-Awuku A, Durbin T. Regulated Emissions, Air Toxics, and Particle Emissions from Si-Di Light-Duty Vehicles Operating on Different Iso-Butanol and Ethanol Blends. SAE International Journal of Fuels and Lubricants 7, no. 1 (2014): 183-99.

[218] Kumar R, Chaurasia O. 2019. A Review on Performance and Emissions of Compression Ignition Engine Fueled with Ethanol-diesel Blend. Journal Européen des Systèmes Automatisés, 52: 205-14.

[219] Liang X, Zhang S, Wu X, Guo X, Han L, Liu H, Wu Y, Hao J. 2020. Air quality and health impacts from using ethanol blended gasoline fuels in China. Atmospheric Environment, 228.

[220] Myung C-L, Choi K, Cho J, Kim K, Baek S, Lim Y, Park S. 2020. Evaluation of regulated, particulate, and BTEX emissions inventories from a gasoline direct injection passenger car with various ethanol blended fuels under urban and rural driving cycles in Korea. Fuel, 262.

[221] Roth P, Yang J, Peng W, Cocker DR, Durbin TD, Asa-Awuku A, Karavalakis G. 2020. Intermediate and high ethanol blends reduce secondary organic aerosol formation from gasoline direct injection vehicles. Atmospheric Environment, 220.

[222] Sakai S, Rothamer D. 2019. Impact of ethanol blending on particulate emissions from a spark-ignition direct-injection engine. Fuel, 236: 1548-58.

[223] Schuchmann B, Crawford R. 2019. Alternative Oxygenate Effects on Emissions. Alpharetta, GA (United States).

[224] Yang J, Roth P, Durbin T, Karavalakis G. 2019a. Impacts of gasoline aromatic and ethanol levels on the emissions from GDI vehicles: Part 1. Influence on regulated and gaseous toxic pollutants. Fuel, 252: 799-811.

[225] Yang J, Roth P, Zhu H, Durbin TD, Karavalakis G. 2019b. Impacts of gasoline aromatic and ethanol levels on the emissions from GDI vehicles: Part 2. Influence on particulate matter, black carbon, and nanoparticle emissions. Fuel, 252:812-820.

[226] Zheng X, Wu X, He L, Guo X, Wu Y. 2019. Black Carbon Emissions from Light-duty Passenger Vehicles Using Ethanol Blended Gasoline Fuels. Aerosol and Air Quality Research, 19: 1645-54.

[227] Kazemiparkouhi et al. 2022a, 2022b.

[228] Kazemiparkouhi et al. 2022c.

[229] Darlington TL, Kahlbaum D, Van Hulzen S, Furey RL. 2016. Analysis of EPAct Emission Data Using T70 as an Additional Predictor of PM Emissions from Tier 2 Gasoline Vehicles.

[230] EPA. 2013. Assessing the Effect of Five Gasoline Properties on Exhaust Emissions from Light-Duty Vehicles Certified to Tier 2 Standards: Analysis of Data from EPAct Phase 3 (EPAct/V2/E-89): Final Report. EPA-420-R-13-002 ed.: Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency.

[231] Karavalakis G, Durbin TD, Tang T. 2022 Comparison of Exhaust Emissions Between E10 CaRFG and Splash Blended E15. Final Report. Riverside, CA: California Air Resources Board (CARB), Growth Energy Inc./Renewable Fuels Association (RFA), and USCAR.

their cleaner combustion and higher amounts of acetaldehyde, which is produced directly from ethanol combustion.[232,233,234,235,236,237,238,239,240,241,242,243,244]

Less consistent was the impact of ethanol fuel blends on emissions of NOx, for which trends varied by study perhaps due to their reactivity and sensitivity to other species in the emission effluent. However, our recent study of low to mid ethanol fuel blends (E0 to E30) and CARB's 2022 study show that NOx did not change with increasing ethanol content. Acrolein emissions also did not change with increasing ethanol content, while formaldehyde emissions showed little to no significant change.[245]

To the extent that ethanol is a substitute for octane-enhancing aromatics in fuel (as discussed in the Corn Ethanol Fuel Blends section), our review of the literature and results from our emission studies demonstrate that higher ethanol fuel blends reduce emission for PM, BTEX, 1-3 butadiene, BC, and PN with no concomitant increase in emissions for CO, THC, NOx, or acrolein. A presentation by researchers at the University of California, Riverside who contributed to the CARB 2022 report further predict that "the introduction of E15 will likely reduce air toxics from current technology vehicles."[246] Based on the currently available data, we agree with this expectation that E15 will reduce local pollutants when compared with E10 and E0.

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[232] Badrawada IGG, Susastriawan AAP. 2019. Influence of ethanol–gasoline blend on performance and emission of four-stroke spark ignition motorcycle. Clean Technologies and Environmental Policy, 21: 1891-96.

[233] Clark et al. 2021.

[234] Gunst 2013.

[235] Karavalakis 2018.

[236] Karavalakis G, Durbin TD, Shrivastava M, Zheng Z, Villela M, Jung H. 2012. Impacts of ethanol fuel level on emissions of regulated and unregulated pollutants from a fleet of gasoline light-duty vehicles. Fuel, 93: 549-58.

[237] Karavalakis et al. 2022.

[238] Kazemiparkouhi et al. 2022c.

[239] Mourad M, Mahmoud K. 2019. Investigation into SI engine performance characteristics and emissions fuelled with ethanol/butanol-gasoline blends. Renewable Energy, 143: 762-71.

[240] Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL), and Argonne National Laboratory (ANL). 2016. Summary of High-Octane, Mid-Level Ethanol Blends Study. In.: Oak Ridge National Laboratory.

[241] National Renewable Energy Laboratory (NREL). 2013. "Statistical Analysis of the Phase 3 Emissions Data Collected in the Epact/V2/E89 Program." edited by National Renewable Energy Laboratory. Golden, CO. New York State Climate Action Council Draft Scoping Plan (DSP). 2021.

[242] Roso VR, Souza Alvarenga Santos ND, Castilla Alvarez CE, Rodrigues Filho FA, Pacheco Pujatti FJ, Molina Valle R. 2019. Effects of mixture enleanment in combustion and emission parameters using a flex-fuel engine with ethanol and gasoline. Applied Thermal Engineering, 153: 463-72.

[243] Theiss T. 2016. Summary of High-Octane Mid-Level Ethanol Blends Study.

[244] Wayson. 2016. Evaluation of Ethanol Fuel Blends in Moves2014 Model. Renewable Fuels Association.

[245] Kazemiparkouhi et al. 2022a, 2022b, 2022c; Karavalakis et al. 2022.

[246] Tang T, Durbin TD, Johnson KC, Karavalakis G. 2022. Aiming at the increase of California's ethanol 'blend wall': gaseous and particulate emissions evaluation from a fleet of GDI and PFI vehicles operated on E10 and E15 fuels. Presentation.

CORN ETHANOL FUEL BLENDS AND AIR QUALITY

The estimated reductions in air pollutant emissions discussed above, particularly of PM, indicate that increasing ethanol content will result in improvements in air quality. We reviewed over 45 studies that examined issues related to ethanol blended fuel impacts on air quality and air pollutant exposures, with many of these studies conducted outside the US. Results from these studies were generally consistent with those from emissions testing studies. Numerous studies have shown that lower PM emissions result in lower ambient PM concentrations and exposures.[247,248] A study in Wisconsin found lower levels of CO after introduction of E10[249] were consistent with emission testing data that showed a reduction in CO emissions with higher ethanol content (as discussed in the prior section). Similarly, an analysis of US-wide air quality measurements found that reductions of targeted aromatics in fuel were associated with lower summertime ozone levels.[250]

Less well-studied is the impact of ethanol-based fuels on acetaldehyde and formaldehyde concentrations; however, atmospheric measurements indicate that use of E10 and other ethanol blends do not increase concentrations of acetaldehyde and formaldehyde above background levels in ambient air, indicating that emissions from other sources are larger than from light-duty vehicles.[251,252]

It is worth noting that we did not include results from the recent EPA Anti-Backsliding Study (ABS), which examined the impacts of changes in vehicle and engine emissions from ethanol-blended fuels on air quality and health.[253] The ABS used fuels that are not representative of real-world fuels. The ABS used inaccurate fuel property adjustment factors in its modeling,

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[247] Kheirbek I, Haney J, Douglas S, Ito K, Matte T, 2016. The contribution of motor vehicle emissions to ambient fine particulate matter public health impacts in New York City: a health burden assessment. Environmental Health, 15(1), pp.1-14.

[248] Pan S, Roy A, Choi Y, Eslami E, Thomas S, Jiang X, Gao HO. 2019. Potential impacts of electric vehicles on air quality and health endpoints in the Greater Houston Area in 2040. Atmospheric Environment, 207, pp.38-51.

[249] Foley TA, Rendahl CS, Kenski D. 2003. The effect of reformulated gasoline on ambient carbon monoxide concentrations in southeastern Wisconsin. Journal of the Air & Waste Management Association, 53: 1003-10.

[250] Auffhammer M, Kellogg R. 2011. Clearing the Air? The Effects of Gasoline Content Regulation on Air Quality. American Economic Review, 101 (6): 2687-2722.

[251] Sommariva R, de Gouw JA, Trainer M, Atlas E, Goldan PD, Kuster WC, Warneke C, Fehsenfeld FC. 2011. Emissions and photochemistry of oxygenated VOCs in urban plumes in the Northeastern United States. Atmospheric Chemistry & Physics, 11: 7081–96.

[252] de Gouw JA, Gilman JB, Borbon A, Warneke C, Kuster WC, Goldan PD, Holloway JS, Peischl J, Ryerson TB, Parrish DD, Gentner DR, Goldstein AH, Harley RA. 2012. Increasing atmospheric burden of ethanol in the United States. Geophysical Research Letters, 39.

[253] EPA 2020. Clean Air Act Section 211(v)(1) Anti-backsliding Study. Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency.

reducing aromatics by only 2%,[254] which is substantially lower than the reductions found in our paper and in fuel survey data,[255,256] as discussed earlier. As a result, ABS's findings on air quality and their extension to public health impacts are not generalizable to real world conditions.

Another chemical of concern is benzene, which has been classified as a known human carcinogen by the EPA, the National Toxicology Program, and the International Agency for Research on Cancer. This classification is based in large part on findings from animal studies which show benzene exposures cause tumors after inhalation or ingestion and from epidemiological studies which show an excess risk of leukemia in humans exposed to benzene.[257,258] Given that 40% of benzene emissions are attributed to the transportation sector and that higher ethanol fuel content has been shown to have lower emissions of BTEX (which includes benzene), greater use of higher ethanol fuel blends would further reduce benzene concentrations and their associated cancer risk.

CORN ETHANOL FUEL BLENDS AND PUBLIC HEALTH

We identified over 20 studies that evaluated public health impacts of consumption of ethanol blends and/or E0, all of which used risk assessment approaches. We further identified seven recent epidemiological studies that examined associations between motor vehicle related exposures and cause-specific mortality, which together with results from emissions studies (detailed in the Corn Ethanol Fuel Blends and Tailpipe Emissions section), help to inform human health impact assessments.

Epidemiology studies have not focused on impacts related directly to ethanol in fuels, but instead they focus on pollutants such as PM, ozone, and benzene.[259] These studies generally show adverse human health effects associated with exposure to these pollutants, e.g., PM and ozone exposures are shown to be associated with adverse respiratory and cardiovascular outcomes. Numerous studies have also shown that lower PM emissions result in lower ambient PM concentrations and exposures, which in turn are causally associated with lower risks of total

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[254] EPA 2020, Anti-backsliding Study. Table 5.3.

[255] Kazemiparkouhi et al. 2022a

[256] EPA. 2017. Fuel Trends Report: Gasoline 2006-2016.

[257] Filippini et al. 2019.

[258] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (IARC). 2018. Benzene. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 120. 3. Cancer in Experimental Animals. Lyon (FR): International Agency for Research on Cancer.

[259] Ostro B, Hu J, Goldberg D, Reynolds P, Hertz A, Bernstein L, Kleeman MJ. 2015. Associations of mortality with long-term exposures to fine and ultrafine particles, species and sources: results from the California Teachers Study Cohort. Environmental Health Perspectives, 123: 549-56.

mortality and cardiovascular effects.[260,261,262,263] Cardiovascular disease is a leading mortality cause in the U.S., with approximately 700,000 deaths per year.[264] Using higher ethanol fuel blends therefore would reduce PM concentrations and adverse cardiovascular and respiratory outcomes.

We find considerable support from the emissions and epidemiological literature that substitution of ethanol for aromatics in automobile fuel may yield net public health benefits. In a US analysis, authors estimated that secondary fine particulate matter ($PM_{2.5}$), formed from aromatic compounds in gasoline, accounted for approximately 3,800 premature mortalities nationwide annually and $28B in total social costs.[265]

A few of the studies that we reviewed found net disbenefits for ozone, PM_{10} or $PM_{2.5}$, including one study in the US [266] and two in Brazil[267,268]. However, the inputs to those analyses are either outdated (e.g., emissions data reflect outdated vehicle fleet composition), or not documented fully (e.g., missing detailed descriptions of fuel properties, which have a significant impact on emissions as discussed in earlier sections), which limits the reliability of their results. Further, these results contradict the results of the emissions analyses discussed above.

DISCUSSION OF IMPACTS TO ENVIRONMENTAL JUSTICE COMMUNITIES

The benefits to air quality and public health associated with higher ethanol fuels may be particularly great for EJCs. EJCs are predominantly located in urban neighborhoods with high traffic density and congestion; these communities are thus exposed to disproportionately higher

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[260] Laden F, Schwartz J, Speizer FE, Dockery DW. 2006. Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. American journal of respiratory and critical care medicine, 173(6), pp.667-672.

[261] Pun VC, Kazemiparkouhi F, Manjourides J, Suh HH. 2017. Long-term PM2. 5 exposure and respiratory, cancer, and cardiovascular mortality in older US adults. American journal of epidemiology, 186(8), pp.961-969.

[262] EPA 2019. Integrated Science Assessment for Particulate Matter. Center for Public Health and Environmental Assessment.

[263] Wang B, Eum KD, Kazemiparkouhi F, Li C, Manjourides J, Pavlu V, Suh H. 2020. The impact of long-term PM2.5 exposure on specific causes of death: exposure-response curves and effect modification among 53 million U.S. Medicare beneficiaries. Environ Health, 19, 20.

[264] CDC. Heart Disease Facts. https://www.cdc.gov/heartdisease/facts.htm

[265] von Stackelberg et al. 2013.

[266] Jacobson MZ. 2007. Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States. Environmental Science & Technology, 41: 4150-7.

[267] Miraglia SG. 2007. Health, environmental, and economic costs from the use of a stabilized diesel/ethanol mixture in the city of Sao Paulo, Brazil. Cad Saude Publica, 23 Suppl 4: S559-69.

[268] Scovronick N, Franca D, Alonso M, Almeida C, Longo K, Freitas S, Rudorff B, Wilkinson P. 2016. Air Quality and Health Impacts of Future Ethanol Production and Use in Sao Paulo State, Brazil. International Journal of Environmental Research and Public Health, 13.

concentrations of PM emitted from motor vehicle tailpipes.[269,270,271] For example, in New York, people of color (POC) are exposed to more $PM_{2.5}$ from light-duty gasoline vehicles and heavy-duty diesel vehicles than average (+35% and +42%).[272]

Further, vehicle trips within urban EJCs tend to be short in duration and distance, with approximately 50% of all trips in dense urban communities under three miles long.[273,274,275] As a result, a large proportion of urban vehicle operation occurs under cold-start conditions,[276] when PM emissions are highest. Given the evidence that ethanol-blended fuels substantially reduce PM during cold-start conditions,[277] it follows that ethanol-blended fuels may present an effective method to reduce air pollution-related health risks for EJCs.

Additionally, while the market-share of gasoline-powered light-duty vehicles is expected to decrease over the next 10 years due to electric vehicles (EVs), gasoline and diesel vehicles currently still account for 99% of light duty vehicles driven by the US population, as of January 2023.[278] EVs also have higher upfront costs than gasoline powered vehicles ($19,000 higher on average) [279] which may limit their market penetration until prices become more comparable.[280] Given the financial barriers to acquire an EV and the disproportionate exposure to traffic pollution for EJCs,[281] alternatives such as using higher ethanol blends may provide benefits to these communities.

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[269] Bell ML, Ebisu K. 2012. Environmental inequality in exposures to airborne particulate matter components in the United States. Environmental Health Perspectives, 120, 1699-1704.

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[272] Tessum CW, Paolella DA, Chambliss SE, Apte JS, Hill JD, Marshall JD. 2021. PM2. 5 polluters disproportionately and systemically affect people of color in the United States. Science Advances, 7(18).

[273] De Nazelle A, Morton BJ, Jerrett M, Crawford-Brown D. 2010. Short trips: An opportunity for reducing mobile-source emissions? Transportation Research Part D: Transport and Environment, 15, 451-457.

[274] Reiter MS, Kockelman KM. 2016. The problem of cold starts: A closer look at mobile source emissions levels. Transportation Research Part D: Transport and Environment, 43: 123-132.

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[276] de Nazelle et al. 2010.

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[278] US DOE. 2023. The U.S. National Blueprint for Transportation Decarbonization. https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf

[279] Hearst Autos Research. 2021. How Much Is an Electric Car?

[280] Muehlegger and Rapson 2019.

[281] Tessum et al. 2021.

PUBLIC HEALTH BENEFITS FROM INCREASED ETHANOL FUEL CONTENT: A CASE STUDY OF NEW YORK CITY

We estimated the potential health benefits associated with the adoption of E30 gasoline blends using the motor vehicle fleet for New York City (NYC; New York, Kings, Bronx, Richmond, and Queens counties) as a case study. NYC was selected given that it would likely have higher public benefits than other US cities given its (1) high density of primary PM2.5 emissions from motor vehicles, (2) urbanicity, with large numbers of people living near roadways, and (3) high proportion of vehicle cold-starts, when PM and VOC emissions reductions for ethanol-blended fuels are greatest. We estimated public health benefits by estimating light duty vehicle (LDV) tailpipe emissions for NYC using EPA’s Motor Vehicle Emission Simulator (MOVES) model and inputting estimated emissions into the CO-Benefits Risk Assessment (COBRA) tool to estimate corresponding air quality and human health benefits.

Our analysis showed that using real-world fuel properties, the PM2.5 and VOC emissions associated with E30 are lower than E10 in NYC with modest public health benefits. When LDVs moved from E10 to E30 fuels, we found a 2% reduction in motor-vehicle associated premature deaths. This small reduction in premature deaths is consistent with the fact that (1) LDVs are responsible for ~20% of all PM2.5 emitted from mobile sources,[282] which is a significant but still small portion of all motor vehicle emissions, and that (2) primary PM emissions decrease 15-18% on average with each 10% increase in ethanol content under cold-start conditions. [283]

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[282] National Emission Inventory, 2014

[283] Kazemiparkouhi et al. 2022a

CONCLUSION

We thank the Agency for this opportunity to comment on the proposed RFS Program Standards for 2023-2025 and the related 2022 DRIA.

In Part I of our letter, we began with a review of recent iLUC studies to reveal a downward trend in corn starch ethanol iLUC estimates, reflecting a 2 to 4-fold decrease from older, unrefined estimates. We discussed the basis for our LUC estimate of 3.9 gCO2e/MJ from Scully et al. 2021 and showed that recent estimates from Europe also fall within our range of -1.0 to 8.7 gCO2e/MJ. We then addressed five examples of analysis refinements, further supporting that using updated models and the best available data inputs results in a lower range of iLUC values. We also shared a recent report by IEA in which empirical statistics do not correlate US biofuel production with LUC; this conflicts with older, unrefined models that assign a large portion of ethanol's CI to LUC.

Part II focused on the topics EPA presents for comment in the Set Proposal. We appreciate EPA's literature-focused approach to developing an updated corn starch ethanol CI value. There is sufficient updated information available for EPA to adopt, at least on an interim basis, a carbon intensity estimate that is closer to current central estimates and relies on the current state of the science. If EPA does conduct a new analysis, we ask that these numbers are made available for public review and comment before they are finalized or used to inform policy.

A major component of Part II is our evaluation of the studies EPA considers in developing a well-to-wheel CI range for corn starch ethanol in the 2022 DRIA. Given that studies represent a range of scientific quality, we presented an illustrative evaluation system EPA for assessing the studies under consideration. Our example criteria assesses whether each analysis follows a generally accepted approach, utilizes refined modeling tools, uses complete data, and documents a transparent process. We also recommend that EPA's range includes several recent studies that estimate LUC only, and we evaluate those studies as well. When we look at the expanded range, the analyses that meet all four criteria have an average well-to-wheel CI of 52 gCO2e/MJ, which is in line with the 51 gCO2e/MJ central estimate from the detailed analysis in our Scully et al. 2021 study.

Within Part II, we also encouraged EPA to amortize all CI results over 30 years and consider that advancements in GHG mitigation technologies will continue to drive reductions in the CI for corn starch ethanol. We also noted that additional research is needed to understand the full CI of the petroleum gasoline baseline. We closed this section by clarifying the takeaways from a recent article about the illustrative scenario presented in the DRIA, which shows a net reduction of GHG emissions when using the proposed biofuel volumes for 2023-2025.

And for Part III, we summarized the best available science on the relationships between ethanol, tailpipe emissions, and health. As shown by papers we have published, a recent report from CARB, and numerous other studies, higher ethanol blends are associated with reductions in emissions of multiple pollutants, including BTEX and PM. As discussed, these pollutants adversely impact health and disproportionately impact EJCs. Thus, increased use of higher ethanol blends can support the RFS's GHG reduction goals and reduce the health impacts of fuels on residents, including those living in EJCs. We encourage EPA to consider these findings when generating new policies around fuel standards.

In closing, we appreciate EPA's consideration of our feedback as the Agency continues to use the best available science to refine the CI of corn starch ethanol, understand the GHG reduction benefits of corn starch ethanol, and develop related policy to maximize these benefits.

RESOURCES

Public Comments from EH&E

- EH&E. 2022. Comments on the 2022 Workshop on Biofuel Greenhouse Gas Modeling. 1 April 2022. Available within: Comment Submitted by POET, LLC, pp. 9-37. https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0921-0047
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- EH&E. 2022. Comments on the New York State Climate Action Council Draft Scoping Plan. 1 July 2022. Available within: POET Draft Scoping Plan Comments, pp. 44-69. https://www.nyserda.ny.gov/-/media/Project/Climate/Files/2022-Comments/DSP-Comment-Cover-Letter
- EH&E. 2022. Comments on the Draft Washington Clean Fuels Program Rule (Chapter 173-424 WAC). 25 April 2022. Available within: POET Comments Re: Washington Clean Fuels Program, pp. 4-26. https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did1008/pid_202037/assets/merged/rb01iqv_document.pdf
- EH&E. 2022. Comments on the Washington Clean Fuels Program Rule (Chapter 173-424 WAC). 31 August 2022. Available within: POET Washington State Clean Fuels Program Rule Comments, pp 15-49. https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did1008/pid_202971/assets/merged/6f01ig9_document.pdf

Select Papers by EH&E Authors

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- Alarcon Falconi, T.M., Kazemiparkouhi, F., Schwartz, B. and MacIntosh, D.L., 2022. Inconsistencies in domestic land use change study. Proceedings of the National Academy of Sciences, 119(51), p.e2213961119. https://www.pnas.org/doi/abs/10.1073/pnas.2213961119
- Kazemiparkouhi, F., Falconi, T.M.A., MacIntosh, D.L. and Clark, N., 2022. Comprehensive US database and model for ethanol blend effects on regulated tailpipe emissions. Science of The Total Environment, 812, p.151426. https://www.sciencedirect.com/science/article/pii/S0048969721065049
- Kazemiparkouhi, F., Karavalakis, G., Falconi, T.M.A., MacIntosh, D.L. and Clark, N., 2022. Comprehensive US database and model for ethanol blend effects on air toxics, particle number, and black carbon tailpipe emissions. Atmospheric Environment: X, 16, p.100185. https://www.sciencedirect.com/science/article/pii/S0048969721065049

Additional Studies We Recommend for EPA's Range

- Carriquiry, M., Elobeid, A., Dumortier, J. and Goodrich, R., 2019. Incorporating sub-national Brazilian agricultural production and land-use into US biofuel policy evaluation. Applied Economic Perspectives and Policy, 42(3), pp.497-523. https://onlinelibrary.wiley.com/doi/abs/10.1093/aepp/ppy033
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Criticisms of Lark et al. 2022 Study

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- Taheripour, F., Mueller, S., Kwon, H., Khanna, M., Emery, I., Copenhaver, K., Wang, M. and CropGrower, L.L.C., 2022. Response to comments from Lark et al. regarding Taheripour et al. March 2022 comments on Lark et. al. original PNAS paper. https://greet.es.anl.gov/files/comment_environ_outcomes_us_rfs2
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