Comments of

URBAN AIR INITIATIVE,

CLEAN FUELS DEVELOPMENT COALITION, 25x'25 ALLIANCE,

NEBRASKA ETHANOL BOARD, and

NEBRASKA ETHANOL INDUSTRY COALITION

On the U.S. Environmental Protection Agency's Proposed Rule

RENEWABLE FUEL STANDARD PROGRAM:

STANDARDS FOR 2018

AND BIOMASS-BASED DIESEL VOLUME FOR 2019

Docket ID No. EPA-HQ-OAR-2017-0091

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EXECUTIVE SUMMARY

Urban Air Initiative, Clean Fuels Development Coalition, 25x'25 Alliance, Nebraska Ethanol Board, and Nebraska Ethanol Industry Coalition (Commenters) respectfully submit these comments on the United States Environmental Protection Agency's Proposed Rule: *Renewable Fuel Standard Program: Standards for 2018*. In the Proposed Rule, EPA continues to ignore new data concerning ethanol's lifecycle emissions of greenhouse gases (GHG). EPA last conducted a lifecycle analysis (LCA) in its regulatory impact analysis accompanying the 2010 Renewable Fuel Standard (RFS) Rule. Seven years later, EPA continues to rely on its outdated 2010 LCA to meet its cost-benefit analysis obligations and to approve pathways under the RFS.

Despite EPA's recognition that the Proposed Rule is "an economically significant regulatory action," EPA admits that it "ha[s] not quantified benefits for the 2018 proposed standards." EPA is required by Executive Order to "use the best available techniques to quantify anticipated present and future benefits and costs as accurately as possible." But the Proposed Rule offers merely an "illustrative" analysis of costs limited to wholesale fuel costs and justifies its failure to conduct a full cost-benefit analysis by pointing to the 2010 LCA. This does not satisfy EPA's cost-benefit obligation, because the Agency has failed to update the 2010 LCA, despite "committing" in 2010 "to further reassess . . . the lifecycle estimates."

In addition, EPA's continued reliance on its outdated 2010 LCA increases RFS compliance costs by making it harder for existing ethanol producers to qualify under the 20% threshold needed to generate non-grandfathered RINs.

EPA's continued reliance on the 2010 LCA is improper. The best available science shows that blending ethanol into gasoline reduces emissions of GHGs far more than EPA projected in 2010. In particular, new evidence shows that:

- Increased demand for corn causes much less land-use change and related emissions than EPA predicted in 2010. This evidence includes improved economic models and newly available land-use data from periods of increasing corn ethanol production, which show significant increases in yield but no significant increases in forest conversion.

- Improved agricultural practices and technologies are substantially reducing the carbon intensity of ethanol by increasing the soil carbon that is captured from the atmosphere by the corn plant and retained deep below ground. This evidence includes a growing body of science demonstrating that conservation tillage practices sequester more carbon in the soil than previously thought. In fact, the evidence suggests that many corn fields are net carbon "sinks," capturing more carbon than land-use change and corn farming releases.
- More efficient agricultural practices and technologies have reduced nitrogen fertilizer losses of the greenhouse gas nitrous oxide (N_2O), and updated guidance has reduced the weight given to N_2O compared to other GHG pollutants.
- Ethanol plants have become much more efficient, as yields have continued to increase. Ethanol plants are also producing new co-products that reduce the carbon intensity of ethanol. In addition to distillers' grains, used as animal feed, ethanol plants now produce corn oil, which replaces soy-based biodiesel.
- By contrast, petroleum-based fuels are becoming increasingly carbon-intensive. As a result, the gasoline carbon intensity baseline is higher than EPA suggested, increasing the comparative benefit of corn ethanol.

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A review of the scientific literature confirms that EPA fundamentally erred in the conclusions it reached in 2010 about the lifecycle GHG emissions of corn ethanol. A recent study by the Department of Agriculture estimates that corn ethanol produces 43% and 48% less greenhouse gas emissions than EPA's gasoline baseline, in 2014 and 2022, respectively, without fully accounting for soil carbon sequestration. But despite a growing body of updated scientific studies, EPA continues to rely on its 2010 LCA in the Proposed Rule. We urge EPA to correct its 2010 LCA or adopt USDA's updated model and to conduct a new cost-benefit analysis in light of the best available science.

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INTRODUCTION

In 2010, EPA conducted a comprehensive lifecycle analysis of corn ethanol and gasoline in support of its RFS program (2010 LCA).[1] EPA's 2010 LCA included GHG emission inventories based on future industry projections and the scientific evidence available at the time.[2] As EPA noted, that data was subject to many uncertainties.[3] EPA "recognize[d] that as the state of scientific knowledge continues to evolve in this area, the lifecycle GHG assessments for a variety of fuel pathways will continue to change."[4] EPA therefore committed to "further reassess . . . the lifecycle estimates" on an ongoing basis,[5] and to incorporate "any updated information we receive into a new assessment of the lifecycle GHG emissions performance of the biofuels being evaluated in [the 2010] rule."[6]

As EPA predicted in 2010, new science now shows that its past projections no longer represent "the best available information."[7] As summarized in a recent lifecycle analysis report commissioned by the Department of Agriculture (USDA), "a large body of information has become available since 2010—including new data,

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[1] *See* Renewable Fuel Standard Program, Regulatory Impact Analysis (2010) [hereinafter 2010 RFS RIA]. The Energy Independence and Security Act requires EPA to estimate lifecycle emissions, including emissions from land-use change. *See* 42 U.S.C. § 7545(o)(1)(H).

[2] Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, 75 Fed. Reg. 14,670, 14,785 (Mar. 26, 2010) [hereinafter 2010 RFS Rule] (representing that the 2010 LCA included the "most up to date information currently available on the GHG emissions associated with each element of the full lifecycle assessment.").

[3] *Id.* at 14,677, 14,765, 14,785. To illustrate the magnitude of EPA's scientific uncertainty, while EPA estimated a GHG reduction of 21% for corn ethanol in 2022 using advanced pathways, EPA's "95% confidence interval" ranged from a 7% to a 32% reduction. *Id.* at 14,786.

[4] *Id.* at 14,765.

[5] *Id.* at 14,765 ("Therefore, while EPA is using its current lifecycle assessments to inform the regulatory determinations for fuel pathways in this final rule, as required by the statute, the Agency is also committing to further reassess these determinations and lifecycle estimates."); *accord id.* at 14,785.

[6] *Id.*

[7] 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. at 14,785.

scientific studies, industry trends, technical reports, and updated emission coefficients—that indicates that . . . actual emissions . . . differ significantly from those projected" by EPA's 2010 LCA.[8] As the USDA study demonstrates, corn ethanol results in less GHG emissions than EPA predicted in its 2010 LCA. Thus, the best available science demonstrates that blending ethanol into gasoline lowers GHG emissions.

But despite this growing body of evidence, and despite EPA's assurances that it would reassess its initial estimates as the science evolved, the Proposed Rule fails to update EPA's 2010 cost-benefit analysis to include updated lifecycle emissions information. Instead of performing a comprehensive cost-benefit analysis based on the best available science, the Proposed Rule provides an "illustrative cost analysis for the proposed reductions" based solely on wholesale fuel costs.[9] And the Proposed Rule attempts to justify its omission by pointing out that the relevant costs and benefits, including "GHG emissions," "were analyzed in the 2010 [LCA]."[10]

EPA's failure to update its lifecycle analysis affects more than the cost-benefit analysis of the present rule. EPA also continues to evaluate corn ethanol producer pathway petitions based on the same "feedstock modeling . . . done as part of the March 2010 [LCA]."[11] This makes it harder for new producers of renewable fuel to demonstrate their eligibility for RINs under the RFS.

EPA should update its lifecycle analysis to reflect the best available science.

Part I of these comments describes the commenters' interest in the accuracy of EPA's lifecycle analysis of ethanol and gasoline. Part II explains how EPA continues to rely on its outdated 2010 LCA. Part III summarizes the best available science on

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[8] ICF, A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol 4–5 (Jan. 12, 2017) [hereinafter 2017 USDA LCA].

[9] Renewable Fuel Standard Program: Standards for 2018 and Biomass-Based Diesel Volume for 2019, 82 Fed. Reg. 34,206, 34,237 (July 21, 2017) [hereinafter Proposed Rule].

[10] *Id.*

[11] EPA, Al-Corn Clean Fuel Pathway Determination under the RFS Program 7 (Aug. 15, 2017) [hereinafter EPA, Al-Corn Determination].

the GHG emission effects of corn ethanol and gasoline and explains why EPA's 2010 LCA is inaccurate.

I. THE COMMENTERS' INTEREST IN EPA'S 2010 LCA

Urban Air Initiative is a non-profit organization dedicated to improving air quality and protecting public health by reducing vehicle emissions. UAI is focused on increasing the use of clean burning ethanol in our gasoline supply to replace harmful aromatic compounds in gasoline. UAI is helping meet public policy goals to lower emissions and reduce carbon in the environment through scientific studies and real-world data to promote new fuels, engine design, and public awareness.

The Clean Fuels Development Coalition was established in 1988 and works with auto, agriculture, and biofuels interests in support of a broad range of energy and environmental programs.

25x'25 Alliance is a national coalition united behind the goal of securing 25 percent of the nation's energy needs from renewable sources by the year 2025. The 25x'25 goal has been endorsed by nearly 1,000 partners, 35 current and former governors, 15 state legislatures and the U.S. Congress through the Energy Independence and Security Act of 2007.

The Nebraska Ethanol Board is a state agency supporting ethanol development programs throughout the state, and assisting the industry with a range of technical, marketing, and regulatory issues.

The Nebraska Ethanol Industry Coalition is a statewide non-profit organization working together on issues of common interest to their members with a particular focus on market development and expansion.

Because the best available science shows that ethanol is cleaner and gasoline dirtier than EPA believed in 2010, EPA's continued use of its 2010 LCA frustrates the commenters' mutual interest in advancing a clean, low-carbon energy future while reducing harmful air pollution.

II. EPA CONTINUES TO RELY ON ITS OUTDATED 2010 LCA.

EPA correctly classifies the Proposed Rule as "an economically significant action" subject to regulatory review under the relevant Executive Orders.[12] Therefore, "in deciding . . . how to regulate[,]" EPA "should assess all costs and benefits of available regulatory alternatives" and "select those approaches that maximize net benefits."[13] In assessing the costs and benefits of the Proposed Rule, EPA must "use the best available techniques to quantify anticipated present and future benefits and costs as accurately as possible."[14] Moreover, EPA must "ensure the objectivity of any scientific and technological information and processes used to support the agency's regulatory actions."[15] In short, the Proposed Rule must be "based on the best available science."[16]

But in the Proposed Rule, EPA's analysis "do[es] not take into consideration the benefits of the program."[17] Eschewing "comprehensive estimates" of the Proposed Rule's costs and benefits, EPA offers only simplistic analyses of the cost of producing the additional volumes of ethanol required to be blended with the cost of producing an energy-equivalent amount of gasoline.[18] EPA provides these estimates "solely for the purpose of illustrating how the cost to produce a gallon of 'representative' renewable fuels could compare to the costs of producing petroleum fuels"[19]—not to assess the actual costs and benefits of its annual standard. For

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[12] Proposed Rule, *supra* note 9, 82 Fed. Reg. at 34,243.

[13] Exec. Order No. 12,866 § 1(a), 3 C.F.R. 638 (1994), *reprinted as amended* in 5 U.S.C. § 601 app. at 45-49 (2006).

[14] Exec. Order No. 13,563 § 1(c), 76 Fed. Reg. 3,821, 3,821 (Jan. 18, 2011).

[15] *Id.* § 5, 76 Fed. Reg. at 3,822.

[16] *Id.* § 1, 76 Fed. Reg. at 3,821.

[17] Proposed Rule, *supra* note 9, 82 Fed. Reg. at 34,238.

[18] *Id.* at 34,237.

[19] *Id.*

analysis of the impacts of the RFS generally, the Proposed Rule directs the reader to EPA's cost-benefit analysis performed "in the 2010 final rulemaking."[20]

But EPA's cost-benefit analysis was premised on its erroneous 2010 LCA. EPA must update its analysis of the lifecycle emissions of ethanol and gasoline to enable a comprehensive evaluation of the costs and benefits of the Proposed Rule and the RFS program as whole.

In addition, EPA continues to rely on its 2010 LCA to implement the RFS. Under the RFS program, non-grandfathered ethanol fuel must "achieve[] at least a 20 percent reduction in in lifecycle greenhouse gas emissions compared to baseline lifecycle greenhouse gas emissions."[21]

In its March 2010 rule, EPA finalized pathways that corn ethanol producers could use to generate corn ethanol renewable identification number credits under the RFS.[22] These pathways are based on EPA's 2010 LCA, which concluded that by 2022, corn ethanol plants using natural gas and corn oil fractionation technology would achieve annual lifecycle greenhouse gas (GHG) emissions savings of only 21% compared to EPA's 2005 gasoline carbon intensity baseline of 93 grams of carbon dioxide equivalent per megajoule (g CO_2e/MJ).[23] By contrast, EPA predicted that grandfathered ethanol plants that do not use advanced technologies would

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[20] *Id.*

[21] 42 U.S.C. § 7545(o)(2)(A)(i).

[22] 40 C.F.R. § 80.1426(f)(1).

[23] 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. at 14,786 ("The results for this corn ethanol scenario are that the midpoint of the range of results is a 21% reduction in GHG emissions compared to the gasoline 2005 baseline."); 2010 RFS RIA, *supra* note 1, at 469–70. EPA's central estimate of corn ethanol's carbon intensity in 2022 using these technologies was 79 kg CO_2e/mmBTU (million British thermal units), *id.* at 14,788, which is equivalent to 74.9 g CO_2e/MJ. EPA reported the carbon intensity baseline for 2005 gasoline at 98.2 kg CO_2e/mmBTU, which is equivalent to 93.1 g CO_2e/MJ. 2010 RFS RIA, *supra* note 1, at 467.

The conversion factor used to convert kg CO_2e/mmBTU to g CO_2e/MJ is 0.947817. All carbon intensity numbers are rounded to a single decimal.

achieve only a 16.8% reduction in GHG emissions relative to 2005 gasoline.[24] EPA continues to use its 2010 LCA to evaluate ethanol producer petitions.[25]

Over half of the assessed GHG emissions of the typical grandfathered ethanol plant are estimated "upstream emissions" over which these ethanol plants have no control—the emissions from changes in international land-use patterns, as well as domestic farm inputs and emissions from fertilizer.[26] This high estimate of upstream emissions makes it more difficult for new corn ethanol producers to qualify to generate non-grandfathered RINs, and this in turn increases the cost of RINs. EPA should update its 2010 LCA to reduce these compliance costs.

III. EPA'S GREENHOUSE GAS EMISSIONS ESTIMATES ARE ERRONEOUS.

While EPA's findings were doubtful in 2010, they are now demonstrably erroneous, given the wealth of newly available scientific and economic data that undermines EPA's 2010 LCA. As a lifecycle analysis of corn ethanol GHG emissions commissioned by USDA recently found, "a large body of information has become available since 2010—including new data, scientific studies, industry trends, technical reports, and updated emission coefficients—that indicates that . . . actual emissions . . . differ significantly from those projected" by EPA's 2010 LCA.[27] Using this updated information, USDA's study—which largely tracks the methodology of EPA's 2010 LCA—estimates that in 2014 corn ethanol was 43% less carbon-intensive than EPA's 2005 gasoline baseline, and that corn ethanol's advantage will grow to 48% by 2022.[28] This is a much greater benefit that EPA's median estimate

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[24] EPA, Al-Corn Determination, *supra* note 11, at 11, Table 2.

[25] *Id.*

[26] *Id.*; 2010 RFS RIA, *supra* note 1, at 470.

[27] 2017 USDA LCA, *supra* note 8, at 4–5.

[28] *Id.* at 166. The study estimated corn ethanol's lifecycle emissions at 55,731 g CO_2e/MMBtu in 2014, equivalent to 52.8 g CO_2e/MJ, *id.* at 151, and at 50,553 g CO_2e/MMBtu in 2022, *id.* at 166, equivalent to 47.9 g CO_2e/MJ.

that corn ethanol will produce only 21% less greenhouse gas emissions than baseline gasoline in 2022.[29]

Studies by the Department of Energy confirm that EPA's 2010 LCA understates corn ethanol's carbon reduction benefit. The Department of Energy's influential model of transportation sector GHG emissions (the GREET model) estimated a 35% lifecycle GHG emissions reduction for corn ethanol produced in 2015 compared to 2005 gasoline.[30] And Department of Energy scientists have suggested that further improvements in corn ethanol production "could render corn ethanol as having a 50% reduction in life-cycle GHG emissions as compared to gasoline."[31]

Corn ethanol's relative carbon intensity is even lower than these numbers suggest, because the carbon intensity of gasoline has increased since 2005, even as ethanol's carbon intensity has steadily fallen.[32]

EPA should evaluate the costs and benefits of ethanol blending in light of the best available science concerning the lifecycle emissions of ethanol and gasoline. Section A will address upstream emissions from corn production, including indirect emissions from land-use change, emissions from domestic land-use change, and emissions from domestic and international farm input and fertilizer nitrous oxide

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[29] 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. at 14,786.

[30] *See* Zhichao Wang et al., *Influence of Corn Oil Recovery on Life-Cycle Greenhouse Gas Emissions of Corn Ethanol and Corn Oil Biodiesel*, 8 Biotechnol. Biofuels 178, 178, 183, Fig. 3 (2015) (using GREET2015 to estimate an average corn-ethanol carbon intensity of 62 to 59 g CO_2e/MJ); Susan Boland & Stefan Unnasch, Life Cycle Associates, GHG Emissions Reductions Due to RFS, LCA.6075.11.2015, at 9 (2015) (using GREET2015 to estimate an average corn ethanol carbon intensity of 59.2 g CO_2/MJ).

[31] Wang et al., *supra* note 30, at 186.

[32] Amgad Elgowainy et al., *Energy Efficiency and Greenhouse Gas Emission Intensity of Petroleum Products at U.S. Refineries*, 48 Envtl. Sci. & Tech. 7612, 7623 (2014) (estimating that the "total life-cycle GHG emissions for gasoline" are 94 g CO_2e/MJ); *see also* Hao Cai et al., *Well-to-Wheels Greenhouse Gas Emissions of Canadian Oil Sands Products: Implications for U.S. Petroleum Fuels*, 49 Envtl. Sci. & Tech. 8219 (2015) (predicting greater emissions due to the growing share of Canadian oil sands gasoline in the U.S. market).

(N_2O) emissions.[33] Section B will address biorefinery emissions. Section C will discuss gasoline's lifecycle emissions.

A. Corn Production

EPA's estimate of "upstream emissions" from corn production (and its alleged indirect effects), accounts for the majority of the GHG emissions that the 2010 LCA attributes to corn ethanol.[34] Within upstream emissions, international land-use change emissions (ILUC) account for the greatest fraction (40%) of EPA's estimate of corn ethanol's carbon intensity, followed by domestic farm input and fertilizer emissions (13%) and international farm input and fertilizer emissions (7%).[35] *See* Figure 1.

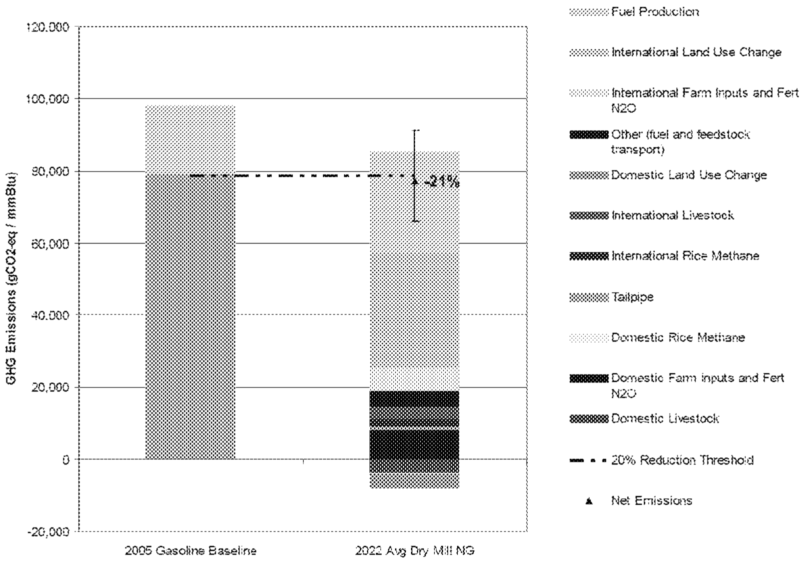

Figure 1: 2010 RFS RIA (Figure 2.6-2)

New evidence has exposed significant flaws in EPA's estimate of corn ethanol's upstream GHG emissions. Updated models and empirical evidence of actual land-use patterns demonstrate that carbon emissions from land-use change are much lower than the estimate in EPA's 2010 LCA. EPA's assessment of domestic and international farm input and fertilizer N_2O emissions, are also outdated and in need of correction. As explained below, correcting these upstream emission estimates based on the updated science noted in

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[33] These comments do not address all GHG emission categories included in EPA's 2010 LCA. For a comprehensive, updated analysis, see 2017 USDA LCA, *supra* note 8.

[34] 2010 RFS RIA, *supra* note 1, at 470, Figure 2.6-2.

[35] *See id.*

the USDA's study would reduce EPA's estimate of corn ethanol's upstream emissions in these categories from 45.5 g to 11.1 g CO_2e/MJ in 2022—a 76% reduction. *See* Table 1.

Table 1: EPA Upstream Emissions Compared to Updated USDA Upstream Emissions

Upstream Emissions	EPA 2022 (g CO_2e/MJ)	USDA 2014 (g CO_2e/MJ)	Δ (g CO_2e/MJ)	USDA 2022 BAU (g CO_2e/MJ)	Δ (g CO_2e/MJ)
ILUC	30.3	1.3	-29.1	1.3	-29.1
Dom. Farm	9.8	8.6	-1.2	7.8	-2
Intl. Farm	5.4	2.1	-3.3	2.1	-3.3
Total	45.5	12.0	-33.6	11.1	-34.4

In addition, EPA's analysis of domestic land-use change does not account for the adoption of crop management techniques that improve soil carbon sequestration in corn croplands, particularly when combined with corn ethanol's high yields. Accounting for these practices would further reduce corn ethanol's emissions.

1. International Land-Use Change Emissions

EPA's 2010 LCA estimated ILUC emissions for corn ethanol in 2022 at 30.3 g CO_2e/MJ, accounting for 40% of corn ethanol's estimated carbon intensity.[36] As EPA explained, "the majority of international land use change emissions originate in Brazil . . . . This is largely as a consequence of projected pasture expansion . . . especially in the Amazon region where land clearing causes substantial GHG emissions."[37] Indeed, in EPA's 2010 LCA, more than two-thirds of corn ethanol's predicted ILUC emissions were attributable to predicted land-use changes in Brazil.[38]

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[36] 2010 RFS RIA, *supra* note 1, at 407, Table 2.4-47 (estimating ILUC at 31.8 kg CO_2e/mmBTU); 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. at 14,788.

[37] 2010 RFS RIA, *supra* note 1, at 470.

[38] *Id.* at 470 (showing that 22 out of 31.8 kg CO_2e/mmBTU are attributable to Brazil).

At the time, EPA acknowledged that these results were subject to great uncertainty.[39] In fact, the estimates reported in these early analyses were never accurate, and they have since been refuted by the best available science.

Parameters related to intensification, yield improvement, land displacement, and the type of land converted are key drivers of ILUC emissions, but EPA's models failed to accurately reflect these complexities. For example, EPA's ILUC model does not "distinguish what types of land will be affected by a given shock to the agricultural system."[40] More recent models of indirect land-use change have included "a more detailed assessment of yield improvement, land cover type, soil carbon stocks, and other parameters," resulting in significantly lower estimates of land-use change emissions.[41]

EPA's ILUC assessment in 2010 relied on outdated economic models developed by the Food and Agricultural Policy and Research Institute, maintained by the Center for Agricultural and Rural Development (FAPRI-CARD).[42] EPA also "opted to use the GTAP [Global Trade Analysis Project] model to inform the range of potential GHG emissions associated with land use change resulting from an increase in renewable fuels."[43]

Since 2010, more accurate land-use change models have shown that EPA's initial estimates were too high.[44] As one recent study explained, "prior to the last couple of years, there was insufficient data on global land-use change during the

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[39] 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. at 14,765 ("The indirect, international emissions are the component of our analysis with the highest level of uncertainty.").

[40] 2017 USDA LCA, *supra* note 8, at 121.

[41] Boland & Unnasch, *supra* note 30, at 20.

[42] The agency used FAPRI-CARD to model international land-use emissions, and FASOM to model domestic emissions. 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. at 14,768.

[43] *Id.* at 14,781.

[44] *See, e.g.*, Jennifer B. Dunn et al., *Land-use change and greenhouse gas emissions from corn and cellulosic ethanol*, 6 Biotech. for Biofuels 51 (2013).

biofuels boom era. However, now we have that data, and it can be used to better calibrate prior estimates of land-use change."[45] Accordingly, Purdue's agricultural economists recalibrated the GTAP model in 2013.[46] As a result of these changes, the GTAP model now projects "less expansion in global cropland due to ethanol expansion"; a "lower U.S. share in global cropland expansion"; and a "lower forest share in global cropland expansions."[47] More recently GTAP analysts have also refined the land carbon stock estimates used by the model.[48] Department of Energy scientists now say that, in light of GTAP model refinements, a more realistic estimate of corn ethanol's ILUC emissions is 5.1 g CO_2e/MJ.[49] EPA's ILUC estimate should be corrected using the updated GTAP model to accord with the Department of Energy's estimate.

Even more importantly, EPA failed to account for the intensification of agriculture in its ILUC estimate. Empirical data cited in USDA's new study has discredited EPA's predicted ILUC emissions in Brazil and other countries: corn ethanol has not significantly increased deforestation in the Amazon region or elsewhere.[50] Contrary to EPA's FAPRI-CARD model predictions, empirical evidence shows that during the period of corn ethanol expansion, Brazilian deforestation actually fell significantly, and farmers responded to changes in price primarily by using available land resources more efficiently—mostly by harvesting

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[45] *See, e.g.*, Farzad Taheripour & Wallace E. Tyner, *Biofuels and Land-use Change: Applying Recent Evidence to Model Estimates*, 3 Appl. Sci. 14, 15 (2013).

[46] *Id.*

[47] *Id.*

[48] *See, e.g.*, Holly Gibbs et al., New Estimates of Soil and Biomass Carbon Stocks for Global Economic Models, Global Trade Analysis Project (GTAP) Tech. Paper No. 33, at 21 (2014), *available at* http://bit.ly/1TuJq98.

[49] *See* Jennifer B. Dunn et al., DOE Argonne Nat'l Lab., Carbon Calculator for Land Use Change from Biofuels Production, ANL/ESD/12-5, at 25 (2016), *available at* http://1.usa.gov/1M84WIT.

[50] *See* 2017 USDA LCA, *supra* note 8, at 60–66.

land more often ("double cropping")—not expanding acreage.[51] That is particularly true for Brazil.[52]

EPA's 2010 LCA, however, does not take into account the "non-yield" intensification of cropland through techniques like double cropping.[53] Thus, EPA overstated the carbon intensity of corn ethanol.[54] As the USDA's recent lifecycle analysis shows, when the updated 2013 GTAP model is further adjusted to account for this new empirical evidence, ILUC emissions for corn ethanol fall to an almost insignificant 1.3 g CO_2e/MJ.[55]

Despite this new evidence, EPA's 2016 response to a Request for Correction of Information (RFC) submitted by Urban Air Initiative stated that no correction to its ILUC estimate for corn ethanol was required. The Agency claimed that because "[s]tudies published between 2011 and 2015 vary" widely and EPA's estimate "is still within the range.[56] Six of the twelve studies cited by EPA, however, are European biofuel studies of no apparent relevance to ILUC emissions from corn ethanol produced in the United States.[57] Another study cited by EPA is based on a 2009 working paper that uses the same erroneous FAPRI-CARD model as EPA's

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[51] *Id.* (citing Bruce A. Babcock & Zabid Iqbal, *Using Recent Land-use Changes to Validate Land-use Models*, 14-SR 109 (2014)).

[52] *See id.* at 63 (showing that 76% of the increase in harvested land in Brazil is due to changes in double cropping).

[53] *See* Babcock & Iqbal, *supra* note 51, at 20–22 (criticizing the FAPRI-CARD model).

[54] *See id.* ("The pattern of recent land use changes suggests that existing estimates of greenhouse gas emissions caused by land conversions due to biofuel production are too high because they are based on models that do not allow for increases in non-yield intensification of land use. Intensification of land use does not involve clearing forests or plowing up native grasslands that lead to large losses of carbon stocks.).

[55] 2017 USDA LCA, *supra* note 8, at 125, Table 3.43 (estimating ILUC emissions at 1,326 g CO_2e/mmBTU).

[56] EPA, Response to RFC 16003, at 1 (Dec. 8, 2016), *available at* https://www.epa.gov/sites/production/files/2016-12/documents/epa_response_to_rfc_16003.pdf.

[57] *See id.* at 1, nn. 4, 6, 8, 9, 10, 11 (citing studies).

2010 LCA analysis.[58] In the other studies EPA cited in its response to the RFC, the mean ILUC emissions are lower than EPA's 2010 estimate.[59]

USDA's study shows that a plausible range of ILUC emissions from corn ethanol based on recent scientific estimates extends from 18.9 g CO_2e/MJ to 1.3 g CO_2e/MJ, significantly below EPA's 2010 LCA estimate of 30.3 g CO_2e/MJ.[60]

2. Domestic Land-Use Change Emissions

In its 2010 LCA, EPA estimated that corn ethanol's domestic land use change emissions would reduce corn ethanol's carbon intensity by 3.8 g CO_2e/MJ.[61] EPA developed its estimate using the Forest and Agricultural Sector Optimization Model designed by Texas A&M.[62]

This estimate may be too low, because EPA's model assumes corn ethanol is grown with conventional tilling practices.[63]

Since EPA's 2010 LCA, new evidence has demonstrated that reduced tillage practices—particularly no-till agriculture—significantly increase soil organic carbon in corn soils. A multiyear study of South Dakota surface soil samples (0-15 cm in depth), led by soil scientist David Clay, found clear evidence that no-tillage practices (and higher corn yields) increase soil carbon sequestration.[64] The study used laboratory surface soil samples submitted by agricultural producers. From the

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[58] *Id.* at 1 n.3 (citing Jerome Dumortier et al., Sensitivity of Carbon Emission Estimates from Indirect Land-Use Change, Working Paper, 09-WP 493 (July 2009), http://www.card.iastate.edu/products/publications/pdf/09wp493.pdf.)

[59] *See id.* at 1, n. 5, 7, 12, 13, 14 (citing studies).

[60] 2017 USDA LCA, *supra* note 8, at 127, Figure 3-4.

[61] 2010 RFS RIA, *supra* note 1, at 362, Figure 2.4-19.

[62] *Id.* at 355.

[63] 2017 USDA LCA, *supra* note 8, at 155.

[64] *See* David E. Clay et al., *Corn Yields and No-Tillage Affects Carbon Sequestration and Carbon Footprints*, 104 Agron. J. 763 (2012) [hereinafter Clay et al., *Carbon Sequestration*]; *see also* David Clay et al., *Tillage and Corn Residue Harvesting Impact Surface and Subsurface Carbon Sequestration*, 44 J. Environ. Qual. 803 (2015) [hereinafter Clay et al., *Tillage and Corn Residue*].

laboratory results, Clay concluded that the soils studied were now net "carbon sinks," thanks, in part, to the adoption of reduced tillage and no-tillage practices, as well as increased corn crop yields over the years.[65] Over a period of three years, Clay found that the average carbon sequestration rate was 341 kg of carbon per hectare per year.[66] Over a longer period of 25 years, Clay concluded that the average carbon sequestration rate was 386 kg of carbon per hectare per year.[67] This is equivalent to an annual carbon intensity credit of 18.2 CO_2e/MJ for that time period.[68]

Studies of deeper soil samples have shown even greater increases in soil carbon from reduced tillage. For example, a 2012 USDA study collected soil samples from as deep as 150 cm below the surface of experimental no-till fields in Nebraska, measuring changes in soil organic content over nine years.[69] The study found that improved agricultural management practices can double or even quadruple total soil organic carbon when deep soil is taken into account.[70] The study found average annual increases of more than 2 metric tons of soil organic carbon per hectare, with over 50% of the carbon sequestered deeper than 30 cm in the soil profile.[71] The sequestration rates found by the study "greatly exceed the soil carbon credits that have been used in modeling studies to date for maize and switchgrass grown for bioenergy."[72] Other recent USDA studies have reached similar results.[73]

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[65] Clay et al., *Carbon Sequestration*, *supra* note 64, at 769.

[66] *Id.* at 768.

[67] *Id.*

[68] *See* Appendix, *infra* p. 23.

[69] Ronald F. Follett et al., *Soil Carbon Sequestration by Switchgrass and No Till Maize Grown for Bioenergy*, 5 Bioenerg. Research 866, 867 (2012), *available at* http://bit.ly/1QIHAPv.

[70] *Id.* at 867.

[71] *Id.* at 873.

[72] *Id.*

[73] *See* Ardel D. Halvorson & Catherine E. Stewart, *Stover Removal Affects No-Till Irrigated Corn Yields, Soil Carbon, and Nitrogen*, 107 Agron. J. 1504 (2015).

In light of these studies, EPA should update its lifecycle analysis to include a pathway for corn cultivated with reduced tillage practices.[74]

3. Domestic Farm Inputs and Fertilizer N_2O

According to EPA's 2010 LCA, domestic farm inputs accounted for 9.8 g CO_2e/MJ of corn ethanol's lifecycle emissions in 2022, or 13% of total lifecycle emissions.[75] A significant fraction of these emissions result from N_2O emissions from the application of nitrogen fertilizer to corn fields, as the applied nitrogen is released as N_2O through a biochemical process of microbial "nitrification" and "denitrification" that is stimulated when nitrogen fertilizer application exceeds plant needs.[76]

EPA's estimate for domestic farm inputs needs correction for at least two reasons. First, it uses outdated U.N. Intergovernmental Panel on Climate Change (IPCC) guidelines to calculate the effect of N_2O emissions on global warming. Second, it ignores available technologies that reduce N_2O emissions by reducing fertilizer losses.

a. The 2010 LCA Uses Outdated IPCC Guidelines.

Because a molecule of N_2O contributes more to climate change than a molecule of CO_2, a conversion factor, known as a global warming potential (GWP), is used to convert N_2O emissions to a CO_2-equivalent.[77] For its 2010 LCA, EPA used the GWP from the IPCC's Second Assessment Report, which was 310.[78] This value is outdated. The IPCC's Fourth and Fifth Assessments both recommend a lower GWP of 298 for N_2O, and in 2013, the UN updated its GHG reporting guidelines to

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[74] *See* Appendix, *infra* p. 55 (estimating carbon intensity credits from several studies).

[75] 2010 RFS RIA, *supra* note 1, at 334, Table 2.4-13.

[76] *Id.* at 330, Table 2.4-8.

[77] *Id.* at 313.

[78] *Id.* at 313, Table 2.3 3.

require EPA to use a GWP of 298 for N_2O emissions.[79] Applying this updated GWP would reduce the contribution of N_2O emissions to corn ethanol's lifecycle emissions.

b. The 2010 LCA Ignores Technologies that Reduce Farm N_2O Emissions.

Second, because the EPA's 2010 LCA does not include updated USDA data on farm practices, EPA fails to account for "an increase in crop and nutrient management strategies" that greatly decrease N_2O losses.[80] The most important technologies that EPA's 2010 LCA ignores are the increased use of nitrification inhibitors to delay the nitrification process, and the use of precision agriculture to optimize fertilizer application and minimize losses to the environment.[81]

Studies show that the use of nitrification inhibitors alone can reduce N_2O emissions from fertilizer by 19% to 60%.[82] But because EPA's 2010 LCA does not include the latest USDA data, it does not include "changes in emissions caused by these increasingly common practices."[83]

In its recent response to Urban Air Initiative's Request for Correction, EPA stated that no correction to its N_2O emissions estimate for corn ethanol was required because its projected fertilizer application rate for 2022 was not inconsistent with 2010 data.[84] But application rate is a separate issue from the GHG reductions

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[79] EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015, 1-9, 1-10 (Apr. 2017).

[80] 2017 USDA LCA, *supra* note 8, at 15–16.

[81] *Id.* at 15.

[82] *Id.* at 15–16 (collecting studies).

[83] *Id.* at 16.

[84] EPA, Response to RFC#16003, at 2 (Dec. 8, 2016) (emphasis added).

achieved by nitrification inhibitors, and EPA's data still does not account for the effect of nitrification inhibitors on N_2O losses.[85]

According to the USDA's recent study, an updated lifecycle analysis would yield a domestic farm inputs and fertilizer N_2O emissions value of 8.6 g CO_2e/MJ in 2014.[86] By 2022, the USDA study estimates these emissions will be even lower, at 7.8 g CO_2e/MJ, a significant reduction relative to EPA's estimate of 9.8 g CO_2e/MJ in 2022.[87]

4. International Farm Inputs and Fertilizer N_2O

In its 2010 RIA, EPA estimated that international farm inputs and fertilizer emissions resulting from its projected increase in corn ethanol would be 5.4 g CO_2e/MJ,[88] or 7% of total corn ethanol lifecycle emissions, mostly as a result of increased N_2O losses resulting from an increase in crop acreage abroad.[89]

This estimate is too high, for at least two reasons. First, as already mentioned, EPA applied an outdated GWP for N_2O emissions that was too high. Second, the international land-use changes on which EPA's estimate was predicated are based on outdated models, and have not in fact occurred.[90] The USDA's recent lifecycle analysis estimates a more realistic 2.1 g CO_2e/MJ for international farm inputs and NO_2 emissions from fertilizer, significantly below EPA's 2010 LCA estimate.

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[85] 2017 USDA LCA, *supra* note 8, at 15 (stating that while USDA data "already reflect the effects of precision agriculture through the reduced fertilizer use per bushel of corn harvest . . . use of nitrification inhibitors is not reflected in estimation of N_2O emissions.").

[86] *Id.* at 95, Table 3-10.

[87] *Id.* at 157, Table 4-3.

[88] 2017 USDA LCA, *supra* note 8, at 95, Table 3-47 (reporting EPA's value at 5,720 g CO_2/mmBTU).

[89] *See* 2010 RFS RIA, *supra* note 1, at 342, Table 2.4-16 (estimating corn ethanol international N_2O emissions at 3.38 kg CO_2e/mmBTU).

[90] 2017 USDA LCA, *supra* note 8, at 95.

B. Ethanol Fuel Production

In its 2010 LCA, EPA estimated that ethanol fuel production at biorefineries would account for 28.4 g CO_2/MJ, or 38% of EPA's estimated carbon intensity for corn ethanol.[91] This value needs to be corrected because it underestimates ethanol plant yields and it fails to fully account for corn ethanol co-products.

1. Ethanol Plant Yields

EPA's estimate of ethanol fuel production emissions is in part a result of its underestimation of the ethanol yield—the amount of ethanol that biorefineries produce from each bushel of corn. EPA's 2010 LCA predicted a yield of "2.71 gallons per bushel for dry mill plants and 2.5 gallons per bushel for wet mill plants."[92] This implies a weighted average yield of 2.63 gallons per bushel for ethanol plants.[93]

Based on recent data from the Energy Information Administration and USDA, the current average yield for both wet and dry mill ethanol plants is 2.84 gallons per bushel, significantly above the yields built into EPA's models.[94] Correcting the 2010 LCA's yield assumption would significantly reduce EPA's estimate of ethanol fuel production emissions.

2. Corn Oil

A proper lifecycle analysis of corn ethanol would fully account for biorefinery co-products that displace GHG emissions elsewhere. EPA's based its 2010 LCA emission estimated in part on the assumption that "70% of dry mill ethanol plants"

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[91] *Id.* at 145, Table 3-63 (reporting EPA's value).

[92] 2010 RFS RIA, *supra* note 1, at 425.

[93] EPA estimated ethanol plants in 2022 would consist of 63% dry mill and 37% wet mill. *Id.* at 471, Figure 2.6-3.

[94] *See* Renewable Fuels Ass'n, Industry Statistics: Monthly Implied Average Ethanol Yield (Gallons per Bushel) (last updated August 1, 2017), *available at* http://www.ethanolrfa.org/resources/industry/statistics/#1461259890924-697180ef-b2a8 (reporting an average yield for 2016 of 2.84).

would extract corn oil for use as biodiesel in 2022.[95] More recently, Department of Energy scientists estimated that as of 2014, over 80% of the dry mill ethanol plants now generate corn oil for biodiesel plants.[96] A bushel of corn currently produces about 0.55 pounds of corn oil.[97] And corn oil displaces soy oil used as a feedstock for biodiesel, reducing GHG emissions.[98] GREET has been updated to include a one-to-one displacement credit to account for the displacement of soy oil.[99] But EPA has not updated its 2010 LCA to reflect the increase in corn oil co-products.

C. Gasoline Lifecycle Emissions

Since EPA's 2010 LCA, petroleum-based fuels have become more carbon-intensive. As a result, the baseline gasoline carbon intensity value that EPA relied upon in the 2010 RFS Rule is inaccurate. Even if EPA is obligated to use an arbitrary 2005 petroleum baseline to approve renewable fuel pathways,[100] EPA *is not* obligated to use that baseline to calculate the GHG benefits of the program. As the National Academy of Sciences noted in 2011, a proper "comparison scenario" for ethanol should include marginal GHG emissions "resulting from any change in the use of oil sands and other nonconventional sources of petroleum."[101] Because gasoline's carbon

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[95] *See* 2010 RFS RIA, *supra* note 1, at 428.

[96] *See* Zhichao Wang et al., Argonne Nat'l Lab., Updates to Corn Ethanol Pathway and Development of an Integrated Corn and Corn Stover Ethanol Pathway on the GREET Model, ARGONNE/ESD-14/11 (2014).

[97] *See* Scott Irwin, *The Profitability of Ethanol Production in 2015*, 6 Farmdoc Daily, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, (Jan. 6, 2016), *available at* http://bit.ly/1phwLdh.

[98] Wang, *supra* note 96, at 4.

[99] *Id.* at 5.

[100] *See* 42 U.S.C. §§ 7545(o)(1)(C), 7545(o)(2)(A)(i).

[101] NRC, Renewable Fuel Standard, Potential Economic and Environmental Effects of U.S. Biofuel Policy 195 (2011).

intensity has increased, the corresponding GHG benefits of the RFS have also increased.

Gasoline GHG emissions are trending upwards because of increased "use of oil sands and other nonconventional sources of petroleum."[102] Unlike renewable fuel producers, which are required to achieve lifecycle reduction benefits to qualify for the RFS, EPA does not hold gasoline producers accountable for their increased lifecycle GHG emissions.[103]

Methane flares from shale oil extraction have increased GHG emissions from oil production.[104] Tar sand recovery often requires carbon-intensive steam injection, additional carbon-intensive processing to separate bitumen from tar sands, and chemicals to reduce the viscosity of the product for transportation, increasing extraction emissions.[105] Emissions associated with refining a barrel of tar sand oil are also higher.[106] And even conventional oil is becoming more carbon-intensive. Oil

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[102] Jeremy Martin, Union of Concerned Scientists, Fueling a Clean Transportation Future, at 1 (2016) ("As oil companies increasingly go after unconventional, hard-to-reach sources such as tar sands and use more intense extraction techniques such as hydraulic fracturing (fracking), dirtier sources of oil have become an increasingly large part of the mix, and wasteful practices are needlessly increasing emissions."). Oil is the largest fossil fuel contributor to global warming in the United States, contributing more than coal and natural gas. *Id.* at 8. For other studies on the high marginal emissions of unconventional oil sources, see Deborah Gordon et al., Know Your Oil: Creating a Global Oil-Climate Index, Carnegie Endowment for Global Peace (2015); Susan Boland & Stefan Unnasch, Life Cycle Associates, Carbon Intensity of Marginal Petroleum and Corn Ethanol Fuels, LCA.6075.83.2014 (2014).

[103] *See* Martin, *supra* note 102, at 5 ("[E]lectricity and biofuels are getting cleaner because producers are subject to careful scrutiny of the global warming emissions associated with the fuels' production, and public policy is holding producers accountable to reduce these emissions. However, the same level of scrutiny is not being applied to the different sources and methods of producing gasoline. In addition, oil companies are not obligated to reduce emissions from their supply chains. For the United States to avoid the worst consequences of climate change, all fuel producers have to minimize their global warming pollution."). While regulation might help mitigate GHG emissions from tight oil, "[t]he most obvious way for the United States to reduce the problems caused by oil use is to steadily reduce oil consumption through improved efficiency and by shifting to cleaner fuels." *Id.* at 7, 12.

[104] *Id.* at 16–17.

[105] *Id.* at 19–20.

[106] *Id.* at 20.

producers are injecting additional steam, chemicals, and gases (including methane) to enhance oil recovery, increasing the energy and carbon intensity of conventional oil extraction.[107]

EPA's 2010 LCA understates the carbon intensity of gasoline. When EPA's skewed carbon intensity baseline for gasoline is corrected, corn ethanol is an even more attractive substitute. Because of tight oil, the Department of Energy estimated that carbon intensity of gasoline in 2014 was 94 g CO_2e/MJ, higher than EPA's 2005 baseline value.[108]

CONCLUSION

In 2010, EPA predicted that blending corn ethanol into gasoline would reduce GHG emissions. The Agency was right about that, but ethanol is even better at cutting carbon emissions than EPA gave it credit for. In the 2010 RFS Rule, EPA estimated corn ethanol would have a carbon intensity of 74.9 g CO_2 e/MJ in 2022.[109] The USDA's recent estimate is 36% lower—47.9 g CO_2e/MJ.[110] And when adjusted for the soil carbon sequestration of the corn plant, the carbon intensity of corn ethanol may fall by 18.2 g or more, depending on soil conditions, tillage practices, and corn crop yield, resulting in a carbon intensity of 29.7 g CO_2e/MJ or less.[111] At that rate, ethanol would generate at least 68% less lifecycle GHG pollution than 2005 baseline gasoline on an energy-equivalent basis. The GHG benefits of ethanol will only grow as ethanol production becomes increasingly efficient, and gasoline production continues to get dirtier.

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[107] *Id.* at 15.

[108] *See* Elgowainy et al., *supra* note 32, at 7623 (estimating that the "total life-cycle GHG emissions for gasoline" are 94 g CO_2e/MJ).

[109] 2010 RFS Rule, *supra* note 2, 75 Fed. Reg. 14,788.

[110] 2017 USDA LCA, *supra* note 8, at 166.

[111] *See* Clay et al., *Carbon Sequestration*, *supra* note 64, at 769; Appendix, *infra* p. 23.

This analysis does not account for the fuel efficiency gains that would be possible if ethanol were blended above the 10% level of most U.S. gasoline. By enabling the auto industry to produce engines with higher compression ratios and more fuel-efficient vehicles, high-octane mid-level ethanol fuel blends could achieve significant downstream, as well as upstream, GHG reductions.[112]

The data and studies that were available to EPA in 2010 were inaccurate, and they are now obsolete. The 2010 LCA is not a sound basis for estimating the costs and benefits of the Proposed Rule or for evaluating the carbon intensity of new ethanol producers. EPA must either adopt USDA's updated estimate and allow for situation-specific soil carbon adjustments, or correct the inaccuracies in its outdated lifecycle analysis to reflect the best available science.

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[112] *See Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards*, 79 Fed. Reg. 23,414, 23,528–29 (Apr. 28, 2014) ("E30 or higher ethanol blends . . . could help manufacturers who wish to raise compression ratios to improve vehicle efficiency as a step toward complying with the 2017 and later light-duty greenhouse gas and CAFE standards. This in turn could help provide a market incentive to increase ethanol use beyond E10.").

APPENDIX

Study & Year	**Clay et al (2012 Long-Term)[i]**	**Clay et al (2015)[ii]**	**Follett et al (2012)[iii]**	**Halvorson & Stewart (2015)[iv]**
Soil Depth	0-15 cm	0-30 cm	0-150 cm	0-60 cm
Tillage	Various	No-Till & Chisel	No-Till	No-Till
Study Length (years)	25	5	9	7
SOC gain (Mg. /Ha./Yr.)[v]	0.368	0.53	2.6	0.856
Avg. Corn Yield in Study (Bushels/Ha./Yr.)[vi]	334	449	240	347
Ethanol Yield (Gallons/Bushel)[vii]	921	1240	663	959
Ethanol Energy Yield (MJ/Gallon)[viii]	74,144	99,826	53,378	77,214
Grams Soil Carbon /MJ[ix]	4.96	5.31	48.71	11.09
C to CO_2 conversion (CO = C * 3.664)[x]	3.664	3.664	3.664	3.664
Credit in Grams CO_2 eq./MJ[xi]	**18.2**	**19.5**	**178.5**	**40.6**

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[i] Clay, *Carbon Sequestration*, *supra* note 64. The 2012 Clay paper includes two studies. The first, a seven-year study, estimated that surface soil carbon sequestration reduces the carbon intensity of corn ethanol by as much 19.6g CO_2e/MJ in the North-Central and Southeast regions of North Dakota. *Id.* at 769. The data in this study is based on the second study, a twenty-five year study.

[ii] Clay et al., *Tillage and Corn Residue*, *supra* note 64.

[iii] Follett et al., *supra* note 69.

[iv] Halvorson & Stewart, *supra* note 73.

[v] Soil Organic Carbon (SOC) gain is expressed in annual Megagrams (Mg.) (1 Mg. = 1,000 Kg.) of carbon sequestered per year, per hectare (ha.). The .368 Mg. SOC for Clay's 2012 study is based on the reported average over the 25 years of the study. Clay et al., *Carbon Sequestration*, *supra* note 64, at 768 ("[D]uring the past 25 yr, surface SOC amounts have increased at an average rate of 368 kg C (ha × yr).$^{-1}$"). The 2.65 Mg. SOC gain for Clay's 2015 study is based on the average SOC gain, with no stover removal. Clay et al., *Tillage and Corn Residue*, *supra* note 64, at 808 ("[I]n the combined 0- to 15- and 15- to 30-cm soil zones . . . 2.65 Mg SOC ha^{-1} were sequestered . . . in the 0% residue removal treatment[]."). The 2.6 Mg. SOC gain for Follett's study is based on the observed gain applying 120 kg/ha of nitrogen fertilizer, with no stover removal. Follett et al., *supra* note 69, at 873 ("At the 120 kg ha^{-1} N fertility rate with no stover harvest, the annual increase in soil C was 2.6 Mg ha^{-1} year.$^{-1}$[.]"). The .856 Mg. SOC gain figure for Halvorson & Stewart's study is based on the annual average, with no stover removal. Halvorson & Stewart, *supra* note 73, at 1510 ("The estimated annual rate of SOC gain from the FR [full stover retained] treatments over the 7yr of this study would have been . . . 856 kg C h^{-1} from the . . . 0 to 60-cm soil depths.").

[vi] One bushel equals 25.40 kg of corn grain. *See* Iowa State, Ag Decision Maker Metric Conversions, C6-80 (May 2013), *available at* http://bit.ly/1VxnEks. The average yield for Clay's 2012 study is based on USDA historical data for the counties tested. Nat'l Agric. Research Serv., Quick Stats, *available at* http://www.nass.usda.gov/Quick_Stats/; *see also* Clay et al., *Carbon Sequestration*, *supra* note 64, at 768 & fig. 6. The average yield for Clay's 2015 study is based on the reported yield of 11,408 kg. per ha., with no stover removal. Clay et al., *Tillage and Corn Residue*, *supra* note 64, at 806, Table 1. The average yield for Follett's study is based on the reported figure for corn grain using 120 kg of nitrogen fertilizer per ha., with no stover removal. Follett 2012, *supra* note 69, at 873. The average yield for Halvorson & Stewart's study is 8,824 kg. per ha., with no stover removal. Halvorson & Stewart, *supra* note 73, at 1507.

[vii] The ethanol yield is conservatively based on the USDA's average yield of 2.76 gallons per bushel in 2010, multiplied by the number of bushels produced every year. USDA, 2015 Energy Balance for the Corn Ethanol Industry, Table 1 (Feb. 2016).

[viii] The ethanol energy yield is based on multiplying the ethanol yield by the heating value of undenatured ethanol used by CARB: 80.53 MJ per gallon of ethanol. CARB, Calculation of Denatured Ethanol CI and CA RFG, http://bit.ly/1oCEj9k.

[ix] Grams of soil carbon are derived by converting Mg. SOC gain into grams and dividing it by the ethanol energy yield.

[x] The carbon to CO_2 conversion factor is based on a molecular weight conversion from carbon to CO_2: 1 gram of carbon = 3.664g CO_2. *See* Carbon Dioxide Information Analysis Center, Conversion Tables, Oak Ridge Nat'l Lab., Table 3, http://cdiac.ornl.gov/pns/convert.html.

[xi] The carbon intensity credit is arrived at by multiplying the carbon conversion factor by grams of soil carbon per MJ.