Comments of

THE ENERGY FUTURE COALITION, URBAN AIR INITIATIVE, GOVERNORS' BIOFUELS COALITION, 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 2017 AND BIOMASS-BASED DIESEL VOLUME FOR 2018

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EXECUTIVE SUMMARY

The Energy Future Coalition, Urban Air Initiative, Governors' Biofuels Coalition, 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 2017*. In the Proposed Rule, EPA continues to ignore new science concerning ethanol's lifecycle emissions of greenhouse gases (GHG) and other pollutants. EPA last conducted a lifecycle analysis of ethanol in the 2010 Regulatory Impact Analysis (2010 Lifecycle Analysis) accompanying EPA's 2010 Renewable Fuel Standard (RFS) Rule. Six years later, EPA continues to rely on this 2010 analysis to assess the costs and benefits of its annual standard.

Despite its recognition that the Proposed Rule is "an economically significant regulatory action," EPA admits that it "ha[s] not quantified benefits [and costs] for the 2017 proposed standards." This omission is significant, because EPA's partial waiver of the renewable fuel blending levels set by Congress diminishes the GHG, air quality, and health benefits of the RFS. EPA is required 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 "illustrat[ive]" cost-benefit analyses and relies on EPA's 2010 analysis of ethanol's lifecycle emissions.

EPA's continued reliance on the outdated 2010 Lifecycle Analysis is improper. The best available science shows that blending ethanol into gasoline has reduced emissions of GHGs and other air pollutants far more than EPA projected in 2010. EPA's emissions estimates were inaccurate when they were published six years ago, and they have only become more inaccurate in the intervening years as ethanol production has become cleaner and gasoline has become dirtier. EPA's reliance on erroneous lifecycle estimates downplays the costs of its partial waivers of the blending levels set by Congress and suppresses production of the Nation's only viable low-carbon fuel.

EPA should correct its lifecycle analysis and include a comprehensive cost-benefit analysis in the Final Rule.

GREENHOUSE GAS EMISSIONS

New evidence shows that GHG emissions from ethanol are lower than EPA predicted in its 2010 Lifecycle Analysis, and much lower than the lifecycle emissions of gasoline. 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 ability of soil to capture and retain carbon deep below ground. This evidence includes updated science on soil organic carbon, which indicates 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 also reduced the per bushel amount of nitrogen fertilizer applied to the corn crop and converted into the greenhouse gas nitrous oxide (N_2O).

- Biorefineries have become much more efficient, using less natural gas and electricity to produce each gallon of ethanol. Biorefineries are also producing new co-products that reduce the carbon intensity of ethanol. In addition to distillers' grains, used as animal feed, these include corn oil, which replaces soy-based biodiesel, and other co-products that lower the carbon intensity of corn ethanol.

- By contrast, petroleum-based fuels are becoming increasingly carbon-intensive. As a result, the gasoline carbon intensity baseline should be significantly higher than EPA suggested, increasing the comparative benefit of ethanol.

Considered in light of this new evidence, the lifecycle GHG benefits of the RFS are much greater than EPA predicted in 2010. Indeed, blending the volumes of renewable fuel called for by the RFS through 2022 would result in substantial cumulative reductions in carbon emissions. Already the RFS has prevented more than 354 million metric tons of GHG pollution, according to a recent conservative estimate, and it will result in even higher savings in the future.

EPA should also consider the following information when updating its lifecycle analysis:

- CO_2 emissions associated with the RFS ramp-up are now "sunk costs," since corn ethanol has already reached the levels projected by the RFS. Thus, continued ethanol use is substantially less carbon-intensive than EPA suggested in 2010 and offers net GHG savings compared to the gasoline it displaces.

- Other tailpipe emissions associated with conventional gasoline aromatic hydrocarbons (which ethanol can replace), produce non-GHG "climate forcing agents" such as black carbon that contribute to climate change, whereas ethanol *reduces* those emissions.

- Ethanol's pollution-reducing benefits could be even greater if it were used to produce higher-octane fuel blends, replacing toxic and carbon-intensive fuel additives while allowing carmakers to increase vehicle fuel economy through next-generation engine design.

In light of this new evidence, EPA should correct its 2010 Lifecycle Analysis to conform to the best available science.

CONVENTIONAL AIR POLLUTANTS

The Agency's 2010 Lifecycle Analysis also contains erroneous estimates of ethanol's effect on emissions of non-GHG (or "conventional") pollutants. In particular, new evidence shows that:

- Farming technologies that have increased yields and lowered carbon intensity have also reduced emissions of conventional air pollutants.

- Improved pollution control technologies and other innovations have lowered emissions from biorefineries.

- U.S. gasoline is increasingly produced from "tight oil," which does more damage to the nation's air quality because it is produced domestically and because it produces higher air toxic emissions during extraction and refining.

- The negative health effects of aromatics—the octane additives in gasoline that are displaced by ethanol—are worse than previously estimated, increasing urban particulate matter and other air toxics.

The latest fuel effects studies also show that EPA significantly underestimated the tailpipe pollution reduction benefits of E10. In particular, new evidence shows that:

- E10 reduces benzene, toluene, ethylbenzene, and xylene emissions.

- E10 reduces particulate matter, especially in modern gasoline direct injection engines.

- E10 also reduces dangerous polycyclic aromatic hydrocarbons, as well as secondary organic aerosols.
- E10 reduces nitrogen oxide emissions.
- E10 reduces emissions of volatile organic compounds.

In addition to the emissions reductions ethanol has already achieved, transitioning to gasoline blends with a higher ethanol content, such as E30, would further reduce lifecycle emissions and improve air quality.

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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 emissions of GHGs and other pollutants from ethanol. Despite significant improvements in the relevant technology and a growing body of updated scientific studies, EPA continues to rely on its 2010 Lifecycle Analysis in the Proposed Rule. We urge EPA to correct its analysis of the comparative lifecycle pollution effects of ethanol and gasoline and 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.[1] EPA's 2010 Lifecycle Analysis included GHG and air pollutant emission inventories, future industry projections, and the scientific evidence then available.[2] As EPA noted, the scientific evidence that the Agency relied upon to model lifecycle emissions was subject to many uncertainties and would change as the science improved.[3] EPA recognized that its lifecycle analysis would need to be updated as newly available science, improved emissions estimates, and new data became available.[4] EPA therefore committed to "further reassess . . . the lifecycle estimates" on an ongoing basis.[5]

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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 Lifecycle Analysis 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 14,765 ("EPA recognizes 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."); *Id.* at 14,786 ("EPA recognizes that the state of scientific knowledge in this area is continuing to evolve, and that as the science evolves, the lifecycle greenhouse gas assessments for a variety of fuel pathways will continue to change."). To illustrate the magnitude of EPA's scientific uncertainty, while EPA estimated a GHG reduction of 21% for corn ethanol, EPA's "95% confidence interval" ranged from a 7% to a 32% reduction. *Id.* at 14,786. This variance was primarily the result of EPA's uncertainty over GHG emissions from land-use change. *Id.* 14,765 ("The indirect, international emissions are the component of our analysis with the highest level of uncertainty.").

[4] *Id.* at 14,765 ("EPA recognizes 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.").

[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."); *Id.* at 14,785 ("Therefore, while EPA is making regulatory determinations for fuel pathways as required by the

As EPA predicted in 2010, new science now shows that its projections no longer represent "the best available information."[6] In fact, the scientific evidence shows that EPA's 2010 Lifecycle Analysis substantially underestimated ethanol's benefits at the time, and the assumptions EPA relied on in 2010 have been overtaken by significant advances in agricultural production and biorefining, improved modeling, and new data. At every stage, corn ethanol results in less GHG emissions and air toxic pollution than EPA predicted in its 2010 Lifecycle Analysis, and significantly less than gasoline. Thus, the best available science demonstrates that blending ethanol into gasoline is lowering GHG emissions associated with climate change and improving human health. And ethanol's benefits would be even greater if it were blended at higher levels.

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 continues to rely on EPA's 2010 Lifecycle Analysis to "illustrat[e]" the costs and benefits of its annual fuel standards.[7]

EPA should update its lifecycle analysis to reflect the best available science on the lifecycle emissions of ethanol and gasoline.

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 the Proposed Rule continues to rely on EPA's outdated 2010 Lifecycle Analysis. Part III summarizes the best available science on the GHG emission effects of corn ethanol and gasoline and explains why EPA's 2010 Lifecycle Analysis is inaccurate, beginning with "upstream" emissions from feedstock production and fuel refining

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statute in this final rule based on its current assessment, EPA is at the same time committing to further reassess these determinations and the lifecycle estimates.").

[6] 2010 RFS Rule, 75 Fed. Reg. at 14,785.

[7] *See* Renewable Fuel Standard Program: Standards for 2017 and Biomass-Based Diesel Volume for 2018, 81 Fed. Reg. 34,778 (May 31, 2016) [hereinafter Proposed Rule].

and moving on to "downstream" emissions from fuel evaporation and combustion. Part IV does the same for "conventional" (non-GHG) air pollution.

I. THE COMMENTERS' INTEREST IN EPA'S LIFECYCLE ANALYSIS

The Energy Future Coalition is a bipartisan public policy initiative that brings together business, labor, and environmental leaders to address challenges and opportunities in the transition to cleaner energy technologies. The Energy Future Coalition seeks to identify and advance innovative policy options that appeal to a diverse array of competing interests and attract broad political support.

Urban Air Initiative is a group of concerned citizens, non-profit groups, agriculture organizations, businesses of all types, and other stakeholders determined to reduce the threat to public health posed by our use of petroleum-based fuels, especially in urban areas where citizens are exposed to mobile source emissions at dangerous levels.

The Governors' Biofuels Coalition is a group of twenty-one state governors who believe that clean-burning biofuels can decrease the nation's dependence on imported energy resources, improve public health and the environment, and stimulate the national economy.[8] The Governors' Biofuels Coalition supports activities designed to (i) educate the public and demonstrate the benefits of biofuels; (ii) promote research and market developments to develop biofuel production and use; and (iii) encourage investments in infrastructure to support expansion of the alternative fuels market.

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.

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[8] The members of the Governors' Biofuels Coalition are the governors of Alabama, Arkansas, Colorado, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Maryland Minnesota, Missouri, Montana, Nebraska, New York, Ohio, Oregon, South Dakota, Tennessee, Washington, and Wisconsin.

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 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 comment 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 Lifecycle Analysis frustrates the commenters' mutual interest in advancing a clean, low-carbon energy future while reducing harmful air pollution.

II. THE PROPOSED RULE RELIES ON EPA'S ERRONEOUS AND OUTDATED 2010 LIFECYCLE ANALYSIS.

As EPA points out, the Proposed Rule is an "economically significant action" subject to regulatory review under the relevant Executive Orders.[9] 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."[10] 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

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[9] Proposed Rule, *supra* note 7, 81 Fed. Reg. at 34,814.

[10] 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).

costs as accurately as possible."[11] Moreover, EPA must "ensure the objectivity of any scientific and technological information and processes used to support the agency's regulatory actions."[12] In short, the Proposed Rule must be "based on the best available science."[13]

But in the Proposed Rule, EPA "did not quantitatively assess [the] direct and indirect costs or benefits of [its proposed blending levels] such as . . . GHG reduction benefits [and] air quality impacts," which EPA admits "are to some degree affected by the proposed rule."[14] Eschewing "comprehensive estimates" of the Proposed Rule's costs and benefits, EPA offers only simplistic analyses of the cost of producing the additional amount of ethanol required to be blended by 2017 with the cost of producing an energy-equivalent amount of gasoline.[15] EPA provides these estimates "solely for the purpose of illustrating how the cost to produce renewable fuels could compare to the costs of producing petroleum fuels"[16]—not to assess the actual costs and benefits of its annual standard. For analysis of the impacts of the RFS generally, the Proposed Rule directs the reader to EPA's cost-benefit analysis "in the 2010 final rulemaking."[17] EPA entirely fails to quantify the costs of lowering the statutory

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

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

[13] *Id.* § 1, 76 Fed. Reg. at 3.821.

[14] Proposed Rule, *supra* note 7, 81 Fed. Reg. at 34,801; *see id.* at 34,803 ("[W]e have not quantified benefits for the 2017 proposed standards. We do not have a quantified estimate of the GHG impacts for a single year (*e.g.*, 2017).").

[15] *Id.* at 34,801–03.

[16] *Id.* at 34,803.

[17] *Id.* at 34,801.

blending levels, implying that the Agency's 2010 analysis satisfies its obligation to consider the costs and benefits of the Proposed Rule.[18]

But EPA's 2010 Lifecycle Analysis is erroneous and outdated for the reasons described below. EPA must update its analysis of the lifecycle emissions of ethanol and gasoline to enable a reasonable evaluation of the costs and benefits of the Proposed Rule.

III.   GREENHOUSE GAS EMISSIONS

In its 2010 Lifecycle Analysis, EPA concluded that by 2022, corn ethanol would achieve on average annual lifecycle greenhouse gas (GHG) emissions savings of only 21% compared to EPA's 2005 gasoline carbon intensity baseline of 93.01 grams of carbon dioxide equivalent per megajoule (g CO_2e/MJ).[19] And EPA's cumulative (as opposed to annualized) data on the GHG-effects of the RFS was even less favorable.[20]

While EPA's findings were doubtful in 2010, they are now doubly so, given the wealth of newly available scientific and economic data that undermines EPA's 2010 Lifecycle Analysis.

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[18] *Id*. ("For the purpose of this rulemaking, we have not quantified benefits for the 2017 proposed standards. . . . EPA estimated GHG, energy security, and air quality impacts and benefits in the 2010 RFS2 final rule assuming full implementation of the statutory volumes in 2022.").

[19] 2010 RFS Rule, 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. The 95% confidence interval around that midpoint ranges from a 7% reduction to a 32% reduction compared to the gasoline baseline."). EPA reported its carbon intensity baseline for 2005 gasoline as 98.205g CO_2e/mmBTU, which is equivalent to 93.01g CO_2e/MJ. 2010 RFS RIA, *supra* note 1, at 467.

[20] Reviewing EPA's data, the National Academy of Sciences cautioned that the RFS "might not achieve the intended GHG reductions" on a cumulative, as opposed to annualized, basis. National Research Council, National Academy of Sciences, Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy 201 (2011) [hereinafter NAS Report].

For example, EPA's estimates of GHG emissions are flatly inconsistent with the subsequent findings of experts at the Department of Energy. As early as 2012, Argonne National Laboratory's (Argonne) Energy Division, which develops the annual Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model for comparing lifecycle GHG emissions,[21] estimated a much lower carbon intensity figure, taking into account land-use effects. Argonne estimated that GHG lifecycle emissions from corn ethanol were 19% to 48% lower than those of gasoline in 2012 (with a mean value of 34%), even accounting for indirect land-use change.[22] This compares favorably with EPA's 2010 Lifecycle Analysis estimate of a 7% to 32% reduction in GHG emissions in 2022,[23] and even more favorably with the 2010 Lifecycle Analysis of GHG emissions effects for 2012, which erroneously indicated that the RFS would increase emissions during its initial years.[24] Thus, the foremost experts in lifecycle analysis of transportation fuels estimated that much greater GHG reductions had already been achieved from ethanol by 2012 than EPA estimated in its 2010 Lifecycle Analysis could be reached by 2022.

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[21] Argonne has devoted nearly two decades of expertise to researching lifecycle emissions, refining its GREET model every year to reflect improvements in accounting, newly available data, and peer reviewed science. *See* Michael Q. Wang et al., *Development and Use of the GREET Model to Estimate Fuel Cycle Energy Use and Emissions of Various Transportation Technologies and Fuels*, DOE Argonne Nat'l Lab.; ARGONNE/ESD-31 (1996). The model is extremely influential and used by a variety of regulatory agencies, including EPA and the California Air Resources Board. *See Rocky Mountain Farmers Union v. Corey*, 730 F.3d 1070, 1081–82 (9th Cir. 2013) (explaining the GREET model).

[22] Michael Q. Wang et al., *Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane, Corn Stover, Switchgrass, and Miscanthus*, 7 Environ. Res. Lett., at 9 (2012). Argonne found that ethanol made from sugarcane, corn stover, switchgrass and miscanthus could reduce lifecycle GHGs even further—40–62%, 90–103%, 77–97%, and 101–115%, respectively. *Id.*

[23] 2010 RFS Rule, 75 Fed. Reg. at 14,786. EPA's central estimate of corn ethanol's carbon intensity in 2022 was 79 kg CO_2e/mmBTU, equivalent to 74.82g CO_2e/MJ. *Id.* at 14,788.

[24] NAS Report, *supra* note 20, 201 (collecting EPA data from the 2010 RFS RIA showing initial positive emission values for the year 2012).

Indeed, using Argonne's GREET 2015 inventory, a conservative estimate puts the carbon impact of corn ethanol at 59.21g CO_2e/MJ—39% lower than gasoline's carbon intensity of 96.89g.[25] This means that from 2008 to 2015, the RFS prevented more than 354 million metric tons of GHG pollution.[26] This is equivalent to removing more than 74 million passenger vehicles from the road for one year.[27] As explained below, this is a conservative estimate, as it does not incorporate new data on soil organic carbon sequestration. When one accounts for the carbon stored in the soil by corn plants, ethanol may have zero carbon emissions from a lifecycle perspective.[28]

And unlike the lifecycle GHG emissions of petroleum-based gasoline, which have been trending higher, the lifecycle emissions of ethanol are trending lower. A 2014 study by the National Renewable Energy Laboratory (NREL) notes that because of "green" innovation in the agriculture and biofuels industry, "the production and use of corn ethanol emitted 44% fewer GHG emissions, consumed 54% less fossil energy and required 44% less land in 2010 compared to 1990 on a life cycle basis."[29] These dynamic improvements in the ethanol industry highlight the importance of considering the most recent, updated evidence, as well as predicted industry trends, on an ongoing basis.

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[25] Susan Boland & Stefan Unnasch, Life Cycle Associates, GHG Emissions Reductions Due to RFS, LCA.6075.11.2015, at 9 (2015). Another 2015 estimate by a biofuels industry group places the total cumulative reduction achieved by the RFS from 2006 to 2015 at 589.33 million metric tons of CO_2. Biotech. Indus. Org., The Renewable Fuel Standard: A Decade's Worth of Carbon Reductions, at http://bit.ly/1MeDbNT.

[26] *Id.*

[27] The number was calculated using EPA's GHG equivalencies calculator. *See* U.S. EPA, Greenhouse Gas Equivalencies Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (last updated May 2016).

[28] *See infra* p. 23.

[29] Helena L. Chum et al., *Understanding The Evolution Of Environmental and Energy Performance of the U.S. Corn Ethanol Industry: Evaluation of Selected Metrics*, 8 Biofuels, Bioproducts, & Biorefining 224 (March/April 2014).

As described below, at every stage of their respective lifecycles—*i.e.*, corn agriculture and petroleum extraction, fuel refining, and finally, combustion in vehicle engines—the evidence shows that the carbon intensity of corn ethanol is trending lower than that of petroleum-based fuels. Section A will address land-use change. Sections B, C and D will address the other "upstream" emissions from corn agriculture and biorefinery operations compared to the corresponding stages of gasoline production. Section E will discuss "downstream" emissions at the tailpipe.

A. Land-Use Change

New evidence has exposed significant flaws in EPA's estimate of land-use change GHG emissions. Updated science on soil sequestration and empirical evidence of actual land-use patterns demonstrate that carbon emissions from land-use change are much lower than the estimate EPA continues to rely on.

This section summarizes the "first-generation" land-use change science and explains how new data and modeling undermine EPA's 2010 Lifecycle Analysis, which inaccurately suggested that the RFS would increase cumulative GHG emissions.[30] Current science suggests that the impact from land-use change due to ethanol production is negligible.

1. First-Generation Land-Use Studies

The interest in land-use change as a distinct topic in biofuel lifecycle analysis was sparked by a 2008 study by a team of scientists led by Timothy Searchinger.[31] Searchinger conjectured that an increased demand for corn would raise prices, which would in turn incentivize the conversion of forests and grassland to crop agriculture

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[30] NAS Report, *supra* note 20, at 202.

[31] Timothy Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change*, 319 Science 1238 (2008).

in the United States and elsewhere, releasing naturally stored CO_2 through land conversion.[32] Using FAPRI-CARD—the same model that EPA used to estimate international land-use change GHG emissions[33]—Searchinger predicted that the carbon intensity value for land-use change induced by biofuels was a whopping 104g CO_2e/MJ[34]—more than the entire lifecycle carbon intensity of baseline gasoline.[35] If true, this would mean that on a lifecycle basis corn ethanol has nearly *double* the GHG emissions of gasoline over thirty years.[36]

Only two years later, even as land-use change assessment was rapidly improving in response to Searchinger's controversial study, EPA's 2010 Lifecycle Analysis estimated overall corn-ethanol land-use change emissions in 2022 at 30kg $CO_2e/mmBtu$, equivalent to 28.5g CO_2e/MJ.[37]

The estimates reported in these early analyses were never accurate, and they are not supported by the best available science.

Parameters related to yield improvement, land displacement, and the type of land converted are key drivers of modeled GHG emissions from land-use change,[38] but early analyses of land-use change—including EPA's own analyses—failed to accurately reflect these complexities. For example, EPA did not account for many of

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[32] *Id.*

[33] 2010 RFS Rule, 75 Fed. Reg. at 14,768; 2010 RFS RIA, *supra* note 1, at 302.

[34] Searchinger, *supra* note 31, at 1239.

[35] EPA's baseline gasoline carbon intensity for the year 2005 was 98.205g $CO_2e/mmBTU$ (or 93.01g CO_2e/MJ). 2010 RFS RIA, *supra* note 1, at 467.

[36] Searchinger estimated ethanol's total lifecycle GHG emissions to be 93% greater than gasoline's. Searchinger, *supra* note 31, at 1239.

[37] 2010 RFS Rule, 75 Fed. Reg. at 14,788; *see also* NAS Report, *supra* note 20, at 193–194.

[38] NAS Report, *supra* note 20, at 191. For an early criticism of Searchinger, see Michael Q. Wang & Zia Haq, *Response to February 7, 2008* Science*express Article*, *available at* http://bit.ly/1phwhEa.

the fallow or marginal agricultural lands that could be converted to grow corn, or the potential for growing multiple harvests on a single piece of land ("double cropping"). Later 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.[39]

EPA's own land-use change assessment 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) and the Forestry and Agricultural Sector Optimization Model (FASOM) developed by Texas A&M.[40] 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."[41] The GTAP model has now been updated, and the FAPRI-CARD model is no longer supported, but EPA continues to rely on its 2010 estimates based on the outdated models.

Most importantly, empirical data has discredited early model assumptions on forest conversion: Contrary to EPA's predictions, ethanol has not increased the global rate of deforestation.[42] For this and other reasons, over the years the scientific community has rejected EPA's estimate for land-use change emissions from corn ethanol as unrealistically high as compared with real-world data.[43]

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[39] Boland & Unnasch, *supra* note **Error! Bookmark not defined.**, at 20.

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

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

[42] *Id.* at 19; *see also* 2010 RFS RIA, *supra* note 1, at 351 ("For instance, in 2022, as demand for corn ethanol increases in the corn ethanol scenario . . . total cropland pasture decreases by 0.9 million acres . . . [and] forestland decreases by 0.03 million acres.").

[43] 2010 RFS Rule, 75 Fed. Reg. at 14,785–86. Although the actual results of these studies may not always be readily compared (given the different target years and production volumes

Since 2010, GTAP has consistently estimated lower emissions from land-use change than EPA. A GTAP/Purdue study in 2010 refined the GTAP model to include more realistic assumptions about land types, land conversion rates, and the response of crop yields to prices.[44] Applying these assumptions, Purdue projected a carbon intensity value of 14g CO_2e/MJ for land-use change in 2022 due to corn-ethanol expansion under the RFS, half of EPA's annualized estimate for 2022. But Purdue's estimate is in fact much higher than current, updated estimates.[45]

To be sure, when EPA conducted its 2010 Lifecycle Analysis, the science of land-use change analysis was in its infancy—there remained substantial uncertainty in models of soil organic carbon and in economic models of global land-use change.[46] Reviewing EPA's 2010 Lifecycle Analysis and other lifecycle studies that included land-use change, the National Academy of Sciences concluded that "additional data are needed."[47] "In coming years," the NAS Report predicted, "scientists will

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modeled), the key point is that refined models predict lower carbon intensity values for land-use change than those predicted by EPA.

[44] The study estimated that every thousand gallons of ethanol produced would require an increase of 0.32 acres of cropland, with 24% of the associated land-use change occurring in the United States. Of these 0.32 acres, Tyner estimated that 33% of the added cropland would be converted forest, and 67% would be converted grassland. For an explanation of the refinements, see Wallace E. Tyner et al., Land-use Changes and Consequent CO_2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis: Final Report (April, 2010), *available at* http://1.usa.gov/1Tt8Y6v.

[45] *See infra* pp. 13–19.

[46] *See* NAS Report, *supra* note 20, at 5, 245.

[47] NAS Report, *supra* note 20, at 190. In its 2010 RFS Rule, EPA committed itself to seek further input from the NAS Report and other experts on its lifecycle analysis. 2010 RFS Rule, 75 Fed. Reg. at 14,785 ("As part of the ongoing effort, we will ask for the expert advice of the National Academy of Sciences as well as other experts and then reflect this advice and any updated information in a new assessment of the lifecycle GHG emission performance of the biofuels being evaluated today. EPA will request that the National Academy of Sciences evaluate the approach taken in this rule, and the underlying science of lifecycle assessment and in particular indirect land use change, and make recommendations for subsequent rulemakings on this subject.").

undoubtedly continue to refine their models to improve estimates of GHG emissions from land-use changes."[48]

After several years of biofuels policy, this "additional data" is now readily available. Updated economic models of land-use change uniformly predict lower lifecycle emissions. There is no reason for EPA to continue relying on its erroneous estimates.

2. Second-Generation Land-Use Studies

Since EPA's 2010 Lifecycle Analysis, more accurate lifecycle emission models have shown that initial estimates of emissions from first-generation land-use studies were too high.[49] As one recent study explained, "prior to the last couple of years, there was insufficient data on global land-use change during the biofuels boom era. However, now we have that data, and it can be used to better calibrate prior estimates of land-use change."[50] Accordingly, economists have recalibrated their models.[51] Argonne's most recent peer-reviewed estimate for the carbon intensity of land-use change is 7.6g CO_2e/MJ for corn ethanol,[52] and Argonne scientists now say that, in light of GTAP model refinements, a more realistic estimate is 3.2g

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[48] *Id.* at 192.

[49] *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).

[50] *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).

[51] *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 (2014), *available at* http://bit.ly/1TuJq98.

[52] Boland & Unnasch, *supra* note **Error! Bookmark not defined.**, at 6.

CO_2e/MJ.[53] As explained below,[54] even this estimate is too high, because it is based on the inaccurate assumption that all corn ethanol is grown with conventional tilling practices, and it does not include Argonne's latest update to land-use change emissions.[55]

a. *Argonne's 2013 Estimate for Land-Use Change*

GREET's updated carbon intensity value for land-use change is based upon an influential peer-reviewed study led by Argonne's Jennifer Dunn, published in 2013.[56] The study predicts significantly lower lifecycle CO_2 emissions than most previous estimates, mostly as a result of refined modeling of soil organic carbon and refinements in the GTAP model.[57]

Soil organic carbon and the carbon sequestration rate of biomass are crucial parameters in land-use change models; together, these factors determine: (1) how much carbon is stored in an ecosystem before a "disturbance" (like conversion to cropland) releases some of the carbon; (2) how much carbon is released by a given

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[53] *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 21, *available at* http://1.usa.gov/1M84WIT.

[54] *See infra* pp. 19–23.

[55] Dunn et al., *supra* note 53, at 21.

[56] Dunn et al., *supra* note 49.

[57] *Id.* at 3. The updated GREET model's assumptions are explained in detail in previous Argonne publications. *See* Ho-Young Kwon et al., *Modeling State-Level Soil Carbon Emission Factors Under Various Scenarios for Direct Land-use Change Associated with United States Biofuel Feedstock Production*, 55 Biomass & Bioenergy, 299–310 (2013). Argonne studies used the CENTURY model, which has been validated for use in analyzing different land types, at different soil levels. For a summary of Century, see Zhangcai Qin et al., DOE Argonne Nat'l Lab., Incorporating Agricultural Management Practices into the Assessment of Soil Carbon Change and Life-Cycle Greenhouse Gas Emissions of Corn Stover Ethanol Production, ARGONNE/ESD-15/26 (2015).

disturbance; and (3) how much (and how fast) carbon is stored again in the soil over the years.[58]

Previous land-use change model assumptions of soil organic carbon and carbon sequestration, however, were based on unrepresentative soil samples.[59]

Argonne addressed these shortcomings. Using the GTAP land-use change model in combination with refined soil organic carbon models,[60] Argonne estimated that corn ethanol land-use changes contributed a carbon intensity of 7.6g CO_2e/MJ to ethanol's lifecycle GHG emissions—with a possible range of 4.7g to 11g.

Another recent Argonne study on soil organic carbon points out an additional flaw in the first-generation land-use change models. These models relied on soil carbon data from unjustifiably shallow soil samples; deeper soil samples reveal higher sequestration rates for corn and other biofuel crops, because the roots of the corn plant store carbon deep in the soil.[61] Moreover, past models failed to properly account for the rate at which new cropland can restore carbon released by its initial conversion. Previous models assumed uniform sequestration rates over the years and tended to measure land-use change according to arbitrary time frames (for example, 30 years).[62]

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[58] Dunn et al., *supra* note 49, at 5–6. This process may be roughly analogized to a loan; the initial disturbance is a "debt" which must be "paid back" over a limited period; the "foregone" carbon sequestration determines the amount of "interest" that must be paid on the "debt;" and biomass sequestration "pays back" the debt, as the soil returns to a carbon equilibrium. *Id.*

[59] *Id.* at 2.

[60] Dunn, *supra* note 49, at 2.

[61] Zhangcai Qin et al., *Soil Carbon Sequestration and Land-use Change Associated With Biofuel Production: Empirical Evidence*, GCB Bioenergy (2015), *available at* http://bit.ly/1USWULe.

[62] Qin et al., *supra* note at 61, at 2. The NAS Report noted this problem as well. *See* NAS Report, *supra* note 20, at 197. EPA believed its own choice of a 30 year time frame was reasonable. 2010 RFS Rule, 75 Fed. Reg. at 14,780.

b. *GTAP's Model Update*

Argonne's 2013 estimate for land-use change was too high because it relied on an old version of GTAP to model the economics of land-use change. Both GTAP economists and Argonne scientists have now acknowledged that the old GTAP model was inaccurate. The new GTAP model predicts lower land area changes, particularly in high-carbon forests. As a result, land-use change emissions estimates relying on GTAP have to be lower.

As GTAP economists have explained, the costs of converting existing pasture or forests to cropland are not the same; generally it is less expensive to convert pasture.[63] And it is even less expensive to simply switch crops on existing cropland. This difference in cost is influenced by regulatory requirements. For example, the RFS *excludes* from its definition of "renewable fuel" any fuel produced from crops grown on land that was not actively managed or fallow before enactment of the Energy Independence and Security Act of 2007.[64] Federal regulations in turn place onerous record-keeping requirements on biofuel producers, requiring them to prove that their biomass is not derived from converted forests.[65]

Despite these regulatory and economic barriers, previous land-use models assumed that it would cost the same to convert forest or pasture into croplands.[66] Recognizing this significant flaw, Purdue has updated the GTAP model to factor in the higher costs of converting forests into cropland in most countries.[67] Purdue has

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[63] Taheripour & Tyner, *supra* note 50, at 16.

[64] Pub. L. No. 109-58, § 201(I)(i), 121 Stat. 1492.

[65] Jody M. Endres, *Barking up the Wrong Tree? Forest Sustainability and Emerging Bioenergy Policies*, 37 Vt. L. Rev. 1, 9 (2013).

[66] Taheripour & Tyner, *supra* note 50, at 16.

[67] *Id*. at 27 ("In the real world often it is not as easy or inexpensive to convert forest to cropland as pasture. For example, farmers frequently switch back and forth from pasture and

also updated GTAP to reflect the declining historical rates of conversion from forest to cropland.[68]

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."[69] According to Argonne, this new version of GTAP reduces corn ethanol "land-use change GHG emissions by 3g CO_2e/MJ," resulting in an overall land-use change carbon impact estimate of 3.2g CO_2e/MJ, assuming conventional tilling practices.[70] Using this updated land-use number, the carbon impact of corn ethanol falls from 59.21g to 54.81g CO_2e/MJ.[71]

Moreover, when accounting for reduced tillage or no-till farming, Argonne further reduces the land-use change emissions of corn ethanol to 2.89g and 2.15g CO_2e/MJ, respectively.[72] EPA's 2010 Lifecycle Analysis does not reflect this improved modeling.

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grassland to crop production and vice versa in the Northern Plains regions of the USA (including parts of Iowa, Minnesota, North Dakota, South Dakota and Montana) where converting grasslands to crop production and vice versa is not costly. However, transforming managed forests to cropland is not a common practice.").

[68] Purdue uses FAOSTAT harvested land data, which does not account for double or triple cropping, but Purdue attempts to correct for this bias. *Id.* at 19.

[69] *Id.*

[70] *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 21, http://1.usa.gov/1R8tumy. Indeed, domestic land-use emissions are negative, as a result of increased sequestration (-1.9g CO_2e/MJ). Only international land-use emissions are positive, at about 5.1g, summing up to 3.2g. *Id.*

[71] The carbon impact is calculated by subtracting the old land-use change value from the new land-use change value (7.6g - 3.2g = 4.4g). The difference (4.4g) is subtracted from the old carbon impact number, which used the old land-use value (59.21 - 4.4 =54.81).

[72] *See* GREET1_2015 (summarized in Appendix I, *infra* p. 67).

c. New Land-Use Data

New empirical data on land-use change shows that previous models overestimated land-use change by an order of magnitude. When real-world data does not fit the model, the model must be wrong.

Despite increases in commodity prices and a 10-billion-gallon increase in domestic ethanol production, recent USDA data for the United States reveals "that while corn acreage has increased in parallel with the build-up of the corn ethanol industry between 2004 and 2013, total principal crop acreage has remained fairly constant and constituted 311 million acres in 2013."[73] Corn grown as biomass has largely replaced other croplands, not forests or grasslands. Contrary to original predictions, there has been no significant increase in U.S. cropland acreage despite commodity price increases.[74]

As Bruce Babcock and Zabid Iqbal have shown in a recent empirical study of land-use change, increases in food crop production across the globe have been driven by crop "intensification"—increased yields per acre and double or triple cropping—not extensive conversions to croplands.[75] Past models used to estimate land-use changes, like the FAPRI-CARD model EPA used in its 2010 Lifecycle Analysis,[76]

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[73] Michael Wang & Jennifer B. Dunn, *Comments on Avoiding Bioenergy for Food Crops and Land by Searchinger and Heimlich*, at 2 (February 6, 2015), *available at* http://1.usa.gov/1RB1E2F.

[74] Indeed, transitions from other crops to corn may actually be reducing atmospheric carbon, because, depending on the geographic region, as well as soil and yield conditions, corn soils may sequester comparatively more carbon than other crops. As Argonne found in a recent analysis, soil organic carbon "increased 15–23%" in general crop to corn transitions. Qin et al., *supra* note 61, at 2.

[75] Bruce A. Babcock & Zabid Iqbal, *Using Recent Land-use Changes to Validate Land-use Models*, 14-SR 109, at 31 (2014). Global data shows that there has been a very minor increase in cropland acreage when compared to global crop intensification. The authors estimated that the intensive response—the increase in acreage productivity—has been 15 times larger than the increase in acreage. *Id.* at 17.

[76] 2010 RFS Rule, 75 Fed. Reg. at 14,768; 2010 RFS RIA, *supra* note 1, at 302.

relied on historical harvest data that did not take into account the "non-yield" intensification of cropland through techniques like double cropping.[77] Thus, EPA overstated the carbon intensity of corn ethanol. And even when new acres have been devoted to corn, "the type of land converted to accommodate biofuels was not forest or pastureland but rather cropland that did not go out of production."[78]

In sum, the erroneous assumptions embedded in EPA's land-use change models overstated the extent of land-use change and its effect on GHG emissions.[79]

B. Corn Agriculture

1. Soil Organic Carbon

a. Agricultural Management Practices

Since EPA's 2010 Lifecycle Analysis, new evidence shows that improved agricultural practices have substantially increased soil carbon sequestration, reducing the carbon intensity of ethanol. In fact, recent soil analyses suggest that corn soils in certain areas of the Corn Belt are a net carbon "sink," sequestering more carbon than the amount of CO_2 release during the production of corn.

As mentioned above, soil sequestration is an important factor in estimating the lifecycle emissions of corn ethanol. Growing plants absorb atmospheric carbon and sequester it into the soil, resulting in a carbon "credit" in a proper lifecycle analysis.[80] Moreover, corn is part of small subset of "C_4 plants"—named after the 4-carbon molecule present in these plants—which photosynthesize CO_2 more

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[77] Babcock & Iqbal, *supra* note 75, at 30 (concluding 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.").

[78] *Id.* at 26.

[79] *Id.*

[80] *See, e.g.*, Qin et al., *supra* note 57.

efficiently than "C$_3$ plants" do.[81] Crop yields also have an effect on carbon sequestration: Higher yields generally correlate with increased amounts of carbon stored in the soil, because above-ground biomass is roughly equal to below-ground biomass. Thus, when corn, a crop that yields 10.5 tons per hectare, displaces soybeans with a yield of 3 tons per hectare, significantly more carbon is sequestered.[82]

The actual effect of agricultural management practices on soil organic carbon has, until recently, been underestimated.

For example, reviewing the studies available as of 2011, the National Academy of Sciences suggested that the effect of no-till and reduced tillage practices on soil organic carbon sequestration rates "is inconsistent and depends on the depth of soil sampling and crop management."[83] According to the National Academy of Sciences, studies that assessed the carbon content of the entire soil profile (0–60cm) "did not find higher soil carbon in no-till fields than in conventionally tilled fields."[84] Perhaps for this reason, EPA's 2010 Lifecycle Analysis only included soil carbon for the top 30cm of soil, and did not include no-till or reduced-tillage estimates.[85]

New evidence, however, shows that agricultural management practices like no-till have a substantial effect on soil organic carbon. A multiyear study of South Dakota soil samples, led by soil scientist David Clay, found clear evidence that no-

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[81] *See generally*, Colin P. Osborne & David J. Beerling, *Nature's Green Revolution: The Remarkable Evolutionary Rise of C4 Plants*, Philosophical Transactions of the Royal Soc'y B 173, 173 (2006).

[82] *See* A.J. Lorenz et al., *Breeding Maize for a Bioeconomy: A Literature Survey Examining Harvest Index and Stover Yields and their Relationship to Grain Yield*, 50 Crop Sci. 1 (2010).

[83] NAS Report, *supra* note 20, at 186.

[84] *Id.*

[85] 2010 RFS RIA, *supra* note 1, at 396, 415.

tillage practices (and higher corn yields) increase carbon sequestration. The study used laboratory surface soil samples submitted by agricultural producers,[86] recording information on their agricultural practices, fertilizer use, and expected yield associated with the samples. The study also used benchmark soil samples to estimate the change in soil carbon sequestration associated with improved agricultural practices (higher yields and no-till farming).

From the laboratory results, Clay concluded that many of the cropland soils studied were now net "carbon sinks," thanks, in part, to the adoption of reduced tillage and no-tillage practices, as well as increased crop yields over the years.[87] Over a period of three years, Clay found that the average carbon sequestration rate was 341 kg of carbon per hectare per year.[88] Over a longer period of 25 years, Clay further concluded that the average carbon sequestration rate was 386 kg of carbon per hectare per year.[89] This is equivalent to an annual carbon credit of 18.19 CO_2e/MJ, more than five times Argonne's estimate of land-use change from corn-ethanol.[90]

The study's estimate of the carbon footprint of corn, however, was based on surface samples that missed the soil organic carbon sequestration occurring deeper in the soil. Studies testing deeper soil levels have shown that certain corn soils may sequester more carbon than previously thought.

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[86] *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*].

[87] Clay, *Carbon Sequestration*, *supra* note 86, at 769.

[88] *Id.* at 768.

[89] *Id.*

[90] *See* Appendix II, *infra* p. 71.

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.[91] The study found that improved agricultural management practices can double or even quadruple total soil organic carbon when deep soil is taken into account.[92] The study found average annual increases of more than 2 megagrams (tons) of soil organic carbon per hectare, with over 50% of the carbon being sequestered deeper than 30 cm in the soil profile.[93] 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."[94] Other recent USDA peer-reviewed studies have reached similar results.[95]

In light of these studies, corn ethanol would receive a significant soil sequestration credit in a properly executed lifecycle analysis. Although the precise value is uncertain (soil sequestration credit values range from about 18.19g CO_2e/MJ to much higher numbers, depending on the soil depth analyzed and other factors),[96] even a low-end credit of 18.19g would bring GREET's current lifecycle estimate for corn ethanol down to 36.62g CO_2e/MJ, 62% lower than today's gasoline.[97]

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[91] 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.

[92] *Id.* at 867.

[93] *Id.* at 873.

[94] *Id.*

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

[96] *See* Appendix II, *infra* p. 71.

[97] The number is based on the conservative carbon impact number of 54.81g, minus the 18.19g credit. The percentage is based on a gasoline carbon impact of 96.89g CO_2e/MJ. *See infra* note 135, and accompanying text.

2. Nitrogen Fertilizer

Agriculture is the main source of nitrous oxide emissions in the United States. EPA estimates that 68% of total emissions of nitrous oxide (N_2O) result from farming soil management practices.[98] Because N_2O is a powerful GHG pollutant, it accounts for a significant portion of the lifecycle emissions of corn ethanol (17g CO_2e/MJ).[99] Most N_2O is released primarily through the chemical process of microbial "nitrification" and "denitrification" that is stimulated when nitrogen fertilizer application exceeds plant needs.[100]

In 2015, USDA estimated that corn producers applied nitrogen fertilizer at an average rate of 136.50 lbs. per acre in 2010.[101] Taking into account corn yield increases, however, per bushel fertilizer has fallen by more than 20% since the 1990s,[102] and agriculture N_2O emissions have also fallen thanks in part to new technologies such as nitrogen stabilizers, controlled release nitrogen, soil testing and remote sensing, and the use of GPS tracking technologies.[103] These developments

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[98] *Id.* at 185.

[99] According to Argonne's 2012 calculations, fertilizer N_2O application accounted for 17g CO_2e/MJ, and fertilizer production accounted for 10g CO_2e/MJ, of the total carbon intensity value of ethanol. *See* Michael Q. Wang et al., *Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane, and Cellulosic Biomass for US Use*, 7 Environ. Res. Lett. 045905, at 9 (2012).

[100] NAS Report, *supra* note 20, at 185.

[101] 2015 Energy Balance for the Corn-Ethanol Industry, USDA, Table 1 (Feb. 2016) [hereinafter 2015 Energy Balance].

[102] *Id.* at 2; *see also* 2008 Energy Balance for the Corn Ethanol Industry, USDA, Table 2 (June, 2010).

[103] *See* Steffen Mueller & John Kwik, 2012 Corn Ethanol, Emerging Plant Energy and Environmental Technologies (2013); *Public Hearing for the 2014, 2015, and 2016 Standards for the Renewable Fuel Standard Program*, Kansas City, KS, Testimony of Iris Caldwell & Steffen Mueller, *available at* http://bit.ly/1QMnnoL.

reduce corn ethanol's N_2O emissions. But EPA's 2010 Lifecycle Analysis did not foresee such industry-wide innovations.[104]

C. Ethanol Production

Since EPA's 2010 Lifecycle Assessment was prepared, biorefineries have become more efficient, using less natural gas and electricity to produce each gallon of ethanol. New co-products that substitute for other products in the market have also reduced the proportion of GHG emissions that can properly be attributed to ethanol.

1. Biorefinery Energy Efficiency

As the National Academy of Sciences points out, the bulk of GHG emissions from the typical biorefinery result from natural gas and electricity usage.[105] Ethanol biorefineries, however, have experienced dramatic gains in energy efficiency in the past few years.[106] Dry mill ethanol plants have improved plant-wide energy consumption and thermal integration.[107] Improvements in "[e]nergy efficiency and fuel switching . . . reduce the [carbon intensity] of corn ethanol."[108]

Most biorefineries have completed the switch from coal to less carbon-intensive natural gas.[109] By 2012, only 13% of U.S. ethanol production capacity used

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[104] *Id.*

[105] NAS Report, *supra* note 20, at 199.

[106] *See generally* Mueller & Kwick, *supra* note 103 (discussing industry gains in energy and process efficiency between 2008 and 2012).

[107] More energy-intensive wet mill plants have become increasingly scarce. Today, it is estimated that "[d]ry mill plants correspond to 83% of U.S. capacity and have experienced a 90% growth in production since 2000. Wet mill plants today account for only 10 to 12% of installed capacity, and less than 10% of the total number of plants."[107] Boland & Unnasch, *supra* note 20, at 18.

[108] *Id.* at viii.

[109] In general, using natural gas to power biorefineries has lower GHG emissions than using coal, and using biomass may have lower emissions still. NAS Report, *supra* note 20, at 195.

coal as a thermal energy source.[110] Ethanol plants have also dramatically reduced their energy needs (and electricity demand) through innovation. From 36,000 Btu per gallon of ethanol in 2000, biorefineries have reduced their energy consumption to less than 24,000 Btu on average for 2012, and less than 20,000 Btu for some biorefinery configurations.[111] Moreover, a recent USDA report shows that biorefinery yields increased dramatically from 2005 to 2010, reducing the net corn energy input from 9,812 Btu to 9,007 Btu per gallon of ethanol, "an 8.2% decline" in only five years.[112]

As reflected by Argonne's most recent GREET model, reductions in energy use and improved biorefinery yields translate into a reduced carbon intensity value for corn ethanol.[113] These reductions will grow in the future due to the increasing use of lignin (corn residue) to substitute for natural gas, and other biorefinery process innovations.[114]

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[110] Mueller & Kwick, *supra* note 103, at 1.

[111] *See id.* at iv–v; Hosein Shapouri et al., USDA, The Energy Balance of Corn Ethanol: An Update, AER-814 (2001).

[112] 2015 Energy Balance, *supra* note 101, at 2.

[113] *See* Zhichao Wang et al., Updates to the Corn Ethanol Pathway and Development of an Integrated Corn and Corn Stover Ethanol Pathway in the GREET Model, ANL/ESD-14/11, at 3 (2014).

[114] *Id.* at 1 ("Co-located corn stover and corn ethanol plants have the potential to reduce the costs, energy consumption, and [GHG] emissions of ethanol production because these facilities could burn the corn stover, or its lignin fraction, to produce process energy, reducing the need for consumption of fossil energy sources such as natural gas. Moreover, process utility integration between the grain- and stover-based ethanol plants is a possibility that could also reduce energy consumption and subsequent GHG emissions.").

2. Biofuel Co-Products

a. Distillers' Grains

Modern ethanol plants produce more valuable co-products than in the past, reducing the carbon emissions of their market substitutes. Distillers' grains are an important economic component of ethanol production at dry mills,[115] providing on average 10% to 20% of total plant revenues.[116] Dry milling generates on average 15 pounds per bushel of fiber-rich distillers' dried grains with solubles (DDGS), which can be used as a higher quality feedstock to substitute for soy, primarily in the diets of cattle and other ruminants. This substitution or "displacement" results in a carbon credit, lowering the lifecycle emissions of corn ethanol.[117]

Many studies in the past erroneously assumed that DDGS are nutritionally equivalent to corn.[118] EPA did not commit this basic error; based on a 2008 Argonne study, the Agency estimated a "maximum" substitution rate of 1.196 pounds of

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[115] NAS Report *supra* note 20, at 30, 136–37.

[116] Salil Arora et al., *Estimated Displaced Products and Rations of Distillers' Co-Products from Corn Ethanol Plants and the Implications of Lifecycle Analysis*, 1 Biofuels 911, 912 (2012), *available at* http://1.usa.gov/1UUjGSZ.

[117] In 2012, for example, Argonne estimated a distillers' grains credit of 14 CO_2e/MJ for corn ethanol. Wang et al., *supra* note 99, at 9.

[118] Rita Mumm et al., *Land Usage Attributable to Ethanol Production in the United States: Sensitivity to Technological Advances in Corn Grain Yield, Ethanol Conversion, and Co-Product Utilization*, Biotech. for Biofuels 7, 14 (2014) ("Thus, it is assumed that DDGS included in diets fed to beef cattle replaces corn at a 1:1 rate, although it is acknowledged that substitution rates of 1.1:1 or 1.2:1 have been proposed.").

corn.[119] But this figure is too low given new evidence.[120] A recent USDA study predicts that 1 pound of DDGS substitutes for approximately 1.22 pounds of corn when used to feed beef cattle—more than EPA and Argonne predicted in the past.[121]

b. Corn Oil

More recently, Argonne scientists have updated the GREET carbon intensity calculation for corn ethanol to reflect the emergence of corn oil as a significant co-product of ethanol. Over 80% of the dry mill ethanol plants now generate corn oil for biodiesel plants.[122] A bushel of corn currently produces about 0.53 pounds of corn oil or more.[123] And while corn oil production results in negligible decreases in DDGS,

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[119] 2010 RFS Rule, 75 Fed. Reg. at 14,836 ("For the proposal, we assumed that one pound of DGS replaced one pound of total of corn and soybean meal for all fed animals. We received numerous comments on this assumption. Many commenters suggested that we adopt the replacement rates included in the recent research by Argonne National Laboratory (ANL) and others. The ANL study found that one pound of DGS can be used to replace 1.196 pounds total of corn and soybean meal for various fed animals due to the higher nutritional content of DGS per pound compared to corn and soybean meal. For the final rulemaking analysis, these replacement rates are incorporated in both the FASOM and FAPRI–CARD models, and are treated as a maximum replacement rate possibility that is fully phased in by 2015." (footnote call omitted)).

[120] Argonne recently investigated whether new corn oil extraction rates from DDGS could reduce its performance as animal feed, reducing its replacement value. Argonne concluded that there was not enough evidence to "adjust DGS conventional feed displacement ratios in GREET." Wang et al., *supra* note 113, at 4.

[121] Linwood Hoffman & Allen Baker, USDA Econ. Res. Serv., *Estimating the Substitution of Distillers' Grains for Corn and Soybean Meal in U.S. Feed Complex*, FDS-11-I-01, at 30 (2011); *see also* Salil Arora et al., *Estimated Displaced Products and Ratios of Distillers' Co-Products from Corn Ethanol Plants and the Implications of Lifecycle Analysis*, 1 Biofuels 911 (2010). It should also be noted that some lifecycle analyses have failed to credit the nutritional value of excess stover used for feed. But stover for feed is quite common in certain areas of the Corn Belt. *See* Steffen Mueller, *Handling of Co-Products in Life Cycle Analysis in an Evolving Co-Product Market: A Case Study with Corn Stover Removal*, 3 Advances in Appl. Agr. Sci. 8 (2015).

[122] *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).

[123] *Id.* at 3. More recent data suggests that biorefineries in 2012 produced 0.55 pounds of corn oil per bushel of corn. *See* Scott Irwin, *The Profitability of Ethanol Production in 2015*, 6 Farmdoc Daily,

corn oil displaces soy oil used as a feedstock for biodiesel, reducing net GHG emissions.[124] GREET has been updated to include a one-to-one displacement credit to account for the displacement of soy oil.[125] EPA has not updated its 2010 Lifecycle Analysis to reflect this change.

D. Gasoline Production

Since EPA published its lifecycle estimates in 2010, 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 new sources of renewable fuel,[126] 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."[127] Because gasoline lifecycle emissions are now higher, the corresponding GHG benefits of the RFS are also higher than EPA estimated.

Gasoline GHG emissions are trending upwards because of increased "use of oil sands and other nonconventional sources of petroleum."[128] Unlike renewable fuel

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Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, (Jan. 6, 2016), *available at* http://bit.ly/1phwLdh.

[124] Wang, *supra* note 122, at 4.

[125] *Id.* at 5.

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

[127] NAS Report, *supra* note 20, at 195.

[128] 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

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.[129]

Methane flares from shale oil extraction dramatically increase GHG emissions.[130] And 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.[131] Emissions associated with refining a barrel of tar sand oil are also higher.[132] And even conventional oil is becoming more carbon-intensive. Oil producers are injecting additional steam, chemicals, and gases (including methane) to enhance oil recovery, increasing the energy and carbon intensity of conventional oil extraction.[133]

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).

[129] *See* Martin, *supra* note 128, 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.

[130] *Id.* at 16–17.

[131] *Id.* at 19–20.

[132] *Id.* at 20.

[133] *Id.* at 15.

EPA's 2010 Lifecycle Analysis significantly understates the carbon intensity of gasoline.[134] When EPA's skewed carbon intensity baseline for gasoline is corrected, corn ethanol is an even more attractive substitute. Because of tight oil, the carbon intensity of gasoline is no longer 93.01g, as it was in 2005, but 96.89g CO_2e/MJ.[135] Because tight oil's share of the gasoline market is likely to increase in the future, the carbon impact of petroleum-based fuels is also likely to increase.

This comparison tilts even further in ethanol's favor because aromatic hydrocarbons (for which ethanol substitutes in gasoline blends) are among the most energy-intensive (and thus carbon-intensive) products of the refining process.[136]

E. Tailpipe Emissions

1. Black Carbon

While EPA focused heavily on GHG emissions, it failed to consider the climate-forcing effects of black carbon, or "elemental carbon,"[137] more commonly

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[134] Boland & Unnasch, *supra* note **Error! Bookmark not defined.**, at v. Argonne in particular has undertaken major studies of Canadian oil sands, demonstrating that Canadian oil sand products are much more GHG-intensive than previously thought. Hao Cai et al., *Well-to-Wheels Greenhouse Gas Emissions of Canadian Oil Sands Products: Implications for U.S. Petroleum Fuels*, 49 Environ. Sci. Technol. 8219 (2015); Jacob G. Englander, *Oil Sands Energy Intensity Assessment Using Facility-Level Data*, 29 Energy Fuels 5204 (2015). *See also* Adam R. Brandt, Argonne Nat'l Lab., Energy Intensity and Greenhouse Gas Emissions from Crude Oil Production in the Bakken Formation: Input Data and Analysis Methods (September 2015).

[135] *Id.*

[136] Because ethanol has a high octane number, it allows refineries to displace carbon-intensive reformate aromatics from the blendstock, reducing GHG emissions. *See* Vincent Kwasniewski et al., *Petroleum Refinery Greenhouse Gas Emission Variations Related to Higher Ethanol Blends At Different Gasoline Octane Rating And Pool Volume Levels*, 10 Biofuels, Bioprod. Bioref. 36, 44 (2016), *available at* http://bit.ly/1RB2gp1.

[137] The term is interchangeably used with the term elemental carbon, or EC. The terms refer to different measurement methods that capture roughly the same substance. *See* Final Revisions to the National Ambient Air Quality Standards for Particulate Matter, Regulatory Impact Analysis, at 6-39 (2012) [hereinafter PM RIA] ("BC and elemental carbon (EC)(or particulate elemental carbon (PEC)) are used interchangeably in this report because EPA traditionally estimates EC emissions rather than

known as "soot," a form of particulate matter commonly emitted from light-duty vehicle tailpipes.[138] In a cursory footnote, EPA simply noted that "[o]ther non-GHG climate impacts" were "currently outside the scope [its] analysis."[139] EPA's lapse is significant; the climate forcing effects of black carbon are estimated to be second only to the effects of CO_2 as an agent of climate change.[140]

Indeed, the same year that EPA published its 2010 Lifecycle Analysis, EPA acknowledged black carbon's role as a significant climate-forcing agent.[141] The scientific literature has linked black carbon to "increased temperatures, accelerated ice and snow melt, and disruptions on precipitation patterns."[142] Black carbon's climate-forcing potential rests on its capacity to absorb sunlight and darken snow and ice covers, decreasing reflectivity.

Vehicle and fuel emissions studies have repeatedly linked particulate matter emissions, and black carbon in particular, with the use of aromatic additives used to

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BC and for the purpose of this analysis these measures are essentially equivalent."), *available at* http://1.usa.gov/24S42Mf; *see also* Gwami Shrestha et al., *Black Carbon's Properties and Role in the Environment: A Comprehensive Review*, 2 Sustainability 294, 307 (2010), *available at* http://bit.ly/1p9vrZf.

[138] *See* Gwami Shrestha et al., *Black Carbon's Properties and Role in the Environment: A Comprehensive Review*, 2 Sustainability 294, 307 (2010), *available at* http://bit.ly/1p9vrZf.

[139] 2010 RFS RIA, *supra* note 1, 314.

[140] Veerabhadran Ramanathan, *Indian Ocean Experiment: An Integrated Analysis of the Climate Forcing andEffects of the Great Indo-Asian Haze*, 106 J. Geophys. Res. 28,371 (2001), *available at* http://1.usa.gov/1QFheN8; Chul E. Chung et al., *Global Anthropogenic Aerosol Direct Forcing Derived from Satellite and Ground-Based Observations*, 110 J. Geophys. Res. D24207 (2005), *available at* http://bit.ly/1M85YVv.

[141] EPA, Report to Congress on Black Carbon: Department of the Interior, Environment, and Related Agencies Appropriations Act, 2010, at 11 (2012) [hereinafter Black Carbon Report], *available at* http://1.usa.gov/1UUk9EB.

[142] *Id.*

raise octane.[143] In fact, some studies trace substantially all black carbon emissions from light-duty gasoline vehicles to incomplete combustion of aromatic hydrocarbons.[144]

Mobile sources are responsible for a majority of black carbon emissions.[145] Gasoline-powered vehicles in particular are major contributors to black carbon pollution. According to a recent CARB study, elemental carbon accounts for approximately 70% of all particulate matter (PM) mass emissions from gasoline-powered light duty vehicles.[146] Moreover, recent evidence shows that emissions of black carbon from light duty gasoline-powered vehicles are likely an order of magnitude greater than previously estimated.[147] Somewhat counterintuitively, new technologies, like gasoline direct injection (GDI) engines, have increased black carbon emissions from gasoline-powered vehicles.[148]

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[143] James E. Anderson et al., *Issues with T50 and T90 as Match Criteria for Ethanol-Gasoline Blends*, 7 SAE Int. J. Fuels Lubr. 1027, 1031 (2014) ("As discussed in several papers, high-boiling point gasoline hydrocarbons with low vapor pressure and high-double-bond equivalent (DBE) value, primarily aromatics, hydrocarbons, have been identified as the predominant contributors to PM emissions"); Koichiro Aikawa et al., *Development of a Predictive Model for Gasoline Vehicle Particulate Matter Emissions*, 3 SAE Int. J. Fuels Lubr. 610 (2010).

[144] *See* J.R. Odum et al., *The Atmospheric Aerosol-Forming Potential of Whole Gasoline Vapor*, 276 Science 96, 96 (1997). Because aromatics are "high-distillate," they do not burn during combustion, and they are emitted from the tailpipe as part of vehicle exhaust. *See* Aikawa et al., *supra* note 143, at 611.

[145] Black Carbon Report, *supra* note 141, at 88.

[146] California Air Resources Board, LEV III PM Technical Support Document: Development of Particulate Matter Mass Standards for Future Light-Duty Vehicles 123 (Dec. 7, 2011).

[147] John Liggio et al., *Are Emissions of Black Carbon from Gasoline Vehicles Underestimated? Insights from Near and On-Road Measurements*, 46 Envtl. Sci. & Tech. 4819 (2012).

[148] Robert A. Stein et al., *Ethanol Blends' Impacts on SI Engine Performance, Fuel Efficiency, and Emissions*, SAE Int. J. Engines 470 (2013); John Liggio et al., *Are Emissions of Black Carbon from Gasoline Vehicles Underestimated? Insights from Near and On-Road Measurements*, 46 Envtl. Sci. & Tech. 4819 (2012).

As a substitute for gasoline aromatics, ethanol reduces particulate emissions in general, and black carbon in particular, reducing the risk of global warming.[149] Significantly greater black carbon reductions would be possible with higher levels of ethanol.[150]

2. Further GHG Reductions from Mid-level Ethanol Blends

EPA's Proposed Rule would again waive renewable fuel requirements for 2017 due to "hurdle[s]" in the demand for higher ethanol blends.[151] To clear these "hurdles," the Proposed Rule notes that EPA is "currently considering and evaluating regulatory provisions that should enhance the ability of the market to increase . . . the use of higher-level ethanol blends such as E15 and E85."[152] As it considers its options, EPA also should consider a high-octane, mid-level blend of ethanol (E25 to E40) that would overcome impediments to increased renewables while helping to realize the GHG and energy independence benefits of the RFS.

Tailpipe CO_2 emissions following fuel combustion are the largest source of GHG emissions in the lifecycle of most fuel sources, accounting for 332g out of 409g CO_2e per mile in internal combustion vehicles using E10, or 81% of all GHG

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[149] *See* Hao Cai & Michael Wang, DOE Argonne Nat'l Lab., Estimation of Emission Factors of Particulate Black Carbon and Organic Carbon from Stationary, Mobile, and Non-point Sources in the United States for Incorporation into GREET, ANL/ESD-14/6, at 23 (2014) ("Gasoline with ethanol blending reduces BC emissions compared with gasoline"), *available at* http://1.usa.gov/1QHUCgi.

[150] *See* M. Matti Maricq et al., *The Impact of Ethanol Fuel Blends on PM Emissions from a Light-Duty GDI Vehicle*, 46 Aerosol Sci. & Tech. 576, 581 (2011) (Black carbon "decreases slightly from 0% to 17% ethanol, but falls by ~45% for E32 and E45.").

[151] Proposed Rule, *supra* note 7, 81 Fed. Reg. at 34,790–91.

[152] *Id*. at 34,784.

lifecycle emissions.[153] While ethanol has a lower energy content per gallon than gasoline, ethanol also has a lower carbon content per unit of energy than gasoline. On a grams-per-mile basis, the tailpipe GHG emissions of ethanol are lower than gasoline's.[154]

Ethanol has the potential to achieve even greater tailpipe GHG reductions, because higher concentrations of ethanol, in the form of mid-level ethanol blends, would enable more efficient engines. Many studies have shown that ethanol's high octane rating (the knock-resistant quality of fuel) can be harnessed to increase vehicle fuel economy, reducing both lifecycle emissions[155] and tailpipe GHG emissions on a grams-per-mile basis.[156]

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[153] *See* GREET1_2015_results (Oct. 2015), *available at* https://greet.es.anl.gov/results; *see also* Hao Cai et al., Regional Differences in Life-Cycle Greenhouse Gas and Criteria Pollutant Emissions of Light-Duty Vehicles in the United States, at 11, *available at* http://1.usa.gov/1pyymeL.

[154] *See* Stein et al., *supra* note 148, at 9 ("CO_2 emissions per unit of heating value [energy content] . . . are about 3% lower for ethanol than for gasoline. The cumulative effect of improved efficiency and lower H/C ratio is an improvement in CO_2 emissions of about 6–9% for ethanol compared to gasoline at equal [brake mean effective pressure (BMEP)] and engine speed at [minimum spark advance for the best torque (MBT)]. For ethanol-gasoline blends, it is expected that this benefit in CO_2 emissions will scale approximately linearly with the molar fraction of ethanol in the blend."); Hosuk H. Jung et al., *Effect of Ethanol on Part Load Thermal Efficiency and CO_2 Emissions of SI Engines*, 6 SAE Int. J. Engines (2013).

[155] Transitioning to higher ethanol blends would substantially reduce refinery GHG emissions. *See also* Kwasniewski et al., *supra* note 136; David Hirshfeld et al., *Refining Economics of U.S. Gasoline: Octane Ratings and Ethanol Content*, 48 Environ. Sci. & Technol. 11064, at S128 (2014).

[156] *See, e.g.*, Jeongwoo Han et al., DOE Argonne Nat'l Lab., Wells-to-Wheels Greenhouse Gas Analysis of High-Octane Fuels with Various Market Shares and Ethanol Blends, ANL/ESD-15/10 (2015); Thomas G. Leone et al., *The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency*, 49 Environ. Sci. Tech. Lett. 10778 (2015); Thomas G. Leone, *Effects of Fuel Octane Rating and Ethanol Content on Knock, Fuel Economy, and CO_2 for a Turbocharged DI Engine*, 7 SAE J. of Fuels & Lubricants 9 (SAE Technical Paper No. 2014-01-1228); Derek A. Splitter & James P. Szybist, *Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR. 1. Engine Load Range and Downsize Downspeed Opportunity*, 28 Energy & Fuels 1418 (2014); Raymond L. Speth, *Economic and Environmental Benefits of Higher-Octane Gasoline*, 48 Environ. Sci. Technol. 48, 6561 (2014); James E. Anderson et al., *High Octane Number Ethanol-Gasoline Blends: Quantifying the Potential Benefits in the United States*, Fuel 5–10 (Mar. 23, 2012); Eric Chow,

Ethanol's high-octane blending value would enable vehicle manufacturers to build next-generation engines with higher compression ratios, and therefore increased thermal efficiency. By increasing the current engine compression ratio by two points (from 10:1 to 12:1), vehicle manufacturers could increase vehicle efficiency by 5% to 7%; increasing the compression ratio by three points (from 10:1 to 13:1) could increase vehicle efficiency by 6% to 9%.[157] These efficiency gains can be translated into improved fuel economy through engine downsizing and other proven engineering strategies.[158]

A recent study estimates that increasing an engine compression ratio by a single point would require a 2.5 to 6 increase in the research octane number (RON) of the fuel, in order to avoid engine knock.[159] Ethanol—well-established as an octane enhancer—is a proven, low-GHG substitute for the aromatic additive components in gasoline.[160] A recent Oak Ridge National Laboratory study of mid-level ethanol blends found that the use of an E30 blend in optimized spark-ignited engines would result in significant increases in engine efficiency and provide expanded downsizing

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Exploring the Use of a Higher Octane Gasoline for the U.S. Light-Duty Vehicle Fleet, *available at* http://bit.ly/1TtytEL.

[157] *See* David Hirshfeld et al., *Refining Economics of U.S. Gasoline: Octane Ratings and Ethanol Content*, 48 Environ. Sci. & Technol. 11064, 11065 (2014).

[158] Jeongwoo Han et al., DOE Argonne Nat'l Lab., Wells-to-Wheels Greenhouse Gas Analysis of High-Octane Fuels with Various Market Shares and Ethanol Blends, ANL/ESD-15/10, at 44 (2015); Derek A. Splitter & James P. Szybist, *Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR. 1. Engine Load Range and Downsize Downspeed Opportunity*, 28 Energy & Fuels 1418 (2014).

[159] Hirshfield, *supra* note 157, at 11065; Raymond L. Speth et al., *Economic and Environmental Benefits of Higher-Octane Gasoline*, 48 Environ. Sci. Technol. 48, 6561 (2014).

[160] Splitter & Szybist, *supra* note 158.

and downspeeding opportunities, which can translate into significant improvements in vehicle fuel economy.[161]

Tailpipe GHG reductions from increased compression engines would be significant. A 2014 study conducted by Ford and GM concluded that blending E30 to produce a 101 RON fuel for use in high-compression engines could reduce baseline tailpipe GHG emissions by 7%.[162]

Other studies have reached similar conclusions. A 2013 MIT study estimates that engine efficiencies enabled by mid-level ethanol blends would have great social benefits: A 98 RON blend of E20 could reduce annual CO_2 emissions by 35 million metric tons while saving consumers $12.63 billion a year, resulting in net social benefits of $14.92 billion per year.[163] Indeed, recent estimates show that splash-blending an additional 20% of ethanol into an E10 fuel to create a 93 AKI fuel (equivalent to today's premium blend) would cost 9 cents a gallon *less* than regular gasoline using 2014 prices.[164]

Finally, an Argonne lifecycle study simulating several market-penetration scenarios for mid-level ethanol blends found that the change in lifecycle GHG emissions "was dominated by the positive impact associated with vehicle efficiency gains and ethanol blending levels."[165] In particular, "5% . . . MPGGE [miles per gallon of gasoline-equivalent] gains" achieved through mid-level ethanol blends of

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[161] *Id.*

[162] Thomas G. Leone et al., *The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency*, 49 Environ. Sci. Tech. Lett. 10778, 10785 (2015).

[163] Speth et al., *supra* note 159, at 6565. E10 fuels would not be able to achieve such high octane levels without the addition of costly and carbon-intensive aromatic hydrocarbons that harm human health. *See* Hirshfield, *supra* note 157, at S128.

[164] Thomas Darlington et al., The Economics of Eco-Performance Fuel, at 2 (Apr. 22 2014), *available at* http://bit.ly/1pzkKzU.

[165] Jeongwoo Han et al., *supra* note 158, at xii.

E25 and E40 reduced lifecycle GHGs "by 10% and 15%, respectively."[166] A 100 RON blend of E40 could reduce GHG lifecycle emissions by 18%, delivering a 10 MPGGE increase in vehicle fuel economy.[167]

The best available science therefore shows that significant additional GHG reductions could be achieved through mid-level blends of ethanol. EPA's Proposed Rule, however, entirely fails to consider the steps EPA could take to facilitate of a mid-level ethanol future, ameliorating the E10 "blendwall" while delivering billions of dollars in net social benefits. EPA should not continue to ignore this aspect of the problem.

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In 2010, EPA predicted that blending corn ethanol into gasoline would significantly 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 74.81g CO_2 e/MJ in 2022, relative to the baseline gasoline carbon intensity of 93.01g CO_2e/MJ.[168] A recent conservative estimate would place corn ethanol's carbon intensity at 59.21g CO_2e/MJ and gasoline's carbon intensity at 96.89g CO_2e/MJ— without any credit for soil carbon sequestration.[169] When updated to reflect Argonne's latest estimate for land-use change in a conventional-till scenario, the

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[166] *Id.*

[167] *Id.* at xiii.

[168] 2010 RFS Rule, 75 Fed. Reg. 14,788. EPA reported the carbon intensity of corn ethanol as 79g CO_2e/mmBTU (equivalent to 74.82g CO_2e/MJ) with a range of 54 to 97g CO_2e/mmBTU (or 51.14 to 91.86g CO_2e/MJ). EPA's baseline gasoline carbon intensity for the year 2005 was 98.205g CO_2e/mmBTU (or 93.01g CO_2e/MJ). 2010 RFS RIA, *supra* note 1, at 467.

[169] *See supra* note 71 and accompanying text.

carbon intensity of corn ethanol falls to 54.81g CO_2e/MJ.[170] And when further updated to reflect recent estimates for soil carbon sequestration, the carbon intensity of corn ethanol falls by at least an additional 18.19g, to a carbon intensity of 36.62g CO_2e/MJ.[171] This means that over their respective lifecycles, ethanol results in at least 62% less carbon pollution than gasoline on an energy-equivalent basis. And that does not account for the fuel efficiency gains that are possible with higher ethanol blends. The GHG benefits of ethanol will only grow as ethanol production becomes increasingly efficient, and gasoline production continues to get dirtier. EPA's current GHG lifecycle analysis is clearly in need of correction.

IV. CONVENTIONAL AIR POLLUTANTS

As with GHG emissions, new evidence shows that corn ethanol produces less air pollution over its lifecycle than previously estimated. But EPA continues to rely on its 2010 Lifecycle Analysis, which does not account for the latest innovations in corn ethanol production. Nor does EPA's analysis take into account the growing market share of "tight oil," which increases lifecycle emissions from gasoline. As a result, EPA's lifecycle analyses do not accurately model the conventional air pollution emissions attributable to ethanol and gasoline.

New evidence from fuel emissions studies shows that blending ethanol into gasoline has already significantly reduced tailpipe emissions and that these reductions would be even more pronounced for mid-level ethanol blends. Because EPA has the authority to facilitate the switch to higher ethanol blends, the Agency should consider studies that show additional lifecycle reductions from transitioning to mid-level blends of ethanol.

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[170] GREET1_2015 (summarized in Appendix I, *infra* p. 69).

[171] *See supra* note 97 and accompanying text; Appendix II, *infra* p. 73.

EPA's analysis of the RFS's air quality effects is methodologically flawed, incomplete, and out of date. At every stage in the fuel life cycle, corn ethanol is now cleaner, and gasoline dirtier than EPA estimated.

A. Lifecycle Analysis of Conventional Pollutants

Few studies have comprehensively modeled the lifecycle impacts of ethanol and gasoline on non-GHG emissions.[172] While some early studies focused on $PM_{2.5}$ and its precursors,[173] EPA's 2010 Lifecycle Analysis emphasized increases in ground-level ozone, or "smog," from increased emissions of nitrogen oxides (NO_X), volatile organic compounds (VOCs),[174] and carbon monoxide (CO) from biofuel production

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[172] *See supra* pp. 30–32. For an early but outdated example, see Jason Hill et al., Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline, 106 PNAS 2077 (2009).

[173] PM is a mixture of solid particles and liquid droplets suspended in the atmosphere. PM is classified as either "primary" PM—particulates emitted directly into the atmosphere from a tailpipe or smoke stack—or "secondary" PM, which is formed through complex atmospheric reactions when gases interact with particles. Control of Air Pollution From Motor Vehicles, Tier 3 Rule Motor Vehicle Emission and Fuel Standards, 79 Fed Reg. 23414, 23429 (Apr. 28, 2014) [hereinafter Tier 3 Rule]. For regulatory purposes, EPA also classifies PM according to particle diameter—fine particles of less than 2.5 micrometers in diameter are classified as $PM_{2.5}$. $PM_{2.5}$ is more dangerous than PM_{10}, because it penetrates deeper into the lungs, entering into the bloodstream. EPA, Integrated Science Assessment for Particulate Matter 3–6 (2009). $PM_{2.5}$ is associated with a host of negative health effects, including premature death, cardiovascular problems, developmental delay, and carcinogenic, mutagenic, and genotoxic effects, most prominently, lung cancer. Tier 3 Rule, 79 Fed Reg. at 23430. PM has been designated by the World Health Organization as a Group 1 carcinogen. World Health Organization, 109 IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Outdoor Air Pollution 443 (2015).

[174] VOCs photochemically react to form ozone, but not all VOCs are created equal when it comes to ozone. The smog-forming potential of VOCs depends on their relative tendency to react with sunlight to create ozone—their ozone-forming potential. *See* National Academy of Sciences, Ozone-Forming Potential of Reformulated Gasoline 33–72 (1999) (discussing VOCs and the science of ozone reactivity). EPA excludes organic compounds with low photochemical reactivity such as methane from its definition of VOCs. 40 C.F.R. 51.100(s) (defining VOC to mean "any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions."). Immediately following the definition is a list of organic compounds that "have been determined to have negligible photochemical reactivity." *Id.* The two most important organic compounds that are not classified as VOCs are methane and ethane. *Id.*

under the RFS.[175] EPA estimated between 36 and 160 additional cases of adult mortality from exposure to ozone as a result of the RFS.[176]

Following the 2010 Lifecycle Analysis, EPA scientists led by Rich Cook published their lifecycle analysis of the RFS in a peer-reviewed journal, focusing on "criteria" pollutants and on certain species of "air toxics"—pollutants that cause cancer and other health effects.[177] In its peer-reviewed study, EPA found "little net impact" on the overall cancer risk as a result of the RFS.[178] Ozone concentrations, by contrast, would increase in some (but not all) areas by as much as 1 part per billion—mostly as a result of increased NO_X and VOC emissions from agriculture, biorefineries, and fuel combustion.[179] EPA scientists conceded that significant uncertainty remained in the modeling of ozone emissions, especially given limited data on the tailpipe effects of E10 in modern vehicles.[180]

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[175] Ozone is known to cause asthma, pulmonary inflammation, and premature death. Studies have also associated ozone with heart problems and vascular disease. *See* National Ambient Air Quality Standards for Ozone, 80 Fed. Reg. 65292, 65302 (Oct. 26, 2015). It is the product of photochemical reactions of VOCs, NO_X, and CO in the atmosphere. *Id.* at 65299. Ozone formation depends on heat and sunlight; prolonged high temperatures and sunlight with stagnant air can build up ozone in the atmosphere. *Id.* at 65300. The reactions are complex and non-linear. Proposed Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone, Regulatory Impact Analysis, at 2-1 (2015). When VOCs levels are high relative to NO_X, as in rural areas, NO_X tends to increase ozone. By contrast, when VOC levels are low relative to NO_X, as in many urban areas, increases in NO_X may actually decrease ozone. *Id.*

[176] 2010 RFS RIA, *supra* note 1, at 5.

[177] Rich Cook et al., *Air Quality Effects of Increased Use of Ethanol under the United States' Energy Independence and Security Act*, 45 Atmospheric Environ. 7714, 7714 (2011).

[178] *Id.* at 7723.

[179] Those ozone increases would mostly occur in rural areas. Cook predicted that in urban (NO_X saturated) areas with serious ozone problems—for example, southern California—increases in NO_X emissions would reduce ozone by more than 0.05 parts per billion. *Id.* at 7718.

[180] *Id.* at 7723.

Subsequent studies and technological innovations have demonstrated that the 2010 Lifecycle Analysis is not a reliable or useful measure of the current lifecycle emissions of either ethanol or gasoline.

B. Corn Agriculture

Feedstock production is responsible for a substantial portion of the expected air pollution costs of ethanol.[181] Farmers emit PM by using tractors and other diesel equipment, by tilling soils, and by applying fertilizer and pesticides to the soil, which emit PM and PM precursors during the production, transportation, and application process.[182] In 2010, corn ethanol fared poorly relative to other biofuel alternatives "because it requires, per unit of fuel produced, more fossil fuel and fertilizer inputs that emit large amounts of . . . $PM_{2.5}$."[183] But as a 2009 study noted, the "[e]nvironmental costs per unit of ethanol decline with higher biomass yield, lower fertilizer and fuel inputs into biomass production, and improvements in biomass to biofuel conversion efficiencies."[184]

Just as predicted, the adoption of no-till and other forms of conservation tillage has reduced NO_X, $PM_{2.5}$ and PM_{10} emissions in the Corn Belt, by reducing both dust from the disturbance of soils, and diesel used during tillage. This trend is likely to continue in the future, as farmers realize higher crop yields from no-till and

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[181] Jamil M. Kusiima & Susan E. Powers, *Monetary Value of the Environmental Health Externalities Associated with the Production of Ethanol from Biomass Feedstocks*, 38 Energy Pol'y 2785, 2791 (2010).

[182] U.S. EPA, Biofuels and the Environment: First Triennial Report to Congress, National Center for Environmental Assessment, EPA/600/R-10/183F, at 3-24 (2011) [hereinafter 2011 Report to Congress].

[183] Hill et al., *supra* 172*,* at 2080.

[184] *Id.* at 2078.

reduced-tillage practices.[185] The use of GPS technology and new harvesting techniques—like single pass-harvesting—have also allowed farmers to reduce diesel consumption and the consequent NO_X and $PM_{2.5}$ emissions.[186] Reductions in NO_X from agriculture are expected to continue as the States find ways to comply with EPA's new ozone standards.[187]

$PM_{2.5}$ and NO_X lifecycle emissions from corn production have fallen in response to new technologies and improvements in farming. As discussed above, corn yields have increased while nitrogen application rates have remained constant.[188] Farmers have invested in controlled-release nitrogen technologies that apply nitrogen efficiently and limit NO_X and NH_3 (ammonia) formation, further reducing the per-gallon $PM_{2.5}$ emissions of ethanol.[189]

C. Petroleum Extraction

A 2009 study warned that "a shift from crude oil to oil sands . . . would greatly increase emissions, unless accompanied by simultaneous improvements in abatement technology."[190] That warning has proven true, and no abatement panacea

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[185] *See* Neil C. Hansen et al., *Research Achievements and Adoption of No-Till, Dryland Cropping in the Semi-Arid U.S. Great Plains*, 132 Field Crops Res. 196, 198 (2012). Since 1972, when USDA began keeping statistics, the adoption of no-till has increased on average by 2.3% a year—over the past four decades, no-till farming has grown from 3.3 million acres to more than 96 million acres. *See* John Dobberstein, *No-Till Movement in U.S Continues to Grow*, No-Till Farmer (Aug. 1, 2014), *available at* http://bit.ly/1phxg7b.

[186] *See* Mueller & Kwik, *supra* note 103, at 19–23; *see also* USDA, NRCS, Particulate Matter (explaining that precision farming reduces PM emissions), *available at* http://1.usa.gov/1TNlsX2.

[187] *See* Bob Stallman, *Nation's Farmers to Feel the Impact of EPA's Proposed Ozone Rule*, The Hill (Jul. 20, 2015).

[188] *See supra* p. 23.

[189] *See* USDA, Addressing Ozone and Particulate Matter from Agricultural Sources, NRCS, *available at* http://1.usa.gov/1RSfO27.

[190] Hill et al., *supra* note 172, at 2078.

has emerged. Since EPA first disseminated its 2010 Lifecycle Analysis, "tight oil" sources have claimed an ever larger share of the market, and dirty sources of crude like Canadian tar sands are expected to become the new normal. Tar sands, a notoriously dirty source of gasoline, accounted "for 9.4% of the total crudes processed in U.S. refineries in 2013," and that level is "forecast to reach 13.6% in 2020."[191] Shale oil, also dirtier than conventional oil, accounted for 50% of U.S. crude oil production in 2015.[192]

New evidence shows that the shift to tight oil sources has significantly increased gasoline's lifecycle emissions of $PM_{2.5}$, VOCs, NO_X, and carcinogenic hydrocarbons like benzene and polycyclic aromatic hydrocarbons (PAHs).

1. Tar Sands Extraction

Canadian tar sands or oil sands are "one of the world's dirtiest and most environmentally destructive sources of fuel."[193] Tar sand deposits consist of water, sand, and bitumen, which can be recovered via surface mining or steam injection.[194] After the bitumen is recovered, it is either upgraded to synthetic crude oil using an energy-intensive combination of heat, water, pressure, and catalysts on site, or diluted for further transportation.[195] Because bitumen is a highly dense and viscous

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[191] Cai et al., *supra* note 134; Englander et al., *supra* note 134.

[192] Marcelo Prince & Carlos A. Tovar, *How Much U.S. Oil and Gas Comes From Fracking?* Wall Street J. (Apr. 1, 2015), http://on.wsj.com/1G6QAtt.

[193] NRDC, Tar Sands Crude Oil: Health Effects of a Dirty and Destructive Fuel, Issue Brief, at 1 (Feb. 2014), *available at* http://on.nrdc.org/1P0Tzm6.

[194] Erin N. Kelly et al., *Oil Sands Development Contributes to Polycyclic Aromatic Compounds to the Athabasca River and Its Tributaries*, 106 PNAS 22346, 22346 (2009).

[195] Kelly et al., *supra* note 194; Cai et al., *supra* note 134; Martin, *supra* note 128, at 19–20 (discussing how tar sand extraction leaves behind highly polluted water).

substance, toxic chemicals are added to reduce the viscosity of the substance for transportation via pipelines.[196]

Oil sand production also results in emissions of carcinogenic PAHs and a variety of trace metals.[197]

Unsurprisingly, areas near tar sand extraction sites have a high incidence of cancer.[198] The overall cancer rate at these locations is much greater than previously

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[196] *See* National Academy of Sciences, Spills of Diluted Bitumen from Pipelines: A Comparative Study of Environmental Fate, Effects, and Response, at 24 (2015).

[197] PAHs are complex chemicals built on three to five benzene rings. Kelly et al., *supra* note 194, SI at 1. EPA acknowledges PAHs to be probable human carcinogens. Tier 3 Rule, 79 Fed Reg. at 23436. Indeed, some common PAHs are demonstrated carcinogens—benzo[a]pyrene (BaP), a common PAH found in petroleum-based gasoline, is a Group 1 carcinogen. *See* Benzo[a]pyrene, IARC Monograph, at 138, *available at* http://bit.ly/1QIIhZd. *See also* Takeshi Ohura et al., *Polycyclic Aromatic Hydrocarbons in Indoor and Outdoor Environments and Factors Affecting their Concentrations*, 38 Environ. Sci. & Tech. 77 (2004). Naphthalene, another PAH found in gasoline, is believed to cause cancer and other toxic health effects. Tier 3 Rule, 79 Fed Reg. at 23436. According to California's Office of Environmental Health Hazard Assessment (OEHHA), the "unit cancer risk" for PAHs—the risk that a certain dose will cause cancer over an individual's lifetime, Final New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry, Regulatory Impact Analysis, at 4-12 & n.36 (2012)—is approximately 407 times greater than the corresponding unit risk for acetaldehyde, 38 times greater than the unit risk for benzene, and about 184 times greater than the unit risk for formaldehyde. Stefan Unnasch & Ashley Henderson, Life Cycle Associates, Change in Air Quality Impacts Associated with the use of E15 Blends Instead of E10, LCA.6091.94.2014, at 11 (2014). In addition to being highly carcinogenic and mutagenic, PAHs have been linked to a host of negative health effects, including adverse birth outcomes, development delays, anxiety, depression, and attention deficit disorder, particularly in urban children exposed to high-levels of coal and vehicle exhaust. Tier 3 Rule, 79 Fed Reg. at 23436; Frederica P. Perera et al., *Prenatal Polycyclic Aromatic Hydrocarbon (PAH) Exposure and Child Behavior at age 6-7*, 120 Environ. Health Persp. 921 (2012).

[198] Isobel J. Simpson et al., *Air Quality in the Industrial Heartland of Alberta, Canada and Potential Impacts on Human Health*, 81 Atmosph. Enviro. 72 (2013).

estimated and has been linked to oil sands operations.[199] The increased cancer risk is likely due to high emissions of PAHs from oil sands production.[200]

Diluted bitumen ("dilbit") and synthetic crude transportation to U.S. refineries also pose lifecycle risks to human health within the United States. Dilbit exports have doubled since 2008, up to 550,000 barrels per day, representing more than half of all tar sand oil imports into the United States.[201] Dilbit spills impose particularly heavy costs on society—a recent dilbit spill in Michigan had cleanup costs exceeding $1 billion[202] and significant health impacts due to the release of benzene and PAHs into the water and the ambient air.[203]

2. Tight Oil Extraction

Tight oil extraction is a source of many air pollutants that affect human health in the United States; in addition to benzene and other known toxics, the production of tight oil and gas involves heavy diesel vehicles and equipment that emit

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[199] Yiqun Chen, Alberta Health Services, Cancer Incidence in Fort Chipewyan, Alberta 1995–2006 (2009); *see also* Marty Klinkenberg, *Oil Sands Pollution Linked to Higher Cancer Rates in Fort Chipewyan for First Time: Study*, Financial Post (July 8, 2014).

[200] Abha Parajulee & Fran Wania, *Evaluating Officially Reported Polycyclic Aromatic Hydrocarbon Emissions in the Athabasca Oil Sands Region with a Multimedia Fate Model*, 111 PNAS 3344 (2014); Kelly et al., *supra* note 194, at 22350 ("Due to substantial loadings of airborne PAC [polycyclic aromatic compounds], the oil sands industry is a far greater source of regional PAC contamination than previously realized"); *id*. at Supplemental Information 1.

[201] *See* National Research Council, National Academy of Sciences, Spills of Diluted Bitumen from Pipelines: A Comparative Study of Environmental Fate, Effects, and Response 9 (2015); Anthony Swift et al., NRDC, NWF, PST, Sierra Club, Tar Sands Pipelines Safety Risks 5 (Feb. 2011).

[202] National Research Council, National Academy of Sciences, Spills of Diluted Bitumen from Pipelines: A Comparative Study of Environmental Fate, Effects, and Response 38 (2015).

[203] Michigan Department of Community Health, Public Health Assessment, Kalamazoo River/Enbridge Spill, Final Report (2013), *available at* http://1.usa.gov/1phxtXZ.

substantial ambient PM$_{2.5}$.[204] Because on average, a fracking well requires "between 2 and 5 million gallons of water per hydraulic fracturing event . . . it has been estimated that approximately 2,300 trips by heavy-duty trucks are required for each horizontal well[.]"[205] Moreover, because shale wells are concentrated in particular "hot spots," concentrated diesel PM$_{2.5}$ and benzene have increased the incidence of cancer and respiratory disease in those areas.[206]

Tight oil extraction also emits significant amounts of PM$_{2.5}$ precursors and VOCs, which have worsened smog problems in Colorado and Utah.[207] Moreover, air measurement studies show that current emission inventories underestimate the emissions of benzene and VOCs from shale.[208] A recent study by the National Oceanic and Atmospheric Administration (NOAA) concludes that VOC emissions are underestimated by a factor of at least two and that benzene emissions are seven-fold higher than reported in Colorado's inventory.[209]

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[204] *See, e.g.*, Seth B. Shonkoff et al., *Environmental Public Health Dimensions of Shale and Tight Gas Development*, 122 Environ. Health Persp. 787 (2014); Anirban Roy, *Air Pollutant Emissions from the Development, Production, and Processing of Marcellus Shale Natural Gas*, 64 J. Air & Waste Mgmt. Ass'n 19 (2014).

[205] Shonkoff et al., *supra* note 204, at 791.

[206] *Id.* A NIOSH field investigation is currently investigating the risk posed by PM emissions of diesel exhaust to oil and gas workers and their families. *See* NIOSH, Field Effort to Assess Chemical Exposure Risk, Fact Sheet, *available at* http://1.usa.gov/1UUkszm; *see also* NIOSH, Oil & Gas Extraction, OSHA, *available at* http://1.usa.gov/1LS2oUv.

[207] *See* Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector, Regulatory Impact Analysis, at 4-19 (2015).

[208] Gabrielle Pétron et al., *A New Look at Methane and Non-Methane Hydrocarbon Emissions from Oil and Natural Gas Operations in the Colorado Denver-Julesburg Basin*, 119 J. Geophys. Res. Atmospheres 6836 (2014) [hereinafter Pétron et al., *Hydrocarbon Emissions from Oil and Natural Gas*]; Gabrielle Pétron et al, *Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study*, 117 J. Geophys. Res. 236 (2012).

[209] Pétron et al., *Hydrocarbon Emissions from Oil and Natural Gas*, *supra* note 208.

Furthermore, as the *amount* of pollution from petroleum extraction is increasing, the *domestic share* of that pollution is increasing as well. Unlike conventional oil, which is largely produced in foreign countries, tight oil production occurs mostly in the United States.[210] Conventional air pollutants are location-specific (unlike GHGs), so increased U.S. production of new petroleum sources has a direct effect on domestic air quality.

EPA's 2010 Lifecycle Analysis does not account for the growing market share of "tight oil." EPA's analysis therefore excludes the higher emissions of $PM_{2.5}$ NO_X, SO_X, and other pollutants from oil sands and from tight oil production—a significant omission given that tar sands account for 10% of all crude processed by U.S. refineries (and are forecast to reach 13.6% by 2020),[211] and shale oil accounts for 50% of total United States oil production.[212]

D. Fuel Production

1. Ethanol Biorefineries

Corn ethanol biorefineries are a source of $PM_{2.5}$, both because they directly emit PM precursors, including volatile organic compounds VOCs, SO_2 and NO_X, and because they consume significant amounts of natural gas.[213]

But, as with farming, the lifecycle PM emissions of corn ethanol production are falling: increased ethanol yields, new and higher co-product yields, and the use of

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[210] *See* U.S. Energy Information Administration, Annual Energy Outlook, at D-14 to D-15 (2015) (predicting increased United States production of oil between 2013 and 2020).

[211] Cai et al., *supra* note 146.

[212] Marcelo Prince & Carlos A. Tovar, How Much U.S. Oil and Gas Comes From Fracking? Wall Street J. (Apr. 1, 2015), *available at* http://on.wsj.com/1RSfTTn.

[213] Joost De Gouw et al., *Airborne Measurements of the Atmospheric Emissions from a Fuel Ethanol Refinery*, 120 J. Geo. Res: Atmosph. 4385, 4338 (2015).

combined heat and power and other improvements in biorefinery energy efficiency have reduced natural gas usage in ethanol plants, reducing emissions of PM$_{2.5}$ and its precursors.[214]

Biorefineries also emit VOCs through a variety of processes, mostly through evaporative emissions of ethanol and acetaldehyde from boilers.[215] While these chemicals contribute to ozone, they are significantly less toxic than the hydrocarbons emitted during the lifecycle of gasoline.[216] Existing pollution control technologies are being implemented at a low cost to substantially reduce these biorefinery emissions.[217] It is therefore critical that lifecycle emissions estimates be based on representative technology.[218]

Any analysis of biorefinery emissions must take into account the relatively low toxicity of ethanol and acetaldehyde emissions compared with the VOCs emitted from gasoline refineries. And such an analysis must also consider the proximity of

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[214] *See* Mueller & Kwik, *supra* note 103, at 2-18; 2011 Report to Congress, *supra* note 182, at 4-5.

[215] *See* Prevention of Significant Deterioration, Nonattainment New Source Review, and Title V: Treatment of Certain Ethanol Production Facilities Under the "Major Emitting Facility" Definition, 72 Fed. Reg. 24060, 24070 (May 1, 2007); *see also* Cook et al., *supra* note 177, at 7715 ("VOCs emitted in the largest quantity from ethanol plants include formaldehyde and acetaldehyde").

[216] Unlike ethanol and acetaldehyde, which typically cause eye irritation, refineries emit substantial amounts of benzene, a known carcinogen. *See* Final New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry, at 4-14 (Apr. 2012).

[217] Dan Despen*, Accurate VOC, HAP Measurement Critical for Permit Compliance*, Ethanol Producer Magazine (Oct. 15, 2014), *available at* http://bit.ly/1p9tr3g.

[218] Studies of outdated technology will report outdated results. For example, NOAA air measurements of an ethanol plant suggested that VOC emissions from ethanol plants might be greater than EPA estimates. In particular, NOAA's air measurements suggested that refinery emissions of ethanol and acetaldehyde are underestimated by current inventories. De Gouw et al., *supra* note 213. But NOAA scientists took their air measurements from a single unrepresentative plant in Decatur, Illinois—one of the few remaining coal-powered wet-mill ethanol refineries left in the country. *Id.* at 4390. Further studies are needed to determine the accuracy of current inventories.

these facilities to humans. Because ethanol refineries are mostly co-located with corn fields in rural areas, they have lower impacts on human health per unit of pollution than gasoline refining, which occurs largely near urban areas.[219]

2. Petroleum Refineries

Petroleum refineries are a significant source of urban pollution, including $PM_{2.5}$ and other air toxics like benzene. Unlike biorefineries, crude oil refineries are located near urban populations.[220] According to EPA, more than 6.1 million people live within three miles of a petroleum refinery—disproportionately low-income minorities and vulnerable community groups.[221] In addition to being subjected to dangerous amounts of benzene and PAHs, petroleum processing and fossil fuel combustion from refineries subject these residents to significant quantities of $PM_{2.5}$ and $PM_{2.5}$ precursors like SO_2—up to 247,000 tons of SO_2 and 30,000 tons of direct

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[219] *See infra* note 220.

[220] *See* Hill et al., *supra* note 172, at 2078; Christopher W. Tessum et al., *A Spatially and Temporally Explicit Life Cycle Inventory of Air Pollutants from Gasoline and Ethanol in the United States*, 46 Environ. Sci. & Tech. 11408, at Supplemental Information 2-1 (2012) (finding that 80% of refineries are near population centers, compared to only 10% of biorefineries). The Tessum study omits Canadian refinery emissions, which contribute to cross-border pollution in the United States. *See, e.g.*, Canada-United States Air Quality Agreement Progress Report (2012) (stating that the petroleum industry accounts for 21% of all Canadian NO_X), *available at* http://bit.ly/1M83Ywe; *see also* Natural Resources Canada, Canadian Refineries Government of Canada (location of Canadian refineries), at http://bit.ly/1RSdBUs.

[221] EPA, Final Petroleum Refinery Sector Risk and Technology Review and New Source Performance Overview, Fact Sheet, *available at* http://1.usa.gov/1R8suPi.

PM$_{2.5}$ per year.[222] Refinery emissions of xylene and other hydrocarbons also contribute to ozone.[223]

Refineries pollute more today than in the past because of the source of the petroleum. Tar sands products increase refinery emissions: dilbit and synthetic crude contain higher amounts of benzene and heavy metals, which evaporate during the refining process. They are also harder to break down into light gasoline products, increasing VOC emissions and ozone.[224]

E. Tailpipe Emissions

Unlike upstream air toxic emissions from producing ethanol, which affect air quality of areas primarily in the rural Midwest, tailpipe emissions are ubiquitous and disproportionately affect densely populated urban areas. According to EPA, mobile sources are responsible for approximately "47 percent of outdoor toxic emissions, over 50 percent of the cancer risk, and over 80 percent of the noncancer hazard."[225]

Blending ethanol into gasoline reduces air pollution from motor vehicles, improving the lifecycle health effects of ethanol. But EPA relied on outdated, flawed studies to support contrary conclusions in its 2010 Lifecycle Analysis. By

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[222] *See* EPA, Addressing Air Emissions from the Petroleum Refinery Sector, Public Outreach Presentation, Office of Air Quality Planning and Standards 3 (2011), *available at* http://1.usa.gov/1RB11WX. These numbers remain high despite the fact that gasoline refineries have been subjected to EPA and state enforcement for decades. *See* James H Wilson Jr. & Maureen A. Mullen, Including the Emission Effects of Refinery Cases and Settlements in Projections for the EPA's CAAA Section 812 Analysis (2015), *available at* http://1.usa.gov/1TNjExm.

[223] *See* William P.L. Carter, Updated Maximum Incremental Reactivity Scale and Hydrocarbon Bin Reactivities for Regulatory Applications (Jun. 22, 2009), *available at* http://bit.ly/1U4vNxq.

[224] NRDC, Tar Sands Crude Oil: Health Effects of a Dirty and Destructive Fuel 5 (Feb. 2014), *available at* http://on.nrdc.org/1A6w1Y1.

[225] 2010 RFS RIA, *supra* note 1, at 604.

underestimating the tailpipe benefits of existing ethanol blends, EPA systematically underestimated the air quality benefits of corn ethanol. Moreover, by ignoring future mid-level ethanol blends, EPA ignored the lifecycle benefits that can be achieved in a high-ethanol, high-octane future.

In its 2010 Lifecycle Analysis, EPA correctly stated that for E10 "most studies show reductions in emissions of . . . benzene, and 1,3-butadiene[.]"[226] However, according to EPA, "data . . . are more equivocal for NO_X and VOC."[227] Based on "limited data," EPA assumed that E10 decreased VOC emission rates by 7% to 10%, but increased NO_X by over 7%.[228] In fact, E10 reduces NO_X.[229]

More fundamentally, EPA's 2010 Lifecycle Analysis failed to fully account for the toxic effects of PM from aromatics, which ethanol reduces, and failed to account for the risk of aromatics when compared to other, less harmful toxics associated with ethanol. As discussed below, new evidence shows that blending ethanol into gasoline reduces or at least has no effect on most pollutants, with the exception of acetaldehyde, which is a relatively non-toxic irritant. Thus, the lifecycle air quality benefits of ethanol are much greater than EPA assumed in 2010.

1. Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)

Benzene, toluene, ethylbenzene, and xylene (collectively, BTEX), are the main aromatic hydrocarbons currently added by refiners to gasoline boost fuel "octane."[230] BTEX are emitted directly from the tailpipe and have carcinogenic and

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[226] Cook et al., *supra* note 177, at 7715.

[227] *Id.*

[228] *Id.* at 7716.

[229] *See infra* pp. 57–60.

[230] Benzene, toluene, ethylbenzene, and xylene were designated as Hazardous Air Pollutants by the 1990 Amendments to the Clean Air Act. *See* 42 U.S.C. § 7412(b)(1).

mutagenic effects.[231] In addition, BTEX are an important source of secondary PM formation and ozone.[232] Recent evidence suggests that BTEX exposure has negative health effects at much lower concentrations than EPA has deemed safe.[233]

A Health Effects Institute study recently concluded that "gasoline-powered vehicles are the main sources of VOCs (including BTEX) at the near-road sites."[234] In particular, gasoline exhaust is the source of between 70% to 100% of on- and near-road concentrations of VOCs, and the source of substantially all on- and near-road concentrations of BTEX.[235]

Because ethanol is a source of fuel octane, it reduces the need to add aromatics to the gasoline blendstock. EPA estimates that due to E10, the average aromatics content in summer gasoline has fallen by 4% to 5%, to about 24% to 25% of the total volume in 2011.[236] Ethanol naturally reduces BTEX emissions because ethanol is a simple, high-octane molecule that contains no aromatic hydrocarbons.[237]

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[231] Ashley L. Bolden et al., *New Look at BTEX: Are Ambient Levels a Problem?*, 49 Environ. Sci. & Tech. 5261, 5261 (2015).

[232] *See* Katherine Von Stackelberg et al., *Public Health Impacts of Secondary Particulate Formation from Aromatic Hydrocarbons in Gasoline*, 12 Environ. Health 1, 1–2 (2013).

[233] Bolden et al., *supra* note 231, at 5270.

[234] Eric Fujita, Concentrations of Air Toxics in Motor Vehicle Dominated Environments, Health Effects Inst., Research Report No. 156, at 2 (Feb. 2011); *see also* Von Stackelberg, *supra* note 232, at 5 ("Source-specific speciation of total VOC in the 2005 National Emissions Inventory reveals that the U.S. emissions of single-ring aromatic hydrocarbons are 3.6 million tons per year, of which 69% are from gasoline-powered vehicles").

[235] Fujita, *supra* note 234, at 2 ("Apportionment of BTEX showed that gasoline was the dominant source (94% to 100%) for all on-road samples").

[236] Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule, Regulatory Impact Analysis, at 3-5 (2014) [hereinafter Tier 3 RIA]; *see also*, Bolden et al., *supra* note 231, at 5261 (noting that recent studies show that in 1998, before ethanol was blended into gasoline, "BTEX collectively comprised as much as 27.5% of high octane at the pump").

[237] Aikawa et al., *supra* note 143, at 610–11.

New evidence from recent fuel studies overwhelmingly shows that blending ethanol into gasoline results in significant decreases in BTEX pollution. A 2015 vehicle study modeling fuel with different aromatic contents in both GDI and port fueled injection (PFI) engines found that raising the level of aromatics from 25% to 35% raises BTEX emissions by between 81% and 194%—and that raising aromatics content from 15% to 35% raised BTEX emissions by between 107% and 376%.[238]

2. Particulate Matter (PM)

Gasoline exhaust is a "ubiquitous source of particulate matter."[239] While EPA has historically associated $PM_{2.5}$ emissions with diesel engines, "recent studies report that a substantial amount of PM emissions are produced not only by diesel engines, but by gasoline engines as well."[240] Moreover, direct injection technology is expected to dramatically increase the number and mass of fine (and particularly dangerous ultra-fine) PM emissions from motor vehicles.[241]

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[238] Georgios Karavalakis et al., *Evaluating the Effects of Aromatics Content in Gasoline on Gaseous and Particulate Matter Emissions from SI-PFI and SIDI Vehicles*, 49 Environ. Sci. & Tech. 7021, 7026 (2015).

[239] Tier 3 Rule, 79 Fed Reg. at 8440.

[240] *See* Aikawa et al., *supra* note 143, at 617; Manufacturers of Emission Controls Association, Ultrafine Particulate Matter and the Benefits of Reducing Particle Number in the United States, *available at* http://bit.ly/1RB1kks.

[241] *Id.* In GDI engines, fuel particles attach to (or impinge on) cylinders and pistons, preventing fuel from fully vaporizing and mixing with air during combustion, thereby increasing particle emissions. *See* Georgios Karavalakis et al., *Assessing the Impacts of Ethanol and Isobutanol on Gaseous and Particulate Emissions from Flex-Fuel Vehicle*s, 48 Environ. Sci. Technol. 14016, 14021 (2014). For a discussion of the dangers of ultrafine particles, see A.B. Knol et al., *Expert Elicitation on Ultrafine Particles: Likelihood of Health Effects and Causal Pathways*, 6 Particle Fibre Toxicol. at 2 (2009); EPA Integrated Science Assessment for Particulate Matter, at 5-3 & n.34 (2009) ("[T]he greater surface per unit volume of UFPs could potentially deliver relatively more adsorbed soluble components to cells," and "may have more opportunity to interact with cell surfaces.").

Blending ethanol into gasoline reduces PM emissions, in terms of both mass and particle number.[242] This is mainly because ethanol displaces aromatics, which are responsible for most of the PM emissions from fuel combustion.[243] Depending on the engine calibration, E10 can reduce PM mass emissions by up to 20% in new GDI engines, as compared to E0.[244] Higher ethanol blends reduce PM even more.[245] A recent study shows dramatic reductions in PM mass and number from transitioning to E83 in both GDI and PFI engines.[246]

3. Secondary Organic Aerosol (SOA)

Secondary organic aerosol (SOA), a species of secondary $PM_{2.5}$, is one of the major contributors to the $PM_{2.5}$ burden in the United States, and it causes a range of negative health effects.[247] Vehicle emissions represent the largest source of anthropogenic urban SOAs.[248]

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[242] Anderson et al., *supra* note 143, at 1031. While EPA's recent EPAct study found that "other things equal," ethanol raises PM emissions, recent studies have shown that EPA's study confounded the effect of aromatics and other hydrocarbons with the effect of ethanol. *Id.*; *see also* Thomas L. Darlington et al., *Analysis of EPAct Emission Data Using T70 as an Additional Predictor of PM emissions from Tier 2 Gasoline*, SAE International, 2016-01-0996 (Apr. 5, 2016).

[243] Karavalakis et al., *supra* note 241, at 7027. Honda scientists have shown that PM is correlated with high-boiling, aromatic hydrocarbons in an empirical model. Aikawa et al., *supra* note 143.

[244] Maricq et al., *supra* note 150, at 580.

[245] *Id.* at 581 (PM "decreases slightly from 0% to 17% ethanol, but falls by ~45% for E32 and E45.").

[246] Karavalakis et al., *supra* note 241, at 14021.

[247] *See* Von Stackelberg et al., *supra* note 232, at 7-8; Lynn M. Rusell et al., Secondary Organic Aerosol Formation from Fossil Fuel Sources Contribute Majority of Summertime Organic Mass at Bakersfield, *available at* http://bit.ly/1phxwTE.

[248] R. Bahreini et al., *Gasoline Emissions Dominate over Diesel in Formation of Secondary Organic Aerosol Mass*, 39 Geophys. Res. Lett. L06805 (2012); Michael J. Kleeman et al., *Source Apportionment of Secondary Organic Aerosol During a Severe Photochemical Smog Episode*, 41 Atmos. Environ. 576 (2007).

A growing body of scientific evidence shows that the entire SOA formation potential of gasoline is attributable to the aromatic hydrocarbons added to enhance fuel octane.[249] And recent EPA studies confirm that ethanol does not contribute to SOA.[250]

The health impacts of SOA formation from aromatics are dramatic: The Harvard study estimates that SOA carries a social cost of up to $34.9 billion a year,[251] and reducing them through displacement of aromatics would provide a commensurate social benefit. To put this number in perspective, another Harvard study recently estimated the net benefits of the Clean Power Plan at $38 billion per year in 2020, including both co-benefits from air toxic reductions and GHG reductions.[252]

While EPA's vehicular pollution controls reduce other primary pollutants, they do not significantly reduce SOA precursors.[253] However, the SOA-forming potential of gasoline—and the associated $PM_{2.5}$ burden—can be substantially reduced

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[249] Von Stackelberg et al., *supra* note 232, at 2; *see also id.* ("[E]vidence is growing that aromatics in gasoline exhaust are among the most efficient secondary organic matter precursors."); L. Hildebrandt et al., *High Formation of Secondary Organic Aerosol from the Photo-Oxidation of Toluene*, 9 Atmos. Chem. & Phys. 2973 (2009); Odum et al, *supra* note 144, at 96.

[250] 2010 RFS RIA, *supra* note 1, at 575–81. EPA is currently conducting further studies on SOA. *See* Sherri Hunt, *Research Partnership Advancing the Science of Organic Aerosols* (June 19, 2013), *available at* http://1.usa.gov/1U4vYc7.

[251] Von Stackelberg et al., supra note 232, at 6; Neal Fann et al., *The Influence of Location, Source, and Emission Type in Estimates of the Human Health Benefits of Reducing a Ton of Air Pollution*, 2 Air Qual. Atmos. Health 169 (2009).

[252] Jonathan J. Buonocore et al., *An Analysis of Costs and Health Co-Benefits for a U.S. Power Plant Carbon Standard*, 11 PLoS ONE e0156308 (June 7, 2016), *available at* http://bit.ly/29oe8vu.

[253] T.D. Gordon et al., *Secondary Organic Aerosol Formation Exceeds Primary Particulate Matter Emissions for Light Duty Gasoline Vehicles*, 13 Atmos. Chem. Phys. Discuss. 23173, 23176, 23197 (2013) (finding that even though the contribution of light duty vehicle emissions to ambient PM levels is "dominated" by secondary SOA and nitrates, "catalysts are optimized to reduce emissions of regulated pollutants (NO_X, NMOG, and CO), not SOA precursors.").

by substituting aromatic hydrocarbons with ethanol. As EPA has recognized, "[d]ue to the high octane quality of ethanol, it greatly reduces the need for . . . aromatics including toluene."[254] EPA's 2010 Lifecycle Analysis fails to account for these benefits, because EPA's widely used CMAQ model vastly underestimates the SOA-forming potential of gasoline—by a factor of at least 3.8.[255]

4. Polycyclic Aromatic Hydrocarbons (PAHs)

The high-molecular-weight PAHs present in gasoline are particularly dangerous to human health because they bond with ultra-fine particles and directly enter the bloodstream.[256] According to EPA, "the majority of PAHs are adsorbed onto particles less than 1 [micrometer] in diameter."[257] SOAs coat and protect PAHs, turning them into long-range pollutants.[258] Gasoline particles are also a major source of PAH deposition in water, which has "increased by 200% to 300% over the last forty years and correlates with increased vehicle use."[259]

Motor vehicle emissions are estimated to account for 46% to 90% of outdoor PAHs in urban areas.[260] PAHs are emitted through vehicle tailpipes in either gas or

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[254] 2010 RFS RIA, *supra* note 1, at 579. EPA's own model also predicts that SOA from biogenic sources could be reduced by as much as 50% though reduction in anthropogenic sources of pollution, including mobile PM. Annmarie G. Carlton et al., *To What Extent Can Biogenic SOA Be Controlled?*. 44 Environ. Sci. Technol. 3376 (2010).

[255] Von Stackelberg et al., *supra* note 232, at 3.

[256] *See* Yuling Jia et al*., Estimated Reduction in Cancer Risk due to PAH Exposures If Source Control Measures during the 2008 Beijing Olympics Were Sustained*, 119 Environ. Health Perspect. 815, 820 (2011).

[257] Tier 3 RIA, *supra* note 236, at 6-25.

[258] Alla Zelenyuk at al., *Synergy Between Secondary Organic Aerosols and Long-Range Transport of Polycyclic Aromatic Hydrocarbons*, 46 Environ. Sci. Technol. 12459 (2012).

[259] Tier 3 RIA, *supra*, note 236, at 6-25.

[260] Cathryn C. Tonne et al., *Predictors of personal polycyclic aromatic hydrocarbon exposures among pregnant minority women in New York City*, 112 Environ. Health Perspect. 754 (2004); *see also* Tier 3 RIA, *supra*, note 236, at 6-25 ("Major sources of PAHs include mobile sources.")

particle form, as a result of the incomplete combustion of the aromatic fraction of gasoline.[261] Because PAHs combust only at very high temperatures, they significantly increase the PM burden in urban and heavy-traffic areas.[262] Indeed, fuel studies have shown that PM emissions from gasoline-powered vehicles are overwhelmingly made up of PAHs.[263]

Blending ethanol to displace octane-enhancing aromatics has been shown to reduce PAH emissions: One recent study found that E10 reduces PAH emissions by approximately 70%, and that E85 reduces PAHs by 85%, relative to E0.[264] EPA's 2010 Lifecycle Analysis fails to account for this reduction because it does not account for PAH emissions at all.

5. Nitrogen Oxides (NO$_X$)

In its 2010 assessment of the lifecycle emissions effects of the RFS, EPA wrongly assumed E10 increased NO$_X$ emissions.[265] EPA's assumption contradicted

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[261] Karavalakis et al., *supra* note 238, at 7021, 7027 ("Aromatic hydrocarbons are unsaturated compounds with a benzene ring-like structure and are known to form polycyclic aromatic hydrocarbons (PAHs), which are precursors of soot particles . . . . Aromatic compounds can act as seed molecules for molecular growth and polymerization to form larger hydrogen-deficient molecules (PAHs) that produce soot."); *see also* Tier 3 RIA, *supra*, note 236, at 6-25.

[262] Karavalakis et al., *supra* note 238, at 7027.

[263] Aikawa et al., *supra* note 143, at 610, 611 ("PN increased in a majority of gasoline blends to which hydrocarbons had been added. Partly because only hydrocarbons were added to the gasoline, . . . all of the additional PN is considered a PAH (polycyclic aromatic hydrocarbon) with a high boiling point or soot. The higher the boiling point hydrocarbon added, the more the PN increases. This trend is particularly notable with aromatic substances.").

[264] M.A. Costagliola et al., *Combustion Efficiency and Engine Out Emissions of a S.I. Engine Fueledwith Alcohol/Gasoline Blends*, Applied Energy 1, 9 & fig. 17 (2012) (finding "reduction of toxic equivalents [of the carcinogenic PAH benzo(a)pyrene (B(a)p)] when moving from gasoline to alcohol blends," including a 60% to 70% reduction for splash blended E10, E20, and E30 as compared to gasoline, with even better results for E85); *see also* Dabrina D. Dutcher et al., *Emissions from Ethanol-Gasoline Blends: A Single Particle Perspective*, 2 Atmosphere 195 (2011).

[265] *Cf.* 2010 RFS RIA, *supra* note 1, at 508 (assuming a NO$_X$ increase of over 7% in Tier 2 and earlier vehicles).

EPA's own scientists, who had noted that ethanol decreases NO_X in modern vehicles equipped with oxygen sensors that control and calibrate air-fuel ratios.[266] Indeed, EPA's 2010 Lifecycle analysis contradicted its own analysis of 19 vehicles at two temperatures in support of the RFS rule. That analysis concluded that a "10% ethanol blend (E10) did not have a statistically significant effect on . . . NO_X emissions relative to gasoline containing no ethanol (E0) at either test temperature.[267]

To reach its unsupported conclusion about ethanol's alleged NO_X effect, EPA's 2010 Lifecycle Analysis extended the results of the "so-called 'Predictive Model,' " developed more than 16 years ago to assess California's request for an oxygenate waiver in Tier 0 vehicles, and used outdated test data from trade groups including Exxon Mobil and the Mexican Petroleum Institute.[268] Even though the Agency admitted that "there was not enough consistency across these studies to confidently predict the impact of oxygenated fuel on . . . NO_X emissions,"[269] EPA applied these unsubstantiated fuel results to Tier 1 vehicles based on a single flawed study published by the Coordinating Research Council that was designed to model the effect of oxygen and RVP on carbon monoxide, not NO_X.[270] Even Sierra

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[266] *See* Mathew Brusstar (EPA) & Marco Bakenhaus, *Economical High-Efficiency Engine Technologies for Alcohol Fuels* (Presented at ISAF XV International Symposium on Alcohol Fuels, Sep. 28, 2005), http://1.usa.gov/1XeaEil.

[267] Aron Butler, Staff Engineer, U.S. EPA, Summary of Recent Findings For Fuel Effects of a 10% Ethanol Blend on Light Duty Exhaust Emissions, EPA-HQ-OAR-2005-0161 (Jan. 29, 2010).

[268] 2010 RFS RIA, *supra* note 1, at 604.

[269] *Id.* at 507.

[270] *Id.* at 507–08. ("[I]n our analysis for this final rule, we extended these effects to Tier 1 and NLEV cars and light trucks (through the 2003 model year) based on a recently published study from CRC.) (citing Coordinating Research Council, Effects of Vapor Pressure, Oxygen Content, and Temperature on CO Exhaust Emissions, CRC Report E-74b (2009) [hereinafter CRC Report E-74b], *available at* http://bit.ly/1S3F2Il). The CRC E-74b program "was designed primarily to evaluate the effects of RVP and oxygenate content on exhaust CO emissions under conditions similar to those found in the Phoenix and Las Vegas areas during the winter on recent model-year vehicles." CRC Report E-74B, at 1. The study only incidentally reported NO_X emission effects. *Id.* at 5. Moreover, the

Research, a consultant for the American Petroleum Institute, criticized EPA for relying on a study that "does not support the extrapolation of Tier 0 E10 exhaust corrections to Tier 1 vehicles."[271]

Although EPA found in 2010 that the data did not justify attributing these NO_X effects to Tier 2 vehicles,[272] the Agency has stated in subsequent studies that "E10 was assumed to . . . increase NO_X emissions by over 7%" without limitation.[273] EPA has never explained this reversal or given any justification for attributing a NO_X increase to all vehicles, including Tier 2 vehicles.

EPA's conclusion in 2010 that E10 increased NO_X emissions is contradicted by other studies, in addition to the EPA studies cited above.[274] Indeed, subsequent studies show that NO_X emissions actually decrease when a properly calibrated modern vehicle transitions from E0 to E10.[275]

Ethanol's NO_X-reducing effect is probably due to its high heat of vaporization, which translates to lower compressed gas temperatures during the compression stroke, and the fact that ethanol displaces heavy aromatics which tend

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methodology used in the study, which match-blended T50 for ethanol-gasoline blends, is questionable and unnecessary. *See* Anderson et al., *supra* note 143.

[271] Sierra Research, Technical Review of EPA Renewable Fuel Standard Program (RFS2) Regulatory Impact for Non-GHG Pollutants, Report No. SR2010-05-01Prepared for the Am. Petroleum Inst., at 20 (May 4, 2010).

[272] 2010 RFS RIA, *supra* note 1, at 508.

[273] Cook et al., *supra* note 170, at 7716.

[274] *See supra* notes 266 and 267 and accompanying text.

[275] Maricq et al., *supra* note 150, at 580 (finding decreases in NO_X emissions of "about 20%" when the ethanol content of fuel is increased from 0% to 17% or higher); Mustafa Canakci et al., *Impact of Alcohol-Gasoline Fuel Blends on the Exhaust Emission of a Spark Ignition Engine*, 52 Renewable Energy, 111–17 (2013) (finding decreases in NO_X emissions of 11% and 15.5% when ethanol content is increased from 0% to 5% and 10%, respectively, in a 1.4L gasoline engine (used in the Honda Civic) with a 10.4:1 compression ratio).

to form chamber deposits.[276] The effect of ethanol on NO_X emissions depends on engine calibration,[277] and in modern vehicles, oxygen sensors mitigate any adverse effect on NO_X emissions.

EPA should correct its lifecycle analysis to reflect that ethanol reduces NO_X emissions in modern vehicles.

F. Future Fuels

Blending ethanol into gasoline has reduced air pollution by displacing aromatics. However, recent evidence shows that transitioning from a blend of E10 to a mid-level blend of approximately 30% ethanol (E30) would further reduce pollutant tailpipe and evaporative emissions. Many studies have established that mid-level ethanol blends would reduce PM mass and number,[278] BTEX,[279] NO_X,[280] and other pollutants to an even greater extent than E10.[281] Additionally, blending a

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[276] *See* Health Effects Institute, Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects 3 (2010). EPA's new EPAct study predicts that other things equal, ethanol increases NO_x, but this reflects EPA's arbitrary "match-blending" methodology, which fails to properly control for variation in the fuels and uses unrealistic test fuels. *See* Anderson et al., *supra* note 143.

[277] Carolyn Hubbard et al., *Ethanol and Air Quality: Influence of Fuel Ethanol Content on Emissions and Fuel Economy of Flexible Fuel Vehicles*, 48 Environ. Sci. & Tech. 861, 861, 865 (2014).

[278] Karavalakis et al., *supra* note 241, at 14021; Costagliola et al., *supra* note 264, at 9; Maricq et al., *supra* note 150, at 580.

[279] *See, e.g.*, Karavalakis et al., *supra* note 241, at 14020 ("Benzene emissions for E83 showed statistically significant decreases of 60% and 58%, respectively, relative to E10 and E51. For toluene, ethylbenzene, m/p-xylene, and o-xylene compounds as a group, the statistically significant reductions in emissions ranged from 66% to 85% for E83 compared to E10, from 66% to 84% for E83 compared to E51"); Costagliola et al., *supra* note 264, at 9; Maricq et al., *supra* note 150, at 580.

[280] Hubbard et al., *supra* note 275.

[281] E15 also reduces butadiene and formaldehyde relative to E10, despite recent EPA model predictions to the contrary. Anderson et al., *supra* note 143, at 1034. E15 is difficult to commercialize because EPA has chosen to deny the one-pound RVP waiver for E15 fuels. *See* Jeremy P.

higher volume of ethanol into gasoline would reduce the RVP of the fuel mixture, which would reduce evaporative emissions associated with E10.[282]

EPA should act on its regulatory authority to facilitate mid-level ethanol blends, which would fully realize the goals of the RFS.[283] In addition to lowering fuel consumption and reducing GHG emissions, mid-level ethanol blends could provide a smooth transition to cleaner fuels, significantly advancing the Clean Air Act's overarching goal of promoting the "public health and welfare and the productive capacity of the population."[284]

In sum, the weight of the evidence shows that transitioning to mid-level ethanol blends would dramatically reduce tailpipe emissions of aromatics, particle mass and number, NO_X, VOCs, and ozone. But EPA's 2010 Lifecycle Analysis and entirely fails to account for the benefits of mid-level blends.[285] By continuing to rely on its outdated 2010 Lifecycle Analysis, EPA neglects its duty to protect the nation's air quality.

1. BTEX

BTEX would be reduced through the use of mid-level biofuel blends. The University of California has shown that a fuel blend of 51% ethanol (E51) reduces benzene, toluene, and xylene relative to E10, and the reductions are greater in even

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Greenhouse, *E15: Cracking the RVP Nut: New Blend Won't Qualify for One Pound Waiver, Presenting Huge Hurdle*, Ethanol Producer Mag. (Oct. 18, 2011).

[282] Anderson et al., *supra* note 143, at 1029–30; Stein et al., *supra* note 148.

[283] In the Proposed Rule, EPA claims it is currently considering "regulatory provisions" that would facilitate the introduction of higher blends of ethanol. 81 Fed. Reg. at 34,784.

[284] 42 U.S.C. § 7401(a)-(b).

[285] EPA curtly discussed infrastructure issues related to the deployment of EPA, but EPA consciously disregarded evidence of the pollution benefits of mid-level blends in light of a pending application for an E15 waiver. *See* 2010 RFS RIA, *supra* note 1, at 256–57.

higher ethanol blends.[286] This is particularly important because some BTEX are carcinogenic,[287] and because BTEX contribute to ozone and SOA.[288]

BTEX emissions are correlated with aromatics content, so replacing aromatics with ethanol reduces BTEX emissions.[289] Raising total aromatics content from 15% to 25% raises BTEX emissions by about 52% to 103%.[290]

2. PM and PN

Mid-level ethanol blends would facilitate dramatic reductions in PM tailpipe emissions. In general, ethanol reduces PM because it replaces aromatic hydrocarbons with high double bond equivalent (DBE) values which "disproportionately contribute to PM formation."[291] But ethanol also tends to reduce PM for two additional reasons: first, ethanol's relatively high vapor pressure and low boiling point (78°C) allow it to lower the boiling point of the fuel mixture, improving combustion; second, ethanol's higher oxygen content helps it to promote leaner combustion and avoids the impingement of soot in GDI engines.[292]

Numerous studies confirm that in both GDI and port fuel injection (PFI) engines, mid-level ethanol blends reduce PM mass and particle number (PN)

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[286] Georgios Karavalakis et al., *Assessing the Impacts of Ethanol and Isobutanol on Gaseous and Particulate Emissions from Flexible Fuel Vehicles*, 48 Envtl. Sci. & Technol. 14016, 14021 (2014).

[287] *See supra* note 231 & accompanying text.

[288] *See supra* note 232 & accompanying text.

[289] E15, which is currently legal but practically unavailable, reduces benzene emissions. Anderson et al., *supra* note 143, at 1034.

[290] Karavalakis et al., *supra* note 238, at 7027. *See also* Stein et al., *supra* note 148.

[291] Stein et al., *supra* note 148, at 11. Double bond equivalent value, or DBE, is a measure of the number of double bonds and rings in the fuel molecule, defined as the number of hydrogen atoms which would be required to fully saturate the molecule. *Id.*

[292] *Id.*

emissions.[293] A recent University of California study found that a fuel with 51% ethanol reduced PM mass emissions by 61% and reduced PN emission by 50%, relative to E10.[294] The study attributed these emissions reductions to "the increased oxygen content of the fuel which facilitates more complete combustion, or the lower hydrocarbon content."[295]

Many other studies corroborate these predictions. Oak Ridge Laboratory studies conducted in 2010 and 2012 show that E20 reduces average PM and PN relative to E10 and E0.[296] A more recent Oak Ridge study confirms that E30 also reduces PM and PN.[297] Another recent study found that transitioning to higher ethanol blends could cut PN emissions in half.[298] A Ford Motor Company study of GDI engines also found that raising ethanol content to about 30% lowers PM and PN by 30% to 40%.[299] In another study, raising aromatics content from 15% to current levels of 25% was found to raise PM mass emissions by 148%.[300]

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[293] Anderson et al., *supra* note 143, at 1031 (collecting studies).

[294] Karavalakis et al., *supra* note 286, at 14021, 14022.

[295] *Id.* at 14021.

[296] John M. Storey et al., *Exhaust Particle Characterization for Lean and Stoichiometric DI Vehicles Operating on Ethanol-Gasoline Blends*, SAE Tech. Paper (2012); John M. Storey et al., *Ethanol Blend Effects On Direct Injection Spark-Ignition Gasoline Vehicle Particulate Matter Emissions*, 3 SAE Int. J. Fuels Lubr. 650 (2010).

[297] John M. Storey et al., *Novel Characterization of GDI Engine Exhaust for Gasoline and Mid-Level Gasoline Alcohol Blends*, 7 SAE Int. J. Fuels Lubr. 571 (2014).

[298] Costagliola et al., *supra* note 264, at 6.

[299] Maricq et al., *supra* note 150.

[300] Karavalakis et al., *supra* note 238, at 7027.

3. NO$_X$, VOCs, and Ozone

Mid-level ethanol blends would also reduce emissions of NO$_X$ and organic compounds that contribute to ozone. The 2014 Ford study found that in modern vehicles calibrated to sense the higher oxygen content of ethanol, "emissions of NO$_X$ decreased by approximately 70% as the ethanol content increased from E0 to E20–E40."[301] This trend is confirmed by multiple studies that find significant NO$_X$ reductions from mid-level ethanol blends.[302]

Likewise, non-methane organic gases (NMOG) and total hydrocarbon emissions "exhibit a clear minimum around E20–E40," lowering emissions from a flex-fuel vehicle by 25% and 35% relative to E0.[303]

And increasing ethanol content above 10% reduces the RVP of the fuel, lowering VOC emissions.[304]

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[301] Hubbard et al., *supra* note 275, at E.

[302] Bang-Quan He et al., *A Study on Emission Characteristics of an Electronic Fuel Injection Engine with Blended Gasoline Fuels*, 37 Atmospheric Environment, 949 (2003) (finding that E30 can reduce NO$_X$ emissions up to 33%, compared to E0); M. Bahattin Celik, *Experimental Determination of Suitable Ethanol-Gasoline Blend Rate at High Compression Ratio for Gasoline Engine*, 28 Applied Thermal Engineering 396 (2008) (finding a 33% decrease in NO$_X$ emissions from E50 relative to E0 in a small single-cylinder engine at stoichiometric fuel conditions, with a compression ratio of 6:1; Koichi Nakata et al., *The Effect of Ethanol Fuel on a Spark Ignition Engine*, SAE Technical Paper (2006) (finding a 25% decrease in NO$_X$ emissions from E50 relative to E0 in a 1.5L engine with a compression ratio of 13:1 (used in the Toyota Corolla); *see also* Hosuk H Jung et al., *Effect of Ethanol on Part Load Thermal Efficiency and CO$_2$ Emissions of SI Engines*, 2013-01-1634, 6 SAE Int'l J. of Engines 456 (2013) (finding a a 25% to 45% decrease in NO$_X$ emissions, depending on speed and load, from E85 relative to E0, for a 5.0L gasoline engine with a 9.5:1 compression ratio).

[303] Hubbard et al., *supra* note 275, at C.

[304] Anderson et al., *supra* note 143, at 1029–30; Karavalakis et al., *supra* note 241, at 14021.

As the Ford study concludes, the emissions results of mid-level ethanol blends "point to future opportunities for emission reductions of [ozone] from FFVs."[305]

EPA's Proposed Rule, like its 2010 Lifecycle Analysis, neglects the added benefits of mid-level ethanol blends.

CONCLUSION

A lifecycle analysis used by the primary environmental regulator and submissions to Congress should reflect the most up-to-date scientific research. The data and studies that were available to EPA in 2010 were inaccurate, and they are now obsolete. A careful analysis of the best available science at every stage in the lifecycles of gasoline and ethanol clearly establishes the emissions reductions that ethanol has already achieved, and the even more substantial reductions that it can achieve in the future.

The social benefits of ethanol are great. Even though EPA grossly underestimated ethanol's emissions reduction potential, the Agency still found in 2010 that blending ethanol into gasoline reduces lifecycle GHG emissions, and that the monetized annual benefits of the RFS's GHG reduction ($600 million to $12.2 billion, depending on the social cost of carbon[306]) exceed the relatively small air quality costs that EPA predicted from ethanol's effect on conventional air pollution ($630 million to $2.2 billion[307]).

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[305] *Id.* at F. This is consistent with other studies. For example, a 2010 Honda study testing emissions in a GDI light-duty vehicle found that E45 reduced NO_X and hydrocarbon emissions by 20%. Maricq et al., *supra* note 150, at 580.

[306] 2010 RFS RIA, *supra* note 1, at 6 (estimate for 2022, the first year in which the RFS would be fully phased in).

[307] *Id.*

But ethanol's benefits are even greater than EPA predicted in 2010. The best available science demonstrates that ethanol's carbon intensity is significantly lower than EPA predicted (36.62g or less instead of 74.81g CO_2e/MJ), and gasoline's is significantly higher than EPA predicted (96.89g instead of 93.01g CO_2e/MJ).[308]

By the same token, air pollution costs associated with ethanol production are relatively slight compared to ethanol's air quality benefits in light of the toxic aromatics that ethanol displaces, innovations in corn agriculture and ethanol production, and increasingly dirty gasoline produced in the United States.[309]

EPA must correct the inaccuracies reflected in its 2010 Lifecycle Analysis to reflect the best available science.

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[308] *See supra* p. 38.

[309] *See supra* pp. 38–61.

GREET 1 2015 Land Use Change for Corn Ethanol

Default Values: Corn Ethanol 2011 Case, Conventional Till,

8.3) CO_2 Emission Estimates from Land Use Changes and Land Management Changes of Farming: grams/gal of ethanol

    8.3.a) Land Use Change Scenario Options

	Corn Ethanol
Select Corn Ethanol Case	2011
Select Domestic Emissions Modeling Scenario	Century
Select International Emissions Modeling Scenario	Winrock
Domestic Emissions Modeling Scenario	yield_increase
Soil depth considered in modeling	100 cm
Harvested Wood Product (HWP) Scenario	HEATH
Land Management Practice for Corn and Corn Stover Production	Conventional Till
Forest Prorating Factor	Yes

8.3.c) CO_2 Emissions from Potential Land Use Changes of Farming: grams/gal of Ethanol

	Corn
Inclusion of CO_2 Emissions from Land Use Change	2
Domestic (Data Cell)	212
Foreign (Data Cell)	399
Domestic (Grams/Mj)	2.64
Foreign (Grams/Mj)	4.95
Total LUC (Grams/Mj)	**7.59**

Scenario 1 – Use Corn Ethanol 2013 Case

8.3) CO$_2$ Emission Estimates from Land Use Changes and Land Management Changes of Farming: grams/gal of ethanol

    8.3.a) Land Use Change Scenario Options

Select Corn Ethanol Case	Corn Ethanol 2013
Select Domestic Emissions Modeling Scenario	Century
Select International Emissions Modeling Scenario	Winrock
Domestic Emissions Modeling Scenario	yield_increase
Soil depth considered in modeling	100 cm
Harvested Wood Product (HWP) Scenario	HEATH
Land Management Practice for Corn and Corn Stover Production	Conventional Till
Forest Prorating Factor	Yes

8.3.c) CO$_2$ Emissions from Potential Land Use Changes of Farming: grams/gal of Ethanol

	Corn
Inclusion of CO$_2$ Emissions from Land Use Change	2
Domestic (Data Cell)	-156
Foreign (Data Cell)	413
Domestic (Grams/Mj)	-1.93
Foreign (Grams/Mj)	5.12
Total LUC (Grams/Mj)	**3.19**

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Scenario 2 – Corn Ethanol 2013, Reduced Till

8.3) CO$_2$ Emission Estimates from Land Use Changes and Land Management Changes of Farming: grams/gal of ethanol

    8.3.a) Land Use Change Scenario Options

Select Corn Ethanol Case	Corn Ethanol 2013
Select Domestic Emissions Modeling Scenario	Century
Select International Emissions Modeling Scenario	Winrock
Domestic Emissions Modeling Scenario	yield_increase
Soil depth considered in modeling	100 cm
Harvested Wood Product (HWP) Scenario	HEATH
Land Management Practice for Corn and Corn Stover Production	Reduced-Till
Forest Prorating Factor	Yes

8.3.c) CO$_2$ Emissions from Potential Land Use Changes of Farming: grams/gal of Ethanol

	Corn
Inclusion of CO$_2$ Emissions from Land Use Change	2
Domestic (Data Cell)	-180
Foreign (Data Cell)	413
Domestic (Grams/Mj)	-2.24
Foreign (Grams/Mj)	5.12
Total LUC (Grams/Mj)	**2.89**

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Scenario 3 – Corn Ethanol 2013 Base Case, No-Till

8.3) CO$_2$ Emission Estimates from Land Use Changes and Land Management Changes of Farming: grams/gal of ethanol

    8.3.a) Land Use Change Scenario Options

Select Corn Ethanol Case	Corn Ethanol 2013
Select Domestic Emissions Modeling Scenario	Century
Select International Emissions Modeling Scenario	Winrock
Domestic Emissions Modeling Scenario	yield_increase
Soil depth considered in modeling	100 cm
Harvested Wood Product (HWP) Scenario	HEATH
Land Management Practice for Corn and Corn Stover Production	No-Till
Forest Prorating Factor	Yes

8.3.c) CO$_2$ Emissions from Potential Land Use Changes of Farming: grams/gal of Ethanol

	Corn
Inclusion of CO$_2$ Emissions from Land Use Change	2
Domestic (Data Cell)	-239
Foreign (Data Cell)	413
Domestic (Grams/Mj)	-2.97
Foreign (Grams/Mj)	5.12
Total LUC (Grams/Mj)	**2.15**

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]	**18.19**	**19.45**	**178.47**	**40.62**

[i] Clay, *Carbon Sequestration*, *supra* note 86. 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 86.

[iii] Follett et al., *supra* note 91.

[iv] Halvorson & Stewart, *supra* note 95.

[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 86, 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 86, 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 91, 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 95, 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 86, 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 86, 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 91, at 873. The average yield for Halvorson & Stewart's study is 8,824 kg. per ha., with no stover removal. Halvorson & Stewart, *supra* note 95, at 1507.

[vii] The ethanol yield is based on the USDA's average yield of 2.76 gallons per bushel in 2010, multiplied by the number of bushels produced every year. 2015 Energy Balance, *supra* note 101, at Table 1.

[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 impact credit is arrived at by multiplying the carbon conversion factor by grams of soil carbon per MJ.