September 9, 2020

Administrator Andrew Wheeler
U.S. Environmental Protection Agency
William Jefferson Clinton Building
1200 Pennsylvania Avenue, N.W.
Mail Code: 1101A
Washington, D.C. 20460

Re: Petition for Rulemaking to Clarify that Carbon Dioxide Emissions from Agricultural Crops are Exempt from PSD and Title V Permitting Requirements

Dear Administrator Wheeler:

The Biogenic CO2 Coalition[1] hereby petitions EPA for a rulemaking to amend its PSD and Title V regulations at 40 C.F.R. § 51.166, 40 C.F.R. § 52.21, 40 C.F.R. § 70.2, and 40 C.F.R. § 71.2 to clarify that carbon dioxide emissions from agricultural crops used in food processing and other manufacturing activities are *de minimis* and therefore are not subject to regulation under those provisions.

When biogenic feedstocks are processed at stationary sources, carbon dioxide emitted from the feedstocks are offset completely by the carbon dioxide that the feedstocks absorbed during photosynthesis. This is particularly true for agricultural crops, as carbon emissions are offset rapidly during the crops' next growing season. There is a broad scientific consensus that, because of photosynthesis, emissions from processing agricultural crops are carbon neutral or *de minimis*. And they accordingly are treated as carbon neutral under regulatory schemes for stationary sources around the world, as well as several other regulatory programs in the United States.

Yet, in the PSD and Title V programs, EPA currently treats biogenic emissions the same as emissions from fossil fuels. The Biogenic CO2 Coalition therefore respectfully requests that EPA bring its PSD and Title V regulations in line with scientific evidence and the prevailing regulatory treatment of biogenic emissions by exempting carbon dioxide emissions from agricultural crops.

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[1] The Biogenic CO_2 Coalition is composed of trade associations that represent a cross-section of interests in agriculture and related industries. It advocates for rational, science-based policies that recognize the carbon benefits of agricultural crops. Members include: American Farm Bureau Federation (AFBF), Corn Refiners Association (CRA), Hemp Industries Association (HIA), National Corn Growers Association (NCGA), National Cotton Council of America (NCC), National Cottonseed Products Association (NCPA), National Farmers Union (NFU), National Grain and Feed Association (NGFA), National Oilseed Processors Association (NOPA), North American Millers Association (NAMA), and the Plant Based Products Council (PBPC).

Doing so would eliminate a roadblock to further development in the United States' agricultural system, which is essential to feeding our country, creating jobs, and developing important bioproducts like medical-grade alcohols and bioplastics. It would also reduce an administrative burden on EPA and state agencies, while retaining those agencies' ability to regulate other emissions from corn mills and similar stationary sources. Furthermore, it would not conflict with EPA's treatment of biogenic emissions under other regulatory programs like the RFS.

This petition discusses the scientific and legal support for such a rule, analyzes the treatment of biogenic CO_2 in other jurisdictions and under other U.S. regulatory programs, and provides an example of potential regulatory language. The Biogenic CO_2 Coalition requests a technical meeting to review the petition with EPA staff and discuss any additional questions they may have regarding this petition or any of those topics.

I. Background

Under EPA's current regulatory framework for the PSD and Title V programs, greenhouse gas emissions from agricultural crops are treated the same as greenhouse gas emissions from fossil fuels. *See* 40 C.F.R. § 51.166; 40 C.F.R. § 52.21; 40 C.F.R. § 70.2; 40 C.F.R. § 71.2. As a result, carbon dioxide emissions from agricultural crops that are processed in fermentation units or other equipment at stationary sources may be subject to PSD and Title V permitting requirements. That regulatory burden has caused facilities that generate food, beverages, fuel, and bioproducts either to incur substantial costs or, in many cases, avoid investments that would expand their operations but require additional permitting and compliance obligations.

EPA can fix that problem. EPA has recognized that emissions from biogenic feedstocks including annual agricultural crops *could* be considered carbon neutral or *de minimis* for purposes of stationary source regulations. In its 2011 rule deferring regulation of biogenic emissions under the PSD and Title V programs (the "Deferral Rule"), EPA acknowledged that biomass feedstocks including agricultural crops could potentially "be used to produce energy or other products" in a way that would "have a negligible impact on the net carbon cycle, or even a positive impact." 76 Fed. Reg. 43,490, 43,499 (July 20, 2011). Nonetheless, EPA chose not to make a determination at that time as to whether emissions from particular biomass feedstocks are carbon neutral or *de minimis*. *Id.*[2]

Additionally, a 2014 memo authored by Janet McCabe described EPA's intent to promulgate regulations identifying categories of biogenic emissions that would be exempt from Best Available Control Technology (BACT) requirements under the PSD program. EPA has not promulgated such regulations to date.

As the Deferral Rule and the 2014 McCabe memo recognized, EPA has authority to determine that biogenic carbon emissions from certain feedstocks are *de minimis* and therefore

[2] The Deferral Rule was later vacated by the D.C. Circuit Court in *Ctr. for Biological Diversity v. EPA*, 722 F.3d 401, 404 (D.C. Cir. 2013) for reasons unrelated to EPA's authority to exempt biogenic carbon dioxide emissions from the PSD and Title V programs.

exempt from requirements under the PSD and Title V programs. That authority was further noted in in *UARG v. EPA*, 573 U.S. 302, 333 (2014), in which the Supreme Court acknowledged that "EPA may establish an appropriate *de minimis* threshold below which BACT is not required for a source's greenhouse-gas emissions." Indeed, the Supreme Court held that EPA *must* make such a *de minimis* determination because "EPA may require an anyway source to comply with greenhouse-gas BACT *only* if the source emits more than a *de minimis* amount of greenhouse gases." *Id.* (emphasis added).

EPA should promulgate a rule that clarifies that carbon dioxide emissions from agricultural crops are not subject to the requirements of the PSD and Title V programs, including BACT. As explained in further detail below, such a rule would provide significant economic and administrative benefits, is supported by abundant scientific evidence, and would be consistent with both other countries' treatment of biogenic emissions from stationary sources and with other regulatory programs in the United States.

II. Scientific Consensus Regarding Emissions from Agricultural Crops

There is scientific consensus that emissions from agricultural crops are carbon neutral when comparing the uptake of carbon dioxide by those crops to the emissions from a stationary source. A recent literature review found that 104 out of 108 peer-reviewed scientific articles consider emissions from agricultural crops and other biomass to be carbon neutral.[3] Notably, the authors of those articles took several different approaches to assessing the emissions from biogenic sources, including input-output approaches, modified Global Warming Potential ("GWP") assessment, and neutrality approaches, and every one either concluded or assumed that biogenic emissions were carbon neutral.[4]

The few articles that have questioned the carbon neutrality of biogenic emissions suffer from methodological uncertainties and rely on oversimplified modeling. As Dr. Seungdo Kim of Michigan State University has explained, models that have concluded biogenic emissions add carbon to the atmosphere "struggle[] with uncertainties related to inconsistent system boundaries, selection of periods for evaluation, economic conditions and weather dependence."[5] In particular, those models assume that all changes in agricultural systems are a result of biofuel and bioenergy use despite a myriad of factors that can contribute to those changes.[6] For example, factors such as changes in demand for agricultural products or improvements in the yields of crops can offset or obscure any relationship between biofuels and land use.[7]

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[3] Seungdo Kim, *Literature Review of Biogenic CO2 Emissions From Industrial Processes Associated with Annual Crops* (July 21, 2020) (attached as Exhibit A).
[4] *Id.*
[5] *Id.*
[6] *Id.*
[7] *See id.*; Dermot Hayes, *Land Use Impacts of a Reform of the U.S. Environmental Agency Rule Associated with Carbon Dioxide Emissions from Processing of Annual Crops* at 3 n.3 (2020) (attached as Exhibit B) (acknowledging that "I and several of my coauthors on the Searchinger

The consensus view that biogenic emissions are carbon neutral is reflected in the guidelines of the Intergovernmental Panel on Climate Change ("IPCC") for greenhouse gas inventories. The IPCC's guidelines, which are based on the common understanding of scientists from around the world, exclude biogenic emissions when assessing national or sectoral carbon emissions.[8] Following the IPCC's Guidelines, EPA's Inventory of Greenhouse Gas emissions for the United States likewise do not include biogenic emissions in the emissions totals for the energy sector.[9]

The science is particularly clear for annual crops because of their short lifecycle. Any emissions from fermentation or other processing of agricultural crops are quickly offset by the carbon absorbed during those crops' next growing season. As the IPCC has explained, the biomass stock of agricultural crops lost due to harvesting and processing "equal[s] biomass carbon stock gained through regrowth in that same year and so there are no net CO2 emissions or removals from biomass carbon stock changes."[10] Relying in part on the IPCC's analysis, USDA has also found that there are no net carbon dioxide emissions from the lifecycle of agricultural crops.[11] And researchers from Michigan State University have specifically found that processing of annual crops through activities such as wet and dry milling of corn is not a net source of carbon emissions.[12]

While EPA has previously noted its 2014 *Framework for Assessing Biogenic CO2 Emissions from Stationary Sources* that "[c]arbon neutrality cannot be assumed for all biomass energy a priori,"[13] that statement was based on considerations other than the balance between emissions from stationary sources and the uptake of carbon by crops. In particular, the 2014 Framework considered "biological carbon cycle effects related to leakage, such as indirect land use change induced by displaced feedstock or feedstock substitute production."[14] The 2014 Framework was

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report I later showed that the key Searchinger land use result could be offset if higher corn prices induced higher corn yields.")

[8] *See* 2006 IPCC Guidelines for National Greenhouse Gas Inventories Vol. 2 at 2.3.3.4.

[9] EPA, *Inventory of Greenhouse Gas Emissions and Sinks 1990-2018*, ES-9 (2020); *see also id.* at ES-9 ("In line with the reporting requirements for inventories submitted under the UNFCCC, CO2 emissions from biomass combustion have been estimated separately from fossil fuel CO2 emissions and are not included in the electricity sector totals and trends.")

[10] IPCC, *Frequently Asked Questions - IPCC Task Force on National Greenhouse Gas Inventories (TFI), General Guidance and Other Inventory Issues*, https://www.ipcc-nggip.iges.or.jp/faq/FAQ.pdf (last visited May 31, 2020).

[11] USDA, Office of Chief Economist, *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*, at 3-43 (July 2014), *available at* http://www.usda.gov/oce/climate_change/estimation.htm.

[12] *See, e.g.,* S. Kim and B. Dale, *The Biogenic Carbon Cycle in Annual Crop-Based Products*, Department of Chemical Engineering and Materials Science Michigan State University (Nov. 22, 2013).

[13] EPA, *Framework for Assessing Biogenic CO2 Emissions from Stationary Sources* (Nov. 2014), *available at* https://archive.epa.gov/epa/sites/production/files/2016-08/documents/framework-for-assessing-biogenic-co2-emissions.pdf.

[14] *Id.* at 7.

thus considering indirect emissions attributed to use of biomass, not just the emissions from the processing or combustion of biomass itself.

The 2014 Framework did not dispute that emissions from agricultural crops are carbon neutral when comparing uptake by crops to emissions from stationary sources. It also acknowledged that "the scope for assessing the net atmospheric contributions of biogenic CO2 emissions can be narrow or quite broad, depending on the purposes and objectives of assessment."[15] As discussed in further detail Section V, the appropriate scope for purposes of the PSD and Title V programs is to recognize that any carbon dioxide emissions from agricultural crops at a stationary source are offset entirely by the uptake of carbon from growing crops.

Indeed, EPA's Science Advisory Board recently criticized the failure of the 2014 framework to "identify the specific metric of climate impact (or 'objective') with resulting regulations that [Biogenic Assessment Factor] estimate should reflect."[16] The Science Advisory Board also explicitly noted that carbon dioxide emissions from agricultural feedstocks "have no net impact on above-ground carbon stocks" because "the time lag between harvest, CO2 emissions from conversion to energy, and regrowth on land is likely to be close to one year."[17]

Moreover, even if potential indirect land use changes are considered, carbon emissions from agricultural crops at stationary sources nonetheless would be *de minimis*. A recent analysis by Professor Dermot Hayes of Iowa State University found that, if EPA exempted carbon dioxide emissions from agricultural crops from PSD and Title V regulations, it would trigger at most an annual increase in land conversion of about 24,500 hectares per year, which would be equivalent to carbon emissions of about 28,000 tons per year.[18] That total amount is less than the 75,000 tons per year that EPA has considered *de minimis* for a *single stationary source*.[19]

III. Treatment of Agricultural Emissions in Other Jurisdictions and Other U.S. Regulatory Programs

The scientific consensus is that emissions from agricultural crops are not a significant source of GHGs. That consensus is reflected in the stationary source regulations of other countries and jurisdictions and in other regulatory programs in the United States.

For example, all biogenic emissions are treated as carbon neutral under Europe's Emissions Trading System. Europe's Emissions Trading System is a cap-and-trade program that sets an overall cap on emissions from covered sources and then allows companies to purchase or sell

[15] *Id.*
[16] EPA Science Advisory Board, *SAB review of* Framework for Assessing Biogenic CO2 Emissions from Stationary Sources, EPA-SAB-19-002, 1 (Mar. 5, 2019).
[17] *Id.* at 13.
[18] Dermot Hayes, *Land Use Impacts of a Reform of the U.S. Environmental Agency Rule Associated with Carbon Dioxide Emissions from Processing of Annual Crops* at 9 (2020) (attached as Exhibit B).
[19] *Id.*

emissions allowances.[20] Operators of stationary sources and other covered sources must calculate their GHG emissions based on the releases from their activities, multiplied by an "emissions factor" specific to the type of industrial activity and fuel used.[21] The Emissions Trading System directive sets the emissions factor for all biomass at zero.[22] As a result, "no allowances for emissions stemming from biomass have to be surrendered, and the associated costs are avoided."[23]

Similarly, Canada excludes biogenic emissions from its regulations governing emissions from certain Electrical Generation Units ("EGUs"). Specifically, Canada's regulations subtract the amount of biogenic emissions from the calculation of the carbon dioxide emitted by an EGU.[24] In response to comments on those regulations, Canada's Governor General in Council explained that Canada's treatment of biogenic emissions is based on the determination in the IPCC's 2006 guidelines that "CO2 emissions from biomass combustion are not accounted for because they are assumed to be reabsorbed by vegetation during the next growing season."[25]

EPA also has considered biogenic emissions to be carbon neutral in other contexts. As discussed above, EPA does not include biogenic emissions in the energy sector totals of its National Inventory of Greenhouse Gases.[26] In addition, EPA's regulations implementing the Renewable Fuel Standard ("RFS") program treat tailpipe emissions from automobiles as carbon neutral when assessing the lifecycle emissions of biofuels. 75 Fed. Reg. 14,670, 14,787 (Mar. 26, 2010). EPA reasoned that including those emissions would be inaccurate "because the carbon emitted as a result of fuel combustion is offset by the uptake of biogenic carbon during feedstock production." *Id.*; *see also* 74 Fed. Reg. 24,904, 25040 (May 26, 2009) ("[O]ver the full lifecycle of the fuel, the CO2 emitted from biomass-based fuels combustion does not increase atmospheric CO2 concentrations, assuming the biogenic carbon emitted is offset by the uptake of CO2 resulting from the growth of new biomass.")

The Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation ("GREET") model, which EPA relied on in developing its RFS regulations, likewise assumes that carbon emissions from fermentation or combustion of

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[20] *See* European Commission, *EU Emissions Trading System*, https://ec.europa.eu/clima/policies/ets_en (last visited Aug. 10, 2020).
[21] Directive 2003/87/EC of the European Parliament and of the Council, Annex IV (Oct. 13, 2003), *available at* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003L0087&from=EN.
[22] *Id.*
[23] European Commission, *Guidance Document: Biomass issues in the EU ETS* (Nov. 17, 2017), *available at* https://ec.europa.eu/clima/sites/clima/files/ets/monitoring/docs/gd3_biomass_issues_en.pdf.
[24] Government of Canada, Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations, P.C. 2012-1060 (Aug. 30, 2012), *available at* http://www.gazette.gc.ca/rp-pr/p2/2012/2012-09-12/html/sor-dors167-eng.html.
[25] *Id.*
[26] EPA, *Inventory of Greenhouse Gas Emissions and Sinks 1990-2018*, ES-9 (2020).

agricultural feedstocks is zero.[27] The Argonne National Laboratory explained that while processes such as the conversion of corn starch to ethanol "produce[] excess CO2 emissions," they "should not be classified as CO2 emissions" "because the CO2 generated is from the atmosphere during the photosynthesis process."[28]

IV. Benefits of Recognizing the *De Minimis* Nature of Emissions from Agricultural Crops

The U.S. agricultural system feeds the nation and provides important bioproducts made from corn, oilseeds, agricultural residues, and other agricultural feedstocks, including medical-grade alcohol and bioplastics. As of 2016, America's bioeconomy was valued at $495 billion and provided 4.65 million American jobs, with each job creating an additional 1.78 jobs in other sectors across rural America. Sound regulatory policies that maximize certainty would help facilitate further growth in that important economic sector going forward.

EPA's current policy regarding biogenic carbon emissions creates an unnecessary burden that discourages investment in the bioeconomy. In order to avoid compliance and permitting costs, companies have canceled or modified their plans for new or expanded facilities. Promulgating a rule exempting carbon dioxide emissions from agricultural crops from PSD and Title V requirements would eliminate that roadblock and help unleash additional investments. Without the burden of those costs, companies that process agricultural crops would be able to expand operations in ways that would provide additional high-paying jobs and would have significant positive impacts on the rural economy. In addition, those companies would have more opportunity to innovate, including through developing new bioplastics or other beneficial bioproducts. Companies might also invest in efficiency measures that would reduce GHG emissions and emissions of other pollutants per unit output.

Moreover, EPA's current regulations create a competitive disadvantage for the U.S. bioeconomy because they present additional hurdles and costs not faced by manufacturers of bioproducts, food, and beverages in Europe or other jurisdictions. Bringing the United States' treatment of carbon emissions from agricultural crops in line with the prevailing treatment of those emissions around the world would level the playing field.

Another benefit of exempting carbon dioxide emissions from agricultural crops from PSD and Title V permitting requirements would be preserving administrative resources. It would eliminate the obligations of EPA and state agencies to develop complicated quantification and control measures for biogenic emissions from a variety of different crops and processing activities. It would also reduce the burdens of permit review that typically fall on state agencies, many of which already have strained resources. And such a rule would not hinder the ability of EPA and state agencies to regulate other emissions at corn mills and other processing facilities—such facilities would still need to comply with PSD and Title V requirements for GHG emissions from fossil fuels and for emissions of other pollutants, as well as state permitting requirements

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[27] *See* M.Q. Wang, *GREET 1.5 - Transportation Fuel-Cycle Model, Vol. 1: Methodology, Development, Use, and Results*, at 76 (ANL/ESD-39, Vol. 1) (Aug. 1999), *available at* https://greet.es.anl.gov/publication-20z8ihl0.
[28] *Id.*

and reporting obligations.

V. Relationship to Other Regulatory Programs

Other regulatory programs in the United States analyze or quantify aspects of biogenic carbon emissions in different ways. But that does not mean that promulgating a rule exempting carbon dioxide emissions from agricultural crops from PSD and Title V permitting requirements would be inconsistent with those programs. Rather, those programs are tackling different problems using different statutory authorities.

Such a rule would not conflict with the RFS. The RFS is an incentive program designed to encourage adoption of biofuels, rather than a regulatory program like PSD and Title V that establish permitting requirements and technological controls for emissions from stationary sources. Under the RFS, EPA assesses emissions associated with a variety of components of the broader renewable fuel economy, including the energy inputs of growing feedstocks and the energy used in transporting feedstocks and fuels.[29] That type of lifecycle analysis is mandated by the RFS statute, which requires EPA to assess GHG emissions "related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer." 42 U.S.C. § 7545(o)(1)(H). The RFS is a different statutory scheme than the statutory scheme for PSD and Title V programs, which focus on permitting and emissions limitations for major stationary sources. *See* 42 U.S.C. § 7475(a)(1); 42 U.S.C. § 7661c. And it is different in an important way: the RFS compares all of the energy used to produce, transport, and distribute renewable fuels to the same energy inputs for petroleum. In contrast, the PSD and Title V programs only assess the emissions of fossil fuels *from stationary sources*—considering factors like the energy used to transport agricultural crops and other biomass under PSD and Title V would therefore be inappropriate when those factors are not considered for fossil fuels.

Moreover, EPA's RFS regulations recognize that biogenic emissions from automobile tailpipes are carbon neutral because they are canceled out by the uptake of carbon by biofuel feedstocks. 75 Fed. Reg. 14,670, 14,787 (Mar. 26, 2010); *see* Section III, *supra*. As discussed above, the emissions from the tailpipes of cars are the part of the renewable fuel lifecycle that is most analogous to emissions from stationary sources. What causes renewable fuels to have positive net lifecycle emissions values for RFS purposes are other factors, particularly the energy inputs of transporting feedstocks and finished products. The emissions from mobile sources transporting biomass are not properly regulated under Title V and PSD, which are programs that regulate only emissions from stationary sources.

Nor would such a rule be in tension with EPA's mandatory GHG reporting regulations. While those regulations require reporting of biogenic GHG emissions for certain stationary sources, they are clear that such reporting is not a trigger for any particular control or permitting

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[29] *See* EPA, *Lifecycle Analysis of Greenhouse Gas Emissions under the Renewable Fuel Standard*, https://www.epa.gov/renewable-fuel-standard-program/lifecycle-analysis-greenhouse-gas-emissions-under-renewable-fuel (last visited Aug. 15, 2020).

obligation. 74 Fed. Reg. 56,260, 56,351 (Oct. 30, 2009). Moreover, the way biogenic emissions are treated in the GHG reporting rule recognizes their unique nature—biogenic emissions are not counted for purposes of a facility's reporting threshold, and once a facility meets the threshold based solely on non-biogenic GHG emissions, it then reports biogenic emissions as a separate category. *Id.* In the preamble to the GHG reporting rule, EPA described its system as consistent with the IPCC's treatment of biogenic emissions. *Id.* EPA explained that while the IPCC guidelines and other national inventories account for biogenic emissions "as part of a comprehensive system-wide tracking of carbon dioxide emissions and sequestration in the land-use, land-use change and forestry sector and the agriculture sector, rather than at the point of fuel combustion," it is nonetheless useful to collect information on both biogenic and non-biogenic GHG emissions because such information is "useful and informative." *Id.*

As EPA has recognized, different approaches to quantifying biogenic carbon emissions can be appropriate in different contexts.[30] For the PSD and Title V programs, the appropriate approach is to recognize that the carbon dioxide emissions attributable to processing of agricultural crops at stationary sources is offset by the uptake of carbon by crops and is therefore *de minimis*.

VI. Conclusion

For the foregoing reasons, EPA should amend its regulations to clarify that carbon dioxide emissions from agricultural crops processed at stationary sources are not subject to the requirements of the PSD and Title V programs.

One way to accomplish such an amendment would be to insert the following language in paragraph (b)(49)(ii)(a) of 40 C.F.R. § 52.21, paragraph (b)(48)(ii)(a) of 40 C.F.R. § 51.166, paragraph (2) of 40 C.F.R. § 70.2, and paragraph (2) of 40 C.F.R. § 71.2:

> For purposes of this paragraph, the mass of the greenhouse gas carbon dioxide shall not include carbon dioxide emissions attributable to agricultural crops (including agricultural products, by-products, residues, and wastes) used in food processing or manufacturing activities such as: (a) fermentation; (b) baking; or (c) other methods used to generate food, fuel, beverages, or bioproducts.

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If you have any questions regarding the issues raised in this petition, please do not hesitate to contact John Bode at (202) 534-3499.

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[30] EPA, Framework for Assessing Biogenic CO2 Emissions from Stationary Sources (Nov. 2014), *available at* https://archive.epa.gov/epa/sites/production/files/2016-08/documents/framework-for-assessing-biogenic-co2-emissions.pdf.

Respectfully Submitted,

John Bode
President & CEO, Corn Refiners Association
Chairman, Biogenic CO2 Coalition

Enclosures:

Exhibit A—Seungdo Kim, *Literature Review of Biogenic CO2 Emissions From Industrial Processes Associated with Annual Crops* (July 21, 2020).

Exhibit B— Dermot Hayes, *Land Use Impacts of a Reform of the U.S. Environmental Agency Rule Associated with Carbon Dioxide Emissions from Processing of Annual Crops* (2020).

Literature Review of Biogenic CO_2 Emissions From Industrial Processes Associated with Annual Crops

July 21, 2020

Dr. Seungdo Kim

Prepared for the Biogenic CO_2 Coalition

Introduction

I have been asked by the Biogenic CO_2 Coalition to review peer-reviewed scientific articles that address biogenic carbon dioxide emissions from annual crop-based product systems and their potential impact on atmospheric greenhouse gases, with a particular focus on how biogenic CO_2 emissions from stationary sources are calculated in greenhouse gas (GHG) accounting schemes. Relevant scientific articles published from 2010 to present were selected for review from the Web of Sciences database using the Boolean search terms below. About 100 articles have been deemed suitable for review, and the majority of articles reviewed here are concerning biofuel or bioenergy.

(biogenic OR CO_2 OR "greenhouse gas" or GHG) AND ("carbon accounting" or "greenhouse gas accounting" or "GHG accounting" or LCA or "life cycle analysis" or "carbon footprint") AND (corn or soybean or cotton or "annual crop") NOT (wood or tree or "woody material" or forest or animal or dairy or manure or "anaerobic")

Biogenic CO_2 emission sources associated with the annual crop-based product system are: (1) carbon stock loss due to direct land conversion from forest/grassland to cropland, (2) carbon stock loss by indirect land use change (ILUC) (3) soil organic carbon loss, (4) stationary sources (e.g., fermentation, etc.), and (5) combustion of biomass and biofuel. The first three emission sources are out of the scope of this literature review since the focus is on biogenic CO_2 released from stationary sources. Therefore, this review focuses on the last two emission sources.

There are three main approaches to dealing with the biogenic carbon dioxide emissions in GHG accounting: (1) Neutrality, (2) Input-output and (3) Additionality.

Neutrality

In the Neutrality approach, biogenic CO_2 emissions from stationary and mobile sources associated with annual crops are carbon neutral. The biogenic carbon released as CO_2 from any stationary/mobile sources (e.g., fermentation, combustion of annual crop, etc.) does not affect climate change. This is a steady state condition because all biogenic CO_2 released into the atmosphere is absorbed by biomass growth over a short period of time. Therefore, biogenic CO_2 emissions are excluded from GHG accounting. Most of articles reviewed here (83 out of 108 articles) use this Neutrality approach in their GHG accounting without including biogenic CO_2 emissions. Furthermore, the Neutrality approach has been widely used in regulation (EPA, 2010) and international guidelines (UNFCCC, 2006; IPCC 2006).

Input-output

In the input-output approach, carbon flux taken up by biomass and biogenic carbon releases are taken into account in the GHG calculations. Some LCA studies reviewed here (14 articles) use this approach and show that carbon uptake by crops completely offsets biogenic CO_2 emissions associated with annual crops. Articles from Argonne National Laboratory (Wang et al., 2012, Dunn et al., 2012, Cai et al. 2013) also use the input-output approach. These articles subtract the biogenic carbon credit from combustion of biofuel, but do not include biogenic CO_2 emissions from fermentation in their GHG calculations. van der Voet et al. (2010) found that exclusion of biogenic carbon generates the same results when co-products are not produced in the biofuel system. However, for biofuel systems with co-products, excluding biogenic carbon produces different results due to the allocation method. It is clear that the magnitude of carbon uptake by biomass allocated to biofuel is not always the same as the magnitude of biogenic carbon emissions from biofuel, because allocation is usually done by physical (e.g., mass, energy, etc.) or economic properties, not molecular weight. Before the allocation, carbon uptake by biomass is the same as biogenic carbon emissions. Therefore, this is an allocation issue, not a carbon neutrality issue.

Additionality

Currently, several studies (Searchinger, 2010; Haberl et al., 2012; DeCicco, 2015; DeCicco et al., 2016; DeCicco, 2018) have questioned the carbon neutrality of biogenic CO_2 emissions, especially biogenic CO_2 emissions in the bioenergy/biofuel system. “Additional biomass (or additional carbon uptake on cropland)” is the key concept in those studies. They claimed that if no bioenergy were produced, plants for bioenergy would not be harvested and would continue to absorb carbon, helping to reduce CO_2 in the air. In global projections of atmospheric carbon, treating biogenic CO_2 emissions released in the bioenergy system as carbon neutral is a “double-counting error”. Atmospheric carbon is absorbed by plants regardless of bioenergy. Therefore, biogenic CO_2 emissions should be offset by additional carbon uptake on cropland. DeCicco et al. (2016) claimed that only 37% of the biogenic CO_2 emissions in corn-based ethanol fuel production systems should be offset by carbon uptake by additional corn production, so only 37% of biogenic CO_2 emissions are carbon neutral.

However, this analysis struggles with uncertainties related to inconsistent system boundaries, selection of periods for evaluation, economic conditions and weather dependence

(De Kleine et al., 2016; De Kleine et al., 2017; Khanna et al., 2020). De Kleine et al. (2017) pointed out that biogenic carbon in corn grain is released into the atmosphere in a short time, even when used as biofuel or food/feed. As a result, there is no substantial change in net carbon emissions to the atmosphere. Wang et al. (2015) raised two questions about the additional biomass:

- "Would farmers/growers continue to grow biomass if there were no demand for biomass due to bioenergy production? In particular, if there were no cellulosic biofuel industry demanding cellulosic biomass, can one assume that farmers/growers would grow cellulosic biomass anyway?"
- "When bioenergy production results in managed biomass growth, how does the growth rate differ from that of natural biomass growth?"

The additional biomass (or additional carbon uptake on cropland) relies heavily on value-choice and scenario-based modeling. Similar to ILUC, the additionality approach assigns to biofuel/bioenergy all the changes in the crop system in spite of many inter-related factors that also contribute to changes in the crop system. These inter-related factors include local and global economic conditions, weather, national policy, international trade, dietary preferences, biofuel/bioenergy, technology improvements, etc. In other words, the "additionality approach" is oversimplified.

Other approaches

Cherubini et al. (2011) quantified global warming potentials (GWP) for biogenic CO_2 emissions, taking into account the timing of biogenic CO_2 emissions and uptake by biomass regrowth (at the end of the rotation period). Therefore, the modified GWP for biogenic CO_2 emissions depends on the biomass rotation period, as seen in Table 1. The modified GWP for biogenic CO_2 emissions released form one-year rotation biomass (e.g., annual crop, grass, etc.) is zero, implying that biogenic CO_2 emissions associated with one-year rotation biomass have no negative impact on the climate per unit of biogenic CO_2 emitted from stationary/mobile sources associated with annual crops.

Downie et al. (2014) investigated three different GHG accounting methods: 1) the biogenic method, which includes biogenic CO_2 emissions, even though they may be neutral over the timeframe; (2) the stock method, which excludes biogenic CO_2 emissions, but includes credit for biogenic carbon not released for a long-term C cycle (e.g., biochar, etc.); and (3) the simplified method, in which the net biogenic CO_2 flux is neutral over the timeframe. The biogenic method is corrected if the term for carbon uptake by biomass is added. The stock method is the most accurate method to forecast the net change in atmospheric GHG for activities that involve biogenic carbon. When all biogenic carbon is released over a short time of period, results from the simplified method are equal to those from the stock method.

Table 1 Modified GWPs for biogenic CO_2 emissions (Cherubini et al., 2011).

Rotation period (years)	**Modified GWP for biogenic CO_2 emission (time horizon = 100 years)**
1	0.00
10	0.04
20	0.08
50	0.21
70	0.30
100	0.43

Discussion

Brandao et al. (2013) pointed out that biogenic carbon management differs from fossil-fuel carbon management in that biomass can sequester and release carbon into the atmosphere. They were also concerned about the time differences between uptake and release of CO_2, even though CO_2 release is balanced by carbon uptake by biomass. The time lag between uptake and release of CO_2 will lead to different trajectories of atmospheric CO_2 concentrations and thus different cumulative radiative forcing, which have different impacts on climate change. In annual crop-based systems, uptake and release of CO_2 occur within one year. As seen in Cherubini et al (2011), the effects of the time lag in the annual crop-based systems can be negligible. Thus, the time lag issues are not relevant in the annual crop systems.

Table A in the Appendix A lists articles, their feedstock types and the biogenic CO_2 accounting approach. For clarity, the text of each article on biogenic carbon is also quoted in the table if available. Biogenic CO_2 emissions associated with annual crops, perennials and other biomass in 104 articles out of 108 are regarded as carbon neutral <u>regardless</u> of the biogenic carbon accounting approaches (i.e., Neutrality, Input-out approaches and Modified GWP). Note that some articles do not mention biogenic carbon in their text at all, suggesting that biogenic carbon is not taken into account. The 104 articles reviewed here show that biogenic CO_2 emissions from stationary/mobile sources associated with annual crops are completely balanced by biomass regrowth over a short period of time; i.e., carbon neutral.

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Appendix A. Table A. List of articles

	Approach	Biomass	*Quotation*/Remark
Zhang X, Witte J, Schildhauer T, Bauer C. (2020)	Neutrality	anaerobic digestion of sewage sludge and green waste	*"Biogenic CO_2 emissions are not accounted for assuming a closed carbon circle."*
Sharara MA, Sahoo K, Reddy AD, Kim S, Zhang XS, Dale B, et al. (2020)	Neutrality	corn stover	not explicitly mentioned
Pecanha Esteves VP, Vaz Morgado CdR, Fernandes Araujo OdQ. (2020)	Neutrality	soybean and livestock	not explicitly mentioned
Oliveira MdCTBE, Rosentrater KA. (2020)	Neutrality	corn	not explicitly mentioned
Moreno J, Iglesias J, Blanco J, Montero M, Morales G, Melero JA. (2020)	Neutrality	corn	*"… sorbitol production starting from corn starch has been evaluated using a cradle-to-gate life cycle assessment (LCA) approach* *including biogenic carbon for calculations makes that CO_2 fixed during corn cultivation almost compensates the emissions of the rest of the process steps, highlighting the importance of using autotrophic biomass as raw materials."*

	Approach	Biomass	*Quotation*/Remark
Mahmud N, Rosentrater KA. (2020)	Neutrality	oil palm frond	*"According to the IPCC, only non-biogenic CO_2 emissions should be considered as greenhouse gas (GHG) emissions, which eventually contribute towards an increase in global warming potential (GWP). The biogenic CO_2 is not considered as GHG emission, because, throughout plants' life, they are conducting a photosynthesis process by taking CO_2 from the atmosphere (49). The biogenic CO2 emissions fractions in most of the simulated models were higher than that of non-biogenic, because of the large fraction of CO_2 generated during the fermentation process and the waste fibers burning in the CHP generation system."*
Khanna M, Wang W, Wang M. (2020)	Additionality	corn	Criticize uncertainty associate with selecting time frame for evaluation, economic conditions, and weather dependency
Bartocci P, Zampilli M, Liberti F, Pistolesi V, Massoli S, Bidini G, et al. (2020)	Neutrality	food waste	not explicitly mentioned
Akmalina R, Pawitra MG. (2020)	Neutrality	empty fruit bunch	*"Carbon dioxide released from the biomass-based process can be considered as biogenic carbon. It is the carbon contained in biomass during plant growth, involving photosynthetic process. In other words, this substance is possibly to be removed from the atmosphere through a carbon cycle."*

	Approach	Biomass	*Quotation*/Remark
Yang Y, Ni J-Q, Bao W, Zhao L, Xie GH. (2019)	Neutrality	corn stover	*"It was assumed that carbon in the form of CO_2 from vehicular ethanol combustion originated from biogenic carbon that was derived from corn stover because more than 96% of all carbon in the process entered as biomass feed, with only small amounts of additional carbon coming from glucose (for enzyme production) and fermentation nutrients such as corn steep liquor 33). Thus, CO_2 emissions from ethanol in the vehicle-use stage were negligible in this study."*
Smullen E, Finnan J, Dowling D, Mulcahy P. (2019)	Neutrality	switchgrass	not explicitly mentioned
Prieler M, Lindorfer J, Steinmueller H. (2019)	Neutrality	grass silage	*"The GWP excludes biogenic carbon so the bound carbon in the grass silage is not included."*
Obnamia JA, Dias GM, MacLean HL, Saville BA. (2019)	Neutrality	corn stove	*"The LCA software packages apply this approach by determining total emissions in the fuel use stage and then subtracting CO_2 emissions traceable to the fuel's biogenic carbon component. This leads to net zero GWP for CO2 from the fuel's biogenic carbon content (i.e., biofuel fraction) while CO_2 from the fuel's fossil carbon fraction and all other non-CO_2 GHGs emitted in the fuel use stage are still accounted for."*
Lienhardt T, Black K, Saget S, Costa MP, Chadwick D, Rees RM, et al. (2019)	Neutrality	pea and wheat	not explicitly mentioned
Knoope MMJ, Balzer CH, Worrell E. (2019)	Neutrality	soybean	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Kim S, Dale BE, Zhang XS, Jones CD, Reddy AD, Izaurralde RC. (2019)	Neutrality	corn stover	*"Biogenic carbon dioxide emissions released from combusting ethanol fuel are not included as GHG emissions."*
Kim S, Dale BE, Jin M, Thelen KD, Zhang X, Meier P, et al. (2019)	Neutrality	corn stover	not explicitly mentioned
Han D, Yang X, Li R, Wu Y. (2019)	Input-output	corn stover	*"For GWPs, the percentage of absorption of carbon in the biomass production is higher than its release in the production process; thus, the net GWP is negative, and that the entire life cycle is absorbing GHGs."*
Guzman-Soria D, Taboada-Gonzalez P, Aguilar-Virgen Q, Baltierra-Trejo E, Marquez-Benavides L. (2019)	Neutrality	corn	not explicitly mentioned
Bicalho T, Sauer I, Patino-Echeverri D. (2019)	Neutrality	sugarcane and corn	not explicitly mentioned
Abraha M, Gelfand I, Hamilton SK, Chen J, Robertson GP. (2019)	Neutrality	switchgrass, restored prairie, and corn	*"We present a whole-system LCA of the global warming impact (GWI) of all converted fields over eight years by measuring GHG fluxes (CO_2, N_2O and CH_4), farming operations, agronomic inputs and a fossil fuel offset credit that include co-products.* *A fossil fuel offset credit for ethanol was computed from the dry mass yield (kg m^{-2} yr^{-1}), its ethanol production potential (L kg^{-1}), and its ethanol energy content (MJ L−1) compared to the equivalent energy and CO2 emissions for the gasoline use the ethanol would offset (table S6).*
	Approach	Biomass	*Quotation*/Remark

Wang C, Chang Y, Zhang L, Chen Y, Pang M. (2018)	Neutrality	corn stover	*" The GHG emissions of the CSPGS were categorized into two parts: 1) onsite emissions, including N_2O emission from the nitrification and denitrification processes in the soil, CO_2 emission from the soil tilling and erosion processes, CH_4 and N_2O emitted by biomass burning, and GHG emitted by fossil energy combustion; and 2) supply-chain emissions derived from material (building materials, fertilizers, pesticides, and water) production, power-plant equipment manufacturing, services provision (including transport, installation, and repair services), and fossil energy production and supply."*
Viskovic M, Djatkov D, Martinov M. (2018)	Neutrality	corn stover	*"Global warming potential (GWP 100 years) excluding biogenic carbon."*
Tabatabaie SMH, Tahami H, Murthy GS. (2018)	Neutrality	camelina	not explicitly mentioned
Staples MD, Malina R, Suresh P, Hileman JI, Barrett SRH. (2018)	Neutrality	soybean, rapeseed, jatropha and oil palm; maize grain, sorghum grain and cassava; sugarcane and sugar beet; switchgrass, miscanthus and reed canary grass	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Semba T, Sakai Y, Sakanishi T, Inaba A. (2018)	Neutrality	sugarcane and corn	*"It was assumed that PET was incinerated at the disposal stage and that biomass derived GHG emissions were carbon neutral.* *CO_2 emissions from biomass were assumed to be carbon neutral."*
Rathnayake, M.; Chaireongsirikul, T.; Svangariyaskul, A.; Lawtrakul, L.; Toochinda, P. (2018)	Neutrality	cassava, cane molasses, and rice straw	*"The carbon neutral rule is applied for biogenic CO_2 emissions (Neamhom et al., 2016)."*
Michailos, S. (2018)	Input-output	sugarcane	*"the amount of CO2 absorbed by photosynthesis during the sugarcane growth is subtracted from the total emissions of the system. The equivalent amount of CO2 stored in the sugarcane is estimated using the stoichiometric relationship of CO2 to carbon of 3.66 kg/kg 38."*
Liu H, Ou X, Yuan J, Yan X. (2018)	Neutrality	corn stover	not explicitly mentioned
Liu C, Huang Y, Wang X, Tai Y, Liu L, Liu H. (2018)	Input-output	corn stover	Carbon uptake (CO_2 absorption): 0.12 kg/MJ) Biogenic CO_2 emissions: 0.07 kg/MJ But before allocation, carbon uptake equals to biogenic CO_2 emissions
Liptow, C.; Janssen, M.; Tillman, A.-M., (2018)	Modified global warming potential	wood; sugarcane	*"In the case of boreal wood, this re-growth takes around 100 years, causing an impact of 3–4 t CO_2,eq/t PE using the GWPbio and the WF methods. In contrast, the sugarcane grows very fast, leading to an almost instantaneous uptake of emissions and hence an impact close to 0 t CO_2,eq/t PE."*

	Approach	Biomass	*Quotation*/Remark
Kim S, Zhang XS, Dale BE, Reddy AD, Jones CD, Izaurralde RC. (2018)	Neutrality	corn stover	not explicitly mentioned
Kim S, Zhang XS, Dale B, Reddy AD, Jones CD, Cronin K, et al. (2018).	Neutrality	corn stover	not explicitly mentioned
Khoshnevisan B, Rafiee S, Tabatabaei M, Ghanavati H, Mohtasebi SS, Rahimi V, et al. (2018)	Neutrality	castor	*"The origin of biomass, i.e., plants, absorbs atmospheric CO_2 during photosynthesis. This CO_2 is approximately equal to the amount of CO_2 released during their subsequent conversion and combustion (Naik et al. Osamu and Carl 1989). Therefore, biofuels not only can alleviate world's dependence on fossil-based fuels but also can simultaneously reduce global CO_2 production.* *… the CO_2 released from castor biodiesel was considered to be completely biogenic as the ethanol and methanol used for biodiesel production were assumed to be of biomass origin (ethanol was completely supplied internally by the biorefinery)."*
Heng L, Zhang H, Xiao J, Xiao R.(2018)	Neutrality	corn stover	*"The reduction in GHG emissions is mainly attributed to the biogenic CO_2 credit from the uptake of atmospheric CO_2 during growth of biomass. The biogenic CO_2 credit can offset the biogenic carbon emissions from biomass pyrolysis, bio-oil upgrading, biofuel consumption, and the disposal of carbonaceous organics in wastewater. Obviously, if the atmospheric CO_2 absorbed by biomass is returned to the atmosphere, the net greenhouse effect is nearly zero."*

	Approach	Biomass	*Quotation*/Remark
Heng L, Xiao R, Zhang H. (2018)	Neutrality	corn stover	*"The corn stover plays a role of carbon fixation via the uptake of atmospheric CO_2 during its growth. The biogenic carbon credit from CO_2 uptake can cancel out all the biogenic CO_2 emission from various unit processes including the disposal of carbonaceous organics in waste water."*
DeCicco JM. (2018).	Additionality	corn	Additional carbon uptake
Chen R, Qin Z, Han J, Wang M, Taheripour F, Tyner W, et al. (2018)	Input-output	soybean	accounting biodiesel combustion and biogenic carbon credit of the same scale
Buchspies B, Kaltschmitt M. (2018)	Neutrality	wheat straw	*"Emissions originating from the combustion of biofuels are considered to be carbon neutral due to the biogenic origin of carbon."*
Zhang Y, Kendall A. (2017)	Neutrality	corn grain and corn stover	not explicitly mentioned
Vargas-Ramirez JM, Wiesenborn DP, Ripplinger DG, Pryor SW. (2017)	Neutrality	Sugar beet	*"Carbon dioxide emitted during ethanol combustion was excluded from this analysis because it is biogenic and does not contribute to global warming potential (Muñoz et al., 2013)."*
Valli L, Rossi L, Fabbri C, Sibilla F, Gattoni P, Dale BE, et al. (2017)	Neutrality	cattle slurry, potato scraps, cereal by-products, corn silage, poultry droppings, sorghum silage, triticale silage, citrus pulp, olive and whey	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Song S, Liu P, Xu J, Chong C, Huang X, Ma L, et al. (2017)	Neutrality	corn stover	*"we first assume that biomass utilization is carbon neutral, which means that the CO_2 fixed by photosynthesis in the biomass equals the CO_2 emissions from burning the biomass."*
Pellegrino Cerri CE, You X, Cherubin MR, Moreira CS, Raucci GS, Castigioni BdA, et al. (2017).	Neutrality	soybean	*"Our study did not mention the emissions from the final stage (i .e ., combustion) of the life cycle, because the combustion of soybean biodiesel emits biogenic CO_2, which is covered in the agriculture stage, and was considered as zero in this study."*
De Kleine, R. D.; Anderson, J. E.; Kim, H. C.; Wallington, T. J., (2017)	Additionality	corn	Criticize inconsistent system boundary
Adom FK, Dunn JB. (2017)	Input-output	corn stover	Biogenic carbon was treated as stored within the bioproduct in cradle-to-gate analyses. acconting CO_2 uptake during feedstock growth and CO_2 release upon degradation of the same scale
Zhao L, Ou X, Chang S. (2016)	Neutrality	corn stover	Subtracting biogenic CO2 from overall CO_2 emissions associated with E10 fuel
Ukaew S, Shi R, Lee JH, Archer DW, Pearlson M, Lewis KC, et al. (2016)	Neutrality	canola	*"The CO_2 emission from HEFA fuel combustion is considered as carbon neutral; therefore, this emission is not counted in the GHG analysis."*
Shuai W, Chen N, Li B, Zhou D, Gao J. (2016)	Neutrality	common reed	*"Because biogenic GHG emission was climate neutral, only GHG emissions from fossil fuel and other non-renewable resources were counted in calculation."*

	Approach	Biomass	*Quotation*/Remark
Pourhashem G, Adler PR, Spatari S. (2016)	Neutrality	residue of corn, wheat and barley	*"Biogenic carbon released by biofuel production and combustion is assumed to be captured again by annual cropping."*
Kim S, Dale BE. (2016)	Neutrality	corn stover	not explicitly mentioned
Hums ME, Cairncross RA, Spatari S. (2016)	Neutrality	grease trap waste	*"The CO_2 credit for biodiesel was represented in the fuel's combustion. The CO_2 produced from biogenic sources was considered zero because of the recent sequestration of carbon from the atmosphere."*
DeCicco JM, Liu DY, Heo J, Krishnan R, Kurthen A, Wang L. (2016)	Additionality	corn	Additional carbon uptake
Daylan B, Ciliz N. (2016)	Neutrality	corn stover	*"Biofuels have a large reduction potential for CO_2 emissions throughout their life cycle, since the vehicle combustion of biofuels does not contribute to net emissions of CO_2, which is absorbed by the biomass feedstock through photosynthesis."*
Carvalho M, da Silva ES, Andersen SLF, Abrahao R. (2016)	Neutrality	soybean	not explicitly mentioned
Canter CE, Dunn JB, Han J, Wang Z, Wang M. (2016)	Neutrality	corn and corn stover	*"We treat CO_2 emissions from ethanol combustion during vehicle operation as offset by carbon uptake during feedstock growth, which in the case of corn grain and corn stover occurred in the recent past."*
Yang Y, Suh S. (2015)	Neutrality	corn	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Tsang M, Fox-Lent C, Wallace S, Welp T, Bates M, Linkov I. (2015)	Neutrality	soybean and algae	*"The burning of biodiesel is a closed loop carbon system, meaning that the carbon dioxide emissions during fuel combustion originate from carbon consumed from the atmosphere during growth of the feedstock. Such carbon is considered biogenic and their resulting release into the atmosphere during combustion does not add to the global greenhouse gas burden."*
Su M, Huang C, Lin W, Tso C, Lur H. (2015)	Neutrality	corn, rice straw, switchgrass, sweet potato, sweet sorghum and sugarcane	Not including biogenic CO_2 emissions
Sastre CM, Gonzalez-Arechavala Y, Santos AM. (2015)	Neutrality	wheat straw	*"The emissions of carbon dioxide from straw combustion have not been accounted because CO_2 was previously fixed from the air by the crop no more than one year before being burned."*
Murphy CW, Kendall A. (2015)	Neutrality	corn stover and switchgrass	*"All CO_2 emitted from combusting process byproducts is biogenic and assumed to not to contribute to changing atmospheric CO_2 and, in accordance with widely accepted carbon accounting methods, is not included in calculations."*
Kim S, Dale BE. (2015a)	Neutrality	barley straw, corn stover, oat straw, sorghum stubble, wheat straw, energy sorghum, switchgrass and willow	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Kim S, Dale BE. (2015b)	Neutrality	corn stover	*"Biogenic carbon dioxide emissions are released from the fermentation and the cogeneration facilities."*
Jeswani HK, Falano T, Azapagic A. (2015)	Neutrality	wheat straw, poplar, miscanthus and forest residue	*"As per standard LCA practice, biogenic CO_2 emissions are excluded from the GWP as they are part of the natural carbon cycle. Similarly, biogenic carbon storage in the products is not considered as this carbon will be released during the use of ethanol in vehicles* *for ethanol the biogenic CO_2 emitted during its use is not taken into account as that is equivalent to the amount of CO_2 sequestered from the atmosphere by the feedstocks during their growth."*
Daystar J, Treasure T, Reeb C, Venditti R, Gonzalez R, Kelley S. (2015)	Input-output	pine, eucalyptus, natural hardwood, switchgrass, and sweet sorghum	Carbon uptake and biogenic CO_2 emissions are accounted.
Borjesson P, Prade T, Lantz M, Bjornsson L. (2015)	Neutrality	hemp; sugar beet; maize; triticale; ley crops; wheat (grain)	*"The calculation of life cycle emissions of GHGs includes carbon dioxide (CO_2) of fossil origin and based on changes in soil organic carbon (SOC) content, methane (CH_4) and nitrous oxide (N_2O)."*
Belboom S, Bodson B, Leonard A. (2015)	Neutrality	wheat	*"During crop cultivation, carbon dioxide from atmosphere is converted by the plant into biomass. In this study, we do not take this benefit into account as recommended by the Annex V of the RED (3) neither the emissions of biogenic CO_2 released during combustion phase."*

	Approach	Biomass	*Quotation*/Remark
Aguirre-Villegas HA, Larson R, Reinemann DJ. (2015)	Neutrality	manure, corn stover and switchgrass	*" …to account for the CO_2(b) recycling process that takes place during plant growth as it is assumed that the carbon contained in biomass has been previously captured as CO_2"*
Souza SP, Seabra JEA. (2014)	Neutrality	sugarcane and soybean	not explicitly mentioned
Sanscartier D, Dias G, Deen B, Dadfar H, McDonald I, MacLean HL. (2014)	Neutrality	corn cobs	*".. . biogenic CO_2 emitted during the combustion of the pellets is not counted in calculations as it does not have a net contribution to the global warming effect."*
Olukoya IA, Ramachandriya KD, Wilkins MR, Aichele CP. (2014)	Neutrality	red cedar	not explicitly mentioned
Nguyen L, Cafferty KG, Searcy EM, Spatari S. (2014)	Input-output	corn stover	Carbon uptake by biomass and Biogenic CO_2 emission are accounted. Biogenic carbon uptake: −234 gCO_2/MJ Fermentative CO_2: 34 gCO_2/MJ Boiler: 122 gCO_2/MJ Ethanol combustion: 71 gCO_2/MJ
Munoz I, Flury K, Jungbluth N, Rigarlsford G, Canals LMI, King H. (2014)	Neutrality	maize corn stover sugarcane wheat and sugar beet	*"… global warming potentials (GWP) from carbon dioxide (CO_2) and methane were used as proposed by Muñoz et al. (2013) for a 100-year period, accounting for methane oxidation in the atmosphere and considering biogenic CO2 emissions as neutral, with the exception of those resulting from land use change (LUC)."*
Moller F, Slento E, Frederiksen P. (2014)	Neutrality	rapeseed	*"RME consists of 100% renewable carbon and therefore its CO_2 emissions are considered neutral."*

	Approach	Biomass	*Quotation*/Remark
Martinez-Hernandez E, Campbell GM, Sadhukhan J. (2014)	Neutrality	jatropha seeds	*"CO_2 emissions from the processing and end use (e.g. combustion) were considered as balanced as they originate from the carbon contained in Jatropha seeds."*
Garba NA, Duckers LJ, Hall WJ. (2014)	Neutrality	corn and soybean	*"Biofuels are considered 'carbon neutral' because they are produced within the short-term carbon cycle, and their combustion only returns as much CO_2 to the atmosphere as that is captured during plant growth.*
Downie A, Lau D, Cowie A, Munroe P. (2014)	Neutrality, Input-output	wheat straw, animal manures, forestry residue	biogenic method (input-output); stock method (neutrality); simplified method (neutrality)
Yan X, Boies AM. (2013)	Neutrality	wheat	*"we assume complete combustion whereby the CO_2 emitted is initially absorbed from the atmosphere during wheat growing."*
Weinberg J, Kaltschmitt M. (2013)	Neutrality	wheat and sugar beet	not explicitly mentioned
Patrizi N, Caro D, Pulselli FM, Bjerre AB, Bastianoni S. (2013)	Neutrality	wheat, barley and oat straw	*"The combustion of bioethanol by transportation is considered "carbon neutral", since the combustion of biomass releases the same amount of CO_2 as was captured by the straw during its growth."*
Martinez-Hernandez E, Ibrahim MH, Leach M, Sinclair P, Campbell GM, Sadhukhan J. (2013)	Neutrality	wheat	*"The biogenic carbon capture is not affected by these parameters and therefore CO_2 binding and carbon emissions from end use of products are not changed."*

	Approach	Biomass	*Quotation*/Remark
Hajjaji N, Pons M-N, Renaudin V, Houas A. (2013)	Neutrality	wheat and cattle manure	*"The biological CH4 reforming systems contribute less to the global warming potential impact. CO_2 emissions from biogenic sources (biomethane and bioethanol reforming processes) are not included in this paper."*
Grau B, Bernat E, Rita P, Jordi-Roger R, Antoni R. (2013)	Neutrality	rapeseed	*"CO_2 emissions for SVO (straight vegetable oil) have been considered null because they are compensated by the amount of this gas absorbed during the growth of the rapeseed plant (CO_2 neutral balance)*
Eranki PL, Manowitz DH, Bals BD, Izaurralde RC, Kim S, Dale BE. (2013)	Neutrality	corn stover	not explicitly mentioned
Cai H, Dunn JB, Wang ZC, Han JW, Wang MQ. (2013)	Input-output for combustion of biomass and biofuel (not for CO_2 emissions from fermentation)	sorghum	*"WTW GHG emissions are separated into WTP, PTW, and biogenic CO2 (i.e., carbon in bioethanol) emissions. Combustion emissions are the largest GHG emission source for all fuel pathways. However, in the bioethanol cases, the uptake of CO2 during feedstock production almost entirely offsets ethanol combustion GHG emissions."*
Han J, Elgowainy A, Dunn JB, Wang MQ. (2013)	Input-output	corn stover and forest residue	*"The large observed reduction in WTW GHG emissions for all pyrolysis pathways are mainly due to the biogenic CO2 credit (CO2 absorbed during growth of biomass that is converted into fuel) that cancels out the GHG emissions from the vehicle's operation. Note that pyrolysis, stabilization and upgrading generate large biogenic carbon emissions (CO2, CO, VOC and CH4). These emissions are offset, however, by the uptake of atmospheric carbon during feedstock growth."*

	Approach	Biomass	*Quotation*/Remark
Wang M, Han J, Dunn JB, Cai H, Elgowainy A. (2012)	Input-output for combustion of biomass and biofuel (not for CO_2 emissions from fermentation)	corn, sugarcane, corn stover, switchgrass and miscanthus	*"…biogenic CO2 in ethanol offsets ethanol combustion GHG emissions almost entirely."*
Dunn JB, Mueller S, Wang M, Han J. (2012)	Input-output for combustion of biomass and biofuel (not for CO_2 emissions from fermentation)	corn, corn stover and switchgrass	*"…biogenic CO2 emissions from the cellulosic ethanol plant are not included."*
Roy P, Tokuyasu K, Orikasa T, Nakamura N, Shiina T. (2012)	Neutrality	corn stover	*"Biomass combustions are assumed to be carbon neutral."*
Kumar D, Murthy GS. (2012)	Neutrality	grass straw	*"The CO_2 released during ethanol fermentation and lignin burning was sequestered from environment by photosynthesis process during grass straw production. Hence, CO_2 emissions produced during fermentation process and lignin residue burning were not accounted into calculations."*
Krohn BJ, Fripp M. (2012)	Neutrality	soybean and canola	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Eerhart AJJE, Faaij APC, Patel MK. (2012)	Neutrality	corn	*"When comparing PEF with PET, it is important to distinguish between fossil and biogenic GHG emissions. For petrochemical products, such as PET, the method for determining GHG emissions is broadly accepted. Accounting for CO_2 emissions arising from biobased products is more complex as there are two concepts which can be considered, i.e. carbon neutrality or carbon storage***. However, these two methods yield the same result for the system cradle-to-grave which has been chosen in this paper; therefore, we do not discuss here possible further implications and instead refer the reader to Pawelzik and Patel."*
Acquaye AA, Sherwen T, Genovese A, Kuylenstierna J, Koh SCL, McQueen-Mason S. (2012)	Input-output	rapeseed, corn, soybean, and sugarcane	*"The carbon released through combustion of biofuels is biogenic CO_2; this was captured in the process LCA ecoinvent data (39). It was calculated using the principle of carbon balance (input of carbon=output of carbon); that is, the uptake of carbon during plant growth plus all inputs of biogenic carbon with all pre-products minus biogenic carbon emissions should equal the biogenic carbon content of the biofuel or the product after all allocations have been done."*
Zamboni A, Murphy RJ, Woods J, Bezzo F, Shah N. (2011)	Neutrality	corn and soybean	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Reinhard J, Zah R. (2011)	Neutrality	rapeseed	*"We have not considered the biogenic CO~~2~~ uptake of the biofuels. Thus, we did not take account of its release but rather added the combustion of diesel in the baseline scenario in order to account for the full differences in the emissions of the analysed systems."*
Melamu R, von Blottnitz H. (2011)	Neutrality	sugarcane bagasse	*"… biogenic carbon dioxide emissions from burning bagasse are taken not to contribute to global warming."*
Kauffman N, Hayes D, Brown R. (2011)	Neutrality	corn	*"Given that bio-oil is composed of biogenic carbon, there are thus no GHG emissions associated with hydroprocessing."*
Kaliyan N, Morey RV, Tiffany DG. (2011)	Neutrality	corn	*"Combustion emissions of CO_2 are not included for biomass fuels because the CO_2 released by biomass fuel was removed from the atmosphere during photosynthesis."*
Fazio S, Monti A. (2011)	Neutrality	miscanthus, giant reed, switchgrass, cynara, fibre sorghum , maize, wheat, rapeseed, and sunflower	*"The amount of emitted CO_2 during combustion of biomass crops was considered equal to that absorbed by crops through photosynthesis."*
CHERUBINI, F.; PETERS, G. P.; BERNTSEN, T.; STRØMMAN, A. H.; HERTWICH, E., (2011)	Modified global warming potential		GWP_{bio} = 0 for annual crop

	Approach	Biomass	*Quotation*/Remark
Voet Evd, Lifset RJ, Luo L. (2010)	Input-output		*"In chains where coproducts are not important, exclusion of biogenic carbon generates the same results. However, Luo and colleagues show that, in cases of chains with coproducts, it does make a difference. Allocation may put the credits for extracted CO_2 in a different part of the multiproduct chain than the debits for emitted CO_2, while ignoring biogenic CO_2 would not have this effect."*
Schumacher B, Oechsner H, Senn T, Jungbluth T. (2010)	Neutrality	corn and triticale	not explicitly mentioned
Scacchi CCO, Gonzalez-Garcia S, Caserini S, Rigamonti L. (2010)	Neutrality	wheat	*"… the amount of carbon dioxide released in the combustion step is the same as the amount stored during the growing phase of the wheat. Therefore the carbon dioxide emissions counted come from the combustion of only the fossil fraction contained in the fuel."*
Kusiima JM, Powers SE. (2010)	Neutrality	corn, corn stover, switchgrass and forest residue	*"The CO_2 released during lignin combustion is considered biogenic carbon that was sequestered during feedstock growth. This biogenic carbon is treated as an additional credit. Biogenic carbon credits could also be assigned for the combustion of ethanol in an automobile."*
Kaufman AS, Meier PJ, Sinistore JC, Reinemann DJ. (2010)	Neutrality	corn-grain and corn-stover	*"The CO_2 released during stover combustion is negated by the CO2 captured during plant growth, resulting in no net CO_2 impact."*

	Approach	Biomass	*Quotation*/Remark
Iriarte A, Rieradevall J, Gabarrell X. (2010)	Neutrality	rapeseed	*"… The flows of CO_2 associated with the capture of atmospheric carbon in photosynthesis during crop growth and its release by oxidation are considered neutral. As a result, these flows are not included in the analysis of greenhouse gases, in agreement with the standard approach related to the carbon cycle in agriculture ..."*
Gonzalez-Garcia S, Teresa Moreira M, Feijoo G. (2010).	Neutrality	alfalfa stems, flax shives, hemp hurds, poplar and ethiopian mustard	*"… the carbon released as CO_2 from combustion and production of the fuel would be incorporated into the re-growth of the plant."*
Feng H, Rubin OD, Babcock BA. (2010)	Neutrality	corn	*"The emissions from the burning of ethanol are cancelled by the absorption of carbon as corn grows and therefore are not considered."*

Land Use Impacts of a Reform of the U.S. Environmental Agency Rule Associated with Carbon Dioxide Emissions from Processing of Annual Crops

Prepared for the Biogenic CO_2 Coalition

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Executive Summary

This report evaluates the land use impacts of a reform to the U.S. Environmental Protection Agency's (EPA), Prevention of Significant Deterioration (PSD) and Nonattainment New Source Review (NSR) permitting programs for CO_2 emissions from the processing of annual crops. The procedure used in this report is exactly that used to derive the original land-use change results in Searchinger *et al*. First, the projected impact on annual crop use in the US is taken from an earlier analysis of the economic impact of the rule change conducted by the Policy Navigation Group (PNG). These PNG projections are adapted for current circumstance in the US corn processing industry. Second, the dollar investments to build new, or adapt old plants in the PNG analysis are converted into a change in worldwide corn demand using a dry mill ethanol plant as a benchmark. Third, the projected increase in corn demand is input into the economic model used by Searchinger *et al.* and is shown to increase world corn prices by $0.03 per bushel. This results in a worldwide increase in land use of 24,500 hectares per year, of which 6,363 ha/year would be in Brazil. These impacts are tiny relative to the Searchinger *et al.* result and should therefore meet any reasonable *De Minimis* criteria.

Introduction

I have been asked by the Biogenic CO_2 Coalition to estimate the land use impacts of providing relief from including biogenic CO_2 emissions in the Clean Air Act Permitting Programs, specifically those emissions from fermentation of annual crop-derived plant biomass. I am familiar with the economic forces that drive direct and indirect land use change. I am an author on the highly cited Searchinger paper[1] and on two earlier papers[2] that explained the economic modelling and derived key economic results in the Searchinger paper. I, therefore, feel well qualified to provide these calculations.

Economic Forces Driving Land Use Change

In our 2006 and 2007 papers, we estimated the impact of a policy change; a volumetric ethanol excise tax credit (VEETC) of $0.51 per gallon offered to refiners for blending ethanol with gasoline. We then explained that with the ethanol prices current at that time and the tax credit there was arbitrage in US ethanol production because ethanol producers could buy inexpensive corn to produce expensive ethanol. We then predicted the growth in US ethanol production that would be required to drive these arbitrage profits to zero. We calculated that with this additional demand for corn, the world price of corn would increase significantly and that this increase would stimulate additional worldwide corn production. This additional production would come in part from conversion of pasture and forest land into cropland. All the modelling in these two papers was done using the CARD-FAPRI commodity model. The incremental contribution of the Searchinger paper over and above the two earlier papers was to show that

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[1] Searchinger, Timothy, Ralph Heimlich, Richard A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. "Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change." *Science* 319, no. 5867 (2008): 1238-1240.

[2] Tokgoz, Simla, Amani E. Elobeid, Jacinto F. Fabiosa, Dermot J. Hayes, Bruce A. Babcock, Tun-Hsiang Edward Yu, Fengxia Dong, Chad E. Hart, and John C. Beghin. "Emerging biofuels: Outlook of effects on US grain, oilseed, and livestock markets." (2007).

Elobeid, Amani E., Simla Tokgoz, Dermot J. Hayes, Bruce A. Babcock, and Chad E. Hart. "The long-run impact of corn-based ethanol on the grain, oilseed, and livestock sectors: A preliminary assessment." (2006).

if one included the Green House Gases (GHGs) released from this converted land, the environmental benefits of ethanol would be reduced[3].

Marginal Impact of Policy Changes

The key to understanding the land use impacts in the Searchinger paper is that at the margin, policy changes caused ethanol prices to increase and this in turn caused an increase in world crop land area via high corn prices. To separate out the impact of the policy change, we ran the model to establish a baseline and then ran it again with the VEETC in place. The difference between the two runs was interpreted as the impact of VEETC. Economists use the term *ceteris paribus* to describe this procedure. It means that the impact of the policy change is evaluated while holding all other variables constant. Following this logic, the land use implications of a change in the way EPA regulates CO_2 emissions from plants that process crop-derived biomass would be to first calculate the impact of the rule change on the processing of annual crops in the US. Second, net out the displacement effect that large new processing facilities will have on smaller facilities and on facilities in other countries. Third, evaluate the net impact on world corn prices. Fourth, use the model underlying Searchinger paper to calculate the impact of an increase in world corn prices on worldwide land use. Note that in the real world, there will be many forces, such as the US trade war with China, and changes in environmental policy in Brazil that drive land use change. These other forces will be excluded from the results using the marginal analysis described above. These forces need to be excluded because they would happen with or without the EPA permitting change.

Prior Economic Work

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[3] I and several of my coauthors on the Searchinger report I later showed that the key Searchinger land use result could be offset if higher corn prices induced higher corn yields. I am therefore being very conservative in using the Searchinger assumptions. See: Jerome Dumortier, Dermot J. Hayes, Miguel Carriquiry, Fengxia Dong, Xiaodong Du, Amani Elobeid, Jacinto F. Fabiosa, Simla Tokgoz, Sensitivity of Carbon Emission Estimates from Indirect Land-Use Change, Applied Economic Perspectives and Policy, Volume 33, Issue 3, Autumn 2011, Pages 428–448, https://doi.org/10.1093/aepp/ppr015

In 2018, the Policy Navigation Group conducted a detailed economic analysis on the impact of the EPA rule change on the processing of annual crops in the US[4]. The focus of the study was on the economic activity that would be generated by the rule change. The study used a database on NSR applications and the frequency of minor permit applications. The report concluded that for corn processing, the primary effect of the change would be to enable projects that modify existing wet mills to produce bio-products such as bioplastics and biofuels. For other sectors including oilseed processing, fluid milk processing, bakeries and breweries, the impact is due to enabling construction or modification of facilities that were downsized or deferred due to NSR permitting restrictions[5]. They argue that these facilities were often constructed at less than optimal scale to avoid the NSR permitting progress. The conclusion of the report is an annual additional capital investment of $747 million of which $385 to $580 million is for dry and wet mill corn plants and $167 million is for the other impacted sectors.

Current Status of the Wet and Dry Mill Corn Processing Plants

One possible result of the rule change would be to allow for expansion or construction of large-scale corn wet mills or dry corn ethanol plants. It is, therefore, worth asking if there are circumstances where the rule change, on its own, would bring about an expansion of corn processing in the US. In a project I did for the State of Iowa, I surveyed the existing wet corn mills in the state to ask about possible response to a state tax credit[6]. I learned that there is excess capacity to produce corn sweetener in the US due to a reduction in consumer demand.

The owners of these plants were very interested in partnerships to produce advanced bio products that would use this excess sugar. There was no interest in expansion of existing plants.

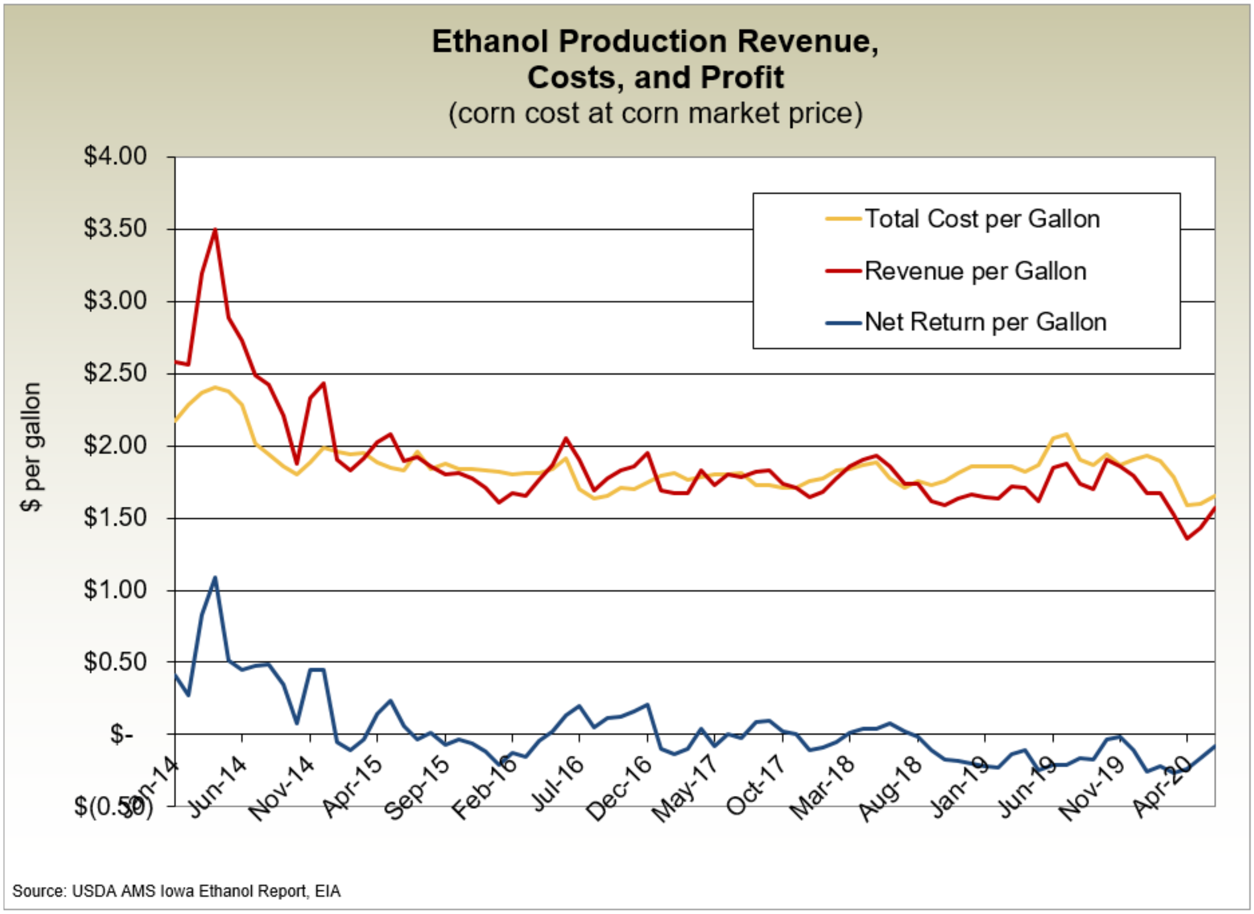
[4] See: GRES2TE0/Biogenic%20NSR%20Report%20Final%20(002)%20(002).pdf

[5] The NSR rules is written as follows. (a) At a new stationary source that will emit or have the potential to emit 100,000 tpy CO2e; or (b) At an existing stationary source that emits or has the potential to emit 100,000 tpy CO2e, when such stationary source undertakes a physical change or change in the method of operation that will result in an emissions increase of 75,000 tpy CO2e or more. See https://www.govinfo.gov/content/pkg/FR-2010-06-03/pdf/2010-11974.pdf

[6] Biobased Chemicals: The Iowa Opportunity Dermot Hayes, Brent Shanks and Jill Euken Iowa State University November 25, 2015

One of the individuals I interviewed,, described the company's attempts to repurpose a $400 million dollar corn processing facility. It had been completed in 2010 and was seldom at capacity. He also described the company's intent to find "Over-the-Fence" opportunities. In this business-model, a third party seeking to commercialize new technology would co-locate adjacent to the corn wet milling facilities. Another interviewee, who had 27 years of experience in grain processing, biochemicals and energy, said that Iowa had a huge surplus of industrial sugars such as dextrose, glucose and fructose produced from corn. These products were available from wet mills located in Clinton and Fort Dodge, Iowa and Blair, Nebraska.

The situation for dry corn ethanol plants is even worse. These plants benefited from the 15 billion-gallon RFS mandate up to the point where US ethanol production exceeded the mandate. Once this happened, the excess ethanol was sold based on its energy value relative to gasoline. In a commodity market, if an excess gallon is sold at a discount, then all gallons sold on that day will also sell at the reduced price. Once this happened, the US ethanol industry entered a period of economic decline. Some plants are not even covering their variable costs and many have closed.



US ethanol production exceeded 15 billion gallons sometime in 2015[7] and as can be seen from the chart above, the industry has never been profitable on an annual basis since then. As a result, there is no interest in building additional ethanol production capacity in the US. This situation will not change unless the ethanol mandate is increased and there seems little likelihood that this will occur. Even if it did, the EPA would be positioned to evaluate the land use impacts. I can, therefore, rule out any expansion of corn processing in the US. This means that the additional capital investment in corn processing plants identified by the Policy Navigation Group would involve modifications of existing plants to produce bio-products and biochemicals. This would have no impact on US corn demand and can be ruled out as a contributor to land use change.

[7] https://afdc.energy.gov/data/10342

Other Capital Investments

Of the $167 million in new investment outside of the corn-processing sector identified by the Policy Navigation Group, some of the investment would involve expansion of processing and some would involve modifications of existing plants. Where new plants are constructed to process soybeans or milk, the end-product will be sold as a commodity on the domestic or international market. A portion of any increase in US production due to the construction of larger plants will be offset by reduced growth elsewhere. For breweries and bakeries, the additional production from larger plants will be offset by reductions in output from smaller plants.

The Policy Navigation Group does not provide enough information to calculate the proportion of investments that will lead to additional output versus modifications to additional plants. Nor does it allow me to calculate how much of any additional output will be offset by reductions in output or a reduction in the rate of growth elsewhere. I have conservatively assumed that two thirds of the new investments lead to additional output and that one third of the additional output is offset by reduced production in other countries or from smaller plants in the US. This means that $74 million of the new investment will be in newer plants where output is not offset by a reduction elsewhere.

Next, I need to calculate how much additional demand for annual crops will be generated by an annual investment of $74 million. For this, I use dry corn ethanol as a benchmark. In doing this, I am assuming that each dollar spent on facilities that expand production for annual crops results in the same increase in corn demand as the same dollar spent on new dry mill ethanol facilities. Again, this is conservative because dry mill corn ethanol plants are much less capital intensive per bushel consumed than bakeries, breweries or milk processing facilities.

It costs $2.15 per gallon to build a new dry corn ethanol plant[8]. This means that an annual investment of $74 million would lead to an increase in ethanol production of 34.5 million gallons. If we then assume a corn to ethanol conversion of 2.8 gallons per bushel, then the annual increase in corn consumption is 12 million bushels.

A Comparison with the Searchinger Result

As mentioned earlier, the key economic result in the Searchinger paper was based on an earlier paper by Elobeid et al [9][10]. This paper used a ten-year partial equilibrium commodity model to predict the market impact of a huge expansion in US ethanol production. The projected expansion caused the US ethanol industry to increase US ethanol production by 56 billion liters or 14.79 billion gallons and corn use by 5.28 billion bushels over a ten-year period. This is equivalent to an annual increase of 528 million bushels. In comparison, the predicted annual increase in US corn from the EPA rule change is 12 million bushels. This means that the Searchinger impact is 44 times greater. A large-scale new ethanol plant would potentially use 100 million bushels per year. This means that the impact of the EPA rule change would be to build one new ethanol plant in the US every 12 years.

Land Use Impact

I can use the assumptions and methodology of the Searchinger *et al.* paper to calculate the land use impact of a ten-year increase of 120 million bushels. This results in a worldwide increase over ten years of 245,000 hectares, of which 63,636 Hectares (6,363 Ha/year) would be in Brazil.

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[8] See https://www.flowcontrolnetwork.com/home/article/15551961/ethanol-plant-construct-costs-are-on-the-rise#:~:text=The%20study%20says%20while%20just,meaning%20the%20same%20100%20million

[9] Elobeid, Amani E., Simla Tokgoz, Dermot J. Hayes, Bruce A. Babcock, and Chad E. Hart. "The long-run impact of corn-based ethanol on the grain, oilseed, and livestock sectors: A preliminary assessment." (2006).

[10] Tokgoz, Simla, Amani E. Elobeid, Jacinto F. Fabiosa, Dermot J. Hayes, Bruce A. Babcock, Tun-Hsiang Edward Yu, Fengxia Dong, Chad E. Hart, and John C. Beghin. "Emerging biofuels: Outlook of effects on US grain, oilseed, and livestock markets." (2007).

The land use change described above assumes that the economic model is linear and that no matter how small the demand change, there will be a price impact to which US and Brazilian farmers would respond. The original Searchinger *et al*. paper resulted in an increase in world corn price of $1.49 per bushel. This EPA rule change would increase corn prices by $0.03 per bushel. It is very clear that a $1.49 increase in world corn prices would induce a supply response. It is not clear that corn farmers would notice and respond to a $0.03 cent increase in world prices. Moreover, the economic work behind the Searchinger et al. result was done in 2006, a time when expansion into new acres was relatively easy. The actual increase that has occurred since then, coupled with policy responses to slow new conversions, have probably increased the threshold price that is required.

The *De Minimis* Standard

The De Minimis threshold the EPA has used for clean air permitting is 75,000 tons per year CO_2 equivalent per facility. Kim and Dale calculated the gross carbon emissions from CO_2 released from a dry mill ethanol plant is 647 lbs per acre or 4.69 lbs per bushel[11]. The additional 12 million bushels estimated earlier would therefore generate 56,260,869 lbs of CO_2 equivalent. This is equal to 28,130 tons per year nationally, and is only 37.5% of the De Minimis standard EPA would apply to a single facility. From a land use perspective, and back calculating from Searchinger, it would take a conversion of 64,000 hectares per year to meet the 75,000 threshold. The annual conversion of 24,500 hectares estimated above at the national level is similarly 37.5% of the threshold EPA would apply to a single facility.

[11] See Figure 5 of S. Kim, PhD and B. Dale, PhD, The Biogenic Carbon Cycle in Annual Crop-Based Products, Department of Chemical Engineering and Materials Science Michigan State University (Nov. 22, 2013, They assume a corn yield of 138 bushels per acre.