



# The sobering truth about corn ethanol

Jason Hill<sup>a,1</sup>

Agricultural interest groups promote corn ethanol as an environmentally beneficial alternative to gasoline, but many independent scientists have long questioned this view (1–3). Nevertheless, the United States has aggressively pursued measures to expand biofuel production. The key policy has been the Renewable Fuel Standard (RFS2) in the Energy Independence and Security Act of 2007, which requires greater use of ethanol up to the current level of 15 billion gallons annually. Ethanol proponents have argued that this reduces greenhouse gas (GHG) emissions, but as Lark et al. (4) show in PNAS, the opposite occurs. The authors find that the life-cycle GHG emissions of the ethanol produced to meet RFS2 are no less than those of gasoline, and are likely even greater. This is because using more corn for biofuel has led to an increase in the intensity and the extent of corn farming in the United States. Thus, RFS2 not only fails to mitigate climate change but is actually counterproductive. Furthermore, the authors conclude that RFS2 has exacerbated other environmental problems commonly associated with row crop production, including poor water quality and soil erosion.

## Findings

Lark et al. (4) present a detailed accounting of how GHG emissions from US agriculture increased due to greater demand for corn to meet RFS2-mandated ethanol volumes. Farmers responded to higher corn prices by applying more fertilizer to their fields and by reducing the diversity of crops planted in rotation so as to include more corn. They also grew corn on cropland previously planted to other crops such as soybeans and wheat, raising their prices as well. Higher crop prices led, in turn, to expansion of the total cropland area. The consequence of this intensification and extensification of US cropland has been substantially greater GHG emissions. Near the start of RFS2 over a decade ago, three independent studies showed that expanding biofuel production could result in large GHG emissions from land use change (5–7). These concerns are confirmed in the work of Lark et al. (4), which provides a retrospective look at the environmental consequences of implementing RFS2. They accomplish this by integrating economic and biophysical modeling with high-resolution land use change observations at the farm field level.

The findings of Lark et al. (4) are all the more striking in that their estimate of GHG emissions from RFS2 represents a floor, not a ceiling. They draw this conclusion from observations of changes in farming that occurred in the United States, but there are other major emissions sources they did not explore that, when accounted for, only add to the emissions attributable to corn ethanol. Lark et al. (4) note no fewer than three such sources: 1) greater production of nitrogen fertilizers, which are derived from fossil fuels; 2) international land use change, such as when farmers in

other countries convert forests and grasslands to agriculture in response to higher commodity prices; and 3) the fuel market rebound effect, which is an overall rise in fuel consumption in response to greater fuel supply. Other studies have indicated that emissions from these sources can be substantial in their contribution to total biofuel emissions (8–10).

## Implications

While the focus of the study of Lark et al. (4) is RFS2, their work also calls into question the effectiveness of other climate change mitigation policies that promote the use of corn ethanol and other biofuels. These include current and proposed Low Carbon Fuel Standards at the state and federal levels, which like RFS2, may also increase GHG emissions or, at the very least, be overstated in their benefits. The findings of Lark et al. (4) also suggest that greater scrutiny should be given to the models that are used in a regulatory context to evaluate the GHG emissions associated with fuels of all types. The authors compare their results with those from three other modeling efforts—1) the US Environmental Protection Agency's Regulatory Impact Assessment for RFS2; 2) the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model from Argonne National Laboratory, and 3) the Global Trade Analysis Project (GTAP) model as used by California Air Resources Board—all of which show considerably lower GHG emissions from domestic land use change caused by recent production of corn ethanol. This difference supports other recent concerns that these commonly used models underestimate the emissions consequences of land use change (11–13), which in turn leads to their overestimating the climate change benefits of corn ethanol (e.g., refs. 14–16).

Evidence that RFS2 increases rather than reduces GHG emissions adds to long-standing criticism of its high economic and environmental costs. At current prices, \$20 billion of corn is converted to ethanol annually, which is approximately a third of all corn grown in the United States. This requires an area of cropland equivalent to all the land planted to corn in Iowa and Minnesota, the first

Author affiliations: <sup>a</sup>Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN 55108

Author contributions: J.H. designed research, performed research, analyzed data, and wrote the paper.

The author declares no competing interest.

Copyright © 2022 the Author(s). Published by PNAS. This open access article is distributed under [Creative Commons Attribution-NonCommercial-NoDerivatives License 4.0 \(CC BY-NC-ND\)](https://creativecommons.org/licenses/by-nc-nd/4.0/).

See companion article, "Environmental outcomes of the US Renewable Fuel Standard," [10.1073/pnas.2101084119](https://doi.org/10.1073/pnas.2101084119).

<sup>1</sup>Email: hill0408@umn.edu.

Published March 9, 2022.

and fourth largest corn-producing states, yet it offsets just 6% of domestic gasoline use. To put this in perspective, the current US average vehicle fuel economy is 22 miles per gallon (MPG), and a modest improvement of just 2 MPG (from 22 to 24) would, all else being equal, offset as much gasoline. What is more, this 6% offset is a gross value, not net, and does not account for fossil fuel use in ethanol production. Ethanol's small contribution to the domestic fuel supply, while providing a sizable guaranteed market for corn farmers and ethanol producers, comes at substantial cost to the American public, three times over in fact. First, they pay higher taxes to subsidize crop insurance programs. Second, they pay more for fuel at gas stations and for food at supermarkets and restaurants. Third, they pay the economic costs of climate change, reduced water and air quality, degraded soils, habitat loss, and other environmental damage caused by corn ethanol production and use (8, 17).

**The paper by Lark et al. provides us with yet more evidence that our corn-based biofuel initiatives run counter to our nation's and the world's environmental, economic, and social goals.**

## Moving Forward

The current policy environment is vastly different from 2007 when RFS2 became law. The United States has shifted from being a net oil importer to exporter, reducing concerns about energy independence. Also, the potential benefits of next-generation biofuels (1, 2) have largely been unrealized. Even more important, perhaps, has been the steady progression toward vehicle electrification, which eliminates tailpipe emissions that worsen climate change

and air quality. Electrification, done wisely, can mitigate climate change and provide other environmental benefits (18). Whereas in 2007 the public discourse centered on ethanol as an alternative to gasoline, today the interests of ethanol and gasoline are united against electrification. Perhaps nowhere is this more apparent than in the ethanol industry's current push to construct pipelines to move carbon dioxide from ethanol plants to oil fields for use in enhanced oil recovery (19). By maintaining market share for liquid fuels in transportation, our current national biofuel policy is more closely aligned with the fossil fuel industry than it is with the current climate agenda.

Corn ethanol production under RFS2 is slated to continue indefinitely, even as it is all the more clear that this, our nation's most prominent biofuel policy, is making climate change and other problems worse. Furthermore, the United States is pursuing this policy of using some of the most productive farmland in the world for fuel production at a time when demand to feed the growing and increasingly affluent global population continues to needlessly expand agriculture into natural ecosystems (20). The paper by Lark et al. (4) provides us with yet more evidence that our corn-based biofuel initiatives run counter to our nation's and the world's environmental, economic, and social goals. It is worth questioning the wisdom, logic, and ethics of continuing to use large expanses of our best farmland to produce a small amount of fuel at great environmental cost when better transportation alternatives exist.

**ACKNOWLEDGMENTS.** I thank Madeleine Bray, Kimberly Colgan, Madeline Faubion, Stephen Polasky, Sumil Thakrar, and David Tilman for comments on this manuscript.

1. G. P. Robertson *et al.*, Sustainable biofuels redux. *Science* **322**, 49–50 (2008).
2. D. Tilman *et al.*, Beneficial biofuels—the food, energy, and environment trilemma. *Science* **325**, 270–271 (2009).
3. D. Keeney, Ethanol USA. *Environ. Sci. Technol.* **43**, 8–11 (2009).
4. T. J. Lark *et al.*, Environmental outcomes of the US Renewable Fuel Standard. *Proc. Natl. Acad. Sci. U.S.A.*, 10.1073/pnas.2101084119 (2022).
5. T. Searchinger *et al.*, Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* **319**, 1238–1240 (2008).
6. H. K. Gibbs *et al.*, Carbon payback times for crop-based biofuel expansion in the tropics: The effects of changing yield and technology. *Environ. Res. Lett.* **3**, 034001 (2008).
7. J. Fargione, J. Hill, D. Tilman, S. Polasky, P. Hawthorne, Land clearing and the biofuel carbon debt. *Science* **319**, 1235–1238 (2008).
8. National Research Council, *Renewable Fuel Standard, Potential Economic and Environmental Effects of US Biofuel Policy* (The National Academies Press, Washington, DC, 2011).
9. E. Smeets *et al.*, The impact of the rebound effect on the use of first generation biofuels in the EU on greenhouse gas emissions: A critical review. *Renew. Sustain. Energy Rev.* **38**, 393–403 (2014).
10. J. Hill, L. Tajibaeva, S. Polasky, Climate consequences of low-carbon fuels: The United States Renewable Fuel Standard. *Energy Policy* **97**, 351–353 (2016).
11. A. Leland, S. K. Hoekman, X. Liu, Review of modifications to indirect land use change modeling and resulting carbon intensity values within the California Low Carbon Fuel Standard regulations. *J. Clean. Prod.* **180**, 698–707 (2018).
12. C. Malins, R. Plevin, R. Edwards, How robust are reductions in modeled estimates from GTAP-BIO of the indirect land use change induced by conventional biofuels? *J. Clean. Prod.* **258**, 120716 (2020).
13. S. A. Spawn-Lee *et al.*, Comment on “Carbon intensity of corn ethanol in the United States: State of the science.” *Environ. Res. Lett.* **16**, 118001 (2021).
14. U. Lee, H. Kwon, M. Wu, M. Wang, Retrospective analysis of the U.S. corn ethanol industry for 2005–2019: Implications for greenhouse gas emission reductions. *Biofuels Bioprod. Biorefin.* **15**, 1318–1331 (2021).
15. J. Lewandowski *et al.*, The greenhouse gas benefits of corn ethanol—assessing recent evidence. *Biofuels* **11**, 361–375 (2020).
16. M. J. Scully, G. A. Norris, T. M. Alarcon Falconi, D. L. MacIntosh, Carbon intensity of corn ethanol in the United States: State of the science. *Environ. Res. Lett.* **16**, 043001 (2021).
17. L. Chen *et al.*, The economic and environmental costs and benefits of the renewable fuel standard. *Environ. Res. Lett.* **16**, 034021 (2021).
18. C. W. Tessum, J. D. Hill, J. D. Marshall, Life cycle air quality impacts of conventional and alternative light-duty transportation in the United States. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 18490–18495 (2014).
19. Renewable Fuels Association, Response to Request for Information (RFI). Regulations.gov. Comment ID USDA-2020-0003-0115. [https://downloads.regulations.gov/USDA-2020-0003-0115/attachment\\_1.pdf](https://downloads.regulations.gov/USDA-2020-0003-0115/attachment_1.pdf). Accessed 6 February 2022.
20. P. Potapov *et al.*, Global maps of cropland extent and change show accelerated cropland expansion in the twenty-first century. *Nat. Food* **3**, 19–28 (2022).