Testimony on

The Environmental Impact of the Renewable Fuel Standard

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The Environmental Impact of the Renewable Fuel Standard

INTRODUCTION

The Renewable Fuel Standard (RFS) was first established by the Energy Policy Act of 2005, which amended the Clean Air Act to require that 7.5 billion gallons of renewable ethanol be blended into the nation's gasoline supply by 2012. The RFS was expanded by the Energy Independence and Security Act of 2007 (EISA) to target a total of 36 billion gallons of renewable fuel by 2022 along with specific requirements for certain categories of advanced, cellulosic and biomass-based diesel fuels to meet specified levels of greenhouse gas (GHG) reduction, relative to the petroleum-based fuels they replace, as determined by the Administrator of the Environmental Protection Agency (EPA) through lifecycle analysis (LCA). Starch-based ethanol from facilities placed into operation after the enactment of EISA must also meet a lifecycle GHG intensity ("carbon intensity" or "CI") threshold, specified as being 20% lower than that of baseline 2005 petroleum gasoline.

Three public policy rationales underpin the RFS and other policies to promote biofuels. One is to support the domestic agricultural sector by creating an additional market for corn and soybeans, thereby bolstering prices for these commodities and enhancing farmer and processor incomes. The second is energy security, which could be strengthened by developing domestic sources of liquid fuels that can replace the petroleum fuels that involve dependence on imported oil. The third rationale, which was elevated in the expanded RFS called for by EISA, is environmental. It rests on the potential for biofuels, which utilize carbon recycled from the atmosphere through crop growth, to reduce carbon dioxide (CO_2) emissions from the transportation sector. Such so-called "low-carbon" renewable fuels can include biomass-based ethanol and biodiesel as well as potential "drop-in," i.e., fully fungible, fuels derived from biomass that might without limit be incorporated into existing transportation fuel distribution and use systems. This testimony focuses on the environmental rationale for the RFS and examines whether the program has reduced CO_2 emissions when evaluated using real-world data on fuel production and use over the ten years since the policy was established.

From an energy policy perspective, a longstanding assumption has been that renewable fuels are inherently "carbon neutral," meaning that the CO_2 emitted when they are burned is fully offset by CO_2 uptake during feedstock growth. That assumption leads many scientists to presume that environmental impact assessments need only consider production-related GHG emissions throughout a biofuel's lifecycle. The carbon neutrality assumption is an accounting convention that is built into the LCA models used to compare the carbon intensity (CI, meaning lifecycle GHG emissions impacts) of different fuels. Such is the case for the GREET model[1] that is developed and maintained by Argonne National Laboratory (ANL) with support from the U.S. Department of Energy (DOE). It is also the case for the LCA models developed to administer the RFS, as seen in EPA's statement that "CO_2 emissions from biomass-based fuel combustion are not included in their lifecycle emissions results."[2]

Nevertheless, biofuel carbon neutrality is just an accounting convention and when it is used uncritically in lifecycle comparisons of biofuels with fossil fuels, it results in greatly misleading estimates of the actual impact of fuel substitution. Such erroneous comparisons underpin not only EPA's analyses for the RFS, but also California's LCA-based fuels regulation known as the Low-Carbon Fuel Standard (LCFS)[3] as well as numerous GREET analyses,[4] including those used to claim GHG reductions for the RFS.[5] The notion that using a renewable fuels automatically reduces CO_2 emissions (short of processing impacts) is based on a scientifically incomplete, and therefore incorrect, understanding of how carbon is recycled through plant growth. Only under limited conditions does substituting a biofuel for a fossil fuel neutralize tailpipe CO_2 emissions. However, the lifecycle models used for public policy to date assume carbon neutrality for biofuels without checking whether the conditions under which that assumption might be true are verified for actual biofuel production.

A careful examination of actual renewable fuel production since the RFS was established shows that the carbon neutrality conditions are not met in practice. As a first step in explaining this finding, the next section of the paper describes the principles that underpin scientifically verifiable carbon accounting for interactions among the terrestrial biosphere (which is the source of biofuel feedstocks), the geosphere (the source of fossil fuel feedstocks) and the atmosphere (in which excess CO_2 concentrations can disrupt the climate).

PRINCIPLES FOR VERIFIABLE CARBON ACCOUNTING

A crucial foundation for any analysis of biofuels is the fact that CO_2 is always cycling between the biosphere and the atmosphere, whether or not biomass-based products are being used for fuel. Figure A-1 at the end of this document depicts the major flows of the global carbon cycle. The small diagram in Figure 1 highlights the key flows need for a proper analysis of the substitution of biofuels for fossil fuels, based on the "Biofuels Carbon Balance" paper published in the journal *Climatic Change.*[6]

In this diagram, P stands for Net Primary Production (NPP), which is the amount of carbon absorbed into plants as they grow after subtracting plants' own metabolic release of CO_2. R stands for heterotrophic respiration (often designated R_h), which is the CO_2 respired by organisms that consume plants. That includes humans and livestock, but the vast majority of such respiration is from soil bacteria, fungi and other organisms collectively known as decomposers. These creatures form a critical part of the food chain that sustains all living things. Carbon is the fuel of life. In nature, no carbon is wasted; it is all put to use whether or not it is used commercially. On average, P exceeds R, which enables carbon to accumulate in the biosphere.

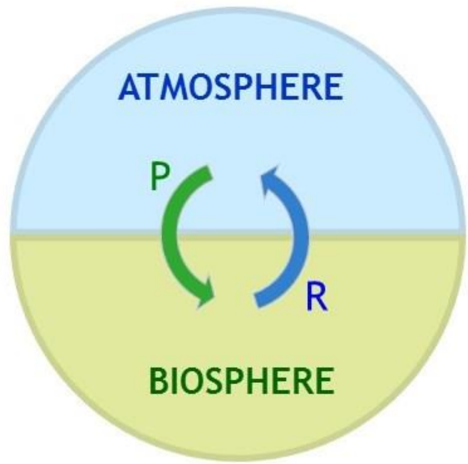

Figure 1. The main flows of the terrestrial carbon cycle: P = net primary production; R = heterotrophic respiration.

Another key tenet is the fact that the total amount of carbon in the world is fixed. Otherwise put, whether as food for biological processes, CO_2 in the atmosphere, fuel for motor vehicles or in living biomass such as forests, wetlands and other carbon-rich ecosystems, carbon utilization occurs in a closed system. This reflects the law of conservation of mass as applied to the use of carbon. Unfortunately, however, this basic principle it is neglected in the LCA models used to analyze biofuels. This serious error is related to the fact that these models were designed without properly accounting for CO_2 uptake (that is, P in the diagram above) even though they track CO_2 emissions throughout a fuel's lifecycle. The failure to respect the law of conservation of mass is one of the reasons why most prior evaluations of the RFS (and biofuel use generally) give results that inconsistent with the realities of carbon uptake in the biosphere.

Using these key principles for carbon accounting, a scientifically rigorous analysis of what happens when a biofuel substitutes for a fossil fuel is quite straightforward. The situation is depicted in Figure 2, which shows the carbon flows associated with fuel use in addition to the basic carbon cycle flows illustrated in Figure 1. Also shown is the P-minus-R difference, which is termed Net Ecosystem Production (NEP).[7] It is given as a downward arrow and reflects the net flow of carbon from the atmosphere to the biosphere.

At the center of the figure is fuel combustion. Whether the source of carbon in the fuel is biomass (B) or fossil (F), the amount of CO_2 emitted (E) when burning the fuel is essentially the same per unit of useful energy. In other words, using a biofuel (such as ethanol or biodiesel) instead of a fossil fuel (such as gasoline or diesel from petroleum) does not appreciably change the rate at which CO_2 flows into the atmosphere, e.g., from vehicle tailpipes or jet engines. As a matter of basic chemistry as far as climate is concerned, it is clear that if biofuels have a benefit, it's not when they are burned.

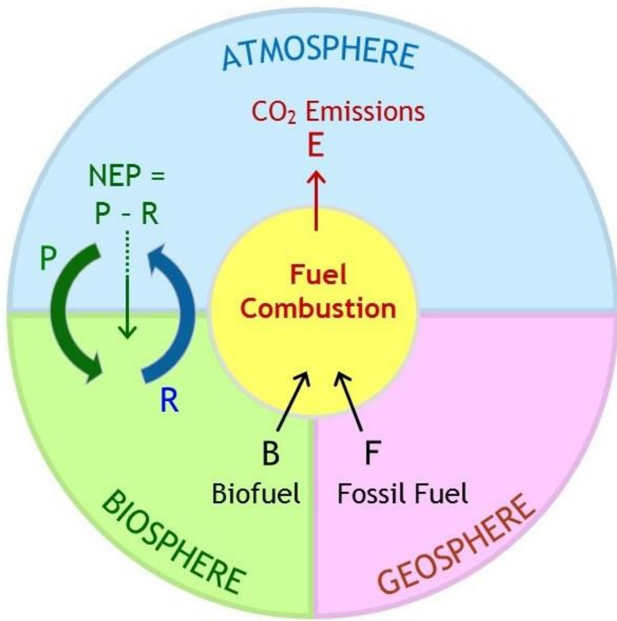

Figure 2. An increase in Net Ecosystem Production (NEP) is needed for biofuels to have a potential climate benefit.

To measurably reduce CO_2 buildup in the atmosphere, the emissions from fuel combustion must be balanced by *increasing* NEP, that is, speeding up how quickly CO_2 is removed from the atmosphere on cropland. Mathematically, this condition is written as

$$d(NEP)/dt > 0$$

and it means that there must be an acceleration of rate at which CO_2 flows from the atmosphere into biosphere. If this condition is not met, biofuels cannot provide a climate mitigation benefit and biofuel use is not carbon neutral. Moreover, this failure to reduce net GHG emissions comes even before considering the emissions involved in growing the feedstock and processing it into

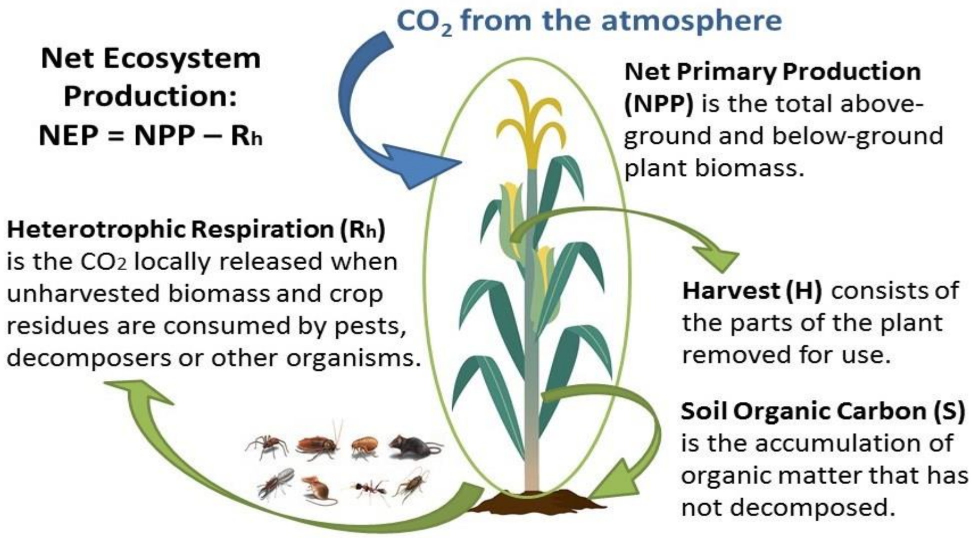

Figure 3. Carbon exchanges associated with an annual crop
Image Credit: Jane Thomas, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/)

fuel. It is also before considering the land-use change impacts that have become so prominent in the biofuels debate.

NEP can be evaluated over any area of land from a farm field up to the entire globe. To determine the potential climate protection benefits of a biofuel, it is necessary to evaluate how NEP changes on the cropland from which the feedstock is harvested. Figure 3 shows how NEP can be evaluated for an annual crop such as corn. In annual crops, very little carbon accumulates in the soil from year to year; as NRC (2011) points out, the uncertainties in soil carbon changes are large relative to the magnitudes involved, and so it is fair to assume no change in soil carbon on average. Therefore, NEP is essentially proportional to the harvest (H as shown in Figure 3).

For example, on a 40 acre farm field that grows corn with an annual yield of 160 bushels per acre, the amount of carbon removed in the harvest is roughly 59 metric tons.[8] That means that the downward rate of carbon flow from the atmosphere into the biosphere over the field (that is, its NEP) is 59 tons of carbon per year. Corn is among the most productive of crops in terms of yield, and so the NEP on a cornfield is significantly higher than that of other crops. An average soybean yield is 44 bushels per acre, and so a similar calculation for a 40 acre soybean field implies a NEP of roughly 18 tons of carbon per year.[9] As noted in the analysis discussed below, a gain in NEP occurs when rotating from soy to corn; conversely, a loss in NEP occurs when rotating back to soy.

DIRECT CARBON BALANCE EFFECTS FOR ETHANOL PRODUCTION

The extent to which biofuel feedstock production results in an increase in NEP is the empirical test that can be used to evaluate whether the GHG reductions predicted by LCA models actually occur in practice. To answer this question, we examined a case study for a state-of-the-art natural gas dry mill corn ethanol biorefinery and the farmland that serves it. The method we used relies on the directly measurable carbon flows associated with crop growth, refining and other production processes associated with both ethanol and gasoline, and the tailpipe ("end-use") CO_2 emitted when vehicles are driven.

Figure 4 is a schematic illustration of the items to be analyzed in a careful carbon balance. Notable, this analysis always includes carbon uptake on cropland, because it occurs whether or not the crops are used for fuel. As shown it also include process emissions, including any process-related CO_2 that comes from biomass itself (known as biogenic emissions), which for ethanol production includes the CO_2 released during fermentation. As also shown in the diagram, flows of fixed carbon (as opposed to CO_2) are exported across the fuel system boundary in the form of biomass products (corn, soybeans and other agricultural products or coproducts)

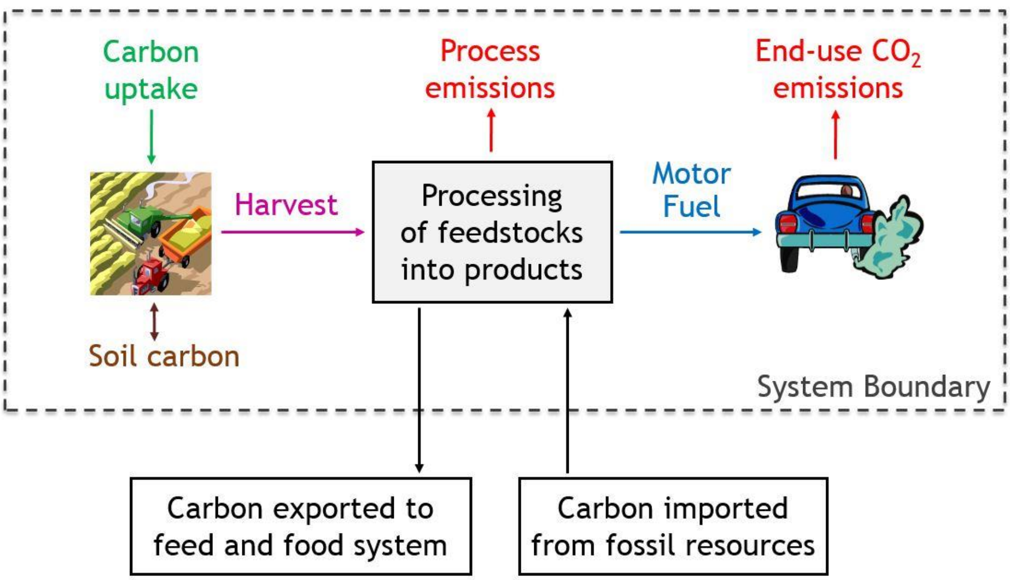

Figure 4. Schematic diagram for direct carbon balance analysis of motor fuel GHG impacts

and are imported across the system boundary from fossil resources such as crude oil. Changes in these external flows result in displacement effects, such as reduced corn and soybean consumption in the food and feed system, which is partly offset by coproducts such as distillers' grains, and petroleum that remains unused by motor vehicles but which can induce a rebound effect in fuel markets. However, these flows of fixed carbon do not result in CO_2 emissions to the atmosphere from the vehicle-fuel system itself, which is the subject of an analysis of the extent to which tailpipe CO_2 emissions are offset by CO_2 uptake on cropland.

Table 1 summarizes what we found, based on the detailed analysis documented in our recent report.[10] The first line gives the carbon uptake on land, shown as a negative emission and reflecting the downward flow of CO_2 from the atmosphere into growing biomass, including carbon removed in the harvest plus any gain in soil carbon [units are thousand metric tons (10^6 kg) of carbon mass per year, kt_c/yr]. The difference column shows the change in carbon uptake; it is negative because the rate of carbon removal from the atmosphere by the cropland went up from the baseline year to the ethanol production year. The main reason for this large gain in uptake is a shift from growing soybeans on nearly half the cropland serving the facility to growing all corn when ethanol was produced; corn yields are higher than soybean yields, which means that a corn field removes more CO_2 from the atmosphere than a soybean field. The second line gives process emissions, which are higher for ethanol production than for petroleum refining. These values are consistent with typical LCA estimates of the GHG emissions from feedstock and fuel processing, but for ethanol the ABC method also includes biogenic process emissions, notably the CO_2 released during fermentation. Vehicle tailpipe CO_2 emissions differ only slightly, with ethanol 2.2% lower than gasoline.

Table 1. Summary of direct annual basis carbon (ABC) flows for a unified vehicle-fuel system using gasoline in a baseline year and corn ethanol the following year

Carbon-equivalent mass flows, thousand metric tons per year (kt_c/yr)	$Year_0$ using gasoline	$Year_1$ using ethanol	$Year_1$ - $Year_0$ Difference
Carbon exchange on cropland	(119)	(189)	(70)
Process emissions	39	115	76
Vehicle emissions	89	87	(2)
Net emissions impact of the system	**10**	**14**	**4**
Biomass carbon exported from system	119	65	(53)

Source: combined pathway results from DeCicco & Krishnan (2015); note that 1 kt_C/yr = (12/44)kt_{CO2}/yr

Summing these values indicates that the net GHG emissions impact of the unified system (cropland, upstream and downstream processing and motor vehicles) is higher when ethanol is used than when gasoline is used. The difference is about 4 thousand metric tons of carbon per year (kt_c/yr), which in relative terms is 4.3% of the baseline 89 kt_c/yr end-use CO_2 emissions from gasoline use. This estimate is not a lifecycle ("well-to-wheels") CI metric, but simply the difference in direct GHG emissions from the circumscribed system of Figure 4 when using corn ethanol instead of gasoline. This increase in direct GHG emissions contradicts the previously published GREET analysis of the facility's first year of operation, which found a lifecycle CI for the corn ethanol that was 40% lower than that of gasoline.

The bottom row of Table 1 shows the changes in the rate at which carbon leaves the system in exported biomass. In the baseline year when gasoline is used, corn and soybeans are supplied to the external food system. When fuel ethanol is produced, only the coproducts are supplied to the food system. This large change in the supply of food-related biomass drives the displacement effects analyzed using the consequential modeling that has become part of LCA for fuels policy. For the case study examined here, the 53 kt_c/yr loss of biomass exports represents 45% of the baseline 119 kt_c/yr of exported biomass. Although not shown in the table, there is a reduction of 111 kt_c/yr of fossil carbon imported into the system as petroleum. Nevertheless, this reduction of fossil fuel use does not result in a direct reduction of CO_2 emissions because vehicle emissions do not significantly change.

This analysis highlights the critical importance of pre-existing CO_2 uptake on the land from which a biofuel feedstock is sourced. In the LCA methods used for the RFS, such baseline carbon uptake is automatically and fully credited against tailpipe CO_2 emissions, a modeling convention equivalent to assuming that uptake was zero before the feedstock was harvested for producing biofuel rather than for feed and food. But CO_2 uptake is never zero on productive land and is in fact substantial for existing cropland, the main source of biofuels produced at commercial scale. For the facility analyzed here, a gain in CO_2 uptake occurred because of the shift from growing soybeans to growing corn on nearly half the cropland serving the facility.

Corn-soy is the dominant crop rotation on U.S. farmland, but farms cannot permanently shift from soy to all corn, and so the case illustrated in Table 1 represents a best-case scenario for carbon uptake. We conducted a sensitivity analysis different baseline conditions for crop rotation and yield; those results are detailed in the aforementioned report. We found that a situation that just involves diverting corn from food and feed markets to the fuel market, and which does not credit a yield gain that would mostly likely have occurred anyway, resulted in an emissions increase of 61 kt_c/yr, implying that using corn ethanol would increase GHG emissions by nearly 70% compared to baseline tailpipe CO_2 emissions using gasoline. This can be considered an upper bound scenario, in contrast to the relatively insignificant 4 kt_c/yr emissions increase shown in Table 1, which can be considered a best-case scenario. The conclusion is that the change in direct CO_2 emissions when using corn ethanol instead of gasoline is insignificant at best, and it could make matters worse.

In other words, the biofuel carbon neutrality assumption built into LCA models does not hold up for real-world biofuel production. Direct accounting of actual carbon flows shows that, at best, corn ethanol production fails to reduce CO_2 emissions relative to petroleum gasoline, and even that result depends on the gain in cropland carbon uptake that occurs with a large shift from growing soybeans to growing corn. If the baseline land use was corn production, then the increase in GHG emissions due to ethanol production would be significantly higher. Finally, if consequential effects including ILUC were to be included, the result would be a yet even higher estimate of the adverse net GHG emissions impact of biofuel use.

Our next and still ongoing phase of research is doing a data-driven carbon balance analysis of the effect of the RFS nationwide since 2005. To perform this analysis, we are examining how carbon uptake changed on all U.S. cropland from 2005 through 2013, which was the year of most recently available complete data when we started the analysis.

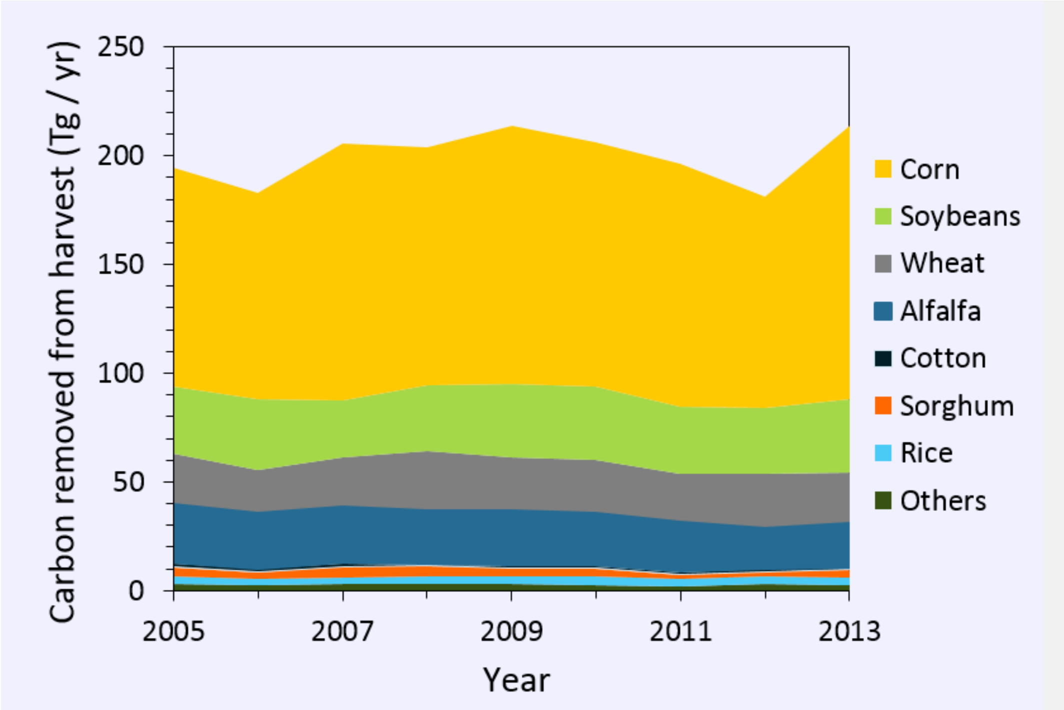

Figure 5. Rate of carbon uptake on U.S. cropland, 2005-2013.
Source: Derived from USDA Crop Production Summary data.

The preliminary results are shown in Figure 5, which shows the rate of CO_2 uptake on cropland in teragrams (10^{15}g) of carbon per year (TgC/yr), which is the same as millions of metric tons of carbon per year.[11] and we find that there The gain from 2005 to 2013 amounted to roughly 20 TgC/yr, indicating an increase of 10% in the net rate at which CO_2 flows downward from the atmosphere into vegetation growing on cropland. It reflects changes in harvested area, crop mix and yield. The estimated 20 TgC/yr gain in CO_2 uptake is essentially an upper bound on the potential offset of end-use CO_2 emissions that might be achieved when substituting biofuels derived from the cropland for fossil fuel products. The amount of this gain in uptake that can be reasonably attributed to the demand for grains created by the RFS is less than the total amount of carbon contained in the harvest supplied to biorefineries. That means that once processing and direct land-use change emissions are factored in, there is no significant reduction in net GHG emissions due to the use of the corn ethanol and soy biodiesel. Using EPA's estimates for indirect land-use change then pushes the total CO_2 impact to a much higher level, imply substantially higher cumulative CO_2 emissions overall.

Net CO_2 uptake on cropland (i.e., NEP) can be increased by using crop residues to make fuel, as now being pursued at a small scale through cellulosic ethanol production. NEP then increases because R decreases, e.g., by collecting corn stover that would otherwise decompose and thereby reducing the CO_2 emissions from cornfields after grain is harvested. In any case, it is necessary to do a careful, location-specific assessment of how NEP actually changes when biofuel feedstocks are produced; one cannot just assume (as lifecycle models now do) that the carbon in a harvest fully offsets CO_2 emissions during fuel combustion. Ecologically speaking, the extent to which one can safely "starve the decomposers" by harvesting residues is likely to be limited.

The implication is that, while it may be possible for biofuels to contribute to climate mitigation, the conditions under which they actually do so are much more restricted than is commonly assumed. Moreover, because any climate benefit hinges not on biofuel use per se, but rather on raising the net rate of CO_2 removal from the atmosphere, there are likely to be other ways to accomplish that task which are less costly and more ecologically sound.

OTHER ENVIRONMENTAL IMPACTS

Although my own studies have focused on the GHG emissions impacts of renewable fuel use, excess CO_2 emissions are not the only environmental harm caused by the RFS.

Other researchers at University of Michigan conducted a detailed, geographically explicitly assessment of how the cropland expansion related to the rising mandated demand for corn ethanol has destroyed habit for waterfowl and other wildlife.[12] Expanded corn production to meet the ethanol mandate is worsening water pollution, contributing to algae blooms and oxygen-starved zones in the Gulf of Mexico and Lake Erie.[13] Biofuel processing also releases other forms of air pollution; for example, recent research has found that the country’s third largest corn ethanol refinery emits 30 times more air pollution than was assumed for the RFS regulatory analysis.[14] Ethanol's corrosive properties are also incompatible with many cars already on the road and degrade the operation of lawn mowers, motor boats and other gasoline-powered equipment used by homeowners and businesses alike.

CONCLUSION

My studies identify the flaws in the lifecycle modeling done for the RFS, and I have shared these findings with EPA and other agencies. The recently announced EPA Inspector General investigation of the RFS lifecycle analysis is a promising step that will hopefully shed further light on these issues. Nevertheless, my research indicates that the RFS has been harmful to the environment to date. The program has resulted in higher cumulative CO_2 emissions than otherwise would have occurred and has also damaged the environment in many other ways. In summary, careful scientific analysis indicates that the lifecycle studies used to justify the RFS were flawed. A correct carbon accounting reveals that the production and use of corn ethanol mandated by the policy has increased CO_2 emissions to date.

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[1] Wang (1999).

[2] EPA (2009), RFS2 NPRM, Federal Register 74(99), p. 25040.

[3] CARB (2010).

[4] For example, Wang et al. (2007, 2011, 2012).

[5] BIO (2015).

[6] DeCicco (2013).

[7] Lovett et al (2006).

[8] The assumptions for this calculation are that a bushel of corn weighs 56 pounds; that its moisture content is 14% and that its carbon content is 42.1% of the dry mass.

[9] For soybeans, the parameters are a weight of 60 lbs/bu, 12.5% moisture and 42.6% carbon.

[10] DeCicco & Krishnan (2015).

[11] Unless otherwise noted, values are reported on a carbon rather than CO_2 mass basis, where $C:CO_2 = 12:44$; this includes CO_2 equivalences of other GHGs as weighted by 100-year global warming potential.

[12] Brooke et al (2010).

[13] Cho (2011).

[14] de Gouw et al (2015).

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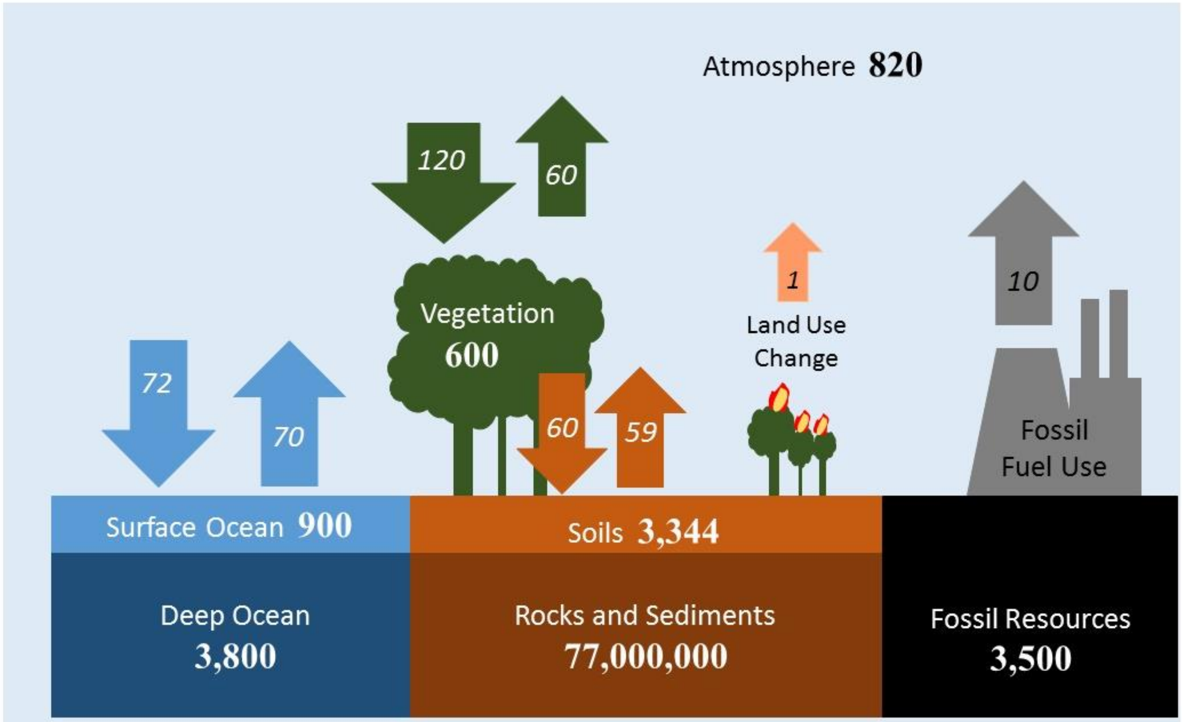

Stocks in petagrams (10^{15}g) of carbon (PgC) in **bold serif**, flows in PgC/year in *italic sans serif*
Sources: Churkina (2013) as updated by GCP (2015); illustration by Angelika Kurthen

Figure A-1. Major stocks and flows of the global carbon cycle.