Discussion Paper

A Comparison of Corn Ethanol Lifecycle Analyses: California Low Carbon Fuels Standard (LCFS) Versus Renewable Fuels Standard (RFS2)

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For:
Renewable Fuels Association
and
Nebraska Corn Board

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Note on this Report

The purpose of this report is to provide an independent view of some of the major differences between recent U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) estimates of the lifecycle greenhouse gas (GHG) emissions associated with corn ethanol production and use. Estimating these lifecycle emissions is complex, and because EPA and CARB used considerably different approaches, we were not able to compare every difference in a consistent manner.

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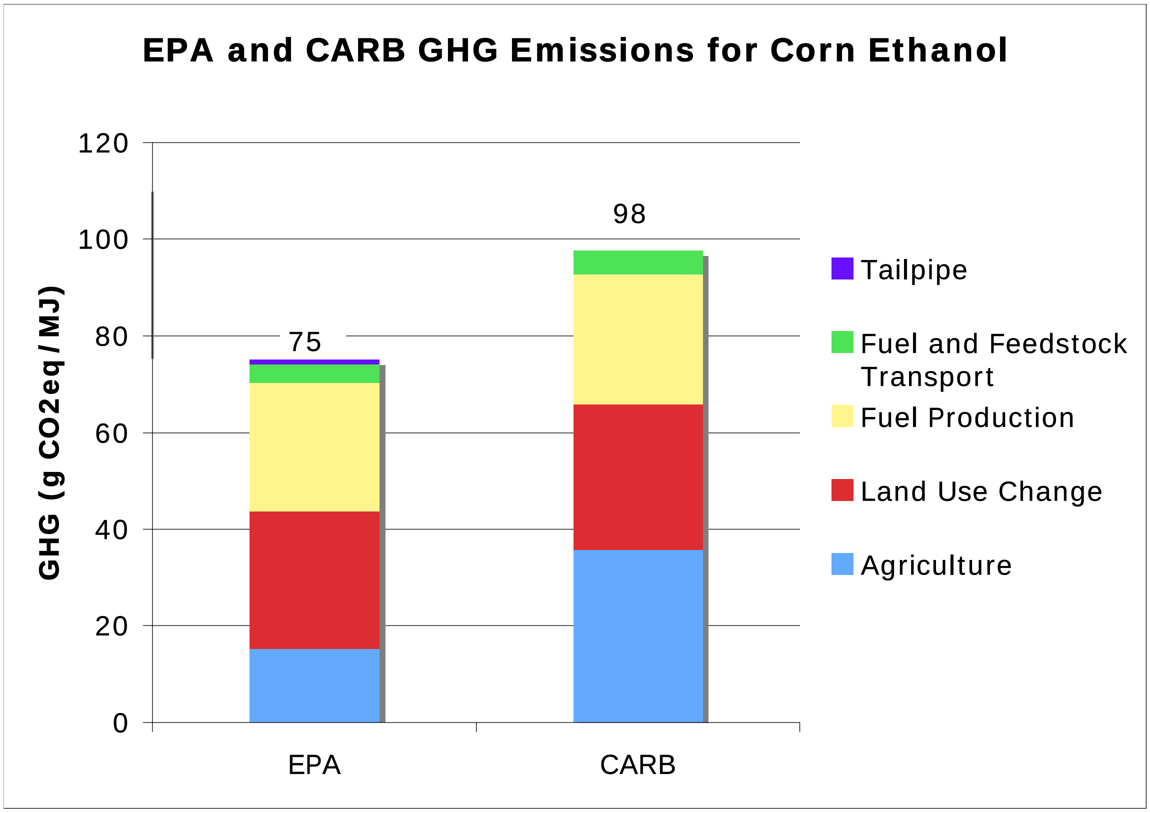
Differences in CARB and EPA Lifecycle Modeling for Corn Ethanol

1.0 Summary

In early 2009, CARB released its estimates of the carbon intensity (CI) of corn ethanol, including emissions from land use changes (LUC). The agency's analysis was described in the Initial Statement of Reasons for the Low Carbon Fuel Standard (LCFS) (March 2009), as well as a California GREET model corn ethanol report (February 2009). In February 2010, EPA released its final estimates of the carbon intensity of corn ethanol, including emissions from LUC, with their Renewable Fuel Standard (RFS2) final rule. A comparison of these two estimates for corn ethanol is shown in the figure below.

CARB estimates that gasoline has a carbon intensity of about 96 grams of CO2-equivalents per mega-joule of energy delivered (g/MJ), so most corn ethanol, which is estimated to have a carbon intensity of 98 g/MJ, has no GHG benefit relative to gasoline in the CARB analysis. EPA uses a value of 93 g/MJ for gasoline in the RFS2 analysis. Thus corn ethanol, with its estimated carbon intensity of 75 g/MJ, has a 20% GHG benefit relative to EPA's baseline gasoline in the EPA analysis.



The largest differences between the two estimates are related to emissions from agriculture and fuel production. The LUC emissions estimates appear to be similar, but the modeling systems, methods, and data inputs are very different between the two estimates. The similarity in the magnitude of LUC emissions between the two analyses appears to be mostly a coincidence.

EPA’s estimates of agriculture emissions are lower than CARB’s due to two primary reasons:

- EPA’s estimates are based on the FASOM model, while CARB’s estimates are based on modifications CARB made to the Argonne GREET model for corn. The FASOM model assumes a lower fertilizer input than GREET for corn.

- EPA’s system boundaries for agriculture are much different than CARB’s. EPA evaluates the changes in *net* agriculture emissions, where CARB only evaluates emissions from agriculture inputs to corn. EPA broadly evaluates the entire global agriculture system’s response to increases in corn use for ethanol. For example, FASOM estimates that increasing corn ethanol will reduce U.S. rice and livestock production, leading to methane emissions reductions.

EPA’s fuel production emissions are lower than CARB’s for the following reasons:

- EPA estimates emissions for the biorefinery in calendar year 2022 with expected efficiency improvements, where CARB estimates emissions for the biorefinery based on current GREET model defaults, which are meant to reflect recent practices.

- The primary biorefineries being compared are somewhat different. In the final rule, EPA’s biorefinery assumes 37% of the distillers’ grains (DG) output will not be dried and 63% of the distillers’ grains will require drying. EPA also assumes 90% of the biorefineries will separate corn oil from the DG or fractionate the corn germ. In the CARB GREET model documentation, CARB’s primary values are for a biorefinery in the Midwest with 100% dry distiller grains, and CARB assumes corn oil is not separated from distillers’ grains.

As indicated earlier, the land use emissions values from both analyses appear to be similar. However, the modeling systems, modeling inputs, and data used are quite dissimilar. Thus, this apparent alignment is mostly a coincidence, and to make improvements in land use modeling, these differences need to be clearly understood. For example, the EPA modeling predicts that most (75%) of the LUC emissions will take place in Brazil, whereas the CARB modeling estimates that the LUC emissions will be approximately equally divided between the US and the rest of the world (ROW) with only 4% occurring in Brazil. This is shown further in the table below. CARB estimates only 1.3 g/MJ of land use emissions occur in Brazil, while EPA estimates 21 g/MJ. They both estimate similar emissions in the rest of the world outside of the U.S. and Brazil. But for the U.S., CARB estimates 17.8 g/MJ of LUC emissions and EPA estimates -2 g/MJ.

Land Use Change GHG Emissions for Corn Ethanol (g/MJ)		
Location	CARB	EPA
Brazil	1.3	21
ROW, non-U.S.	10.9	9
U.S.	17.8	-2
Total International	30	28

Clearly more work needs to be done to better understand how these two modeling systems and approaches can estimate such different results for the U.S., Brazil, and the rest of the world, before much credence is placed in these estimates from the two agencies.

Furthermore, the land use values being developed by researchers are in a constant state of flux. A paper by Searchinger and others originally estimated the corn ethanol LUC impact at 103 g/MJ. For the final LCFS rule, CARB estimated 30 g/MJ for the average of seven scenarios. For the Renewable Fuel Standard proposed rule, EPA estimated 63 g/MJ. For the final rule, EPA estimated LUC emissions at 28 g/MJ. Finally, a recent paper by Purdue researchers utilizing an improved version of the GTAP model estimates a value of 14 g/MJ. The latest Purdue results are for a scenario that projects 1% crop yield growth to 2015 as well as growth in the demand for food between 2007 and 2015.

2.0 Introduction

CARB released its estimates of the carbon intensity of corn ethanol, including LUCs, with the most recent version of the California GREET model for corn ethanol, and the Initial Statement of Reasons for the Low Carbon Fuel Standard (LCFS). [1,2] EPA released its final estimates of the carbon intensity of corn ethanol, including LUCs, with their final Renewable Fuel Standard rule, or RFS2. [3,4] A comparison of these two estimates for corn ethanol is shown in Table 1.[1] CARB's estimates are in g/MJ of ethanol, and EPA's are in kg CO_2eq/mmBTU of ethanol, so we have converted the latter into the former units by multiplying by the former by the appropriate conversion factor of 0.95.

Table 1. Comparison of EPA and CARB Carbon Intensities for Corn Ethanol

Parameter	EPA (Kg/mmBTU)	EPA (g/MJ)	CARB (g/MJ)
Agriculture (domestic and international, including chemicals), and including co-product credit	16	15	24
Land use change (domestic and international)	30	28	30
Fuel Production	28	27	38
Fuel and feedstock transport	4	4	5
Tailpipe	1	1	0
Total	79	75	97

The comparison shows that EPA's estimates for corn ethanol emissions by lifecycle phase are much lower (38%) than CARB's estimate for agriculture emissions; about the same as CARB's estimate for LUC emissions; much lower (29%) than CARB's estimate for fuel production emissions; and nearly equal to CARB's estimates for fuel and feedstock transport. Tailpipe emissions are small, but different. Overall, compared to CARB's estimate of gasoline at 96 g/MJ, the CARB estimate for corn ethanol shows no benefit relative to gasoline, and the EPA estimate shows about a 22% benefit relative to gasoline.

EPA and CARB used quite different methods and assumptions to arrive at these estimates. The purpose of this paper is to describe the differences for each parameter.

One of the most uncertain aspects of these estimates is the LUC emissions, where EPA estimates 28 g/MJ, and CARB 30 g/MJ. The two agencies used very different models to make these estimates. At first glance it would seem that if

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[1] The CARB numbers for fuel production come from the February 27, 2009 GREET Corn Ethanol report, and the EPA fuel production numbers are from the Final Rule. The plants assumed in both cases are not the same – the CARB plant is a 2010 natural gas plant with 100% dried DGs and no corn oil separation, and the EPA assumption is a 2022 natural gas plant with 37% wet DGs/63% dry DGs and 90% corn oil separation.

both agencies arrived at approximately the same LUC estimates using two different models, that the results confirm each other. However, not only are the models very different, but the key inputs to the models are very different. If the same basic inputs were used with the two different models, and they achieved similar result, then we would agree that the results could be said to confirm each other. But that is not the case. Very different inputs and boundary conditions were used with the two different modeling systems. Thus, we conclude that it is simply a coincidence that these two estimates are close to one another, and the fact that they are close does not indicate any kind of “convergence” of the estimates. This is discussed in more detail later in the paper.

This paper is divided into the following sections:

- Agriculture
- Land use change
- Fuel Production

For the purposes of this report, we are ignoring fuel and feedstock transport and tailpipe emissions because of the small differences between the two agencies’ estimates.

3.0 Agriculture

3.1 Boundary Conditions

One of the reasons that CARB and EPA estimate different values for agriculture emissions is because of the difference in setting boundary conditions. CARB uses the GREET model to estimate agriculture emissions. This model estimates all of the inputs needed for planting and farming corn, such as gasoline, diesel fuel, electricity, natural gas, seed, fertilizer, and herbicide/pesticide. This model does not consider changes in other agricultural or livestock systems brought about by an expansion of corn ethanol. For example, if corn ethanol is expanded, some economic models predict an increase in corn price and acreage, and a resultant reduction in rice production. Rice production emits a significant amount of methane, so the reduction in rice production can lead to a reduction in rice methane, which mitigates some of the agriculture emissions attributed to expanded corn production

EPA draws a large boundary around the entire agriculture system, both nationally and internationally, and examines "net" changes in CO_2, methane, and N_2O due to a certain volume expansion of corn ethanol. EPA uses the FASOM model domestically, and the FAPRI/CARD modeling system internationally, to estimate agriculture emissions.

3.2 CARB Agriculture Emissions Estimate Based on GREET

CARB's estimates for agriculture emissions are itemized in Table 2.

Table 2. CARB's Estimates for CI of Agriculture for Corn Ethanol

Item	Dry Mill (g/MJ)
Corn farming	5.7
Ag Chemicals	30.2
Co-product credit (Distillers grains) from ethanol plant	-11.5
Total agriculture	24.4

Agriculture includes corn farming, agriculture chemicals, and the co-product energy credit from distillers grain from the ethanol plant. Corn farming includes the energy used to farm corn, including the energy in producing seed. Agriculture chemicals include the energy used to produce fertilizer, emissions from fertilizer after applied, and the energy input into herbicides and pesticides.

In CARB's analysis, there is a single co-product from the corn ethanol process and that is distillers grains, or DGs. CARB did not separately estimate any possible co-product credit associated with corn oil, which can be separated from the distillers grains through fractionation or extraction (EPA, however, does take this factor into account, and this will be discussed presently).

In the CA-GREET Corn Ethanol report, California does not group the co-product credit with agriculture, but the fact that they do not is a matter of form and not substance. EPA includes the co-product credits for distillers' grains and corn oil with agriculture, and we have done so for our discussion of the California analysis as well to promote an equivalent comparison (the co-product credit cannot easily be "backed out" of the EPA estimates). As EPA states in its Regulatory Impact Analysis:

> …in traditional lifecycle analyses, the energy consumed and emissions generated by a renewable fuel plant must be allocated not only to the renewable, but also to each of the byproducts. However, for corn ethanol production, this analysis accounts for the DGs and other co-products used directly in the FASOM and FAPRI-CARD agriculture sector modeling described above. DGs are considered a partial replacement for corn and other animal feed and thus reduce the need to make up for the corn production that went into ethanol production. Since FASOM takes the production and use of DGs into account, no further allocation was needed at the ethanol plant.

The CARB co-product credit (for DGs) of 11.5 g/MJ is developed by determining the total energy inputs needed to produce the amount of corn that is replaced by the DG co-product. In this analysis, CARB assumed that 1 lb of DGs replaces exactly 1 lb of corn meal, for all livestock types.

The largest component of the agriculture emissions in CARB's analysis is agriculture chemicals, at 30 g/MJ. Table 3 shows the different components of this category for a dry mill.

Table 3. Components of CARB's Agriculture Chemical Emissions

Fertilizers	10.3 (34% of total)
Herbicide	0.8
Pesticide	0.08
Soil N_2O	15.9 (53% of total)
CO_2 from lime	2.4
CO_2 from urea	0.6
VOC and CO (CO_2 eq)	0.06
Total	30 (rounded)

Source: Table B of CARB GREET Corn Ethanol Report

Table 3 shows that the energy input to fertilizers and soil N_2O emissions make up 87% of the total emissions from agriculture chemical emissions. All of the soil N_2O emissions are from the nitrogen component in the fertilizer. GREET assumes a 420 g/bu nitrogen fertilizer input, and 1.3% of the nitrogen is converted to N_2O.

3.3 EPA Estimate Based on FASOM and FAPRI/CARD

As stated in section 3.1, since EPA has large boundary conditions for agriculture emissions, EPA evaluates the net change in agriculture emissions both domestically and internationally. The values are shown in Table 4, along with the total agriculture emissions.

Table 4. EPA's Estimates of Net Agriculture Emissions for Corn Ethanol

Agriculture type	Carbon intensity (g/MJ)
Net domestic agriculture (from FASOM)	4
Net international agriculture (from FAPRI/CARD)	11.5
Total net agriculture	15.5

Source: Net domestic and international agriculture are from Table V.C-1 of the FRM. Note: Table 2.4-13 of the Final RIA lists a value of 10 g/MJ for domestic agriculture. For this report we are assuming the value of 4 g/MJ in the FRM document is the correct value. EPA has confirmed the 4 g/MJ value.

EPA estimated these emissions by first running a Control Case that assumed 15 bgy of corn ethanol, and other volumes for cellulosic ethanol and biodiesel. This was compared to a Corn Only case in which the only change was a lower corn ethanol value of 12.3 bgy. Hence the change in emissions between the two cases could be attributed solely to the 2.7 bgy of corn ethanol.

There are three basic components to domestic agriculture emissions, as follows:

- Farm inputs (fuels, fertilizer, herbicides, from all crops)
- Livestock (manure and enteric fermentation)
- Rice methane

The estimates of these three categories of domestic agriculture emissions are shown in Table 5. There is an increase in the farm inputs category, but a decrease in livestock emissions due to a smaller livestock herd, and improved emissions per head due to the use of distillers' grains from ethanol plants. There is also a small reduction in rice methane emissions.

Table 5. EPA Net Domestic Agriculture Emission Changes

Source	Value (g/MJ)
Farm Inputs	9.8
Livestock (manure and enteric fermentation)	-3.5
Rice methane	-0.2
Total	6.1

Source: Table 2.4-13 of Final RIA, converted to g/MJ. For net domestic agriculture, this table is inconsistent with the FRM.

For nitrogen application to cornfields in the U.S., EPA assumes 105 lbs per acre. With a 2022 corn yield of 180 bu/acre, this works out to 260 g/bu, significantly lower than the nitrogen application rate assumed in GREET of 420 g/bu. [2] [5] EPA used the DAYCENT/CENTURY model to estimate N_2O conversion. N_2O conversion was estimated as a function of region, crop, irrigation status, and crop residue treatment.

EPA's estimate of co-product credits for DGs and corn oil separated from the DGs are also included in the farm inputs. The farm inputs are less than they would be if the co-product credits were not included, because some animal feed is being replaced by DGs, and some food-grade vegetable oil and biodiesel is being replaced with corn oil extracted from the DGs. EPA's assumptions of co-product credits are different than CARB's, and are consistent with Argonne's analysis, and are shown in Table 6. [5,6]

Table 6. Co-product Credits Used in FASOM and FAPRI/CARD Modeling Based (per 1 lb of DGS)

Livestock Type	Corn,(lbs)	Soybean Meal, (lbs)	Total, (lbs)
Cattle – beef	1.196	0	1.196
Cattle – dairy	0.731	0.633	1.364
Swine	0.89	0.110	1.000
Poultry	0.79	0.21	1.000

Source: Final FAPRI Report

As noted in table 6, the co-product credits for beef and dairy cattle are higher than for the CARB case where 1 lb of DGs is assumed to replace 1 lb of corn. In addition, in the EPA analysis, DGs are replacing some soybean meal for all species except beef, which will have a different credit per unit mass than corn.

EPA is estimating that in 2022, 90% of dry mill plants will use either fractionation (20%) or extraction (70%) to remove corn oil from DGs. The fractionation process produces food-grade corn oil, and the extraction process produces non food-grade corn oil that can be used as a biodiesel feedstock or livestock and poultry feed additive. The fractionation process is assumed to produce 0.144 gal corn oil/bu, and extraction is assumed to produce 0.193 gal corn oil/bu. Oil produced by these processes replaces corn and soybean oil, which brings about reductions in domestic agricultural inputs in FASOM. There are similar inputs for international agriculture emissions, as shown in Table 7.

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[2] Current corn yields are closer to 160-165 bu/acre, and if this value were used instead of 180 bu/acre, the per bushel nitrogen rate would be 292, which is a little closer to 420 g/bu, but still significantly less.

Table 7. International Agriculture Emission Changes

Source	Value (g/MJ)
Farm Inputs	6.3
Livestock (manure and enteric fermentation)	3.2
Rice methane	2.0
Total	11.5

Source: Table 2.4-25 of Final RIA.

The emissions from international farm inputs are lower than domestic farm inputs, while the livestock and rice methane emissions are considerably higher. If we add domestic and international agriculture together, the farm inputs become 16.1 g/MJ, the livestock becomes -0.2 g/MJ, and rice methane becomes 1.8 g/MJ, for a total of 18 g/MJ.

3.4 Comparing CARB and EPA Agriculture Estimates

CARB’s estimate of agriculture emissions is 60% more than the EPA value – 24 g/MJ versus 15 g/MJ. In the EPA case, adding livestock and rice methane effects has little impact on the overall comparison, since the addition of these components both domestically and internationally adds 1.6 g/MJ to the basic overall farm inputs on a net basis and brings them closer together rather than further apart. Therefore, we conclude that the major difference between the EPA and CARB estimates are due to differences in overall farm inputs such as energy, nitrogen fertilizer application rates, and the estimated conversion rate of nitrogen to N_2O, and co-product credits. It is difficult to determine which factor is most important without examining each of the EPA final spreadsheets. In addition, it must be remembered that EPA is evaluating the net difference for all agriculture products due to an increase in ethanol, whereas CARB is only evaluating the corn inputs. Overall, the EPA methodology appears to be much more comprehensive than the CARB methodology.

4.0 Land Use Changes

The land use comparison between CARB and EPA for corn ethanol is shown in Table 8.

Table 8. Land Use Change Emissions Comparison (g/MJ)
30 Year average emissions, undiscounted

	Domestic	International	Total
CARB	18	12	30*
EPA	-2	30	28

*Average of 7 scenarios. The domestic versus international split was estimated by AIR from detailed GTAP6 output, where AIR replicated CARB's 7 scenarios. The source for the EPA values is the Final RIA.

While the total values may be close (28 g/MJ versus 30 g/MJ), the LUC emissions reflect very different emissions domestically and internationally. For example, the domestic LUC emissions in the EPA analysis are -2 g/MJ (implying that domestic LUC results in a net GHG reduction) and the international LUC emissions contribute 30 g/MJ. For CARB, the LUC emissions are higher domestically than internationally. Clearly, there are some major differences in how domestic and international LUCs are estimated, and these should be clearly understood.

Table 9 contains a comparison between the CARB and EPA analyses of the estimated land converted (from pasture or forest, or other non-crop uses to crops), and a comparison of the land converted normalized by ethanol volume increase (ROW = rest of world).

Table 9. Comparison of Land Converted

Source	Location	Amount (million acres)	Ethanol volume increase (billion gallons)	Acres converted/1000 gal ethanol
CARB	U.S.	3.85	13.25	
	ROW	5.75		
	Total	9.61		0.7
EPA	U.S.	1.40	2.7	
	ROW	1.94		
	Total	3.34		1.2

Sources: CARB values are from Table IV-10 of LCFS Initial Statement of Reasons, EPA from Final RIA.

The CARB modeling scenario assumed an increase in ethanol of 13.25 bgy, from 2001 to 2015. The EPA modeling scenario evaluated the difference between a Reference Case with no RFS2 and a Control Case (with RFS2) in calendar year

2022, so the amount of this increase in corn ethanol was 2.7 bgy. The acres converted per 1000 gals of ethanol for the EPA case is 71% higher than for the CARB modeling. So, while the numbers are similar in Table 8, the land use values shown in Table 9 are not similar. Table 10 shows the divergence in the two agencies' estimates for Brazil.

Table 10. International LUC for Corn Ethanol (g/MJ)

Location	CARB	EPA
Brazil	1.3	21
ROW, non-U.S.	10.9	9
Total International	12.2	30

Sources: CARB estimates are from AIR's replication runs using GTAP6 of the CARB 7 scenarios. EPA values are from Figure 2.4-41 in the Final RIA.

There are many differences between these two estimates, which are discussed in this section. The section is divided into the following subsections:

- Overview of Scenarios and Modeling Systems Used
- Models Used
- Elasticity inputs
- DG land use credits
- Carbon emission factors
- Carbon sequestration in wood products
- Does the Similarity in the Land Use Values Indicate Convergence?

4.1 Overview of Scenarios and Modeling Systems

CARB used the Purdue Global Trade Analysis Project Model (GTAP) with a 2001 database, and simulated an increase in corn ethanol from 1.75 billion gallons per year in 2001 to 15 bgy, for a total increase of 13.25 bgy. The GTAP model as configured estimates the amount of land converted by country, the type of land converted to crops in each country (forest or pasture), and also produces total emissions estimates by country, which it then aggregates to obtain a total emissions impact. In other words, the model produces the final result in g/MJ of fuel.

In EPA's simulations, the Forest and Agricultural Sector Optimization Model (FASOM) model is used to determine domestic agriculture and LUC emissions, and the Food and Agriculture Research Institute (FAPRI) model is used to estimate international LUC amounts. EPA then takes the international LUC amounts by country and utilizes satellite data from 2001 to 2007 to determine what type of land would be converted by 2022, and the emissions released from that conversion. EPA ran a Reference Case without the RFS2, and then ran a Control Case that included the RFS2 volumes. The net increase in corn ethanol volume between the two cases was 2.7 bgy.

A summary comparison of modeling approaches is shown in Table 11.

Table 11. Comparison of CARB and EPA Land Use Modeling

Source	Shock (billion gallons)	Baseline Future Projection?	Location	Model Used	Method/Model Used to Determine Land Types Converted	Emissions by Land Type
CARB	13.25	No – shock is implemented with 2001 database.	Domestic and International	GTAP6	GTAP6	Woods Hole for above and below ground
EPA	2.7	Yes – called Reference Case	Domestic	FASOM	FASOM	CENTURY for below ground, FASOM estimates above ground
			International	FAPRI	Satellite data of land transitions from 2001 to 2007	Winrock for above and below ground

As noted in the table, the ethanol increases, or “shocks” being modeled (“shock” is the term applied to the process of increasing a biofuel demand in one of the models), are very different – 13.25 bgy versus 2.7 bgy, which results in very different total emissions. However, both agencies normalize the emissions to the volume of the shock, so the emission values in g/MJ are comparable. The CARB analysis does not include a baseline projection without ethanol or without an LCFS policy in place. The GTAP model simply starts with a 2001 database, and the system is shocked with 13.25 bgy of ethanol and the model decides how much land is needed to accommodate the volume increase, as well as where and what type of land needs to be converted. The 13.25 bgy shock is derived from the difference in the expected 2015 corn ethanol volume of 15 bgy and the 2001 historical volume of 1.75 bgy.

The GTAP model does not try to predict the changes in overall global economic conditions between 2001 and 2015. For example, the model as run by CARB was not adjusted for overall corn demand increases or oil price changes between 2001 and 2015. As such, the model is merely answering the question: “Given all the economic conditions that exist in 2001, if the ethanol volume were ramped up by 13.25 bgy in that one year, how much land would be needed, where is it, and what type is it?”

EPA's 2.7 bgy increase comes from a comparison of ethanol demand in 2022 *without* the RFS2 to ethanol demand in 2022 *with* the RFS2. EPA predicts that ethanol from corn without RFS2 would be at 12.3 bgy, and at 15 bgy in 2022 with RFS2. Therefore, this modeling system does utilize a baseline projection to 2022 without the RFS2, and determines the incremental land needed to meet RFS2 in 2022. Changes in the global economy between 2010 and 2022 are taken into account (for example, projections of oil prices, and the increase in demand for non-ethanol uses of corn).

GTAP6 is used for both domestic and international LUCs in the CARB analysis, but the EPA analysis uses two different models – FASOM and FAPRI. The use of one model only in the CARB analysis has some distinct advantages due to the model being internally consistent for the entire world (even though it may have other drawbacks). EPA attempted to use similar inputs and elasticities for both FASOM and FAPRI, but the two models are not integrated with each other, so there is a limit to how much consistency can be achieved between the two models. For example, with the same shock of 2.7 bgy, the two models predict a different effect on U.S. exports and commodity prices. These are key drivers of international LUCs; so this begs the question of which model represents the U.S. the best? Apparently EPA believes FASOM does, but if that were so, then FAPRI should use the same estimates for the impacts on exports and prices as are outputted from FASOM. But that was not what was done in the EPA analysis. Both models were allowed to arrive at different price and export impacts. So the key drivers of LUCs were not made consistent between the two models, most likely because this is very difficult to accomplish when the models are not integrated.[3]

GTAP6 was used in the CARB analysis to select the different land types that are converted in different countries. FASOM did the same thing in the U.S. for the EPA analysis, but FAPRI is not designed to select land types by country for the international component of EPA's analysis. As indicated earlier, EPA examined satellite data on LUCs between 2001 and 2007 (for all reasons, not just biofuels expansion), and assumed that the pattern that existed from 2001 to 2007 would be the same for its 2.7 bgy incremental shock in 2022. CARB used the Woods Hole data on emissions for land clearing for both the U.S. and outside the U.S., while EPA used the CENTURY model results (which are integrated in FASOM) for the U.S., and Winrock's analysis of emissions for countries outside of the U.S.

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[3] The draft RIA contained a comparison of FASOM and FAPRI's predictions of corn ethanol impacts on grain prices and exports. FAPRI showed a greater impact on exports than FASOM, and a greater increase in corn prices than FASOM. For example, FASOM predicted that the increase in ethanol would increase the price of corn by $0.15/bu, and soybeans by $0.29//bu. FAPRI predicted the price of corn would increase by $0.22 per bushel, and soybeans by $0.42/bu. The FAPRI price increases, on which the international land use changes are based, were ~45% higher than FASOM, which would lead to a significant overestimate of international land use changes. EPA did not include this comparison in the final rule,.

It is clear that there are many differences between these modeling approaches, and that not all of the assumptions used in these modeling approaches are equally valid or invalid. The following sections expand on some of the elements of both approaches.

4.2 Models Used

Two very different economic modeling systems are used by the two agencies. CARB used Purdue's GTAP model, while EPA used a combination of the FASOM model for the U.S. LUCs, and the Food and Agriculture Research Institute FAPRI-CARD model for international LUCs.

4.2.1 GTAP

The GTAP is a computable general equilibrium (CGE) model developed and supported by researchers at Purdue University. Within the GTAP's scope are 111 world regions, some of which consist of single countries, while others are comprised of multiple neighboring countries. Each region contains data tables that describe every national economy in that region, as well as all significant intra- and inter-regional trade
relationships. GTAP has been extended for use in land-use change modeling by adding land use data on 18 worldwide agro-ecological zones, a carbon emissions factor table, and a co-products table. It adjusts GHG emission impacts based on the market displacement effects of co-products such as the dried distillers' grains. Predicted LUC impacts are aggregated by affected land use type (forest, and pasture). The model not only predicts the amount of land converted and what type (pasture or forest), it also predicts the location of the land.

Further details on the application of the GTAP model to biofuels is contained in a number of GTAP working papers. [7, 8, 9, 10] This is not a complete list of GTAP references for biofuels.

The database for the GTAP model employed by CARB uses 2001 global economic data. The model is shocked with a 13.25 bgy ethanol expansion to represent the ethanol expansion from 2001 to 2015, and the model determines the amount of land converted in major countries and the type of land converted in these countries (forest or pasture). The model then estimates the CO2 emissions resulting from these land conversions based on the "Woods Hole" emission rates for converting land (more on this in section 4.4).

GTAP includes a number of elasticities that can be modified by the user. Two of the most important elasticities are the price-yield elasticity and the elasticity of crop yields with respect to area expansion. The price-yield elasticity determines how much the crop yield will increase in response to a price increase for the crop. If the price yield elasticity is 0.25, then a 1% increase in price results in a 0.25% increase in yield. In estimating land use emissions for corn ethanol, CARB conducted GTAP runs with a range of price yield elasticities from 0.2 to 0.4, with a mean of 0.32.

The elasticity of crop yields with respect to area expansion expresses the yields that will be realized from newly converted lands relative to yields on acreage previously devoted to that crop. CARB assumed that all of the land that is well-suited to crop production has already been converted to agricultural uses, so yields on newly converted lands are almost always lower than corresponding yields on existing crop lands. If this elasticity is 0.5, this means that newly converted land is only 50% as productive as existing land. The lower the value of this parameter used in the model, the more land is converted. CARB varied this parameter from 0.5 to 0.75, with a mean of 0.59.

While GTAP includes a price-yield elasticity factor, it cannot endogenously take into account other significant technological drivers of corn yield, for example, improved seed technology. For the purposes of the CARB analysis, GTAP researchers suggested that trends in yield growth be taken into account exogenously. The method they used first estimated the percent increase in yield during a given time period. From this percent increase in yield, they estimated the reduction in area due to yield growth, and applied that reduction only to the net land used for producing ethanol. Yield improvements occurring on land not used for ethanol are assumed to be fully utilized by feed demand (or other non-ethanol demand) increases. For example, a 20% increase in yield causes a slightly smaller (17%) reduction in land area.[4] If the model predicts that ethanol expansion from 2001 to 2015 causes the conversion of 5 million acres of land, then the adjusted amount of land converted with the yield improvement would be 17% less, or 4.2 million acres. If yields increase faster than feed demand, then this method will over-predict the land converted. Conversely, if yields increase slower than feed demand, the method will under-predict the land converted.

GTAP also accounts for some market-mediated impacts. For example, when the model is shocked for an increase in corn ethanol, corn and other crop prices increase. The increase in prices leads to a small reduction in demand for these crops, and an increase in livestock prices and a reduction in meat consumption as well.

The GTAP model also accounts for the impact that distillers' grains (DGs) from ethanol plants have on reducing the need for animal feed, and therefore land use. Section 3 discussed the impact of DGs on reducing agricultural inputs, but DGs also have land use credits, and accounting for these land use credits does not amount to "double counting" the benefits of DGs. Both land and energy inputs to land are used to produce corn (animal feed). Therefore, it stands to reason that if DGs replace animal feed, there will be credits to both land and inputs to land for utilizing DGs. DGs assumptions are discussed in more detail in the next section.

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[4] The reduction in area for a 20% increase is estimated as (1-1/1.2)*100

GTAP likely results in more accurate assessments when the projection year (or projection ethanol volume) is close to the base year, or 2001. But CARB uses the model to project land use over a 14-year period from the base year of 2001 to 2015. Undoubtedly, the model loses accuracy over a long period of time such as this, because many things can change. GTAP researchers see this as a net positive, because they believe trying to predict many other items that have an effect on land use such as currency value changes, economic growth, oil prices, and so on, would confuse the results. Others think this is a significant limitation.

The GTAP version employed by CARB includes cropland, forest, and pasture for each country in its land database. The forest included is commercial forest, not unmanaged forest. The version of GTAP used for the LCFS does not contain Conservation Reserve Program (CRP) land in its U.S. land inventory. Currently there are about 33 million acres enrolled in this program. The GTAP model also does not include a separate category of “idle cropland” in the U.S., i.e. cropland that is currently unused. Not including idle lands is very problematic and results in overestimating land use effects, because these are the first lands that would be used to expand production, rather than converting pasture or forest.

Recently researchers from Purdue University completed a study of land use attributed to corn ethanol for Argonne National Laboratory. [11] This study addressed a number of concerns that have been raised with estimating land use emissions using GTAP. For example, procedures were developed for utilizing the model to produce a better dynamic estimate of LUC over the period from 2001 to 2015. These procedures incorporated expected yield improvements and demand increases *inside the model*. The modeling also assumed that, because the forestlands contained in the model are managed (i.e., commercial) forests, 25% of forest carbon would be sequestered in building products or in landfills. Further, two new categories of land were added to the model – cropland/pasture and CRP land. Assuming actual crop yield growth between 2001 and 2006, and further assuming a 1% growth in crop yields between 2006 and 2015 (with demand increases), the LUC emissions estimated for corn ethanol were 14-15 g/MJ, about one-half of the value estimated by CARB for the LCFS. This recent work illustrates that the LUC estimates for corn ethanol are still changing dramatically as models are improved and new information becomes available.

4.2.2 FASOM and FAPRI-CARD

The two models used by EPA are partial equilibrium models, in that they do not contain all of the major goods produced and consumed in the economic system, but rather all of the agriculture and energy goods. FASOM is used to estimate domestic LUCs and FAPRI is used, in conjunction with satellite data, to estimate international LUCs.

FASOM is a very detailed model of the U.S. forest and agriculture sectors. [5] Unlike GTAP, the model utilizes a starting year and ending year, and predicts agriculture production every five years between the starting and ending years. Results obtained in the equilibrium balance for one five-year period are used as inputs to the equilibrium balance in the next five- year period. Thus, FASOM takes into account trends in yield improvements from the beginning to the ending year. In running FASOM to evaluate LUC emissions, EPA ran a baseline case without the RFS-2 (called the Reference Case) and a Control Case that included the total RFS-2 volumes.

The FASOM land cover database includes the following categories of land:

- Cropland pasture
- Forest pasture
- Rangeland
- Forestland
- Developed land
- Conservation Resource Program land

The version of FASOM used for the final RFS2 does *not* take into account the effect of price increase on yields (see page A-20 of the final FASOM report). The model also assumes that newly converted lands have the same crop yields as existing land.

FASOM also evaluates the impact of DGs on land use, but the feed replacement ratios used by EPA in both FASOM and FAPRI are different from GTAP. This is discussed in the next section.

The FAPRI documentation refers to the FAPRI-CARD models as a “set of multi-market, partial-equilibrium, and non-spatial econometric models.” [6] The models cover all major temperate crops, sugar, ethanol, dairy, and livestock and meat products for all major producing and consuming countries and are calibrated on the most recently available data. The models are used for generating ten-year baseline projections for the agricultural markets and for policy analysis.

In general, for each commodity sector, the economic relationship that quantity supplied equals quantity demanded is achieved through a market-clearing price for the commodity. In many countries domestic prices are modeled as a function of the world price using a price transmission equation.

The model for each commodity consists of a number of countries and regions, including a rest-of the-world aggregate to close the model. The models specify behavioral equations for production, use stocks, and trade between countries/regions. The models solve for representative world prices by equating excess supply and demand across countries.

Within the context of how EPA used the two models to estimate LUCs, there are significant issues with respect to the consistency between FASOM and FAPRI. As explained in the Background section and in Section 4.1, the extent of price increases in crops like corn and the extent of modeled export losses are the drivers of land conversion, both domestically and internationally. FASOM is a domestic model, and the FAPRI model contains a domestic model as well. Thus, whether these two models predict the same impact for the U.S. is an important issue to examine. For example, if FAPRI predicts a greater corn price increase and export loss than FASOM, then it will over-predict international LUCs. Conversely, if FAPRI were to predict a smaller price increase and smaller export impact, it would perhaps under-predict the international LUCs.

4.3 Elasticity Inputs

Table 12 shows a comparison of elasticity inputs for the CARB and EPA modeling. There are many different elasticities in both models, but the two shown in the table are key inputs to both models.

Table 12. Comparison of Price-Yield and Area Expansion Elasticities

Source	CARB – GTAP (average of 7 scenarios)	EPA	
		FASOM	FAPRI
Price/yield elasticity	0.32	0.0	0.013/0.074
Area expansion elasticity*	0.59	1.0	-0.023

* values are not directly comparable, see explanations below

<u>Price/yield elasticity</u> – the CARB GTAP modeling shows an average price/yield elasticity of 0.32, which means a 1% increase in price leads to a 0.32% increase in yield. The final FASOM report indicates that no price/yield elasticity factor was used for domestic LUC modeling. FAPRI uses a short-term value of 0.013%, and a longer-term value of 0.074%.

The short-run yield elasticity is the percentage change in yield due to a one-year 1% increase in price. If the price were to drop the following year, then yield would decrease by the same percentage. The long-run elasticity is the percentage change in yield due to a permanent 1% change in price. This is modeled by taking the 10-year average change in price. Both of the FAPRI price yield effects are much lower than the value used by CARB in GTAP modeling.

<u>Area expansion elasticity</u> – For the CARB-GTAP case, the expansion elasticity is really a ratio of the productivity of newly converted land relative to current land. For example, a value of 0.59 means that the new land brought into production from either pasture or forest is only 59% as productive as the current land. FASOM assumes that new land brought into production in the U.S. (pasture, forest, or CRP land) is as productive as the current land. FAPRI's value, however, is the percent change in yield of the total area due to a 1% increase in

total area, which means a 1% increase in area results in a -0.023% decrease in yield. A 10% increase in area would lead to a -0.23% decrease in yield, which is not very much.

4.4 Distillers Grains Land Use Credits

As stated earlier, distillers' grains (DG) co-products from ethanol plants have two distinct impacts on GHG emissions attributable to producing ethanol. First, some of the energy used to produce ethanol goes into producing DGs, so there is an energy credit associated with DGs. Second, since they replace animal feed, there is also an attendant land use credit. The land use credit attributable to DGs is dependent on the mass replacement ratio of DGs for animal feed, and the types of feed DGs replace. Both the replacement ratio and type of feed being replaced depends on the animal type. Originally, DGs were mainly fed to beef cattle. Today, they are fed to beef cattle, dairy cattle, poultry, and swine, and are also exported all over the world.

Table 13 shows a comparison of overall mass replacement rates between GTAP and FASOM/FAPRI.

Table 13. Co-product Comparison Modeling Based (lb per 1 lb of DGs)

	EPA FASOM and CARD/FAPRI			CARB/GTAP		
Livestock Type	Corn	Soybean Meal	Total	Corn	Soybean Meal	Total
Cattle – beef	1.196	0	1.196	1.00	0.00	1.00
Cattle – dairy	0.731	0.633	1.364	1.00	0.00	1.00
Swine	0.89	0.110	1.000	1.00	0.00	1.00
Poultry	0.79	0.21	1.000	1.00	0.00	1.00

Results show that for FASOM and CARD/FAPRI, the replacement rates are higher than 1 lb. for 1 lb. of DG for cattle (beef and dairy), and that there is replacement of soybean meal for three livestock types. GTAP assumes a 1 lb. for 1 lb. replacement, with no soybean meal being replaced (GTAP does not model feed replacement by livestock type, but only for all feed).

The EPA replacement rates would result in a greater land use credit for DGs than the CARB/GTAP replacement rates for two reasons: (1) the replacement rates for cattle are higher than 1 lb. for 1 lb., and (2) a significant amount of soybean meal is being replaced for three livestock types. Assuming that soybeans are not grown strictly for the oil, the replacement of soybean meal by DGs has a greater land use credit than the replacement of corn, because soybean yields are considerably lower per acre than corn yields.

Another factor relating to the land use credit of DGs is the treatment of corn oil. EPA estimates that 90% of the dry mill plants will utilize corn oil fractionation or extraction from the DGs. CARB/GTAP assumes no fractionation or oil extraction.

The corn oil is a replacement for soybean-derived biodiesel and, in some cases, food-grade vegetable oil. If it replaces some soybean biodiesel, then fewer soybeans need to be grown to produce biodiesel, and there is a land use credit for this. It is clear that corn oil extraction is not addressed by CARB/GTAP, but it is unclear how FASOM and CARD/FAPRI address corn oil extraction and fractionation from a land use standpoint.

4.5 Carbon Emission Factors

Ultimately, the land use GHG emissions depend on the amount and type of land converted and the GHG emission rates of the different land types during conversion. CARB and EPA use two different sources for these emission rates. CARB uses emission rates developed at Woods Hole Research Institute (Massachusetts). EPA uses emission rates developed by Winrock International for international LUCs, and the FASOM model for domestic LUCs. FASOM contains soil carbon emissions from the CENTURY model, and also contains estimates of above ground carbon by foliage type.

The two regions that are most important to make a comparison of carbon emissions are the U.S. and Brazil. We were unable to locate the above ground carbon emissions for forests from FASOM, so we are unable to make a comparison for the U.S.

Tables 14 and 15 show a comparison of Winrock above ground forest emissions for Brazil and Woods Hole above ground forest emissions for Latin America (there are no separate Woods Hole estimates for Brazil). One problem aside from the fact that we are comparing Brazil to Latin America is that the Winrock emissions are by region, while the Woods Hole emissions are by forest type. However, we were unable to determine allocation of forest type by region to provide for a consistent comparison. We have averaged the emissions for Brazil from both sources, which is not correct for the reasons mentioned above, but the analysis seems to indicate that the Woods Hole emissions for forests likely are higher than the Winrock emissions. A more detailed analysis of these data is necessary to resolve which emissions are most appropriate and why. This needs to be done for all of the countries, at a minimum for above ground carbon stored in forests, since this is the primary driver of indirect LUC emissions.

Table 14. Winrock CO_2 Above Ground Emissions, Forest, Brazil	
Location	CO_2,T/Ha
Amazon Biome	606
Northeast Coast	145
North-northeast Cerrado	244
Central-West Cerrado	290
Southeast	243
South	225
Average	292

Source: “10_Winrock_Emission_Factors_Docket.xls”, part of EPA RFS docket materials for RFS2.

Table 15. Woods Hole CO2 Above Ground Emissions, Forest, Latin America	
Forest type	CO_2, T/Ha
Tropical Evergreen Forest	733
Tropical Seasonal Forest	513
Tropical Open Forest	202
Temperate Evergreen Forest	616
Temperate Season Forest	367
Average	486

Source: Appendix E of Purdue report for Argonne, Reference 11.

4.6 Carbon Sequestration in Wood Products

When commercial forests are converted to either pasture or crops, trees must be harvested. Some of the wood that is cut is used in building and paper products, and eventually may be land-filled. Thus, some fraction of the carbon in trees that are cut down does immediately produce carbon dioxide.

CARB currently does not account for this factor in its modeling. EPA also does not account for this factor for international LUCs, but the FASOM model does account for carbon storage in building products and landfills for domestic forest changes. The following is a brief discussion of how FASOM performs forest carbon accounting.

Forest carbon accounting in FASOM is similar to the FORCARB model developed by the U.S. Forest Service, which in turn is used for periodic aggregate assessments of forest carbon sequestration. Tree carbon is the largest forest carbon pool and is modeled as a function of three factors: (1) merchantable volume, (2) the ratio of growing stock volume to merchantable volume, and (3) parameters of a forest volume-to-biomass model developed by the U.S. Forest Service. Harvest age is allowed to vary, thus, the growth of existing and regenerated/reforested stands must be modeled. Carbon in live and standing dead trees is calculated using the parameters of the forest volume-to-biomass model equations for live and dead tree mass densities. One key assumption is that the mass of wood is approximately 50% carbon.

Soil carbon is the second largest carbon pool. FASOM assumes soil carbon on a reforested stand remains at a steady-state value. Afforested land coming from crop or pasture use starts with the initial soil carbon value for that land/region combination reported by the CENTURY model. The land then accumulates carbon until reaching the steady-state values for forest of the type planted in the region afforestation takes place.

Forest floor carbon constitutes the third largest carbon storage pool, but is much smaller than tree or soil carbon pools. Forest floor carbon consists of carbon from limbs and fallen trees. The model for net accumulation of forest floor carbon is a continuous and increasing function of age, although the rate of accumulation eventually approaches zero.

When timber is harvested, FASOM tracks the fate of the carbon that had been sequestered in the harvested land. The carbon after harvest consists of two categories, logging residue and harvested logs. The logging residue becomes a part of the forest floor carbon, and the harvested logs go to several types of manufacturing: wood and paper products, mill residue (which a portion of can also go to wood and paper products), and fuelwood. A portion of the mill residue decomposes, but some mill residue is used as renewable fuel.

The distribution of product carbon changes over time and FASOM tracks the fate of product carbon for each end-use using two pools: carbon remaining in-product and carbon leaving the product. Carbon that leaves the product ultimately makes its way to emissions or is permanently sequestered in landfills. The fraction remaining in the product is based on a model specifying half-life values for a set of end-use categories. The half-life represents the time it take for approximately half of the product to decompose. Carbon stored in paper is assumed to have a relatively short half-life, with 50% of the carbon decomposing within 2 years, whereas carbon stored in wood used in single family homes has a half-life of 100 years. FASOM assumes that 67% of carbon leaving the wood product pool and 34% of carbon leaving the paper product pool goes to landfills. The remainder of the carbon leaving the wood and paper product pools goes into CO2 emissions to the atmosphere.

Harvested fuel logs and the associated carbon are used to produce energy at mills. For fuel wood, FASOM assumes that 100% of the fuel wood burned in the sawtimber and pulpwood production process is used to offset fossil fuels.

FASOM contains a more detailed accounting of forest changes than either FAPRI or GTAP. For the EPA and CARB analyses, the latter two models simply assume that all above-ground carbon and a portion of the below-carbon is converted to CO2 immediately. These are worst-case assumptions, especially for the U.S. (for GTAP). On the other hand, the result of land-filling wood products is sequestration of the carbon for years. These products do not decompose by oxidation in landfills, rather a small fraction decompose by anaerobic digestion, which releases methane, a GHG that is 23 times as powerful as CO2. It is not clear how this process is handled in FASOM. Many U.S. landfills collect this methane and combust it in generators to produce electricity.

4.7 Does the Similarity In the Land Use Values Indicate Convergence?

Estimates of LUC emissions of corn ethanol have varied from 0-103 g/MJ. Both the CARB and EPA estimates are approximately 30 g/MJ. Does this indicate a convergence in estimates?

We believe the answer to this question is no, for the following reason. At the simplest, the LUC emissions estimates are the product of the area converted from either pasture or forest to crops, and the emissions of this conversion, as follows:

GHG = area * emission factor

This process is simply repeated for different land types, regions, etc. The emissions are then averaged over a 30-year period and summed.

A key point is that the area and emission factors are completely independent of each other, and a second key point is that CARB and EPA chose different modeling methods for determining land conversion area, and different data sources for the emission factors. So, this raises the question of what modeling system and what emission factors are the best (even though tools to assess LUC are continually undergoing change and improvement)? Whatever tools are the best for both of these factors should at least be combined, and this is not likely to lead to an affirmation of the current numbers.

For example, suppose we take two numbers, 2 and 5, whose product is 10 (the two numbers represent area and emission factor for CARB, for example). Of course the product of 1 and 10 is 10 also (EPA, for example). But if the best numbers are really 1 and 5, then the answer is 5. Or, if the best values are 2 and 10, then the answer is 20, a factor of 4x different than 5. Thus, it is very important to carefully examine both land use and emission factors to improve these estimates.

5.0 Fuel Production

As indicated in Table 1, the corn ethanol production emissions for EPA are 27 g/MJ, and for the CARB analysis are 38 g/MJ. These estimates are described in further detail below.

5.1 EPA Estimate

One of the key sources of information on energy use for corn ethanol production that EPA used was a study from the University of Illinois at Chicago Energy Resource Center. [12] EPA points out that in traditional lifecycle analyses, the energy consumed and emissions generated by a renewable fuel plant must be allocated not only to the renewable fuel, but also to each of the by-products. For corn ethanol production, the EPA analysis accounts for the DGs and other co-products in the FASOM and FAPRI-CARD agricultural sector modeling. DGs are considered a partial replacement for corn and other animal feed and thus reduced the need to make up for the corn production that went into ethanol production. Since FASOM takes the production and use of DGs into account, no further allocation was needed at the ethanol plant.

There is much variation in energy used at renewable fuel facilities based on process type and type of boiler fuel used. There can also be variation between the same type of plants using the same fuel source based on the age of the plant and types of processes included. EPA's approach was to differentiate between facilities based on the key process and technological differences between plants, namely the type of the plant and the type of the boiler fuel used. One other key difference modeled between plants was the treatment of co-products. One of the main energy uses in ethanol plants is drying of the DGs. Plants that are located near cattle feedlots or dairies have the ability to provide the co-product without drying, substantially reducing energy use at the biorefinery. This has such a large impact on the overall results that EPA defined a specific category for wet versus dry DGs. An additional factor that has a large impact on GHG emissions is corn oil fractionation or extraction from DGs.

EPA estimates the 27 g/MJ value for an average 2022 corn ethanol dry mill plant. The plant is assumed to use fractionation to separate corn oil, and the plant is further assumed to dry 63% of the DGs, with the other 37% being wet. The derivation of this is shown in the table below.

Table 16. Fuel Production Emissions for Dry Mill NG Plants

Plant Type	Percent of Plants in 2022	GHG Emissions g/MJ
Dry Mill NG with fractionation, dry DGs	63%	30.5
Dry Mill NG with fractionation, wet DGs	37%	21
Weighted average	100%	27

The results show that drying the DGs is worth 9.5 g/MJ. Our analysis of EPA's other results (not shown here) is that fractionation and oil extraction for a plant with100% dry DGs is worth 5.4 g/MJ (i.e., if fractionation/extraction were not used, the values shown in Table 16 would be 5.4 g/MJ higher.

The above table only shows two of the many different types of plants that EPA modeled, and the weighted average emissions of those types of plants.

5.2 CARB Estimate

CARB utilizes the GREET model to estimate production emissions for corn ethanol. The 38 g/MJ is for a dry mill, natural gas fired plant with 100% dry DGs and no fractionation. Thus, part of the reason for the difference between EPA and CARB is that their primary scenarios do not compare the same plants. [5] This is shown further in Table 17.

Table 17. Comparison of Basic Dry Mill Plants

Source	Fuel	Dry/Wet DGs %	Fractionation
EPA	Natural gas	63%/37%	Yes
CARB	Natural gas	100%/0%	No

Like EPA, CARB estimated ethanol production energy emissions for many different types of plants, so it is possible to compare EPA and CARB's estimates for the same plant. Table 18 shows both CARB and EPA's estimates for a natural gas dry mill plant with 100% dry DGs and no fractionation. The energy values include both natural gas and electricity.

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[5] The CARB Corn Ethanol report does include a table (Table C) that reports the carbon intensity of different types of corn ethanol plants, including dry mill, wet mill, dry DGS, wet DGS, and so on. But the primary scenario in the CARB Corn Ethanol report appears to be a natural gas Midwest plant with dry DGS.

Table 18. CARB and EPA’s Estimate of a Midwest NG Dry Mill Plant			
Source	Plant Type	Production Emissions	
		BTU/gal	g CO2 eq/MJ
EPA (2022)	100% dry DGs, no fractionation	30,911	33.4
CARB (current)	Midwest, 100% dry DGs no fractionation	36,000	38.3

The differences in energy use for a dry mill plant with 100% dry DGs and no fractionation are probably due to the differences in the timeframe of projection since the EPA estimate is a best estimate for the 2022 timeframe and the CARB estimate is for current plants.

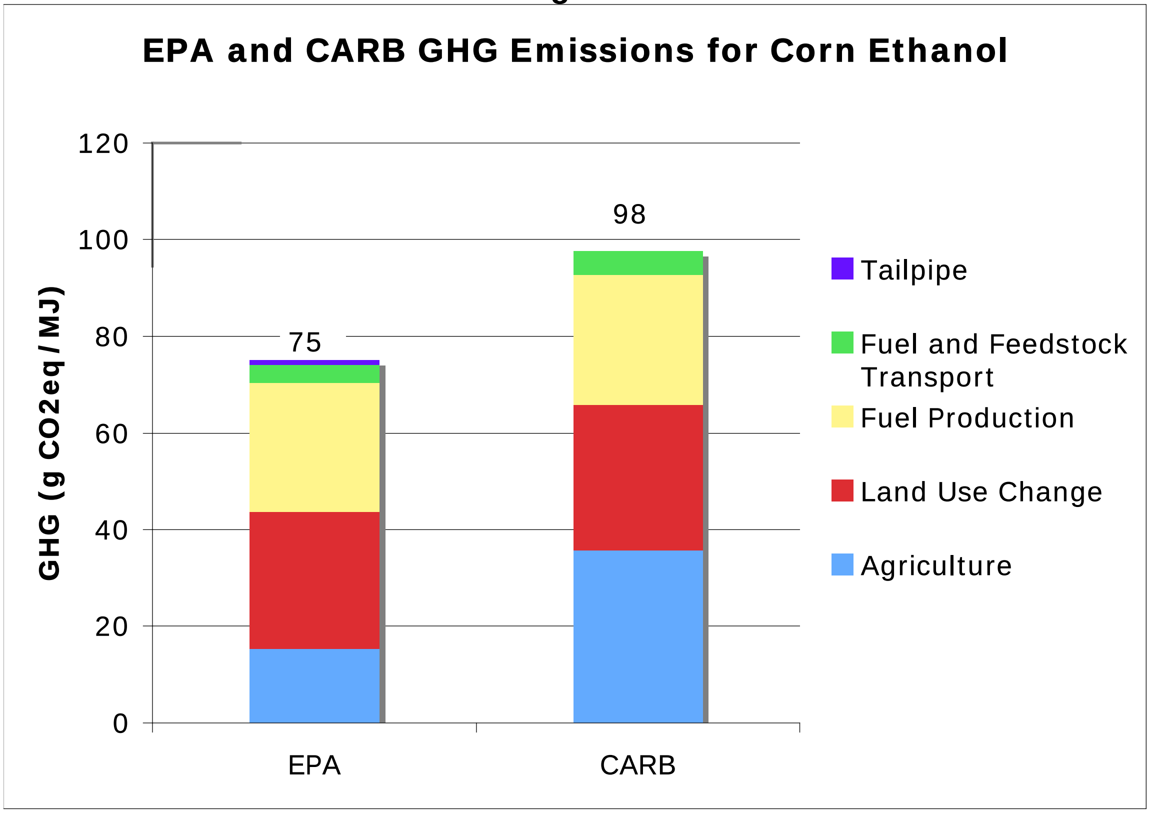
In conclusion, the primary differences in CARB and EPA default estimates for ethanol production are:

- EPA assumes 63% dry DGs/37% wet DGs, while CARB assumes all DGs are dried
- EPA estimates most plants will have fractionation or extraction of corn oil, while CARB assumes no plants will utilize these practices
- EPA’s estimates are for a plant in the 2022 timeframe, while CARB’s estimate is supposed to represent current plants

6.0 Conclusions

A comparison of EPA's and CARB's lifecycle GHG emissions for "average" corn ethanol is shown in Figure 1. The emissions are shown in g CO_2 eq/MJ. CARB estimates gasoline at about 96 g/MJ, so currently CARB estimates no benefits for most corn ethanol relative to gasoline. EPA's GHG estimate for corn ethanol is about 20% lower than CARB's.

Figure 1



The largest differences in the two estimates are in fuel production and agriculture. EPA's estimates of agriculture emissions are lower than CARB's due to two primary reasons:

- EPA's estimates are based on the FASOM model, while CARB's estimates are based on modifications CARB made to the Argonne GREET model for corn. The FASOM model assumes a lower fertilizer input (260 g/bu) than GREET for corn (420 g/bu).

- EPA's system boundaries for agriculture are much different than CARB's. EPA evaluates the changes in *net* agriculture emissions, where CARB only evaluates emissions from agriculture inputs to corn. EPA broadly evaluates the entire global agriculture system's response to increases in corn use for ethanol. For example, FASOM estimates that increasing corn ethanol will reduce rice and livestock production, leading to methane reductions.

EPA’s fuel production emissions are lower than CARB’s for the following reasons:

- EPA estimates emissions for the biorefinery in calendar year 2022 with expected efficiency improvements, where CARB estimates emissions for the biorefinery based on current GREET model defaults, which are meant to reflect current practices.

- The primary biorefineries being compared are somewhat different. In the final rule, EPA’s biorefinery assumes 37% of the distillers’ grains (DG) output will not be dried and 63% of the distillers grains will require drying. EPA also assumes 90% of the biorefineries will separate corn oil from the DG. In the CARB GREET model documentation, CARB’s primary values are for a biorefinery in the Midwest with 100% dry distiller grains, and CARB assumes corn oil is not separated from distillers’ grains.

As indicated earlier, the land use emissions values from both analyses appear to be similar. However, the modeling systems, modeling inputs, and data used are quite dissimilar. Thus, this apparent alignment is mostly coincidental, highlighting the fact that much more work should be conducted with both modeling systems to further evaluate the emissions of LUCs for corn ethanol.

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