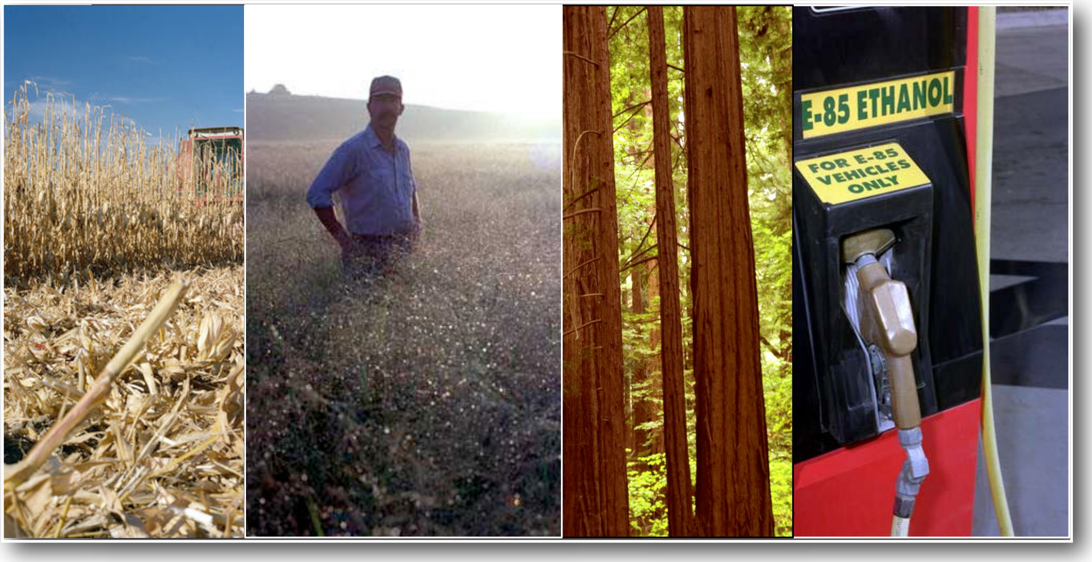
SHEEHANBOYCE, LLC

SUSTAINABLE BIOFUELS

A COMMONSENSE PERSPECTIVE ON CALIFORNIA'S APPROACH TO BIOFUELS AND GLOBAL LAND USE



Prepared for
the Biotechnology Industry Organization

by

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DRAFT

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Performance-based sustainable fuels policies

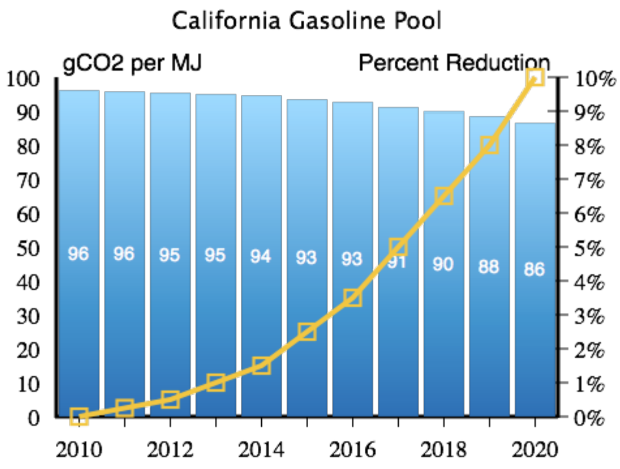
An unprecedented effort is now underway in California and in the US at the federal level to encourage the use of sustainable transportation fuels. Unlike previous attempts to introduce alternative fuels through arbitrary incentives and mandates for specific fuels, these new regulatory approaches include at least some elements of a performance-based requirement for these fuels. They actually use real measures of the sustainability of the fuels based on societal goals. In California and at the federal level, these new policies focus on reducing greenhouse gas emissions, measured as carbon or CO_2 emissions per unit of fuel energy.. This is a huge step forward in US policy, and one which should be applauded.

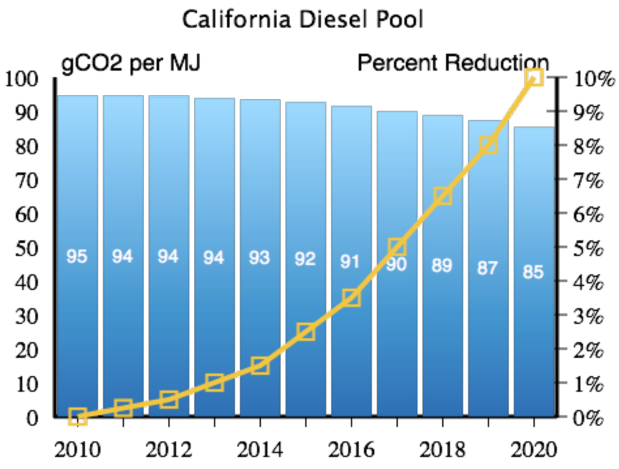
While there are many similarities in the approaches used by the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency (USEPA), the overall structure of the policies is fundamentally different. California's Low Carbon Fuel Standard (LCFS) is entirely performance-based. It characterizes fuels in terms of their relative ability to contribute to reducing the carbon intensity of California's fuel supply. The USEPA's policy is based more on arbitrary mandates for specific types of fuels, but with minimum requirements for carbon reduction potential.

CONCLUSIONS: Both CARB and the USEPA are to be congratulated for adopting policies that focus on performance-based criteria for encouraging sustainable biofuels. Performance-based policies that reflect the values of society are the only sensible approach to guaranteeing that these policies actually encourage the kinds of outcomes that society desires. The industry supports such a shift in policy, and will work with the regulators to ensure that 1) measurements of performance are based on sound science; and 2) the implementation of such performance-based policies is fair and equitable for both existing biofuels producers and new generation biofuels technology developers.

California's Low Carbon Fuel Standard

The California LCFS sets legal targets for reducing the carbon intensity of its fuel supply. Those targets are shown below for the gasoline and diesel fuel pools.



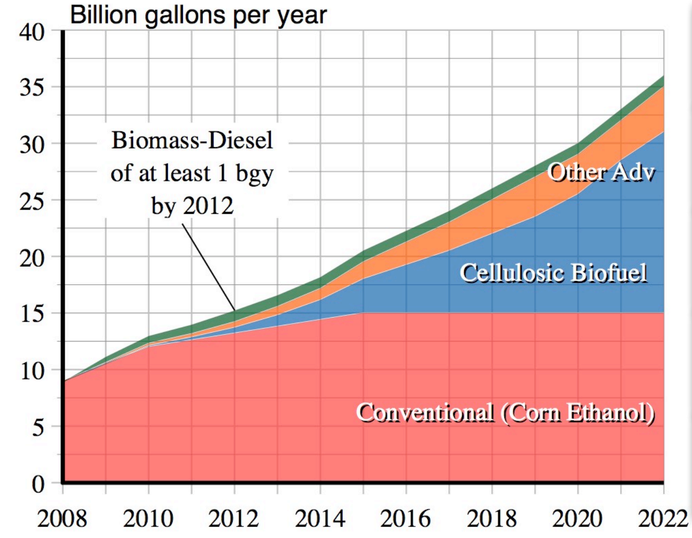


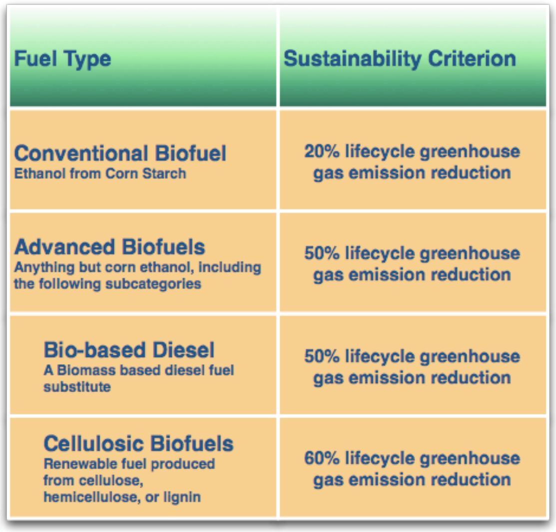
The LCFS calls for a gradual reduction of the carbon intensity of California's transportation fuel supply by 10% between now and 2020. While this may seem like a small dent in the carbon impacts of the transportation system, meeting these targets will take significant resources and investment in new low carbon fuels, fuel delivery infrastructure, and compatible vehicle technologies.

The Revised Federal Renewable Fuel Standard (RFS2)

Under the Energy Independence and Security Act of 2007 (EISA 2007), the US Congress established aggressive new targets for use of renewable fuels in the US transportation sector. Its RFS2 represents a hybrid between the traditional fuel-specific mandate approach of the past and a performance-based approach that sets minimum requirements for GHG emission reductions.

The requirements of RFS2 are summarized below.





Fuel Type	Sustainability Criterion
Conventional Biofuel Ethanol from Corn Starch	20% lifecycle greenhouse gas emission reduction
Advanced Biofuels Anything but corn ethanol, including the following subcategories	50% lifecycle greenhouse gas emission reduction
Bio-based Diesel A Biomass based diesel fuel substitute	50% lifecycle greenhouse gas emission reduction
Cellulosic Biofuels Renewable fuel produced from cellulose, hemicellulose, or lignin	60% lifecycle greenhouse gas emission reduction

The chart on the left reflects the traditional approach of mandating specific fuels. It allows for up to 15 billion gallons per year of corn ethanol as part of meeting the national targets. It also establishes minimum contributions from from biodiesel, cellulosic biofuels and “other advanced biofuels.” RFS2 calls for a total of at least 36 billion gallons per year of renewable fuels in the US transportation fuel supply by 2022. The table on the right forces a performance measure on top of these mandates by specifying minimum criteria for greenhouse gas reductions for each category of fuel in the mandate.

Interactions between California and federal policies

Under EISA 2007, the US Congress attempted to meld two different policy approaches, each reflecting both existing and new political demands. The former reflecting the political realities of existing biofuels investors and the latter reflecting the genuine political pressure to meet new public demands for reducing greenhouse gas emissions. California’s LCFS, by contrast, focuses exclusively on encouraging fuels that meet the public’s demand for reducing greenhouse gas emissions.

California’s approach is less prescriptive than the US Congress’s approach. California sets a public goal, and allows all fuels to contribute to meeting it, regardless of the individual fuel’s relative ability to reduce greenhouse gas emissions. The choice of the mix of fuels is up to the overall economics of these fuels in the marketplace. By contrast, the RFS2 actually sets minimum hurdles for participation related to the ability of the prescribed fuels to meet greenhouse gas reductions.

The difference in how each policy approaches greenhouse gas reduction criteria could complicate the situation for fuel providers who want to participate in both the California and the federal RFS2 markets. Advanced biofuels that fall below the 50% carbon reduction criterion for the RFS2, for example, may well be competitive in California’s LCFS markets, but find themselves excluded from participating in the federal RFS2 markets.

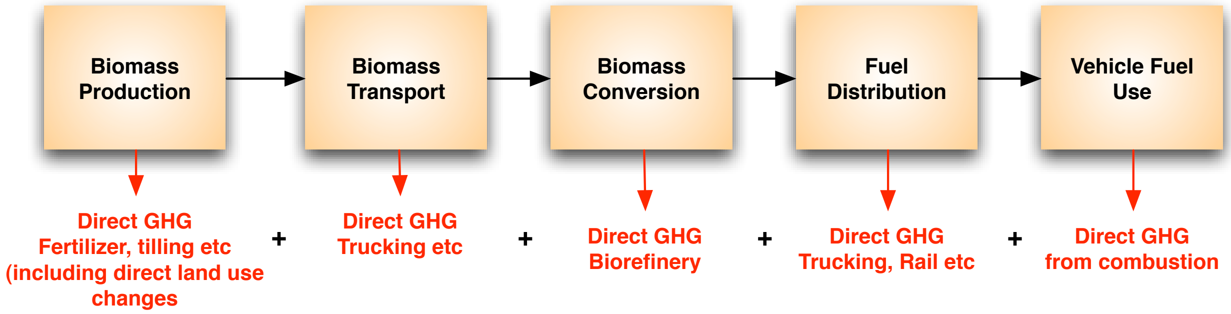
RECOMMENDATION: The California and federal policies should seek to align their policies with respect to greenhouse gas emissions, preferably by moving the federal standards closer to the less prescriptive approach adopted by California. It is important to understand that the USEPA is bound by many of the restrictions imposed on the agency in the Congressional language of EISA 2007. Congress should be encouraged to adopt language for EPA that allows for greater flexibility and less proscription on the part of Congress.

Measuring carbon intensity:
The devil in the details

The central issue facing the development of both CARB's and USEPA's fuel policies is the ability to measure the carbon footprint of fuels. Measuring the carbon intensity or potential carbon savings of fuels is not simple. It involves a variety of complex political and technical questions, some of which have not yet been entirely resolved.

Direct greenhouse gas emissions of biofuels—the "attributive" LCA

The "simplest" aspect of measuring the carbon footprint of fuels is assessing the direct greenhouse gas emissions of the fuel. The analytic framework used for such analyses is life cycle assessment (LCA). In the case of greenhouse gas emissions, LCA's attempt to capture all sources of emissions that occur throughout the life cycle of the fuel is shown conceptually below.



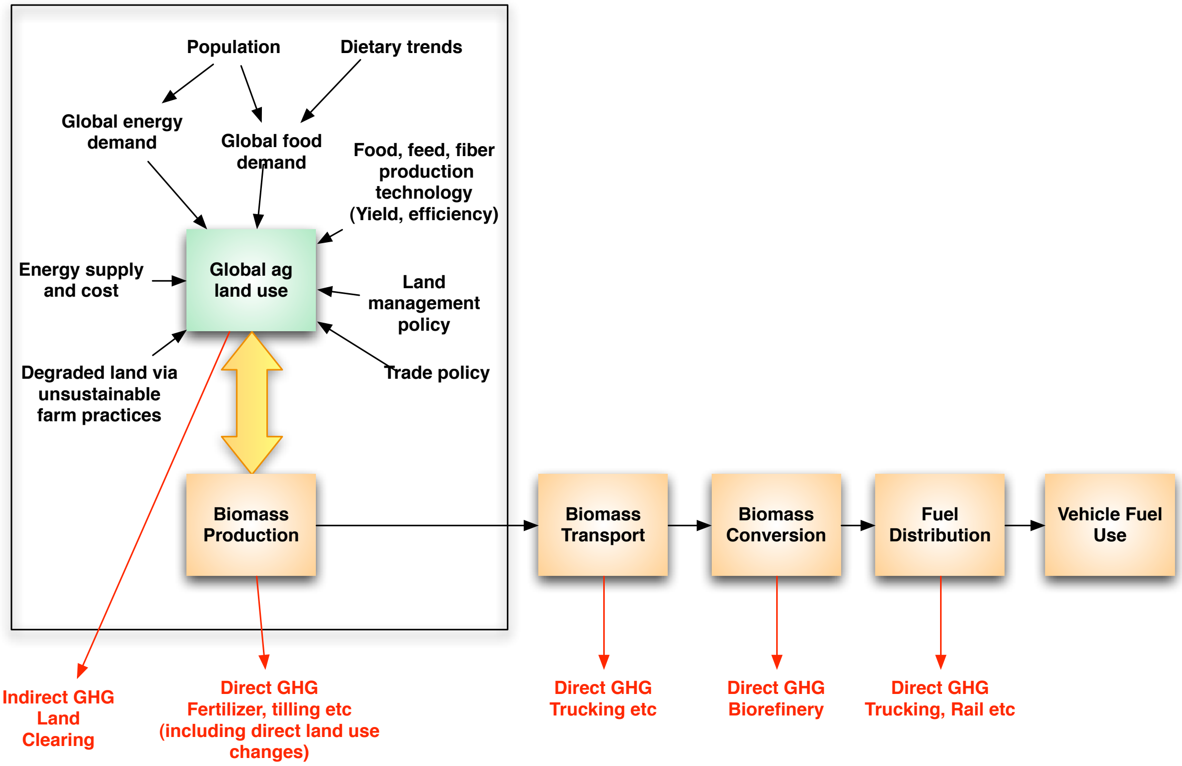
The peer reviewed literature on this type of LCA for biofuels is quite extensive. Though this is the most straightforward calculation that can be done, the disparity in the range of the direct emissions (and net energy requirements) for biofuels is large. (See for example, the University of California Berkeley review of corn ethanol energy balance estimates (Farrell et al 2006).)

Both CARB and USEPA rely heavily on estimates of direct emissions for biofuels taken from Argonne National Laboratory's GREET model (Burnham et al 2006; Wang et al 2005). The value of GREET is that it is an open source tool available to anyone who chooses to use it. GREET offers an ability to do comparative GHG emission analyses across a wide variety of fuel and vehicle technologies for transportation. The downside of the tool is that it must be more inherently generic with respect to fuel production technologies in order to accommodate a broad range of options. It cannot, therefore, adequately represent the specific circumstances and approaches that individual fuel producers may be using to provide a biofuel that both reduces petroleum dependence and reduces greenhouse gas emissions relative to its petroleum counterpart.

The science of life cycle assessment is changing rapidly. Today, what was once called life cycle assessment is not caveated with the term “attributional” life cycle assessment. This new term recognizes the fact that our view of the impacts of fuels has been broadened. There is now recognition in the field of LCA ((Ekvall, & Weidema 2004; Schmidt 2008; Kløverpris et al 2007)) that the actual impacts of a fuel, product or service may involve indirect impacts. Much of the controversy facing CARB and USEPA revolves around the question of how to appropriately account for such indirect effects.

Indirect greenhouse gas emissions—the “consequential” LCA

Last year, two papers in Science raised an issue that had not received much attention in the LCA community—the greenhouse gas emission impacts of global land use change indirectly caused by demand for biofuels. The concept is illustrated below.



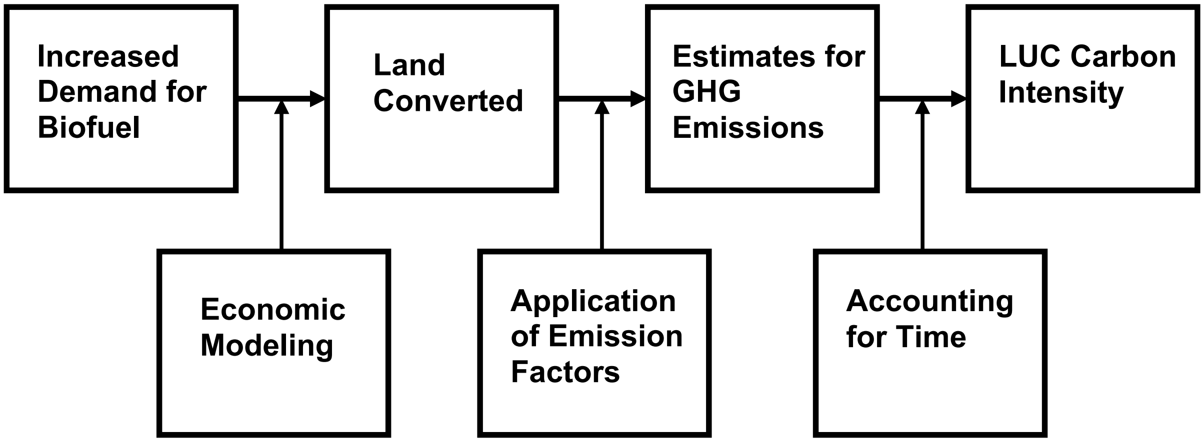
These papers posit that increased use of land for biofuels will (in the case of (Searchinger et al 2008b)) and could (in the case of (Fargione et al 2008)) lead indirectly to clearing of forest and grassland elsewhere in the world. If this land is cleared by burning, the amount of CO_2 emitted could overwhelm the fossil CO_2 savings associated with the substitution of petroleum fuels with biofuels. Calculating indirect land use change is, however, fraught with complexity and uncertainty. It requires the use of economic models to predict global agricultural and economic responses that are simply not well understood. Furthermore, establishing a direct causality between biofuels land demand and other land use changes is problematic at best because there are many other local and global factors that can lead to land clearing. These other factors are not only independent of any land demand effects associated with biofuels, but their overall impact on land clearing may be much larger than the amount of land potentially displaced by biofuels (GEIST, & LAMBIN 2002). Early arguments from biofuels advocates relied heavily on the uncertainty and complexity of indirect land use change as a basis for saying that it should not be included as part of the regulatory framework for biofuels (Kline, & Dale 2008). This is an argument based on obfuscation, and not a legitimate basis for ignoring land use change effects.

CONCLUSIONS. The science of indirect land use change are in early days. It is well accepted that that the there are many underlying and proximate causes of land use change. The most important of these are economic conditions, infrastructure and local government policies. But uncertainty is not a reason to ignore this potential impact in evaluating the carbon impacts of biofuels. Ignoring indirect land use makes an assumption of zero impact. This answer is no more defensible than the attempts by CARB to assign some value. The uncertainty and the rapidly changing understanding of indirect land use change does require regulators to remain flexible in their attempts to estimate and regulate the indirect effects of biofuels.

California findings to date

The California approach to indirect land use

Both California and EPA have adopted approaches similar to that used by (Searchinger et al 2008b). California's approach is shown schematically on the next page (taken from (CARB 2009)). California has chosen the GTAP (Global Trade Analysis Project) model to do the economic modeling of biofuels' impacts. This is an equilibrium model that is used to guesstimate the response of the global agricultural economy to a sudden spike in increased biofuel demand. It has been modified and augmented in order to be able to estimate global land use changes related to biofuels demand (Hertel 1997; Hertel et al 2008; Taheripour et al 2008). CARB chose this model because it is open source and it has extensive capabilities to look at international trade relationships and how these will lead to shifts in agriculture globally.



OBSERVATIONS ON THE MODELING TOOLS FOR INDIRECT LAND-USE CHANGE

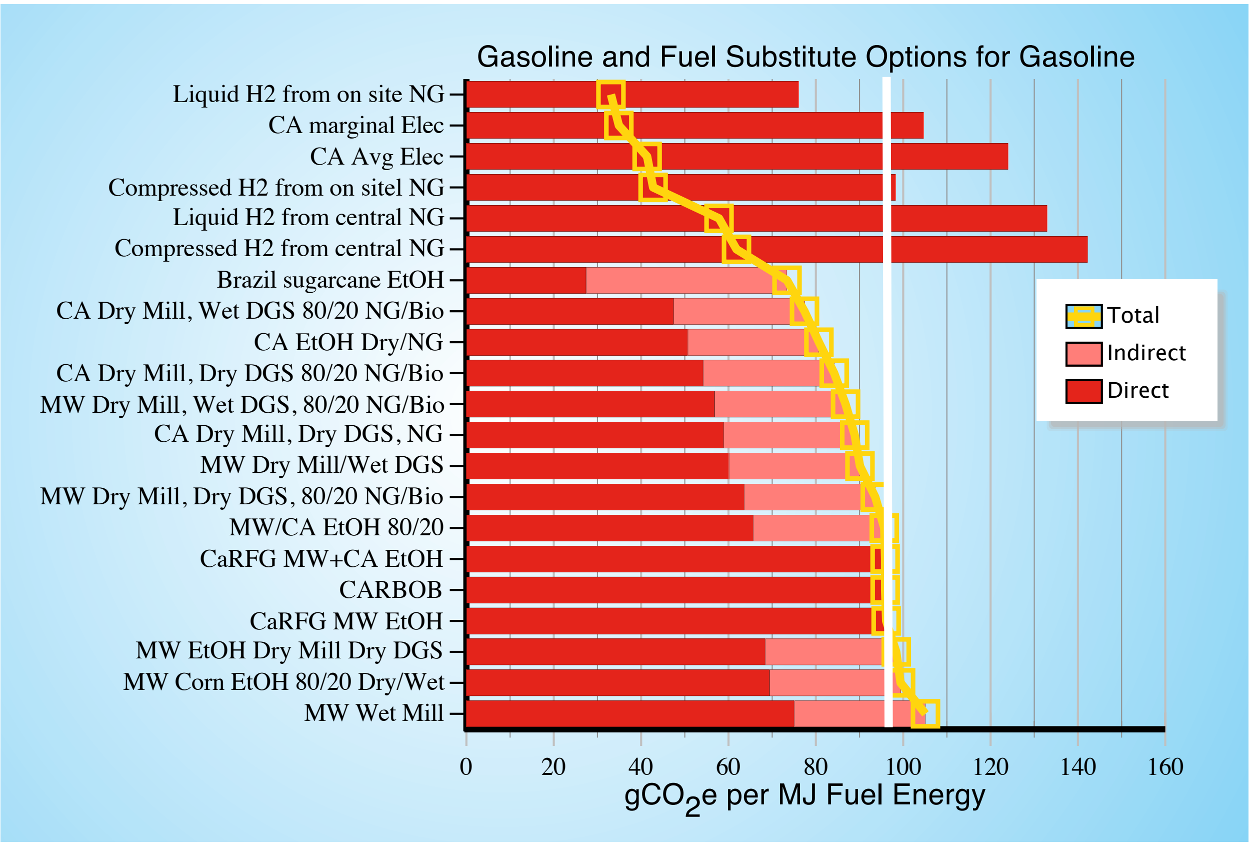
The choice of an open source model is good. That, coupled with the efforts by CARB to providing training resources for running GTAP, exemplifies the desire on the part of CARB to make the development of the regulation as open and accessible as possible. There are a number of concerns with the model. These include:

1. Much of the transparency in the model is lost due to the complexity of the model itself
2. Understanding the data sources underlying the model can be difficult
3. The model is not dynamic. This creates a number of problems including
    - An inability to deal with dynamic improvements in agricultural yields and energy crop yields
    - An inability to deal with future trends for population and food demand
    - A limited single year snapshot of agriculture in 2001
4. The model is rigid and does not accommodate changes in assumptions well
    - As an example, just to bring 2001 yields to 2008 levels, modelers were forced to externally correct yields after the fact when running the model

The current CARB lookup tables

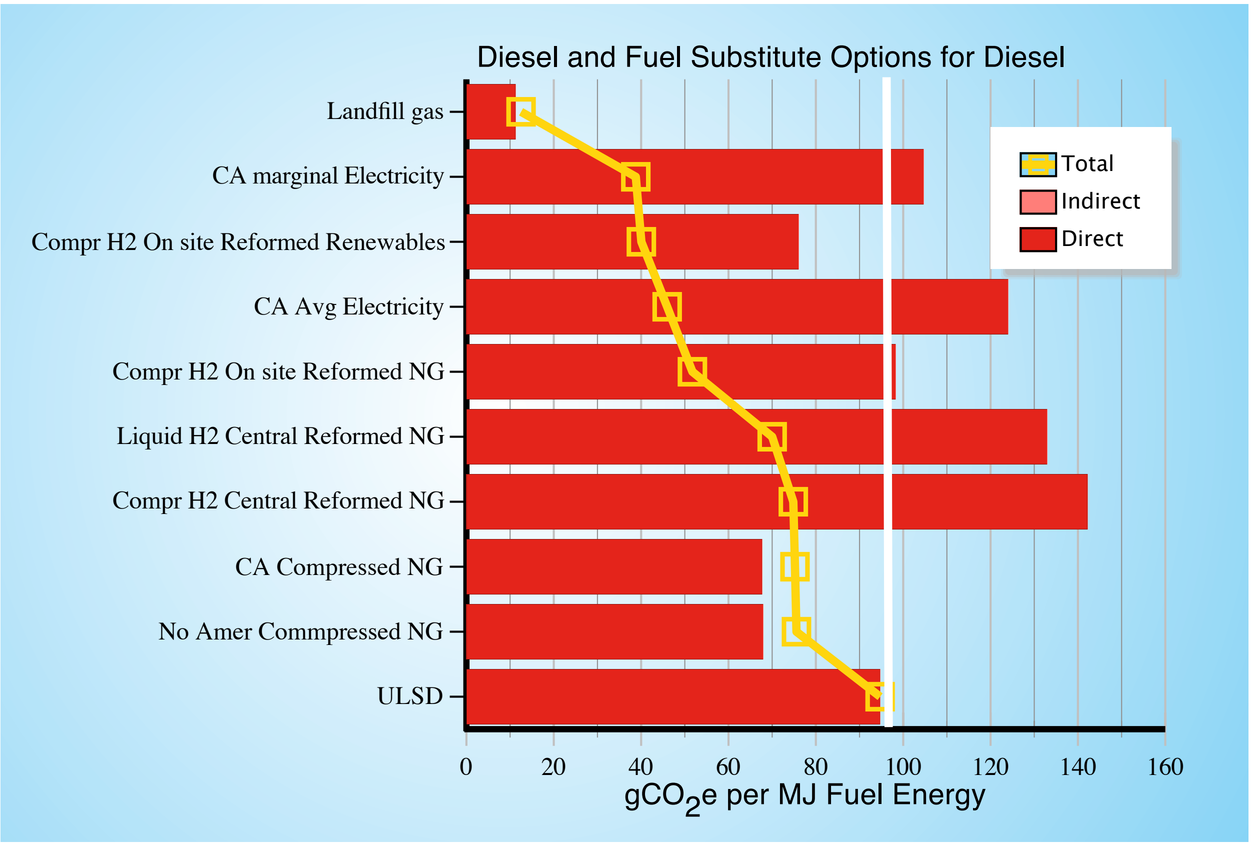
CARB has separate targets for gasoline substitution in the light and medium duty vehicle markets and diesel fuel substitution in the heavy duty vehicle market. CARB’s current list of default values for carbon intensity in the gasoline market are shown on the next page. The direct emission impacts are shown in dark red, and the indirect land use change effects are added on top (shown in lighter red). The white line shows the baseline carbon intensity for current California RFG containing 10% midwest ethanol. The yellow line shows the net carbon intensity of each fuel as estimated by CARB.

Net carbon intensity for hydrogen and electricity based fuels are much lower than the direct carbon intensity of the fuels because CARB has adjusted the carbon intensities downward to account for the dramatically higher efficiency of the hydrogen and electricity vehicle power trains. While it makes sense to account for the improved efficiencies of electric drives, it is important to acknowledge that these scenarios rely on vehicle technology that is not yet available on a practical and cost effective basis. Furthermore, because of the arbitrary distinction between gasoline and diesel markets, the efficiency gains and fuel related carbon savings associated with the introduction diesel vehicles and clean diesel fuel substitutes in the gasoline markets is not appropriately accounted for.



The addition of land use change effects dramatically reduces the benefits of existing midwest corn ethanol. Only the California ethanol scenarios that include a portion of biomass-powered ethanol production meet the minimum EPA threshold of 20% reduction in carbon intensity.

CARB's current list of default values for the diesel market are summarized in the chart on the next page. The only scenarios reported thus far are for natural gas, electricity and hydrogen fuels. None of these fuels are likely to meet the demands of the majority of the heavy duty fuel market. No biofuels options have as yet been finalized.



OBSERVATIONS ON THE CURRENT LOOKUP TABLES:

The list of available default values is remarkable more for what is not available than for what is available. In the gasoline market, virtually no second generation biofuels technologies are reported. No biofuels (existing or future) alternatives for the diesel market are available to comment on. This makes it difficult for the biofuels industry to respond to the fairness or validity of the approach being used by CARB.

The list of corn ethanol scenarios in the gasoline substitutes points to another problem with the approach taken by CARB. The number of permutations for this "one" technology will quickly become overwhelming. In CARB's lookup table, corn ethanol technology already has ten different permutations reflecting a combination of existing technology options and location options. Even so, these ten permutations do not properly reflect the circumstances of all the individual corn ethanol producers. For example:

1. Ethanol producers using biomass for heat and power are commingled with those who do not[1]
2. Differences in farming practices among feedstock suppliers are ignored
3. There is so far no accounting for emerging corn ethanol technology options[2]
4. No accounting for diesel fuel substitution is

If the biofuels industry is to rely on the default analyses provided by CARB, then CARB is faced with the prospect of producing many more permutations on the technology options than has so far been produced. It may not be practical to rely on such default analyses. Instead, it will be important for regulators to offer flexibility in allowing companies to offer their own documentation and modeling of the specific conditions reflected in their fuel pathways and technology choices.

Finally, the arbitrary distinction between gasoline and diesel markets does not allow CARB to account for the reduced emissions of introducing clean diesel vehicle technology and clean diesel fuel substitutes in the light and medium duty markets assumed to be served exclusively by gasoline. While CARB gives credit to hydrogen and electric vehicle technology for its inherent efficiency improvements, it ignores this benefit in the case of light duty and medium duty diesel vehicle technology.

CARB sensitivity results

CARB modelers ran a number of scenarios reflecting different economic responses to overall agricultural yields. These scenarios focused on five key assumptions:

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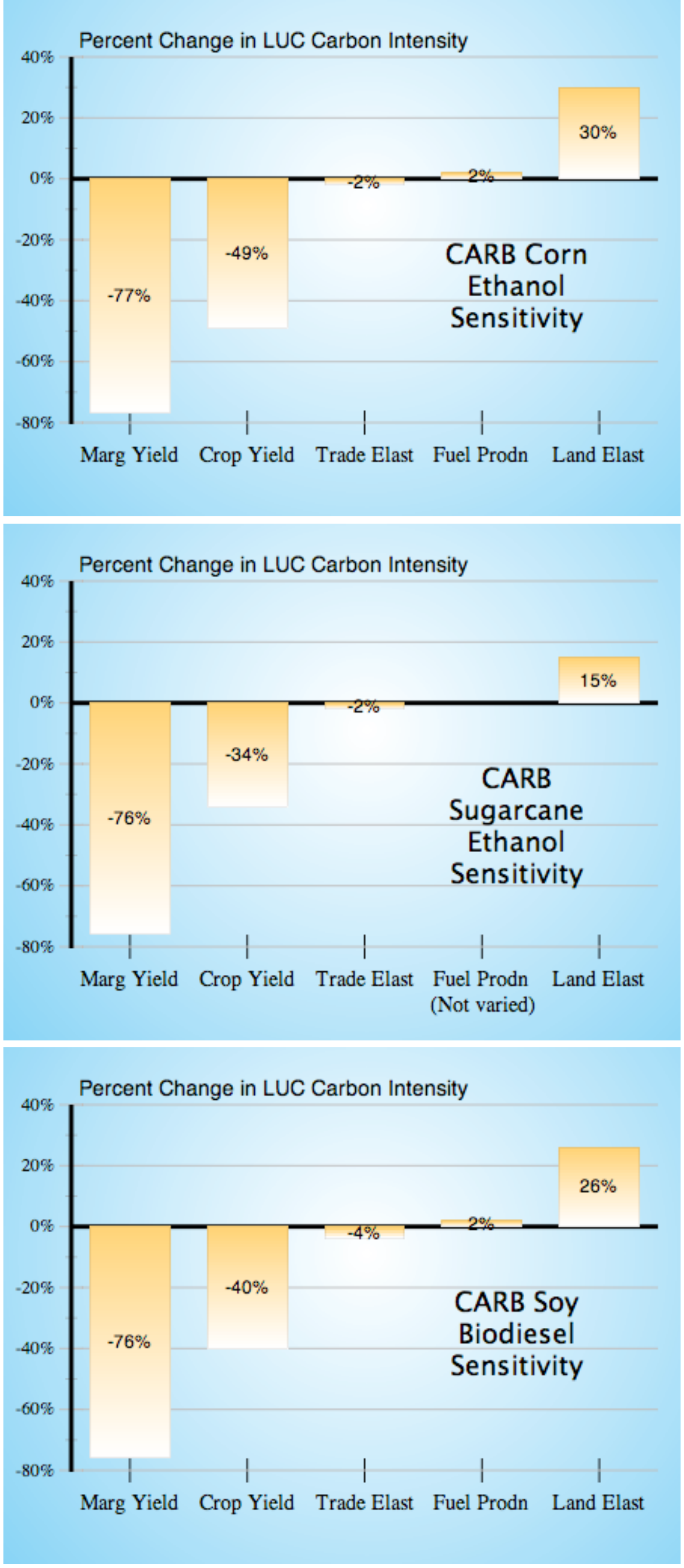
[1] Why should one fuel scenario arbitrarily assume an 80/20 mix of natural gas versus biomass fueled ethanol plants?

[2] This includes a range of technology improvements in the existing corn ethanol industry that fall between simple designations of 1st generation corn technology and This could include scenarios such as pretreatment systems for dry mill corn ethanol plants that allow for separate recovery of corn oil or facilities which convert corn fiber in the kernels to ethanol.

1. A range of fuel production levels
2. Crop yield elasticity
3. Elasticity of land transformation
4. Elasticity of crop yields with respect to area expansion
5. Trade elasticity



Crop yield elasticity refers to how much crop yield could increase as a function of prices—the theory being that higher prices will encourage improvements in plant breeding and genetics, farm practices and also intensification of farming. Elasticity of land transformation captures the response of land conversion to increased prices. The elasticity of crop yields with respect to area expansion captures the notion that, as more marginal land is brought into production. the overall productivity of that new land will decline. Items 2 and 4 both capture yield effects.

The figure on the right summarizes CARB's sensitivity results for these five model parameters for corn ethanol, sugarcane ethanol and soy biodiesel (CARB 2009). The take home message is simple—yield matters. When yields in the GTAP model are allowed to increase, whether through assumptions of increased marginal land yields or increased overall crop yields, the carbon intensity effect of land use change drops dramatically.

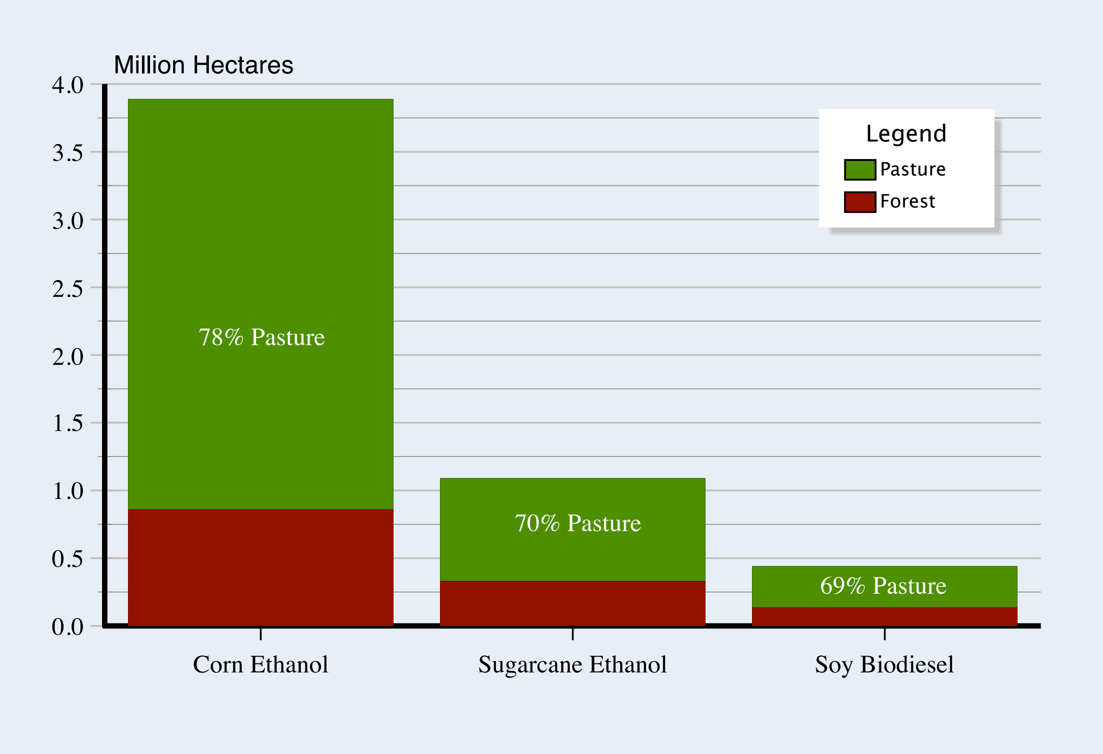
Ironically, these results argue against CARB's approach of looking at the global agricultural economy at a fixed point in time. Yields in global agriculture have steadily increased over the past sixty years, as is shown later in this report for results of a dynamic modeling exercise I have conducted to look at land use change effects of cellulosic ethanol.

CARB's modelers argue that the high values for elasticity of marginal land and crop yield are not realistic. They may be right. Our understanding of these relationships is poor at best. But this mechanism is the only internal modeling mechanism they have for reflecting yield improvements.

CONCLUSIONS. CARB's own sensitivity analysis demonstrate that yield elasticity assumptions are tremendously important in assessing the carbon intensity impacts of land use change. Putting aside the arcane economic arguments over such questions as yield response to prices, these findings support the notion that future yield improvement must be considered in any analysis of future land use change impacts of biofuels.

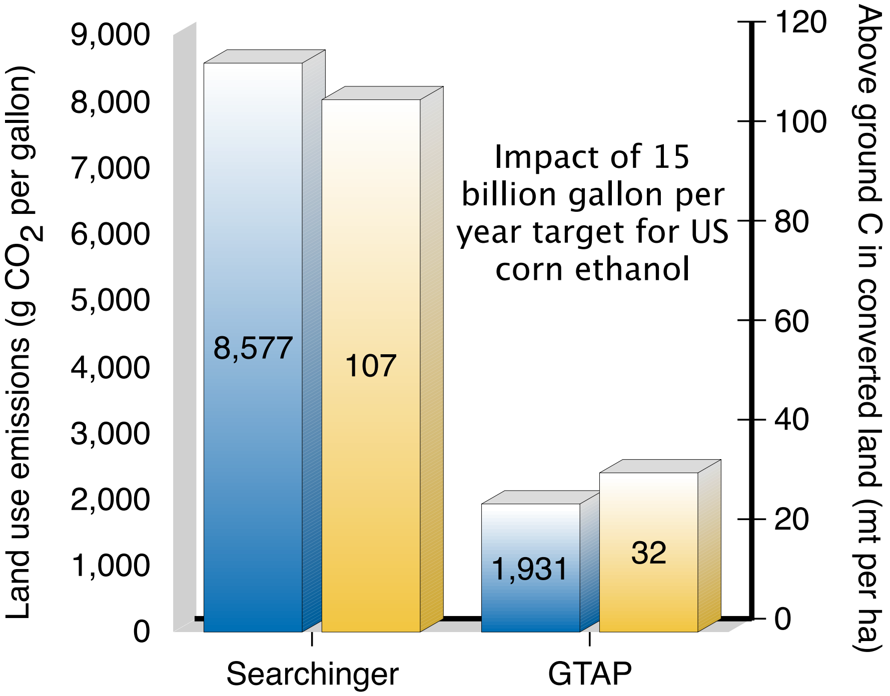
CARB analysis of land types transformed to agriculture

The types of land converted to agriculture, according to CARB, are shown below.



The three sets of sensitivity runs conducted by CARB for corn ethanol, sugarcane ethanol and biodiesel demonstrate that the lion's share of land transformed to agriculture comes from grassland and not from forestry. Even for soy biodiesel—often pointed to as a culprit in Brazilian rainforest clearing—70% of the land conversion occurs in pasture.

For comparison, consider what the numbers looked like in the original analysis by Searchinger et al. Based on the information available in the supplemental data for this paper (Searchinger et al 2008a), the average above ground carbon in the land displaced by corn ethanol was 107 tonnes per hectare. Assuming a value of 200 tonnes per hectare for forest and 10 tonnes per hectare for pasture, Searchinger's above ground carbon translates to 51% forest and 49% pasture. Using the same estimates for forest and pasture land above ground carbon, the 78% pasture land estimate from CARB corresponds to an average carbon content of only 32 tonnes per hectare in the above ground carbon lost to clearing in CARB's analysis of corn ethanol iLUC. This large difference in estimate of the above ground carbon debt could explain why recent numbers from the GTAP modelers at Purdue are so much lower than Searchinger's original estimates (Tyner et al 2009), as shown in the figure below.



Source of LUC emissions comparison: Tyner et al (2009). Land Use Change Carbon Emissions due to US Ethanol Production. Purdue University (Draft)
Source of above ground C comparison: Searchinger et al (2008) and estimates done by the author

CONCLUSIONS. The declining land clearing debt estimates in CARB's GTAP analysis relative to the first published estimates by Searchinger in 2008 reflect progress being made in the refinement of the estimates of iLUC impacts, particularly with regard to the types of land affected by the increased demand for biofuels production. The sharply differing estimates between 2008 and 2009 demonstrate how rapidly our understanding the iLUC phenomenon is changing.

A different way to look at land use change

There are a number of important conclusions that can be drawn from the analyses reported by CARB thus far:

1. It is possible to estimate land use change effects of biofuels
2. Input assumptions to the model have a large affect on the magnitude of the LUC impact.
3. Assumptions about yield are among the strongest influences on the results, as indicated by CARB's sensitivity analysis of yield elasticities in the model.
4. The estimate of the distribution of land types converted as a result of increased demand for biofuels has a similarly large influence.

A simple, dynamic model of land use change

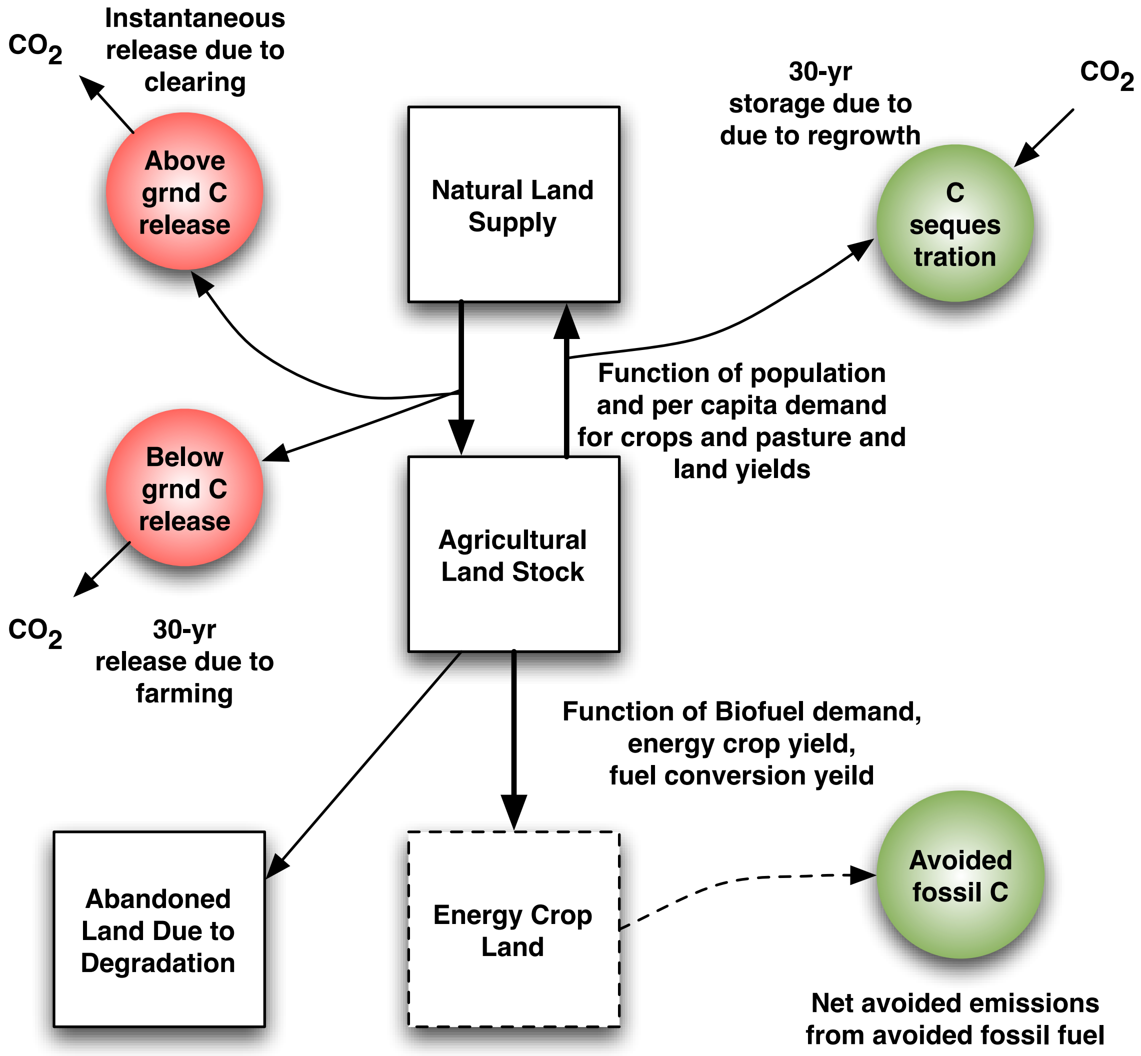
CARB and the USEPA have focused on economic models to predict the effect that increased biofuels demand will have on land use change globally. These models are complex and, as such, can be difficult to work with and rigid in terms of how they can be used to look at different long term scenarios. Much of the public debate that has occurred with respect to these models falls on deaf ears because of the arcane nature of the technical issues that are raised.

To try to better understand the core issues, SheehanBoyce, LLC has constructed a very simple system dynamics model to look at the physical stocks and flows of land movement in agriculture. It has virtually no economic considerations in it at all. The model has been used to look at some very basic questions, such as:

1. Do we necessarily have to face a land-constrained world for agriculture? This is an assumption implicit in much of the economic modeling work.

2. How do background yield improvements in global agriculture affect the LUC carbon debt for biofuels, irrespective of whether or not biofuels demand accelerates the rate of yield improvement?
3. What is the effect of improving bioenergy crop yields on the LUC equation for biofuels?
4. What is the effective of the types of land cleared due to biofuels expansion?
5. What is the effect of burdening the emergent biofuels industry with problems in global land management that are causing land clearing irrespective of overall agricultural land demand?

The model was built using the STELLA™ modeling system dynamics modeling tool (ISEE 2009). The conceptual framework of the model is shown below.



The model considers just four simple types of land stocks:

1. Land that is in its native state (undisturbed)
2. Land that is dedicated to agriculture, including grains, oilcrops and pasture
3. Land that is required for production of cellulosic biomass (energy crops)
4. Land that is abandoned because it has been badly degraded through unsustainable farming practices.

The model includes a number of important simplifying assumptions. It looks only at the effect of introducing dedicated energy crops on prime agricultural land. It does not allow for the possibility that grasses for energy production might be done on marginal land. This is a "worst case" scenario for cellulosic biomass. It ignores all other biofuels demands (for corn ethanol, biodiesel, sugarcane ethanol or other advanced crops).

Factors influencing the total stock of land in agriculture are:

1. Overall yield improvement trends for cereals, oilcrops and pasture land[3]
2. Population growth
3. Per capita demand for agricultural products (cereals, oilcrops and pasture land)

In the model, when land flows from the native land stock to agricultural land stock, there is a release of carbon associated with clearing of the land and subsequent release of soil carbon from that land. As energy crop demands grow, land flows from the agricultural land stock to the energy crop land stock. The model also captures an opportunity cost for land that could have flowed from the agricultural land stock back to the native land stock. Finally, the model allows for the fossil carbon savings associated with the substitution of petroleum fuels by cellulosic ethanol.

The model has two scenarios: one in which yields remain constant after 2007—equivalent to a scenario in which land for agriculture is constrained, meaning that any new biofuels demand must result in a land clearing effect. The second scenario allows agricultural yields globally to continue their previous historical trends.

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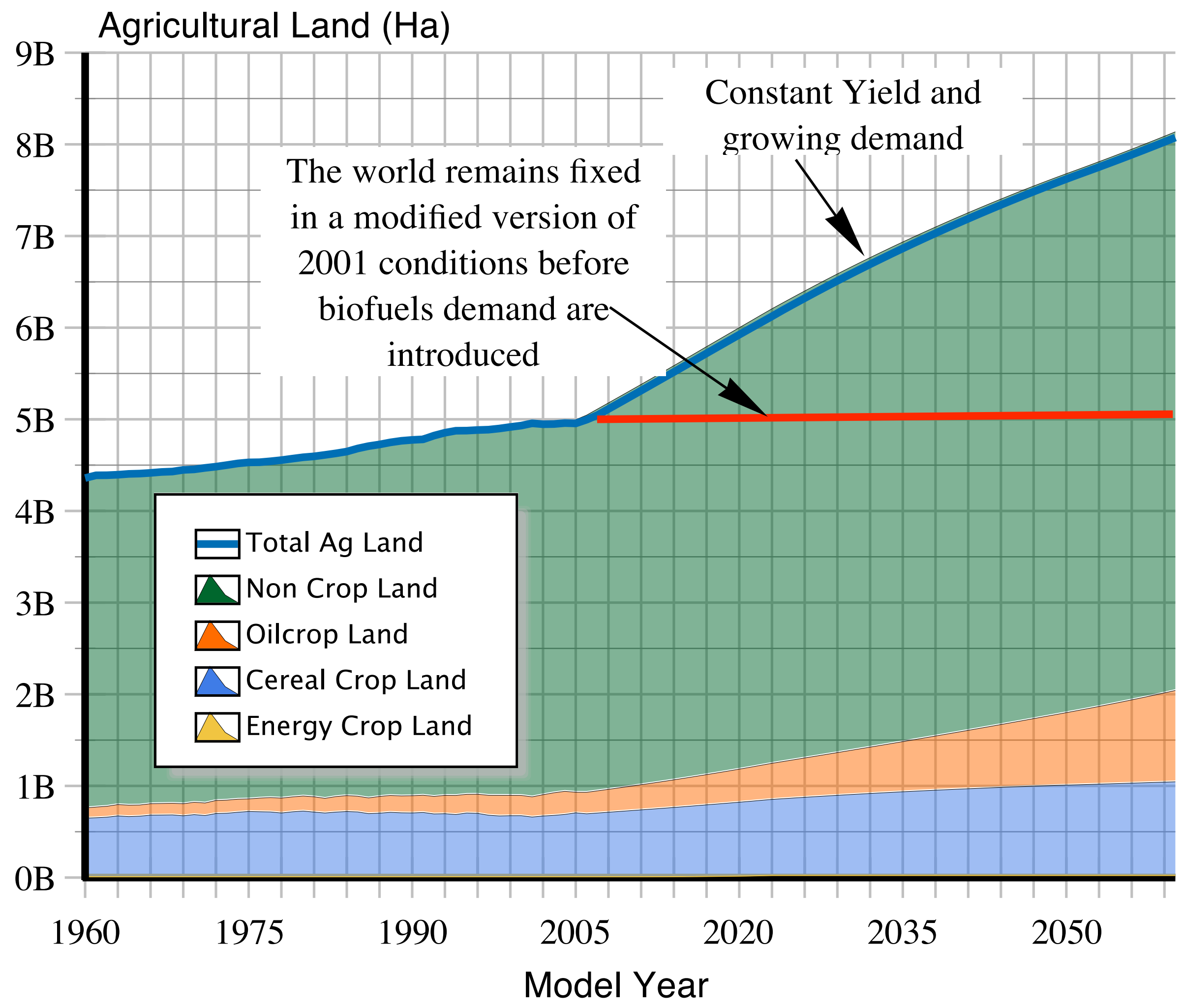
[3] Yield on pasture land is not measured directly, but rather through a proxy of the amount of pasture land in production per capita. This measure captures both growing per capita demand for animal protein and efficiency of animal husbandry on pasture land.

Do we face a land-constrained world for agriculture?

This is a critical question. If we assume that we are in a land-constrained world, then it is likely that we face some form of added carbon debt due to biofuels. The chart below depicts two scenarios for a land-constrained world.



If we assume (as Searchinger does) that yields physically will not increase because of losses in yield due to introduction of lower productivity land and we allow for continued population growth and increased food demand, then growth in demand for agricultural land rises dramatically at a rate completely inconsistent with historical data. The GTAP scenario used by CARB is illustrated by the flat line case showing a constant demand for agricultural land (without energy crops) projected forward from 2008. In other words, the GTAP model, because it is not dynamic, must basically project present day land demand into the future. Any additional demand for land from biofuels in either scenario will, by definition, lead to an incremental amount of new land being cleared for agriculture. Thus, these two scenarios will predict land clearing effects due to biofuels because they are based on *a priori* assumptions that force land clearing to occur. The only conditions that allow for avoiding land use change require a reduction in food demand due to high food prices or a yield improvement response triggered by higher prices, neither of which is a large enough to offset new biofuels-driven land nor particularly desirable (in the case of reducing people's purchasing power for food).

CONCLUSION. The CARB/GTAP and Searchinger models for land use change are, in a way, based on circular reasoning. They set up conditions such as fixed pre-biofuels land demand (in the case of GTAP) and constant yield (in the case of Searchinger), which make it almost impossible to avoid indirect land use changes.

If the dynamic model is allowed to project forward the historical trends for yield and for food demand, it paints an entirely different picture (see figure on next page). Without inducing any yield improvement above what is already happening in agriculture (based on historical trends),[4] the model predicts that ultimately the total amount of land required in the agricultural stock will begin to decline. In other words, historical trends in yield improvement are more than sufficient to offset growing demand from world population. To the extent that this demand declines, there is now room in the future for biofuels expansion that does not lead to new land clearing. There are many caveats to this result. These include:

- The FAO data sets used to extrapolate future trends are not entirely reliable. Global data is inconsistent across countries.
- It is reasonable to question the ability to continue historical yield growth rates, though there are certainly ways to envision dramatic improvements in average global yield by reducing the disparity between food productivity in developed and developing countries.
- Per capita demand for food may actually rise faster than historical rates would predict because of the rising incomes in many of the developing nations.

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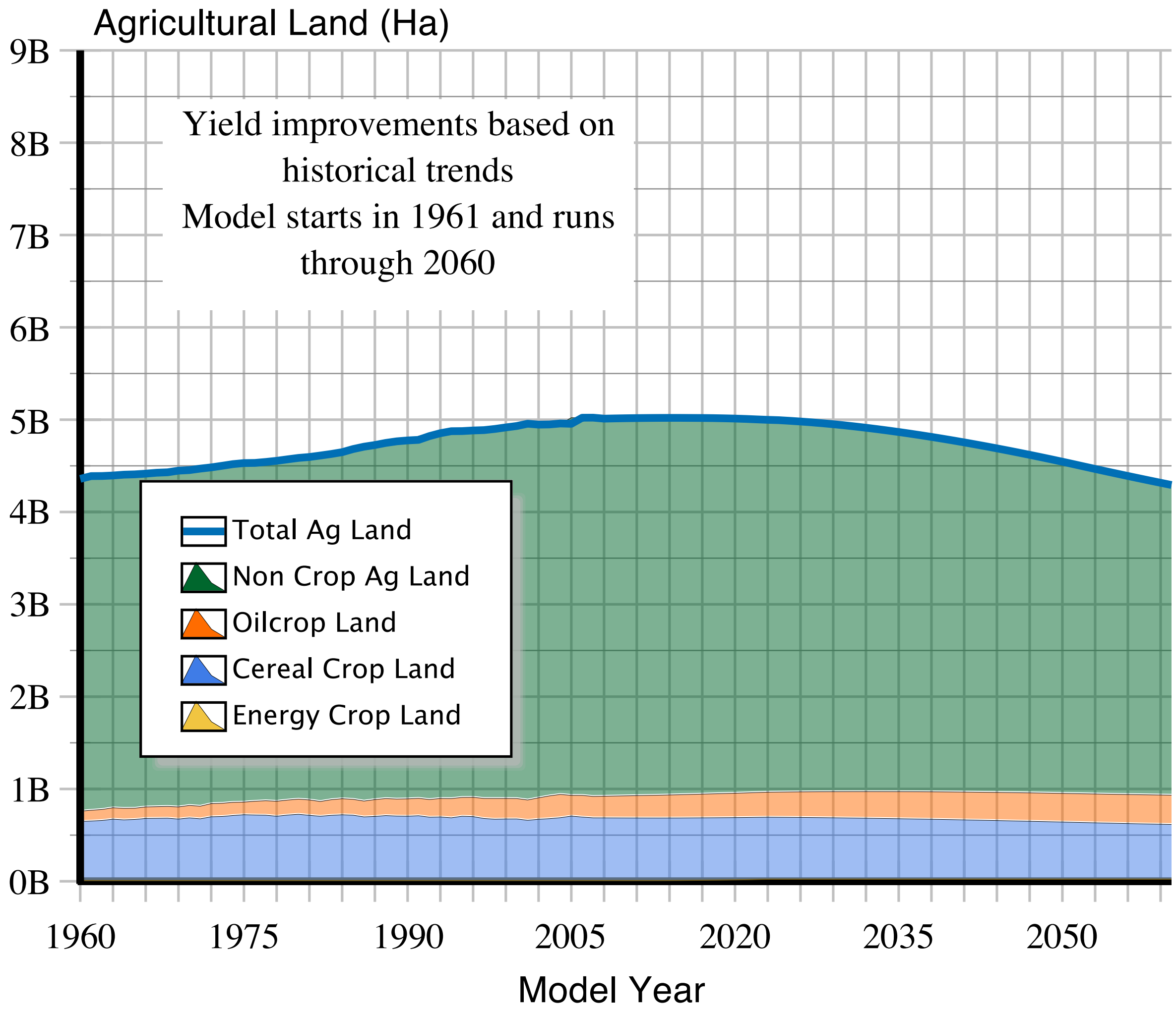
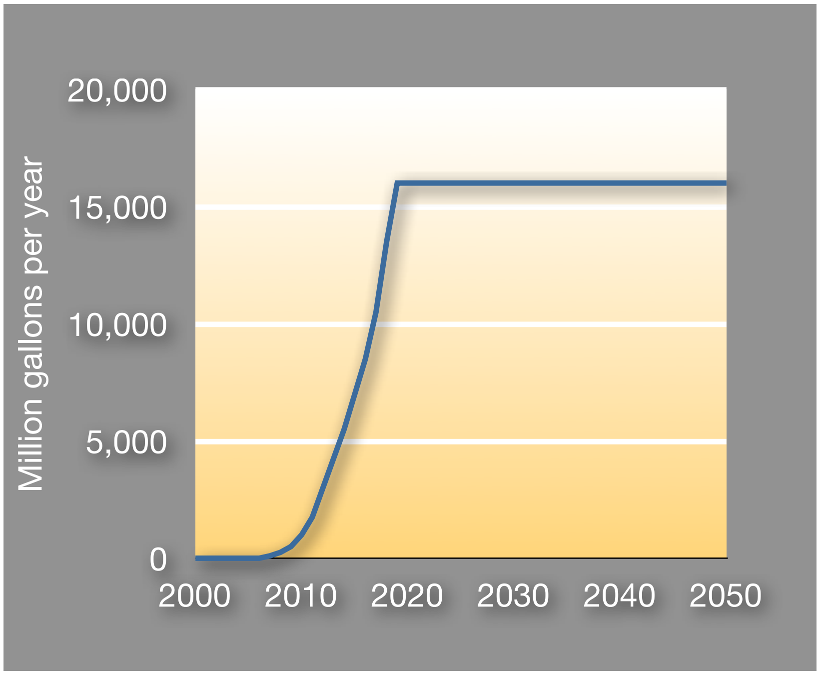
[4] That is, without requiring a major price-induced yield improvement response.

CONCLUSION. We are not necessarily locked into a future of land deficits—a prediction that is almost guaranteed by the implicit and explicit assumptions in the GTAP and Searchinger models. To the extent that the demand for global agricultural land could decline, there is room for expansion of biofuels without the potentially large carbon debt associated with land clearing.

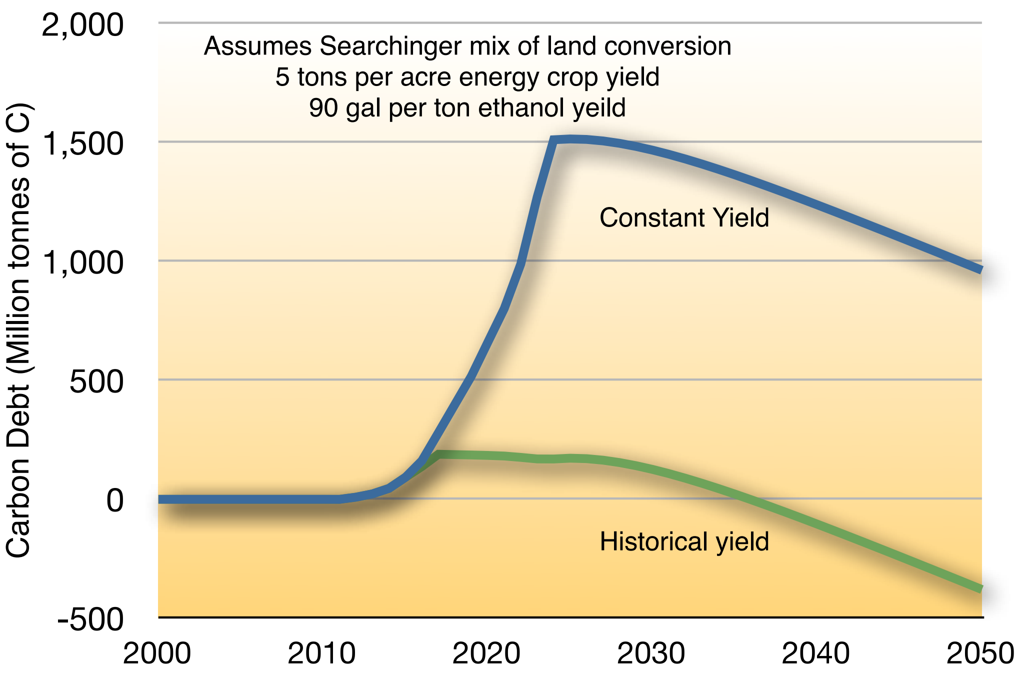


How does background yield growth effect the LUC carbon debt of cellulosic ethanol?

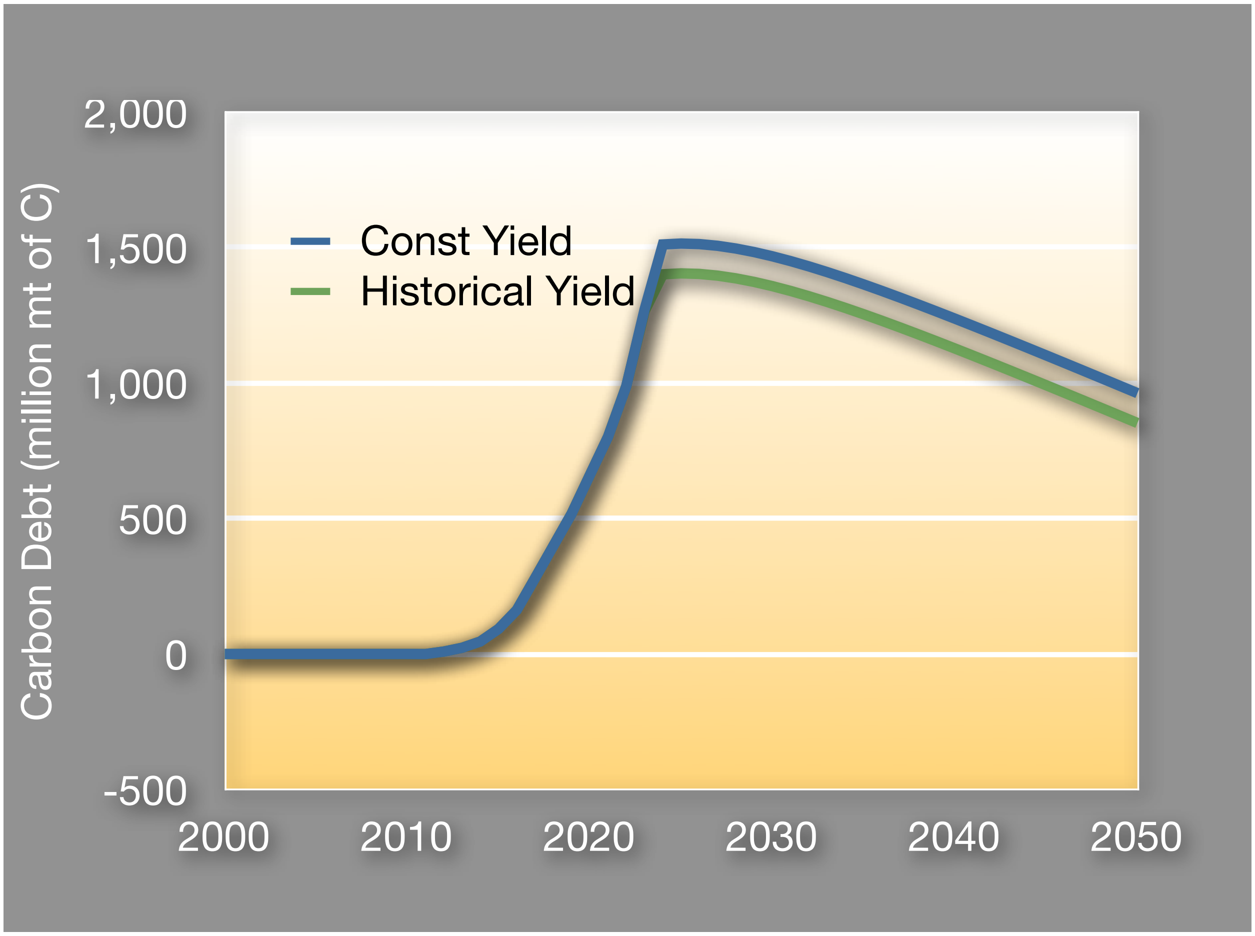
The model has been used to test the effect of introducing 16 billion gallons per year of by the year 2022, per the schedule laid out in EISA 2007 RFS2, as shown in the figure on the next page.



The associated carbon debt associated with this amount of additional cellulosic ethanol, assumed to be grown on agricultural land and not marginal land, is shown in the figure below.

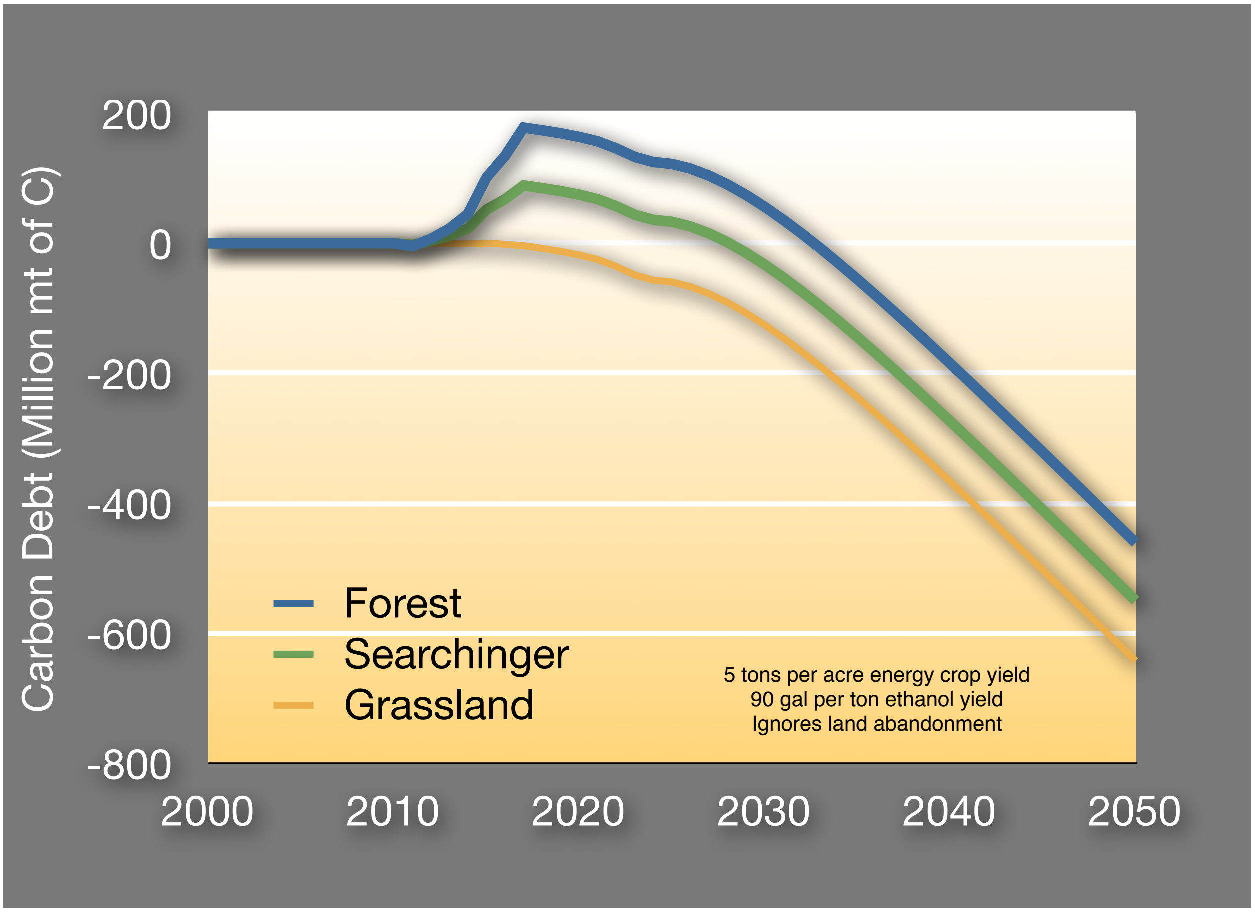


In the constant yield case, the carbon debt is quite substantial, especially since the mix of land that is cleared is assumed to be 51% forest land per Searchinger's original analysis. When historical trends for global yield growth are allowed to continue, This carbon debt is dramatically reduced. While there is still an opportunity cost effect associated with the notion that excess land could have been put back into its native state rather than diverted to energy crop production, the effect is much smaller than the land clearing debt that occurs when no excess land is available. Keep in mind that these results do not account for other causes of land clearing, particularly the problem of land abandonment due to unsustainable farming practices in many developing nations. But there is a legitimate debate about whether such unrelated land use change problems should be counted against biofuels, particularly in a scenario where the net demand for agricultural land is declining. If the burden of replenishing the abandoned land is counted against biofuels, then the carbon debt remains high, even with historical yield growth:



What is the effect of the type of land converted to agriculture?

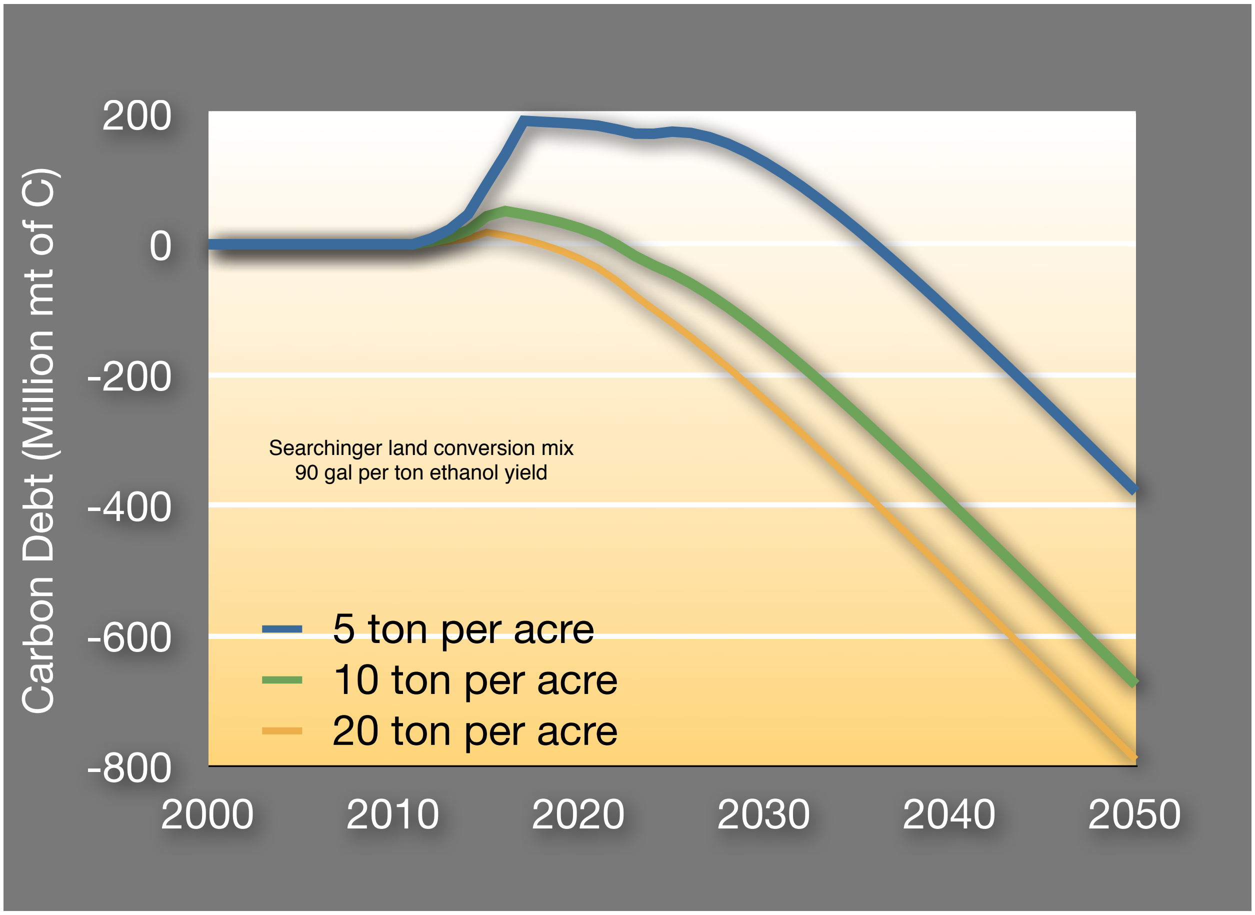
As noted earlier, the GTAP analyses done for CARB show a dramatically different mix of land types being converted, relative to the mix predicted by Searchinger et al. This one assumption has a huge effect on the carbon debt for cellulosic ethanol:



If the land converted is predominantly grassland, the carbon debt is extremely small, and it takes only a few years for the savings in fossil CO2 to begin paying off.

What is the effect of energy crop yield assumptions on the LUC carbon debt?

Equally important is the assumption of yield for energy crops on prime agricultural land. As the figure below shows, even with the Searchinger mix of land converted to agriculture, the yield of energy crops can dramatically reduce the carbon debt, as shown in the figure on the next page.



CONCLUSIONS AND RECOMMENDATIONS FROM THE MODEL

The number of factors affecting the carbon impacts of land use change for biofuels is significant. Many of them are outside the control of the biofuels industry. The model shows any number of scenarios in which the carbon debt of land use change for biofuels can be almost eliminated. For these reasons, indirect land use change should be regulated in flexible way that incentivises sustainable land management practices, rather than in a way that a priori penalizes the biofuels industry.

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