LAND USE EFFECTS OF U.S. CORN-BASED ETHANOL

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1.0 Executive Summary

This study assesses land use changes and related greenhouse gas (GHG) emission impacts due to expansion of corn-based ethanol production in the United States. The land use change estimates discussed in this paper were developed for a scenario where U.S. corn-based ethanol production expands from approximately 2 billion gallons per year in 2000/2001 to 15 billion gallons per year (bgy) in 2015/16. The overall conclusion of this report is that 15 bgy of corn ethanol production in 2015/16 should not result in new forest or grassland conversion in the U.S. or abroad.

Two basic factors are required to estimate land use change impacts of corn-based ethanol. The first factor is how much non-crop land such as pasture, grassland, or forest must be converted to cropland in the U.S. and around the world to ensure heightened corn demand for ethanol production can be met, while the food and feed demands of the world are also being met (significant amounts of land are converted from one crop to another, but this does not result in a carbon dioxide release). The second factor is the GHG emissions released when the various types of land are converted to cropland. For example, when converting pasture to crops, the land is typically tilled and the grass and roots decompose, thereby releasing carbon dioxide through decomposition. Stored carbon in the soil is also converted to carbon dioxide and released.

For the first factor, we relied on projections of global agricultural land use performed by Informa Economics for the Renewable Fuel Association (RFA). We modified these projections using data from a more recent study on the use of distillers grains in livestock rations performed by Argonne National Laboratory. Informa estimated the land needed for crops in the U.S. and other major countries from 2000/01 to 2015/16. Informa used historical yield data from the U.S. Department of Agriculture (USDA) for the major crops from 2000 to 2007, and then projected yields for these crops to 2015 from trend analysis and an analysis of emerging technologies that would affect yields in the 2008-2015 time period. Informa's yield projections are higher than projections by the USDA for the 2008-2015 period. For example, Informa estimates that the yield for corn will expand from 151.1 bushels/acre in 2007/08 to 183 bu/acre in 2015/16. The corresponding USDA projected yield for 2015/16 is 169.3 bu/acre. Yield trajectories were estimated for other major crops in the U.S., and for all crops in countries outside of the U.S.

Informa's projections indicate that the increase in corn use for U.S. ethanol production through 2015 can be met without a decline in exports or a decline in stocks. The firm projects that, given an increase to 15 bgy of ethanol by 2015/16 and all else being equal, U.S. corn exports will stay constant at between 1.8-2.0 billion bushels per year, wheat exports will be constant, and soybean exports will increase steadily through 2015. Of course, exports could theoretically be higher without an increase in ethanol from corn, but we do not know how much higher. We are assuming in this analysis that land use changes abroad due to increased demand for corn are not attributed to ethanol as long as U.S. exports remain constant or increasing. It is also noteworthy that distillers grains exports have increased dramatically in recent years, effectively displacing some amount of corn and soybean meal exports.

While most of the new demand for corn will be met through higher yield per acre, Informa projects that incremental amounts of land for additional corn production in the U.S. could come from soybeans, wheat, cotton, and some land currently in the Conservation Reserve Program (CRP). As indicated later in this summary, we believe CRP land will not be needed to meet incremental corn ethanol demand. Land devoted to wheat has been on the decline over the long term due to slightly increasing yields and less demand because of increased demand for higher protein diets. In addition, some of the lost U.S. cotton production has moved to China and India, where genetically engineered cotton has improved yields there.

Informa's projections include a land use credit for distillers grains (DGs), a major co-product from ethanol processing that is fed to livestock.[1] Since this co-product replaces some grain and protein meal (typically soybean meal) used for feed, it reduces the land use impact of corn used for ethanol production. Informa's base case assumes that DGs replace base corn feed only on a pound-for-pound basis, and this leads to a 31% credit in land use impacts.[2] We believe this is a conservative assumption, as recent research by Argonne conducted after the Informa estimates were prepared indicates that the replacement mass ratio is about 1.28 lbs. of DG replacing 1 lb. of base feed (due to higher protein and fat content) and that the DGs replace some soy meal (or other protein meal) in addition to corn. Since soybean yields are much lower than corn yields per area, any soy meal that is replaced by DG has a greater land-use impact than if only corn is replaced. With this updated data, the land use credit would be nearly 71%.

With a 31% DG credit, Informa estimates that by 2015/16, 34.6 million hectares (mha) in the U.S. will be in corn, with a net amount of about 7.8 mha (23%) devoted to ethanol. This 7.8 mha is 6% of total U.S. cropland, not including CRP, and 0.9% of the world's cropland. However, if the recent Argonne analysis of DG replacement is used, the amount of land used for ethanol in the U.S. would be

[1] Feed co-products from ethanol production are marketed in several varying forms. Distillers Dried Grains with Solubles (DDGS) and Wet Distillers Grains (WDG) are the most common feed co-products. For simplicity, we refer to all of these products simply as Distillers Grains, or DG.

[2] Informa's analytical framework does not address the amount of soybean meal that is displaced by DG because past analyses have not dictated this level of detail. The firm acknowledges that the 31% DG credit may be conservative, in that it addresses only the displacement of corn but not soybean meal.

3.4 mha, or less than 10% of the U.S. corn crop on a net basis. This 3.4 mha is 3% of the U.S. cropland without the CRP, and 0.5% of the world's cropland.

If we use Informa's overall analysis of land needs, coupled with the recent Argonne analysis of the impact of DGs on livestock feed rations, no new pasture or forest land should be converted in the U.S. or outside the U.S. to meet 15 bgy of corn ethanol in 2015, and the land use change emissions therefore are likely zero. Even if we assume the somewhat lower USDA projected yield of 169.3 bu/acre in 2015/16, no new pasture or forest land should be converted in the U.S., based on the Argonne DG credit.

The California Air Resources Board (CARB) currently estimates the CO_2 emissions from gasoline at about 96 grams of carbon dioxide-equivalent/Megajoule (g CO_2eq/MJ), and the CO_2 emissions from corn ethanol from a natural gas-powered dry mill ethanol plant at about 68 g CO_2eq/MJ, without the land use impacts. This represents about a 30% GHG reduction benefit for corn ethanol. There would be no change in this benefit with the addition of land use impacts as modeled in this paper.

The results from this study stand in stark contrast to results from at least one other study, and recent work conducted by CARB. The results from Searchinger, et al., released February 2008 in *Science Express* (hereafter referred to simply as the Searchinger paper) suggest the corn ethanol lifecycle GHGs attributable to land use change are 104 g CO_2eq/MJ per gallon. Searchinger used the Center for Agricultural and Rural Development (CARD) system of models to evaluate the land use changes associated with an increase from 15 bgy of ethanol to 30 bgy of ethanol. It estimated that when U.S. ethanol was increased from 15 to 30 bgy, that U.S. exports would decline (corn by 62%, wheat by 31%, and soybeans by 28%), and that these export declines would have to be met through increased production overseas at lower productivity rates. Therefore, the land use change impacts would be greater than if the conversion took place in the U.S. The CARD modeling did take into account a DG credit of about 33%, which is nearly the same as the Informa projections referenced above. However, the Searchinger study assumed that yield improvements in corn production on existing land *would be completely offset by much lower yields on the new lands brought into production*. This assumption was made without performing any robust analysis on the productivity of marginal lands, or of recent trends in corn yield growth outside of the United States.

Recent CARB work presented at a January 30, 2009 workshop in Sacramento indicated that CARB expects the land use emissions for corn ethanol to be 30 g CO_2eq/MJ, much lower than the earlier Searchinger estimates. ARB has been assisted in this work by researchers from U.C. Berkeley (UCB) and Purdue University. The CARB modeling uses a different analytical framework (the Global Trade Analysis Project, or GTAP, model), but uses the same per-acre emissions rates as the earlier Searchinger analysis. The GTAP model's baseline land use database is for the 2000/2001 time period. The static model is "shocked" for a 13.25 bgy ethanol increase in the U.S. and the model converts other cropland, forest and pasture in the U.S. and around the world (U.S. exports decline) to accommodate the shock. No matter what size the shock, the model must somehow handle the entire shock instantaneously, instead of over time. Thus, the model is answering the question of how much land would be needed if ethanol were suddenly increased in 2001, not how much land is needed if ethanol is increased over a gradual period of time like 2001 to 2015. These are two completely different questions with different answers.

The GTAP model also uses a 33% land-use credit for DGs, and divides the total emissions by 30 years, the same as the Searchinger analysis. The GTAP model was used to estimate the emissions from a 13.25 bgy increase in ethanol (the difference between 2015 ethanol volume and 2001 ethanol volume), which is very similar to this study, as well as the 15 bgy increase assumed by Searchinger (although the Searchinger analysis started at a higher base level of 15 bgy). Crop yields are projected to increase with crop prices in response to the shock, but the net effect of this is negligible. In the GTAP analysis, corn yields in the U.S. increase on the shock only a few percentage points, from about 138 bu/acre to roughly 141 bu/acre, far below actual realized yields in the 2002 to 2008 period and the USDA projections for 2009 to 2015. There is a price-yield elasticity built into the model (endogenous effect), but it does not take into account crop yield increases due to technology changes (i.e., so-called exogenous yield improvements) that have occurred between 2001 and 2008, much less expected improvements between 2008 and 2015. As a result, too much pasture and forest is converted in the U.S and abroad in the CARB analysis. Researchers at UCB and Purdue have proposed a method to adjust their results for exogenous yield changes, and this is currently being evaluated. Overall, we think that a number of corrections need to be made to GTAP before it can be utilized to fairly project land use changes due to any biofuel increases.

Based on the 1990 to 2008 trend and recent literature on yield potential, we believe average yields will continue to improve (especially in the U.S., but also outside the U.S.). Observed yield improvements since 2001 and projected yield increases should be incorporated into land use change modeling; we have done this appropriately in this study. Secondly, we think the Argonne analysis shows that the land-use credit for corn-based ethanol is much higher than 33%, and when this is incorporated, neither forest nor pasture will be converted to crops as a result of the increase in the biofuel mandate to 15 bgy in 2015.

2.0 Introduction

Until early 2008, ethanol made from corn and blended with gasoline was estimated to reduce GHGs by about 20-30% relative to gasoline, with the percentage reduction depending largely on the production facility's source of process energy and drying practices for feed co-products. For example, a 2007 analysis by Argonne National Laboratory using the GREET model (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model) indicated a typical natural gas-fueled dry mill reduces GHGs by 28% compared to gasoline on a lifecycle basis. [1]

On December 17, 2007, the President signed into law the Energy Independence and Security Act of 2007 (EISA), which among other provisions, required an expanded renewable fuel standard (RFS2) that increases biofuels production to 36 bgy by 2022. Of this amount, the law requires that 15 bgy come from "conventional" (corn starch-based) ethanol. EISA established several different categories of biofuels, characterized by their reductions in "life-cycle" GHGs versus the baseline fuel the biofuels were blended with (gasoline or diesel fuel). For lifecycle analysis of biofuels, EISA also required the U.S. Environmental Protection Agency (EPA) to evaluate the indirect GHG emissions, such as those presumed to result from indirect land use changes. For example, so-called "advanced biofuels" in the Act are those with lifecycle emissions at least 50% less than the lifecycle GHG emissions of baseline gasoline.

The Act defines lifecycle GHG emissions as "the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all states of fuel and feedstock production and distribution, from feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass of values for all greenhouse gases are adjusted according to account for their relative global warming potential." [2] The policy provision requiring assessment of indirect GHG effects was the first of its kind to be included in a major public law.

In California, Executive Order S-1-07, the Low Carbon Fuel Standard (LCFS) (issued on January 18, 2007), calls for a reduction of at least 10 percent in the carbon intensity of California's transportation fuels by 2020. It instructed the California Air Resources Board (CARB) to coordinate activities between the University of California, the California Energy Commission and other state agencies to develop and propose a draft compliance schedule to meet the 2020 target. Furthermore, it directed CARB to consider initiating a regulatory proceeding to establish and implement the LCFS. In response, CARB identified the LCFS as an early action item with a regulation to be adopted and implemented by 2010.

In August 2007, UCB researchers completed a study of the LCFS for CARB. The second part of the UCB study discussed policy implications of the LCFS. Recommendation 14 of the policy analysis was for CARB to:

> "Develop a non-zero estimate of the global warming impact of the direct and indirect land use change for crop-based biofuels, and use this value for the first several years of the LCFS implementation. Participate in the development of an internationally accepted method for accounting for land use change, and adopt this methodology following appropriate review." [3]

California has been following this recommendation, and there have several CARB workshops where the development of preliminary land use change GHG values have been discussed.

In February 2008, a paper published by Searchinger and others in *Science Express* provided a first estimate of the indirect GHG emissions resulting from land-use changes brought about by increased production of ethanol made from corn. [4] The numbers were much higher than earlier estimates of direct land use effects (such as the default estimate in the GREET model). The study estimated that corn ethanol, instead of reducing GHG emissions by 20% relative to gasoline, increased these emissions by about 100%. Since its publication, the study has been the center of a lively debate about the land use impacts of corn ethanol and other biofuels.

In the last year, both U.S. EPA and CARB have been studying land use impacts. EPA has been analyzing land use change for implementing the expanded RFS in accordance with EISA, and CARB has been evaluating land-use impacts as a part of its LCFS development process. CARB is working toward an April 2009 Board Hearing for the LCFS regulations. EPA plans to release its RFS2 Notice of Proposed Rulemaking in 2009, which will contain much of its analysis of direct and indirect land use impacts.

CARB and the U.S. EPA are using different economic models to evaluate land-use changes. They are also using different methods of estimating the carbon loss when land is converted from some other use to crops. Thus, the two agencies could derive different results, even though the land use impact of expanding corn ethanol production to the levels stipulated by the RFS2 (if there is one) should theoretically be the same.

This study was undertaken to provide an independent estimate of the land-use effects of corn used for ethanol.[3] This flowed from concerns that: (1) there is a large difference between the GREET and Searchinger estimates of the GHG impacts of corn ethanol; (2) both U.S. EPA and CARB were planning to use

[3] The study does not yet address the land use effects of biofuels from other grown feedstocks, for example, woody biomass and various grasses.

either partial equilibrium or general equilibrium models to predict the size and location of the land use change and it is not clear the extent to which these models have been validated for this purpose; (3) it was not clear what inputs (projected crop yields, for example) would be used by the agencies in performing their analysis of land use change; and (4) it was not clear what data would be used to estimate the carbon emissions released for land that was converted.

Not everyone agrees that indirect land use changes should be considered in biofuels analysis. Proponents insist that it be included, while opponents generally cite the fact that estimating indirect land use changes from biofuels alone is a daunting challenge, and that the science for estimating indirect effects of any sort is in its infancy. Opponents further argue that if the agencies make significant mistakes in quantifying land use changes, it could dramatically discourage further development of biofuels production and investment in renewable energy. There is no consensus on what the most appropriate approach is to determining indirect land use changes, and many stakeholders believe no single model can capture all of the intricacies of such complex interactions. However, since the debate is moving forward quickly and has real implications for the future of the renewable fuels industry, we felt compelled to provide an analysis based on different methods.

This study uses as its foundation for land use changes a projection of global land use made by Informa Economics. Informa is a recognized economic consulting firm in the agribusiness sector, and makes and updates its projections of crops and land use in the U.S. and around the world on a frequent basis.[4] Informa does not utilize any particular partial or general equilibrium agricultural economic model to make these forecasts. Instead, it relies on quantitative analysis, its experience in evaluating economic and agricultural trends over a long period of time, and a large variety of data sources.

As a part of this study, we also compare our estimates of land use and emission changes with other estimates recently released, and provide our preliminary comments on the two economic modeling systems being used by CARB and U.S. EPA. This latter effort has been somewhat hampered by the fact that the model U.S. EPA is using is not publicly available and the agency has not yet released its draft analysis. Once we obtain the exact versions of the models, the inputs, and other information used by both U.S. EPA and ARB to generate their current estimates, we will further compare their results with the results of this study, and revise this study if necessary.

[4] Informa updates their projections every time the USDA publishes new crop reports and supply/demand estimates, which is on a monthly basis.

This report is organized in the following sections:

- Background
- Method
- Informa Economics Land Use Inventory and Projections
- Comparison with Economic Models
- Discussion

There is also one appendix:

Appendix A: Renewable Fuel Association's Comments on ARB's October 16, 2008 Workshop

3.0 Background

This section is organized into the following subsections:

- Estimating land use effects
- The role of distillers grains
- GREET model land-use GHG estimate
- Economic models
- Searchinger, et al. analysis

3.1 Estimating Land Use Effects

The general equation for estimating land use effects for fuels that use crops as a feedstock is shown below:

LUC (tons CO_2eq) = *Land converted* (acres) x *CO_2 emissions released* (CO_2eq tons/acre) + *Foregone carbon sequestration of land before conversion* (years) – *Carbon sequestered by crop system after conversion* (years)

Where:

LUC = land use change GHG emissions in tons or metric tons

Land converted = the total land converted from either grassland or forest to grow the crop used to make the fuel, and perhaps also any additional land converted to make up the reduction in the total crop due to the crop being used for fuel

CO_2 emissions released = CO_2 emission released by converting either forest or grassland to the crop

Foregone carbon sequestration = the carbon sequestration forgone for a number of years by converting either forest or grass

Carbon sequestered by crop system = the carbon sequestered by the new crop system

There are several items in the equation that bear further discussion. One is that CARB defines any land conversion to meet the demand for ethanol as an "indirect effect." [5] According to CARB, "direct effects" of increased ethanol production are the increased intensification of inputs on existing land. Thus, if a farmer uses more fertilizer to increase yield on the same acreage, and sells the extra corn for use in making ethanol, this is a direct effect. But if the farmer converts an additional 40 acres of pasture to corn, this is considered by CARB to be an "indirect effect." If the farmer switches 40 acres from soybeans to corn, and someone else in the world converts 40 acres of pasture to corn to make up the lost 40 acres of soybeans, this is considered an “indirect effect.” However, if the farmer converts 40 acres that were previously wheat to corn, and that 40 acres of wheat is not made up by a farmer somewhere else in the world, then there is no land use change effect per se, since the land is going from one crop to another crop.

The second item to note is that usually the CO_2 emissions released are from three basic sources – the plant material above the ground, some of the roots below the ground, and some of the organic carbon on or below the ground level. Generally, the conversion to carbon of plant material on the ground to CO_2 is considered relatively short. Conversion of root mass to CO_2 may take somewhat longer (3-5 years), and, release of carbon from the ground may also take longer.

Foregone carbon sequestration is the carbon that would have been sequestered had the grass in the previous example been undisturbed for a number of years, and there is also the potential for carbon to be sequestered by the new crop system. The last two terms can be combined into a “net” carbon sequestration effect, but the individual levels must be calculated.

Carbon released over time from aboveground plant material, soil, and roots, and carbon sequestered by the new crop system over time is sometimes discounted to net present value (NPV) using different discount rates, and then annualized over a fixed number of years. The CARB and U.S. EPA are currently exploring different methods of discounting and annualizing for land use change emissions.

The third item to note is that agricultural practices put into place after land conversion can have a very significant effect on reducing the impact of the initial carbon impact. Practices like no-till or reduced-till farming, and the use of winter cover crops can significantly reduce the GHG impacts of farming and can accelerate the payback time of an initial carbon debit. Quantification and implementation of these practices are very important but are beyond the scope of this particular analysis. This topic is covered in detail in a recent *Environmental Science & Technology* paper by Kim and Dale. [6] In this analysis, we conservatively assume no special abatement practices are applied to newly converted land that are not currently being applied to existing land. This is an area for future investigation.

The key questions to answer in estimating emissions using this expression are:

- What is the total quantity of land converted?
- Where is it converted?
- What type of land was converted (other crops, grass/pasture, forest, etc.)?
- How long a period should be used to amortize the emissions from the initial conversion?
- Should the future net carbon sequestration effect be discounted to net present value?

Obviously, the quantity of land converted is important; the higher the quantity of land converted for a given ethanol volume change, the greater the GHG effect per gallon. Where the land is converted is also important. This is because in countries where crop yields are relatively low, the amount of land required to make up for lost production in a country with higher yields is higher, and vice versa. The type of land converted also has a large effect. For example, if forest is assumed to be converted to crops, then there is the potential for significant carbon release and foregone sequestration. On the other hand, if land with little natural vegetation is converted and irrigated and fertilized, then there is the potential for net carbon sequestration almost immediately, rather than carbon release. There are other types of land (pasture, etc.) between these two extremes.

Finally, there is the issue of whether to discount the lost sequestration, initial and gradual carbon emissions, and carbon sequestration by the new crop to net present value, and how long a period to annualize the missions over. If emissions are discounted to net present value, they are lower. The longer the period emissions are amortized over (whether discounted or not), the lower they are.

Not all grasses release the same amount of carbon when the land is converted. Grasses can generally be divided into "native" grasses and "pasture." Native grasses store more carbon than pasture or other grasses that have been recently planted. This is because pasture is significantly disturbed by livestock, and grasses recently planted have not had time to store much carbon in their root systems. [5] Many farmers also follow a practice of cropping land for 10 years or so, and then converting it to pasture for a period of time to restore the nutrients, and then converting to crops again. Similarly, there can also be large differences in the carbon stored in different types of forests. The carbon stored above ground is a function of the size of the trees, their density, the number of trees per unit area, and other factors.

In our view, there are several questions concerning the conversion of forest. If land conversion were necessary, it is our belief that any forests that would be converted to pasture or crops would be commercial forests that are logged. It is unlikely that one would simply cut down a commercial forest releasing all of the carbon, without using some or all of the wood for productive causes. The area would be harvested heavily first, and the wood would be used in building products and other uses. Carbon would be stored in these products until they reach a landfill, and probably well beyond. Research conducted by Skog and Nicholson (USDA Forest Service) indicates:

> "The length of time wood, as opposed to paper, remains in end uses may have only a minor effect on the net amount of carbon sequestered in products in the long run. If, when taken out of use, products are disposed

[5] Personal communication with Dr. Steve Ogle, Colorado State University.

of in a modern landfill, the literature indicates that they will stay there indefinitely with almost no decay." [7]

Also, there is the issue of carbon allocation upon conversion. If a forest is converted to cropland directly, then a valid question is: should half of the carbon release be allocated to the wood harvesting operation, and the other half to the new cropland, instead of allocating all of the carbon to just the crop? Forests, however, are usually converted to pastures before being converted much later to cropland. In this case, perhaps 33% allocation to each purpose is more appropriate. These issues are important to consider and discuss because at least one major study (the Searchinger study) allocated all the above-ground carbon in a converted forest to the crop, and in turn to biofuels, directly. Even the current CARB analysis is allocating all of the forest conversion to biofuels, without subtracting the mass of wood that can be used in construction or some other purposeful application, where carbon is not released for a long time.

In addition to the above factors, we also add an additional factor that depends on the trajectory of U.S. exports. If U.S. exports are constant or increasing from the onset of ethanol increases in the U.S. (we are assuming this is 2000/2001, although ethanol use has been increasing for much longer) we assume that non-U.S. land converted to crops to meet non-U.S. demand is not attributable to ethanol expansion. If U.S. exports were to decline from 2000/2001 levels, we would assume an international land use effect could be applied to ethanol expansion.

3.2 The Role of Distillers Grains

Distillers grains (DGs) are a co-product of producing ethanol from corn. DGs are a protein and fat-rich feed source that is used to feed livestock and poultry. In the corn ethanol lifecycle, production of DGs fulfills two purposes. First, the energy of these co-products can be subtracted from the total energy used to produce ethanol, resulting in a lifecycle "energy credit." Second, they significantly reduce the land use impact of ethanol made from corn by displacing some of the corn and other feed ingredients in livestock diets.

The GREET model uses the displacement method to estimate the DG energy credit. The energy credit is estimated as the energy required to produce a product that would be a suitable substitute for the DGs.

DGs can be provided from the ethanol plant in the "wet" or "dry" form. If they are dried, then the ethanol plant uses more energy (typically natural gas to fuel dryers). Conversely, energy use by the ethanol plant is much lower if DGs can be provided in the wet form. However, in the wet form they must be fed to livestock relatively quickly before they degrade.

With regard to land use, DGs are important in reducing the land requirement of ethanol from corn. Most corn in the U.S. is used to feed livestock, so when DGs from an ethanol plant are used to feed livestock, they supplant some raw corn products. As a result, somewhat less corn needs to be planted to feed livestock, and less land is used than if DGs were not fed to livestock. In addition, the U.S. is exporting significantly more DGs (4.51 million metric tons in 2008, compared to 787,000 metric tons in 2004.). This displaces some amount of demand for corn and soybean meal exports for animal feed. In fact, the amount of distillers grains exported in 2008 is equivalent in feed value to 4.3 mmt (~170 million bushels) of whole corn *and* 1.3 mmt of soybean meal.

The amount of land credit applied to DGs is a function of two factors. One is the mass ratio of raw corn and soy products that DGs replaces in the livestock diet. Recent research by Argonne National Laboratory indicates that 1 pound of DGs replaces about 1.28 pounds of conventional corn- and soy-based feed in aggregated rations.[6] [8] This greater-than-one-to-one replacement ratio is due to the fact that DGs are generally higher in protein and fat than the diet they are replacing.

The second item that affects the land use credit is the amount of soy meal in the base diet that is being replaced. Because the yield of soybeans per hectare is much lower than corn on a volume basis, the more soybean meal in the base diet that DGs are replacing, the greater the land use credit. The recent Argonne analysis found that 24% of the 1.28 lbs of base diet (or 0.303 lbs) replaced by 1 lb of DGs was soybean meal. We utilize Argonne's estimate of DG land use credits later in this report in section 5.10, and provide further discussion there.

By comparison, the 2005 Renewable Fuel Standard Regulatory Impact Analysis (RIA) published by U.S. EPA assumed that DGs replace base feed on a one-for-one mass basis, and that 90% of the base feed replaced was corn meal, and 10% soy meal. [9]

The CARB Corn Ethanol GREET report states that the formulas for total feed corn and soybean meal displaced are based on an U.S. EPA assumption that 1 ton of DG replaces 0.5 ton of corn meal and 0.5 ton of soybean meal. [10] However, CARB appears to have made this assumption only for estimating the net energy use in the ethanol plant and does not appear to apply a land use credit in CARB's land use change analysis that assumes some amount of soybean meal is being replaced by DGs. Recent documentation for the GTAP model used by CARB in estimating land use effects shows that Purdue modified the GTAP model only to replace corn meal, and not soy meal. [11] Thus, these two assumptions are inconsistent within the CARB modeling framework. GTAP estimates that the DG land use credit is about 33%, meaning that the DG credit

[6] Other lifecycle analysis models use a similar mass replacement ratio. In fact, GHGenius, a model developed by Natural Resources Canada, also estimates 1 lb. of DG replaces 1.28 lbs. of corn and soybean meal in livestock rations.

reduces the total land use impact of corn used to make ethanol by 33%. Based on the recent report from Argonne and other research on how DGs are being fed to livestock, we believe the GTAP credit is too low. [7]

3.3 GREET Model Land Use Estimate

Even though the issue of including land use change in lifecycle modeling has only recently gained significant attention, the GREET model has included a land use change factor since 1999, when ethanol volumes were much smaller than they are today. [12] The land use estimate used the following procedure:

- The USDA's Office of Energy Policy and New Uses simulated the changes in production and consumption of major crops that would be caused by a selected, presumed change in corn ethanol production. The simulation was conducted on the basis of an assumption that the amount of corn used for ethanol production would increase by 50 million bu/year beginning in 1998. In the study, the total corn increment to be diverted to ethanol production was 650 million bushels from 1998 to 2010, a demand that would double ethanol production to over 3 bgy.

- The USDA's simulation showed an increase in planted land in the US of 97,400 acres between 1998 and 2010. In the analysis, the additional acres were assumed to be from idled crop or pastureland. On this basis, and with an emissions factor of 204,000 g CO_2/acre for this land, Argonne estimated an increase in lifecycle GHG emissions for corn of 57 g/bu.

- The USDA simulation showed that increased U.S. ethanol production would reduce domestic corn exports to other countries. Argonne estimated the lost protein from the reduced exports, and assumed that 50% of the lost protein would be made up by planting corn in other countries. Using lower corn yields in these countries than in the U.S., and that pastureland would be converted in these countries, Argonne estimated an additional 333 g CO_2/bu from areas outside the US.

- The total GHG emissions estimated were therefore 57 g + 333 g/bu, or 390 g/bu. This converts to 1.9 g CO_2eq/MJ ethanol.

Argonne acknowledges that these numbers need to be updated using more recent information, and at much higher ethanol volumes. Also, the Argonne values here do not reflect their latest research on land use credits due to DGs. Argonne has efforts underway to update these numbers.

3.4 Economic Models

[7] For example, see Klopfenstein et al., 2007; Anderson, 2006; and Birkelo et al., 2004.

There are two economic modeling systems that are being primarily used to produce estimates of land use change: the Center for Agricultural Development (CARD) system, which includes the Forest and Agriculture Sector Optimization Model (FASOM) and the Food and Agriculture Policy Research Institute (FAPRI) model; and the Purdue University Global Trade Analysis Project (GTAP) model. It is notable that neither of these modeling systems was developed expressly for land use change analysis.

FASOM is a dynamic, partial equilibrium, optimization model of the U.S. economy. It models the response of American forest and agricultural sectors to policy changes. It accomplishes this by predicting optimal allocations of available land to competing agricultural and forestry uses, subject to standard economic constraints. It then estimates the impacts on the commodity markets supplied by these lands and the net greenhouse gas emissions associated with these changes.

The FAPRI is a partial equilibrium model; it estimates agricultural sector impacts in countries with which the U.S. maintains agricultural trade relationships. Although FAPRI can estimate the amount of land demanded in each crop and livestock activity, it does not explicitly model the land markets themselves.

GTAP is a general equilibrium model. Within GTAP's scope are 111 world regions, some of which consist of single countries, others of which are comprised of multiple neighboring communicates. Each region contains data tables that describe every sector in every national economy in that region, as well as significant intra- and inter-regional trade relationships. GTAP has been extended for land use change GHG emissions modeling by the addition of a land use module that includes data on 19 agro-ecological zones for each region of the model, as carbon emissions factor table, and a co-products module, which adjust GHG emission impacts based on the market displacement effects of co-products such as the distillers grains which ethanol production yields. [13,14,15,16,17]

The CARB is currently using GTAP to model land use changes. However, U.S. EPA is using the FASOM and FAPRI models for the same purpose. The FASOM and FAPRI models are not publicly available.

Significant development work is continuing with the GTAP model on the land use module and emission impacts at this time. For example, until May 2008, the model did not include a method of accounting for the impacts of co-products on land use. And, until January 2009, no method was being used to account for very important exogenous yield improvements. Consequently, any research conducted using earlier versions of the GTAP model and the impacts of biofuels on land use is obsolete. As discussed, the current version of the model assumes that 1 lb. of DGs replace 1 lb. of corn (no replacement of soy meal). Thus, the land use credit for DGs in the model is about 33%.

We have identified a number of concerns with using the current GTAP model to develop estimates of land use impacts related to biofuels production. These concerns are explained in Section 6 and Appendix A.

3.5 Searchinger, et al., Analysis of Land Use Effects of Corn Ethanol

The February 7, 2008 edition of *Science Express* contained a report by Searchinger, et al. entitled "Use of Cropland for Biofuels increases greenhouse Gases Through Emissions from land Use Change." The major conclusion from this report was that "Using a worldwide agricultural model to estimate emissions from land use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years." The study estimated the land use change due to corn-based ethanol at 104 g CO_2eq/MJ. This is 55 times the amount estimated previously in the GREET model.

The Searchinger paper used the CARD system of models to predict land use changes occurring throughout the world for an expansion of ethanol volume from 15 bgy to about 30 bgy, an expansion of 15 bgy. Appendix C of the Supporting Materials provided online indicated that net land converted from either forest or grass to crops would be 10.8 mha. In the U.S., new land converted would be 2.25 mha, and the remaining 8.55 mha would be outside of the U.S. Also, in the U.S. there would be 7.8 mha of new corn crop, with a reduction of 3.8 mha of soybeans, and a reduction in 1.8 mha of wheat.

The first factor that had a major impact on these results is that projected yield improvements were assumed to be completely offset by the lower productivity of additional land being converted to crops. This assumption was made in the U.S. as well as outside the U.S.

The CARD modeling utilized by Searchinger predicted significant declines in U.S. exports: a 62% decline in corn, a 31% decline in wheat, and a 29% decline in soybeans. There was also a decline in pork and chicken exports, but an increase in beef exports. Overall, the analysis showed significant declines in U.S. exports to other countries. With the reductions in U.S. exports, the modeling system estimated that other countries needed to significantly ramp up their production to make up for the loss in U.S exports. And because the productivity of agriculture in non-U.S. areas is generally less than the U.S., this resulted in considerably more land being converted outside the U.S than would be the case if the productivity outside the U.S. was the same as within the U.S. If the predicted reduction in U.S. exports does not take place, then it stands to reasons that there would be little land converted outside the U.S., and the Searchinger land use effects estimate would be too high.

A second factor that had a major impact on these results is that projected yield improvements were assumed to be offset by the lower productivity of additional land being converted to corn. This is closely related to the first effect; if exports are lower, then land needs to be converted outside the U.S. And if land outside the U.S. is converted, then perhaps the lower productivity of these lands offsets the yield improvements on existing lands.

The Searchinger analysis did account for the impact of DGs from ethanol plants on land use, but appears to have underestimated the impact. The analysis estimated that DGs reduced the land use impact of corn ethanol by about one-third.

A third factor which had a significant effect on the result is the assumptions of what types of land would be converted in each of the countries and the emissions associated with conversion of the respective land types. For this, Searchinger relied on data from the Woods Hole Research Center for the types of land converted in the 1990s in various countries [18]. For example, the analysis assumed that 62% of the land converted in the U.S. would be grassland, and 36% would be forest. In Brazil, it was assumed to be 24% grassland and 75% forest (1% was assumed to be desert). If the mix of land types that get converted due to increased biofuel production in the 2001-2015 time period is different than the historical conversion estimates, the final result would vary widely.

A fifth factor is that Searchinger used a modeling run that simulated increasing ethanol production in the U.S. from 15 bgy to 30 bgy. The starting and ending ethanol volumes are dramatically higher than the true starting and ending ethanol volumes that would occur from 2001 to 2015, generally understood to be 1.75 bgy to 15 bgy. Searchinger defends the use of these higher volumes by saying that when they evaluated a smaller range of ethanol increase from 15 to 18 bgy, they obtained the same emissions on an emissions/MJ basis. This is not a surprising result, because the analysis of a smaller increase in volume shows a smaller but significant export loss, so there are no net yield improvements (same as base case), and the analysis is assuming the same proportion of the types of land converted as a higher volume. With these assumptions, one could increase the volume by 10x or cut it by 10x and still obtain the same result per MJ). However, in the real world, things are never this linear. For example, it is very likely that the mix of land types converted in various countries (and particularly the U.S.) would significantly change depending on how much land is needed. This is not being taken into account in the Searchinger analysis, and it would have an important effect on the results.

4.0 Methodology Used in This Study

Our original intent in generating an independent corn ethanol land use change estimate was to use either the FAPRI/FASOM system or GTAP to predict the land use changes resulting from increasing corn ethanol production to levels called for by EISA in 2015. However, we believed it would be premature to attempt to use these models without first reviewing the many inputs to them and the sensitivity of the respective models to changing such inputs. Further, the FASOM and FAPRI models employed by EPA for the RFS2 land use change analysis are not publicly available.

Since CARB had stated its intent to use the GTAP model (which is publicly available) for estimating land use changes, we decided to evaluate GTAP for use in making these estimates. As we started to review the GTAP model and supporting literature, we became concerned that there were significant issues associated with using this model for this type of analysis. These concerns are explained in more detail in Section 6. The major underlying concern is that the model does not incorporate a dynamic time element and must be "shocked" for a 13.25 billion gallon ethanol increase (simulating the increase in ethanol between 2001 and 2015). The model must "handle" this extreme adjustment instantaneously. In the real world, market conditions change, new technologies are introduced and dynamic adjustments are made every year. In other words, the "shock" is much slower and sufficiently more complex in the real world, with potentially much different effects than simulated by the model. For this reason and several others, we pursued an alternative approach for estimating land use changes.

RFA approached Informa Economics of Memphis, TN, to conduct a study of land area devoted to the key crops in the world, from 2001 and 2015. Informa's projections were to assume that U.S. corn ethanol production would grow to 15 bgy by 2015, in accordance with the 2007 EISA RFS. They were to make their own, independent projections of yield changes for the various crops, which would not only include the existing land devoted to crops, but also any new land converted from other crops to corn, or from pasture/forest to corn or other crops. Informa indicated that this type of analysis is the company's core competency and that it could conduct this study for the U.S. and other world major crop areas. However, Informa acknowledged that it could not predict what type of land (e.g. forest vs. grassland) was being converted.

Informa produces a variety of agricultural forecasting studies for many different institutional clients on a regular basis. As a result, they make these assessments from many different databases, and also from years of experience in making forecasts. It was our belief that the firm was well suited to make this kind of assessment.

We thought that having Informa make this assessment was advantageous for at least two reasons: (1) it would be a good “reality check” on the various models that may be difficult to validate, and (2) Informa updates its data constantly to reflect the latest data from the USDA and other sources. Consequently, for 2001-2008, they are using actual historical data, and for 2008-2015 (7 years) they are forecasting.

In addition to the amount of land converted, the other basic factor necessary to estimate land use emissions impacts is the type of land and the emissions rate associated with conversion of that type of land. CARB is currently using the “Woods Hole” data to estimate the CO_2 emissions from land use changes.

For the RFS2, U.S. EPA is using data based on satellite imagery from Winrock Corporation for the effects of land use changes outside of the U.S. We believe that U.S. EPA is using the CENTURY model to estimate the carbon released for land being converted within the U.S. We will be able to review these data when the RFS2 Notice of Proposed Rulemaking is published and these data are released by the U.S. EPA.

5.0 Informa Economics Land Use Inventory and Projections

The Renewable Fuels Association contracted with Informa Economics to provide historical data on land use in the U.S. for major crops, and projections to 2015 for land use for major crops. This analysis also included detailed crop forecasts for Brazil, the EU-27, Canada, and China, and a summary of cropland for all other countries. The forecasts were based on a set of assumptions that included the U.S. RFS2.

This section summarizes and discusses our findings, including the implications for how much new land is needed to increase ethanol production in the U.S. This section is organized into the following divisions:

- Informa Analytical Framework
- Informa Macro Level-Assumptions
- U.S. Crop Area
- Brazil Crop Area
- EU-27 Crop Area
- Canada Crop Area
- China Crop Area
- Total Crop Area
- Implications for Land Use
- Conclusions

5.1 Framework

Informa Economics, Inc. ("Informa") maintains a framework for long-term grain and oilseed forecasts, which are updated as necessary for clients and for internal analytic purposes. Informa's world baseline is the summation of supply/use analyses of grains and the oilseed complex for 27 individual countries/regions. The 27 elements summed include 19 individual countries, the European Union and seven geographical regions representing the world as defined by USDA in its Production, Supply and Distribution (PSD) database. The PSD historical database is the historical foundation on which Informa's baseline supply, use and trade analyses are built.

Informa's forecasts of supplies and usage are derived independently. Trade volumes are inferred from supply-use imbalances. Excess supplies imply net exports. Deficient supplies imply net imports.

Grains considered are wheat, rice, corn, sorghum, barley, oats and millet. Oilseeds considered are soybeans, canola/rape, sunflowers, cottonseed and peanuts. In addition, palm oil is included in the oil part of the oilseed complex product fundamentals. Other crops included are cotton, hay, dry edible beans, tobacco, and sugar beets.

Crop supplies are derived as the product of area and yield. The aggregation of area across the 12 crops considered is a critical supply control element. Historical aggregates are respected, and aggregated acreage estimates over the forecast period are constrained in line with physical geographic limits. Forecasted crop yields are dominantly a continuation of historical yield trends for specific countries/regions, acknowledging ongoing agronomic developments.

Usage estimates are significant extensions of historical per-capita usage rates. The continuation of increases or declines, government policies, expected developments and population estimates drive usage forecasts. Grain usage is specifically addressed in two components: feed usage and food/other usage.

5.2 Macro-Level Assumptions and Key Points in the Forecast

Macro level assumptions embodied in the Informa outlook include the following:

- The world political environment will remain dominantly stable over the horizon of the review.
- The global economy will show modest growth, and major grain and soybean producing/consuming countries (most importantly the U.S., Brazil, Argentina, EU and China) will avoid prolonged economic instability.
- The climate of free trade will continue to persist. World Trade Organization (WTO) developments that might occur during this outlook horizon will have little or no impact until later years.
- Changes in U.S. farm policy will not result in idling additional land resources.
- The agricultural outlook assumes an energy environment consistent with price forecasts by the U.S. Department of Energy's ("DOE") Energy Information Administration ("EIA").
- Corn yields will increase on the order of 2% annually, allowing sufficient production with sub-90 million acre plantings by the end of the forecast period
- Corn supplies outside the U. S. dominantly supply non-U.S. needs
- U.S. corn exports will remain constant at 1.8-2 billion bushels per year out to 2015
- Soybean yields benefit significantly from technology that is introduced
- Crush increases 20-25 million bushels annually as U.S. product needs grow

- U.S. soybean exports vary between 0.9 bushels and 1.1 billion bushels per year between 2001 and 2007, then increase to 1.8 billion bushels in 2015, as production expansion exceeds crushing activity

- Wheat yields trend higher, registering annual increases on the order of 0.5%

- Wheat seeded area slips lower as even more yield increases satisfy anticipated usage volume

- U.S. wheat exports remain steady between 0.9 and 1.2 billion bushels annually

- Cotton acres decline materially

- U.S. beef production increases somewhat between 2001 and 2015

- The efficiency of conversion of corn to ethanol is 2.7 gal/bu in 2001 and 2.9 gal/bu in 2015

- DGs are assumed to replace only corn, not a mixture of corn and soy. And, 1 lb of DG is assumed to replace 1 lb of base diet. The net effect is a 31% reduction in land use attributed to DGs. [8]

A significant factor in this analysis is that exports are estimated to remain constant throughout the 2001 to 2015 time period. This stands in contrast to the CARD system and GTAP where exports are estimated to decline, thereby triggering land use changes outside the U.S. to make up for lost U.S. exports.

In the crop year 2007/2008, the Informa analysis expects that 8.5 billion gallons of ethanol will be produced.[9] This is 57%, or more than halfway to the 2015 target of 15 bgy. Figure 1 shows exports in corn and soybeans from 1990 to the present, based on USDA data. There is no discernable downward trend in exports of either crop in the 2001 to 2008 time period. Rather, there is a peak in exports in 2007-08. Certainly, some of this peak in 2007-08 could have been due to the decline in the U.S. dollar and other factors. In addition, DG exports have been growing rapidly in recent years.

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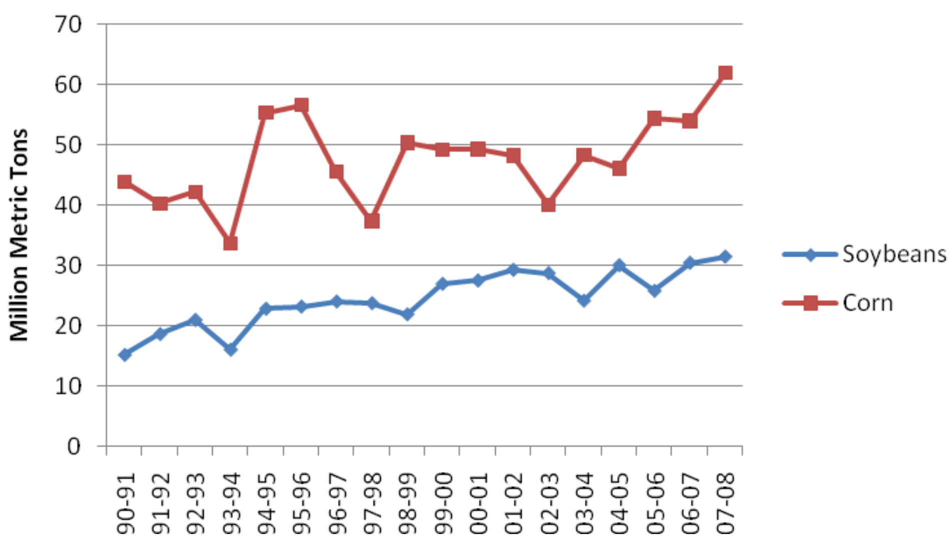
[8] As stated earlier in the report, we believe Informa's estimate of 31% is low. We estimate that with the Argonne DG analysis it is more likely to around 71%. We therefore modify Informa's assumption on this point for our analysis. Informa's analytical framework does not address the amount of soybean meal that is displaced by DG because past analyses have not dictated this level of detail. The firm acknowledges that the 31% DG credit may be conservative, in that it addresses only the displacement of corn but not soybean meal.

[9] The crop year 2007/08 starts in September 2007 and goes through August 2008.

Without an expansion of ethanol from corn, it is possible that corn production could be higher, and that U.S. exports could therefore be higher than observed with the expansion. This could reduce land converted to crops in nations outside the U.S. to meet expanding non-U.S. demand for these crops. This highlights an important question: what should be done with corn yield improvements in the U.S. that are in excess of the U.S. increase in demand for corn? Is it reasonable to use these yield gains to produce fuel? Or should all of the yield gains be used to produce food and expand exports to other nations? Or, should the land freed by yield gains simply be returned to grassland or forest in the U.S. (through the CRP program perhaps), where it can sequester more carbon? Each of these choices will have different greenhouse gas impacts, and we do not attempt to answer all of these questions. In this paper, we assume that yield gains in the U.S. can be used to produce some ethanol without incurring international land use effects, as long as U.S. exports do not decline from the 2001 levels.

Figure 1. U.S. Corn and Soybean Exports



5.3 U.S. Crop Area and the Conservation Reserve Program (CRP)

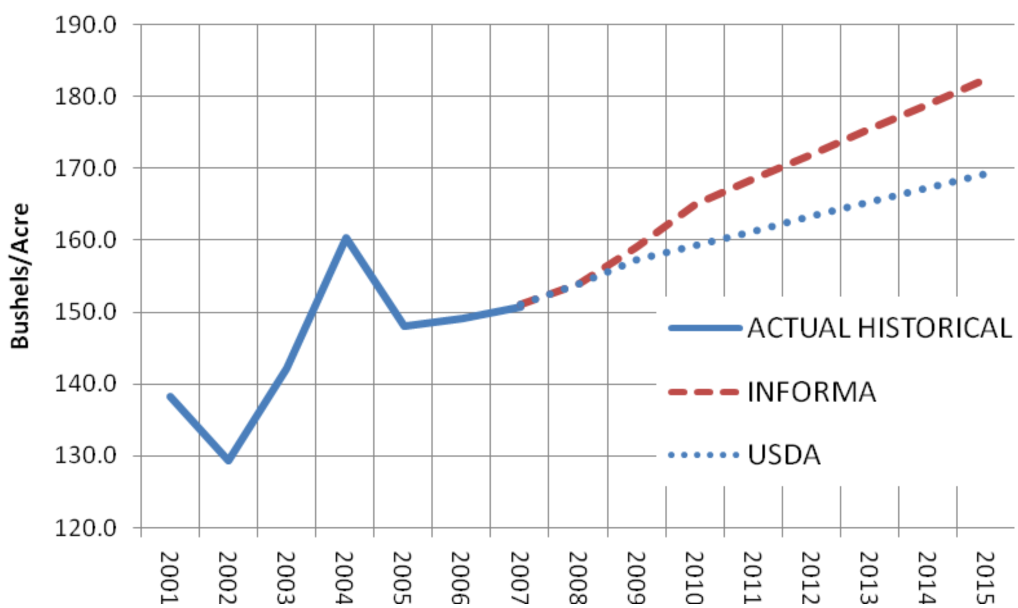
The U.S. planted areas for major crops are shown in Table 1 below for the time period from 2000/2001 to 2015/2016. We summarize the crop trends below.

Area planted for corn in 2000/01 was 32.2 mha, and this grew to 37.9 mha in 2007/2008, but is expected to be reduced somewhat in 2010/11 and down to 34.6 mha in 2015, even though the RFS volumes continue to increase until 2015. Wheat occupied 25.3 mha in 2000/01, and this has seen a decline to 22.5 mha by 2015/16. This is a decrease of almost 3 mha. Soybeans occupied 30 mha in 2000/01, which remained relatively constant until 2006/07, when they increased to 30.6 mha, and then back to 25.7 mha in 2007/08. In 2015/16, soybeans are expected to occupy almost 34 mha, so the temporary decline in soybean area in

2007/08 appears to be an anomaly. Cotton occupies 6.3 mha in 2000/01, and declines to 2.5 mha in 2015/16, a decline of 3.75 mha in this period. Hay occupies 24.4 mha in 2000/01, and this level remains constant throughout the entire period. Land enrolled in the Conservation Reserve Program stood at 12.7 mha in 2000/01, and this increased to 14.9 mha in 2007/08, but is expected to decline to 12.3 mha (about what it was in 2000/01) in 2015/16. For all crops, the area in 2000/01 is 130.2 mha in 2000/01 and 127.7 mha in 2015/16.

Informa's corn yield assumptions are shown in Figure 2, compared to USDA's projections. The values are the same for both Informa and USDA through 2007. After 2007, the values for Informa are higher than for USDA. The improvements in yield are being driven by improved agronomics, breeding, and biotechnology. [19]

FIGURE 2. INFORMA & USDA CORN YIELD PROJECTIONS



Over the entire period from 2001 to 2015, (which represents the major expansion in corn ethanol from about 2 bgy to 15 bgy) corn acreage increases by about 8% and soybean acreage increases by 13%. These increases are mostly offset by declines in wheat (11%) and cotton (60%). The increase in corn and soybean area is 6.3 mha, and the decline in wheat and cotton is a little more at 6.6 mha. These estimates assume corn exports and U.S. corn inventories remain relatively constant, and distillers grains exports increase.

Table 1. U.S. Planted Area

U.S. PLANTED AREA (thousand hectares)

	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
Corn, All	32,194	30,636	31,928	31,810	32,752	33,087	31,699	37,879	37,030	34,601
Sorghum, All	3,721	4,147	3,881	3,812	3,030	2,612	2,639	3,123	3,355	3,209
Barley	2,348	2,004	2,027	2,164	1,832	1,568	1,397	1,627	1,477	1,416
Oats	1,810	1,781	2,021	1,860	1,653	1,718	1,687	1,522	1,376	1,275
All Wheat	25,313	24,052	24,410	25,148	24,150	23,160	23,207	24,457	22,865	22,461
Winter Wheat	17,529	16,569	16,902	18,367	17,544	16,363	16,420	18,206		
Other Spring Wheat	6,191	6,305	6,329	5,602	5,570	5,680	6,030	5,381		
Durum Wheat	1,593	1,178	1,179	1,180	1,036	1,117	757	870		
Rye	538	537	548	546	558	580	565	557	545	524
Rice	1,238	1,349	1,311	1,223	1,355	1,369	1,149	1,117	1,234	1,072
Soybeans	30,055	29,978	29,932	29,706	30,436	29,151	30,563	25,751	30,150	33,994
Peanuts	622	624	548	544	579	671	503	498	563	522
Sunflowers	1,149	1,066	1,045	949	758	1,096	789	837	951	1,153
Rapeseed/Canola	629	605	591	438	350	469	423	479	506	607
Flaxseed	217	237	317	241	212	398	329	143	182	182
Cotton, All	6,280	6,382	5,649	5,455	5,528	5,745	6,181	4,382	3,642	2,529
Cotton, Upland	6,211	6,272	5,550	5,383	5,427	5,635	6,049	4,263	3,541	2,428
Cotton, Am-Pima	69	109	99	72	101	109	132	118	101	101
Hay, All	24,425	25,705	25,877	25,651	25,077	24,981	24,657	24,939	24,889	24,889
Beans, Dry Edible	715	582	781	569	548	660	660	618	597	597
Tobacco	190	175	173	166	165	120	137	144	134	114
Sugar Beets	633	553	578	553	545	526	553	514	446	416
Double-Counted Acres:										
Soybeans Double-Cropped	1,773	1,660	1,691	1,675	1,813	1,138	1,592	2,042	2,023	1,821
Spring Reseeding	81	567	486	121	0	0	40	121	0	0
Crop Total	130,224	128,184	129,440	129,039	127,713	126,775	125,505	126,424	127,917	127,741
Government Acres:										
Conservation Reserve	12,711	13,582	13,715	13,795	14,108	14,108	14,563	14,880	12,950	12,343
Total Government	12,711	13,582	13,715	13,795	14,108	14,108	14,563	14,880	12,950	12,343
Grand Total	142,935	141,765	143,155	142,834	141,821	140,883	140,067	141,303	140,868	140,084

Table 2 shows the U.S. ethanol production relative to corn area. There are at least three rows in this table of interest – the gross area used for ethanol, the net area used for ethanol, and the net % of crop used for ethanol production. The net area used for production takes into account that DG from an ethanol plant are used to feed livestock, and this reduces corn that otherwise would have been used without the DGs. At the peak ethanol production in 2015, the gross area used for ethanol is 11.4 mha, but the net area used after crediting for DGs is 7.8 mha. [10] On a net basis, this represents 25% of the total U.S. corn crop in 2015. The corn yields used in this table start at 137 bu/acre in 2000/01, and increase to 183 bu/acre in 2015/16.

The 7.8 mha net area used for corn ethanol in 2015 represents 5.5% of total crop area including CRP land in the U.S. (140 mha), and less than 1% of total major crop land of the world (903 mha).

Table 2. Ethanol Production Relative to Corn Area

U.S. ETHANOL PRODUCTION RELATIVE TO CORN AREA

	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
Harvested Corn Area (thousand hectares)	29,316	27,830	28,057	28,711	29,798	30,395	28,591	35,023	34,197	31,769
Corn Production (million metric tons)	252	241	228	256	300	282	268	332	354	364
Fuel Ethanol Production (mil metric tons)	5	6	8	10	11	14	18	25	41	45
Corn Used in Fuel Ethanol (million metric tons)	16	18	25	30	34	41	53	76	121	131
Gross % of Crop Used for Ethanol Production	6%	7%	11%	12%	11%	14%	20%	23%	34%	36%
Gross Area Used for Ethanol (thousand hectares)	1,856	2,068	3,113	3,321	3,339	4,384	5,699	8,037	11,644	11,417
Distillers Grains Produced (million metric tons)	5	6	8	9	11	13	17	24	38	41
Net % of Crop Used for Ethanol Production	4%	5%	8%	8%	8%	10%	14%	16%	23%	25%
Net Area Used for Ethanol (thousand hectares)	1,276	1,421	2,140	2,283	2,296	3,014	3,918	5,525	8,005	7,849

[10] If DGs are credited using the results of the recent Argonne study (71%), then the net area would be 3.3 mha, instead of 7.8 mha. This is developed further in section 5.10.

We examined the trends in corn area, production and yield in the U.S. from 2000 to 2015 using the Informa results. The results are shown in Table 3. Corn area increases by 8.2%, and because of yield increases of 33%, production increases by 44%.

Table 3. U.S. Corn Area and Production, 2000 to 2015				
Parameter	2000	2015	Total Percent Increase	Annual Percent Increase
Area (mha)	29.3	31.7	8.2%	0.53%
Production (mmt)	252	364	44.4%	2.5%
Yield (bu/acre)	137	183	33.5%	2.0%

Our preliminary conclusion regarding these forecasts is that they indicate that the increase in land use for ethanol can be met mostly by increased productivity per hectare and changes in U.S. land use.[11] First, Informa assumed that U.S. exports stay constant (corn, wheat) or grow somewhat (soybeans). Second, total U.S. cropland actually is reduced from 2000/01 to 2015/16. There are significant reductions in land used for both cotton and wheat (a total of 6.55 mha), that are not substantially made up for elsewhere in the world. Third, there is a reduction in land in the CRP (2.3 mha). The total land available through the reduction of cotton, wheat and CRP is almost 8.9 mha, which is greater than the net area used for ethanol in 2015 (7.8 mha).

Simplistically, one could argue that because total cropland drops from 2000/01 to 2015/16, the land use change in the U.S. is zero, even though there are shifts between different crops. However, Informa is estimating that 2.3 mha of CRP land may be utilized to meet total demand for U.S. crops. This means that some other land formerly used for wheat or cotton (or other purposes) is being idled and perhaps will go into CRP at sometime after 2015/16. Thus, the possible range of land use change in the U.S. for the biofuels increase based on the Informa results is between 0-2.3 mha.

5.4 Brazil Crop Area

Results for Brazil are shown in Table 4. Corn area increases from 13 mha in 2000/01 to 15.5 mha in 2015/16, an increase of 2.5 mha, or 19%. Wheat increases from 1.5 mha in 2000/01 to 2.25 mha in 2015/16. Cotton shows a small increase. But soybeans increase from 13.9 mha in 2000/01 to 26.4 mha in 2015/16, a gain of almost 90%.

[11] Combined with the effects of projected increased yield for various crops, and the fact that DGs from ethanol plants reduce the land use impact by more than 31%.

Table 4. Brazil Crop Area

BRAZIL CROP AREA (thousand hectares)	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
Corn	12,972	11,827	12,956	12,440	11,561	12,900	14,000	14,600	15,000	15,500
Sorghum	486	418	800	906	840	732	704	850	850	850
Barley	141	155	114	137	140	143	93	140	140	140
Oats	249	257	267	300	326	357	350	350	350	350
Coarse Grains	13,848	12,657	14,137	13,783	12,867	14,132	15,147	15,940	16,340	16,840
Wheat	1,468	1,725	2,043	2,464	2,756	2,360	1,758	1,800	2,250	2,250
Rice	3,142	3,149	3,186	3,732	3,921	2,996	2,975	3,000	3,000	3,000
Food Grains	4,610	4,874	5,229	6,196	6,677	5,356	4,733	4,800	5,250	5,250
										1
Cotton	853	748	735	1,100	1,172	850	1,094	1,150	1,150	1,275
Soybeans	13,934	16,350	18,448	21,520	22,800	22,229	20,700	21,600	24,922	26,423
Rapeseed	20	20	20	20	20	0	0	0	0	0
Sunseed	60	46	43	55	44	70	80	70	50	50
Peanut	102	95	85	100	126	115	115	115	115	115
Oilseeds	14,969	17,259	19,331	22,795	24,162	23,264	21,989	22,935	26,615	28,840
Total Crop Area	33,427	34,790	38,697	42,774	43,706	42,752	41,869	43,675	48,205	50,930

The land use change in Brazil has been driven primarily by the increase in soybean production to meet the increasing world demand for protein, being driven largely by China and other developing nations. The increase in soybeans is not driven by a drop in U.S. exports, because U.S. soybean exports are assumed to increase to 2015 even with a 15 bgy biofuels requirement.

5.5 EU-27 Crop Area

Results for the EU-27 area are shown in Table 5. There is little change in corn area between 2001 and 2015. There is also little change in wheat. Area devoted to rapeseed increases from 4.1 mha to 7.1 mha, an increase of 3 mha. There is little change in total crop area, however.

Table 5. EU-27 Crop Area

EU-27 CROP AREA (thousand hectares)	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
Corn	8914	9457	8995	9138	9677	9227	8596	7749	9100	9100
Sorghum	107	114	117	103	94	94	104	102	105	105
Barley	14067	14100	13993	14051	13726	13790	13741	13628	13500	13250
Oats	3046	3031	3232	3174	2953	2886	2925	2975	2950	2950
Millet	6	6	6	6	0	0	0	0	0	0
Coarse Grains	26140	26708	26343	26472	26450	25997	25366	24454	25655	25405
All Wheat	26471	25927	26419	24318	25996	25833	24491	24781	26000	26000
Rice	409	406	406	416	432	420	410	407	410	410
Food Grains	26880	26333	26825	24734	26428	26253	24901	25188	26410	26410
Cotton	16	16	16	16	539	501	501	466	0	0
Soybean	466	437	343	409	394	403	496	364	440	440
Rapeseed	4124	4159	4270	4198	4572	4845	5374	6541	6300	7150
Sunseed	3557	3549	3444	4152	3654	3568	3977	3600	3450	3200
Peanut	1	0	1	0	1	1	0	1	0	0
Oilseeds	8164	8161	8074	8775	9160	9318	10348	10972	10190	10790
Total Crop Area	61184	61202	61242	59981	62038	61568	60615	60614	62255	62605

5.6 Canada Crop Area

Results for Canada are shown in Table 6. Corn area increases slightly, likely in response to the country's own biofuels goals. Wheat area declines, and canola area increases from 4.8 mha to 6.9 mha. None of this appears to be related to the changes in cropland in the U.S.

Table 6. Canada Crop Area

CANADA CROP AREA (thousand hectares)

	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
Corn	1,088	1,268	1,283	1,226	1,072	1,085	1,061	1,370	1,300	1,300
Barley	4,551	4,150	3,348	4,397	3,841	3,634	3,223	4,000	3,650	3,350
Oats	1,299	1,238	1,379	1,415	1,234	1,271	1,537	1,810	1,350	1,350
Mixed Grains	0	0	0	0	0	0	0	0	0	0
Coarse Grains	6,938	6,656	6,010	7,038	6,147	5,990	5,821	7,180	6,300	6,000
Spring Wheat	0	0	0	0	0	0	0	0	0	0
Durum Wheat	0	0	0	0	0	0	0	0	0	0
Winter Wheat	0	0	0	0	0	0	0	0	0	0
All Wheat	10,963	10,585	8,836	10,215	9,389	9,404	9,682	8,640	8,750	8,375
Rye	0	0	0	0	0	0	0	0	0	0
Food Grains	10,963	10,585	8,836	10,215	9,389	9,404	9,682	8,640	8,750	8,375
Soybean	1,061	1,069	1,024	1,044	1,174	1,169	1,200	1,170	1,200	1,200
Canola	4,816	3,785	3,262	4,689	4,938	5,283	5,240	5,910	6,100	6,850
Sunseed	69	67	95	115	60	75	75	79	85	85
Flax	0	0	0	0	0	0	0	0	0	0
Oilseeds	5,946	4,921	4,381	5,848	6,172	6,527	6,515	7,159	7,385	8,135
Mustard Seed	0	0	0	0	0	0	0	0	0	0
Sugar Beets	0	0	0	0	0	0	0	0	0	0
Dry Beans	0	0	0	0	0	0	0	0	0	0
Fodder Corn	0	0	0	0	0	0	0	0	0	0
Hay	0	0	0	0	0	0	0	0	0	0
Summer Fallow	0	0	0	0	0	0	0	0	0	0
Total Crop Area	23,847	22,162	19,227	23,101	21,708	21,921	22,018	22,979	22,435	22,510

5.7 China Crop Area

Results for China are shown in Table 7. Corn area increases from 23.0 mha in 2000/01 to 29.0 mha in 2015/16, an increase of almost 6 mha. But wheat declines from 26.7 mha in 2001 to 22.5 mha in 2015/16, a decline of 4.2 mha. Cotton increases from 4 mha in 2001 to 6 mha in 2015. The increase in coarse grains is offset by the decrease in food grains. Overall total crop area remains about the same between 2000/01 and 2015/16.

Table 7. China Crop Area

CHINA CROP AREA (thousand hectares)

	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
Corn	23,056	24,282	24,634	24,068	25,446	26,358	26,970	28,000	28,260	29,035
Sorghum	886	782	843	722	568	570	590	600	560	460
Barley	791	770	914	775	785	850	880	860	850	850
Oats	500	500	500	500	500	500	500	500	500	500
Millet	1,250	1,148	1,140	1,024	916	850	880	900	860	760
Coarse Grains	26,483	27,482	28,031	27,089	28,215	29,128	29,820	30,860	31,030	31,605
Wheat	26,650	24,640	23,910	22,000	21,626	22,792	22,960	23,100	22,500	22,500
Rice	29,962	28,812	28,200	26,508	28,379	28,847	29,295	29,600	29,100	28,100
Food Grains	56,612	53,452	52,110	48,508	50,005	51,639	52,255	52,700	51,600	50,600
Cotton	4,058	4,820	4,184	5,110	6,000	5,500	6,000	6,100	6,000	6,000
Soybean	9,300	9,480	9,546	9,313	9,590	9,591	9,280	8,700	9,000	9,000
Rapeseed	7,494	7,095	7,143	7,220	7,272	7,279	6,880	6,600	7,200	7,700
Sunseed	1,229	1,016	1,131	1,173	935	1,020	1,000	990	1,070	995
Peanut	4,856	4,990	4,920	5,057	4,745	4,663	4,571	4,600	4,600	4,600
Other Oilseeds	0	0	0	0	0	0	0	0	0	0
Oilseeds	26,937	27,401	26,924	27,873	28,542	28,053	27,731	26,990	27,870	28,295
Other Grains	0	0	0	0	0	0	0	0	0	0
Misc. Grains	0	0	0	0	0	0	0	0	0	0
Total Crop Area	110,032	108,335	107,065	103,470	106,762	108,820	109,806	110,550	110,500	110,500

5.8 Total Major Crop Area

Results for total major crop area for the different areas of the world are shown in Table 8. For the world, crop area increases from 2000/01 to 2015/16 by 76 mha. Much of this occurs in Brazil, Argentina, the Former Soviet Union-15 and Other Africa, although there are significant increases in other areas as well such as North Africa and the Middle East.

The net land used for ethanol in the U.S. in 2015 is 7.8 mha, or only about 10% of the world increase in land for crops between 2000/01 and 2015/16.

Table 8. Total Major Crop Area

Total Major Crop Area

	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2010/11	2015/16
(thousand hectares)										
USA (harvested area)	94,997	92,084	89,568	93,405	93,173	93,010	89,471	93,000	94,529	94,160
CANADA	23,847	22,162	19,227	23,101	21,708	21,921	22,018	22,979	22,685	22,760
MEXICO	10,278	11,007	10,040	10,847	10,592	9,442	10,218	10,386	10,721	10,721
BRAZIL	33,427	34,790	38,697	42,774	43,706	42,752	41,869	43,675	47,827	49,953
ARGENTINA	23,463	24,385	24,847	25,463	27,053	26,455	28,365	29,581	31,234	31,953
OTHER LATIN AMERICA	12,082	12,135	12,364	13,285	13,467	13,799	14,016	14,735	14,732	15,374
EU-27	61,184	61,202	61,242	59,981	62,038	61,568	60,615	60,393	62,255	62,605
OTHER WEST EUROPE	519	517	530	527	517	520	520	520	517	517
CENTRAL EUROPE	3,804	3,899	3,929	3,813	3,902	3,726	3,627	3,633	3,735	3,760
RUSSIA	44,385	45,004	45,909	43,503	45,235	45,685	46,358	46,363	48,600	49,925
UKRAINE	14,063	15,332	15,605	13,921	17,394	17,483	17,976	17,751	18,340	18,530
OTHER FORMER USSR	22,124	22,687	23,567	23,636	24,408	24,364	24,789	25,285	24,925	24,990
FSU-15	80,572	83,023	85,081	81,060	87,037	87,532	89,123	89,399	91,865	93,445
JAPAN	2,144	2,121	2,122	2,105	2,123	2,121	2,114	2,082	2,062	2,022
TAIWAN	390	379	347	311	271	301	292	290	292	292
SOUTH KOREA	1,255	1,279	1,243	1,187	1,187	1,181	1,140	1,128	1,078	1,003
CHINA	110,032	108,335	107,065	103,470	106,762	108,820	109,806	110,550	110,000	110,000
THAILAND	11,518	11,689	11,633	11,679	11,367	11,568	11,515	11,605	11,910	12,110
INDIA	131,841	130,684	118,702	129,650	130,296	131,078	129,981	133,570	134,425	136,200
INDONESIA	16,097	15,946	15,780	16,440	16,320	16,510	16,081	16,330	16,610	16,810
PAKISTAN	15,993	15,676	15,290	15,974	16,349	16,533	16,798	16,878	17,257	17,744
MALAYSIA	687	666	691	697	677	686	671	687	687	687
TURKEY	14,343	13,973	14,200	14,060	14,096	14,061	14,029	13,968	14,093	14,068
OTHER ASIA	46,196	45,992	46,389	48,023	48,871	49,370	49,534	49,734	50,505	51,265
AUSTRALIA	19,395	19,036	18,243	21,058	22,033	20,420	17,521	19,385	19,920	20,445
SOUTH AFRICA	5,901	6,273	6,244	5,741	5,599	4,441	5,079	5,435	5,650	5,450
N AFRICA & MIDDLE EAST	24,503	27,519	28,903	31,069	31,108	30,561	30,608	29,963	30,371	30,371
OTHER AFRICA	83,074	86,445	84,264	89,414	85,837	92,503	94,173	93,316	94,988	99,494
(mil hectares)										
TOTAL	827.5	831.2	816.6	845.1	856.1	860.9	859.2	873.2	889.9	903.2

Similar to the analysis of the U.S, we have also examined corn production, area, and yields for the rest of the world (ROW). This is shown in Table 9. This shows a production increase of 63% over the period from 2000-2015. Since yields improve by 33%, the area increase is 21%. However, yields in the ROW are still far below the U.S. yields, due to a variety of reasons. If yields could be improved more in the ROW, there would be less need for an area increase due to corn in the ROW. Again, U.S. exports remain constant or increase (for soybeans) in this scenario, so the increase in production for the ROW is logically due to the increased demand for protein in other parts of the world.

Table 9. Corn Area, Production, and Yield in the Rest of the World (ROW)

Parameter	2000	2015	% Increase	Annual % Increase
Area (mha)	108	131	21%	1.4%
Production (mmt)	339	551	63%	3.3%
Yield (bu/acre)	50	68	33%	2.0%

5.9 Implications for Land Use

The net land use for ethanol in the U.S. for 2015 using Informa's analysis is 7.8 mha, which is less than 1% of the cropland in the world. The increase in area devoted to corn and soybeans in the U.S. seems to be offset by almost equivalent reductions in the area devoted to wheat and cotton, and a reduction in land enrolled in CRP. The Informa analysis also estimated that exports and U.S. inventories of corn would be constant due to increasing yields in the U.S. Outside of the U.S., the reduction in wheat is not being made up by other countries, and while cotton and corn are on the increase in China, total crop area is about the same between 2000/01 and 2015/16. Thus, based on these results, it is difficult to conclude that land outside of the U.S. is being converted in any significant amount as a direct result of the U.S. RFS. Our first conclusion, then, is that if land is being converted as a result of the RFS, it is likely in the U.S.

Our second conclusion based on these results is that a very likely range of land converted in the U.S. is in the 0-2.3 mha range for the reasons mentioned earlier (total cropland is reduced over the period of the increasing corn ethanol, but 2.3 mha of CRP land is converted).

The above land use values are mainly driven by the yield improvement and the DG credit assumed by Informa. As noted in Figure 2, the Informa corn yield projections are modestly higher than the USDA long-term estimates. Also, Informa assumes that the land use credit for DGs is 31%.[12] The next section estimates the impacts on land use if the lower USDA corn yields are used. Also, it estimates the land use impacts if the higher DG credits are used from the recent Argonne report.

5.10 Estimate of Land Use Impacts with Alternative Assumptions

The two factors that we examine in this section are the impacts of projected corn yields and distillers grains land use credits. Informa's estimate of efficiency of production of ethanol from corn (2.7 gal/bu in 2001 and 2.9 gal/bu in 2015) appear to be appropriate, as recent survey data obtained by RFA and others indicates an efficiency of about 2.8 gal/bu in 2007/2008 (see footnote 5).

5.10.1 Yield Trends

As indicated earlier, the Informa yield projections for corn are higher than USDA's projections (183 bu/acre in 2015 vs. USDA's 169.3 bu/acre). [20] The difference in yields are 13.7 bu/acre, or about 8%. Informa indicates that corn production for 2015 is 364 million metric tons, or 14,330 million bushels. If the yield is 169.3 bu/acre instead of 183 bu/acre, then the production would be 13,260 million bushels, for a difference of 1,070 million bushels. At 169.3 bu/acre, this would require an additional 4.2 million acres (with the 31% land use

[12] See footnote 2.

credit for DGs), or 1.7 mha. These calculations are shown in Table 10. Thus, the range of land use impacts with these lower USDA yields would be 1.7-4.0 mha.

Table 10. Estimate of Additional Area Needed With USDA Corn Yields

Factor	Estimate
2015 corn production at 183 bu/acre, million bu	14,330
2015 corn production at 169.3 bu/acre, million bu	13,260 (14,330 * 169.3/183)
Difference in 2015 corn production, million bu	1,070 (14,330-13,260)
Area required at 169.3 bu/acre, million ac	6.3 ($1,070*10^6/169.3$)
Area with DG credit 31%, million ac	4.3 (6.3*0.69)
Additional area needed beyond Informa results, mha	1.7 (4.3/2.47)
Range based on Informa yields, mha	0.0-2.3
New range based on USDA yield, mha	1.7-4.0

5.10.2 Distillers Grains Land Use Credit

As indicated earlier, Informa estimated a land use credit of 31% for distillers grains, which was based on the DGs replacing only corn meal on a pound-for-pound basis in animal feed.[13] Newer analysis of the use of DGs, however, is available from Argonne. The results of the Argonne work have a significant effect on the land use credits. In this section, we first summarize the Argonne work. Next, we estimate the land use credits from this work.

Argonne estimates displacement ratios for DGs, which are used to estimate the energy used to produce alternatives to DGs, and these energy values are credited to ethanol production. The displacement ratios are the mass ratio of displaced product per pound of co-product. For example, previous analysis by Argonne indicated that 1 lb of DGs replaced 1.077 lbs of corn meal and 0.823 lbs of soybean meal. Thus, the displacement ratio of corn was 1.077 and for soybean meal was 0.823. Dried DGs have a much higher protein and fat content than corn grain, as shown in Table 11, taken from the Argonne study. [8]

Table 11. Major Components of Corn and DDGS

Item	Corn grain	DDGs
Dry matter (%)	85.5	89.3
Crude protein (%)	8.3	30.8
Fat (%)	3.9	11.1

[13] See footnote 2.

As shown in Table 11, the crude protein levels in DDGS are more than three times the protein levels in corn grain, and nearly three times the fat content.

Argonne goes on to estimate the percent of DGs used by animal type. Dairy cattle consume 44.2%, beef cattle consume 44.2%, and swine consume 11.6% of the DDGs. The estimated inclusion rates were 20% for beef cattle, 10% for dairy cattle, and 10% for swine. For WDGS (wet distillers grains), a 40% inclusion rate was estimated for beef cattle, and 10% for dairy cattle.

The base feed for beef cattle contains little or no soybean meal, but the base feed for dairy cattle contains a significant amount of soybean meal. For example, for 10% DDGS replacement over a dairy cow's lifetime, the cow consumes 1864 kg of DDGS, and this replaces 1266 kg of corn and 1152 kg of soybean meal. The displacement ratios for the different animal types and different meal types are shown in Table 12.

Table 12. Displacement Ratios by Animal Type and Feed Component Type (kg/kg of DGs)

Parameter	Beef Cattle	Dairy Cattle	Swine
Corn Displacement	1.196	0.731	0.890
SBM Displacement	-	0.633	0.095
Urea Displacement	0.056	-	-

The table shows that for each kg of distillers grains consumed by dairy cattle, this replaces 0.731 kg of corn and 0.633 kg of soybean meal. When the results from Table 10 are multiplied by the market shares of DGs supplied to the three animal groups, the overall displacement ratios are 0.955 kg/kg DGs for corn, 0.291 kg/kg DGs for soybean meal, and 0.025 kg/kg DGs for urea. Argonne also estimated the impacts of the 2007 Energy independence and Security Act on the volume of DDGs and these ratios. Argonne found with the 2007 EISA volume of 15 bgy ethanol, the displacement ratios would be as follows:

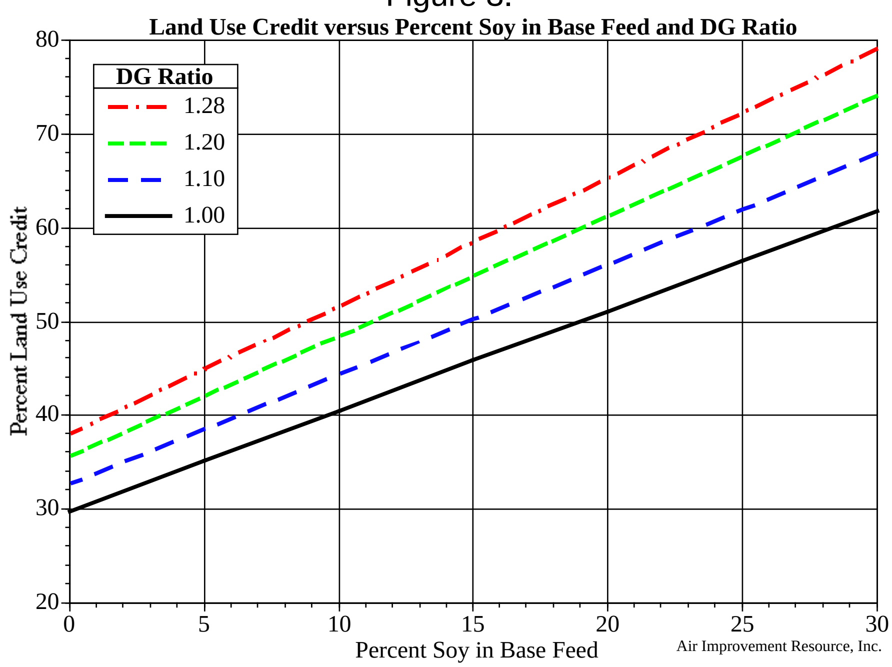
Corn:	0.947 kg/kg DGs
Soybean meal:	0.303 kg/kg DGs
Urea:	0.025 kg/kg DGs
Total:	1.275 kg/kg DGs

These ratios are only slightly different than the base case ratios of 0.955, 0.291, and 0.025.

We estimated the impacts of the Argonne work on land use changes using inputs from the California GREET report for corn ethanol, and information from USDA. [10, 20] The California GREET report for corn ethanol indicates that the DG yield per gallon of anhydrous ethanol is 6.4 lbs. Assuming 151 bu/acre (USDA value for 2007), and 2.6 gal/bu (GREET input), this results in 2513 lbs DGs per acre. The Argonne co-products report indicates that this will replace 3217 lbs of feed, consisting of 2445 lbs of corn meal and 772 lbs of soy meal. Again using USDA's corn and soy yields for 2007 of 8456 lbs/acre (151 corn bu/acre * 56 lbs/bu) and 2502 lbs per acre (42 soybean bu/acre * 60 lbs/bu), the corn acres replaced are 0.29 acres, and the soy acres replaced are 0.42 acres, for a total of 0.71 acres replaced by the DGs produced from making ethanol.[14] Thus, 71% of the acres devoted to corn ethanol are replaced by DGs resulting from the corn ethanol production process.

The sensitivity of the DG land use credit to assumptions on mass replacement of base feed and percent of soy meal replaced is further illustrated in Figure 3, where we have plotted the land use credit in percent vs. the soy percent in base feed replaced by DGs, and also the DG total replacement ratio (i.e., the 1.275 kg/kg DGs above).

Figure 3.



The percent of soy meal in the base feed based on the Argonne research is 24% (0.303/1.275). The total replacement ratio is 1.28/1. Thus, Figure 3 shows that at

[14] In this estimate, we have estimated that 100% of the corn is converted to corn meal, but 73% of the soybean bushel of 60 lbs is converted to soy meal because 26% of the mass has been extracted in the form of soy oil. (Source: CBOT Soybean Crush Reference Guide). Also, the ethanol yield of 2.6 gal/bu may be low – two recent studies of ethanol plants indicate that the yield may be between 2.7 and 2.8 gal/bushel. This would increase the DG land credit from 71% to 77%. (Sources: "Analysis of the Efficiency of the U.S. Ethanol Industry in 2007", May Wu, Argonne, March 27, 2008, and "U.S. Ethanol Industry Efficiency Improvements, 2004 through 2007", Christianson and Associates, August 5, 2008)

25%, and on the line of 1.28, the land use credit is near 71-72%. Figure 3 can be used if different total replacement ratios, or different percentages of displaced soy meal in base feed are determined. Informa estimated that DGs replace only corn, (represented by the DG ratio of 1.00 in Figure 3). This shows a land use credit of 30%, very close to Informa's estimate of 31%. Of course, different estimates of yields of DGs, corn and soybeans per unit area could result in different estimates than the above.

Another conclusion from the above is that as corn and soy yields increase in the future, the DG land use credit increases. The above values were based on 2007 yields. In 2015, if corn yields increase by 21% and soy yields increase by 4% (in accordance with Informa's projections), then the land use credit would be 78% for the 1.28 total replacement ratio line. Thus, the land use credit increases as yields increase, due to increased production of DGs on the same area.

Some critics of this displacement ratio approach for estimating land use credits of DGs have pointed out that the use of DGs fluctuates with its price relative to corn, and therefore, at different times, feedlots may utilize different levels of DGs with the base feed. While this may be true, it does not detract from the approach, because in the end, all DGs produced are consumed by livestock. The only relevant question, then, is what type of feed they are replacing.

Our analysis of the DG credits based on the newer Argonne report results in a land use credit of 71% instead of 33% (see the Background section). With the Informa yields, the gross area used for ethanol in 2015 is 11.4 mha. With the Informa 31% DG credit, the net corn ethanol area is 7.8 mha. However, with a 71% DG credit, the net land use for ethanol would be 3.3 mha instead of 7.8 mha. The difference between 7.8 mha and 3.3 mha is 4.5 mha, and this is greater than the land use impact of 2.3 mha estimated from utilizing CRP land. Thus, in this scenario (i.e., Informa yields and latest Argonne land use credit), there is no land use impact.

If we use the USDA yields, the gross land needed for corn ethanol in 2015 expands to 12.3 mha. With the Informa DG 31% credit, the land requirement is reduced to 8.5 mha. With the 71% credit, the net land needed for corn ethanol is reduced to 3.6 mha. The difference between 8.5 mha and 3.6 mha is 4.9 mha, but the extra CRP land needed in this case is 4.0 mha. This is lower than the 4.9 mha extra due to DGs, so there is no land use impact in this case (i.e. USDA yields and Argonne land use credit) either, although the difference has been narrowed considerably because of the use of lower USDA yields. These estimates are all illustrated further in Table 13.

Table 13. Estimate of Additional Area Needed with Higher DG Credits	
Factor	Estimate
Gross land needed for ethanol with Informa yield (183 bu/acre in 2015) mha	11.4
Informa DG Credit	31%
Net land used for ethanol with Informa yield, mha	7.8
New Argonne DG credit	71%
Net land used for ethanol with Informa yield, mha	3.3
Difference in land used, 31% vs. 71% DG credit, Informa yield, mha	4.5
Extra CRP land needed in 2015, max, mha	2.3
Amount that difference exceeds CRP land, mha	2.2
Gross land needed for ethanol with USDA yield (169.3 bu/acre), mha	12.3
Net land used for ethanol with USDA yield, 31% DG, mha	8.5
Net land used for ethanol with USDA yield, 71% DG, mha	3.6
Difference in land used, 31% vs. 71% DG credit, USDA yield, mha	4.9
Extra CRP land needed in 2015, max, mha	4.0
Amount that difference exceeds CRP land, mha	0.9

5.11 Summary of Impacts

Table 14 shows a summary of all land use impacts based on the different assumptions.

Table 14. Summary of Land use Impacts with Varying Estimates			
Corn Yield Scenario	2015 corn yield, bu/acre	DG Land Use Credit %	Range of U.S. Land Converted, mha
Informa	183	31%	0.0-2.3
USDA	169.3	31%	1.7-4.0
Informa	183	71%	0
USDA	169.3	71%	0

Using a DG land use credit based on the recent Argonne study, the best estimate of land use impacts of expanding corn ethanol in the U.S. between 2001 and 2015 is zero, since we obtain zero with either the Informa or USDA yield projections. This conclusion contradicts conclusions from recent studies. The reasons for this are explained further in the next section.

6.0 Comparison with Economic Model Results

Our conclusions on land use effects of corn ethanol stand in direct contrast to recent predictions from two major economic models that attempt to estimate land use changes as a result of ethanol increases in the U.S. This section examines some of the differences and the possible reasons for those differences.

CARB is basing its land use changes on the Global Trade and Analysis Project (GTAP) model developed by Purdue University and others. The U.S. EPA is currently developing land use change estimates using both the FASOM and FAPRI models from the Center for Agriculture Research and Development (CARD). EPA's land use estimates are expected to be released later this year. The CARD modeling system was also used by Searchinger in evaluating land use changes in the February 2008 *Science Express* article.

6.1 GTAP

This section presents a comparison of our land conversion estimate versus some estimates of the area converted as estimated by CARB using the GTAP model.

In October 2008, ARB presented estimates of land converted utilizing GTAP. Some of these estimates were refined and re-released in January 2009. [5,21] Researchers performed a sensitivity analysis of area conversions in the U.S. and outside of the U.S. using different elasticities, as follows:

- Productivity of marginal land
- Price yield elasticity
- Elasticity of substitution for land cover
- Elasticity of substitution crop areas

The last two elasticities can generally be ignored because they did not have much effect on the land converted. However, the productivity of marginal land and the price/yield elasticity both had very significant effects on the outcome. This is the productivity of land converted, and the projected yield improvements for all land types. Total land converted by varying these two inputs are shown in Table 15.

Table 15. Comparison of Total Area Between Recent GTAP Runs and This Report				
Source	Price-Yield Elasticity	Productivity of Marginal Land	Total area converted (mha)	% of Land Converted in U.S.
GTAP	0.4	0.25	8.9	43%
	0.4	0.50	4.4	43%
	0.4	0.75	2.9	43%
	0.1	0.5	7.3	32%
	0.2	0.5	6.0	37%
	0.6	0.5	3.4	50%
AIR	See note	See note	0.0	no conversion of new land

Note: Informa estimates a 2015 corn yield of 183 bu/acre for all land in use for corn at that time, which incorporates both yield elasticity and marginal land productivity assumptions.

The table shows that GTAP predicts the total land converted to range between 2.9 and 8.9 mha based on varying the elasticities for yield and productivity of marginal land. The model further indicates that 32% to 50% of this land is in the U.S. The U.S. fraction does not change with changes in the productivity of marginal land, but does change with different yield elasticity values. At higher yield elasticity values, more land is predicted to be converted in the U.S. than elsewhere. This makes sense because the base yields in the U.S. are higher than in most of the rest of the world, so changes in price yield elasticity will have a greater effect in the U.S. than elsewhere.

As indicated by CARB's January 2009 results, the agency appears to have settled on using an elasticity for productivity of marginal lands in the range of 0.5 to 0.75, and a price yield elasticity of 0.2 to 0.4. The amount of land converted worldwide is estimated at 3.9 mha, with 1.6 mha of the converted land in the U.S. [21]

Our three most significant concerns with the GTAP modeling are (1) the model shocks all economic systems for the 13.25 bgy ethanol increase all in one year (2001), (2) the model does not include exogenous yield improvements, i.e., those not directly related to the price effects of ethanol volume increase, and (3) the model uses older distillers grains assumptions.[15] As a result of these three problems, the model's results cannot be trusted to provide a reliable estimate of land converted, unless the model's results are somehow adjusted. These three issues are discussed further below.

[15] We have other concerns as well of a lesser magnitude. For example, GTAP assumes that any forest or pasture converted to crops has only 66% the productivity of current land in crops. There appears to be little or no data to make this assumption.

6.1.1 GTAP Model Shock

The database in the GTAP model is 2000/2001. The model is shocked with a 13.25 bgy ethanol increase in that year, which is the difference in 15 bgy in 2015 and 1.75 bgy of ethanol in 2001. Coarse grains increase in price, triggering domestic land use changes, and U.S. exports decline, thereby triggering international land use changes. The model is therefore answering the question "What are the land use changes if all the ethanol increase is shouldered in one year (in this case, 2001)?" However, we would submit that this is *no*t the correct question to answer. The real question is how much new land is converted either domestically or internationally if the 13.25 bgy ethanol increase is phased in from 2001 through 2015? This is a different question that would have a different answer. In our view, it is not possible to answer the real question with GTAP, unless the GTAP results are corrected externally.

6.1.2 Exogenous Yield Improvements

The model does include endogenous yield improvements for coarse grains and other crops, which are those related to the short term price fluctuation brought on by the ethanol shock. However, the model does not include exogenous, longer-term yield improvements for corn or other crops, which are those that are not strictly induced by the price increase of the ethanol shock. These exogenous yield improvements can go a long way in reducing the land use impacts of an ethanol increase.

Recently, CARB proposed an external fix to the model results for exogenous yield improvements. [21] It was theorized that if yields improved by 20% between 2001 and 2020, that the resulting land use result from GTAP should be reduced by 1/1.2 = 17%. For example, if the best estimate land use change impact is 4 mha for corn ethanol, and yield improvements are 20%, then the adjusted land use impact is 3.3 mha (4 mha x 0.83). The appropriateness of this method is currently being evaluated.

6.1.3 DG Land Use Credits Used by GTAP

The version of GTAP used to produce the results in Table 15 uses the older 33% land use credit for distillers grains from ethanol plants. This is similar to what Informa used, but is not based on the latest analysis produced by Argonne. If the GTAP model were updated for the Argonne analysis, the CO_2 emissions from land use impacts would be still smaller.

Like the exogenous yield improvements, the difference in distillers grains credits are very significant. Table 11 showed that the difference between a 31% and 71% DG land use credit using the USDA yield improvement projection was 4.6 mha.

6.1.4 Summary of Views on GTAP

Because the model is shock loaded all at once, includes no exogenous yield impacts, and needs to be updated for the latest analysis of DG credits, we believe GTAP does not predict the impacts of biofuels with any degree of accuracy. If the model is modified somehow for both exogenous yield impacts to 2015 and updated to accurately reflect the land use effects of distillers grains, it may be possible it could arrive at a satisfactory estimate.

6.2 CARD System

The CARD modeling system was utilized by Searchinger in examining land use impacts in his February *Science Express* article. This paper estimated the impacts of a 56 billion liter (15 bgy) increase in ethanol from corn, expanding from 15 bgy to 30 bgy. While the increase is about the same as the 13.25 bgy increase modeled by GTAP, the baseline or starting level was much higher (15 bgy instead of 1.75 bgy). The analysis estimated that total world crop acreage would increase by 10.8 mha, with 2.2 mha (20%) coming from the U.S. Further, this analysis estimated that the increase in ethanol use in the U.S. would result in significant reductions in exports of corn (-62%), wheat (-31%), and soybeans (-29%), which would have to be made up by increased production in the rest of the world. This drove the conversion of 8.6 mha outside of the U.S., making the GHG impacts very high.

The Informa projections and historical data have so far borne out that exports do not decline as ethanol use increases.

One of the most controversial assumptions underlying the Searchinger analysis is that yield improvements were assumed to be completely offset by the lower productivity of land converted to crops. Figure 3 provides evidence that in the U.S. at least, during the period from 2001 to 2008, which saw ethanol use expand from 1.75 bgy to 9.0 bgy, yields improved dramatically. Either no new land was converted, or land that was converted did not offset yield improvements. This provides clear evidence that Searchinger's assumption of offsetting effects on this point is not correct, and is a major reason why these CO_2 emissions effects from this study are not correct.

The CARD land use figures used in the Searchinger analysis are higher than any of the GTAP sensitivity cases shown in Table 8, with a much lower U.S. percentage (20% vs. 32%-50%). This is an area of further investigation.

6.3 Conclusions

We arrive at the following conclusions with regard to these various land use projections:

1. GTAP must be updated with the proper distillers grains displacement effects, based on the recent Argonne study and other literature. Even when this is done, the GTAP results cannot be used directly, but must be further corrected for exogenous yield improvements to 2015.

2. The CARD modeling system and results utilized by Searchinger and others predict world land use changes that exceed even the highest results from GTAP. Reasons for this discrepancy will be evaluated when U.S. EPA publishes its Notice of Proposed Rulemaking on the RFS2.

7.0 Uncertainties

From a broad perspective, the amount of new land converted (i.e., pasture or forest) in response to an increasing ethanol mandate is related to the size of the mandate, the period over which it is implemented, assumed crop yield improvements over the time period, and the land value of the co-products. There are other factors that have an impact, but generally, they have smaller impacts than the primary ones listed above.

The size, location, and time period of the current ethanol mandate is known. Yield improvements between now and 2015 are not known, but there have been dramatic yield improvements in the U.S. for corn, and these are expected to continue to 2015 and beyond. [see reference 19]. It is essential that exogenous yield improvements be included in any projection of land use, and in this study we have included a range of yield improvements for corn from 169.3 to 183 bu/acre for 2015. Under both scenarios, no additional pasture or forest land needs to be converted.

The land value of distillers grains from corn ethanol has been estimated at between 31% and 71%. The 31% assumes DGs only replace corn meal and that DGs have the same basic feed value as corn meal. A recent analysis by Argonne indicates that because DGs have higher protein and fat content than corn, DGs replace base feed on a greater-than-one-for-one basis and soy meal is replaced as well as corn meal. We believe this is a much more robust analysis of DGs, and that it should be used in estimating the land use impact of DGs.

Once the above two factors are included, there are lesser important factors that can be addressed. For example, the Informa analysis assumed ethanol conversion efficiency of 2.7 gal/bu in 2001 and 2.9 gal/bu 2015. GTAP assumes this value is 2.6 gal/bu. Recent survey data for 2007 indicates a value of about 2.8 gal/bu. We think the GTAP value is too low, and the Informa projections are correct.

Uncertainties regarding the productivity of converted pasture and forest, and the emissions from converting these lands can be dealt with if analyses show that these lands are in factor converted as a result of a biofuels mandate, but as indicated in this analysis, these uncertainties do not come into play if a biofuels mandate does not result in the conversion of these lands.

References

1. M. Wang, "Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types" Environ. Research Letters (2007).

2. H.R.6, December 13, 2007.

3. “A Low-Carbon Fuel Standard for California, Part 2: Policy Analysis”, Farrell, et al, University of California Berkeley, August 1, 2007.

4. “Use of U.S Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change”, Searchinger, et al, Science*xpress*, wwww.sciencexpress.org, 7 February 2008, 1151861.

5. “Supporting Documentation for the Draft Regulation for the California Low Carbon Fuel Standard – Draft”, ARB, October 2008.

6. “Biofuels, Land Use Change and Greenhouse Gas Emissions: Some Unexplored Variables”, Kim, Kim, and Dale, Environmental Science and Technology (forthcoming article).

7. “Carbon Sequestration in Wood and Paper Products”, Skog (USDA Forest Service) and Nicholson (Maryland Energy Administration), USDA Forest Service General Technical Report, RMS-GTR-59.2000.

8. “Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis”, Arora, Wu, and Wang, Argonne National Laboratory, September 2008.

9. “Regulatory Impact Analysis: Renewable Fuel Standard Program,” EPA420-R-07-004, USEPA, April 2007.

10. “Detailed California-Modified GREET Pathway for Denatured Corn Ethanol”, Stationary Sources Division, ARB, April 21, 2008.

11. “Biofuels and their By-Products: Global Economic and Environmental Implications, Taheripour et al, Purdue University, June 2008.

12. GREET 1.5 – Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use, and Results

13. “Impact of Biofuel Production on World Agricultural Markets A Computable General Equilibrium Analysis”, Birur, Hertel, and Tyner, Department of Agricultural Economics, Purdue University, GTAP Working Paper No. 53, 2008.

14. “Global Agricultural Land Use Data for Climate Change Analysis”, Monfreda, Ramankutty, and Hertel, June 20, 2007.

15. “An Integrated Global Land Use Data Base for CGE Analysis of Climate Policy Options”, Less, Hertel, Rose, and Avetisyan (no date given).

16. “Biofuels and Their By-Products: Global Economic and Environmental Implications”, Taheripour, Hertel, Tyner, Beckman, and Birur, June 20008.

17. The Indirect Land Use Impacts of U.S. Biofuel policies: The Importance of Acreage, Yield, and Bilateral Trade Responses”, Keeney and Hertel, Department of Agricultural Economics, Purdue University, GTAP Working Paper No. 52, 2008.

18. “Changes in the Landscape of Latin America Between 1850 and 1985 II. Net Release of CO2 to the Atmosphere,” R.A. Houghton, D.L. Skole, D.S. Lefkowitz, Forest Ecology and Management, 38 (1991) 173-199.

19. “Increasing Crop Productivity to Meet Global Needs for Feed, Food, and Fuel,” Edgerton, Plant Physiology, January 2009 Volume 149 pp 7-13.

20. “Agriculture Statistics 2007,” U.S. Department of Agriculture.

21. “Indirect Land Use Technical Considerations,” ARB January 30 Workshop.

Appendix A: RFA Comments on ARB October 16 Workshop Materials

Comments from the Renewable Fuels Association to California Air Resources Board Regarding October 16 Workshop Materials and GTAP Model

November 19, 2008

On October 16, 2008, the California Air Resources Board (CARB) released a draft regulation for the California Low Carbon Fuels Standard (LCFS) and a document entitled "Supporting Documentation for the Draft Regulation for the California Low Carbon Fuels Standard." Our comments are primarily focused on information presented in the supporting documentation report.

Our main comments focus on CARB's current estimates of greenhouse emissions resulting from land use changes (LUC) due to corn ethanol expansion. CARB's analysis of LUCs for corn ethanol is contained in Appendix A of the supporting documentation report. Basically, CARB ran the Global Trade Analysis Project (GTAP) model through a number of different sensitivity cases using various elasticities to estimate a range of land use change impacts. GTAP was used for estimating land use changes and the locations of those changes, and the Woods Hole data was used to estimate emission rates for converting different types of land (e.g., forest vs. grassland). The land use change estimates ranged from 20 to 88 g CO2eq/MJ, with a median estimate of about 35 g CO2 eq/MJ. We note that this represents a factor of more than 4X between the low and high estimate.

We still have a number of concerns with how the GTAP modeling is being conducted, and also with certain applications of the Woods Hole emissions data. These concerns are summarized below, and subsequently expanded upon.

1. CARB likely underestimates the productivity of land being converted to crops in the United States (i.e. "marginal" land).

2. Due in part to item 1, and considering the fact that there is no factor to account for observed and future technology improvements in yield independent of price, the projected crop yields are too low in the most recent GTAP analysis. Because the model is "shocked" with 13.25 billion gallons of new ethanol production instantaneously, and yield values do not take into account the improvement in yields between 2000 and 2015, the model is converting too much land to crops as a result.

3. The GTAP model may not be accounting for natural declines in wheat and cotton in the U.S. expected between 2001 and 2015. Empirical data

indicates lost production of wheat and cotton in the United States over the past several years has not entirely been made up for in other locations.

4. The above three factors cause exports of corn and soybeans to decline significantly in the modeling. Empirical data shows exports have not declined in the period from 2001 to 2007.

5. The distillers grain (DG) land use "credit" being used in the GTAP modeling is likely too low and needs to be modified, taking into account the recent analysis of DG feed displacement performed by Argonne National Laboratory.

6. The land conversions in GTAP do not adequately take into account the economic cost of converting forest and native grasses to cropland.

7. There does not appear to be Conservation Reserve Program land or idle cropland in the GTAP database used for the analysis described in the October 16 documentation.

8. Woods Hole data for native grassland with high carbon storage rates are being used to estimate emissions from non-native grassland and pasture in the U.S. with lower carbon storage rates.

9. Emissions for forest area assume all mass above ground is converted to CO2 immediately, when some is likely to be used in building products that would not be converted for a long time.

These concerns are expanded upon below.

Comment 1: *CARB likely underestimates the productivity of land being converted to crops in the United States (i.e. "marginal" land).*

CARB refers to this factor as the "elasticity of crop yields with respect to area expansion." CARB indicates that "although this is a critical input parameter, little empirical evidence exists to guide the modelers in selecting the appropriate value. Based on the judgment of those with experience in this area, the modelers selected a value of 0.66. For purposes of the sensitivity analysis this parameter was varied from 0.25 to 0.75. This input variable produced by far the greatest variation in the output GHG variable: 77%."

When CARB varied this parameter from 0.25 to 0.75, the GTAP model produced the two extremes in LUC emissions, 88 and 20 g CO2 eq./MJ (the price-yield elasticity was held at 0.4 for this sensitivity analysis).

RFA believes there is empirical data to guide the selection of this important parameter, especially for the U.S. Through our analysis of land use patterns, it has become evident that land devoted to wheat and cotton in the U.S. is declining somewhat, and corn is replacing these crops in some of these areas. In addition, corn-on-corn cropping systems are increasingly replacing traditional corn-soybean rotations. Literature suggests the corn-corn pattern does involve a modest decline in corn yields from a corn-soybean system, but the expected decline for this rotation is not in the range of 25-75%. Finally, farmers may convert some idle land or cropland pasture to corn. Many farmers will crop land for a given period, and then convert it to pasture or fallow the land to regain nutrients and carbon. When the land is re-cropped after fallowing, yields tend to rise.

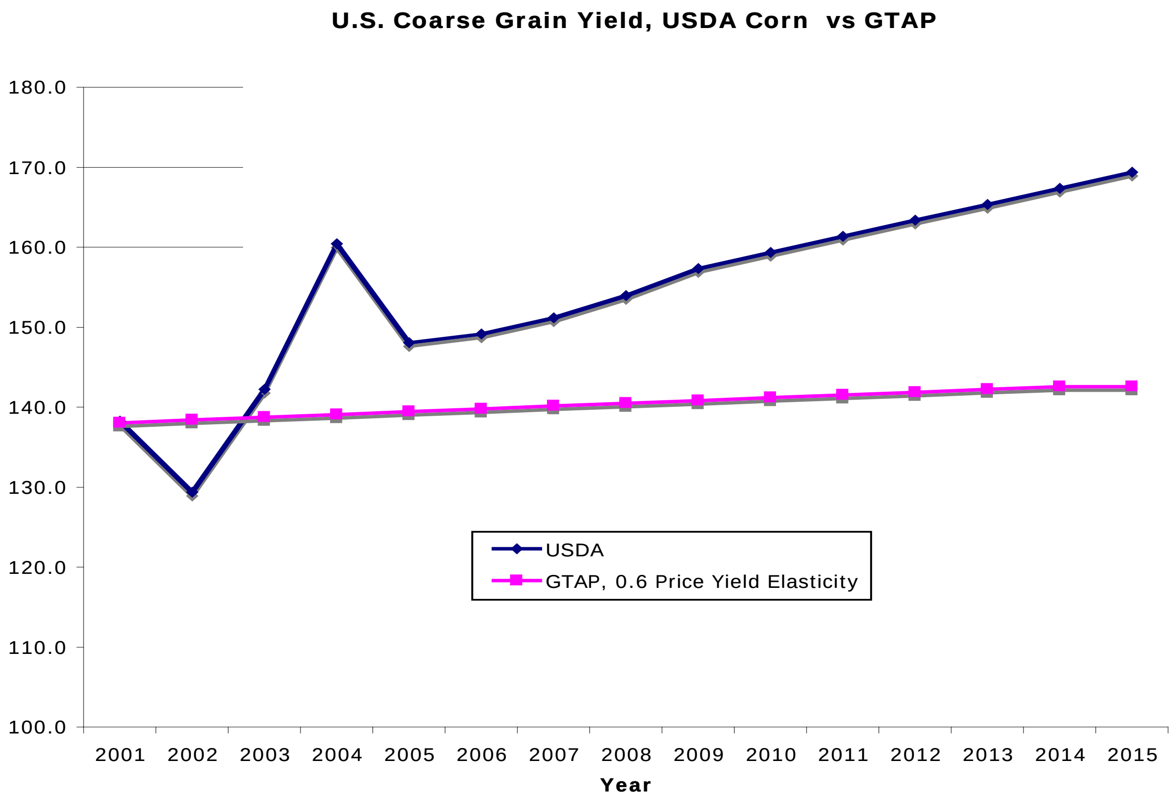
To evaluate the potential yield of corn replacing cotton and wheat, we examined USDA corn yield data for states with the highest cotton and wheat output. The corn yields in these states were a volume-weighted average of 20% below the corn yields in the top 10 corn producing states. The details of this analysis will be described in a forthcoming land use change report by Air Improvement Resource (AIR). As a result, we believe that there is data available in the U.S. that indicates the elasticity of crop yields with respect to area expansion should be 0.8 or higher.

We have not found data for areas outside of the U.S., but that is a different matter. One of the major flaws with the current GTAP model is that it applies the same expansion elasticity to all regions, all agricultural ecological zones (AEZs) within a region, and all crops. This is a parameter that should be input by region, AEZ, and crop (e.g., coarse grains should have a different elasticity value than oilseeds).

Comment 2: *Due in part to the issues described in Comment 1, and considering the fact that there is no factor to account for observed and future technology improvements in yield independent of price, the projected crop yields are too low in the most recent GTAP analysis.*

The GTAP model used for the October 16 report is based on a 2000/2001 database. To simulate ethanol expansion, the model is “shocked” for a 13.25 billion gallon ethanol increase (simulating the increase in ethanol between 2001 and 2015, for example). The model must “handle” this extreme adjustment instantaneously, while in the real world, conditions change every year and dynamic adjustments are made every year. In other words, the “shock” is much slower in the real world, with potentially much different effects than simulated by the model.

Nevertheless, the model outputs the change in yield for different crops in response to the shock. This yield is a function of two factors: the elasticity of crop yields discussed in comment 1, and the price-yield elasticity. CARB ran a sensitivity analysis of the price-yield elasticity, with values ranging from 0.6 to 0.1, while the elasticity of crop yields was fixed at 0.5. In this analysis, LUC impacts varied from 29 to 57 g CO2 eq./MJ, not as sensitive as the elasticity of crop yields, but still quite sensitive. The higher value (0.6) would indicate a higher response of crop yields to crop prices. For its pending report, AIR examined the yield increases before and after the shock, and compared these yields to historical and projected yields obtained from USDA for the time period from 2000-2001 to 2015-2016, which the model is trying to represent. The results are shown in the figure below.



Note: 2001-2007 USDA yield plots are actual recorded values. 2008-2015 yield plots are USDA projections from "Agricultural Long Term Projections to 2017"

Analysis of GTAP output shows that for this scenario, yield values increase by 3.27% in the production region defined as "U.S." The base yield is 138 bu./acre, so a 3.27% increase is 4.5 bu./acre, and, thus, the expected 2015-16 yield in the U.S. is 142.5 bu./acre. This is far too low, as USDA historical yields for the 2004-2007 time period are much higher (in the 150+ bushel/acre range). USDA's projections to 2015-16 show a yield of approximately 170 bu./acre, or 20% higher than the GTAP 2015-16 yield value generated by the 13.25 billion gallon ethanol shock. This underestimation of yield in GTAP results in much more land being converted than is likely to be the case.

Part of the reason the GTAP yields stay low in the U.S. under this scenario is because the elasticity of crop yields with area expansion is set to 0.5. To evaluate only the price-yield effect, we reset the elasticity of crop yields to area expansion to a value of 1.0, left the price-yield elasticity at 0.6, and ran the 13.25

billion gallon shock through GTAP to examine the coarse grain yield increase in the U.S. The results show a coarse grain yield increase of just 3.9%, from 138 bu./acre to 143.4 bu./acre. This is still far below the USDA projection, and a source for significant concern.

One conclusion from this is that the price-elasticity function does not explain all of the yield increases that are anticipated. The model is shocked, coarse grain prices increase somewhat, and the elasticity function predicts a slightly higher yield (but not enough). We believe there is a technology factor in yield that is not necessarily explained with price. This would mean that either the price-yield elasticity value needs to be increased to explain this technology driver, or perhaps a separate factor should be added that would be a technology driver. Either way, the current yield increases in the U.S. being modeled by GTAP on the 13.25 billion gallon ethanol shock are far too low, as demonstrated by actual average yields from the past four years and the projected yield for 2008 of 153.8 bu./acre.

We did try to increase the yield in GTAP by setting the yield expansion elasticity to 1.0 and increasing the price yield elasticity well above 0.4 or 0.6. However, the model applies this price-yield elasticity to every crop in every region. The GTAP model should allow the user to apply different improvements to different crops and different regions. We are attempting to program this characteristic into GTAP so that we can vary price yield elasticity by crop (e.g., oilseeds vs. coarse grains) in the U.S.

Comment 3: *The GTAP model may not account for reductions in wheat and cotton in the United States.*

This issue is based on analysis of trends, just like the previous issue. Information from USDA and other sources indicates that land devoted to cotton and wheat in the U.S. has been declining over the long term, due to a reduction in the demand for wheat (along with productivity improvements), reduction in the demand for cotton, and a shift from cotton growing in the U.S. to some being grown in China and India. Since the GTAP model starts with a 2000/2001 database, and the model is shocked for 13.25 billion gallons, the model may not be appropriately accounting for this change. The model appears to assume that the demand for cotton and wheat are essentially constant, and is therefore forced to make up the loss in these crops elsewhere.

Comment 4: *The three factors described in Comments 1-3 cause exports to decline significantly in the modeling.*

Since the factors discussed in comments 1 and 2 result in yields that are too low for the U.S., and the situation described in comment 3 may not be not properly accounted for, U.S. exports drop significantly on the shock, and the regions outside of the U.S. must make up for the drop in exports. These regions do so by converting land to coarse grains and other crops. However, since yields are lower outside the U.S., more land is converted to meet these shortfalls than would be converted inside the U.S. For this reason, it is very important that GTAP model the U.S. situation as accurately as possible with respect to land elasticity and price-yield elasticity.

Comment 5: *The distillers grain (DG) land use credit is too low and needs to be modified, taking into account the recent analysis of this issue performed by Argonne National Laboratory.*

The GTAP report "Biofuels and their Byproducts: Global Economic and Environmental Implications" (June 2008) indicates that DGs are being modeled as a substitute for coarse grains (see flow diagram on page 12 of the GTAP report) in the livestock sectors of the model. GTAP is using an elasticity of substitution of .30 between coarse grains and DGs. This value was selected by examining the price changes of coarse grains and DGs over the time period of 2001-2006 when ethanol production was rising sharply. Results of simulations with and without coproducts indicate that incorporating these effects reduces the increase in the demand for corn land from 9.8% to 6.3%, a reduction of 36%.

A recent report by Argonne National Laboratory on the use of ethanol co-products in all livestock sectors indicates that 1 lb. of DGs replace around 1.28 lbs. of base animal feed, Of the feed replaced, 0.96 lbs. is corn and 0.29 lbs. is soy meal.[16] There are two important implications for GTAP in the Argonne report. One is that the GTAP model should be modified so that DGs replace not only coarse grains, but also replace some amount of oilseed meal (in the livestock section of the model). Since soybean yields are lower per acre than corn yields, this will have significant land use implications. In other words, referring to page 12 of the GTAP report referenced above, the oilseed part of the feed model should be modified in a similar way as coarse grains were for byproducts. Then, the model will have to allocate a portion of the DGs to coarse grains and oilseeds, according to the allocations developed by Argonne.

The second implication of the Argonne work is that DGs replace base feed on a greater than 1-to-1 basis. It appears this fact is not being included in the GTAP model simply by evaluating historical data of the elasticity of substitution between coarse grains and DGs. Therefore, some factor will need to be incorporated into GTAP for this relationship as well.

We estimated the impacts of the Argonne work on land use changes using inputs from the California GREET report for corn ethanol.[17] The report indicates that the DG yield per gallon of anhydrous ethanol is 6.4 lbs. Assuming 151 bu./acre

[16] "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis," Arora, Wu, and Wang. Argonne National Laboratory. September 2008.
[17] "Detailed California-Modified GREET Pathway for Denatured Corn Ethanol," Stationary Sources Division, ARB, April 21, 2008.

(USDA value for 2007), and 2.6 gal/bu. (GREET input), this results in 2,513 lbs. DGs per acre. The Argonne co-products report indicates that this amount of DG will replace 3,217 lbs. of feed, consisting of 2,445 lbs. of corn meal and 772 lbs. of soy meal. Again using USDA's corn and soy yields for 2007 of 8,456 lbs./acre for corn (151 bu./acre * 56 lbs./bu.) and 2,502 lbs. per acre for soy (42 bu./acre and 44 lbs. of soy meal/bu.), the corn acres replaced are 0.29 acres, and the soy acres replaced are 0.42 acres, for a total of 0.71 acres replaced by the DGs produced from making ethanol from one acre of corn.[18] Thus, 71% of the acres devoted to ethanol are replaced by the resultant DGs. This is significantly higher than the current GTAP assumption of about 36%. Most of this difference is due to the fact that GTAP is not currently assuming that DGs replace any soy meal.

Comment 6: *The land conversions in GTAP may not adequately take into account the cost of converting forest and grasses to cropland.*

The land conversions between cropland, pasture and forest are governed at least in part by the elasticity of land transformation across cropland, pasture, and forestry. This value "was set to the relatively low value of 0.2, based on historical evidence for land cover change in the U.S. over the 1982-1997 period," according to the supporting documentation. We are not sure that this value properly evaluates the costs of converting land from forest to crops and from grass to crops. Research conducted by Colorado State University for the U.S. EPA in estimating conversion of land to cropland in the U.S. indicates that most of the land converted in the last decade to crops in the U.S. has been non-native grassland such as pasture or fields that have been idled, and not forest or native grassland. [19] CARB's "Scenario A" in Appendix A indicates that GTAP expects that 40% of the land converted in the U.S. to be forest, and 60% to be pasture. Other scenarios in this appendix indicate a range of 31% to 50% forest converted. We will be providing further information on forest conversion in the forthcoming AIR land use report.

Comment 7: *There does not appear to be CRP land or Idle Land in the GTAP database.*

In our comments on the previous workshop (June 30, 2008), we indicated that CRP land and idle land should be included in the GTAP model land use database. To our knowledge, this has not yet been done, but we understand CARB, U.C.-Berkeley, and Purdue University may still be working on this.

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[18] Note that in this estimate, we have estimated that 100% of the corn is converted to corn meal, but 73% of the soybean bushel of 60 lbs. is converted to soy meal because 26% of the mass has been extracted in the form of soy oil and other materials. (Source: Chicago Board of Trade "Soybean Crush Reference Guide"). Also, the ethanol yield of 2.6 gal./bu. may be too low – two recent studies of ethanol processing efficiencies indicate that the yield may be between 2.7 and 2.8 gal./bu. This would increase the DG land credit from 71% to 77%. (Sources: "Analysis of the Efficiency of the U.S. Ethanol Industry in 2007", May Wu, Argonne, March 27, 2008; and "U.S. Ethanol Industry Efficiency Improvements, 2004 through 2007", Christianson and Associates, August 5, 2008)

[19] Personal Communication with Dr. Steve Ogle, Colorado State University, November 14, 2008.

This issue is important because it affects the mix of land converted to crops. Idle land and CRP land are both areas of land that previously grew crops. If this land is not available in the model, then the model will instead convert forest, pasture, and other crops to corn. The inappropriate conversion of forest will raise emissions. The inappropriate conversion of pasture will cause a false reduction in livestock output. The inappropriate conversion of other crops will mean that production needs to be made up elsewhere, when this is not likely the case.

A good source of data on idle cropland is the 2003 National Resources Inventory (NRI). [20] This data source is also used by the Colorado State University CENTURY model mentioned earlier. The table below shows trends in cultivated and non-cultivated cropland. CRP land, pasture land, range land, and forest land are separate from these categories in the NRI.

Cultivated and non-Cultivated Cropland by Year (millions of acres)			
Year	Cultivated	Non-cultivated	Total
1982	375.8	44.1	419.9
1992	334.3	47.0	381.3
1997	326.4	50.0	376.4
2001	314.0	55.5	369.5
2003	309.9	58.0	367.9

These data show that the agriculture industry had 58 million acres of non-cultivated cropland in 2003. It is unclear whether this land is part of the GTAP land inventory for the U.S., but based on the modeling results it seems unlikely. Much of the non-cultivated cropland would be utilized for expansion of crops before forest or native grass is converted.

Comment 8: *Woods Hole Research Center data for native grassland with high carbon storage rates are being used to estimate emissions from non-native grassland and pasture in the U.S. with lower carbon storage rates.*

The emissions rate for grassland converted to cropland being used in GTAP is a value of 110 Mg CO2 eq./Ha. This comes from the Woods Hole data, and was developed in Latin America for natural or native grassland in that region. [21]

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[20] 2003 Annual NRI – Land Use, USDA.

[21] "Changes in the Landscape of Latin America Between 1850 and 1985 II. Net Release of CO2 to the Atmosphere", R.A. Houghton, et al, Forest Ecology and Management, 38 (1991). This study indicates that 10 Mg of C/ha is above ground for grassland, and 80 mg of C/Ha is below ground, and that by conversion of the land, 25% of the root carbon is released (10+25%*80 = 30 Mg/ha). This is then converted to CO2 by multiplying by the ratio of molecular weights of CO2 to C (3.67).

ARB is currently applying this rate of 110 Mg CO2 eq./Ha to conversion of all grassland in the U.S. and elsewhere, whether it is native grassland, pasture, or idle farmland. However, it is inappropriate to apply this emission rate to U.S. pasture or idle farmland. Native grassland, since it has been undisturbed for perhaps hundreds of years, would store much more carbon than pasture and idle farmland.[22] And, it is very unlikely that widespread conversions of native grassland are taking place in the U.S. Thus, a different emissions rate must be used for grassland conversion in the U.S., and for pasture conversions outside the U.S.

The Colorado State University (CSU) CENTURY model was used to estimate the emissions from converting land to cropland for the most recent EPA Greenhouse Gas and Sinks Report. [23] According to CSU, most of this land converted was grassland. Using information in various Annexes to this report which show total emissions and total land converted, the average emission rate is about 16 Mg CO2eq/Ha. This is far less than the 110 Mg CO2 eq./Ha being used by CARB. Our review of the EPA report indicates that this is a much more detailed and better method of estimating carbon releases from land conversions in the U.S. than using estimates for native grassland in tropical areas. It should also be used for pasture conversions outside of the U.S., since these are also not "native grasslands."

Comment 9: *Emissions for forest area assume all mass above ground is converted to CO2.*

The emission rates being used for forest converted in the model assume that all forest is converted to CO2. In reality, much of the forest mass is harvested before conversion. Some of this mass is used to produce furniture or to build houses and other products, where it would not be converted to CO2 for many years. ARB should subtract some mass from forest conversion for these products. AIR is evaluating data on these fractions and will supply what we have a later date.

Conclusion

This concludes our comments at this time. We are continuing to evaluate GTAP and emissions rate data for land conversion from different sources. We will have more specific comments on GTAP in the near future. We also continue to review other sections of the draft LCFS regulation ad supporting documentation and may have comments on other aspects of the pending regulation in the near future.

[22] Personal Communication with Dr. Steve Ogle, CSU, November 14, 2008.
[23] "Inventory of U.S. Greenhouse Gases and Sinks: 1990-2006", USEPA, April 15, 2008.