COMMENTS ON CARB ILUC REPORTS

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Date: October 5, 2011

EXECUTIVE SUMMARY

The California Air Resources Board (CARB) has released a number of draft documents and models related to the estimation of indirect land use change emissions. The documents discuss a revised GTAP model that incorporates some of the changes that had been recommended by the Expert Working Group in 2010. The documents also cover revised carbon stock estimates that have been developed for each region in the GTAP model and each AEZ in the regions. This work was also a recommendation of the EWG. Another report documents a revised methodology for estimating emission factors that are derived from the revised carbon stock estimates.

The NBB has reviewed the documents and data that has been released and has also run the revised GTAP model along with the EF Model. The NBB appreciates the development of the new model and updates to the carbon stocks and emission factors that CARB has funded. In general, the new model is a significant improvement over the previous models and this latest model is the first GTAP model that appears to handle the soybean crushing and biodiesel production sectors in an appropriate way so that the price response in the crushing sector is directionally what everyone would expect.

There are still many factors that need to be improved in the new modelling framework and a number of factors that would be nice to see in future updates.

GTAP Model

There are a number of other suggestions that we have for improvements that are needed for the model. We think that all of these are short term actions, although some will take more effort than others.

One of the most important undertakings is to fix the functioning of the CET function so that separate values are used for the different kinds of land. When so much of the land use emissions result from forest conversion, and it is known that the model currently overestimates the quantity of forest being converted, it is difficult to accept how the model could be used for regulatory purposes with a known and large error that is unaddressed.

Within the econometric modelling community it is accepted that models need to be validated. The land use emissions determined using GTAP have never been validated. They should be, but it is unlikely that a successful validation could be achieved without fixing the CET issue.

Cropland pasture should be added to the model for all regions, not just the US and Brazil. It should also be a priority to reconcile the cropland vs. land in crops issue, as there is the potential for 200 million hectares of cropland to be put into production. This would drastically alter the model results. As part of this reconciliation, the issues of CRP and fallow land should be addressed.

The NBB recommends that the 0.25 value be used for the price yield sensitivity. This value has been recommended by Tyner and Babcock, two of the foremost agricultural econometric modellers in the US. The work by Berry, while interesting, is not directly applicable to most of the commodities in GTAP due to crop aggregation, double cropping, and other factors.

The NBB recommends that no changes be made to the food consumption index, as it is unlikely to reflect food nutrition.

The NBB also recommends that the exogenous yield adjustment be applied to the 2004 GTAP results as CARB did previously with the 2001 results. Furthermore, the linearity of the results should be investigated, as soybean biodiesel has not maintained its share of the biodiesel market that it had in 2001. Finally, the unexpected response in Canada to increased US biodiesel demand should be investigated.

Carbon Stocks

The development of spatially explicit carbon stocks for the GTAP model is an improvement over the previous estimates of a single value for a complete region. A check of the proposed values for three important US AEZ regions shows reasonable alignment with the values used in the US National GHG Inventory.

Gibbs and Yui note that newer and better soil carbon estimates are available for the United States, Canada, and Australia. The most recent data should be utilized by CARB if possible but this would have a lower priority than the issues identified for the GTAP model itself.

EF Model

The EF model is overestimating land use emissions due to issues with the values of the carbon pools that have been added (deadwood, litter, and understory), the assumptions about the carbon pools in the undisturbed cases, underestimating the impact of harvested wood products, and overestimating the magnitude of the foregone sequestration. It is not suitable for use until these issues have been resolved.

The NBB recommends that the deadwood, litter, and understory be removed from the inventory as the carbon in these pools will be emitted to the environment whether the land is cleared or not. This will eliminate the need to develop better values for these pools, as the current values are very problematic for many of the regions and AEZs.

The harvested wood products calculations need a much more rigorous analysis. The fraction of the carbon that is sequestered in long term applications is just one part of the emissions picture. The calculations also need to factor in the use of significant portions of the harvested biomass for energy production and the emissions that are avoided by the use of wood over alternative building products.

The calculations of foregone sequestration are too high. In many of the regions and AEZs more carbon sequestration is being lost than exists in the standing forests. In a 30 year time frame this is not a likely scenario. Either the existing calculations are using productivity rates that are too high, or the mortality issue is not being properly accounted for in the analysis. This section should be a high priority.

Finally, it should be reasonably easy to differentiate between regions that are likely to have avoided deforestation vs. reforestation and this should be incorporated into the model to better reflect actual conditions.

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1. INTRODUCTION

On September 14, 2011 the California Air Resources Board (CARB) released a number of draft documents and models related to the estimation of indirect land use change emissions. The documents discuss a revised GTAP model that incorporates some of the changes that had been recommended by the Expert Working Group in 2010. The documents also cover revised carbon stock estimates that have been developed for each region in the GTAP model and each AEZ in the regions. This work was also a recommendation of the EWG. Another report documents a revised methodology for estimating emission factors that are derived from the revised carbon stock estimates.

CARB has requested comments on the documents and models by October 5, 2011. This report provides comments on the reports and models.

This report has three main sections; one includes comments on the GTAP model, one on the revised carbon stock estimates, and a final one on the emission factor model. Each section has a summary of the primary recommendations. A final summary section is also provided.

2. GTAP MODEL

The improved structure of the livestock and oilseed industries in this latest version of GTAP is a significant improvement over previous versions. This is most apparent when the oilseed crushing margins are examined in the different regions. The results are much more consistent and the crushing margins no longer go negative with increased demand for soybean products. The most significant discrepancy in pricing appears to be the much smaller response in Canada than in the US, which is surprising considering how closely the two countries are linked in this sector.

We remain concerned that one of the other significant shortcomings of GTAP that the NBB has consistently pointed out and was included in the EWG recommendations is that of the same value being used for the CET function for the conversion of forest and pasture to cropland (see appendix A). The limited amount of data that is available on this subject suggests that there should be an order of magnitude difference in the two values. This shortcoming has been acknowledged by the GTAP developers at Purdue and it has a significant impact on the final results since the carbon intensity of the converted forest land is so much higher than converting pasture land. We urge CARB to address this issue with the GTAP team as soon as possible.

It is also noted that the Tyner (2011) paper states that:

> *"CGE models have garnered much use recently, particularly in applications related to energy, climate change, and biofuels. However, with few exceptions, these models have not been validated against historical data."*

Piermartini et al (2005), in their WTO report, Demystifying Modelling Methods For Trade Policy, note that:

> *"It is important to note that ex-post evaluations are routine for macroeconometric forecasting models. The modeller compares the model's forecast with the actual outcome. Since a forecast is conditional on the assumptions made about the behaviour of exogenous variables, one possible explanation for a large gap between the forecast and the actual outcome is that one or more of the exogenous variables changed dramatically during the forecast horizon."*

CARB should be urged to consider studies that would validate the model results with actual changes in land use that can be measured over the past decade of very rapid growth in some biofuels in some regions of the world.

2.1 CROPLAND PASTURE

One of the improvements in this version of GTAP is the addition of cropland pasture to the model as a distinct land cover type. We have two suggestions with respect to this important enhancement.

First, the authors incorrectly state that cropland pasture exists only in the US and in Brazil, cropland pasture as a land use exists in many countries other than the US and Brazil. It is recommended that this category be added for all regions of the world. At the very least, it should be added for Canada and the EU, since these are the major trading partners of the US in soybeans and their crushing products. The Canadian data (Statistics Canada) is summarized in the following table.

Table 2-1 Cropland Pasture for Canada

	Statistics Canada	GTAP
	hectares	
Crops	35,912,247	39,573,515
Summerfallow	3,505,573	
Tame and Seeded Pasture	5,694,387	
Natural Pasture	15,441,602	20,352,430
Managed Forest (accessible)	128,843,000	100,376,243

It would appear that perhaps GTAP includes idle summerfallow land in the cropland category and perhaps includes cropland pasture as part of natural pasture.

If we look at the EU-27 we can compare the area in crops according to the FAO in 2008 with the cropland area in GTAP. These are relatively close but there is additional land in summerfallow, which would put the area of crops plus summerfallow above the GTAP value. The difference between the EU permanent grassland and the GTAP pasture is probably the cropland pasture area. The FAO data identifies about 12 million hectares of planted grasses in the "crops" category. This is summarized in the following table.

Table 2-2 Cropland Pasture for EU-27

	Area	Source	GTAP
	hectares		hectares
Crops	121,000,000	FAO	124,830,685
Summerfallow	11,000,000	EU Stats	
Permanent grassland	45,000,000	EU Stats	60,032,444
Utilized agricultural area	185,000,000	EU Stats	
Forest and Wooded Land	177,800,000	EU Stats	152,688,634

Secondly, there appears to be little rationale provided for the choice of parameters that determine how much of the cropland pasture switched to crop production and how much stays in pasture (Cropland transformation elasticity) and the yield on the converted cropland pasture (Cropland/Pasture yield adjustment). The sensitivity analysis that has been done is one way from the central parameter chosen by the modellers. Since a very significant portion of the land required for the expanded biofuel production is supplied by the cropland pasture, the choice of the parameters that determine this ratio deserves a fuller explanation and justification for the chosen values.

2.2 Land Cover Data

The issue of cropland pasture data for countries other than the US and Brazil is a part of an overall bigger issue with the land cover data in GTAP. It is very difficult to categorize land into just three or four categories. It is not clear if GTAP can currently deal with fallow land, idle land, or land that has had a crop failure.

In the US there are issues with CRP (Conservation Reserve Program) land in GTAP. CRP land has already been introduced in the GTAP model, along with cropland/pasture. It was not included in the analysis of LUC because, according to Tyner,

(1) it has not been thoroughly tested, and

(2) Purdue expects the government to continue to support the CRP for a variety of reasons.

CRP has been in the model for over a year, so there should have been adequate time to test whether this part of the model works. While we also expect the government to support the CRP program, nonetheless there have been fluctuations of land in and out of the CRP, and over the last few years, the amount of land in the CRP has declined and has been reconverted to crops, in spite of continued support from the government. This is shown in the following table.

Table 2-3 US CRP Area

	2005	2006	2007	2008	2009
	Million hectares				
US CRP land	14.1	14.6	14.9	14.0	13.6

Most of the land in the CRP is in grass or pasture, and this is the land that would be converted back to crops. Adding another “pasture” land type like CRP would reduce the forest converted due to biofuel, because of the structure of the CET nest.

An inspection of the amount of CRP land available in GTAP in the US found 14,045,541 hectares (34,707,288 acres). This is an appropriate level for the 2004 base year. While other countries do not have CRP programs, they do have areas that perform a similar function to the CRP lands in the US. These lands are not always well documented.

It is recommend including CRP, along with cropland pasture for all countries in the analysis. Validating the results should be straightforward, and there is ample evidence that some CRP lands are being utilized.

A check of the cropland area in GTAP against the sum of the area in the aggregated crops in the model (paddy rice, wheat, coarse grains, soybeans, other oilseeds, and othagri) found significance differences in each of the regions in the model, as shown in the following table.

Table 2-4 Cropland vs. Land in Crops - GTAP

	Land in Crops	Cropland	Variance
		hectares	
USA	167,058,970	175,806,994	8,748,024
EU27	115,728,602	124,830,685	9,102,083
BRAZIL	86,402,977	60,724,246	-25,678,731
CAN	33,513,687	39,573,515	6,059,828
JAPAN	4,184,987	3,680,435	-504,552
CHIHKG	160,839,687	140,644,606	-20,195,081
INDIA	186,799,223	171,418,991	-15,380,232
C_C_Amer	26,686,577	56,671,446	29,984,869
S_o_Amer	56,584,932	58,603,521	2,018,590
E_Asia	4,852,393	5,190,174	337,781
Mala_Indo	35,998,654	71,571,068	35,572,414
R_SE_Asia	60,163,202	53,207,429	-6,955,773
R_S_Asia	43,712,162	46,956,510	3,244,348
Russia	81,228,535	124,542,334	43,313,798
Oth_CEE_CIS	94,998,033	111,522,264	16,524,231
Oth_Europe	1,159,759	933,565	-226,195
MEAS_NAfr	49,932,940	53,633,292	3,700,352
S_S_AFR	175,791,952	211,016,064	35,224,112
Oceania	42,180,991	33,957,546	-8,223,446
Total	1,427,818,264	1,544,484,683	116,666,419

There are at least two types of problems with the information. In many countries there is much more reported cropland than land that is used to produce a crop. The total variance in these countries is almost 200 million hectares. If this is idle land, then there is a significant resource available to produce additional feedstock without any land use change. In other countries there would appear to be 77 million hectares more land producing crops than there is available cropland, while some of this could be due to double cropping, it is also likely indicative of the uncertainty in the cropland database in GTAP.

These variances need to be examined and addressed as they potentially could have a very significant impact of the land use change picture. The treatment of fallow land within the model also needs to be clarified.

2.3 Price Yield Elasticity

Tyner (2011) has done some sensitivity on the price-yield elasticity parameter and a new report by Berry (2011) has examined the data over the past 50 years of individual crop yield and prices.

As part of the EWG, an Elasticity Subgroup was formed to evaluate modeling elasticities. This group recommended a yield-price elasticity of 0.25 as a central value, which is the value that Purdue currently uses.[1] The sub-group stated:

[1] Final Recommendations from the Elasticity Values Subgroup (no date), Babcock, Gurgel, and Stowers.

It is not clear if GTAP can assign different elasticities to different crops in different countries. If not then if the long run price yield elasticity not accounting for double cropping is set at 0.175, and if South America and the United States are the countries that contribute the most incremental commodity production in response to higher prices, then a mid-point value of 0.25 for the price-yield elasticity seems reasonable. If differentiation can occur by country, then setting the price-yield elasticity to 0.175 for countries with no double cropping, 0.25 for the US., and 0.3 for Brazil and Argentina will provide a more reasonable approximation to reality.

In the latest work by Tyner (2011) it is stated that:

There is ample evidence in the literature that research and development (seeds, machinery, infrastructure) follows crop profitability. And certainly crop profit depends in part on crop price. Hence, there is no doubt that there is a yield response to higher crop prices. Estimating the parameter accurately will be very difficult. We know that a one-year estimate is totally inappropriate (emphasis added). We also know that a longer time period would have a larger response (elasticity) than a shorter time period. We do not in reality know if the appropriate value for the yield-to-price elasticity is 0.25 or higher or lower. However, CARB has requested that we do sensitivity analysis only for lower values of 0.05 and 0.10, so that is what is reported in this paper.

If the direction of CARB to Tyner is based on the work by Berry, it is likely that several important factors are being overlooked.

First, there is a significant degree of aggregation that is used in the GTAP model. The corn used for ethanol production is part of the coarse grains aggregation. This includes barley, sorghum, and probably rye and oats. In some regions of the US there has been a shift from barley and sorghum production to corn production. This has been facilitated by new varieties with improved drought resistance and lower heating unit requirements. The yield of corn in these expanded areas may be less than the national average, but it is much higher than the crop it replaces. The impact is that more corn (and more grain) is produced on the coarse grain land. The profitability of the producer is also greatly enhanced.

Similar issues exist with other feedstocks, including oilseeds and wheat. In the case of wheat, the yield of the crop can be strongly influenced by the variety that is grown, high protein bread wheat has a much lower yield than the higher starch feed wheat. Crop shifting in the area of wheat demand for ethanol production can have a significant impact on the yield.

In the case of soybeans, there is the opportunity to double crop in many regions of the world. With regard to double cropping, GTAP does not explicitly account for double cropping, therefore, the only method to include double cropping is with the price-yield effect. The Elasticity Subgroup paper indicates;

Babcock and Carriquiry conclude that the incentive to double crop soybeans with corn and cotton in Brazil justifies the use of a yield elasticity of 0.24 all by itself. The smaller share of U.S. double-cropped soybeans supports a smaller yield elasticity increment (for double cropping) than 0.24.

Another factor that would influence the price yield elasticity is the quantity of crops that are not harvested due to weather issues. Every year some planted area is not harvested because the quantity of crop is not high enough to be economically attractive and the producer collects crop insurance. As the price of a commodity increases, the amount of land not harvested should decrease, as the economic breakeven point will occur at lower production rates.

Clearly, CARB is basing its lower elasticities of 0.1 and 0.05 on the short-term yield-price elasticity work by Berry and Schlenker, which Tyner and Babcock indicate is not appropriate for GTAP. The lower elasticity values do not account for the aggregation of crops into categories, the opportunity for double cropping, and other factors, which are not accounted for in the Berry analyses. The NBB supports the position of Tyner and Babcock.

CARB has used the same elasticity values for all of the biofuels, it may be that in some cases it is entirely appropriate to use different values for different crops and this price-elasticity parameter is a good example where higher values may be appropriate for crops that can be double cropped.

2.4 Exogenous Yield Adjustment

In CARB's and Purdue's previous work for the LCFS, an exogenous yield adjustment was included to alter the land use changes in response to longer-term changes in crop yields.[2] This is important because GTAP is a static rather than a dynamic model, in that it uses a very detailed 2004 equilibrium database. In essence, the model is only designed to answer the question: How much land use change occurs if the biodiesel expansion that takes place in the real world from 2004 to 2015 is all compressed into 2004? The exogenous yield adjustment was utilized to adjust the GTAP-generated land use values for expected increases in crop yields between 2001 and 2009.[3] The best method of dealing with longer-term yield changes is with a dynamic model, rather than a static model, but this exogenous adjustment was thought to be one way to temporarily address the issue of longer term yield changes.

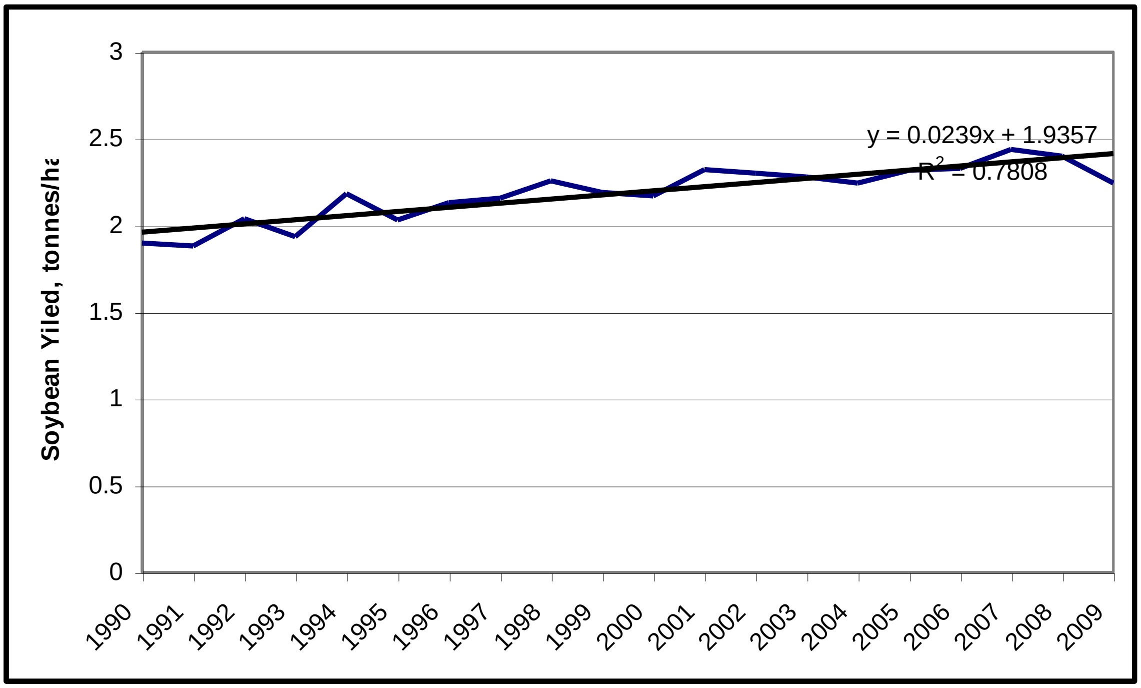
In this newest analysis, there is no mention of an adjustment for exogenous yield changes between 2004 and 2011 or 2004 and 2015. This factor clearly needs more analysis before it is omitted from CARB's new study of land use changes. This analysis should focus on historical yield changes between 2004 and 2011 and also the expected yield improvements between 2004 and 2015.

The world soybean yield is shown in the following figure. While 2009 was a poor year for world soybean yields, the yield has generally been increasing by 1% per year. The yield in 2004 was almost equal to the trend line yield.

[2] Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume II, Appendices, Appendix C5, March 5, 2009.

[3] Even though the soy biodiesel shock occurs between 2004 and 2015, CARB made the adjustment between 2004 and 2009 based on historical data. The base year for the previous GTAP model, GTAP6, was 2001 instead of 2004.

Figure 2-1 World Soybean Yield



2.5 Food Constant Analysis

The NBB does not believe that it is appropriate to artificially constrain the GTAP model in order to have constant food consumption. It is well established (FAO, 2011) that there is more than sufficient food produced in the world to feed all of the planet's inhabitants. It is estimated that the per capita food waste by consumers in Europe and North America is 95-115 kg/year, while this figure in Sub-Saharan Africa and South/Southeast Asia is only 6-11 kg/year. There are, however, significant challenges for the sector in terms of improving the efficiency of food distribution and ensuring adequate nutrition for everyone. The FAO noted that food waste in industrialized countries can be reduced by raising awareness among food industries, retailers and consumers. Increased food prices may be necessary to achieve the required level of awareness.

We would also suggest that GTAP probably can't measure nutrition or changes in nutrition. It is an economic model and it can identify the costs of food, so apparent reductions in food consumption in GTAP could also be accounted for by changing diets to include less red meat and more white meat, or to include more vegetables and less meat, an outcome that many nutritionists would welcome in the developed world.

Given the very small change in the food consumption index (0.04%) in the soybean biodiesel case, and the uncertainty in terms of what this actually means in nutritional terms, the NBB recommends that the GTAP model not be artificially constrained for a constant food consumption.

2.6 Linearity

Soybean biodiesel has not maintained its share of the US biodiesel market at the 86% level that it had in 2004. To the degree that the GTAP results are non-linear, this will result in an overestimation of the land use impacts of increased biodiesel production and consumption. CARB should consider a model run that increases soybean biodiesel demand by 0.5 billion gallons and determine if there is any difference in the land use emissions.

2.7 Individual Country Responses

The projected response to increased biofuel demand is directionally as expected in the United States, more cropland is required and that is supplied by cropland pasture and, to a lesser degree, pasture and forest. The responses in some of the other countries are less obvious.

With respect to actual model results, it is not clear to us why the response in Canada is opposite the responses in the US for the soybean biodiesel case (a decrease in cropland and an increase in forest and pasture). The ag sectors in the two regions are highly integrated with similar policies, in general the same companies operate in the crushing sector in both countries and there has been and continues to be significant trade in oilseeds, oil, meal, biodiesel and biodiesel feedstocks between the two countries.

In addition, the cropland reversion to forest is quite high in Canada in most AEZs with only a couple of AEZs having a forest to cropland conversion. Given that cropland in Canada is privately owned and forests are mostly owned by the Crown it is not clear how this reversion of cropland to forests would happen. For other crops there is significant deforestation that happens in Canada and again it is not clear how this could happen with the current ownership and management of forests in Canada.

2.8 Summary

As stated earlier, the NBB is pleased with the modifications that have been made to GTAP with respect to soybean biodiesel. The model is finally producing price impacts on soybeans and the crush products that are consistent with what one would expect from an industry facing increased demand.

There are a number of other suggestions that we have for improvements that are needed for the model. We think that all of these are short term actions, although some will take more effort than others.

One of the most important undertakings is to fix the functioning of the CET function so that separate values are used for the different kinds of land. When so much of the land use emissions results from forest conversion and it is known that the model currently overestimates the quantity of forest being converted, it is difficult to accept how the model could be used for regulatory purposes with a known and large error that is unaddressed.

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3. CARBON STOCKS

One of the recommendations from the EWG was that the carbon stocks used to determine the land use change emissions should be updated and be developed for each AEZ in each region of the world. This would provide a much better basis for determining the land use emissions.

Gibbs and Yui (2011) present the results of their analysis of a number of geographically-explicit data sets for above ground carbon and soil carbon. They provide estimates of the average amount of soil carbon and biomass carbon stored in pastures, croplands and forests for each GTAP region and AEZ. The spatial detail of their analysis is a major improvement over the look-up tables from the Woods Hole Research Center (WHRC) used in prior CARB analyses. For example, Gibbs and Yui indicate that their new estimates for above ground biomass are over 50 Mg C/ha lower than WHRC values in the US, Canada, Europe, and Russia. This is a particularly important change because 83% of the total forest-to-cropland conversion emissions occur in the U. S., Canada, and Europe in the Tyner 2011 soy biodiesel case. While the new estimates are improved, Gibbs and Yui highlight several remaining important issues. For example, Gibbs and Yui acknowledge that considerable uncertainty still exists because scientists are using a range of available sensors and methods to estimate the spatial distribution of biomass in lieu of the Lidar ideal. In addition, they indicate:

> *The estimates we provide may be under or overestimating the values on the ground due to spatial variability. The science of mapping forest carbon stocks has improved considerably, but more attention has focused on estimating changing areas of forest rather than their carbon stocks. Moreover, our approach took a weighted average of forest carbon stocks within a region, and the actual value of any given forest may be higher or lower than the average.*

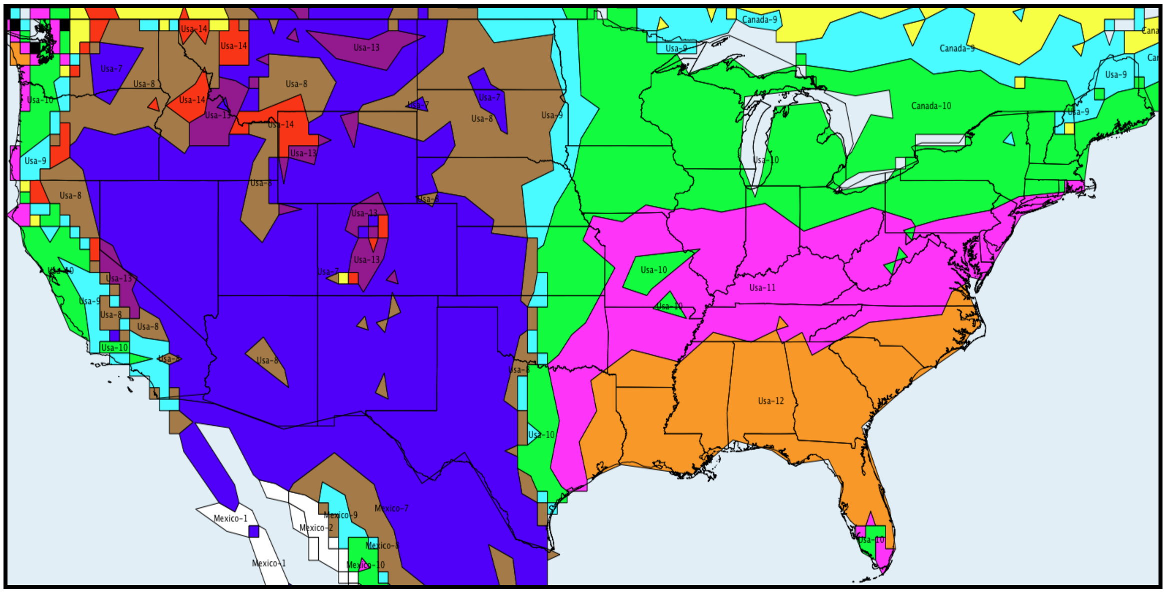
With regard to future improvements, Gibbs and Yui indicate “distinguishing between accessible and inaccessible forest would be an excellent next step.” This is important because Gibbs and Yui acknowledge that they provide estimates for average forest biomass carbon averaged across accessible and inaccessible forests and GTAP deals with land use change in accessible forests.

Gibbs and Yui also indicate that they are aware of some better data sets for soil carbon for Canada, the United States and Australia but that they have not used them. In terms of above ground biomass stocks, a variety of approaches were used, so there is some inconsistency in the approach. Furthermore, in the case of US forests, a dataset from 2000 has been chosen rather than more recent official US Forest Service data.

3.1 FOREST CARBON STOCKS

While the soy biodiesel case involves calculations of land use change and conversion emissions throughout the world, 85% of the emissions are from the conversion of forests to cropland, 90% of those emissions are in the United States, and over 95% of the forest-to-cropland conversion in the U. S. occurs in three of the AEZ regions, numbers 10, 11, and 12. These three zones are located as wide bands across the eastern U. S., in a north to south orientation, with zone 10 (temperate, sub humid) comprised of the northern tier of U. S. states East of the Mississippi, zone 11 (temperate, humid) comprised primarily of central states, and zone 12 (temperate, humid year round) comprised of the southern states. This is shown in the figure below.

Figure 3-1 AEZ Map of the United States



For the soybean biodiesel case, the forest to cropland use changes in these three zones (22,810 ha in zone 10, 14,310 ha in zone 11, and 4,270 ha in zone 12) is actually offset by reforestation (avoided deforestation) in all of the rest of the world as shown in Table 4 of Tyner 2011. Because of the dominance of the land use changes in these three U. S. zones, we have focused our comments on refined estimates of the factors used in the U. S., in general, and in these three zones, in particular.

The first major comment is that the Gibbs and Yui estimates of forest carbon stocks should be compared with the latest U. S. greenhouse gas inventory data from the US EPA (2011). Gibbs and Yui discuss how their results compare with Harris, 2009. However, the 2011 U. S. inventory has detailed estimates of carbon stocks in all the forest categories that should be used to compare with and to refine the ARB estimates. In particular, Table 7-8 has carbon stock estimates for U. S forests that differ in many cases from the new CARB estimates. Annex 3.12 of the U. S. inventory has detailed breakdowns in Tables A-214 and A-216 by region, by state, and by forest type that can be used to compare with the Gibbs and Yui and Plevin et al. estimates. In addition, more detailed data for each state are available through the USDA Forest Service (2010).

In addition, Heath et al. (2011) provide information on the forest carbon stocks in both private and public forests, using methods consistent with the 2010 U. S. inventory. The figures from Heath et al. 2011 are shown below.

Figure 3-2 US Forest Service National Regions

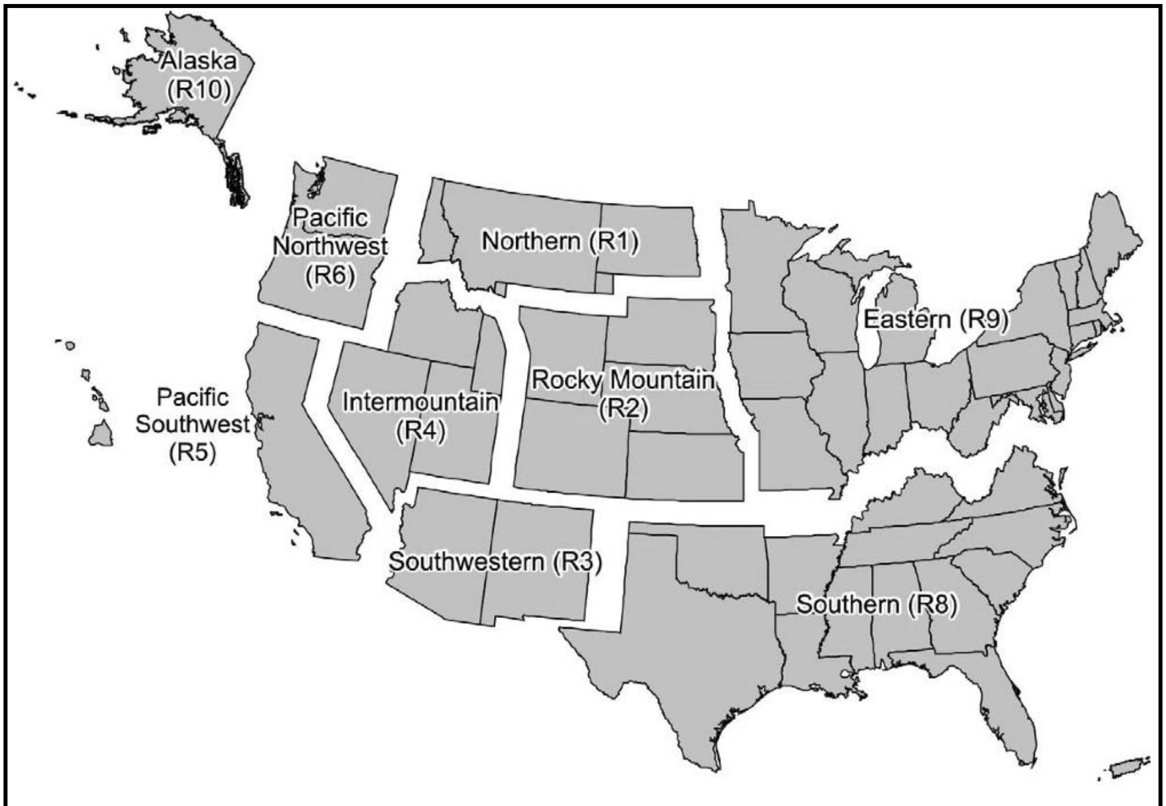


Fig. 1. Map of USDA Forest Service, National Forest System regions.

Figure 3-3 US Forest Carbon Stock Density

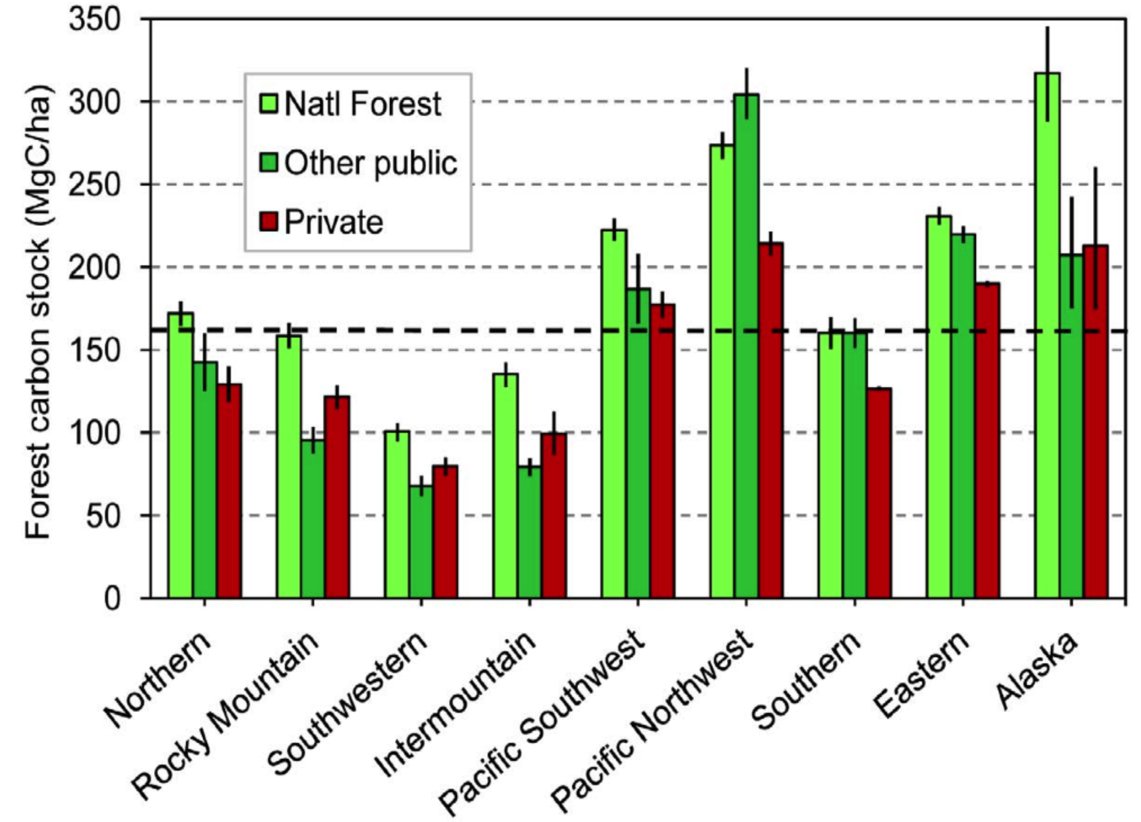


Fig. 2. Mean forest carbon density (Mg C/ha) by ownership by National Forest System region, 2005. Horizontal dashed line represents the overall average carbon stock on U.S. forestland, 162 Mg C/ha. Error bars indicate a 95% confidence interval of uncertainty about the regional average, from carbon conversion factors and sampling error.

Heath et al., in their Figure 2, show that the carbon density in private forests is substantially lower than in national forests and lower than in forests overall in the U. S.

Figure 3-4 US Forest Land by Ownership

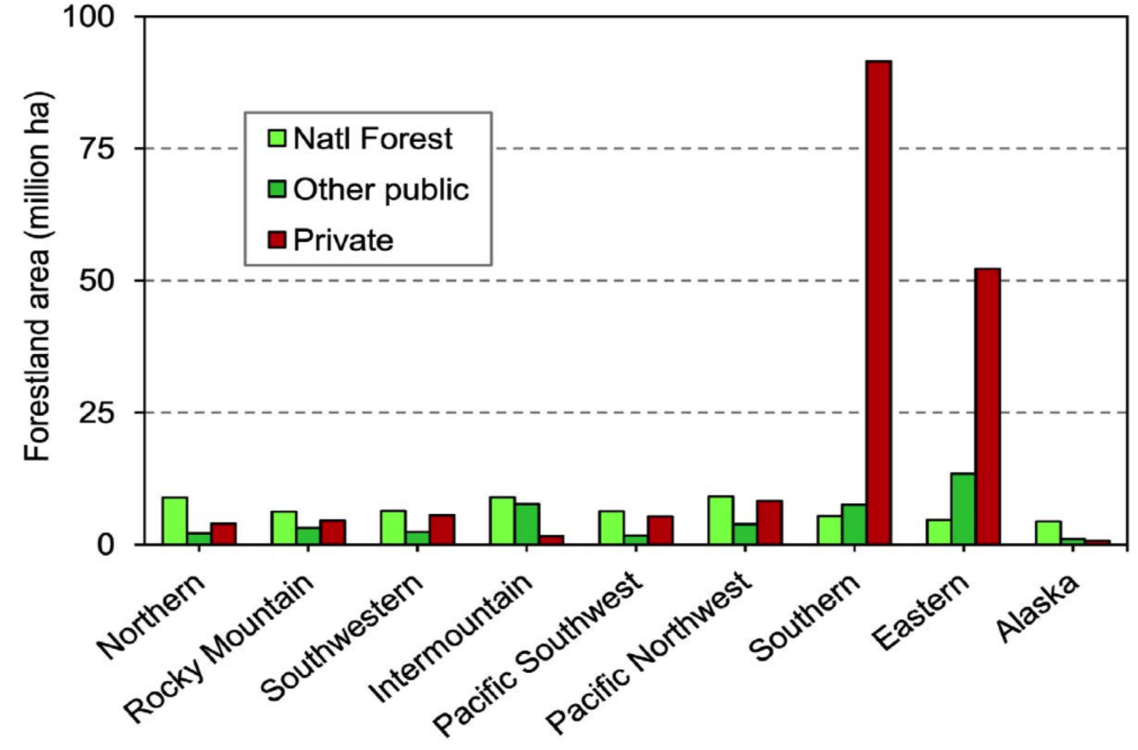


Fig. 3. Forestland area (million hectares) by ownership summed by National Forest System region, 2005. Error bars for a 95% confidence interval of sampling error for forest area are not included because they are too small for the resolution of the figure.

In their Figure 3, Heath et al. show that the vast bulk of private forests are located in the Southern and Eastern Forest Service regions. These two regions, as shown in their Figure 1, essentially overlap with the three AEZ regions used in the CARB analysis. These figures demonstrate that the carbon density in private forests in the same regions, where the ARB predicts land use change, is less than in forests overall. Thus, the results for private forests in the Eastern and Southern regions would be a useful first cut at identifying the carbon density of accessible forests that the GTAP model utilizes. Since the most likely conversions would occur on private forests within areas near existing cropland infrastructure, further refinements could be evaluated by comparing the spatial breakdown of the biomass in the 66 zones of the Kellndorfer et al. data set with the spatial breakdown of the locations of cropland shown in Gibbs and Yui 2011. For example, across the northern tier of states that comprise AEZ region 10, existing cropland is clustered in the Midwestern locations that have lower aboveground biomass in the NBCD Zone map from the Kellndorfer data set.

The comparison of the Gibbs and Yui data with the Forest Service data is shown in the following table.

Table 3-1 Comparison of Forest Carbon Stocks

Gibbs and Yui	Above and Below Ground Biomass	US Forest Service Private Forests	Above and Below Ground Biomass
	Mg C/ha		
AEZ 10	87	Eastern	80
AEZ 11	89	Southern	90
AEZ12	67	Southern	90

This small comparison indicates that the new above and below ground carbon estimates from the two sources are reasonably close.

Table 3-2 Comparison of Forest Soil Carbon Stocks

Gibbs and Yui	SOC	US Forest Service Private Forests	Above and Below Ground Biomass
	Mg C/ha		
AEZ 10	81	Eastern	90
AEZ 11	54	Southern	50
AEZ12	46	Southern	50

This comparison shows that the two sources are reasonably close for these important regions.

Gibbs and Yui do not provide estimates of deadwood and litter, these gaps are filled in by Plevin and will be discussed in the next section.

3.2 Summary

The development of spatially explicit carbon stocks for the GTAP model is an improvement over the previous estimates of a single value for a complete region. A check of the proposed values for three important US AEZ regions shows reasonable alignment with the values used in the US National GHG Inventory.

Gibbs and Yui note that newer and better soil carbon estimates are available for the United States, Canada, and Australia. The most recent data should be utilized by CARB if possible but this would have a lower priority than the issues identified for the GTAP model itself.

4. EMISSION FACTORS

An emission factor model has been developed by Plevin et al to calculate the land use change emissions from the land use changes that are estimated from the GTAP model. The model utilizes the carbon stock data developed by Gibbs, supplements it with other information for pools not specifically covered by Gibbs and applies mostly IPCC factors to derive the emissions from each type of land conversion in each of the regional AEZs in GTAP.

4.1 ADDITIONAL CARBON POOLS

Plevin et al have added data on carbon stored in deadwood, litter and understory to the carbon stocks developed by Gibbs. The data sources and values are described below.

4.1.1 Deadwood

Plevin et al document a number of potential estimates of deadwood but settle on using estimates derived by Pan et al. These are regional estimates and are not broken down by AEZ. The estimates range from 2 to 27 Mg C/ha. In many cases, (e.g. Canada AEZ 7, 13, and 14) the quantity of dead wood in the EF model is greater than the quantity of above ground biomass. This is an unlikely situation. If deadwood were to be included in the EF model, then it would be better to develop a percentage factor that would be applied to the above ground biomass, as many other researchers have done. This factor could then be applied to each AEZ in the model rather than using an average factor for regions.

In the emission factors section below we will present the case on why deadwood and litter should not be included in the EF model.

Table 4-1 Deadwood as a Percentage of Above Ground Biomass

	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR
AEZ1			255				454	238	101				304				69	70
AEZ2			327				78	109	46				3,436,955				59	68
AEZ3			78				35	55	58				40				68	88
AEZ4		259,516	48				24	51	36	38	26	21	32				51	65
AEZ5			27			22	22	41	29	38	29	20	25					32
AEZ6			23			23	19	28	21	34	21	20	24					22
AEZ7	22			125		19	62	13	22	65			14	13	35		7	9
AEZ8	14	10		93		14	13	12	21	28			7	11	11		8	11
AEZ9	12	6		83	10	22	5	16	14	39			6	11	9	19	10	11
AEZ10	15	7	8	74	5	21	5	10	7	39		4	4	11	22	13	8	11
AEZ11	15	5	11	86	5	5	4	8	7	22		3	3	11	18	8		10
AEZ12	19	4	7	208	4	4	3	5	7	5		3	3	525,970	7			8
AEZ13	15	10		109		15	11		43	109			15	64	99	36		
AEZ14	13	13		89		14	17		32	101			15	45	56	204		
AEZ15	9	8		77	35	12	14		35	81		12	11	40	53	84		
AEZ16	6	6				13	12		32			10	10	37	31	81		
AEZ17						13			26									
AEZ18									21									

Any of the estimated percentages that are above 20% are suspect. Given the uncertainty in estimating this carbon pool it would be better to use a fixed percentage of above ground biomass rather than the estimates that are used. A value in the 10% to 15% range would be more appropriate than what has been proposed.

4.1.2 Litter

The litter estimates are based on IPCC emission factors that take a simple average of the values for deciduous and evergreen for various forest types and climates and then apply those to the AEZ. The problem is that the values are not related to the forest biomass inventory that is developed by Gibbs by region and AEZ. The percent rates vary from 3% to 2,375,000% of the standing biomass and even from 17% to 180% within AEZ10.

There are also regions where the litter is higher than the aboveground biomass (e.g. Canada AEZ 7, 8, 13, 14, 15, and 16). Plevin et al state in the report that it is reasonable to estimate the size of the deadwood pool based on the above ground estimates and cite a reference from New Zealand that mentions 16% as the appropriate level, yet the model uses factors that are greater than 100%. This is just not credible. In the following table the quantity of litter as a percentage of the above ground biomass is shown.

Table 4-2 Litter as a Percentage of Above Ground Biomass

	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR
AEZ1			34				61	32	14				41					9
AEZ2			44				11	15	6				462,500					9
AEZ3			10				5	7	8				5					12
AEZ4			6				3	7	5	5	3	3	4					9
AEZ5			4			3	3	6	4	5	4	3	3					4
AEZ6			3			3	3	4	3	5	3	3	3					3
AEZ7	5,327			148		117	380	83	133	398			89	81	213		41	57
AEZ8	35	131		110		88	78	77	128	171			44	71	70		49	65
AEZ9	30	80		99	63	136	31	99	85	239			36	69	56	115	63	66
AEZ10	28	69	35	65	25	97	22	47	34	180		18	17	53	102	58	36	49
AEZ11	27	44	49	76	22	22	16	36	34	100		14	16	48	84	37		45
AEZ12	35	39	33		20	20	13	24	30	24		13	14	2,375,000	34			35
AEZ13	39	130		267		29	22		85	214			30	125	195	70		
AEZ14	34	174		140		28	33		62	198			30	89	111	400		
AEZ15	23	110		115	69	24	27		68	159		23	21	79	104	165		
AEZ16	27	133		165		43	40		105			32	34	122	101	268		
AEZ17						42			87									
AEZ18									69									

The very large numbers in some AEZs are due to the use of a small number in the EF model rather than zero. These can be disregarded, but any value over 30 needs to be revisited. The approach used for litter rates is obviously problematic for many of the regions and AEZs. Again, if litter pools are incorporated, a fixed percentage of above ground biomass is more appropriate.

4.1.3 Understory

Plevin has added biomass carbon stocks for understory. This includes shrubs, herbs, grasses, mosses, lichens and vines. A variety of sources of data are identified but values of 1.5 Mg C/ha are chosen for boreal and temperate forests and 4.5 for tropical forests.

The challenge is whether or not this is double counting material that is already counted in above ground biomass, as the methodology is poorly documented. The carbon stocks are quite small in the overall picture and are even small compared to the uncertainty in the estimates of the other carbon pools.

4.1.4 Comparison to US Forest Service Data

Heath et al. show the breakdown of average forest carbon density in National Forests within the various regions in their Figure 4, as shown in the following figure. This provides the opportunity for a comparison of the values used in the EF model.

Figure 4-1 US Forest Carbon Stocks by Component

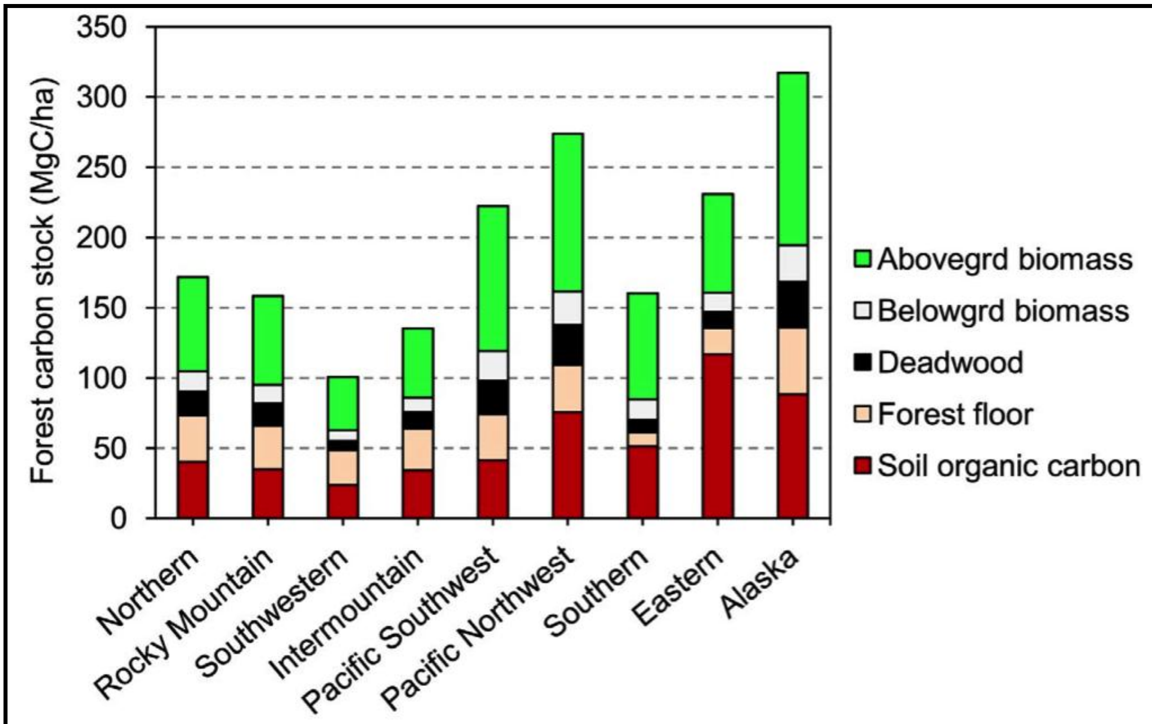


Fig. 4. Mean forest carbon density (Mg C/ha) by component pools for USDA Forest Service forestland only by National Forest Service region, 2005. Biomass includes live trees and understory vegetation.

The comparison of the Plevin assumptions on deadwood, litter and understory with the Heath et al estimates are shown in the following table for the three important US AEZs. The Plevin estimates are close for the Southern forest region but are high for the Eastern region.

Table 4-3 Comparison of Forest Deadwood and Litter Stocks

Plevin	Deadwood, Litter, and Understory	US Forest Service Private Forests	Deadwood and Forest Floor
	Mg C/ha		
AEZ 10	31	Eastern	20
AEZ 11	31	Southern	30
AEZ12	31	Southern	30

4.2 EMISSION FACTORS

The emission factors are developed from the carbon stocks data and consider the fate of the carbon over the 30 year time frame that has been chosen for the ILUC analysis. Comments are provided for each of the major categories below.

4.2.1 Biomass

The CO_2 emissions that are calculated from the loss of above and below ground biomass generally follow the IPCC methodology. The new model accounts for emissions due to decomposition and from fire. Subject to the recommended exclusion of some carbon pools discussed below, the approach is appropriate.

4.2.2 Soil

The approach used for soil carbon losses is to make an estimate of the percentage loss of soil carbon based on using the factors in the IPCC soil carbon tool. Many researchers have found that this tool overestimates carbon losses in some eco-systems, particularly cool and temperate regions. There are other soil carbon change programs that could be investigated or used for comparison.

4.2.3 Deadwood and Litter

Deadwood and litter is biomass that has started to decompose on the forest floor. While it is included in IPPC inventory calculations, it is not appropriate to include it in the EF model, as this material would decompose to CO_2 even if the forest were not converted to cropland. Since the same emissions occur in the reference system and the biofuel system the appropriate treatment is to exclude the emissions from both systems.

The understory material also has a high percentage of short lived biomass that will die and decompose during the 30 year time frame under consideration for the indirect emissions. This carbon pool should also be excluded from the EF model, as the emissions will occur in both the study system and the reference system.

4.2.4 Harvested Wood Products

The proposed EF model makes an allowance for carbon stored in harvested wood products in some regions. Basically, this adjustment is applied in developed countries and is not applied in undeveloped countries. It is noted that further work is underway on trying to quantify this carbon pool.

While this is a step in the proper direction, it would appear to be focused on a very small portion of the issue, the carbon that is “locked up” in harvested wood products and not on the true lifecycle impacts of the wood harvested from the forests. There are at least two other important aspects that should be considered.

The first is that a portion of the wood that is harvested is used for energy and that displaces fossil fuels that would otherwise be used. Heath et al suggest that 35% of the carbon is combusted for energy that would otherwise be generated from fossil fuels. This should be accounted for in the modelling of harvested wood products.

The second aspect is what do the harvested wood products displace? What would be produced if there were no wood products. CORRIM, The Consortium for Research on Renewable Industrial Materials, have developed methodologies and reports on the lifecycle impacts of wood products. CORRIM were originally organized to update and expand a 1976 report by the National Academy of Science regarding the impacts of producing and using renewable materials. They have produced a number of reports on the lifecycle analysis of forests and of harvested wood products. They have found that wood replaces other emission intensive products such as concrete, steel, gypsum wall board and other products. Oneil et al (2009) produced the emission savings of using wood instead of concrete or steel and the results are shown in the following figures.

Figure 4-2 GHG Emissions Wood vs. Concrete

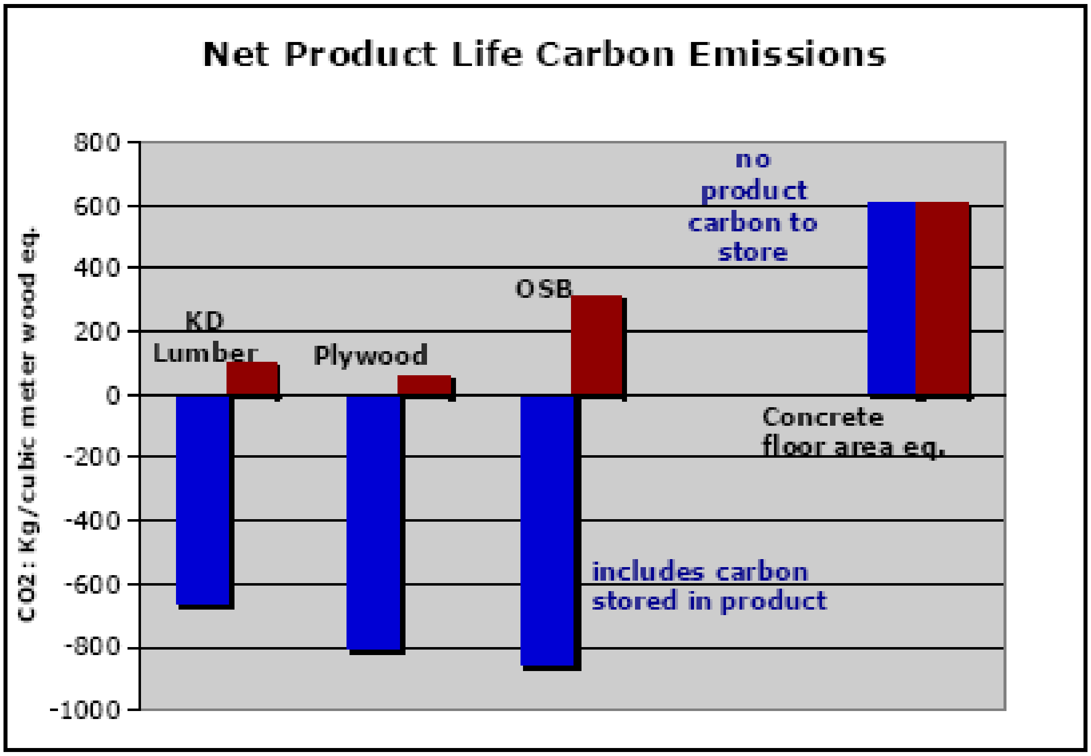
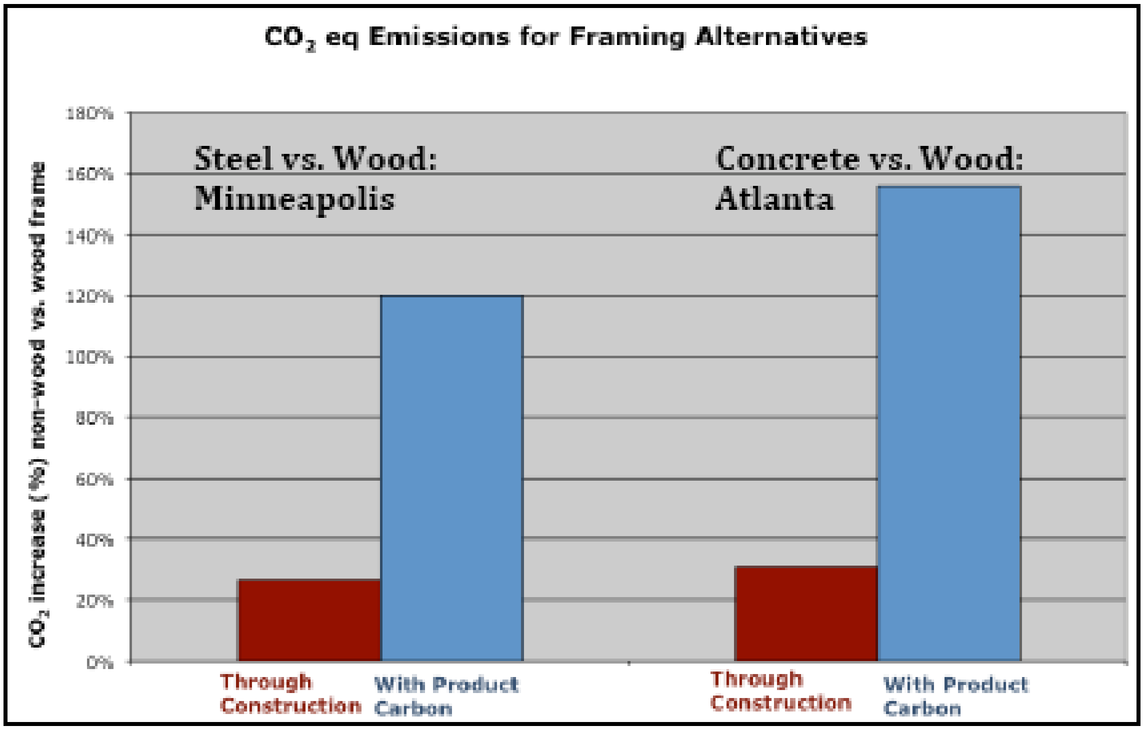


Figure 4-3 GHG Emissions Construction Framing Alternative



Harvested wood products deserves a much more thorough accounting of the GHG emissions avoided that is currently in the EF model. At a minimum, the accounting needs to account for the emission offset from the use of wood residues for energy and the emissions avoided from alternative construction materials.

4.3 Foregone Sequestration

The EF model is calculating foregone sequestration based on IPCC estimates of net above ground biomass mapped to regional values by applying expert judgement by Gibbs. In the following table the foregone sequestration emissions are presented as a percentage of the above and below ground biomass content for each of the regions and AEZ.

Table 4-4 Foregone Sequestration as a Percentage of Above and Below Ground Biomass

	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR
AEZ1			181				483	169	72				324				70	71
AEZ2			232				47	77	28				2,062,500				60	140
AEZ3			106				21	74	35				24				69	181
AEZ4		2,062,500	102				15	108	21	23	61	13	20				52	134
AEZ5			57			13	13	87	17	23	69	12	15					66
AEZ6			49			14	11	60	13	20	50	12	15					45
AEZ7	34			94		75	242	192	85	254			57	52	492		44	126
AEZ8	23	83		70		56	50	177	81	109			28	45	163		52	143
AEZ9	19	51		63	109	86	20	230	54	152			23	44	36		68	144
AEZ10	86	59	36	203	21	83	33	47	34	153		16	26	45	87	287	52	146
AEZ11	84	38	50	237	19	19	51	36	34	233		12	49	41	72	349		132
AEZ12	69	34	34		18	42	40	24	31	57		11	44	7,500,000	29			103
AEZ13	23	77		158		17	13		59	126			17	74	115	67,636,751		
AEZ14	20	103		30		16	20		43	117			18	52	65			
AEZ15	14	65		68	41	14	16		40	94		14	12	46	61			
AEZ16	9	47		58		15	14		37			11	12	43	35	344		
AEZ17						15			31									
AEZ18									24									

Values above 100% are obviously problematic and this is the case for a number of regions and AEZs. Values above 50% should be investigated.

Pan et al (2011) reported net ecosystem production rates by species and age for US forests. He reported that the mean rates range from 0.88 Mg C/ha/year for white and red jack pine in the Northeast forest district to 2.19 Mg C/ha/year for oak and hickory in the same region. Over a 30 year period this would range from 26 to 66 Mg/ha. The value used in the EF model for AEZ 10 (which overlaps with the Northeast forest district) is 75 Mg/ha. This data also suggests that the foregone sequestration rates used in the model are too high.

It is clear that the foregone sequestration values are too high for many regions. Further work is required to develop values that are appropriate for all regions and all AEZs.

4.3.1 Stand Mortality

Given that the above ground biomass estimates that were previously used by CARB were derived from IPCC guidelines and that the new estimates from Gibbs are generally lower, it should not be surprising that using the same general approach for calculating foregone sequestration also provides estimates that are too high.

One of the reasons for this is that the approach fails to account for the mortality of the stand. Trees do not live forever. Trees are living organisms and like all living things they have a life cycle and at the end they die. The end of the lifecycle could be caused by natural fires, by disease or pests, or simply by old age. At the end of the lifecycle the carbon in the above ground biomass starts to decompose and is returned to the atmosphere. Thus, if the forest land use is changed to produce crops and the carbon stored in the trees is released to the environment, then it may not change the total amount of carbon that is released but ***when*** that carbon is released. In a system that discounts future carbon changes this will have an impact on the net present value of the carbon emissions but, in a system that does not discount future changes, the premature release of carbon would not impact the overall emissions.

The IPCC recognize this. Equation 2.11 in the 2006 AFOLU guidelines is;

$$\Delta CL = L_{wood\ -\ removals} + L_{fuelwood} + L_{disturbance}$$

ΔCL = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr-1

$L_{wood-\ removals}$ = annual carbon loss due to wood removals, tonnes C yr-1

$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals, tonnes C yr-1

$L_{disturbance}$ = annual biomass carbon losses due to disturbances, tonnes C yr-1

The disturbances can include wildfires, disease and pests, and natural events (wind damage). The IPCC also makes estimates for mortality separate from disturbances and suggests that in actively managed stands mortality may represent 30% to 50% of the lifetime productivity of the stand.

The IPCC reports that the average mortality rate ranges from 1.16% for evergreen and deciduous forests to 1.77% for tropical forests.

Information on disturbances is more difficult to accurately assemble but the FAO 2005 Global Forest Resource Assessment reported that the annual disturbance rates for all regions due to fire was 0.70%, due to insects was 0.93%, due to disease was 0.78% and due to other factors was 0.21%. The total annual forest disturbance rate was thus 2.6%. This would be in addition to the average mortality rate. The total annual disturbance rate could be as high as 4% to 4.5% per year. The report contains information on individual countries, so an in-depth analysis for each country could be performed.

By properly accounting for the future losses, as well as the future gains, a proper assessment of carbon changes over time can be performed. The approach in the proposal grossly overestimates the carbon losses over time by assuming that forest carbon is permanent, when it is not.

4.4 Avoided Deforestation vs. Reforestation

Since GTAP is a static model and not a dynamic model there is uncertainty over what time period changes in land use will happen but it is clear that they can't be instantaneous. At the same time it is known that the demand for agricultural products will continue to expand due to population growth and increasing GDP. These non biofuel impacts also have the potential to induce land use change. This raises the issue of whether a modelled increase in forest area is reforestation or is avoided deforestation. This is important since the emission benefit from reforestation is less than the emissions from deforestation.

It is currently suggested that long term research is necessary to determine, at the country level, if increases in forest area should be treated as avoided deforestation or as reforestation. We would suggest that it is possible to make some estimates that could be applied to the model now and not after long term research has been completed. After all, estimates are being made for factors such as harvested wood products, burning rates vs. decomposition, etc. In fact we would suggest that the same general matrix could be applied, regions that have been assumed to apply burning to the biomass cleared from the forests should be treated as avoided deforestation and those with the HWP accounted for should be treated as reforestation.

4.5 Summary

The EF model is overestimating land use emissions due to issues with the values of the carbon pools that have been added, the assumptions about the carbon pools in the undisturbed cases, underestimating the impact of harvested wood products, and overestimating the magnitude of the foregone sequestration. It is not suitable for use until these issues have been resolved.

The NBB recommends that the deadwood, litter, and understory be removed from the inventory as the carbon in these pools will be emitted to the environment whether the land is cleared or not. This will eliminate the need to develop better values for these pools, as the current values are very problematic for many of the regions and AEZs.

The harvested wood products calculations need a much more rigorous analysis. The fraction of the carbon that is sequestered in long term applications is just one part of the emissions picture. The calculations also need to factor in the use of significant portions of the harvested biomass for energy production and the emissions that are avoided by the use of wood over alternative building products.

The calculations of foregone sequestration are too high. In many of the regions and AEZs more carbon sequestration is being lost than exists in the standing forests. In a 30 year time frame this is not a likely scenario. Either the existing calculations are using productivity rates that are too high, or the mortality issue is not being properly accounted for in the analysis. This section should be a high priority.

Finally, it should be reasonably easy to differentiate between regions that are likely to have avoided deforestation vs. reforestation and this should be incorporated into the model to better reflect actual conditions.

5. SUMMARY

The California Air Resources Board (CARB) has released a number of draft documents and models related to the estimation of indirect land use change emissions. The documents discuss a revised GTAP model that incorporates some of the changes that had been recommended by the Expert Working Group in 2010. The documents also cover revised carbon stock estimates that have been developed for each region in the GTAP model and each AEZ in the regions. This work was also a recommendation of the EWG. Another report documents a revised methodology for estimating emission factors that is derived from the revised carbon stock estimates.

The NBB has reviewed the documents and data that has been released and has also run the revised GTAP model along with the EF Model. The NBB appreciates the development of the new model and updates to the carbon stocks and emission factors that CARB has funded. In general, the new model is a significant improvement over the previous models and this latest model is the first GTAP model that appears to handle the soybean crushing and biodiesel production sectors in an appropriate way so that the price response in the crushing sector is directionally what everyone would expect.

There are still many factors that need to be improved in the new modelling framework and a number of factors that would be nice to see in future updates.

5.1 GTAP MODEL

There are a number of other suggestions that we have for improvements that are needed for the model. We think that all of these are short term actions, although some will take more effort than others.

One of the most important undertakings is to fix the functioning of the CET function so that separate values are used for the different kinds of land. When so much of the land use emissions result from forest conversion, and it is known that the model currently overestimates the quantity of forest being converted, it is difficult to accept how the model could be used for regulatory purposes with a known and large error that is unaddressed.

Within the econometric modelling community it is accepted that models need to be validated. The land use emissions determined using GTAP have never been validated. They should be, but it is unlikely that a successful validation could be achieved without fixing the CET issue.

Cropland pasture should be added to the model for all regions, not just the US and Brazil. It should also be a priority to reconcile the cropland vs. land in crops issue, as there is the potential for 200 million hectares of cropland to be put into production. This would drastically alter the model results. As part of this reconciliation the issues of CRP and fallow land should be addressed.

The NBB recommends that the 0.25 value be used for the price yield sensitivity. This value has been recommended by Tyner and Babcock, two of the foremost agricultural econometric modellers in the US. The work by Berry, while interesting is not directly applicable to most of the commodities in GTAP due to crop aggregation, double cropping, and other factors.

The NBB recommends that no changes be made to the food consumption index as it is unlikely to reflect food nutrition.

The NBB also recommends that the exogenous yield adjustment be applied to the 2004 GTAP results as CARB did previously with the 2001 results. Furthermore, the linearity of the results should be investigated, as soybean biodiesel has not maintained its share of the biodiesel market that it had in 2001. Finally, the unexpected response in Canada to increased US biodiesel demand should be investigated.

5.2 Carbon Stocks

The development of spatially explicit carbon stocks for the GTAP model is an improvement over the previous estimates of a single value for a complete region. A check of the proposed values for three important US AEZ regions shows reasonable alignment with the values used in the US National GHG Inventory.

Gibbs and Yui note that newer and better soil carbon estimates are available for the United States, Canada, and Australia. The most recent data should be utilized by CARB if possible but this would have a lower priority than the issues identified for the GTAP model itself.

5.3 EF Model

The EF model is overestimating land use emissions due to issues with the values of the carbon pools that have been added, the assumptions about the carbon pools in the undisturbed cases, underestimating the impact of harvested wood products, and overestimating the magnitude of the foregone sequestration. It is not suitable for use until these issues have been resolved.

The NBB recommends that the deadwood, litter, and understory be removed from the inventory, as the carbon in these pools will be emitted to the environment whether the land is cleared or not. This will eliminate the need to develop better values for these pools, as the current values are very problematic for many of the regions and AEZs.

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The calculations of foregone sequestration are too high. In many of the regions and AEZs more carbon sequestration is being lost than exists in the standing forests. In a 30 year time frame this is not a likely scenario. Either the existing calculations are using productivity rates that are too high, or the mortality issue is not being properly accounted for in the analysis. This section should be a high priority.

Finally, it should be reasonably easy to differentiate between regions that are likely to have avoided deforestation vs. reforestation and this should be incorporated into the model to better reflect actual conditions.

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7. APPENDIX A CET FUNCTION

There is very little real world evidence to indicate what the CET values should be. This issue was also one identified by the CARB EWG as one of the areas that needed improvement. A paper by Babcock and Carriquiry (2010) that looked at the GTAP modelling of biodiesel explains the issue in some detail. Portions of this paper are shown below.

> *The way that GTAP allocates land between crops, pasture, and forest is to use a function called the constant elasticity of transformation (CET) supply function. This is a function that allocates land based on a function that depends on the share of revenue from each type of land cover and the transformation elasticity σ. This function is used because of it parsimony and because it gives the necessary convexity so that a solution to the maximization problem can be obtained. However, the convenience of this function imposes some restrictions that are quite important in predicting how much pasture land relative to forest land is converted in response crop price increases related to biofuels expansion.*
>
> *Following the notation on page 4 of Ahmed, Hertel, and Lubowski, the cross price elasticity of the supply of forest land in response to a crop price increase equals* $\varepsilon_{forest,\,crop} = \theta_{crop}\sigma$ *where* θ_{crop} *is the share of revenue from crops. The cross price elasticity of pasture land in response to a crop price increase is* $\varepsilon_{pasture,\,crop} = \theta_{crop}\sigma = \varepsilon_{forest,\,crop}$. *This means that a 10% increase in crop prices will result in the same percent change in pasture and forest land.*[4] *Homogeneity of supply means that the own price elasticity equals (in absolute value) the sum of the cross price elasticities so that the own price elasticity of pasture, forest and crop in GTAP differ only by the share of revenue:*
>
> $$\varepsilon_{pasture,\,pasture} = -\sigma(1-\theta_{pasture})$$
>
> $$\varepsilon_{forest,\,forest} = -\sigma(1-\theta_{forest})$$
>
> $$\varepsilon_{crop,crop} = -\sigma(1-\theta_{crop})\,.$$
>
> *The central value of σ in CARB's biodiesel analysis is -0.2, which is equal to the revenue-share-weighted average of the estimated individual land cover CET parameters (discussed below) after five years. Page 5 of Ahmed, Hertel, and Lubowski report revenue share values of 0.7489 for crops, 0.0975 for pasture, and 0.1023 for forest. This means that the GTAP own return elasticities of supply are 0.05, 0.18 and 0.18 for crops, pasture, and forest respectively.*
>
> *One cost of using the CET function to allocate land is that the own return elasticities for pasture and forest are significantly different than what Ahmed, Hertel, and Lubowski estimate them to be. Their estimates are derived from analysis of plot-level National Resources Inventory data from 1982 to 1996 conducted by Lubowski and Lubowski, Plantinga, and Stavins. Their own estimates of the own price elasticities at five years are approximately 0.045, 0.22, and 0.005 for crops, pasture, and forest*

[4] The equilibrium solution will not typically be exactly the same percent change because the own supply elasticities of forest and pasture may differ and the demand elasticities for forest products may differ from pasture products.

respectively[5]. Thus the GTAP own price elasticities for crops and pasture are roughly equal to the empirically based own price elasticities. ***But the forest elasticity in GTAP is 36 times higher than the estimated value.*** *This difference in forest is particularly important when considering the response of forest land to higher crop prices.*

As stated above, GTAP imposes the homogeneity condition that the own price elasticity equals the absolute value of the sum of the cross price elasticities. Because both cross price elasticities are negative (a higher price of crops leads to less forest land) we know that their value must be between zero and the value of the own price elasticity. Using a forest own price elasticity of 0.18 allows the cross price elasticities to be between 0 and -0.18. For example, if the cross price elasticity of forest with respect to pasture equals -0.08, then the cross price elasticity of forest with respect to crops equals -0.1.[6] If GTAP had instead used 0.005 as the own price elasticity of forests, then this implies that the cross price elasticity of forest land with respect to crop prices would be limited to between 0 and -0.005.

The most important factor affecting the magnitude of the change in greenhouse gas emissions from land use changes is the response of forest land to an increase in crop prices. Thus use of the GTAP own price elasticity of 0.18 instead of the empirically-estimated own price elasticity of forests of 0.005 results in dramatically higher greenhouse gas emissions. The GTAP cross price elasticity of forest with respect to crop price equals

$$\varepsilon_{forest,\,crop} = \theta_{crop}\sigma = -0.7489*0.2 = -0.15$$

This elasticity is 30 times higher than the maximum cross price elasticity that would be possible if the empirically-estimated forest own price elasticity was used in the analysis.

The GTAP cross price elasticity of crops with respect to crops is also equal to -0.15, which may be close to the value that is consistent with the empirical estimates. ***This suggests that a model that used empirically based own and cross price elasticities for forest, pasture, and crops would have pasture land being at least 30 times more responsive to crop prices than forest land in a five year horizon.***

[5] These estimates were obtained from Figure 2 of Ahmed, Hertel, and Lubowski. The approximation of the forest elasticity was difficult because the five year value was so close to zero.

[6] The share of revenue in Ahmed, Hertel, and Lubowski do not sum to one, which implies that "other" land use must be equal to one minus the sum of share to forest, crops, and pasture. The other land use is ignored in this explanation.