ESTIMATING GREENHOUSE GAS EMISSIONS FROM SOY-BASED U.S. BIODIESEL WHEN FACTORING IN EMISSIONS FROM LAND USE CHANGE[1]

Timothy D. Searchinger (Woodrow Wilson School, Princeton University, The German Marshall Fund of the U.S., Georgetown Environmental Law and Policy Institute)– tsearchi@princeton.edu)

Ralph Heimlich (Agricultural Conservation Economics)

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I. The Importance of Emissions from Land Use Change

Lifecycle greenhouse gas calculations for biofuels have traditionally focused on engineering calculations. They have carefully analyzed the emissions involved in producing a feedstock through use of tractors and fertilizer, refining the feedstock into oil, transporting the products, and burning the fuel in the vehicle. Although these engineering calculations are important, biofuels are ultimately a land use decision. The potential of biofuels to reduce greenhouse gas emissions originates with the capacity of land to remove carbon from the atmosphere. Biofuels have the theoretical potential to reduce greenhouse gas emissions because the growth of the feedstock takes the same amount of carbon out of the air that is released when the fuel is burned. By contrast, gasoline and diesel fuel take carbon out of the ground in the crude oil and release it to the air when the fuel is burned. Life-cycle analyses credit biofuels with this carbon removed from the atmosphere by growing the feedstock. In effect, they credit biofuels with the carbon benefit of the land used to grow them. Without this credit for the land use benefit, biofuels will generally result in an increase in greenhouse gas emissions.

Producing biofuels is just one way of realizing the carbon benefit of land, i.e., its capacity to remove carbon from the atmosphere. Used alternatively to grow forest, land sequesters carbon in tree trunks and soil. Using forest lands for biofuels foregoes ongoing sequestration in trees, releases most or all of the carbon in standing vegetation and much of the carbon in soils. Used to grow grasses, land sequesters carbon in the soil, which provides an immediate global warming benefit. Nearly all grasslands also provide forage for cows, sheep or goats, which feed us, which is also true of land used to grow crops, which transforms atmospheric carbon into carbohydrates, proteins and fats. Feeding us is also a

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carbon benefit, and if lands that now feed us are diverted to other uses, we have to generate that carbon elsewhere – on other forest or grassland – sacrificing that other land's alternative carbon benefits.

To determine if biofuels really have the potential to reduce greenhouse gasses, the first requirement is that the carbon benefit of using land for biofuels must exceed the carbon benefit of land in its alternative, existing uses. Put another way, lifecycle analyses for biofuels should only credit the use of land to produce the biofuel if that use of land produces a net carbon benefit compared to its alternative likely land use. Unfortunately, most life-cycle analyses count the gross carbon benefit of using land for biofuels without deducting the cost. They count the carbon sequestered in the feedstock but leave out the carbon storage and ongoing sequestration given up by taking land out of its existing use. This accounting is highly one-sided. It is equivalent to counting the economic benefit of using land to produce a crop without factoring in the rental cost.

Many previous analyses have noted qualitatively the potential of land use change to wipe out many or all of the carbon benefits of biofuels, but they have omitted the emissions from land use change in the quantitative analysis. They tend to present this land use change as a kind of secondary, unintentional effect, hard to estimate, perhaps controllable. It is more helpful to view land use change as the intentional result of biofuels – if only the intentional change in using cropland for fuel instead of for food. Making biofuels is a land use decision, and the first question is whether the use of land for biofuels removes and keeps more carbon from the atmosphere than its alternative. A proper proper life-cycle analysis must incorporate the emissions that occur from direct or indirect land use change to produce biofuels.

II. Estimating Emissions from Soy-Based Biodiesel

A. **General Method**

We have previously calculated the emissions from indirect land use change and incorporated them into the GREET lifecycle analysis for U.S. corn and for switchgrass ethanol if it were produced on good American corn land (Searchinger et al. 2008). This analysis was based on formal, partial-equilibrium modeling by the Center for Agriculture and Rural Development at Iowa State, which takes account of shifts between crops, reductions in demands and different yields in different countries. We found that the emissions from land use change dominate the total emissions for biofuels and cause them to increase emissions significantly by comparison with gasoline dramatically over a 30 year period.

Most estimates, however, find that corn-based ethanol has smaller greenhouse gas benefits (ignoring land use change) than other biofuels (Farrell et al. 2006). For this reason, corn-based ethanol has long been viewed as marginal. Biodiesel from soybeans, by contrast, has a much stronger environmental reputation. Part of this reputation stems from different air quality debates that dominated the discussion of ethanol ten years ago when the primary concern with corn ethanol was its potential increase in emissions of precursors of low-level ozone. Biodiesel, by contrast, had significant ambient air benefits compared to diesel, leading to greater support among environmentalists. In addition, because soybeans require less fertilizer, and because the process of converting soybean oil to diesel fuel requires far less energy than converting corn to ethanol, most life-cycle analyses have found that soy biodiesel has far lower greenhouse gas emissions – generally generating savings of more than 50% compared to diesel or gasoline. (Farrell et. al. 2006)

Despite the greater savings from a pure engineering perspective, soybeans also require good cropland. Vegetable oil is a valuable food substance whose consumption has been growing on a worldwide basis, and whose rising prices have been reported as a major source of hardship in much of the world today. (Bradsher 2008) When soybean oil is diverted to biofuels, the vegetable oil will mostly be replaced, triggering emissions from land use change. Ideally, these emissions would be calculated using a worldwide, partial-equilibrium model that can calculate changes in demand and in production of a wide variety of substitutes, a model used in our corn calculations. Economists at Iowa State are working to adjust their model to evaluate worldwide vegetable oils more rigorously. In the absence of such a model, we believe however it is possible to calculate likely emissions from land use change using alternative scenarios to provide a clear picture of whether biodiesel from soybean has the potential to generate true greenhouse gas savings when incorporating emissions from land use change.

The emissions from land use change depend first on economic forces. Diverting soybean oil into biodiesel production will increase the price of soybean oil and other vegetable oils that are substitutes. As prices rise, their demand for purposes other than biofuels will somewhat decline -- which creates other social costs but reduces the magnitude of increased emissions from land use change. Because elasticity of demand for categories of food products is low – as opposed to the elasticity of demand for one crop or oil -- most diverted vegetable oil will be replaced, and in a free market, replacements crops will be provided in the cheapest way. Part will be replaced by increasing yields on existing lands; and part will be replaced by converting forest or grassland to new production – the amount of each depending on the cost. The amount of land conversion will also depend on the yields of the new lands. With a few exceptions, the yields of corn, soybeans or rapeseed in the developing world do not match those in the U.S. and Europe, and will require more land and therefore more land conversion.

The emissions from land use change will depend on the loss of ecosystem converted. They include: (1) the loss of carbon in vegetation when forest or grassland is converted to produce biofuels directly or indirectly; (2) the loss of carbon in soils from that conversion; (3) the loss of ongoing carbon sequestration that would occur in forest or grassland if the land remained in its original use. To the extent that biofuels keep cropland in production that would otherwise leave production, the emissions include only the foregone carbon sequestration.

B. Emissions Estimates Assuming Full Replacement of Diverted Vegetable Oil Without Decreased Demand or Additional Yield Increases

Soybeans provide the primary feedstock for biodiesel in the United States. Many are exported and most of those used domestically are crushed. Crushing transforms 19% of the original soybean by weight into soybean oil,[2] and the remainder is transformed into soybean meal and other products, which are mostly used as animal feed but some used as food additives. Biodiesel uses only the oil portion of the soybeans, leaving the remaining soybean products intact.

Producing more soy biodiesel in the U.S. could divert either soybeans in total or soybean oil. A liter of biodiesel from soybean oil requires 0.362 bushels of soybeans, or 1.82 kilograms of oil. To produce the representative amount of 1 billion liters of biodiesel from U.S. soybeans would require 361,915,691 bushels of soybeans (9.850 mmt) or 1,825,105,882 kilograms of oil (1.825 mmt). To analyze emissions from land use change, we first examined the emissions that would result from replacing diverted soybean oil under the following assumptions:

(1) there is no reduction in demand for vegetable oil for non-fuel uses,
(2) while crop yields continue to increase at current trends, the rise in prices will not trigger additional average yields because additional yield investments will only balance out use of more marginal land,
(3) oil diverted to soybeans comes entirely out of U.S. oil exports proportionately to exports to the countries now importing these oils (Table B-2);

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[2] According to The Food and Agricultural Policy Research Institute (FAPRI) baseline projections, in 2016/17 the U.S. will produce 85.065 million metric tons (mmt) of soybeans and crushes 54.874 mmt, producing 43.58 mmt of meal (79.4%) and 10.434 mmt of oil (19.0%). U.S. exports are expected to include 24.987 mmt of soybeans and 1.337 mmt of soybean oil. (See Table A-1).

(4) countries now importing soybeans from the U.S. import replacement vegetable oil in proportion to their present consumptive mix of vegetable oils, which may include some palm oil, sunflower oil and other kinds of oils in addition to soybean oil (Table B-2),
(5) major exporting countries, including the U.S., will supply the replacement oil in proportion to their present shares of world exports for each form of vegetable oil (Table B-3).

We then calculated, as shown in Table B-4, the amount of increased crop area required in each country to produce this additional amount of the relevant vegetable oil using FAPRI-predicted yields for 2016-17. Table B-6 shows the total amount of land required to produce the required level of vegetable oil. As discussed for soybean oil, production of the feedstock for some vegetable oils will also produce large quantities of valuable by-products, as oil meal. The production of these by-products will reduce the amount of cropland required for other purposes, in particular the production of soybean meal reduces the amount of land required to produce animal feed. We therefore apportion the land needed to produce the additional soybeans or other feedstocks in part to the by-product and in part to the oil, using proportions by weight. For example, soybeans are only assigned 19% of the increased cropland, and other crops are similarly proportioned in Table 6. The result is that the production of 1 billion liters of U.S. soy biodiesel requires an increase in cropland of 789,100 hectares around the world, with Argentina and Brazil as the major suppliers of soybeans and Indonesia and Malaysia as the major suppliers of palm oil. The large increase attributed to Argentina reflects its extensive processing technology and its large resulting share of soybean oil exports.[3]

New cropland results from the conversion of forest or grassland, releasing virtually all of the carbon in standing vegetation and much of the carbon in soil. The amount of the carbon release depends on the carbon content of the forest or grassland, which varies by region and ecosystem type. To estimate this carbon content, we worked previously with Dr. R.A. Houghton of the Woods Hole Research Center to estimate the proportion of new cropland in the 1990s that came out of different major ecosystem types, the carbon content of each, and the likely carbon emissions for each (Searchinger et al. 2008). This method generated a weighted average emission per converted acre for each major world agricultural region or country. On the assumption that future conversion would come

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[3] In the future, Brazil, which is the world's largest exporter of soybeans, is likely to increase its processing capacity and therefore export more soybean oil and more soybean meal, and Brazil may very well be the largest alternative supplier of soybean oil. However, we attribute the same emissions per converted acre both to Brazil and Argentina because both are in our Latin America region. Thus, this shift would not change our calculations, which may be more consistent with the large conversion expected in Brazil.

proportionately from the same forest and grassland types as conversion in the 1990's, we assigned this weighted average emission to each hectare of conversion by country. (Table B-6, temporarily omitted pending separate publication). The sum of these emissions, 340 million MT, represents the total emissions from land use change to produce 1 billion liters of U.S. soybean biodiesel, not including the associated oil meals. These emissions represent only those emissions from land use change that are likely to occur over a 30 year period.

We then incorporated these emissions for land use change into the lifecycle analysis for soy-based biodiesel in the GREET model (using its 2015 scenario). GREET compares the life-cycle emissions for soy biodiesel with the emissions from using regular and reformulated gasoline and conventional fossil-based diesel fuel. A hectare of soybeans will produce a new amount of biodiesel each year. To represent the emissions from land use change, we amortized the total emissions over a 30 year period, i.e., divided by 30, producing the emissions per liter used over that period. CO2-equivalent emissions per liter are .0113 MT/l, or 11,345 g/l.[4] GREET presents emissions in the form of grams of emissions of greenhouse gasses (CO2 equivalent) per mile driven. In this form, the results are presented in Table 1a.

The result shows that emissions from land use change dominate the total emissions. For example, according to GREET, diesel from fossil fuels emits 304 g/mile and biodiesel emits 139 g/mile, but land use change emissions add 1,074 g/mile [5]

C. Incorporating Demand Changes and Possible Price-Induced Yield Improvements

The above calculations assume that producers will replace all soybean oil diverted to biodiesel. In reality, that diversion will raise prices and depress demand. The press is filled, for example, with reports of riots and changed diets around the world today in response in part to rising prices for vegetable oils (Bradsher 2008). Determining the amount of depressed demand requires a model

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[4] These are calculated by dividing the CO2-equivalent emissions from converting land for crops 1 billion liters of biodiesel and further by 30 years to amortize the carbon change over the period in which it is likely to occur. For example, in the oil-only scenario with oil substitution, 340,351,788 MT/billion liters/30 years is 0.01134506 MT per liter.

[5] This calculation assumes that the emissions associated with producing the vegetable oils to replace soybean oil diverted to biofuels are the same as those involved in producing the soybean oil in the U.S. per unit of oil. These are emissions from tractors, fertilizer, and transportation. While this is a reasonable simplifying assumption, it is also relative unimportant given the dominance of the emissions from land use change.

that would estimate the relative cost of increasing supply and the relative sensitivity of demand on a worldwide basis. In the absence of such an analysis, we assume very conservatively from the standpoint of greenhouse gasses that rising prices would decrease demand by 20%. If that were the case, the emissions from land use change would decline by 20% – 20% less land conversion would be required – but would still amount to 860 g/mile. It is worth emphasizing that while this decline in demand would lessen the increase in greenhouse gasses, it probably represents harsh social consequences.

Rising prices would also trigger efforts to improve yields. The analysis above assumes that these yield investments only balance out reliance on more marginal land. It is possible they could do more. For this sensitivity analysis, we assume conservatively that yield increases provide 20% of the replacement oils, which would have the same result as the demand decreases above. If both occurred, overall emissions from land use change would be 40% lower. At 645 g/mile for land use change, and 784 g/mile emissions in total, biodiesel would increase emissions compared to conventional diesel by 158%. See Table 1b.

D. **Alternative Scenarios**

The above analysis assumes that the shift to biofuels results in reductions in U.S. oil exports. For sensitivity purposes, we analyzed a scenario in which the biofuels instead results in a reduction in U.S. exports of soybeans, and other countries make up the soybeans in response to their share of world soybean exports. In this scenario, the conversion is modestly lower at 656,928 hectares because Brazil assumes the lion’s share of increased production and soybean yields in Brazil are exceptionally high. That results in lower greenhouse gas emissions for land use of 220 million MT, or emissions of 7,317 grams per liter. See Tables C-1 through C-4. Applying the same assumptions of a total 40% reduction in land area needed because of reductions in demand for vegetable oil and increases in yield, biodiesel would increase emissions compared to conventional diesel by 174%. Table 1a. If we assume that price increases would reduce demands for vegetable oil for non-fuel uses by 20%, and 20% of replacement oil were supplied through further yield improvements, greenhouse gas emissions for biodiesel would still increase emissions by 83% compared to conventional diesel.

We also analyzed a scenario in which the U.S. responds to biodiesel solely by reducing soybean oil exports, but they are replaced entirely by soybean oil produced by other exporters. In that scenario, biodiesel increases emissions compared to conventional diesel by 161%. These reductions are lower because virtually all replacement soybean oil comes from Latin America where soybean yields are significantly higher. If we assume the reductions in demand and further yield increases discussed above, greenhouse gas emissions would still increase by 75%.

Finally, it is useful hypothesizing a scenario in which emissions per converted hectare would actually be half of our estimates. Even under those assumptions, and assuming the reductions in demand and the yield improvements reflected in Table 1b, biodiesel would still increase greenhouse gas emissions compared to conventional biofuels. In the scenario that permits a range of vegetable oil replacements, the increase in greenhouse gas emissions over 30 years would still be 52%.

CONCLUSION

The actual market responses to an increase in biodiesel would be more complex than those estimated here. There would be more adjustments within countries as land shifts from one crop to another, and therefore more countries would be increase production on cropland of some kind to supply the replacement crops. Even so, the ultimate determinant of land use change is that supply and demand must meet. More complex modeling would provide a better estimate of the precise amounts of increased production in each country, but the story is relatively clear (1) because a small number of countries dominate the production of different oils, and (2) soybean oil first and then palm oil dominate the overall vegetable oil production. Our analysis provides a useful range of estimates. Our results indicate that biodiesel production, despite its high savings from a pure engineering perspective, dramatically increases greenhouse gas emissions compared to conventional diesel when factoring in emissions from land use change across a broad range of assumptions.

Table 1a – Comparison of Biodiesel to Gasoline and Diesel With and Without Land use Change By Stage of Production and Use[without any assumption about demand reduction and yield increase]

In grams of greenhouse gasses CO_2 eq. per mile

Source of Fuel*	Making Feedstock	Refining Fuel	Vehicle Operation (Burning Fuel)	Net Land Use Effects		Total GHGs*	% Change in Net GHGs for Biodisel vs. Diesel
				Feedstock Uptake from Atmosphere (GREET)	Land Use Change		
Diesel	+18	+40	+246	0	—	+304	—
Biodiesel /(GREET)	+82	+81	+248	-272	—	+139	-54%
Biodiesel + Land Use							
(diverted oil replaced solely by soybean oil)	+82	+81	+248	-272	+656	+795	+161%
(diversion replaced by soybeans only)	+82	+81	+248	-272	+693	+832	+174%
Diverted oil replaced by mix of oils	+82	+81	+248	-272	+1,074	+1,213	+299%

Table 1a – Comparison of Biodiesel to Gasoline and Diesel With and Without Land use Change By Stage of Production and Use[assuming 20% demand reduction and 20% yield increase]

In grams of greenhouse gasses CO_2 eq. per mile

Source of Fuel*	Making Feedstock	Refining Fuel	Vehicle Operation (Burning Fuel)	Net Land Use Effects		Total GHGs*	% Change in Net GHGs for Biodisel vs. Diesel
				Feedstock Uptake from Atmosphere (GREET)	Land Use Change		
Diesel	+18	+40	+246	0	—	+304	—
Biodiesel /(GREET)	+82	+81	+248	-272	—	+139	-54%
Biodiesel + Land Use							
(diverted oil replaced solely by soybean oil)	+82	+81	+248	-272	+394	+533	+75%
(diversion replaced by soybeans only)	+82	+81	+248	-272	+416	+555	+83%
Diverted oil replaced by mix of oils	+82	+81	+248	-272	+645	+784	+158%

APPENDIX A

U.S. Soybean Production and Dispoal

Table A1--U.S. Soybean Production and Disposal, projected for 2016/17 baseline.	
FAPRI U.S. baseline data 2016/17 (thousand metric tons)	
Production	85,065
Crush	54,874
Seed, Residual	5,003
Ending Stocks	11,617
Domestic Use	71,494
Meal	43,580
Oil	10,434
Area harvested (thousand hectares)	27,929
FAPRI U.S. baseline net exports 2016/17 (thousand metric tons)	
Soybeans	24,987
Meal	7,980
Oil	1,337
Source: The Food and Agricultural Policy Research Institute (FAPRI) baseline projections, 2007 at http://www.fapri.iastate.edu/Outlook2007/	

APPENDIX B

TABLES FOR MAIN SCENARIO U.S. SOYBEAN OIL DIVERTED TO BIODIESEL AND REPLACED BY A MIX OF VEGETABLE OILS

Table B-1 Reduction in U.S. Soybean Oil Exports in Response to Diversion of U.S. Soybean Oil to Provide 1 Billion Liters of Biodiesel

			1998-2007 Average		Export reduction
Mexico	Soybean oil	MT	79,587	13.8%	251.5
China, Peoples Republic of	Soybean oil	MT	66,220	11.5%	209.2
Canada	Soybean oil	MT	49,096	8.5%	155.1
Korea, Republic of	Soybean oil	MT	40,990	7.1%	129.5
India	Soybean oil	MT	28,280	4.9%	89.4
Hong Kong	Soybean oil	MT	25,695	4.4%	81.2
Peru	Soybean oil	MT	25,161	4.4%	79.5
Egypt	Soybean oil	MT	21,842	3.8%	69.0
Morocco	Soybean oil	MT	18,732	3.2%	59.2
Cuba	Soybean oil	MT	18,586	3.2%	58.7
Rest of the world	Soybean oil	MT			642.8
Total	Soybean oil	MT	577,616	100.0%	1,825.1

Table B-2--Mix of oils to substitute for displaced U.S. soybean oil exports and based on each country's present mix of vegetable oils

Country	Peanut	Palm	Rapeseed	Soy bean	Sun flower	Total oils
	Thousand metric tons					
Mexico	15.9	75.7	22.6	128.0	9.2	251.5
China	25.3	34.5	17.0	128.5	4.0	209.2
Canada	19.1	0.0	110.7	21.6	3.7	155.1
Korea, Republic of	4.4	20.0	2.3	102.5	0.2	129.5
Hong Kong (same as	10.8	14.7	7.2	54.9	1.7	89.4
India	11.7	33.4	12.2	21.9	2.1	81.2
Peru	0.8	16.9	0.0	60.8	0.9	79.5
Egypt	5.8	5.3	0.0	40.6	17.3	69.0
Morocco	1.5	0.2	1.2	52.8	3.5	59.2
Cuba	1.3	0.0	0.0	57.2	0.2	58.7
United States	0.0	0.0	0.0	0.0	0.0	0.0
ROW	45.2	95.4	75.9	405.0	21.3	642.8
Total	142.1	296.1	249.2	1,073.7	64.0	1,825.1

Source: FAO data on oil consumption in grams/capita/day at http://faostat.fao.org/default.aspx applied to decrease in soybean oil exports.

Table B-3-U.S. Soybean oil export and consumption replacements by major vegetable oil exporters

Country	Soybean	Palm	Rapeseed	Peanut	Sunflower	Total oils
	Thousand metric tons					
Argentina	669	0	0	59	22	749
Brazil	287	0	0	0	0	287
Canada	0	0	200	0	0	200
Indonesia	0	170	0	0	0	170
Malaysia	0	127	0	0	0	127
CIS	0	0	45	0	39	84
ROW	0	0	0	72	0	72
China	0	0	0	9	0	9
Bulgaria and	2	0	2	0	3	6
Australia	0	0	3	0	0	3
India	0	0	0	3	0	3
United States	116	0	0	0	1	117
Total net	1,074	296	249	142	64	1,825

Note: Analytically, the “increase” in exports from the U.S. represents a smaller reduction in exports, but is separately represented here to represent the increased production from the U.S. to maintain some portion of the export market that would otherwise be lost due to the diversion for biodiesel.

Table B-4—Increased crop area, feedstock for oils by exporting country – total area needed to produce crop

	Soybean	Palm	Rapeseed	Peanut	Sunflower	Total
	Thousand hectares					
Argentina	1,146.9			50.1	28.3	1,225.3
Brazil	515.3					515.3
Canada	0.0		254.3			254.3
Indonesia		95.0			95.0	
Malaysia		60.5				60.5
CIS	0.0		76.7		69.5	146.2
ROW	0.0		0.0	192.4	0.0	192.4
China	0.0		0.0	8.6	0.0	8.6
Bulgaria and Romania	4.0		2.6		4.0	10.5
Australia			6.1			6.1
India	0.0		0.0	7.8		7.8
United States	200.6	0.0	0.0	0.0	1.5	202.1
World	1,666.2	155.5	339.7	258.9	101.8	2,522.2

Table B-5—Increased crop area, feedstock for oils – area apportioned for oil only						
	Soybean	Palm	Rapeseed	Peanut	Sunflower	Total
	Thousand hectares					
Argentina	223.9	0.0	0.0	21.6	11.4	256.9
Brazil	99.1	0.0	0.0	0.0	0.0	99.1
Canada	0.0	0.0	106.8	0.0	0.0	106.8
Indonesia	0.0	95.0	0.0	0.0	0.0	95.0
Malaysia	0.0	60.5	0.0	0.0	0.0	60.5
CIS	0.0	0.0	29.8	0.0	28.6	58.4
ROW	0.0	0.0	0.0	62.9	0.0	62.9
China	0.0	0.0	0.0	2.7	0.0	2.7
Bulgaria and Romania	0.7	0.0	1.0	0.0	1.6	3.3
Australia	0.0	0.0	2.4	0.0	0.0	2.4
India	0.0	0.0	0.0	2.6	0.0	2.6
United States	38.1	0.0	0.0	0.0	0.3	38.4
World	361.9	155.5	140.1	89.8	41.8	789.1

Table B-6 Increase in Emissions by Country or Region for Scenario in Which Vegetable Oils Are Replaced by a Mix of Oils			
Region	Area Change, hectares	CO2 Equivalent per hectare metric tons per hectare	Total Emissions, CO2 Equivalent, metric tons
Canada	106,802	311.1913628	33,236,011
Africa	0		0
Europe	3,338	262.2082968	875,318
Former Soviet Union	58,397	196.8970315	11,498,124
Latin America	355,991	336.9466343	119,949,903
North Africa and Middle East	0	0	0
Developed Pacific	2,439	232.3691887	566,840
China/India/Pakistan	5,272	199.0975	1,049,640
Southeast Asia	155,549	1018.57157	158,437,974
United States	38,423	383.5765619	14,737,977
Rest of the World	62,930	0	0
Total	789,142		340,351,788

APPENDIX C

TABLES FOR SCENARIO IN WHICH U.S. REDUCES SOYBEAN EXPORTS, WHICH ARE REPLACED BY SOYBEAN EXPORTS FROM OTHER COUNTRIES

Table C-1--Reduction in U.S. soybean oil exports to importing countries

			1998-2007 Average		Export reduction
Mexico	Soybean oil	MT	79,587	13.8%	251.5
China, Peoples Republic of	Soybean oil	MT	66,220	11.5%	209.2
Canada	Soybean oil	MT	49,096	8.5%	155.1
Korea, Republic of	Soybean oil	MT	40,990	7.1%	129.5
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Hong Kong	Soybean oil	MT	25,695	4.4%	81.2
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Morocco	Soybean oil	MT	18,732	3.2%	59.2
Cuba	Soybean oil	MT	18,586	3.2%	58.7
Rest of the world					642.8
Total	Soybean oil	MT	577,616	100.0%	1,825

Table C-2--Increased soybean exports by other exporters, 2016/17

Net Soybean Exporters	Baseline exports	Production of displaced U.S. exports	New soybean production	New soybean area	New soybean area (oil only)
	(thousand metric tons)			(thousand hectares)	
Argentina	7,878	1,294	1,294	433	85
Brazil	50,529	8,297	8,297	2,863	551
Bulgaria and Romania	46	8	8	3	1
Canada	1,092	179	179	62	10
CIS	433	71	71	61	11
India	5	1	1	1	0
United States	24,987				
Total Net Exports	84,970	9,850	9,850	3,423	657

Table C-3—Greenhouse gas emissions from cropland conversion to replace U.S. soybean exports

Region	Area Change, hectares	CO2 Equivalent per hectare metric tons per hectare	Total Emissions, CO2 Equivalent, metric tons
Canada	0		0
Africa	10,385	311.2	3,231,741
Europe	552	262.2	144,790
Former Soviet Union	10,677	196.9	2,102,179
Latin America	635,165	336.9	214,016,734
North Africa and Middle	0		0
Developed Pacific	0		0
China/India/Pakistan	149	199.1	29,738
Southeast Asia	0		0
Rest of the World	0		0
Total	656,928		219,525,183

Emission rates from deforestation, except rates in Europe and the Former Soviet Union are from afforestation prevented on cropland that would otherwise be retired.

APPENDIX D

TABLES FOR REPLACEMENT OF DIVERTED SOYBEAN OIL SOLELY BY SOYBEAN OIL FROM OTHER COUNTRIES

See Table B-1 for reductions in U.S. soybean oil exports

Table D-1 -Increased soybean oil exports by other oil exporters, 2016/17:

Net Soybean Oil Exporters	Baseline exports	Displaced U.S. exports	New soybean meal production	New soybean production	New soybean area	New soybean area (oil only)
	Thousand metric tons				Thousand hectares	
Argentina	7,711	1,274	5,253	6,527	2,186	427
Brazil	3,313	547	2,299	2,846	982	189
Bulgaria and	20	3	15	19	8	1
United States	1,337					
Total Net	12,381	1,825	7,567	9,392	3,175	617

Note: Because only the soybean oil replaces displaced U.S. exports, only the crop area supporting the oil production should be counted against U.S. soy biodiesel production. This amounts to only 617 thousand hectares (about 19 percent of the total).

Table D-2 Greenhouse gas emissions from cropland conversion to replace U.S. soybean oil exports entirely by soybean oil

Region	Area Change, hectares	CO2 Equivalent per hectare metric tons per hectare	Total Emissions, CO2 Equivalent, metric tons
Canada	0		0
Africa	0		0
Europe	1,358	262.2	355,957
Former Soviet Union	0		0
Latin America	615,566	336.9	207,412,893
North Africa and Middle	0		0
Developed Pacific	0		0
China/India/Pakistan	0		0
Southeast Asia	0		0
United States	0		0
Rest of the World	0		0
Total	616,924		207,768,850

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