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## **Exploring the Implications of Oil Prices for Global Biofuels, Food Security, and GHG Mitigation**

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***Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2014  
AAEA Annual Meeting, Minneapolis, Minnesota, July 27-29, 2014.***

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## **Exploring the Implications of Oil Prices for Global Biofuels, Food Security, and GHG Mitigation**

### **Abstract**

*Efforts to satisfy global energy demand and improve food security while simultaneously taking action to mitigate climate change pose many key challenges for the world. In this study, the Applied Dynamic Analysis of the Global Economy (ADAGE), a computable general equilibrium (CGE) model, is applied to examine the impact of oil price on biofuel expansion, and subsequently, on food supply/price, land use change and climate mitigation potential, when both first and second generation biofuel feedstocks are considered. The results indicate despite a continued increase in land productivity and energy efficiency, increases in population and economic growth lead to a global increase in agriculture production, rising food, agriculture, biofuels, and energy prices, and land conversion from the other four land types to cropland in the REF scenario from 2010 to 2040. Oil price plays an important role in biofuel expansion. Globally, higher oil price leads to the expansion of biofuel production, increasing its share in total liquid fuel consumption in the private transportation sector. Consequently, more land is allocated for biofuel production, reducing global agriculture output and increasing agricultural consumption prices. Although emissions from land-use change increase, the overall emissions including fossil fuel emissions decreases. Regions display different patterns on biofuel expansions, land-use change, prices for food/agriculture and energy/biofuels, and GHG emissions.*

**Key words:** Biofuels, Computable General Equilibrium, Oil Price, Food security, GHG Mitigation

## **Exploring the Implications of Oil Prices for Global Biofuels, Food Security, and GHG Mitigation**

### **1. Introduction**

Efforts to satisfy global energy demand and improve food security while simultaneously taking action to mitigate climate change pose many key challenges for the world. Global biofuel production has been expanding rapidly in recent years, especially in the United States and Brazil. While government policies are often a major driver of bioenergy expansion, the prices of substitute sources of energy also play a significant role. While biofuels expansion can help replace the use of fossil fuels and could reduce emissions, there are potential consequences on the economy and environment that should be taken into account. For example, the additional competition for land to produce bioenergy feedstocks may result in a reduction in food supply as well as higher greenhouse gas (GHG) emissions from land use change as land is converted to crop production. Recent policies have emphasized the importance of high-yielding cellulosic feedstocks for meeting bioenergy demand with reduced impact on land use and food markets, but few global models have incorporated these second generation feedstocks or explored how oil prices may influence the penetration of cellulosic-based biofuels. In this study, the Applied Dynamic Analysis of the Global Economy (ADAGE), a computable general equilibrium (CGE) model, is applied to examine the impact of oil price on biofuel expansion, and subsequently, on food supply/price, land use change and climate mitigation potential, when both first and second generation biofuel feedstocks are considered.

Timilsina, Mevel, and Shrestha (2011) used a CGE model and found that a projected 65% increase in oil price between 2009 and 2020 would increase global biofuel penetration from 2.4% in 2009 to 5.4% in 2020. An increase in oil price of 150% would increase the biofuel penetration to 9% in 2020. Aggregate agricultural output sees small drops in major biofuel producing countries

while there is a bigger decline in other countries. However, this study did not explicitly model cellulosic biofuels, which may significantly alter the portrait of future biofuels production. The breakeven price for cellulosic ethanol from various literature ranges from \$1.12/gal to \$7.15/gal gasoline equivalent, with the majority of estimates falling into a range of \$3.7/gal to \$5.1/gal (Haque and Epplin, 2012). If oil price increase by 150% from the current price of \$3.2/gal, it is likely cellulosic biofuels will become cost competitive and eventually enter the market.

ADAGE-Biofuels is a version of the ADAGE model that focuses on agriculture and bioenergy and is a recursive dynamic, multi-region and multi-sector CGE model. The model projects the global economy, energy use, agricultural activity, and biofuels production and land use from 2010 to 2050 at 5-year time steps. Agriculture consists of eight crop categories, one livestock sector, and one forestry sector. Biofuel sectors include seven first generation biofuels and three second generation biofuels (Beach et al., 2011). The details included on crops and biofuels enable the first and second generation biofuels to be modeled separately, where the first generation biofuels use key crops or oil seeds as inputs, so land are indirectly used through the production of crop or oil seed. For the second generation biofuels, biomass production and biofuels transformation are merged into a single sector, accounting for input uses at all stages in a single production function – thus land enters the production function directly. A nested constant elasticity of substitution (CES) function framework is used to model land-use change, covering both the cost of land conversion and the willingness of conversion in the long run. This model has been used for renewable fuel policy analysis (Beach *et al.*, 2011; Cai, *et al.*, 2013), climate change evaluation (Cai and Beach, 2013) and food, energy and climate mitigation analysis (Cai, Beach, and Zhang, 2014).

## **2. Model**

Our point of departure is the Applied Dynamic Analysis of Global Economy (ADAGE) model described in Ross (2009). ADAGE is a forward looking, intertemporally-optimizing computable general equilibrium (CGE) model. It can be used to simulate global and regional economy, trade, and greenhouse gas emission. Economic data in ADAGE come from the GTAP and IMPLAN databases. Energy data and various growth forecasts come from the International Energy Agency and Energy Information Administration of the U.S. Department of Energy. Emissions estimates and associated abatement costs for six types of greenhouse gases (GHG) are also included in the model. ADAGE is composed of three modules “International, “US Regional” and “Single Country”. Each module relies on different data sources and has a different geographic scope, but all have the same theoretical structure. This allows the model to estimate global results as well as detailed regional and state-level results that incorporate international impacts of policies. Adage is widely used to examine economic, energy, environmental, and trade policies at the international, national, U.S. regional, and U.S. state levels and estimate how an economy will respond over time to these policy announcements (for example, Waxman-Markey climate change Bill and the American Clean Energy and Security Act of 2009).

ADAGE-Biofuel is built upon on the ADAGE “International” module by introducing more details on crops, biofuels and land-use changes components. ADAGE-Biofuel is a recursive dynamic, multi-region and multi-sector CGE model. The base year is 2010. It projects global economy, energy use, agriculture activity, biofuel production and land use from 2010 to 2050 at 5-year time steps. Economic development from 2010 is calibrated to the actual output. Economic growth would match the projection of GDP growth trend from International Energy Agency (IEO). Production and consumption sectors in ADAGE-Biofuel are represented by nested Constant Elasticity of Substitution (CES) functions including special cases such as the Cobb-Douglas and

Leontief. The model is written in the GAMS software system and solved using the MPSGE modeling language (Rutherford, 1995).

## **2.1 Data**

### **2.1.1 Baseline Data**

The major underlying database for ADAGE-Biofuel, the Global Trade Analysis Project (GTAP) database version 7.1 (Narayanan and Walmsley, Ed., 2008), is updated from 2004 to the baseline year 2010 using secondary data from International Energy Agency, Food and Agricultural Organization (Beach et al, 2012). We aggregate the data into 8 regions and 36 sectors<sup>1</sup> (see Table 1 and Table 2) where agriculture consists of eight crop categories, one livestock and one forestry sector. Biofuel sectors include seven first generation biofuels and three second generation biofuels. The sectors are aggregated such that we could focus on the linkages among energy commodities, biofuels, feedstock crops, by-products and other important related sectors, and biofuels producing countries are emphasized in the regional aggregation.

Table 1. Regions in ADAGE-Biofuel

<b>Regions</b>	<b>Definition</b>
USA	United States
BRA	Brazil
CHN	China
EUR	Europe Union 27
XLM	Rest of South America
XAS	Rest of Asia
AFR	Africa
ROW	Rest of World

Since the GTAP data base does not explicitly include biofuel-related data, we used the Splitcom, software developed by Horridge (2005), to break out the existing GTAP sectors. For

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<sup>1</sup> The region and sector specification in ADAGE-Biofuel is flexible. Another version of ADAGE-Biofuel has 25 region and 42 sectors.

example, corn-ethanol is split from food sector (ofd) and soy-biodiesel from the vegetable oils and fats (vol) sector and the sugarcane based ethanol from chemicals sector. The by-products such as distillers dried grains with solubles (DDGS) are introduced such that the total corn-ethanol industry jointly produces both corn-ethanol (ceth) and DDGS (ddgs). In order to split out a new sector in general, we used the information on trade shares, consumption shares, cost share and own use shares, in the existing aggregated sector, based on secondary data sources from Food and Agricultural Organization (FAO), IEA, U.S. Department of Agriculture, Energy Information Administration (EIA), U.S. Department of Energy, etc.

Table 2 Sectors in ADAGE-BIOFUEL

Sectors	Definition	Sectors	Definition
<b>Energy</b>		<b>Industry</b>	
Col	Coal	Eim	Energy-intensive manufacturing
Cru	Crude Oil Extraction	Man	Other Manufacturing
Ele	Electric generation	Srv	Services
Gas	Natural Gas	Trn	Transportation
Oil	Refined Petroleum	Vmt	Household transportation
<b>Agriculture</b>		House	Housing
Wht	Wheat	<b>Biofuels</b>	
Corn	Corn	Ceth	Corn Ethanol
Gron	Rest of Cereal Grains	Weth	Wheat Ethanol
Soyb	Soybean	Scet	Sugarcane Ethanol
Osdn	Rest of Oilseeds	Sbet	Sugarbeet Ethanol
Srcn	Sugarcane	Sybd	Soy Biodiesel
Srbt	Sugarbeet	Rpbd	Rape-Mustard Biodiesel
Ocr	Crops nec	Plbd	Palm-Kernel Biodiesel
Liv	Livestock	Swge	Advanced cellulosic ethanol from switchgrass
Frs	Forestry	Celd	Advanced cellulosic biodiesel
<b>Food</b>		Msce	Advanced cellulosic ethanol from miscanthus
Mea	Meat	<b>Byproducts</b>	
Vol	Vegetable Oils	Ddgs	Distillers grains with solubles (DDGs)
Ofd	Other foods products	Omcl	Vegetable Oil Meal



### 2.1.2 Dynamic data

Economic growth in the future periods is driven by capital savings and investments, technological improvements in energy efficiency, growth in the effective labor supply from population growth and changes in labor productivity and change of natural resources stocks such as energy and land.

The key data include population from World Development Indicators, GDP growth, are based on IEA world energy outlook projections. Energy consumption, energy price are also downloaded from there to compare our results and their projections. The rest data are either directly from EPPA, or following the formulation in EPPA (Reilly et al (2012)).

## 2.2 Model Structure

The general structure of the ADAGE model is discussed in greater detail in Ross (2009). The ADAGE model follows the classical Arrow-Debreu general equilibrium framework covering all aspects of the economy, including production, consumption, trade, investment, etc. Production and household consumption are represented by a nested constant elasticity of substitution framework and discussed in Beach et al (2010). A representative household in each region would maximize its utility subject to budget constraints based on endowments of factors of production (labor, capital, natural resources, and land inputs to agricultural production). Income from sales of factors is allocated to purchases of consumption goods and to investment. All goods, including total energy consumption, are combined using a CES structure to form aggregate consumption goods. This composite good is then combined with leisure time to produce household utility. The elasticity of substitution between consumption goods and leisure, is controlled by labor supply elasticities and indicates how willing households are to trade off leisure for consumption. Keep in

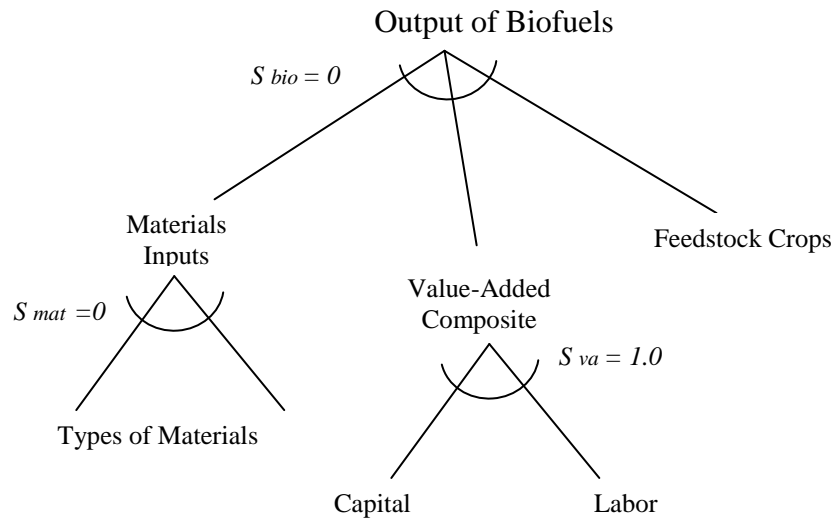
mind that the households are allowed to substitute different types of biofuels to refined petroleum, used in the personal vehicle transportation.

For various sectors in the economy, the general nesting structure of production activities and associated elasticities in ADAGE-Biofuel have been adapted from the EPPA model. Although EPPA has only one crop sector, ADAGE-Biofuel models 8 types of crops, which are produced by utilizing land, labor, capital, energy, and material inputs, with different elasticity of substitution. The livestock production structure in the ADAGE-BIO is separated for ruminants and non-ruminants to reflect differentiated use of biofuel by-products by different animals. At the bottom of the CES production structure, the DDGS is combined with other feed grains, and vegetable-oil meal is combined with oilseeds, and the two composites are allowed to substitute with the processed feed in the livestock production nest.

### 2.2.1 Modeling biofuel production

Currently cellulosic biofuels is not available in the market. We introduced the cellulosic feedstock (corn-stover, switchgrass, and miscanthus) based production technologies for cellulosic ethanol and cellulosic diesel in the model, such that the cellulosic biofuels could be produced in the post-2010 scenarios. The parameters for the second generation biofuels are taken from EPPA.

The first and second generations of biofuels in the ADAGE-BIO model are produced in a Leontief production structure, where the input shares are fixed over time (see figure 4). The feedstock crops enter the top level of the CES production nest in fixed proportions, along with the material inputs and capital-labor composite. The capital and labor are combined in value added composite following the Cobb-Douglas production structure. However, the second generation biofuels are currently not available. They can endogenously enter the market when they become cost competitive with rising energy price.



**Figure 4. Biofuels production in ADAGE-BIO**

### 2.2.2 Modeling land use change

The land use change in Beach et al (2010) is specified as a nested constant elasticity of Transformation (CET) function where the land is first allocated across three cover types (cropland, pastureland, and forestland) and in the second tier cropland is allocated across 8 alternate crops. After shift in cropping pattern within in the cropland, additional demand for land is met by the pasture and forest covers. A land supply elasticity of each type is implied by the elasticity of substitution and implicitly reflects some underlying variation in suitability of each land type for different uses and the cost to or willingness of owners to switch land to another use.

The CET approach can be useful for short term analysis. This approach has been criticized as share preserving which assures that radical changes in land use does not occur, making longer term projections unrealistic. Meanwhile, this approach does not explicitly account for conversion costs, nor address the value of the stock of timber when natural forest land is converted to managed forest land. We also find out total land over time in a region couldn't remain constant, thus fails to maintain the physical account consistency.

Following Gurgel et al (2008), we adopted a CES approach for land use transformation. Land is separated into five types: cropland, pasture land, managed forestry land, natural forest and natural grassland. Cropland could be used to grow various crops and second generation biofuels. Pasture land and managed forest land are exclusively used by livestock sector and forestry sector respectively. Natural grassland and natural forest land could provide no-use value.

Land could be converted from one type to another type. To integrate land use change into the CGE framework, two key requirements have to be retained: (1) consistency between the physical land accounting and the economic accounting in the general equilibrium setting; (2) introduced land use data needs to be consistent with observations as recorded in the base year, so the base year would be still in the equilibrium as observed. To retain consistency between physical land accounting and economic accounting, we assume that one hectare of land of one type is converted to 1 hectare of another type, and through conversion it takes on the productivity level and land rent for that type for that region. It is in that sense that another type of land is “produced.” To achieve the second requirements, the marginal conversion cost of land from one type to another should be equal to the difference in value of these two types. A fixed factor and the elasticity between it and other inputs are introduced into the top level of the land transformation function, representing the long-term response of land use change (see figure 5). The lower level would follow the same structure of agriculture production function. This structure is quite simple for pasture land and forest land as they are exclusively used by livestock sector and forestry sector respectively. It would be more complicated for cropland. As cropland is used for eight types of crops and cellulosic biofuels (once cellulosic biofuels become cost competitive), the production function for cropland is obtained by taking the share of these aggregated eight crops. When natural forest land is converted to forest land, timber is also produced in addition to the “produced”

managed forest land. On the other hand, when managed land can be abandoned and converted to natural land, no cost is associated with the conversion.

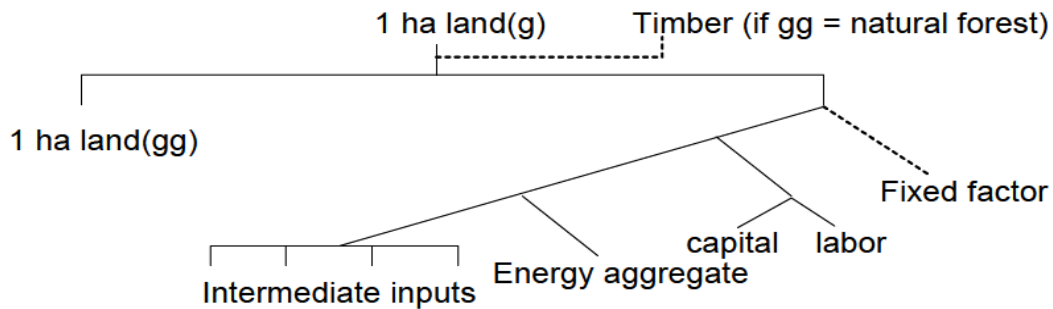


Figure 5. Land use change function ( $g$  is one type of land and  $gg$  is another type of land)

### 2.2.3 Modeling GHG Emissions

As ADAGE-Biofuels has a disaggregated agricultural sector with reasonably fine resolution and covers multiple renewable fuels pathways, including cellulosic biofuels, we consider this model in a good position to capture the long-term role of cellulosic biofuels and uncover the benefit/cost of both the first and second generation biofuels. Combining data from National Greenhouse Gas Emissions Data from U.S. Environmental Protection Agency (EPA) and National Greenhouse Gas Inventories from IPCC, we introduce sectorial GHG emissions as well as emissions from land-use change into the model –thus we are able to examine the implications of biofuels policies on land-use emissions.

### 2.2.4 Implementing the Oil Price Scenarios

For this study, scenarios are developed to be consistent with three scenarios from International Energy Outlook 2013 from U.S. Energy Information Administration (EIA): the Reference case (*REF*), where real oil prices starts from \$72/barrel in 2010 and rise by 77% by 2040. OPEC countries are assumed to account for 42% of the world's total petroleum and other

liquids production each year; Low Oil Price case (*LOP*), where crude oil prices drop by 18% by 2040 as a result of lower economic growth in the non-OECD countries, where their average GDP growth rate is 1.1% lower than in the *REF* case, starting in 2015. OPEC countries increase their share of oil production to 43% of global oil production; High Oil Price case (*HOP*), where oil prices rise by 158% by 2040 as a result of higher economic growth in the non-OECD nations. In this case, GDP growth in the non-OECD countries is 0.6% higher on average relative to Reference case in each year. On the supply side, OPEC countries are assumed to reduce their market share slightly. In these three scenarios, economic growth and oil production over time are calibrated to match the EIA projections using investment and cost of oil resource. As EIA projections span from 2010 to 2040, to be consistent, this study is constrained up to 2040.

### **3. Results and Conclusion**

Our preliminary results indicate despite a continued increase in land productivity and energy efficiency, increases in population and economic growth lead to a global increase in agriculture production, rising food, agriculture, biofuels, and energy prices, and land conversion from the other four land types to cropland in the REF scenario from 2010 to 2040. Oil price plays an important role in biofuel expansion. Globally, higher oil price leads to the expansion of biofuel production, increasing its share in total liquid fuel consumption in the private transportation sector. Consequently, more land is allocated for biofuel production, reducing global agriculture output and increasing agricultural consumption prices. Although emissions from land-use change increase, the overall emissions including fossil fuel emissions decreases. Regions display different patterns on biofuel expansions, land-use change, prices for food/agriculture and energy/biofuels, and GHG emissions. In the United States, we see an expansion of switchgrass and corn production, with more land converted from other crops, and less from pasture and forests. Compared with the *REF*

scenario, price in *HOP* in the U.S. is projected to increase slightly higher for eight crops, than for livestock and forestry. In Brazil, Rest of Latin America, and Africa, land conversions occur in all types of land including natural grassland and natural forestland, leading to higher price growth path for all agricultural sectors than in the U.S. Other regions display less biofuel expansion than these four regions and thus experience less impact on land-use changes, agricultural price and production, as well as GHG emission. From this study, we can assess the potential biofuel expansion that would occur in the absence of policy incentives based on oil markets, especially for cellulosic biofuels under high oil prices.

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