# *THE CONTRIBUTION OF BIOMASS TO EMISSIONS MITIGATION UNDER A GLOBAL CLIMATE POLICY*

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## Overview

Policies in Europe and in the United States have created an expanding market for biofuels, on top of the successful sugar-based biofuels development in Brazil. These biofuels mandates are part of a suite of current or proposed policies to address energy security, climate change and sustainability issues. Greenhouse gas (GHG) emissions abatement through biomass energy production raises a number of questions, such as: (1) Given the multiple pathways with which biomass can be used to produce energy, what bioenergy technologies will prevail? (2) What are the GHG implications of expanding bioenergy when accounting for the potential need to expand cropland or apply nitrogen fertilizer? (3) Where will bioenergy feedstocks be grown? (4) How will large-scale bioenergy production affect food prices and land use?

Although a large body of literature on bioenergy has emerged, most studies consider forced targets with specific and limited fuel conversion pathways, rather than considering the optimal use of biomass feedstocks and conversion technologies in abating emissions while accounting for economic and physical constraints. For example, Rahdar et al. (2014) examined competition for biomass between bioelectricity and biofuels in the US under a renewable electricity standard and renewable fuel mandates. Wise et al. (2014) evaluated the impact of existing, moderate and high (up to 25% of transportation fuel) global biofuel mandates using the Global Change Assessment Model. Melillo et al. (2009) and Reilly et al. (2012) considered large-scale biofuel development with a simplified second-generation biofuel production technology; however, this provided no insight into the potential competition among first- and second-generation biofuel pathways or uses of biomass for fuels, power generation, and industrial heat.

We contribute to the existing literature by evaluating the role of bioenergy under a global carbon price, where the level and composition of bioenergy production is determined on an economic basis, and identifying numerous crops and pathways through which biomass could supply global energy needs. Our analysis employs a global model of economic activity and energy production that is augmented to represent bioenergy in detail.

## Methods

Our modeling framework builds on version 5 of the Economic Projection and Policy Analysis (EPPA) model, a recursive-dynamic, multi-region computable general equilibrium global model of economic activity, energy production and GHG emissions (Paltsev et al., 2005), as augmented to consider land use change (Gurgel et al., 2007, 2011). Bioenergy technologies represented include (1) seven first-generation biofuel crops and conversion technologies; (2) an energy grass and a woody crop; (3) agricultural and forestry residues; (4) two lignocellulosic biofuel conversion technologies, which can operate with and without carbon capture and storage (CCS); (5) an ethanol-to-diesel upgrading process; (6) electricity from biomass, with and without CCS; and (7) heat from biomass for use in industrial sectors. The model also includes explicit representation of bioenergy co-products (e.g. distillers' dry grains and surplus electricity), international trade in biofuels and pelletized woody feedstocks, land-use change with explicit representation of conversion costs and political constraints, limits on the blending of ethanol with gasoline, endogenous changes in land and other production costs, and price-induced changes in energy efficiency and alternative vehicle technologies. Compared to previous investigations, our approach has far more detail on the conversion pathways and potential role of biomass energy.

## Results

The model is used to explore the role of biomass in energy production under a global carbon price that induced ~150 exajoules (EJ) of primary bioenergy production by 2050. The required carbon price is \$15/tCO2 in 2015 and rose to \$59/tCO2 in 2050. If cost reductions follow those in a recent business survey and the blend wall is eliminated by 2030, lignocellulosic (LC) ethanol will account for 57% of final bioenergy production in 2050. When the blend wall constraint is tightened or LC ethanol costs are increased, bioelectricity and bioheat are the major forms of bioenergy.

Under higher LC ethanol costs, first-generation technologies account for 58% of total biofuel production. Lower crop yields reduce the amount of bioenergy produced, but do not have a large impact on the composition of bioenergy. Pricing emissions from land-use change does not significantly decrease the amount of bioenergy produced due to soil carbon credits for some bioenergy crops. In all cases considered, there was a limited role for drop-in biofuels, as they were often more expensive than LC and first-generation ethanol and, when the blend wall was binding, ethanol upgraded to diesel.

With a carbon price applied to all GHGs except those from land-use change, less land is allocated to food crops and, in particular, natural forests than in the absence of a carbon price. Decreases in natural forestland are largest in Africa (which has the lowest political barriers to deforestation) in favor of bioenergy production, or food production for export to regions that produce large quantities of bioenergy. This outcome indicates that regardless of the location of production, incentivizing bioenergy production will lead to deforestation in unprotected areas and calls for a global solution to land-use change issues. However, the impact of bioenergy production on land-use change in our analysis is moderated by (1) the availability of forestry and agricultural residues as feedstocks for bioenergy, (2) the extension of current political deforestation constraints into the future, and (3) improvements in crop yields and energy efficiency when converting biomass to energy. Pricing emissions from land-use change results in reforestation, with a decrease in food crops and managed grassland relative to when land-use emissions were not priced.

In 2050 relative to a reference case, food prices increase by between 2.6% and 3.3% when land-use change emissions were not priced and 4.7% when these emissions were priced. Decomposing these changes into various components reveals that the independent effect of growing biomass to produce energy increased food prices by between 1.3% and 2.6%. Food use decreased by between 2.8% and 4.8% of which between 0.7% and 1.4% was due to bioenergy production.

## Conclusions

Our results from various policy scenarios show that lignocellulosic (LC) ethanol may become the major form of bioenergy, if its production costs fall by amounts predicted in a recent survey and ethanol blending constraints disappear by 2030; however, if its costs remain higher than expected or the ethanol blend wall continues to bind, bioelectricity and bioheat may prevail. Higher LC ethanol costs may also result in expanded production of first-generation biofuels (ethanol from sugarcane and corn) so that they remain in the fuel mix through 2050. Deforestation occurs if emissions from land-use change are not priced, although the availability of biomass residues and improvements in crop yields and conversion efficiencies mitigate pressure on land markets. As regions are linked via international agricultural markets, irrespective of the location of bioenergy production, natural forest decreases are largest in regions with the lowest political constraints to deforestation.

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