Research paper

# Economy-wide Impacts of Forest Bioenergy in Florida: a Computable General Equilibrium Analysis

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## 【Summary】

Florida has high potential to produce forest biomass as a source of renewable energy because of its favorable climate. The Florida government has developed renewable bioenergy programs and policies to reduce the costs of biofuel and compete with fossil fuels, such as the *Florida Renewable Energy Technologies & Energy Efficiency Act*. The main purpose of this paper was to investigate the economy-wide and welfare effects of select bioenergy polices in a computable general equilibrium (CGE) modeling framework. This study simulated 2 scenarios: (1) implementation of an incentive for the production of second-generation bioenergy (a 10% fuel tax reduction applied to the second-generation bioenergy sector) and (2) a scenario anticipating technological gains in forest bioenergy production. The modeling experiments resulted in increased welfare and gross state product, and land shifting from agriculture to forestry. Results indicated that incentives for the second-generation bioenergy sector and investments in technology would result in overall positive outcomes for Florida's economy and household welfare.

**Key words:** biofuels, computable general equilibrium (CGE) model, economic impacts, Florida, forest bioenergy.

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研究報告

# 美國佛羅里達州生質能源政策經濟分析：可計算一般均衡模型

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## 摘 要

美國佛羅里達州(以下簡稱佛州)由於氣候溫和，極具潛力發展森林生質能源，因此佛州政府為了讓生質燃料足以與傳統化石燃料競爭，已規畫若干再生能源的計畫與政策，如佛州再生能源科技與能源有效法案等，藉以降低生質燃料的生產成本。本篇研究的目的即是希望建立一佛州之可計算一般均衡模型(computable general equilibrium model)，由模型觀察不同生質能源的模擬情境下，各相關部門(如農業、林業以及能源部門等)與家計福利所受到的影響。本研究提出兩個政策模擬：(1)針對第二代生質能源降低其燃料稅10%之獎勵措施，(2)期望生產森林生質能源之技術獲得進步。模型結果顯示，兩個政策模擬皆可增加整體家計福利以及佛州的國民所得，同時對於土地的需求，也將會從對農地的需求轉移至對林地的需求，此結果可給予政策制定者在制定政策的過程中有效的資訊。

**關鍵詞**：生質燃料、可計算一般均衡模型、經濟影響、佛羅里達、森林生質能源。

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## INTRODUCTION

The trend of energy consumption in the US has been on the rise. Given declining domestic production of crude oil, increased demand for energy is anticipated to be met to a large degree with a significant growth in imports. About 58% of the current oil consumption is imported, indicating a high level of dependency on foreign oil (EIA 2008a). National security concerns associated with dependency on foreign oil are prompting policymakers to look for alternatives. Meanwhile, US greenhouse gas (GHG) emissions in 2007 were about $7282 \times 10^6$ metric tons of carbon dioxide equivalents. Fossil fuel combustion was responsible for 82.3% of those emissions (EIA 2008b), which is the largest source of anthropogenic GHGs (IPCC 2001). Unlike fossil fuels, bioenergy is thought to be environmentally benign, socially desirable, and even economically competitive (Rabe 2006). According to the EIA (2008c), liquid biofuel production is expected to grow by 3.3% per year until 2030 in the US, although fossil fuels will still supply 79% of total energy use in 2030.

Bioenergy produced from cereal crops (such as corn and wheat), oil crops (such as rapeseed and palm oil), and sugar crops (such as sugar beet and sugarcane) is known as first-generation bioenergy. Some studies have shown that the energy content of first-generation bioenergy is lower than conventional energy and may compete with food and feed crops for land, water, and other inputs (Childs and Bradley 2007, Fargione et al. 2008). These findings have driven research into second-generation bioenergy, which is produced from cellulosic materials (lignocellulosic feedstocks). Recent research identified a number of advantages of second-generation bioenergy over its predecessor. Second-generation bioenergy can reduce competition between crops destined for food and those designated for fuel production; second-generation biofuels have a greater net energy balance; second-generation bioenergy leads to greater reductions in GHG emissions (Hill et al. 2006, Marshall and Greenhalgh 2006, Yen and Huang 2006, Dwivedi and Alavalapati 2009); the use of logging residues to produce electricity can be highly cost-effective when coal-fired electricity plants are assessed emission taxes (Gan and Smith 2006); and the removal of small-diameter forest biomass (which can be used to produce fuel) can improve forest health, enhance biodiversity, and reduce wildfire risk (Polagye et al. 2007).

In 2007, the US government established the *Energy Independence and Security Act* which set a goal of producing $36 \times 10^9$ gallons (around $136 \times 10^9$ L) of biofuels by 2022. Of that, corn ethanol production is capped at $15 \times 10^9$ gallons (around $57 \times 10^9$ L) per year starting in 2015, and the remainder is anticipated to be met by cellulosic-based biofuels. This policy is expected to stimulate new market opportunities for forest biomass. At the same time, the Florida state government has also initiated bioenergy programs and policies to promote bioenergy. One such policy is the issuance of tax credits for energy-efficient products through the *Florida Renewable Energy Technologies & Energy Efficiency Act* of 2006. Meanwhile, Florida has more than $16.5 \times 10^6$ acres (about $6.7 \times 10^6$ ha) of forestland that has a high potential for producing forest biomass that can be utilized to produce liquid biofuels or to generate electricity through co-firing.

This study applied a computable general equilibrium (CGE) model (Lofgren et al. 2002, Holland et al. 2007) since it is effective in shedding light on important intersectoral linkages and in capturing economy-wide impacts of policy implementation. The CGE model has been widely applied to assess effects of environmental policies and bioenergy issues (Zhang et al. 2005, Abdula 2006, Reilly and Paltsev 2007, Banse et al. 2008, Kancs and Wohlgemuth 2008, Taheripour et al. 2008). One of the challenges of evaluating bioenergy issues in the CGE framework is that bioenergy production, in particular second-generation bioenergy, is often not recorded in national accounts or is produced at very low levels. Kretschmer and Peterson (2010) identified 3 approaches to overcome this data limitations. The first approach is an implicit approach where the amount of biomass required to achieve a bioenergy production target is specified without explicitly modeling a bioenergy sector. Banse et al. (2008) adopted this approach using an extended version of the GTAP-E(1) model. The authors modeled biofuels as intermediate inputs to the petroleum industry and adjusted the database to derive initial biofuel shares in the petroleum industry. Policy scenarios introduced a mandatory blending requirement while the subsidy required to achieve the ratio was determined endogenously. The study showed significant shifts in land use resulting from implementation of bioenergy policies in the European Union (EU).

The second approach models latent technologies that exist, although they are inactive and unprofitable in the base year. In counterfactual scenarios, latent technologies can become profitable endogenously through changes in relative input or output prices or exogenously through a policy. Reilly and Paltsev (2007) used this approach to incorporate biomass energy production and competition for land. The authors found that with second-generation biofuels supplying a substantial share of liquid fuel demand, significant effects on land use and conventional agricultural markets in the US would result.

The third approach is to directly disaggregate bioenergy production sectors from existing sectors using a social account matrix (SAM) (Taheripour et al. 2008). Kretschmer and Peterson (2010) indicated that bioenergy data limitations can likely be overcome in the near future, and this is the most promising approach to modeling bioenergy; thus, this approach was adopted in this research.

Although many studies can be found which explored bioenergy issues, an economy-wide analysis in Florida or in the US Southern region is still rare. Hence, in a general equilibrium framework, this study sought to understand the socioeconomic impacts of bioenergy policies in Florida with specific attention to the impacts on related markets, such as agriculture and forestry and trade-offs between sectors.

**Bioenergy policies and programs in Florida**

Florida consumes approximately $9\times10^9$ gallons (around $34\times10^9$ liters) of fossil fuels, which makes up about 97% of its total energy consumption, and it ranks third in total energy consumption and fifth in energy consumption per capita among US states. Moreover, with a growing population, Florida's electricity demand is expected to increase by about 30% by 2016 (FDEP 2006). Thus, Florida needs clean, affordable, and sustainable energy sources to support the future economy, maintain a high quality of life, and ensure energy security. Research indicates that Florida is a state with the highest potential to produce forest biomass. Florida has approximately $16.5\times10^6$ acres (about $6.7\times10^6$ ha) of forestland, and its forest sector produced about $2.5\times10^6$ tons of mill residues in 2007 (USFS 2008). As such, Florida has the potential to supply over 30% of its transportation fuel demand from forest/cellulosic biomass (UF/IFAS 2006).

While the federal government signed the *Energy Independence and Security Act* of 2007, the Florida state government also initiated programs to promote bioenergy. The 2006 *Florida Energy Act* established the Florida Energy Commission and the *Florida Renewable Energy Technologies & Energy Efficiency Act*. Some of the programs related to bioenergy include the Renewable Energy Grant Program, the Bioenergy Grant Program, and the Renewable Energy Corporate Tax Program. The Renewable Energy Corporate Tax Program includes a sales tax exemption on the sale or use of specific "clean fuels", such as biodiesel and ethanol and an investment tax credit of 75% of all capital, operational maintenance, and research and development costs for biofuel production. The legislation also amended the *Florida Power Plant Siting Act* to streamline permission for new power plants and promote the development and use of biodiesel, ethanol, hydrogen, and other renewable fuels.

In 2006, the state government of Florida established the Florida Farm to Fuel Initiative to enhance the market for and promote the production and distribution of renewable energy from Florida-grown crops, agricultural wastes, and wood residues. The initiative includes an educational program and a statewide information campaign to educate the public about the benefits of renewable energy and use of alternative fuels, particularly ethanol.

Furthermore, the Florida state government passed a comprehensive energy bill in 2008 that created new programs associated with bioenergy (2008 FL H.B.7135). The bill set a renewable fuel standard mandating that all gasoline sold in Florida must contain 10% ethanol by volume by the end of 2010. It established an ethanol production credit as well, whereby county governments are eligible to receive waste-reduction tax credits for the use of yard clippings, clean wood waste, or paper waste as feedstock for the production of clean-burning fuels. Impacts of these policies are expected to have spill-over effects on all sectors of the state economy, and assessing them is critical for further decision-making.

The following section presents the modeling framework, data, and scenarios that were implemented in the analysis. Results and discussion are provided, and the paper concludes with a summary of the key findings, policy implications, and future research directions in the final section.

## MATERIALS AND METHODS

### Modeling framework

This study applied a CGE model developed by Lofgren et al. (2002) and customized by Holland et al. (2007) for compatibility with the IMPLAN[2)] (IMpact analysis for PLANning) dataset to assess policy impacts. Some of the adjustments to the model include a more-robust representation of transfers between institutions and the inclusion of indirect business taxes. In addition, the government, investment accounts, and households receive income from the primary factors of production.

Although Input-Output (IO) and Social Accounting Matrix (SAM) models can be useful for applied policy analyses, they are not without their limitations. IO models assume that prices of inputs and outputs are constant, and technological coefficients are fixed. There are also no constraints on the supply of primary factors and no tradeoffs between sectors since the final demand for the output of each sector is exogenous and thus may lead to biased estimates (Alavalapati et al. 1998). Comparatively, a CGE modeling framework is thought to provide greater flexibility and less-biased estimates by incorporating a set of equations that represent the behavior of economic actors and a theoretical structure of the economy in question. Hence, this study developed a Florida CGE model using the 2006 Florida IMPLAN dataset.

In the modeling framework, producers are modeled to maximize profits with a 2-level production technology (Fig. 1). At the first level, intermediate and primary inputs (labor, capital, and land) are demanded in fixed proportions to produce each unit of output. At the second level, the aggregate intermediate input is specified by a Leontief function of disaggregated intermediate inputs, while value added is captured by a constant elasticity of substitution (CES) function of the primary inputs.

The institutions in the model were: 3 household income classes, the state and federal government (including their investments and expenditures), general investment, the rest of the US (ROUS), and the rest of the world (ROW). Households receive income from primary factors of production and transfers from other institutions; they make payments to direct tax accounts, save, consume, and make transfers to other institutions. Household consumption is assumed to maximize a Stone-Geary utility function, which leads to linear expenditure system (LES) demand functions. The government collects taxes, which are at fixed ad valorem rates, and receives transfers from other institutions. Government consumption is fixed in quantity and government transfers to households and investment accounts are indexed to the

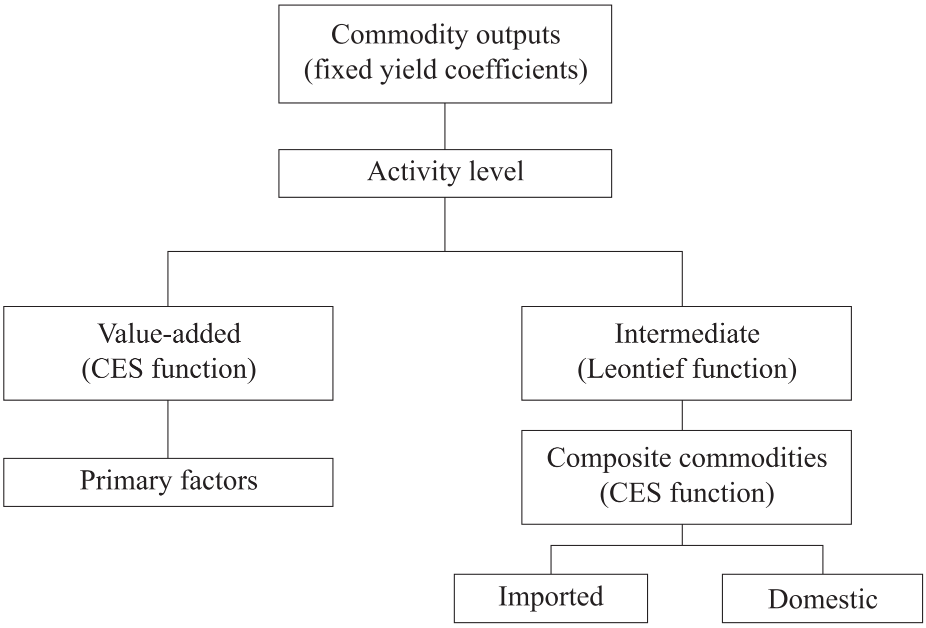

**Fig. 1. Structure of production technology in the model (where CES represents constant elasticity of substitution).**

consumer price index (CPI). The general investment institution receives payments from the primary factors and transfers from other institutions. Investment demand is fixed and defined as the base-year quantity multiplied by an adjustment factor. Transfer payments from the ROW, domestic institutions, and factors are all fixed in foreign currency.

Regarding trade, domestic and imported goods are considered imperfect substitutes by the Armington assumption which applies a CES function to aggregate domestic and imported goods to produce a composite good. The demand of each sector's output is obtained by minimizing the cost of the composite good subject to the CES function. Composite commodity supply is a function of the price of imports and the price of regionally produced commodities. The export supply function is derived from a constant elasticity of transformation (CET) function. It specifies the value of exports based on the ratio of domestic and export prices. The CET function assumes imperfect substitutability between products produced for the domestic and export markets by a given industry.

Meanwhile, the model allowed for imperfect substitutions between state-produced goods and goods from the ROUS and the ROW. To capture the substitution possibilities between state-produced goods and imported goods, an Armington function was applied to both firms and households. The higher the value of the Armington elasticity is, the easier is the substitution between sate-produced and imported goods.

Equilibrium prices are endogenously determined (commodity prices, factor prices, and the exchange rate) to clear the product, factor, and foreign exchange markets. The parameters of these functional forms were calibrated with the 2006 Florida SAM. Hence, the solution of the Florida CGE model entailed finding parameter and elasticity values to feed the model equations. This commonly involves rigorous data gathering to ensure that the real structure of the economy being modeled is approximated as much as possible.

With regard to factor closures, labor supply was modeled as flexible in supply and mobile across sectors within the state, capital was activity-specific and fixed, and land was fixed in supply and mobile across sectors. The foreign exchange rate was assumed to be flexible, and the import price was a function of the world price, the import tariff, and the exchange rate. Total investment was treated as exogenous with outside capital flows adjusted to equate total savings with investment. The CPI was set to be the numeraire. General Algebraic Modeling System (GAMS) software was used to solve the model as a mixed complementary problem using the PATH solver.

### Database

The database was derived from 2006 Florida IMPLAN data and included 509 sectors. To focus on sectors of interest for this study, the 509 sectors were aggregated into 11 sectors, namely: agriculture, logging, sawmill products, pulp-mill products, other wood products, conventional energy, manufacturing, transportation, first-generation bioenergy, second-generation bioenergy sectors, and all other sectors. The forest products industry (including logging, sawmill products, pulpmill products, and other wood products) in Florida generated about US$16.7 billion in output impacts, US$7.0 billion in value-added, and employment impacts of 89,000 jobs in 2006, while the gross state domestic product in Florida is around US$730.1 billion.

Sector code 151 in the IMPLAN data, other basic organic chemical manufacturing, represents first-generation bioenergy. IMPLAN did not provide explicit information on second-generation bioenergy since second-generation bioenergy was not produced in significant quantities in 2006. Thus, the intermediate and primary factor consumption of the second-generation bioenergy sector was disaggregated from the logging, sawmill products, and pulp-mill products sectors by 0.03, 0.01, and 0.01%, respectively (Taheripour et al. 2008, Winston 2009). With regard to households, IMPLAN describes 9 household-income classes. To simplify the analysis, households were aggregated into 3 annual income categories, namely: low-income (< US$25,000), medium-income (US$25,000~75,000), and high-income (> US$75,000) categories.

### Policy scenarios

This research investigated 2 specific scenarios based on policies discussed above to analyze the economy-wide and welfare impacts of biofuels production in Florida. The following scenarios were considered.

#### Bioenergy incentives

Since rising GHG emissions are leading a shift from fossil fuels to renewable energy sources, a price support for bioenergy or a tax on conventional energy could be used to stimulate shifting preferences for clean and efficient energy sources. Currently, most ethanol subsidies are applied to grain-based ethanol, or first-generation bioenergy production. To encourage the development of forest bioenergy, a 10% fuel tax reduction is applied to the second-generation bioenergy sector. This tax reduction can be considered an incentive for cellulosic bioenergy production.

#### Technological progress

Due to the high cost of energy production from woody biomass with current technologies, energy companies are still less likely to use biomass to produce energy. It is expected, however, that technological advancements will eventually render the production of biomass-based bioenergy economically feasible. There are a number of policy alternatives that can be implemented to increase bioenergy production. Policy incentives to reduce the cost of biomass transportation or a production subsidy would stimulate bioenergy production. Improvements in production, harvesting, collection, densification, transportation, storage, and conversion of woody biomass can reduce a cost of biomass-based bioenergy production. Meanwhile, cost-sharing capital investments in constructing woody fuel bioenergy plants would lead to a reduction in the unit cost of bioenergy production. To simulate technological gains, 1 scenario increased the second-generation bioenergy sector's intermediate consumption of logging, sawmill products, and pulp-mill products by an arbitrary amount of 10%.

## RESULTS AND DISCUSSION

In this section, simulation results are presented and interpreted. The results report the policy simulation effects on supply price and quantity, government expenditure and investment, factor demand, and social welfare.

### Supply prices and quantities

The supply price of the second-generation bioenergy commodity decreased by -0.10%, while there were insignificant changes in prices for other products in the bioenergy incentive scenario (Table 1). The bioenergy incentive policy resulted in a very small decline in most supply prices with the exception of agricultural products, conventional energy, and other products which marginally increased. For the technological progress scenario, the supply price of second-generation bioenergy dropped by -1.75%. The supply prices of agriculture, logging, pulp-mill products, conventional energy, and other commodities increased, while those of sawmill products, other wood products, manufacturing, transportation, and first-generation bioenergy decreased. With an increase in the price of logging and pulp-mill products in the technology scenario, we can expect landowners to increase the level and frequency of forest thinning to benefit from the price increase. Furthermore, since second-generation bioenergy is a kind of alternative energy, the price of conventional energy slightly increased when the price of second-generation bioenergy declined in both scenarios.

Since the share of second-generation bioenergy production of the total economic output was very small, it is not expected that the supply of this commodity would change

**Table 1. Percentage changes in producer commodity prices**

| | Bioenergy incentive (%) | Technological progress (%) |
|---|---|---|
| Agriculture | $3.00 \times 10^{-6}$ | $8.40 \times 10^{-5}$ |
| Forest products and logging | $-1.35 \times 10^{-7}$ | $1.94 \times 10^{-4}$ |
| Sawmill products | $-3.00 \times 10^{-6}$ | $-4.00 \times 10^{-6}$ |
| Pulp-mill products | $-2.29 \times 10^{-9}$ | $1.87 \times 10^{-8}$ |
| Other wood products | $-1.00 \times 10^{-6}$ | $-2.30 \times 10^{-5}$ |
| Conventional energy | $1.46 \times 10^{-7}$ | $7.74 \times 10^{-7}$ |
| Manufacturing | $-1.23 \times 10^{-8}$ | $-3.46 \times 10^{-7}$ |
| Transportation | $-1.25 \times 10^{-7}$ | $-3.00 \times 10^{-6}$ |
| Others | $1.42 \times 10^{-7}$ | $1.00 \times 10^{-6}$ |
| First-generation bioenergy | $-1.27 \times 10^{-7}$ | $-3.00 \times 10^{-6}$ |
| Second-generation bioenergy | $-9.60 \times 10^{-2}$ | -1.75 |

much in the scenarios. What is interesting, however, is the direction of effect the policy simulations had on commodity supply. The supplies of all commodities rose in both scenarios with the exception of agricultural commodities (Table 2). The quantity of second-generation bioenergy supply increased by 0.18% in the incentive scenario and by 3.49% in the technology scenario.

### Primary factor demand and the government

With a flexible labor supply, all sectors demanded slightly more labor with the exception of the second-generation bioenergy sector. This can be explained by the fact that intermediate inputs and primary factor inputs are aggregated in fixed shares. The results showed that the use of intermediate inputs increased by 0.19 and 14.05% for second-generation bioenergy in the bioenergy incentive and technological progress scenarios, respectively. Hence, with a fixed labor wage and flexible labor supply, the second-generation bioenergy sector demanded less labor in both scenarios. The price of capital also marginally increased for all sectors and decreased for the second-generation bioenergy sector in order to clear the capital market. Both scenarios resulted in reduced unemployment. With a fixed land supply, there was a contraction in agricultural demand for land and an increase in the logging sector's demand for land in both scenarios (Table 3).

Impacts of the policy simulations on the government are presented in Table 4. The federal government revenue increased as federal expenditure decreased; the state government revenue and expenditure slightly increased in both scenarios. Meanwhile, the federal and state governments collected more indirect business taxes in both scenarios.

### Household and welfare impacts

Net household income increased for all household income classes in both scenarios

**Table 2. Percentage changes in quantities of commodity supplies**

| | Bioenergy incentive (%) | Technological progress (%) |
|---|---|---|
| Agriculture | $-2.00\times10^{-6}$ | $-1.10\times10^{-4}$ |
| Forest products and logging | $9.40\times10^{-5}$ | $3.55\times10^{-3}$ |
| Sawmill products | $1.10\times10^{-5}$ | $1.94\times10^{-4}$ |
| Pulp-mill products | $1.10\times10^{-5}$ | $1.50\times10^{-4}$ |
| Other wood products | $3.00\times10^{-6}$ | $4.00\times10^{-5}$ |
| Conventional energy | $4.17\times10^{-7}$ | $6.00\times10^{-6}$ |
| Manufacturing | $5.57\times10^{-7}$ | $7.00\times10^{-6}$ |
| Transportation | $1.00\times10^{-6}$ | $1.80\times10^{-5}$ |
| Others | $2.90\times10^{-7}$ | $2.00\times10^{-6}$ |
| First-generation bioenergy | $2.00\times10^{-6}$ | $3.70\times10^{-5}$ |
| Second-generation bioenergy | 1.85 | 3.49 |

**Table 3. Percentage changes in demand for land**

| | Bioenergy incentive (%) | Technological progress (%) |
|---|---|---|
| Agriculture | $-8.00\times10^{-6}$ | $-3.10\times10^{-4}$ |
| Forest products and logging | $1.18\times10^{-4}$ | $4.45\times10^{-3}$ |

**Table 4. Percentage changes in government revenues and expenditures**

| | Bioenergy incentive (%) | Technological progress (%) |
|---|---|---|
| Federal government revenue | $2.75\times10^{-6}$ | $5.66\times10^{-7}$ |
| Federal government expenditure | $-6.26\times10^{-8}$ | $-1.00\times10^{-6}$ |
| State government revenue | $1.00\times10^{-6}$ | $2.00\times10^{-6}$ |
| Sstate government expenditure | $1.00\times10^{-6}$ | $2.00\times10^{-6}$ |

**Table 5. Percentage changes in household (HH) utility**

| | Numbers of HHs (% of total HHs) | Bioenergy incentive (%) | Technological progress (%) |
|---|---|---|---|
| Low-income HH | 838,866 (18%) | $1.35\times10^{-9}$ | $-3.12\times10^{-8}$ |
| Medium-income HH | 2,264,843 (49%) | $1.02\times10^{-8}$ | $6.09\times10^{-9}$ |
| High-income HH | 1,529,265 (33%) | $1.19\times10^{-8}$ | $1.41\times10^{-8}$ |

(Table 5). Household utility slightly increased for all household classes in the bioenergy incentive scenario. However, in the technology scenario, household utility declined for low-income households and increased for medium- and high-income households. Results showed that some commodity supply prices increased namely agriculture, logging, pulpmill, conventional energy, and other products. Thus, the negative impact on low-income households may be explained by a negative substitution effect which was greater than the positive income effect.

This study applied the Hicksian equivalent variation (EV) as a measure of both price and income effects rather than simply a measure of change in household income. EV is measured at the level of prices and income present prior to the implementation of a policy. It is the minimum payment the consumer would accept to forgo the policy change. In other words, it is the amount the consumer would need to receive to be as well-off if the policy had been implemented. For the bioenergy incentive scenario, the EV increased for low-, medium-, and high-income classes by US$15, US$327, and US$269, respectively. For the technological progress scenario, the EV decreased for low-income households by US$340 and increased in the case of medium- and high-income households by US$194 and US$319, respectively. Finally, Florida's gross state product (GSP) slightly increases in both bioenergy incentive and technological progress scenarios by US$4086 and US$1227, respectively.

## CONCLUSIONS

Private forests in Florida have high potential to produce forest biomass that can be utilized to produce cellulosic ethanol and generate electricity through co-firing. It is believed that promoting second-generation bioenergy can create job opportunities and stimulate economic growth. This research assessed the socioeconomic impacts of 2 potential cellulosic bioenergy scenarios on the Florida economy. The scenarios evaluated included an incentive for second-generation bioenergy production and technological gains in second-generation bioenergy production. Overall, results indicated that providing incentives for the second-generation bioenergy sector and technological progress would lead to increased welfare and GSP, and land shifting from agricultural production to forest-based activities. The price of first- and second-generation bioenergy dropped in both scenarios. Both federal and state government revenues increased. Moreover, the technological progress scenario showed that the price of logging and pulp-mill products increased. One implication for landowners is that increasing the level and frequency of forest thinning could result in increased income. In addition, thinning can improve forest health, reduce wildfire risk, and enhance biodiversity.

Implementation of incentives for the production of second-generation bioenergy may generate new market opportunities for forest biomass and increase the demand for forest bioenergy resulting in overall positive outcomes for the economy. Investment in technology may reduce the cost of bioenergy production and further stimulate the production of forest bioenergy. To maximize positive policy outcomes, complimentary policies may be required to offset or subsidize the small reduction in the income of low-income households.

Future research directions include the development of a dynamic CGE model to more realistically model policy scenarios and trace socioeconomic impacts through time. Dynamic models are used to simulate impacts of a policy on the economy for a definite time period. The main advantages of this class of models is their ability to shed light on the economic transition path resulting from a policy shock and the short-term costs and longer-term gains resulting from policy implementation (Cattaneo 1999). Furthermore, a regional dataset is also being constructed for the southern US region, which would enable a regional approach to the development and implementation of bioenergy and bioenergy feedstock policies.

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## FOOTNOTES

1) The GTAP-E is an energy-environmental version of the GTAP model. It incorporates energy substitution into the standard GTAP model. The energy substitution includes carbon emissions from the combustion of fossil fuels and this revised version of GTAP-E provides for a mechanism to trade in these emissions internationally.
2) The IMPLAN is created by MIG, Inc. (Hudson, WI, USA), which is the corporation responsible for the production of IMPLAN data and software. The IMPLAN data apply classic input-output data in combination with a regional-specific social accounting matrix and multiplier models.