Hendry County Sustainable Biofuels Research Center

LAND USE REQUIREMENTS FOR PRODUCTION OF BIOFUELS IN FLORIDA

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List of Abbreviations

BTU	British thermal unit
DCA	Department of Community Affairs
EAA	Everglades Agricultural Area
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act
GHG	Greenhouse Gases
G1	First Generation Secondary Biofuels
G2	Second Generation Secondary Biofuels
G3	Third Generation Secondary Biofuels
LUC	Land Use Change
dLUC	Direct Land Use Change
iLUC	Indirect Land Use Change

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Abstract

This study establishes relationships between production of various biofuels crops (Miscanthus, Switchgrass, Sorghum, Corn, Elephantgrass, Sugarcane, Energycane and Eucalyptus), associated biomass and bioethanol yields, land use requirements for these crops, biomass to biofuels conversion methods and the overall fuel demands, particularly in Florida's transportation sector.

An important metric in evaluating the ability of various biofuel potential options to successfully address the above mentioned relationships is the quantity of fuel that can be produced from available agricultural land. Concerns are being raised regarding food production, available land, and water, as well as other resources diverted by biofuels production. With the world having currently 12.08 billion acres of agricultural land for its 7.052 billion inhabitants, there is on average 1.70 acres of agricultural land available per person. Florida has even less available agricultural land per person (0.43 ac), but its favorable climatic conditions, advanced research, modern technologies as well as a traditional leading role in agricultural production make the State one of the nations' forerunning regions in biofuels production.

With Florida having 18,905,048 inhabitants, 14,372,807 registered vehicles with an average annual mileage of 13,348 miles/vehicle/year, an average E10 fuel consumption of 23.5 miles/gallon and assuming bioethanol having 66.7% energy content of petroleum-based gasoline per unit volume, an average 625.7 gallons of bioethanol (E100) per year per Floridian would be needed, if only bioethanol was used as a vehicular fuel.

Results show a range from 0.54 ac/person using Eucalyptus to 2.16 ac/person using Switchgrass to produce the volume of E100 necessary to deliver the equivalent energy of gasoline consumed by the average vehicular fuel needs of one person in Florida. This represents 127% to 507% of all available agricultural land in Florida.

The economic feasibility of bioethanol crops requires further analysis. While the available agricultural land that would be required for producing only bioethanol crops does not compare favorably to the total of Florida's limited available land, there is still a potential to shift some of the Florida energy needs to biofuels.

1. Introduction

With increasing industrialization and transportation needs, limited fossil fuels sources are becoming exhausted. The USA itself has about one-quarter of the world's automobiles and uses almost 25% of the world's oil (Biomass Research & Development Initiative, 2008; CIA, 2011). In a sharp contrast to that, US' share on the global population is only 4% (World Bank, 2011). The American economy heavily depends on liquid transportation fuels, principally derived from petroleum. Biofuels became one of the major U.S. Administration's near-term strategies to address energy security issues, since they can partially replace petroleum fuels - alcohol (bioethanol) fuels can substitute for gasoline in spark-ignition engines and biodiesel is suitable for use in compression ignition engines.

For reasons like greenhouse gases (GHG) mitigation, waste utilization or carbon sequestration, biofuels also appear as potentially the most sustainable and the most environmentally-friendly among various renewable energy source alternatives (Nigam and Singh, 2011). Growing interest in biofuels is rapid - from 1.6 billion gallons of production in 2000, American bioethanol producers provided an estimated 13 billion gallons of domestic renewable fuel in 2010 – an 800+ percent growth (Renewable Fuel Association, 2011). A similar trend is global – between 1980 and 2005, worldwide production of biofuels increased by an order of magnitude, from 1.2 to 13.3 billion gallons, with further dramatic expansions expected in the future (Mulkey, 2007).

Reflecting the global interest in biofuels, the U.S. Government has enacted new regulations and adopted progressive goals to encourage production of biomass crops and theirs use. The Energy Independence and Security Act (EISA) increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022 (U.S. Congress, 2007). Scenarios where the amount of bioethanol allowed in gasoline blends beyond 10 percent (e.g. mixtures like E15 or even E20) are being considered (Biomass Research & Development Initiative, 2008; Schnepf, 2010). Millions of dollars to support research and development in biofuels, bioenergy and related bio-based products are being announced

(Ferrell, 2006). These investments are meant to fuel the economy by homegrown, alternative energy sources, cut America's oil import dependency, introduce clean alternative energy technologies and accelerate the development and commercialization of biofuels.

Individual states like Florida have taken even stronger positions in such respect. With an expected increase in its energy consumption, no oil refineries and no existing large scale bioethanol facilities, the state is fully dependent on importing liquid fuels. On the other hand, with its significant agricultural resources, Florida is aggressively seeking new opportunities for its existing large agricultural industry. The state is leading the way in biomass feedstock production, by some estimates accounting for about 7% of total U.S. biomass output (Enterprise Florida, 2010). “Next generation” crops are being bred and evaluated for production efficiency and new conversion technologies are researched at Florida universities. Demonstration facilities are being introduced and sustainable approaches pursued. However, the entire life cycle of biofuels production and use needs to be considered, as various indirect effects (e.g. energy embodied in equipment and infrastructure, fossil fuel needs for biofuels harvesting, processing, transportation and distribution) seriously impact the effectiveness and success of potential long-term decisions and public policies (such as blending mandates, subsidies, import barriers, tax incentives and others).

The dynamic between agriculture, industry and natural resources is very complex and should not be overlooked. For example, implementing the above mentioned biofuel mandates might intensify various crops production in Florida and thus offer opportunities for new local, national and international industrial fields. However, it could place considerable additional pressure on natural resources, water use, available land and threatened ecosystems not only in Florida, but potentially also in other parts of the world (such as the Amazon rainforest, Africa and Latin America) (FAO, 2008).

While the scope of this paper is limited to selected first and second generation secondary crops that are fully dedicated to bioethanol, the conclusions still help with identifying the basic logic of using wastes versus primary biofuel crops. The scope is also limited to documenting land use implications of biomass production in Florida to demonstrate the overall resource implications associated with bioethanol production for Florida's transportation sector needs. A similar in-depth approach could be transformed to other regions as well though, whether such regions would be similar in physical-geographical parameters (e.g. climate zone) or from social-economic perspectives.

2. Literature review

2.1 Overview

The purpose of this review is to examine the overall attitude toward land use changes caused by increased biofuels production and consequent implications relative to various factors. Due to land use effects, bioenergy use may have adverse effects on biodiversity, soil, water, food prices and it may even fail to guarantee a GHG emissions reduction, in which it would be contra-productive relative to one of the main initial goals – mitigate climate changes. Publications reviewed during preparation of this paper are a set of studies that does not necessarily represent the complete literature preview for land use changes from biofuels and theirs various implications, but it does provide a substantial and representative cross-section of reported work to address the above mentioned objectives from different perspectives.

Humans have been altering the appearance of the landscape for hundreds and thousands of years. Bonin and Lal (2012) document that with the human population increase has also increased alteration of the landscape - from only 5% of land under urban settlements in 1700 to over one-half of global land dominated by humans in 2000. While the area of natural forest and grassland has been steadily decreasing, the acreage of land used for agriculture has been steadily increasing. The competition for land use services is fierce and with the newly emerging interest in bioenergy cropping systems, it is likely to accelerate the change.

Currently, the world is seeking solutions to its energy, environment and food challenges. Biofuels were introduced as one of potential concepts for at least partially addressing these issues. The global community cannot afford not to do the biofuels “right” and even less than that it can afford to do the biofuels “wrong”.

Timilsina and Shrestha (2011) point out that the demand for land to produce biofuels augments the traditional demands of agriculture and forestry. Moreover, global population growth as well as rising per capita consumption of developing countries can be expected to increase demand for land for food supply in the future. Similarly, Leal et al. (2013) mention that there are two main drivers for increased competition for land: the increasing demand for energy, particularly with respect to transport and the increasing demand for food, both to meet growing world population and improvements in nutrition and quality of food. Other sources (e.g. Bonin and Lal, 2012; Piroli et al., 2012; Murphy et al., 2011) introduce theirs research by considering primary drivers for increased land competition. In wider respect, these primary drivers could be summarized as:

- Increasing population
- Increasing food production needs
- Increasing energy needs
- Decreasing fossil fuel reserves
- High oil prices causing reduction in agricultural productivity
- Higher demands for “alternate” energy sources, such as biofuels

The food-energy-environment systems are obviously closely interconnected, Tilman et al. (2009) call them a “trilemma challenge”. When increased demand for food and energy combine, pressure on land conversion is increased, leading to further climate change, this in turn may affect productivity and availability of land, so creating a potential vicious circle.

Changes are needed to meet the food-energy-environment trilemma and a comprehensive understanding of bioenergy crops production land-use dynamics is essential for the development of appropriate policies and sustainable and efficient bioenergy sources.

Leal et al. (2013) define 3 pillars (economic, environmental and social) that have to be observed in order to produce biofuels sustainably. These pillars are equally important, but are complex and dependent on the local conditions of the social, political and economic impacts.

Existing literature does not favor the diversion of food for large-scale biofuels production (Timilsina and Shrestha, 2011), but the regulated expansion of biofuels in countries with surplus lands and a strong biofuel industry cannot be ruled out. The impacts vary from study to study and depend upon the definition of limits of each system.

In the next sections are presented literature review results from several different perspectives – methodological understanding of LUC, related policies, food vs. biofuels competition and regional approach.

2.2 LUC methodology, relationship to GHG

Land Use Change (LUC) is a general term typically covering two distinct (direct, indirect) means by which land can be altered in the pursuit (in this specific case) of biofuels production.

Direct LUC (DLUC) occurs when land previously used for other purposes is converted to biofuel crops production. It involves changes in land use on sites used for food or fiber production (including also changes in crop rotation patterns, conversion of pasture land and changes in forest management) or conversion of natural ecosystems for bioenergy crops land (Gawel and Ludwig, 2011).

Indirect LUC (ILUC) refers to the changes in land use, when other productive activities are displaced by biofuel feedstocks onto new lands and thereby potentially producing large GHG emissions during the land conversion event (Kim et al., 2012).

Witcover et al. (2012) use a term ''market-mediated'' land use change. This occurs when the increased land competition changes agricultural prices, imports, and exports and because price changes affect all commodity production, the ''indirect'' label is often used to encompass all effects, including direct ones.

Land demand estimate is a complicated task, considering all the variables that affect the biofuel demand - such as, oil prices and security of supply, global warming mitigation alternatives, policies promoting biofuel use in different countries, agricultural feedstock prices and technology development in agriculture, biofuel production and final use (Leal et al., 2013). Future biofuel demand varies in a wide range as well, as presented e.g. in the IEA's World Energy Outlook. The land requirements for biofuels to meet 20–30% of the IEA predicted transport fuel demands to 2050 range from 100 million hectares up to about 650 million hectares (Murphy et al., 2011).

Among methodological issues, the estimation of LUC effects, whether direct or indirect, is one of the most problematic, but decisive concerns. It is now recognized that accounting for land use changes can make a significant difference in the GHG emissions balance calculation (Van Stappen et al., 2011; Adler et al., 2007; Hoefnagels et al., 2010; Whitaker et al., 2010). To be more specific - on the example of corn and cellulosic ethanol production, Bonin and Lal (2012) show that without taking LUC into account, some of these production systems show predicted 20% and 70% reductions in GHG compared to gasoline, but after factoring in LUC, these two ethanol systems may actually release 93% and 50% more GHGs.

However, LUC and associated climate changes are not a set of simple equations; they are actually only one part of a complex system. Questions like "What is the total quantity of land converted? Where is it converted? What type of land was converted?" are not sufficient in addressing the issues fully. For example - the LUC can affect climate by affecting the flows of C between the atmosphere and soil/plants, by affecting climate-relevant physical properties of land (e.g. albedo), by affecting the nitrogen cycle, by affecting hydrologic cycle (with further consequences in the direct radiative forcing of water vapor, via evapotranspirative cooling, via cloud formation) and by affecting the fluxes of other pollutants that can affect climate (such as CH4, volatile organic compounds, and aerosols) (Delucchi, 2011).

On the issue of GHG emissions reduction compared to fossil fuel use, there are 2 very polarized groups - biofuel advocates and biofuels opponents.

The supporters believe that biofuels can help mitigate global climate change and regard biofuels as a sustainable alternative to fossil based fuels, since LUC can be quantified and counted for. For example, Fargione et al. (2008) calculates direct LUC impacts on GHG emissions and their corresponding “carbon debt” by estimating loss of soil C stock due to land conversion and ends there.

The critics highlight the fact that in the process of biofuels production, not only the flow of GHGs in the production process needs to be accounted for, but also it has to be counted with the change in the stock of carbon contained in the land converted for feedstock production (Lange, 2011). E.g. Searchinger et al. (2008) believes that focusing only on DLUC would have little effect, because emissions from LUC are likely to occur indirectly. Thus, biofuel opponents claim that biofuels do not mitigate global warming and in fact, due to ILUC releases even more GHG emissions than fossil based fuels. This is of particular importance if land that has not been used before or has been used as forestry or as pasture comes into use for bioenergy production.

It is evident that both direct and indirect land-use changes driven by whatever source of growing demand need to be considered and evaluated. Clearly, calculating indirect effects is more challenging, so some of the older studies did not consider iLUC at all. Recently, there have been a growing number of reports on how to quantify and assess the direct and indirect land use change induced by biofuels (e.g. Ravindranath et al., 2009; Al-Riffai et al., 2010; Hiederer et al., 2010). Still, widely accepted methodology is not available, although a comprehensive discussion about the different models and combinations of models exists (Nassar et al., 2011).

It is now widely recognized that ILUC can have disastrous effects and that there is an urgent need for reliable assessment methodologies. However, according to Van Stappen et al. (2011), it does not seem possible at the present state of knowledge to accurately assess the iLUC effects. Similarly, according to Gawel and Ludwig (2011), there is still no sound and consensual methodology to take into account iLUC. “The potentiality of adverse effects arising from indirect land use change related to biomass cultivation is hardly subject to dispute, the quantification of these effects and especially their policy implications are however contentious”. Gawel and Ludwig (2011) take it further and divide the iLUC related issues to four categories - the problem of (1) causality, (2) measuring, (3) remote attribution and (4) governance.

Kim and Dale (2011) introduce an effort to develop methodologies to observe ILUC change from the historical data, since such approach might as well reduce uncertainties in ILUC estimates or possibly help to form the basis for better biofuels related policies.

In addition to a commonly accepted fact that that the climate effects of LUC depend on the magnitude and timing of changes in soil and plant carbon, Delucchi (2011) also points out in particular on the timing and extent of the reversion of land to original ecosystems at the end of the bioenergy program. He highlights that one can estimate anywhere from zero to very large climate impacts due to LUC, depending on whether one counts the climate impacts of any reversion of land uses and depending on how one values future climate-change impacts relative to present impacts. So the question that needs to be added to the estimation methodology could stand - how long a period should be used to amortize the emissions from the initial conversion?

Kim et al. (2012) ask whether the debate around ILUC is framed correctly at all. He proposes a method for allocating GHGs “caused” by ILUC between biofuels and dietary preferences (assuming that livestock provides protein to human beings, and the choice between vegetable- and animal-based proteins depending on dietary preferences). According to him, the debate should be rather framed in terms of allocation among different land use change drivers, in his specific investigated case between human nutritional needs and biofuel production.

Either way the LUC/GHG issues are looked at, Van Stappen et al. (2011) reminds us that "because it is urgent to ensure bioenergy sustainability, it is crucial to act as soon as possible to manage ILUC effects. While monitoring is required to evaluate these effects, authorities must act decisively in order to limit negative impacts".

It seems that policy makers will face a dilemma, whether ILUC effects that obviously exist should be neglected or whether these effects should be taken into account, although no sound methodology is available. However uncomfortable and challenging, mitigating the competition for land can only occur provided that the complexity of the dynamics is fully addressed (Harvey and Pilgrim, 2011).

2.3 LUC and policy issues

The use of biofuels can increase land competition, which leads to global land use changes. LUC poses risks such as increased greenhouse gas emissions and food prices. The magnitude of the risks is uncertain, but potentially significant. Concerns over the impacts significance of biofuels (whether it'd be on LUC or other factors) have entered the political arena and new rules are starting to guide biofuels theirs way - or better say support theirs way.

Expanded biofuel production, particularly at the scale necessary to meet the biofuels mandates set by US and EU, will have significant impacts on land use around the world. Given the complexity of the issues at stake, biofuels can be expected to keep provoking policy making controversies.

A comprehensive understanding of bioenergy crop production land-use dynamics is essential for the development of sustainable bioenergy and land-use policies. A first step in the policy-shaping process must be reviewing the issues and strategy plans of the world's leading biofuels producers and consumers. This has been conducted in exhaustive detail by Sorda et al. (2010) - individual major player countries are grouped by continent, theirs principal manufactured biofuel feedstocks are identified, the effective key laws, action plans and incentive schemes are reviewed and current output targets, subsidies and import tariffs are highlighted.

It is critical to emphasize that policy makers must bear complexity of the issues in mind when evaluating alternatives for a biofuel programs – they should not forget the important aspects of social, economic and other broader environmental issues in the final assessment of the biofuel impacts (Leal et al., 2013). They should also keep in mind that biofuel mandates on energy substitution for petrol by ethanol have major implications for crop and feedstock choices and the associated land demands globally.

Leal et al. (2013) warn that policy makers have to carefully considerate two critical points: the future size of the biofuel demand and the land required to meet this demand. The former will depend on government policies promoting biofuels, oil prices and GHG abatement potential of biofuels; the latter will depend essentially on the biofuel yields, once the biofuel demand is defined.

Witcover et al. (2012) note that "bioenergy-driven land-use change has affected and will impact most severely on the 'land- and resource-abundant' developing regions, where economic development takes priority over sustainable land-use policies, and the enforcement capability is limited." Huang et al. (2012) investigate this statement consequence somehow further, by looking in the global impact pathways of biofuels production specifically in the developing world. It warns prior a possible vicious circle, where too low energy prices reduce the demand for biofuels and thus require greater government support to meet the targets, while with prices being too high, there is too much space for substituting biofuels for petroleum-based fuels and thus the volume of biofuels produced will exceed the mandates.

Several opportunities are identified by Miyake et al. (2012) for more effective global policies development in relation to bioenergy crop production and its expansion:

(1) give high priority to no and/or less land-using bioenergy feedstock

(2) develop sustainable land-use options for bioenergy crop production

(3) develop agreed international policy mechanisms and instruments for sustainable land-use options for bioenergy crop production

(4) strengthen sustainability requirements and certification schemes

Strategies recommendations to policy makers suggested by Witcover et al. (2012) are similar to some extent:

(1) promote feedstocks that rely less on land;

(2) reduce LUC risk for land-using feedstocks; and

(3) stimulate investments that increase land productivity and environmental protection.

Policymakers face difficult trade-offs in deciding how to address biofuels related LUC. Underestimating high LUC can reduce access for the poor to food or undermine GHG reductions and thus cause various adverse effects. On the flip side, too timid approach can erode biofuels' potential via slow biofuel expansion and thus reduce energy security and decelerate rural development (Wang et al., 2011).

"Ideally, decision-makers will balance policy objectives to set acceptable levels of LUC risk, taking into account the best available information on outcomes of interest and uncertainties about feedstock-specific emissions" (Witcover et al., 2012). Clearly, there are some difficult choices, no simplistic solutions and unfortunately too much space for various interventions that are often trumping the science. New collaboration between environmentalists, economists, technologists, the agricultural community, engaged citizens, and governments around the world will be needed to address the complex issues at stake.

2.4 LUC and biofuels vs. food competition

Biofuel feedstocks, although providing energy and according to some (not all) also potentially reducing GHG emissions, do so at the cost of diverting limited resources of land, water and nutrients from food production (Pimentel et al., 2009). As a result, food and biofuel crops may compete for these limited resources, so biofuel production could potentially jeopardize food security, which is already at high risk. The question is then whether biofuels and food will co-exist or strife for available land.

Research on the effects of competition between agriculture for food and biofuels production is not a recent phenomenon. In the response to the oil shocks in 1970s/1980s, e.g. Brazil adopted ethanol as an important component of its energy mix (Rathmann et al., 2010). Rapid expansion of the liquid biofuels production triggered the need to incorporate new arable land into use, the trend started to be investigated eventually and is now found worldwide. It became a global dilemma, as the needs to feed humanity versus the greater monetary returns to farmers through agro-energy seem to be in direct competition.

In addition to a list of environmental concerns, a rapid increase in bioenergy production demand has led also to various socio-economic issues. It has been linked to the global food crisis in 2008 and sparked the food versus fuel debate (Witcover et al., 2012). Most studies agree that expanded biofuel production puts upward pressure on food prices (by raising demand for feedstock commodities), but there is considerable variation in estimates of (1) the magnitude of this effect and (2) the duration of the effect. According to Rathmann et al. (2010), a shift of areas traditionally used to food production to fuel has contributed to the increase of food prices in the short run, but this change cannot yet be called significant, nor will it last in the long-run. Similarly, Ajanovic (2011) says that "no significant impact of biofuels production on feedstock prices can be observed, hence, a co-existence of biofuel and food production seems possible especially for 2nd generation biofuels." To be more specific on the variability - Bonin and Lal (2012) point out the cost of food has been on the rise since the early 2000s, with a sharp increase in 2008 and a lesser increase in 2010. Between 2007 and 2008, the global price index for food increased by 45%, with biofuel production accounting for anywhere between 3% and 30% of the price increase.

However, part of the literature presents arguments against the existence of land use competition between foods and biofuels at all. According to theirs arguments, nearly all the lands incorporated for biofuels have been otherwise marginal and what competition exists has been mitigated by a continuing increase in agricultural productivity (Goldemberg et al., 2008; Dale, 2007).

Assuming that the conflict actually exists, the estimation of its magnitude is particularly complicated because of several external drivers – market forces such as oil price and currency fluctuation, but also by climate variability or policies specifically demanding the biofuels production growth (Timilsina and Shrestha, 2011). Among these factors, Huang et al. (2012) highlight the importance of the international oil price and the policies forcing the possible substitution between biofuels and gasoline.

A list of studies note that conflicts between biofuels and food production may be decreased by the use of marginal and degraded land for biofuel production (Campbell et al., 2008; Fargione et al., 2008; Millbrandt and Overend, 2008) and intensification of agriculture on current arable land (Pretty, 2008).

Timilsina and Shrestha (2011) argue though that degraded lands are ill suited for agriculture by definition, typically lacking water and nutrients and although some crops are promoted as feedstocks that can withstand such conditions, yields are typically low. On the other hand it also highlights the fact that when and if the production of cellulosic ethanol becomes commercially viable, e.g. perennial grasses and forestry residues that are not currently part of the energy supply chain will be able to contribute to biofuel production, relieving some of the pressure on land.

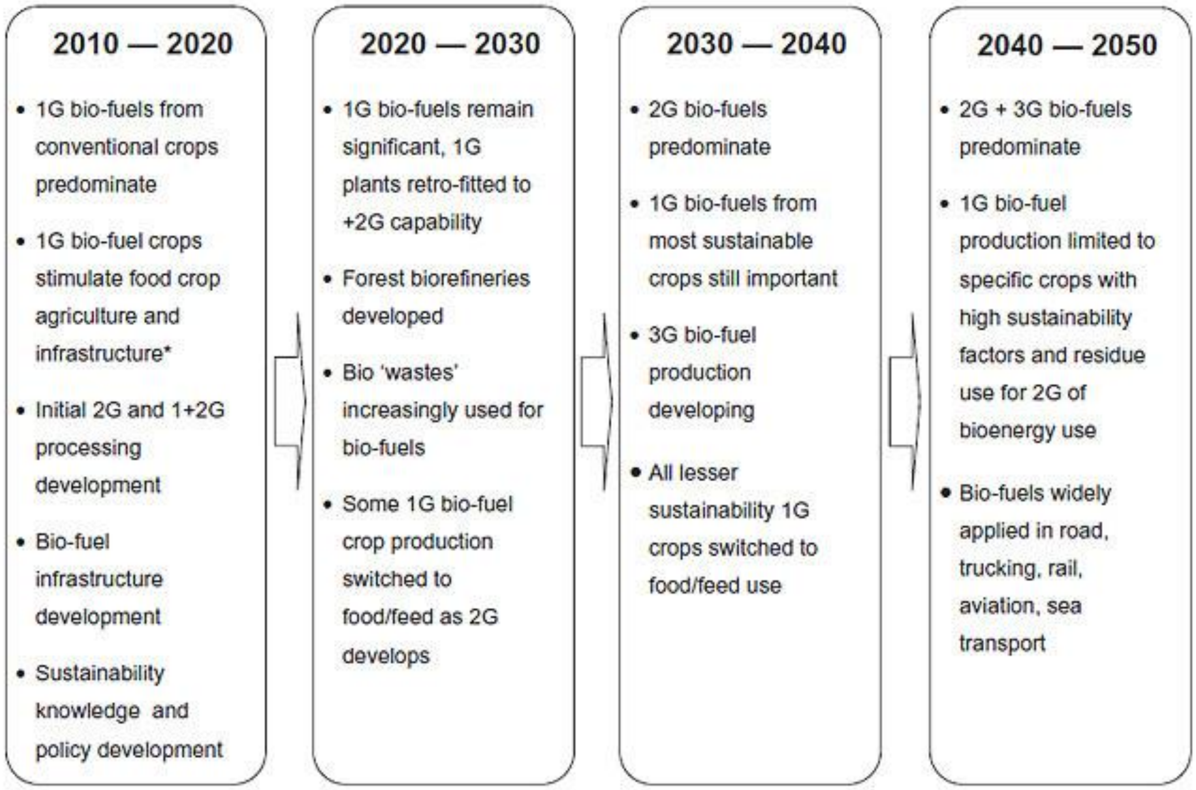
The future impacts of biofuel production on regional agricultural and related sectors over the next decade were assessed by Huang et al. (2012). This study results indicate (based on Global Trade Analysis Project platform) that the impact pathways extend far beyond the borders of the main biofuels consumers (USA, EU and Brazil) and as such, this could have a two-fold effect – (1) growth of biofuels is a good news for agricultural producers, who own their land and are net-sellers of their crops on the market, but (2) it is a bad news for consumers, including those that produce food.

It is inevitable that biofuels will be here for the foreseeable future, so improvements in policy and technology are needed to reconfigure agriculture and land use to gracefully meet global demand for both food and biofuel feedstocks.

2.5 LUC from regional perspective

From the regional perspective, investigated studies research biofuels production and its implications on land use changes, food supply, environment and other issues on several levels.

On a global scale, models were developed to predict land conversion from natural areas to agricultural use in different ways, e.g. by introducing a land supply elasticity based on observed land supply responses or by considering only the direct cost of land conversion (Gurgel et al., 2007). These approaches emphasize the importance of reflecting the non-market value of land in the conversion decisions and they find that the expansion of biofuel cultivation will occur largely at the expense of natural forest and pastures, whereas cropland, managed forest, and natural grassland will show little net change. Murphy et al. (2011) introduce possible pathways to biofuel development to 2050 and their interaction with agricultural commodity crops and land. It predicts a global development, where G1 crops will eventually lose its current role and theirs production will be limited to specific crops with high sustainability factors, while G2 and G3 biofuels will be further enhanced and will eventually dominate among the various biofuels options. Related infrastructure will be developed and biofuels will be widely applied in various transportation systems:



As mentioned by Leal et al. (2013), outlook of land demand for biofuels vary though, because biofuels yields themselves vary widely, even for the same biofuel from different feedstocks and/or from different regions in the world.

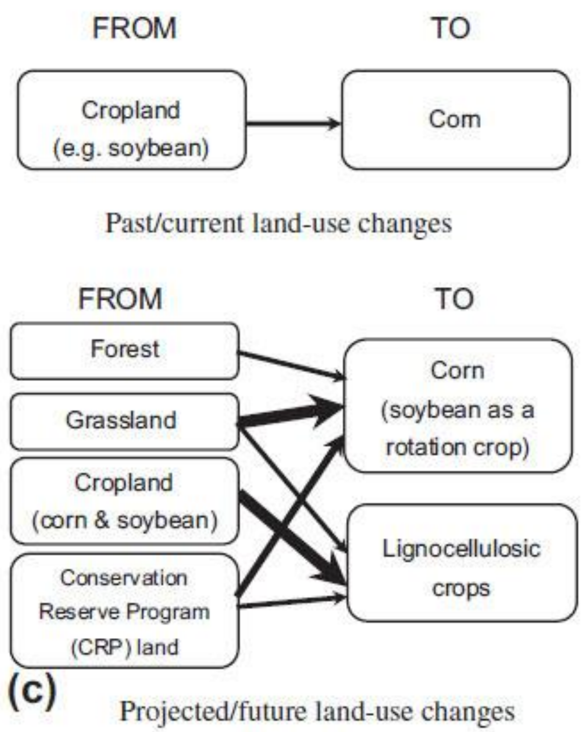
On the "South" vs. "North" scale, several studies suggest a link between bioenergy policies, demand for cropland and adverse LUC, especially deforestation in the 'South' (e.g. Searchinger et al., 2008).

Börjesson and Tufvesson (2011) investigate resource efficiency and environmental performance including direct land use changes on the scale of a multi-nations region (northern Europe). Scaling down further, Witcover et al. (2012) review the dynamics of bioenergy-driven land-use change with a focus on four geographic regions considered as the most prominent locations for those effects - Brazil, Indonesia and Malaysia, USA and EU.

National studies were performed in many countries with various scopes on a list of crops. For example, Yang et al. (2009) investigates the land and water requirements of several biofuel crops (maize, sugarbeet, etc.) with reference to the government biofuel development plans for 2020 in China. The projection suggests that to meet the set biofuel targets, between 5% and 10% of the total cultivated land would be needed, depending on the feedstocks used. Gallardo and Bond (2011) point out on a case study in Sao Paulo area (Brazil) the need to properly evaluate the extent to which the full implications of large scale land use change for sugarcane production are currently being considered by decision-makers. In Thailand various scenarios of cassava and sugarcane production were assessed and theirs implications quantified (Silalertruksa et al., 2009). Modeled scenarios included converting unoccupied land to cropland, yield improvement or displacement of area currently under sugarcane cultivation. Sudha and Ravindranath (1999) assessed the availability of land in India and the potential for local biomass production to meet various demands scenarios for biofuels substitution of expected petrol volumes, so did Schaldach et al. (2011). Several scenarios were modeled and a comprehensive linkage was made between driving forces (such as population change) and policies (such as biofuel usage) that will affect land-use change over the coming decades. Larsen et al. (2012) did a case study about scenarios for biofuel demands, biomass production and land use in Denmark, Howard et al. (2009) on the example of Great Britain investigated various renewable energy sources and theirs relationship to future land use, Colombian case study (Quintero et al., 2008) compared ethanol production from sugarcane and corn. It is obvious that there is no shortage of national case studies. The results might vary considerably (due to difference in methodological approaches, different assumptions about crops yields, conversion efficiencies, etc.), but the connecting argument is that current biofuel development paths could pose significant impacts on food supply, trade and environment.

Investigated studies aiming the USA were done either on a national scale or with a focus on a specific region, predominantly on an area with corn production in the Corn Belt region (Secchi et al., 2011). The rapid corn-based G1 ethanol expansion in the USA initiated a global debate about food security (Mitchell, 2008), GHG benefits (Hammerschlag, 2006; Miller et al., 2007;

Pimentel and Patzek, 2005), and iLUC impacts (Searchinger et al., 2008; Tyner et al., 2010). Documented land use changes in the USA show that main land-use change pathway for bioenergy crops in the USA has been the result of increased corn production in the Corn Belt region, replacing existing soybean cropland (Mitchell, 2008; Schilling et al., 2008). However, as predicted by Miyake et al. (2012), in the future, different primary purpose lands will be converted and the paths will get more inter-connected:



Projected/future land-use changes

The U.S.A.

National-global interconnections are shown e.g. by Bonin and Lal (2012), when pointing out that increased bioethanol demand in the US will affect the allocation of US land area under other crops and ecosystems, but will also indirectly cause changes in land uses around the globe.

Tyner et al., 2010 shows that biofuel policies and mandates under the National Renewable Fuel Standard (RFS) created under the Energy Policy Act of 2005 are as the primary cause of recent bioenergy-driven land-use changes in the USA. Perlack et al. (2005) documents that around 22 million ha of cropland will be available for bioenergy crop production by 2050, although this may be insufficient to meet demand under the current national targets.

Pro et al. (2005) compare the land use impacts of sustainable transportation scenarios. It analyzes 4 different approaches: (1) renewable electricity to electrolytic hydrogen to fuel cell vehicles, (2) renewable electricity to battery electric vehicles, (3) biomass gasified to hydrogen to fuel cell vehicles and (4) biomass liquefied to biofuel to fuel cell vehicles. Overall efficiencies were calculated for each path, as well as the associated land use values and it was concluded that the highest land use was associated with the biomass paths.

The Akinci's et al. (2008) study (partially similar to ours in the sense that various biofuel crops were compared to theirs land requirements) concluded that ethanol or biodiesel production do not appear scalable to make a significant difference on the US fossil fuel demand for transportation. In addition, aspects of this study point to systemic changes that may be required in American lifestyle and attitude toward energy consumption – the US would benefit from reducing consumerism as petroleum is not being replenished and the predictions suggest that biofuel produced within the US borders will not be sufficient to sustain current US petroleum consumption patterns (Huesemann, 2001).

The increasing role of second generation biofuels (not only in the USA, but globally) has been widely recognized. When and if the production of cellulosic ethanol becomes commercially viable, crop and forestry residues that are not currently part of the energy supply chain will be able to contribute to biofuel production, relieving some of the pressure on land. Our study with focus on land use implications of second generation biofuels could be thus seen in this sense as an innovative. Although it targets primarily Florida (a relatively small region), the methodology can be easily transformed to any other regions, where similar climate, water cycle and soil types conditions apply.

3. Methodology

Florida has been experimenting with various crops for its bioethanol production. In our study we aimed those energy crops that were in further detail investigated by UF/IFAS researchers (as shown e.g. at http://edis.ifas.ufl.edu/topic_energy_crops or in Rahmani and Hodges (2009) and Rockwood and Peter (1997). The focus has been mostly on high biomass yield crops (some sugar-bearing), including Miscanthus, Switchgrass, Sweet Sorghum, Corn, Elephantgrass, Sugarcane and Energycane as well as short rotation woody crops such as Eucalyptus. There exist other bioethanol candidates (e.g. Sugar Beets, Cassava, Wheat, etc.), but they are not produced in Florida and therefore were not included in this study.

Biomass and bioethanol yields used in this study are only for the crops planted in Florida. Some crops considered in this study (e.g. corn) might have higher yields in different conditions (e.g. cooler climate zone and different soils types in the mid-western Corn Belt) than in Florida, but for this study were used specifically results as produced in Florida. However, for biomass to bioethanol conversions were used generic values, as technology in this case is not dependent on climate.

Six subsequent equations (1-6, as described in detail in Section 8.4) are used for bioethanol demand estimation for transportation needs in Florida. Given values include E10 fuel consumption, number of registered vehicles, population, number of miles traveled on E10 and fossil fuel to bioethanol efficiency. Calculated values represent annual mileage per vehicle, vehicle mileage per gallon of E10, volume of E10 needed per year per vehicle, volume of E100 needed per year per vehicle, number of vehicles per person and volume of E100 needed per year per person.

We divide the estimated volume of E100 needed per year per person by bioethanol production yields from different crops and that way are able to estimate the annual land requirement to meet bioethanol needs of the Florida transportation sector under E100 scenario (equations 7-9, Section 8.5).

We calculate energy content (BTU) and volumes (gallons) of various blended fuels (and their fossil fuel and ethanol fuel components) needed to travel the same given distance. Increasing ethanol concentration in fuel blends decreases the energy content of those blends (linear relationship), but relationship between the total volumes of fuel blends needed to travel the same distance is non-linear.

We then quantify land requirements for bioethanol crops to cover Florida transportation energy under various modeled scenarios (E10, E15, E20, E85 and E100) and present results in Section 8.6.

We'd like to emphasize that we did not include in our estimation the varying engine performance in miles per joules between different fuel blends. While refining the modeling approach in such fashion has a logical basis, it would go beyond the scope of this paper.

The initial methodology described in this paper has been developed by its authors in cooperation with former interns (Leyens, 2010) hosted by Intelligentsia International during the spring of 2010. There exists a similar paper on this topic as presented by the Canadian Journal on Scientific and Industrial Research (Nahar et al., 2011). We'd like to point out that all 3 authors of that published paper were hosted as interns in Intelligentsia International later on, during the autumn 2010. They then used the already developed methodology for own publishing purposes without providing any adequate referring citations.

4. Biofuels categorization

4.1 Primary and secondary biofuels

Biofuels are referred to as solid, liquid or gaseous fuels derived from organic material accumulated in living plants through photosynthesis. The standard classification of biofuels is divided into primary and secondary categories (Dragone et al., 2010). While primary biofuels (e.g. fuel wood) equal to *unprocessed* biomass, secondary biofuels (e.g. bioethanol) are produced by *processing* biomass. With biomass *processing* are meant various biochemical or thermochemical processes as discussed further.

Primary biofuels are typically not categorized further. Secondary biofuels are divided into 3 generations – first, second and third. These three generations vary based on different parameters, such as type of feedstock, type of processing technology or their level of development.

4.2 First generation secondary biofuels

First generation secondary biofuels mostly rely on food crops as their feedstock. Corn, wheat, potatoes, sugar beets, sugar cane and other similar feedstock are transformed into bioethanol and biobutanol by the fermentation of starches and sugars. Soybeans, sunflowers, coconuts, palms and similar "oily" feedstock are transformed into biodiesel through trans-esterification. While production methods for the first generation of secondary biofuels are well known, relatively simple and widely used, the main drawbacks are direct competition of biofuels feedstock with food production, high cost of production (caused by high cost of feedstock), modest (if any at all) reduction of GHG emissions and low land use efficiency.

4.3 Second generation secondary biofuels

Second generation secondary biofuels (a main focus of this study) are produced from lignocellulosic biomass, which enables the use of non-edible feedstocks. Using these biofuels limits direct food vs. fuel competition, potentially decreases GHG emissions and improves land use efficiency. Feedstocks for lignocellulosic biofuels can be divided into three main categories: (1) originated from natural ecosystems (e.g. forest wood), (2) produced by cultivating dedicated bioenergy crops (next generation high-yield bioenergy grasses and short rotation woody crops) or (3) derived as a residue of any kind of lignocellulosic waste (U.S. DOE., 2007b). Despite its abundance (lignocellulose is the most abundant biological material on earth and it is estimated to make up half of all the organic carbon on the planet (Schubert, 2006)), cellulosic biomass is a complex feedstock that requires more extensive processing than first generation biofuels. Several scientific breakthroughs are needed to make cellulosic biofuels production cost-efficient enough to operate at a commercial scale (USDA, 2007).

4.4 Third generation secondary biofuels

Third generation secondary biofuels are derived from micro- and macro-algae. They are being considered as a viable alternate energy resource that overcomes some of the major drawbacks associated with the first and the second generations of secondary biofuels. Algae have a very short harvesting cycle (days comparing to months/years of traditional crops), potentially high yields (reported as an order of magnitude higher than traditional crops) and could be very effective relative to land use. However, environmental impacts of an algal biofuel sector raise some red flags. Some initial studies show that the energy consumption, greenhouse gas emissions and water use associated with producing algal biofuel might be much higher than that of conventional biofuels (Clarens et al., 2010; Starbuck, 2011). Further research is needed to properly evaluate strengths and weaknesses of the algal biofuels.

5. Biofuels production

5.1 Biomass production – the case of Florida

Biomass is biological material from living or recently living organisms. As an energy source, biomass can be either used directly (primary biofuels) or it can be processed and converted into other usable forms of energy (secondary biofuels). The biomass production yield (measured in tons per hectare or acre) has some degree of uncertainty, depending on several factors. The major ones include climate conditions, soils fertility, water management practices, feedstock species, collection technologies, maintenance regimens, etc. Let's discuss these factors in the case of Florida, keeping in mind that these can be easily transformed to any other regions, where similar conditions apply. For example – humid subtropical climate (typical for Florida) appears also in all other continents - over a large portion of the interior of the Middle and Eastern Africa, southeastern quarter of mainland China and surrounding areas, along the Ganges river, parts of the Caspian Sea and Black Sea shores, southern Brazil and northern Argentina, eastern Australia, small sections of southern Europe and all over the southeastern USA (eastern half of Texas, Oklahoma, Louisiana, Arkansas, Alabama, Mississippi, North Carolina, South Carolina, Tennessee, Georgia, Kentucky, Virginia and sections of West Virginia) (Peel et al., 2007). The prevailing climate influences the dominant soil types (usually ultisols in case of humid subtropical climate), water cycle conditions, length of growing cycle, etc.

5.2 Climate, soils and water resources of Florida

The subtropical to tropical humid climate of Florida makes it a favorable place for growing certain biofuel crops. On average, there are around 1370 mm/year of rainfall, unevenly distributed between the wet and dry seasons. The wet season is from the beginning of June to the end of October and accounts for around two thirds of the annual rainfall. The dry season (November through May) accounts for around one third of the annual rainfall (Southeast Regional Climate Center, 2012). Average annual air temperatures for Florida is reported as 21.4^{o}C with monthly average temperature increasing from 14.6^{o}C in January to 27.4^{o}C in August

(Southeast Regional Climate Center, 2012). The annual average relative humidity is around 80% with annual average minimum and maximum values of around 66% and 92%, respectively. There are 2,800 to 3,200 hours of sunshine annually in Florida (Enterprise Florida, 2010).

Most of Florida's soils are sand-/limestone-based with little organic matter and low water and fertilizer holding capacities. The varying levels of drainage and mineral distribution throughout the soils determine the type. Out of the 12 soil types in the United States, 7 are represented in Florida with 5 of them being common (histosols, spodosols, ultisols, alfisols and entisols) and 2 of them having rather small aerial extent (mollisols and inceptisols) (Myers and Ewel, 1990; Collins, 1998; Shober, 2011).

Histosols (4.0 million acres in Florida), also called *organic or muck soils*, typically form in poorly drained areas where wet conditions limit the decomposition of organic matter (e.g. marshes and swamps). When these soils are artificially drained, they are very fertile. However, once drained, the organic matter component of these soils will quickly decompose, leading to subsidence and high releases of stored organic carbon. These soils are predominantly located in south Florida (Shober, 2011). In the Everglades Agricultural Area (EAA) sugarcane is currently grown on 0.4 million acres of histosols.

Mineral soils in Florida have different qualities and origin. Compared to the organic soils found primarily within the EAA, mineral soils are usually sandy and exhibit low organic matter content, both may limit agricultural production. *Spodosols*, (8.4 million) typical by its spodic horizon, dominate the flatwoods ecosystems of Florida. They tend to be poorly drained and develop in sandy, acid parent materials. Most spodosols are rather poor soils for agriculture, unless well-drained and well fertilized. However, there is potential to use these soils for quick rotation woody crops. *Ultisols* (6.9 million acres), typical for the Panhandle and the central ridge, are usually well-drained loamy to sandy soils, with well-developed argillic horizon. If properly managed, these soils can be highly productive. *Alfisols* (4.6 million acres) are widely interspersed throughout the state. They are well-drained sandy soils, characterized by an argillic horizon. The unique properties of alfisols in Florida are a combination of an argillic horizon, a medium to high amount of bases in the soil, with water generally available to plants during the growing season and an ochric epipedon. In general, these soils are intensively cropped. *Entisols* (7.5 million acres) do not reflect any major set of soil-forming processes. The entisols of the Panhandle and the central ridge are excessively drained thick sands, while the entisols of South Florida are very poorly drained marl or thin sandy soils that are underlain by very porous limestone bedrock. Entisols are able to support any vegetation (Myers and Ewel, 1990; Collins, 1998; Shober, 2011).

Water is among Florida’s most valued resources – there are more than 1,700 streams and rivers, 7,800 freshwater lakes, 700 springs, 11 million acres of wetlands, and underlying aquifers yielding quantities of freshwater needed for both human and environmental needs (Marella, 2008). Continuing agricultural development and population growth place additional stress on the renewable, though finite, water resources.

In 2005, the total water withdrawal of Florida was estimated at 18,359 Mgal/day, with saline water accounting for 11,486 Mgal/d (used from 99.99% for power generation sector) and fresh water accounting for 6,873 Mgal/d. Overall, agriculture with 2,766 Mgal/day was the largest user (40%) of withdrawn freshwater, followed by public supply (37%). The ratio of ground vs. surface freshwater in agriculture was around 47% vs. 53% (Shober, 2011). Monthly withdrawals for agriculture have large seasonal variation, with the greatest withdrawals during the dry season and lowest during the wet season. In 2005, an estimated 3.864 million acres of land was used for agricultural crop production in Florida, with about 1.783 million (46%) irrigated acres (Shober, 2011). 43% of the irrigated land was irrigated by flood systems, 38% by micro systems and 19% by sprinkler systems. Sugarcane itself needed over 31% (875 Mgal/d) of all water withdrawn for agricultural needs. With around 400,000 acres used for sugarcane farming, over 22% of irrigated land in Florida was used for this one potential biofuel crop (Shober, 2011).

5.3 Florida bioethanol crops - biomass and bioethanol yields

For bioethanol production, Florida has been experimenting with various crops. The focus has been mostly on high biomass yield crops (some sugar-bearing), including Miscanthus, Switchgrass, Sweet Sorghum, Corn, Elephantgrass, Sugarcane and Energycane. Citrus growers' by-products, such as orange peels, seeds and molasses are being investigated as well, but since these have an existing use in well-established markets (animal feed, essential oils), their potential for bioethanol production seems currently as not very high. Short rotation woody crops such as Eucalyptus get attention as well, mostly due to their high biomass yields. There are over 16.1 million acres of forests and woodlands in Florida (Mulkey at al., 2008) that could be partially converted to different types of forest, with relatively minor changes in land use scenarios. Either way will the future paths go, there seems to be a consensus that sustainable production of bioethanol in the long term will need to utilize cellulosic materials (and thus develop second generation biofuels) rather than utilize food crops with their competing uses (and continuation of unsustainable first generation biofuels). Unfortunately, it still remains uncertain when the cellulosic bioethanol could become commercialized at full-scale.

Miscanthus (*Miscanthus x giganteus*) is a genus of tall perennial grass species, used primarily for combustion in power plants so far. It also receives attention as a biofuel crop because it has relatively high dry biomass yields (5–15 tons per acre) across a range of environmental and soil conditions and thus a potential for lignocellulosic conversion to bioethanol and other biofuels. However, UF/IFAS researchers found that *Miscanthus x giganteus* was not too well adapted for photoperiods and temperatures in Florida and that biomass yield potentials for Florida were lower (4–8 dry tons per acre). Ongoing breeding efforts may eventually create varieties of Miscanthus better adapted for Florida (Erickson, 2012). Current general cellulosic biomass conversion to bioethanol of 50 gallons/dry ton of biomass (Stricker et al., 1993; Mark et al., 2009) was used for the ethanol yield estimation. Under this scenario, around 300 gallons of ethanol per acre appear to be a realistic yield.

Switchgrass (*Panicum virgatum*) is a perennial grass identified as a potential bioenergy feedstock. While Switchgrass has been mostly directed toward biomass production as a combustion fuel to supplement coal for generation of electricity so far, it is also a potential feedstock for lignocellulosic bioethanol production. Several cultivars (Miami, Stuart, and Alamo) are recommended for Florida and even under low fertility conditions have reasonable dry matter production potential (1.8-3.6 tons per acre). If fertilized, yields in Florida have exceeded 5.4 tons/acre. One dry ton of Switchgrass typically yields between 70 and 90 gallons of bioethanol (Newman et al., 2011; Helsel and Alvarez, 2011). A typical yield is around 290 gallons of ethanol per acre. Less is known about Switchgrass production in Florida than other biofuel crops that have been more widely studied for biomass production in the state. It is known though that diverse mixtures of grasses produce on average more biomass than the same land planted with single prairie plant species, including Switchgrass (National Science Foundation, 2006).

The term 'Sweet sorghum' is used to describe varieties of sorghum (*Sorghum bicolor*), a summer annual, which has a high concentration of soluble sugars in the plant sap or juice. Its advantages are easy accessibility of readily fermentable sugars and high yields of green biomass. Juice from sweet sorghum can be converted to bioethanol using fermentation. The bagasse (crushed stalks) that remains after removal of the juice can be burnt to generate electricity (or steam) as part of a co-generation scheme or utilized as a feedstock, if the technology for cellulosic bioethanol production becomes viable on a commercial scale. In Florida, sorghum is grown for grain and silage. Typically, sweet sorghum varieties have low grain yield, but new varieties with more balanced grain/sugar production have been developed. These varieties can be used as a dual-purpose crop, where the grain is harvested for human or animal consumption and the sugars are fermented to ethanol. Alternatively, these varieties can be used as a dedicated bioenergy crop, where both the sugars and the grain are used for ethanol production (Vermerris et al., 2011).

According to UF/IFAS sweet sorghum field trials at locations across Florida, plant crop green yields (without grain heads) for high-production sweet sorghum cultivars averaged 31.3 wet tons per acre. Sugar content averaged about 14.8%, but was lower for all cultivars grown on muck soils in the Everglades Agricultural Area. These data resulted in estimated sugar yields of 5,075 lbs. per acre (approximately 400 gallons of ethanol per acre) from a single crop (Vermerris et al., 2011). Other research shows that biomass yields of sweet sorghums ranges from 10 to 13 dry tons per acre and juice content ranges from 65% to 80% (Lindsey, 2005). The combined sugar content of the juice varies between 9%–20%. Sugar yields vary from 1.6 to 6.9 tons per acre and fermentation of the sugar in the juice yields between 400–600 gallons of bioethanol per acre (Vermerris et al., 2011). According to Rahmani and Hodges (2009), one acre of sorghum (Rio cultivar) can produce 364 gallons of ethanol, whereas the next best cultivar (M35-1) produced about 166 gallons of ethanol per acre. Based on this data, 1 ton of sorghum can yield 22 to 48 gallons of ethanol, so the best potential scenario for bioethanol yield for sweet sorghum in Florida is estimated around 400 gallons/acre. Clearly, different cultivars show various yields for stem and for grain per acre – higher stem yields usually equals to lower grain yield and vice versa.

In addition to the fermentable sugars contained in sweet sorghum, the bagasse (biomass remaining after the juice is extracted) could be used for conversion to cellulosic bioethanol directly. The ethanol yield is 158 L per ton of sorghum bagasse (Gnansounou et al., 2005). With bagasse being 30% of each one unit of crushed sorghum and using 11.5 ton/acre biomass yields in Florida, additional theoretical 144 gallons cellulosic ethanol per acre could be produced from sorghum bagasse. The efficiency (expressed as the ratio of the amount of ethanol produced to the maximum theoretical ethanol recovery) reaches 80% for sorghum (Gnansounou et al., 2005), so a realistic estimate is around 115 gallons of cellulosic ethanol per acre.

By combining both ethanol production paths (from juices and from bagasse), yields of over 500 gallons/acre are theoretically possible. Without a sorghum-to-ethanol conversion facility to obtain reliable data, any estimates may be somehow speculative though.

Corn (*Zea mays)* is a predominant source for the production of about 4 billion gallons of bioethanol in the United States (mostly produced in Midwest states). However, its production cost in Florida is almost twice that for the major U.S. corn-producing states, thus not economically viable. There is currently a plan by some investors to buy corn from the U.S. Midwestern states as feedstock for corn-to-ethanol production in Florida, but it will take time to find out how economically feasible this commercial endeavor would be. The major obstacle seems to be the fact that the corn has to be transported to/from Florida by trucks or rail (thus increasing production costs), since raw ethanol is corrosive to pipelines. Assuming a scenario of an average yield of 150 bushels of irrigated corn per acre in Florida and 2.7 gallons of bioethanol produced from 1 bushel of grain under established technologies, the grain yield is around 4.2 tons/acre and the bioethanol yield is around 405 gallons/acre (Rahmani and Hodges, 2009; USDA, 2006).

Although removing corn stover can lead to severe water and wind erosion and lowering soil organic matter or carbon levels, cellulosic ethanol production from corn stover is being considered as well. Assuming 4.5 dry tons of stover produced from 150 bushels/acre corn field (Nielsen, 1995) and a theoretical ethanol yield of 143 L/ton of corn stover (Gnansounou et al., 2005), 170 gallons of cellulosic ethanol could be produced per acre theoretically. However, assuming ethanol recovery of 80% and keeping in mind that the best collection method (shredding and raking) harvests only 80% of available stover (Lang, 2002), 109 gallons of cellulosic ethanol per acre is a more realistic value.

Around 8 tons/acre of biomass can be collected from a typical corn field, comprised of 4.2 tons/acre of grain and 3.6 dry tons of stover. Theoretically, combining both ethanol production paths for corn (from grain and from stover) could yield over 500 gallons/acre.

Elephangrass (*Pennisetum purpureum*), also called Napiergrass, is a perennial bunchgrass with large stiff stems at maturity. Woodard and Sollenberger (2012) show its biomass yield of 14 – 18 tons/acre, Prine and Woodard (1995) documents an average yield of around 13.7 tons/acre at four locations in Florida. While Elephangrass is the highest-yielding perennial grass for biomass production in Florida, there are no commercial facilities converting it to bioenergy. There are several issues - in northern and central Florida it creates environmental concerns due to its need for high N fertilization and thus nitrates leaching. In south Florida it is not planted at all due to its potential for invasiveness (Woodard and Sollenberger, 2012).

Elephangrass ethanol yield in Florida was estimated at 35 gallons/dry ton by Mielenz (1997). Since technological knowledge has progressed, current general cellulosic biomass conversion to bioethanol of 50 gallons/dry ton of biomass (Stricker et al., 1993; Mark et al., 2009) was used for the ethanol yield estimation. Under such a scenario, around 800 gallons of ethanol per acre appear as a realistic yield. However, this is just a theoretical estimate, given the currently existing red flag for Elephantgrass production in Florida.

Sugarcane (*Saccharum* spp.) is a perennial grass and one of Florida's major crops that can be grown throughout the State. Average sugarcane yields range from 32 to 38 tons of green biomass per acre (Rainbolt, 2010). Dry weight to fresh weight ratios are 28-29% for green leaves, 17-20% for stalks and 39-64% for brown leaves (Zhao at al, 2010). Green leaves and top represent around 10% of a mature sugarcane plant dry biomass, mature stalk around 85% and dry leaves around 5% (communication with Les Baucum, Agronomic Extension Agent UF/IFAS). Based on these values, dry biomass yield for sugarcane is estimated as 6.77 – 8.04 tons/acre.

Conversion rates for sugarcane juice to bioethanol may vary based on sugar content; varieties with higher sugar content produce more bioethanol. Sugar yields are typically 200 to 300 lbs. of sugar per ton of green biomass. The sugars extracted from sugarcane can be easily fermented to produce bioethanol, around 13 lbs. of sugar converts into 1 gallon of bioethanol. In other words, around 670 gallons of bioethanol can be produced from 1 acre using the molasses sugar (Miller, 2010). Other sources (Shapouri and Salassi, 2006) show (using 141 gallons per ton of sucrose conversion factor) that roughly 19.5 gallons of bioethanol can be produced from 1 ton of sugarcane (12.24% raw sugar recovery rate, plus 41.6 pounds of sucrose from cane molasses = 235.0 pounds of sucrose from raw sugar and 41.6 lbs. of sucrose from molasses = 19.5 gallons of bioethanol). Using these equations, bioethanol yield from fermentable sugars in Florida’s sugarcane is between 624 and 741 gallons/acre.

In addition to the fermentable sugars contained in sugarcane, the bagasse (biomass remaining after the juice is extracted from the stalks) is used by sugar mills to generate steam or electricity. There is also an ongoing effort to ferment sugarcane sucrose to bioethanol or convert sugarcane biomass to cellulosic bioethanol directly.

Generally, 280 kg of humid (45-55%) bagasse is generated from 1 ton of sugarcane. A significant quantity of post-harvest sugarcane leaves is also generated (250 kg dry weight per ton of sugarcane). Despite major research efforts to promote sugarcane bagasse as a bioenergy material, commercial use on an industrial scale has yet to be explored. Theoretically, a single ton of sugarcane bagasse could yield up to 300 L of ethanol. With 28% bagasse/sugarcane ratio and estimated 7.4 tons/ac sugarcane yield, 164 gallons of cellulosic ethanol per acre of sugarcane could be theoretically produced (Chandel et al. 2012). However, there are several parameters that directly affect ethanol yield, such as the quality of bagasse, the process employed for ethanol production and ethanol recovery rate. Realistic estimate is therefore somewhat lower, probably around 130 gallons of cellulosic ethanol per acre. It is also important to mention that if bagasse were used on a large scale for ethanol production, other sources would have to be found to generate heat and electricity (Pancholy et al., 2011).

Theoretically, if both the sugarcane juices and bagasse were processed for ethanol production, 723 to 905 gallons of ethanol/acre could be produced. It has been predicted that 12,000 to 15,000 liters of ethanol per hectare (= 1,285 – 1,306 gal/acre) could be produced in the future (Chandel et al., 2012). This amount could be even higher if sugarcane leaves were employed in the process as well. Clearly, “mixed” approach of sugarcane juices & molasses and cellulose bioethanol production could potentially generate a much higher yield in bioethanol compared to the present production just from the juices. Either way will be processed forward, it is important to mention that in addition to current technological constrains, large volumes of water are needed for cane washing, creating thus high biochemical-oxygen-demand (BOD) wastewater for disposal. This water can’t be released without thorough treatment to the sensitive environment especially in south Florida.

Energycane is from the same genus like sugarcane, *Saccharum*, a hybrid cross between sugarcane (*Saccharum officinarum*) that produces thick stems and a related grass species (*Saccharum spontaneum*) that is adapted to a drier and cooler climate. The major difference between the two is that Energycane is bred for high fiber content, while Sugarcane is bred for low fiber content but high sugar content. Energycane cultivars grown in central Florida demonstrated average yields of 20 to 25 tons/acre of dry biomass (80 to 100 tons fresh weight/acre) (Rainbolt, 2010). Using the current estimate of biomass cellulosic conversion to bioethanol of 50-60 gallons/dry ton of biomass (Stricker et al., 1993; Mark et al., 2009), ethanol yield of over 1100 gallons/acre appears possible. As cellulosic bioethanol plants and technology approach commercialization, the efficiency rate could be even higher (90 gallons/dry ton of biomass) (Schnepf, 2010). Some scientists are excited about the Energycane prospects in Florida. Others don't anticipate any Energycane being grown in the traditional sugarcane growing areas of Florida though, as Sugarcane seems better suited to the region's soil types and subtropical climate (USDA, 2012).

Florida's long growing season and abundant moisture results in highly productive short rotation woody crops. Potential oven-dry annual biomass yields of promising species are: 8.9 ton/acre for cottonwood (*Populus deltoides*), 10.3 ton/acre for closely-spaced slash pine (*Pinus elliottii*), 14.0 ton/acre for leucaena (*Leucaena leucocephala*), 11.2 ton/acre for intensively managed *Eucalyptus amplifolia* in north Florida, and 16.1 ton/acre for *Eucalyptus grandis* in central and south Florida (Stricker et al., 2000). Some of these are considered as a viable source of renewable woody biomass, since e.g. Eucalyptus species including *Eucalyptus grandis* have been grown in Florida with success for several decades with no signs of invasiveness. Its energy-wood may be utilized for example by co-firing with coal for electricity generation by many utilities in Florida. Conversions to bioethanol are still being tested, but with estimates of biomass yields in Florida around 10-15 dry tons per acre and with bioethanol yields of around 85 gallons/ton, they promise very high potential bioethanol yields (Hinchee et al., 2011; Gonzalez et al., 2011; Duke, 1983; Enguidanos et al., 2002). Also, new lignin breakout technologies are being developed and thus the bioethanol potential yields can be much higher (in the future estimated as high as 2250 gallons of bioethanol/acre) (Arborgen Inc., 2010).

As of 2007, forests covered 16.9 million acres in Florida. 94% of that area is considered available for timber production and classified as timberland, the remainder is largely reserved (e.g. parks and preserves) or unproductive. Almost half of Florida is made up of timberland (of which approximately 10.1 million acres are held by private forest landowners) (Florida Department of Agriculture and Consumer Services, 2010). Trees will play a significant role in helping to meet renewable energy standards, but it has to be recognized that multiple, integrated approaches with a variety of different crops and production systems will be required to meet the total renewable energy objectives.

Table 1 summarizes dry biomass production yields of selected bioethanol crops. It shows that the highest yield of dry biomass under typical conditions is obtained from Energycane (22.5 tons/acre), followed by Elephantgrass (16 tons/acre), Eucalyptus (13.7 tons/acre), Sweet Sorghum (11.5 tons/acre), Sugarcane (7.4 tons/acre), Miscanthus (6 tons/acre), Corn (4.2 tons/acre - *first generation only)* and Switchgrass (3.6 tons/acre). Best results are achieved with Energycane (25 tons/acre) under the high yield scenario.

Table 1. Dry biomass production yields of bioethanol crops in Florida (ton/ac and US ton/ha)

	Low		**Medium**		**High**	
	ton/ac	ton/ha	ton/ac	ton/ha	ton/ac	ton/ha
Miscanthus G2	4.00	9.88	6.00	14.82	8.00	19.76
Switchgrass G2	1.80	4.45	3.62	8.94	5.44	13.44
Sorghum G1+G2	10.00	24.70	11.50	28.41	13.00	32.11
Corn G1+G2	6.76*	16.70	7.80*	19.27	8.84*	21.83
Elephantgrass G2	14.00	34.58	16.00	39.52	18.00	44.46
Sugarcane G1+G2	6.77	16.72	7.40	18.28	8.04	19.86
Energycane G2	20.00	49.40	22.50	55.58	25.00	61.75
Eucalyptus G2	11.20	27.66	13.65	33.72	16.10	39.77

** grain only (G1) is 3.6, 4.2 and 4.8 tons*

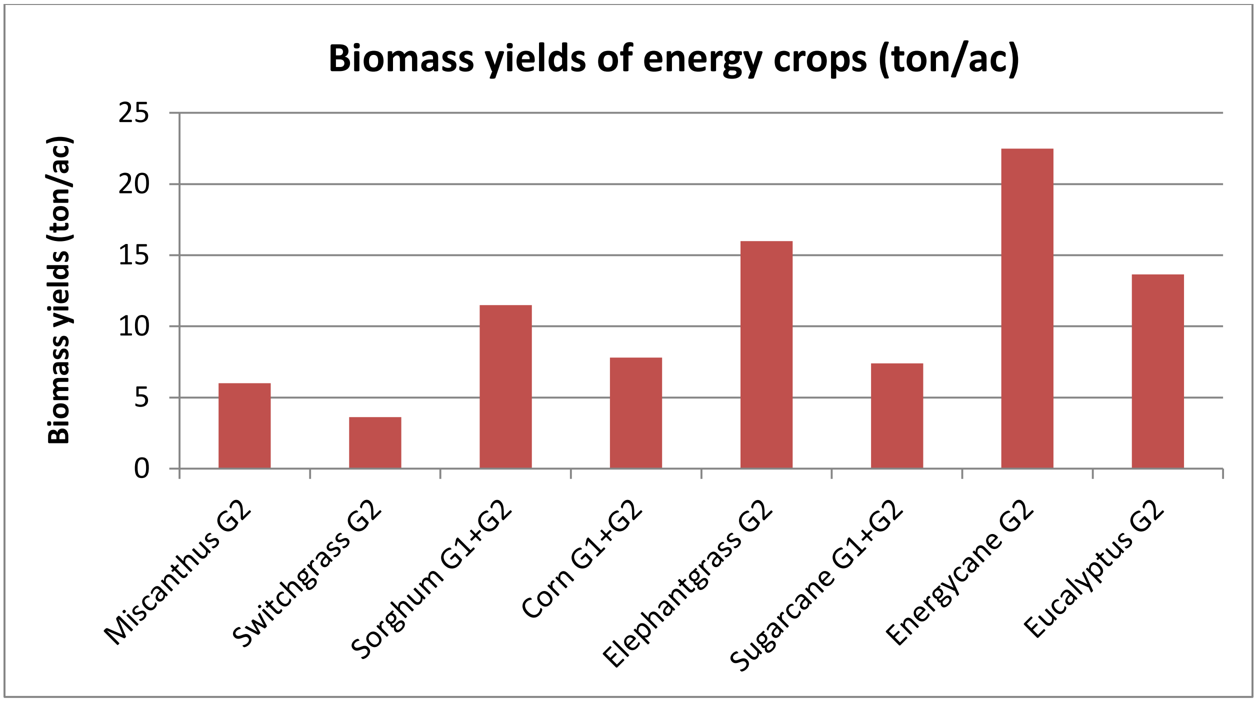


Figure 1. Dry biomass production yields of bioethanol crops in Florida (ton/ac)

Table 2 shows typical ethanol yields obtained from 1 ton of dry biomass for various crops in Florida. Yields from both first and second generation ethanol production paths are included for those crops, where such conversions are possible (Sweet Sorghum, Corn, and Sugarcane). It shows that the highest ethanol yield from 1 ton of dry biomass under typical conditions is obtained from grain of first generation Corn (96 gal/ton), closely followed by sugars of first generation Sugarcane (92 gal/ton). In decreasing order, following highest ethanol yields from 1 ton of dry biomass are second generation Eucalyptus (85 gal/ton), second generation Switchgrass (80 gal/ton) and second generation Sugarcane (64 gal/ton). Second generation Miscanthus, second generation Elephantgrass and second generation Energycane produce roughly 50 gal/ton of dry biomass. Both first and second generation Sorghum and second generation Corn produce around 30 gal/ton of dry biomass.

Table 2. Ethanol yields from 1 ton of dry biomass for various crops in Florida (L/ton and gal/ton)

	Low		Medium		High	
	L/ton	gal/ton	L/ton	gal/ton	L/ton	gal/ton
Miscanthus G2	151	40	189	50	227	60
Switchgrass G2	265	70	302	80	340	90
Sorghum G1	83	22	132	35	181	48
Sorghum G2	95	25	126	33	158	42
Corn G1	328	87	364	96	401	106
Corn G2	91	24	115	30	137	36
Elephantgrass G2	151	40	189	50	227	60
Sugarcane G1	311	82	346	92	381	101
Sugarcane G2	216	57	240	64	264	70
Energycane G2	151	40	189	50	227	60
Eucalyptus G2	284	75	321	85	359	95

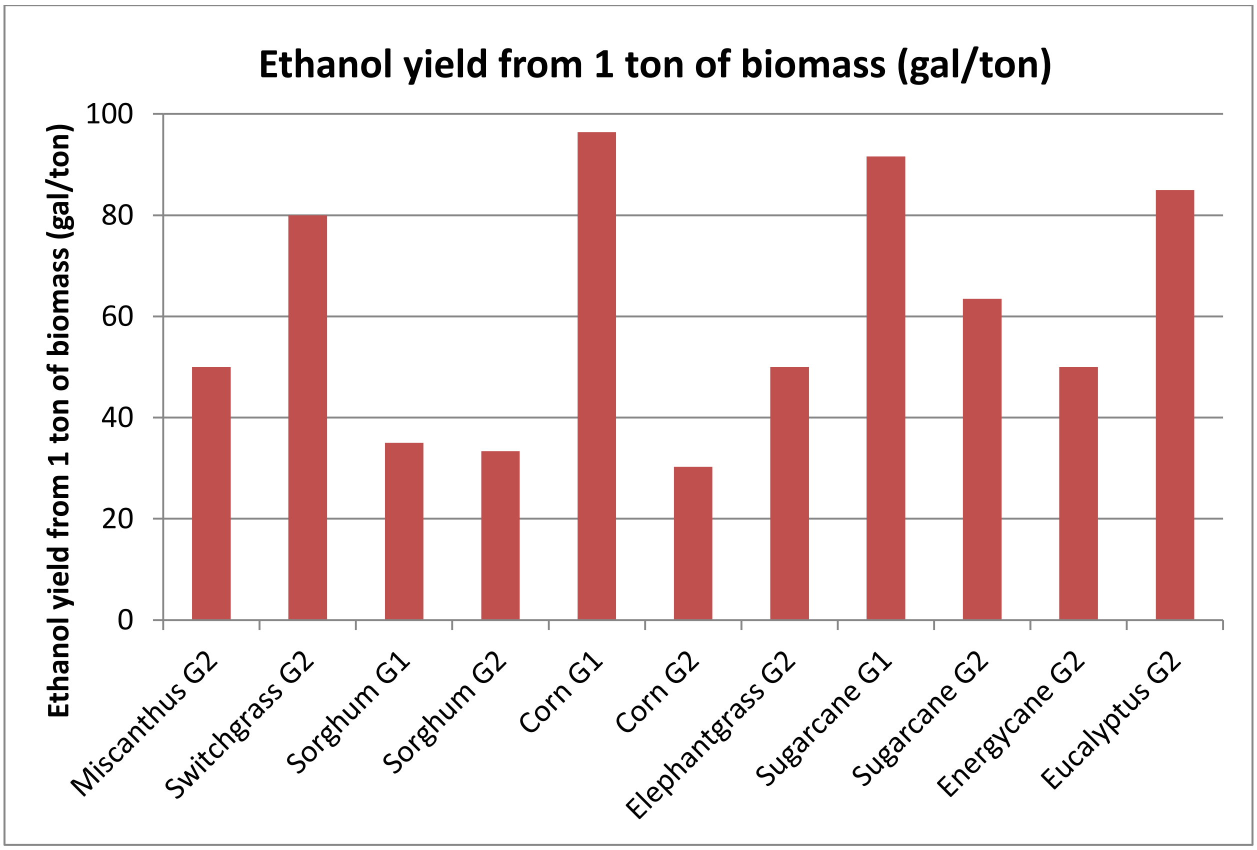


Figure 2. Ethanol yield from 1 ton of energy crops biomass in Florida (gal/ton)

Tables 3 and 4 summarize bioethanol production yield from biomass of selected bioethanol crops. Where possible, a "combined" approach of first and second generation production was used (Sweet Sorghum, Corn and Sugarcane); all other yields are reported as only a second generation path. The results show that the highest yield of bioethanol is obtained from Eucalyptus (1160 gallons/acre) and Energycane (1125 gallons/acre), followed by Sugarcane (809 gallons/acre) and Elephantgrass (800 gallons/acre). Results slightly above 500 gallons/acre are shown by Sweet Sorghum (518 gallons/acre) and Corn (514 gallons/acre). The lowest yield is shown by Miscanthus (300 gallons/acre) and Switchgrass (290 gallons/acre). Best results (high yield scenario) might be achieved with Eucalyptus and Energycane, both around 1500 gallons/acre.

Table 3. Bioethanol energy crops production yields in Florida (L/ha and gal/ac)

	Low		**Medium**		**High**	
	L/ha	**gal/ac**	**L/ha**	**gal/ac**	**L/ha**	**gal/ac**
Miscanthus G2	1496	160	2805	300	4488	480
Switchgrass G2	1178	126	2708	290	4578	490
Sorghum G1	2057	220	3763	403	5834	624
Sorghum G2	704	75	1077	115	1524	163
Corn G1	2954	316	3786	405	4718	505
Corn G2	706	76	1020	109	1385	148
Elephantgrass G2	5236	560	7480	800	10098	1080
Sugarcane G1	5216	558	6338	678	7578	810
Sugarcane G2	1013	108	1230	132	1470	157
Energycane G2	7480	800	10519	1125	14025	1500
Eucalyptus G2	7854	840	10848	1160	14301	1530

Table 4. Bioethanol energy crops production yields in Florida (L/ha and gal/ac)

	Low		Medium		High	
	L/ha	gal/ac	L/ha	gal/ac	L/ha	gal/ac
Miscanthus G2	1496	160	2805	300	4488	480
Switchgrass G2	1178	126	2708	290	4578	490
Sorghum G1+G2	2761	295	4841	518	7359	787
Corn G1+G2	3660	391	4806	514	6102	653
Elephantgrass G2	5236	560	7480	800	10098	1080
Sugarcane G1+G2	6229	666	7568	809	9048	968
Energycane G2	7480	800	10519	1125	14025	1500
Eucalyptus G2	7854	840	10848	1160	14301	1530

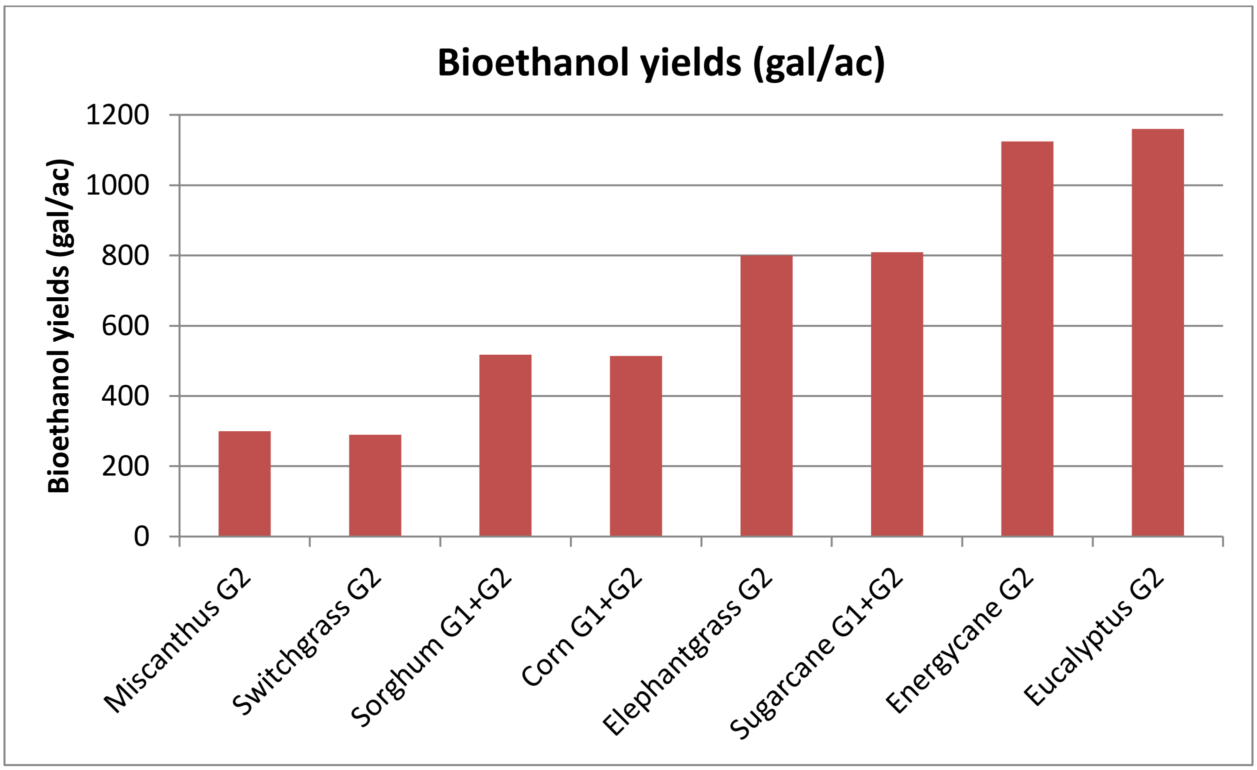


Figure 3. Bioethanol energy crops production yields in Florida (gal/ac)

5.4 Bioethanol production and conversion technologies

Bioethanol (ethyl alcohol, C2H5OH) is a colorless liquid that can be (among other technological means) produced from biomass and serve as a replacement for gasoline and as an oxidant additive that reduces pre-ignition, improves combustion efficiency, and lowers the emissions of carbon monoxide, nitrogen oxide and sulphur oxide pollutants. It is currently the most important biofuel in the USA, mostly used for transportation motor fuels, where blended with traditional fossil gas at rates of 10 - 85%. Bioethanol is divided into 3 (first, second and third) generations just like the general secondary biofuels.

First generation bioethanol is produced by simple fermentation of sugars extracted from starch-laden (e.g. corn) or sugar-laden (e.g. sugarcane) crops. Starch-based biomass produces anhydrous bioethanol (100% ethanol, 0% water), while sugar-based biomass produces hydrated bioethanol (95% ethanol, 5% water). Anhydrous bioethanol production from starch-based biomass includes 4 basic steps: (1) chemical or enzymatic hydrolysis, (2) fermentation, (3) distillation and (4) dehydration. Hydrated bioethanol production from sugar-based biomass needs no initial hydrolysis and the process thus involves only 3 steps: (1) fermentation, (2) distillation and (3) dehydration. The resulting bioethanol is identical in chemical structure and fuel properties. During starch hydrolysis, long chains of glucose are broken down into simpler glucose units. While fermented, glucose is being decomposed into bioethanol and carbon dioxide by microbes. For the bioethanol to be usable as a fuel, most of the water must be removed, which is done during distillation. Dehydration process removes the remainder of water.

Second generation bioethanol (often called *cellulosic bioethanol*) is produced by the thermal or biochemical processing of lignocellulose. The fuel properties of second-generation bioethanol are identical to those of the first-generation equivalents, but the processing steps are somehow different, more complicated and costlier. The basic procedure includes 5 steps: (1) pre-treatment, (2) enzymatic hydrolysis, (3) fermentation, (4) distillation and (5) dehydration (U.S.DOE, 2007). Cellulosic biomass delivered to a biorefinery is grounded into small, uniform particles. Thermal or chemical pre-treatment separates cellulose and hemicellulose, extremely tough polymers of tightly bound sugar chains, from other biomass materials (mostly lignin) and opens up the cellulosic surface to enzymatic attack. A mix of enzymes is added to break down cellulose into simple sugars. Lignin cannot be converted to bioethanol, but it can provide the necessary energy for the conversion process in the production facility (Energy Future Coalition, 2007). From then on, the procedure is similar to the first generation of bioethanol - microbes produce bioethanol by fermenting simplified sugars and the bioethanol is separated and purified from water and other components of the fermentation broth through distillation and dehydration. A key step in cellulosic conversion is finding effective ways to pretreat different feedstocks and break down the cell walls, where most of the sugar is stored. There is a long list of pretreatment options that use a range of chemical and physical processes, and each one has its drawbacks and benefits (Perry, 2010). One of the major difficulties is that most of the sugars derived from cellulose are 5-carbon pentoses, while conventionally used fermentation yeasts (Saccharomyces species) are better suited for 6-carbon hexoses. The core issue in enhancing and boosting the cellulosic bioethanol industry will be finding effective ways of unlocking complex cellulosic polymers (created to resist biological and chemical degradation) into simplified sugars that can be easily fermented (Houghton et al., 2006; U.S. DOE., 2010). There are already several demonstration bioethanol refineries around Florida experimenting with bioethanol production (e.g. in Clewiston, Lake Placid, Mossy Head and Venus), and others are being opened. Their major goals include testing a wide variety of feedstocks, because each biomass crop has a unique combination of constituents (glucan, starch, xylan, mannan, galactan, arabinan, lignin and other), differing from other feedstocks and even within feedstock varieties (Ashworth, 2008).

Simplified production paths of first and second generation bioethanol are shown in Figure 4 – a graphic developed by Leyens et al. (2010) and then also presented, but not cited, by Nahar et al. (2011).

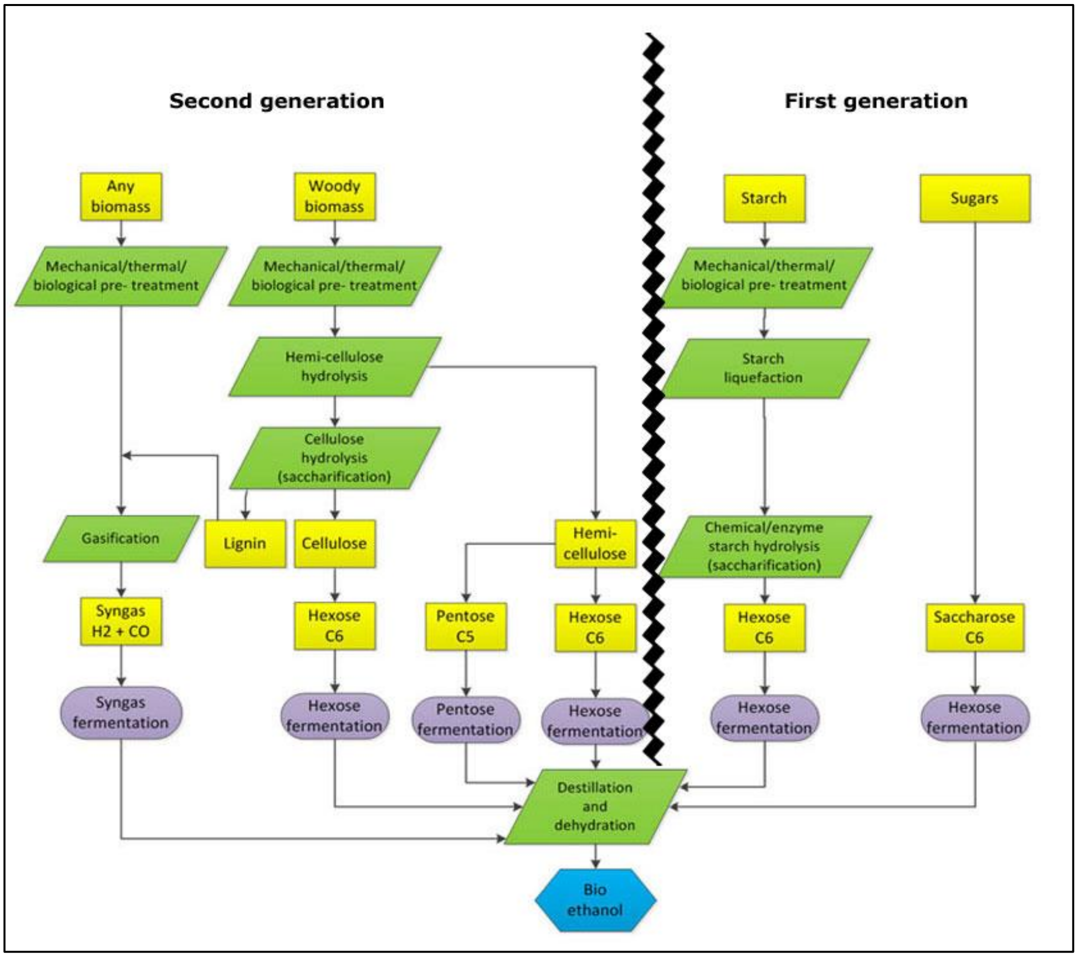


Figure 4. First and second generation bioethanol production paths

Third generation bioethanol is produced by the processing of algae's starch (the storage component) and cellulose (the cell wall component). Lipids in algae oil can be made into biodiesel, while the carbohydrates can be converted to bioethanol. Algae are considered by some (e.g. Singh et al., 2011) as the optimal source for third generation bioethanol, because they are high in carbohydrates/polysaccharides and have thin cellulose walls. Still, there remain various technological and environmental issues to address. Actual third generation bioethanol production includes 5 basic steps: (1) initiating decay of the algae biomass, (2) contacting the decaying biomass with yeast capable of fermenting it, (3) separating the resulting bioethanol from the fermentation solution, (4) distillation and (5) dehydration. Initiating decay means that the biomass is treated in such a way that the cellular structure of the biomass begins to decay (e.g., cell wall rupture) and release the carbohydrates (Oilgae, 2010).

6. Advantages and challenges of biofuels

While biofuels provide many advantages and benefits, there are also related challenges that need to be carefully considered. Main benefits include increased energy and economic security, the generation of new jobs, stimulating rural development and various environmental gains (utilization of waste, reduced pollution and GHG emissions, etc.). Main challenges include food-fuel competition, technological constraints, increased production costs, artificial subsidies and land use changes. The list of issues is much longer, related impacts can be divided into four main categories: (1) social, (2) economic, (3) environmental and (4) technical (Wikipedia, 2011). The issues are being discussed on the example of Florida. Since this paper focuses on land use changes and their implications, these topics are being highlighted.

Social advantages and challenges of biofuels include issues relating mostly to employment, communities, migration, smallholder integration and food security. While planting biofuels in Florida can generate new employment opportunities, it can trigger already existing high worker migration. Biofuels can create and develop new rural communities in Florida, but they can also dislocate existing local communities elsewhere (as a consequence of direct land use changes). While such an approach might improve the well-being of Floridians, it can potentially increase poverty in developing countries by direct food-fuel conflict.

Economic challenges consist for example from energy security, fuel and food costs stability, new and lost employment opportunities and open market vs. subsidies issues. Biofuels can be produced domestically in Florida, thus reduce import of energy sources from unstable regions. They can also be locally distributed, so in Florida's case, a state so far fully dependent on oil/ethanol import, this is a tremendous opportunity to become self-sufficient. Such approach can potentially increase fuel cost stability and generate new employment opportunities. On the other hand, dependency on agriculturally produced biofuels might bring its negative effects due to climate changes (e.g. unusual droughts and low production seasons).

Environmental issues, such as GHG emissions and air quality, soil quality, water use and quality or biodiversity reduction need to be considered closely as well (Wikipedia, 2012). Changes in agricultural production will bring changes in agricultural practices and influence e.g. soil quality, erosion, subsidence fertilizer use and water quality and usage (Simpson, 2007). Natural land use change to crop production results in large releases of carbon stored in vegetation and soils ("carbon debt"), which affects the carbon offset benefits of biofuels substitution for fossil fuels. There is a serious threat for loss of biodiversity in Florida in cases where large mono-cultural crop fields will be created. Changes in land use over the next decade can adversely affect climate change, while climate change itself will alter the form and function of the landscape. Florida climate change mitigation might be thus only relative, as large deforestation for the sake of creating new arable land might happen somewhere else.

Technical issues relate to energy efficiency and energy balance, carbon emissions, development of next-generation high-yield bioenergy crops or the discovery and designs of enzymes and microbes with novel biomass-degrading capabilities. Technological breakthroughs are needed in order to make the cellulosic bioethanol production economically viable. There are facilities in Florida where such research is being conducted. Development of new generation high-yield crops by genetic modifications and bringing in invasive/semi-invasive plants are potential dangers to the whole system though.

Probably the major advantage of biofuels is the fact that there is a potential to produce them in a *sustainable* way (IEA, 2010). Rules for sustainable biofuels production are being defined (IEA Renewable Energy Division, 2011; EPFL, 2008) and efforts for implementing those evaluated (Bloomberg New Energy Finance, 2012). Florida needs to be aiming for the desired targets in a sustainable way, otherwise the challenges' impacts might be just too overwhelming for the system's complexity. It is important to emphasize that the different impact ranges closely overlap and that they cannot be considered separately (Sanderson, 2006). They absolutely need be evaluated in a complex manner, not as isolated independent units. While comparing the impacts, all the issues need to be weighted properly, as e.g. an improvement on issue X can be less important than deterioration of situation on issue Y. This paper focuses mostly on land use changes and theirs implications, but considers them complexly, in relation to other parts of the whole system.

7. Land use changes

7.1 Background

Although humans have continually shaped the landscape for centuries, it has only been within the past few decades that land use and land cover change has been widely recognized as a key driving force of global environmental changes (Turner, 2001). These changes are so omnipresent that, when aggregated globally, they significantly affect key aspects of Earth System functioning (Lambin et al., 2001).

Land Use Change (LUC) is a general term covering two distinct (direct, indirect) means by which land can be altered in the pursuit (in this specific case) of biofuels production.

Direct LUC (dLUC) occurs when land previously used for other purposes is converted to biofuel crops production. It involves changes in land use on sites used for food or fiber production (including also changes in crop rotation patterns, conversion of pasture land and changes in forest management) or conversion of natural ecosystems for bioenergy crops land.

Indirect LUC (iLUC) refers to the changes in land use that take place elsewhere as a consequence of a bioenergy project. For example, displaced food producers may re-establish their operations elsewhere by converting natural ecosystems to agriculture land, or due to macroeconomic factors, the agriculture area may expand to compensate for the losses in food/fiber production caused by a bioenergy project. iLUC is thus defined as the equivalent changes that occur when grassland and forest are converted to cropland or rangeland to meet the demand for commodities displaced by the production of biofuel feedstocks (Berndes, 2002).

In most cases, the effects of iLUC far outweigh those of dLUC and have great un-sustainability effects (Lapola et al., 2010). Unfortunately, there is a lack of standards and policies across the industry, leading to estimations that are difficult to compare. Many older studies either completely ignored the implications of LUC or mentioned it only briefly to explain the difficulty faced in quantifying the effects. Newer analytical studies are beginning to assess the expected changes in land use from increased biofuel demand, but little empirical evidence is yet available on which to base predictions on what, when and how will be directly or indirectly affected (FAO, 2008). LUC as a topic cannot be overlooked, as its importance over time increases. Addressing the ignored gaps is one of the main focuses of this study.

7.2 Land use availability

According to the Food and Agriculture Organization of the United Nations, land area is divided into (1) agricultural area, (2) forest & other wooded land, (3) land with aquaculture facilities and (4) other land (Gong et al., 2009). Agricultural area can be further divided into (1a) arable land & permanent crops and (1b) permanent meadows & pastures. With the world having currently 4.89 billion hectares of agricultural land for its 7.052 billion inhabitants, there is on average 0.69 hectares (1.71 acres) of agricultural land available per person – out of which 0.21 ha is arable land & permanent crops and 0.48 ha are permanent meadows & pastures (FAO, 2011; Gong et al., 2009).

Agricultural crop area expands worldwide (e.g. 31 000 km2 per year during 1995-2002), but is obviously limited. Net change of global available agricultural crops land in 2000 has been only 0.2% (with 0.7% gain and 0.5% loss). It has to be considered that 20% of the agricultural crop land loss was for urbanization and 25% due to degradation (salinization, erosion, etc.) (Holmgren, 2006).

7.3 Land use changes and biofuels production

Concerns are being raised regarding several factors related to potential and actual biofuels production, e.g. diversion of land away from use for food, decreased preservation of biodiversity, increased usage of fertilizers, diverting water and other resources, etc. (FAO, 2008). In 2004, about 13.8 million hectares of land was used worldwide to produce biofuels (about 1% of global available arable land).

As a part of its future outlook, International Energy Agency (EIA) modeled (among other predictions) several scenarios related to biofuels. If current government policies and reasonable technical development trends remain unchanged (*Reference Scenario*) and on the assumption that biofuels are derived solely from conventional crops, biofuels production lands estimate in 2030 will be 34.5 million hectares (2.5% of total arable land) (FAO, 2008). Under the *Alternative Policy Scenario* (where countries adopt all of the policies they are currently considering related to energy security and CO2 emissions and still solely use conventional crops), the share of total arable land used for biofuels grows to 3.8% by 2030 (OECD/EIA, 2006). However, if second-generation technologies based on ligno-cellulosic biomass were widely commercialized before 2030, arable land requirements could be much less per unit of biofuels output. In this *Second-Generation Biofuels Case,* land requirements are only 0.4% higher than in the Alternative Policy Scenario, while pushing the share of biofuels in transport demand globally to 10% in 2030 compared with 5% in the Alternative Policy Scenario and 3% in the Reference Scenario. This shift is caused by the fact that a significant share of the additional biomass needed could come from regenerated and marginal land not currently used for crops or pasture, as well as from agricultural and forest residues and waste. In addition, the conversion efficiency of second-generation technologies is expected to be considerably higher (OECD/EIA, 2006).

Rising food demand, which will compete with biofuels for arable and pasture land, will constrain the potential for biofuels output. However, this effect may be partially offset by higher agricultural yields, applying best management practices, better urban planning, better feedstock choices, increased usage of marginal and non-arable land and similar sustainable approaches. Such strategies can be socially, environmentally and economically viable, and can create jobs and opportunities for enhancing the well-being of generations to come.

There is a wide variation in the total amount of biomass (and potentially bioethanol) that can be produced on a unit area of land, depending on species chosen, soil fertility, climate condition, agronomic treatments, etc. For example, high bioethanol yields per hectare of a first-generation biofuel feedstock (e.g. Sugarcane with 550-810 gallons/acre in Florida) hardly rivals with only moderate productivities that have been achieved with growing second-generation biofuel feedstock so far (e.g. Energycane with 800-1500 gallons/acre) in the same geographical area. It is important to consider that only a fraction of the first generation sugarcane biomass is used for liquid fuel production in a first-generation biofuel facility, while nearly all of the above-ground Energycane plant would be used for production of a second-generation biofuel. However, complex economic feasibility of the biofuels production needs to be measured and quantified as well (Langholtz et al., 2006).

Relationship between the biofuels generations and land use efficiency should be considered thoroughly.

First generation biofuels conflict with food supply, having a limited positive effect relative to land use efficiency, as arable land is needed for planting these crops. As a net outcome, first generation biofuels *decrease* land use efficiency, often in an indirect way. An example of an iLUC would be converting forests to cropland in order to meet the demands for edible commodities displaced by the production of biofuel feedstocks.

Second generation biofuels use non-edible plants, so have a potential to *increase* land-use efficiency, as marginal and non-arable land can be used for planting these crops. Dedicated high-yielding lignocellulosic energy crops show promising results in decreasing the land use negative effects. However, there also exists a potential for land competition - not necessarily for land used for food production, but for land used e.g. for ecosystem or other services. Restoration of degraded lands via second generation biomass-energy crops production may be of an interest and an important way forward (Larson, 2008).

Third generation biofuels (derived from microbes and algae) have a great potential to *overcome* major drawbacks of the first and second generation biofuels. It is estimated that replacing all of U.S. oil consumption with algae fuel would probably require 15,000 square miles of production. By comparison, 35,000 square miles of corn production is currently used to meet just 10% of U.S. fuel needs in the form of bioethanol (Shrank, 2010). However, since this is still a very new research area, various potential consequences need be carefully evaluated.

8. Land use changes – Florida case study

8.1 Land use changes in Florida

Until the end of the 19th century, much of the land cover in Florida remained in a natural state. Only at the beginning of the 20th century, the region opened to extensive residential and commercial development, which dramatically affected local land use (Snyder and Davidson, 1994). Population pressure, rapid urban growth and the need for land to support agricultural activities resulted in significant changes in Florida's land use. Between 1936 and 1995, Florida's population grew more than 8-fold, from 1.7 million to 14.1 million residents. During the same period, Florida's areas occupied by forest land and marsh land decreased 22% and 51%, respectively. The area of cropland, pasture and range lands increased a combined 59% and the area of urban lands increased approximately 628% (Florida Department of Community Affairs, 1997). Florida's population and development growth since then even accelerated (5 million additional people in Florida during last 16 years, so 35% population growth).

Much of the urban development in Florida has been in the form of land-intensive, low-rise, single-family dwellings. Demand for urban land originates primarily from retirees, other in-migrants, and tourists. Residential developments with detached homes and landscaped lots near land-extensive recreational amenities (such as golf courses) increased dramatically during the past decades. Sharp growth in the consumer base increased demand for locally grown produce and thereby encouraged further agricultural development.

Classification system of land use in Florida currently contains 9 main categories – (1) urban & built-up, (2) agriculture, (3) rangeland, (4) upland forest, (5) water, (6) wetlands, (7) barren land, (8) transportation, communication & utilities and (9) special classification (Florida Department of Transportation, 1999). Data acquisition is challenging and determining specific land types from satellite imagery brings technical/mapping difficulties. Despite these obstacles, various agencies keep regularly updated databases. Figures 5 is a large scale map of land use/land cover of Pithlachascotee River watershed in northern Pasco County as published by

Southwest Florida Water Management District (SWFWMD Mapping and GIS Section, 2002). Figure 6 presents Hendry County in a medium scale map according to the National Gap Analysis Program (GAP) of US Geological Survey (USGS, 2012). Figure 7 shows a small scale map of Florida's land use according to National Land Cover Database 2006 (NLCD) of US Geological Survey (Multi-Resolution Land Characteristics Consortium, 2006).

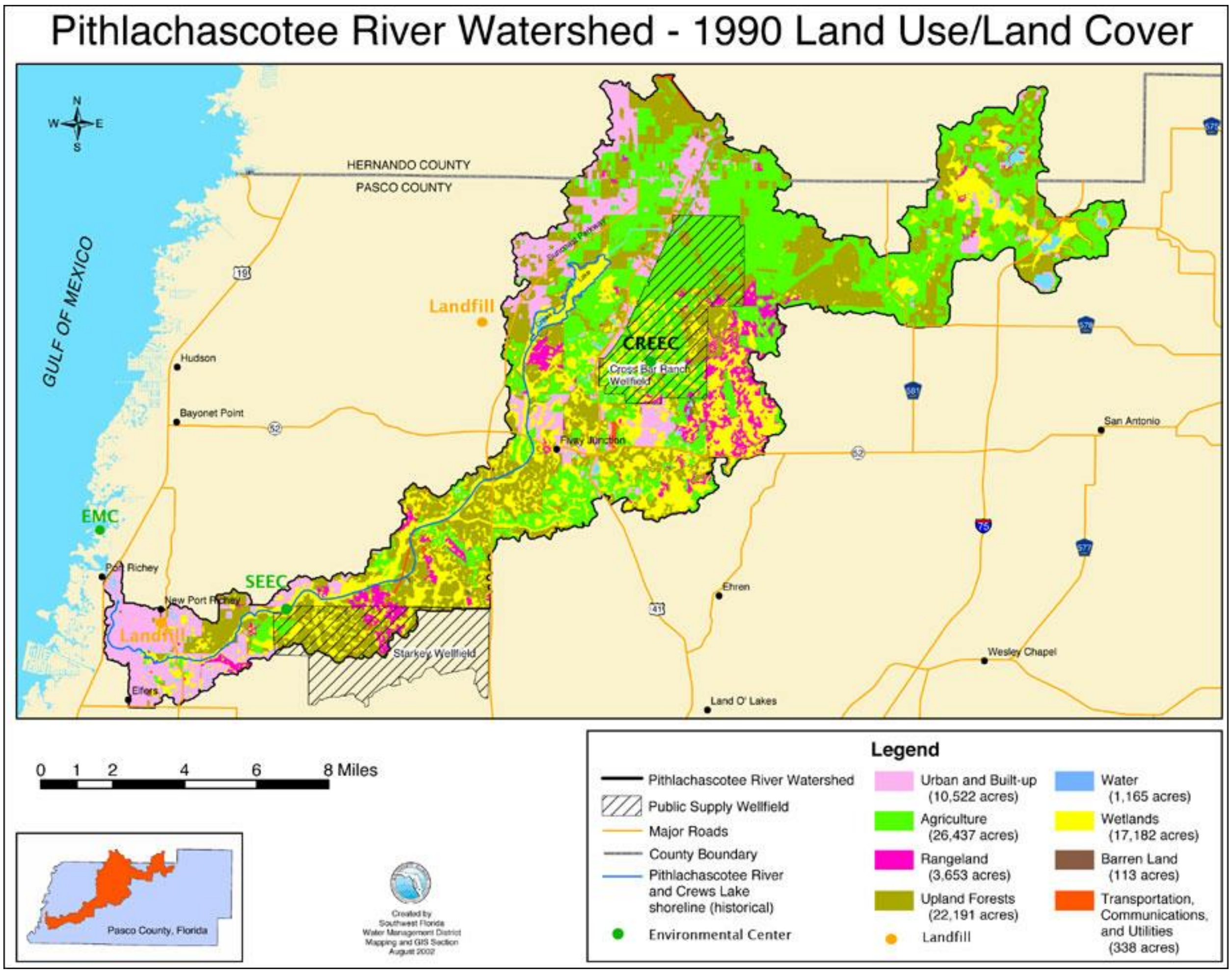


Figure 5. Land use/land cover in large scale (Pithlachascotee River watershed in northern Pasco County) according to Southwest Florida Water Management District

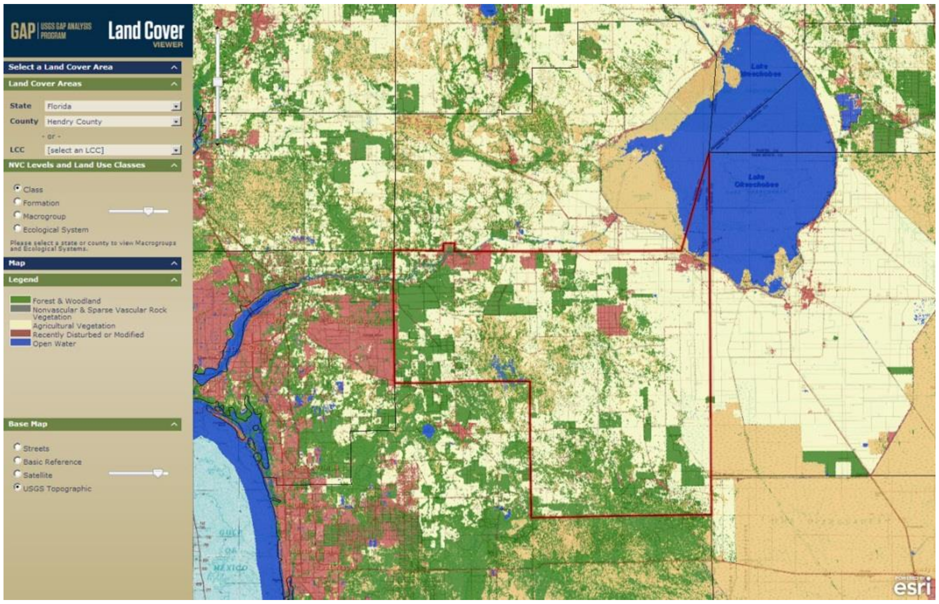


Figure 6. Land use/land cover in a medium scale map (Hendry County) according to the National Gap Analysis Program (GAP) of US Geological Survey

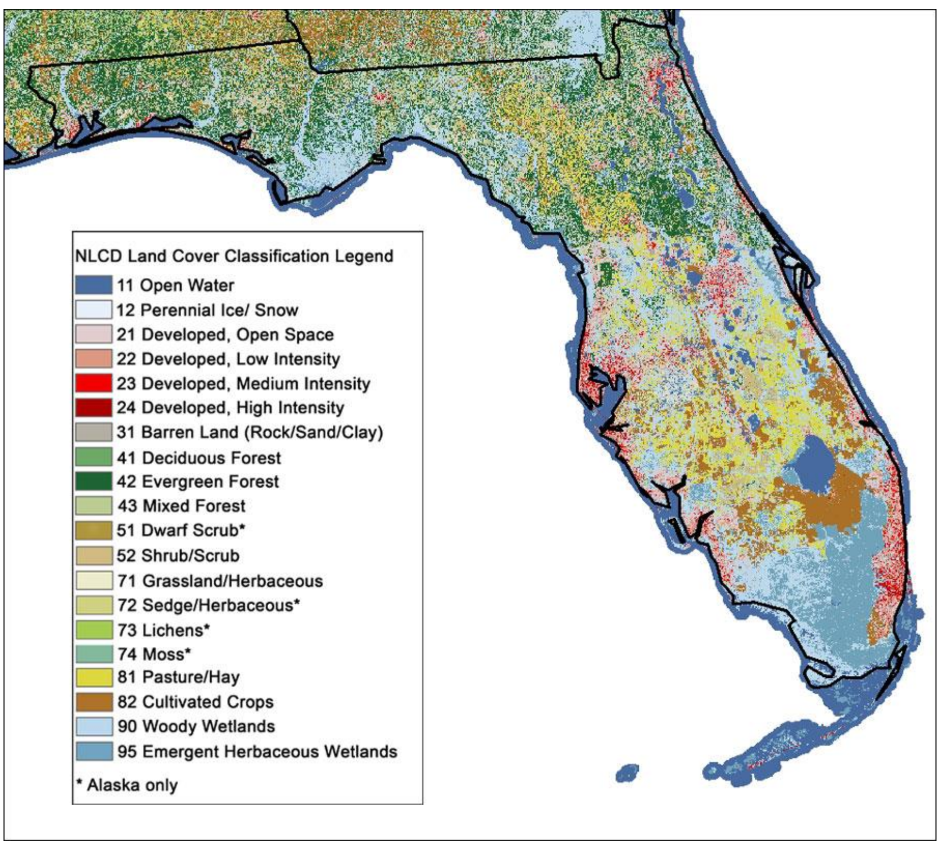


Figure 7. Land use/land cover in Florida according to National Land Cover Database 2006 of US Geological Survey

A relatively recent study by Kautz (2007) compares land use changes in Florida between 1985-89 and 2003. Of 9.86 million ha of natural and semi-natural land cover types present in Florida in 1985–89, 1.32 million ha (13.3%) were converted to urban, developed, or agricultural land uses by 2003. Conversions to urban and developed lands accounted for 0.61 million ha and conversions to agricultural uses accounted for 0.70 million ha. These results clearly indicate the shift away from natural land to land compatible with urban development and agriculture.

Loss of biological diversity is another consequence of land use changes. Exotic species, pollution, overharvest and diseases are important factors, but the major threat is by far the destruction of natural habitat. 13 vertebrates and 14 vascular plants have been driven to extinction or have been extirpated from Florida, many other species are in danger of extinction or have declining populations, and several natural community types have nearly disappeared (Kautz, 1998). For Floridians who wish to ensure the long-term existence of the remaining components of the state's biological diversity, the next several years will be critical.

Florida has approximately 44,500 farms and ranches (USDA, 2008) operating 10.38 million acres of agricultural lands and woodlands (USDA, 2008). Typical are large farms with repetitive production, which is often driven only by profit. In making land use changes, there is a need to include in the decisions other services, since changes in land use over the next decades can have adverse effects.

Land use changes strongly influence regional climate, as changes in vegetation cover significantly affect local variation in temperature and precipitation (Colorado State University, 2009; Marshall et al., 2004) - see Figure 8 (McMahon, 2005; Lindsey, 2005). Over relatively short timescales this effect can be greater than the atmospheric forcing from greenhouse gases (Mulkey, 2007). Land use change and climate change in Florida are thus linked issues.

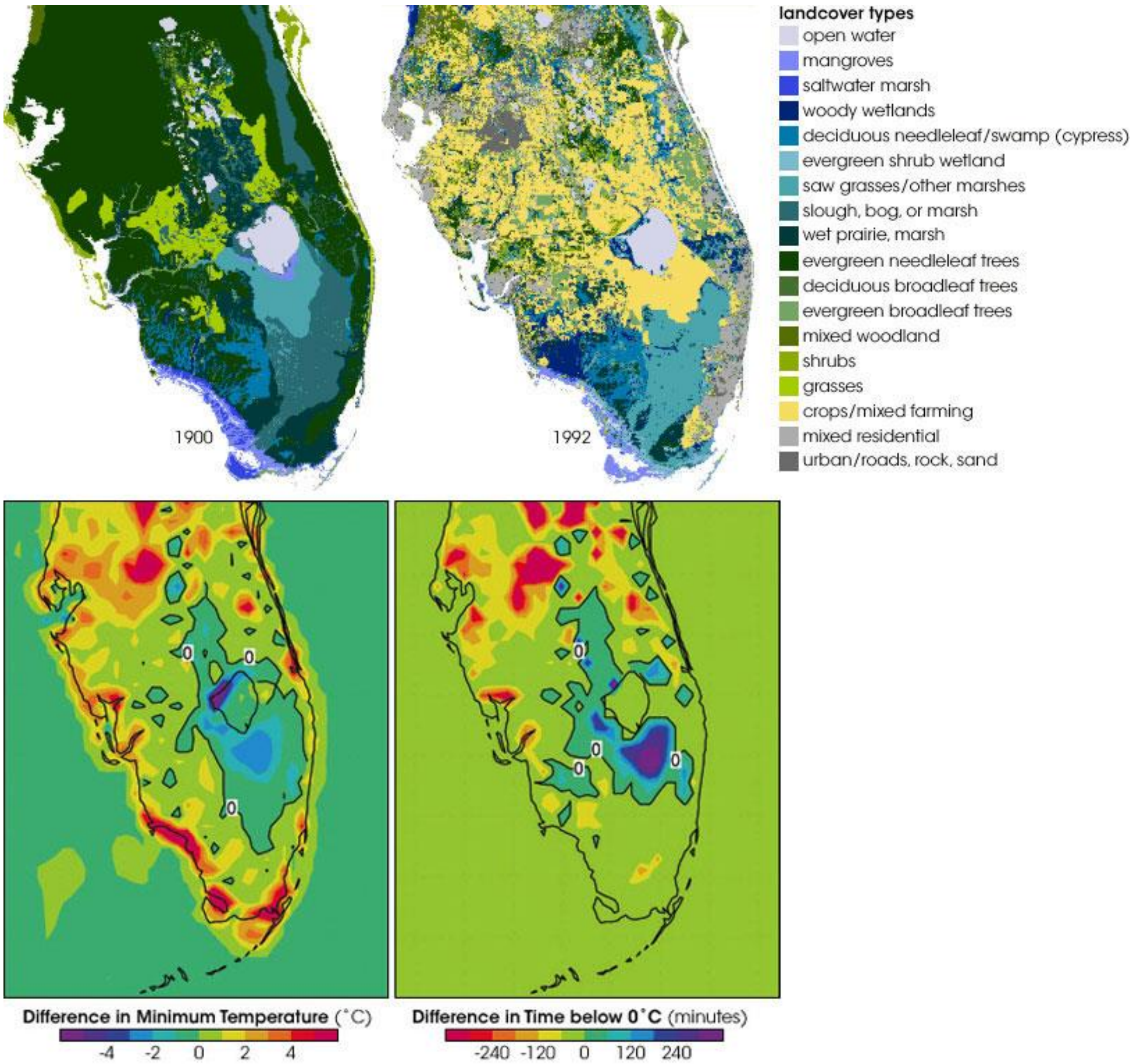


Figure 8. Relationship between land cover changes, minimum temperatures and length of freeze periods in Florida's key agricultural regions

Florida has a complex land use regulatory regime. It requires every development permit to be consistent with local land development regulations as well as local comprehensive plans. In turn, local comprehensive plans must be generally consistent with adopted regional plans and regulations (Carriker, 2006). However, arguments like an elimination of state's review of local plans were used in political campaigns lately and by adopting the Florida House Bill 7207 in 2011, dramatic fundamental changes occurred. The authority of local governments to protect the integrity of their plans through limitations on the approval of plan amendments has been greatly reduced, while on the contrary the ability of the development industry and lobby to pursue theirs goals has been greatly increased. With the Department of Community Affairs (DCA), the state land planning agency, being effectively abolished, this newly pursued legal approach represents a major retreat from the state's commitment to comprehensive planning (Pelham, 2011).

Clearly, Florida is uniquely endowed to become a leader in the negative effects (such as GHG emissions) mitigation through the effective management of agriculture, forestry, and natural ecosystems. Realizing this potential requires policy makers to consider competing land uses and their eventual consequences in a long-term vision. With the newly established trend described in the previous paragraph, this long-term vision faces some very serious obstacles.

8.2 Energy in Florida

Total energy consumption in Florida in 2010 was 4,382 trillion BTU in equivalent heat energy units (around 4.5% of total US consumption, which is slightly lower usage per person than US' average, assuming Florida has a 6% population share on the total population of the USA), with the largest share for transportation (36%), followed by residential (30%), commercial (23%), and industrial (12%) sectors (EIA, 2012).

Estimating future energy consumption is a complex process, as there are many (sometimes almost immeasurable) factors to consider – e.g. type of fuel and how efficient one is over the other, geographical area or region, income levels, types of housing, technological progress, etc. The U.S. Energy Information Administration (EIA) provides a forecast of energy consumption in the USA up to 2035. According to the EIA's findings, the total energy consumption in 2035 would be 114.5 quadrillion BTU's, which is about a 20% increase from current consumption (Florida Department of Transportation, 2009). Assuming simply 20% energy demands increase in Florida by 2035 would not be correct; some of the factors will increase the energy demands growth, some of them will decrease it. For example, population is expected to grow in Florida by 2035 by over 47% (Florida Department of Transportation, 2010), which is more than double of the estimated national average (Campbell, 1996). On the other hand, modernizing e.g. fuel efficiency (under the Corporate Average Fuel Economy (CAFE) Standards) and increasing the number of miles traveled per unit of fuel for newly built vehicles might have a larger influence in Florida, given its large vehicular fleet. Regardless of the specific growth pace, it is certain that the future energy demands of Florida will be considerably higher than they are currently.

Florida has only minor oil reserves and ranks sixth in the US for total GHG emissions (EIA, 2008; Mulkey, 2007), but has a large forestry and agricultural sector. The State is aggressively pursuing the development of a sustainable biofuel industry, while looking for ways to produce liquid biofuels by using enhanced traditional or new technologies, e.g. by experimenting with high-yield cellulosic crops such as Sugarcane, Energycane, Sweet Sorghum, and others.

8.3 Biofuels in Florida

In 2011, the estimated consumption of ethanol in Florida was 19.7 million barrels (= 621 million gallons). 98.5% of the ethanol was used for transportation needs (EIA, 2011).

In 2007, Florida had 8.05 million acres of agricultural area (2.95 million acres of cropland and 5.10 million acres of pastureland) (USDA, 2008) and 16.1 million acres of forests and woodland (Mulkey et al., 2008). With population of around 19 million people (Florida Department of Transportation, 2012b) it translates into only 0.17 ha (0.42 acres) of agricultural land per person – out of which 0.06 ha (0.15 acres) is cropland and 0.11 ha (0.27 acres) pastureland. Agricultural land availability is ultimately the limiting resource for agricultural and biofuels production, both worldwide and even more clearly in Florida.

Still, due to its favorable climatic conditions (mostly abundant rainfall and year-round growing conditions for various crops), advanced research, modern technologies as well as traditional leading role in agricultural production, the potential for production of high-value biofuel crops in Florida is attractive (Greene et al., 2004). Sugarcane is currently being farmed on over

400,000 acres (mostly in the EAA), Sweet Sorghum on 100,000 acres and corn on 70,000 acres (Mulkey, 2008), which in total represents almost 20% of Florida's available agricultural land. There are also plans for introducing cellulosic biofuels farming to south Florida's land currently set aside for future water management and environmental restoration as well as various abandoned farmlands. Studies about hypothetical market for renting and converting forested land into row cropping for biofuel production were conducted and revealed that nearly half of the 1,060 non-industrial landowners sampled in Florida are willing to accept payments for land type conversion (Pancholy et al., 2011). Substitution of fossil fuels with biofuels holds significant promise for reducing GHG emissions, particularly in the light of expected doubled energy demands of Florida by 2030. So clearly, there is an enormous potential for gain.

However, there are clearly also some serious potential consequences that need to be considered and planned for in the future plans. The muck soils of the EAA are a nonrenewable resource and an unaddressed subsidence caused by intensive farming that will seriously affect agricultural productivity (Walker et al., 1997). Other studies reveal that there are consequences for changing climate variability and production yields with increased biofuels crops production as illustrated in the example of maize in the Midwest (Southworth et al., 2000). Biomass has characteristics that lower its economic competitiveness against traditional fossil fuels (i.e. large dispersion across the landscape or seasonal production). Large-scale conversion of land by creating extensive monoculture tracts of biofuel crops might potentially preclude or limit its availability for delivery of other very important services. Similarly, large-scale bioethanol production can require enormous quantities of freshwater, placing a strain on regionally scarce water resources. Shifting the desired biofuels production to other parts of Florida (or even overseas) will inevitably result in the iLUC with its negative effects though.

A detailed investigation of various biofuels crops that could be used to produce bioethanol for transportation in Florida was conducted. First, average transportation needs of a Floridian were calculated. These results were then transformed to estimated land use demands under a scenario that all the transportation needs of Floridians should have been covered by bioethanol. Results presented below indicate that while a solution, where all the transportation needs of Florida would be covered by cellulosic bioethanol, is not viable, it is certainly an approach that needs to be investigated further and considered as a partial or transitional solution for future transportation fuel needs.

8.4 Bioethanol potential demands in Florida

According to the Office of Policy Planning at the Florida Department of Transportation, in 2010 there were 14,372,807 vehicles registered in Florida (Florida Department of Transportation, 2012c). The same source indicates Florida's population in 2011 as 18,905,048 (Florida Department of Transportation, 2012b). With 191,854,954,745 miles traveled during 2011 on Florida's public roads (Florida Department of Transportation, 2012d), the average annual mileage for a Florida vehicle was 13,348 miles/vehicle/year:

$$Annual\ mileage\ in\ FL\ = \frac{191{,}854{,}954{,}745\ \text{miles}}{14{,}372{,}807\ \text{vehicles}} = \mathbf{13,348}\ \frac{\textbf{miles}}{\textbf{vehicle}} \qquad [1]$$

8,152,702,000 gallons of fuel were used in Florida during 2011 (this indicator shows the gross volume of gasoline sales reported by wholesale distributors in Florida and the data includes highway use, non-highway use and losses) (Florida Department of Transportation, 2012a). This is the third highest consumption in the nation (EIA, 2009). The Florida Renewable Fuel Standard Act requires mandatory blending of ethanol for public supply of gas since December 31, 2010, so all the 2011 fuel consumption reported at (Florida Department of Transportation, 2012a) was already E10 – a blend of 90% fossil fuel gasoline and 10% ethanol. Average mileage for a Florida vehicle was 23.5 miles/gallon of E10:

$$Vehicle\ mileage\ in\ FL\ = \frac{191{,}854{,}954{,}745\ \text{miles}}{8{,}152{,}702{,}000\ \text{gal E10}} = \mathbf{23.5}\ \frac{\textbf{miles}}{\textbf{gal E10}} \qquad [2]$$

Annual fuel needs in FL per vehicle yields 568.0 gallons of E10 per vehicle per year:

$$E10\ needs\ in\ FL\ = \frac{13{,}348\,\frac{miles}{vehicle\ /\ year}}{23.5\,\frac{miles}{gal\ E10}} = \mathbf{568.0}\ \frac{\textbf{gal E10}}{\textbf{vehicle / year}} \tag{3}$$

Bioethanol has about 67% energy content of gasoline per unit volume (ORNL, 2008), so for substituting energy content of 1 gallon of fossil fuel gasoline (E0 blend, 114,100 BTU per gallon of E0), around 1.5 gallons of bioethanol (E100 blend, 76,100 BTU per gallon of E100) is needed.

While an average Florida vehicle can travel 13,348 miles/year on 568.0 gallons of E10 (10% ethanol; 110,300 BTU per gallon of E10), the distance travelled in the same vehicle with equivalent volume of fuel and higher concentration of ethanol than E10 would decrease. This is caused by the lower energy content of ethanol comparing to fossil gasoline. To travel the same average distance of a Florida vehicle (13,348 miles/year) on E100 fuel (76,100 BTU per gallon of E100), roughly 44.9% more E100 than E10 would be needed, thus 823.3 gallons/vehicle of E100 are anticipated:

$$E100\ needs\ in\ FL\ per\ vehicle = 568.0\ \frac{gal\ E10}{vhl\ /\ year} + \ 44.9\%\ *568.0\ \frac{gal\ E10}{vhl\ /\ year}$$
$$= \mathbf{823.3}\ \frac{\boldsymbol{gal\ E100}}{\boldsymbol{vhl\ /\ year}} \tag{4}$$

With 14,372,807 registered vehicles and with 18,905,048 Floridians, there is on average 0.76 vehicles per Floridian:

$$Number\ of\ vehicles\ per\ person\ in\ FL\ = \frac{14{,}372{,}807\ vhl}{18{,}905{,}048\ people} = \mathbf{0.76}\,\frac{\textbf{vhl}}{\textbf{person}} \tag{5}$$

Bioethanol demand can be then estimated as 625.7 gallons of E100 per Floridian per year:

$$E100\ needs\ in\ FL\ per\ person = 823.3\ \frac{gal\ E100}{vhl\ year} * 0.76\frac{vhl}{person}$$

$$= \mathbf{625.7}\ \frac{\mathbf{gal\ E100}}{\mathbf{person\ /\ year}} \qquad [6]$$

8.5 Bioethanol land requirements in Florida

Tables 1-4 above document the biomass production yields (ton/acre) and bioethanol production yields (gal/ton of biomass and gal/ac) for eight various biofuels crops considered in this study. To meet bioethanol needs of the Florida transportation sector, annual land requirement per person can be calculated by using the bioethanol production yields for various crops.

For example, with the production of Miscanthus, three different bioethanol yields scenarios were estimated (low = 160 gallons/acre, medium = 300 gallons/acre and high = 480 gallons/acre). With estimated need of 626 gallons of bioethanol per person per year, 3.91, 2.09 and 1.30 acres of land per person, respectively would be needed to cover the potential bioethanol (E100) needs of Floridians:

$$Land\ need\ for\ Miscanthus\ (Low)\ = \frac{626\ \frac{gal\ E100}{yr\ per}}{160\ \frac{gal\ E100}{acre\ yr}} = \mathbf{3.91}\frac{\boldsymbol{acre}}{\boldsymbol{person}} \qquad [7]$$

$$Land\ need\ for\ Miscanthus\ (Medium) = \frac{626\ \frac{gal\ E100}{yr\ per}}{300\ \frac{gal\ E100}{acre\ yr}} = \mathbf{2.09}\frac{\boldsymbol{acre}}{\boldsymbol{person}} \qquad [8]$$

$$Land\ need\ for\ Miscanthus\ (High)\ = \frac{626\ \frac{gal\ E100}{yr\ per}}{480\ \frac{gal\ E100}{acre\ yr}} = \mathbf{1.30}\frac{\boldsymbol{acre}}{\boldsymbol{person}} \qquad [9]$$

Other selected crops and theirs potential land use requirements for E100 scenario in Florida were calculated in a similar way. As summarized in Table 5, the lowest land use requirement show Eucalyptus (0.54 acres/person) and Energycane (0.56 acres/person), followed by Sugarcane (0.77 acres/person) and Elephangrass (0.78 acres/person). Land need of slightly above 1 acres/person is shown by Sweet Sorghum (1.21 acres/person) and Corn (1.22 acres/person). The highest land requirement is shown for Miscanthus (2.09 acres/person) and Switchgrass (2.16 acres/person).

Table 5. Land requirements for bioethanol crops for E100 in Florida (ac/person and ha/person)

	Low		**Medium**		**High**	
	ha/person	**ac/person**	**ha/person**	**ac/person**	**ha/person**	**ac/person**
Miscanthus G2	1.58	3.91	0.84	2.09	0.53	1.30
Switchgrass G2	2.01	4.97	0.87	2.16	0.52	1.28
Sorghum G1+G2	0.86	2.12	0.49	1.21	0.32	0.79
Corn G1+G2	0.65	1.60	0.49	1.22	0.39	0.96
Elephantgrass G2	0.45	1.12	0.32	0.78	0.23	0.58
Sugarcane G1+G2	0.38	0.94	0.31	0.77	0.26	0.65
Energycane G2	0.32	0.78	0.23	0.56	0.17	0.42
Eucalyptus G2	0.30	0.74	0.22	0.54	0.17	0.41

Figure 9. Land requirements (ac/person) for different bioethanol crops (Medium yield scenario) in Florida using E100

8.6 Land use trade-offs in Florida

E10 volume needed to cover averaged travel distance of a vehicle in FL (13,348 miles - equation [1]) is 568.0 gallons of E10/vehicle/year (equation [3] above). Given that there is on average 0.76 vehicles per Floridian (equation [5]), E10 needs to cover averaged travel distance of a Floridian is 431.7 gallons of E10/Floridian/year:

$$E10\,needs\ per\ Floridian\ = 568.0\ \frac{\text{gal E10}}{\text{vehicle / year}} * 0.76\frac{vhl}{person}$$
$$= \mathbf{431.7}\ \frac{\textbf{gal E10}}{\textbf{person / year}} \qquad [10]$$

The volume content of 1 gallons of E10 should be seen as a mixture of 90% fossil fuel gas 10% ethanol. Energy content of gallon of such blend is then 110,300 BTU (102,690 BTU from fossil gas and 7,610 BTU from ethanol). If the ethanol concentration in the fuel mixture is increased to 15% (E15 blend), the energy content of 1 gallon of such blend decreases to 108,400 BTU (96,985 BTU from fossil gas and 11,415 BTU from ethanol).

To quantify eventual land use trade-offs for potentially increased use of bioethanol crops and bioethanol fuel produced in Florida, various scenarios were modeled. As shown in Table 6, by increasing ethanol concentration in fuel blends, the energy content of those blends decreases, so volume of the fuel needed to travel the same distance increases.

Table 6. Energy content of 1 gallon of blended fuels (BTU/gallon) and volume of fossil fuel and ethanol fuel (gallons) per Floridian needed to travel 13,348 miles

Fuel Blend	Energy content of 1 gallon of Total Blended fuel (BTU/gallon)	Fossil fuel content (gal) to travel 13,348 miles	Ethanol fuel content (gal) to travel 13,348 miles	Total Blended fuel content (gal) to travel 13,348 miles
E0	114,100	417.3	0.0	417.3
E10	110,300	388.5	43.2	431.7
E15	108,400	373.4	65.9	439.2
E20	106,500	357.7	89.4	447.1
E85	81,800	87.3	494.8	582.1
E100	76,100	0.0	625.7	625.7

As shown in Figure 10, there is a linear relationship between fuel blend vs. its energy content. However, as shown in Table 6, there is a non-linear relationship between the total volumes of fuel blends needed to travel the same distance.

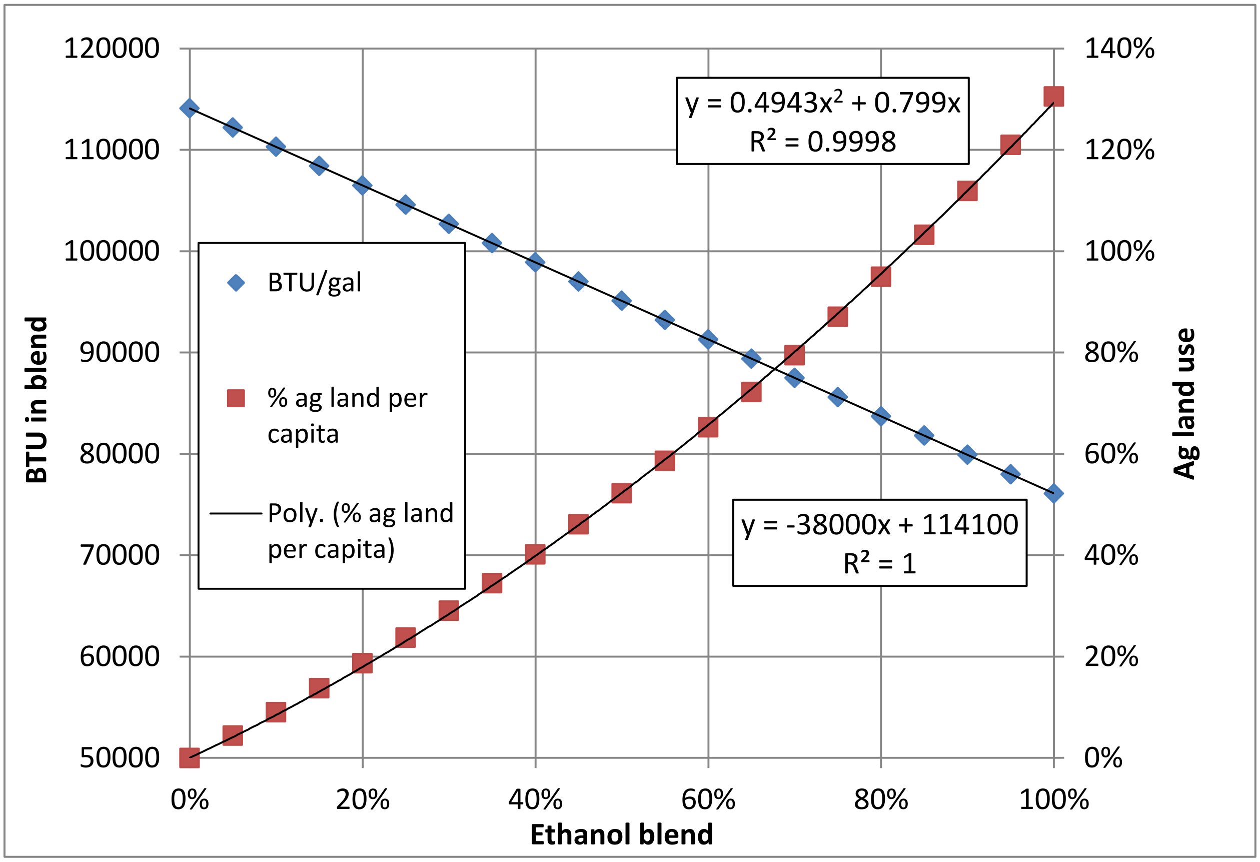


Figure 10. Agricultural land demand in Florida for biofuels crops to cover ethanol volumes in different fuel blends for satisfying annual vehicular transportation needs of Floridians

Knowing the needed volume of blended ethanol per person (as shown in Table 6), knowing the volume of ethanol that could be produced from different crops per acre as (as shown in Table 4) and knowing the acreage of available agricultural land per Floridian (0.43 acres/person), we estimated how much agricultural land would be needed to produce enough ethanol for different fuel blends. The results are presented in Table 7 and Figure 11.

Table 7. Agricultural land demand in Florida for biofuels crops to cover ethanol volumes in different fuel blends for satisfying annual vehicular transportation needs of Floridians

	E10	E15	E20	E85	E100
Miscanthus G2	34%	52%	70%	387%	490%
Switchgrass G2	35%	53%	72%	401%	507%
Sorghum G1+G2	20%	30%	41%	224%	284%
Corn G1+G2	20%	30%	41%	226%	286%
Elephantgrass G2	13%	19%	26%	145%	184%
Sugarcane G1+G2	13%	19%	26%	143%	181%
Energycane G2	9%	14%	19%	103%	131%
Eucalyptus G2	9%	13%	18%	100%	127%

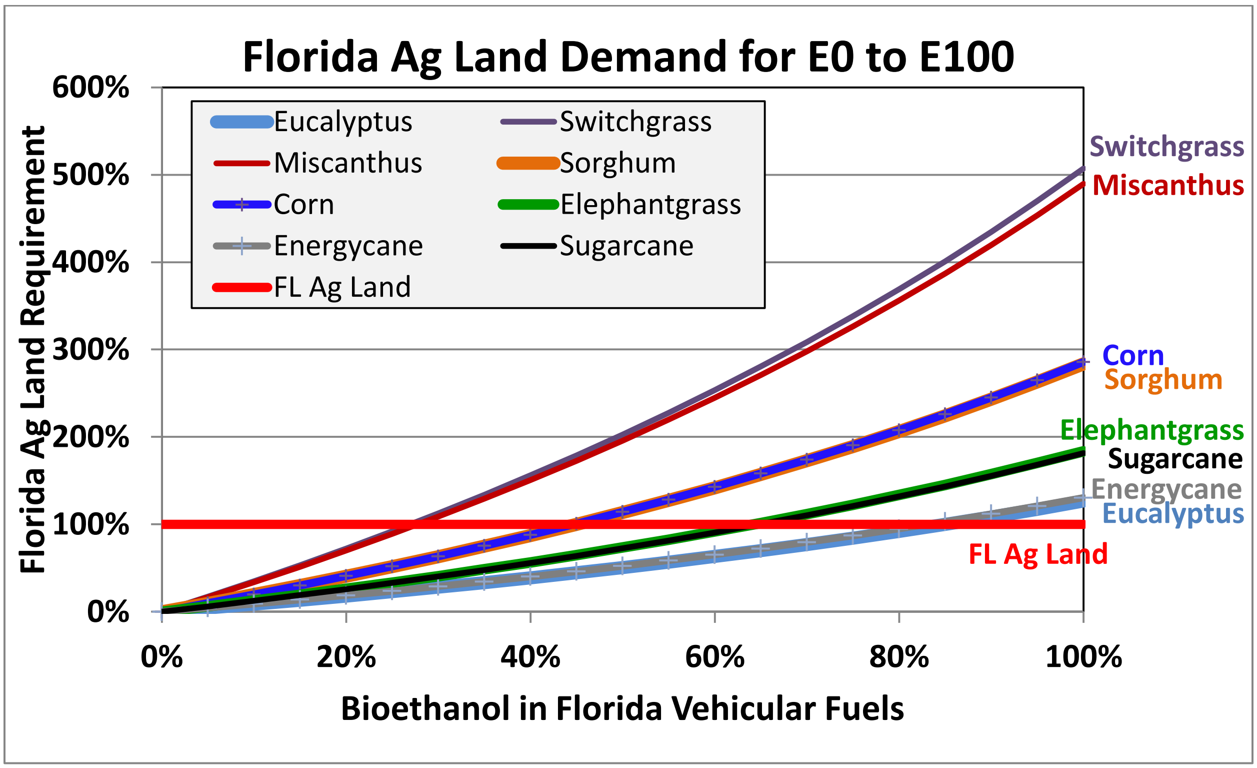


Figure 11. Agricultural land demand in Florida for biofuels crops to cover ethanol volumes in different fuel blends for satisfying annual vehicular transportation needs of Floridians

As can be concluded from Table 7 and Figure 11, the available agricultural land is clearly a limiting factor to a wide-spread expansion of the biofuels sector in Florida. Even the highest yielding biofuels crops (Energycane, Eucalyptus) would need more than 100% of available agricultural land in Florida in a hypothetical case, where all the transportation needs of Floridians would be covered solely by locally produced bioethanol.

It is important to emphasize that vehicular energy represents only 33% of Florida's total energy consumption. If Florida gave up all the available agricultural land for whichever of the investigated biofuel crops (or theirs combination), even the highest yielding crops on all that land would produce only that volume of ethanol, which would cover less than one third of Florida's total energy needs.

9. Conclusions

This study established relationships between production of selected biofuels crops (Miscanthus, Switchgrass, Sorghum, Corn, Elephantgrass, Sugarcane, Energycane and Eucalyptus), associated biomass and bioethanol yields, land use requirements for these crops, biomass to biofuels conversion methods and the overall fuel demands, particularly in Florida's transportation sector.

Dry biomass production yields of the selected bioethanol crops varied between 22.5 tons/acre (Energycane) and 3.6 tons/acre (Switchgrass).

Ethanol yields from 1 ton of dry biomass for both first and second generation ethanol production paths were included for those crops, where such conversions are possible (Sweet Sorghum, Corn, and Sugarcane) and the results varied between 96 gallons/dry ton (first generation Corn) and 35 gallons/dry ton (second generation Sorghum).

Ethanol production yields from biomass of the selected bioethanol crops were estimated and where possible, a "combined" approach of first and second generation production was used. The results showed that the highest yield of bioethanol is obtained from Eucalyptus (1160 gallons/acre) and Energycane (1125 gallons/acre), followed by Sugarcane (809 gallons/acre), Elephantgrass (800 gallons/acre), Sorghum (518 gallons/acre), Corn (514 gallons/acre), Miscanthus (300 gallons/acre) and Switchgrass (290 gallons/acre).

Florida has 18,905,048 inhabitants, 14,372,807 registered vehicles with an average annual mileage of 13,348 miles/vehicle/year, an average E10 fuel consumption of 23.5 miles/gallon. Assuming bioethanol having 66.7% energy content of petroleum-based gasoline per unit volume, an average 625.7 gallons of bioethanol (E100) per year per Floridian would be needed, if only bioethanol was used as a vehicular fuel.

The selected crops and theirs potential land use requirements for covering the E100 scenario were calculated. The lowest land use requirement show Eucalyptus (0.54 acres/person) and Energycane (0.56 acres/person), followed by Sugarcane (0.77 acres/person) and Elephangrass (0.78 acres/person). Land need of slightly above 1 acres/person is shown by Sweet Sorghum (1.21 acres/person) and Corn (1.22 acres/person). The highest land requirement is for Miscanthus (2.09 acres/person) and Switchgrass (2.16 acres/person).

Land requirements for bioethanol crops to cover Florida transportation energy under various modeled fuel blend scenarios (E10, E15, E20, E85 and E100) were quantified. Results at the lower end of ethanol blending vary between 9% (Energycane and Eucalyptus) and 35% (Switchgrass) of agricultural land for the E10 scenario and between 13% (Eucalyptus) and 53% (Switchgrass) for the E15 scenario. Results at the high end of ethanol blending vary between 100% (Eucalyptus) and 401% (Switchgrass) of agricultural land for the E85 scenario and between 127% (Eucalyptus) and 507% (Switchgrass) for the E15 scenario.

The benchmark point varies. In case of the highest yielding crops (Eucalyptus and Energycane), the “break-even” point appears to be E40 - requiring at least 40% of Florida agricultural land to produce. Below that level it requires slightly less of Florida's agricultural land (e.g. E10 requires 9% of land), above that level it requires somewhat more (e.g. E85 requires 100% of agricultural land). In case of all the other investigated crops, the benchmark point is lower than E5.

The available agricultural land is clearly a limiting factor to a wide-spread expansion of the biofuels sector in Florida. Even the highest yielding biofuels crops (Energycane, Eucalyptus) would need more than 100% of available agricultural land in Florida in a hypothetical case, where all the transportation needs of Floridians would be covered solely by locally produced bioethanol. Also, vehicular energy represents only 33% of Florida’s total energy consumption, so even if Florida gave up all the available agricultural land for whichever of the investigated biofuel crops (or theirs combination), the highest yielding crops on all that land would produce only that volume of ethanol, which would cover less than one third of Florida's total energy needs.

Bioethanol (primarily cellulosic) produced in Florida could meet a significant portion of the State's transportation needs, but development of the needed technology and infrastructure, negative effects on biodiversity, climate change and overall land use changes on Florida's limited available land are important factors to be considered for further feasibility studies and analysis.

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