Examining The Impacts Of Switchgrass Derived Biofuels On U.S.

Biofuel Policy And

The Potential Environmental Ethical Dilemmas

by

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ABSTRACT

Overall, biofuels play a significant role in future energy sourcing and deserve thorough researching and examining for their best use in achieving sustainable goals. National and state policies are supporting biofuel production as a sustainable option without a holistic view of total impacts. The analysis from this research connects to policies based on life cycle sustainability to identify other environmental impacts beyond those specified in the policy as well as ethical issues that are a concern. A Life cycle assessment (LCA) of switchgrass agriculture indicates it will be challenging to meet U.S. Renewable Fuel Standards with only switchgrass cellulosic ethanol, yet may be used for California's Low Carbon Fuel Standard. Ethical dilemmas in food supply, land conservation, and water use can be connected to biofuel production and will require evaluation as policies are created. The discussions around these ethical dilemmas should be had throughout the process of biofuel production and policy making. Earth system engineering management principles can help start the discussions and allow anthropocentric and biocentric viewpoints to be heard.

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CHAPTER 1

1 INTRODUCTION AND BACKGROUND

Introduction

The biofuels industry has grown in the U.S. over the past few decades due to multiple drivers including pollution reduction, limited resource management, and energy independence (Demirbas, 2009). Major environmental concerns connected to fuel come from the emission of greenhouse gases (GHGs) from fossil fuels used industrially, commercially, and in the transportation sector (Charles et al., 2007; Dixon et al., 2010; McGee et al., 2011). GHG emissions drive global warming which brings additional environmental concerns such as ecosystem imbalances and altered weather conditions (Gomiero et al., 2010). Energy independence will allow for the U.S. to pursue private energy security, reducing the need to obtain foreign fuel sources (Dixon et al., 2010). This adjustment will also influence the economic sector for the country, changing international trading, taxation, and job opportunities in energy production(McLaughlin et al., 2002). Overall, biofuels play a significant role in future energy sourcing and deserve thorough researching and examining for their best use in achieving sustainable goals.

The motivation for this thesis is to provide insight on unintended consequences and complex issues for switchgrass, a leading biofuel feedstock, before it reaches large scale production. National and state policies are supporting biofuel production as a sustainable option without a holistic view of total impacts. The analysis from this research connects to policies based on life cycle sustainability to identify other environmental impacts beyond those specified in the policy as well as ethical issues that are a concern. This research will contribute to the literature used to help understand uncertainties in biofuel production and consumption.

The work presented in this thesis is based on the potential role of biofuels in the transportation sector. The research is focused on a leading feedstock for biofuels, switchgrass (*Panicum Virgatum L.*), and its contribution to biofuel production for the U.S. The Environmental Independence and Security Act (EISA) and California's Low Carbon Fuel Standard (CA LCFS) serve as examples for policy analysis and the role of switchgrass biofuels. The thesis highlights potential environmental tradeoffs and ethical dilemmas that will need to be addressed as switchgrass-derived fuel is produced to meet such federal and state policies. The research approach combines three disparate methods to consider biofuels in the U.S.; policy analysis, environmental impacts, and environmental ethics. Figure 1 shows that many biofuel research studies incorporate only one or two of the methods to discuss biofuels. The literature lacks discussion considering all three methods of describing the biofuel industry. There is a gap in connecting all three methods in advancing biofuels. The policy analysis for this thesis focuses on EISA and CA LCFS.

Categories of Biofuel Production Reviewed in Research

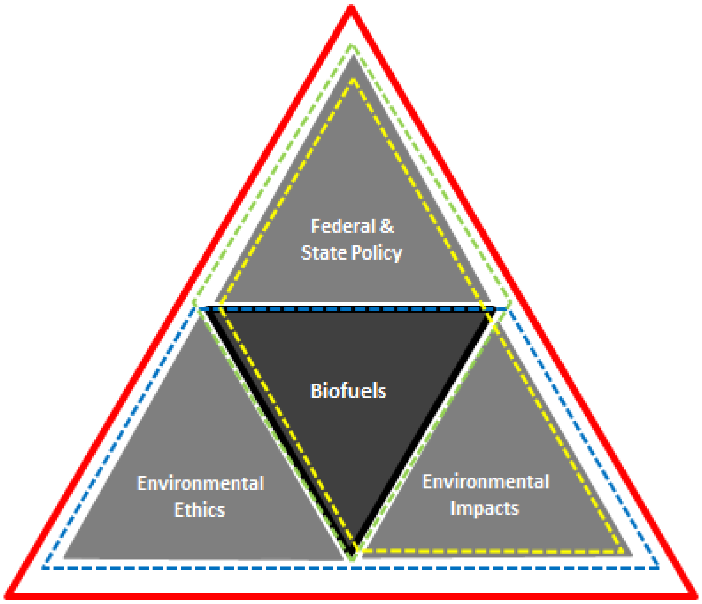

Figure 1- Categories of Biofuel Production Reviewed in Research. The dotted lines indicate studies reviewed during the research. The red solid line shows the unique approach of reviewing biofuels connected to policy, environmental impacts and ethics.

Table 1- Published information on switchgrass biofuel can be found according to the categories outlined in Figure 1. There is a research gap in combining policy, environmental impacts, and ethics

Authors	Year	Title
Charles, Ryan, Ryan & Oloruntoba	2007	Public policy and biofuels: The way forward?
Mabee	2007	Policy Options to Support Biofuel Production
Tyner	2007	U.S. Ethanol Policy - Possibilities for the Future
Chamberlain & Miller	2012	Policy incentives for switchgrass production using valuation of non-market ecosystem services
Cherubini & Jungmeier	2009	LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass
Farrell, Plevin, Turner, Jones, O'Hare and Kammen	2006	Ethanol Can Contribute to Energy and Environmental Goals
McGee & Chan Hilton	2011	Analysis of Federal and State Policies and Environmental Issues for Bioethanol Production Facilities
Schmer, Vogel, Mitchell & Perrin	2007	Net energy of cellulosic ethanol from switchgrass
Tan, Lee & Mohamed	2008	Role of energy policy in renewable energy accomplishment: The case of second generation bioethanol
Wu, Wu & Wang	2006	Energy and Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment
Jensen, Clark, Ellis, English, Menard, Walsh & de la Torre Ugarte	2007	Farmer willingness to grow switchgrass for energy production
McLaughlin & Walsh	1997	Evaluating Environmental Consequences of Producing Herbaceous Crops for Bioenergy
Rossi & Hinrichs	2009	Hope and skepticism: Farmer and local community views on the socio-economic benefits of agricultural bioenergy
Thompson	2007	The Agricultural Ethics of Biofuels: A First Look
Vogel, Rejda, Walters & Buxton	2002	Switchgrass Biomass Production in the Midwest: Harvest and Nitrogen Management

First, it is important to review the role policy is playing on the biofuel industry. Both federal and state policies have provided incentives for biofuels, motivated by energy independence and GHG reduction. In the sector of alternative fuels, overarching federal policies such as the 2007 Energy Independence and Security Act (EISA) in the United States established goals to reduce vehicular fuel from oil, lower GHG emissions, and focus on alternative fuels such as ethanol and biodiesel. Along with such federal policies, state incentives and regulations such as California's Low Carbon Fuel Standard have GHG reduction goals. State policies can contribute to the U.S.'s movement towards energy security and carbon reduction through the use of alternative transportation fuels.

The tailpipe emissions are a major concern for GHG emissions in transportation. Policies that target only tailpipe emission miss upstream impacts before the use phase. When policies limit compliance to certain phases of the biofuel, unexpected consequences appear due to impacts not regulated. Impacts from other phases may show that the desired biofuel, either feedstock, conversion process, or targeted volume replacement, may not be as beneficial intended.

In order to identify upstream and indirect impacts from biofuel production and use, Life Cycle Assessment (LCA) can provide the insight policy makers need when determining the influence of leading biofuel feedstock. LCA can give a holistic view of impacts by indicating environmental impacts throughout all phases of products and processes – production, use, and disposal. Standards on conducting LCA are provided in the International Organization of Standardization standard 14040:2006 (throughout the document this LCA standard is referred to as ISO 14040). The standardized process of conducting an LCA consists of the following steps outlined in Figure 2: 1) defining the goal and scope 2) life cycle inventory (LCI) data collection 3) impact assessment (LCIA) 4) interpretation of all data and results and 5) reporting findings (Organization, 2006).

The ISO 14040 – Environmental Management - Life Cycle Assessment – Principles and Framework describes each step and the overall use and limitations of an LCA. The use of LCAs in biofuel policies will allow for forethought to be used to identify possible unintended consequences.

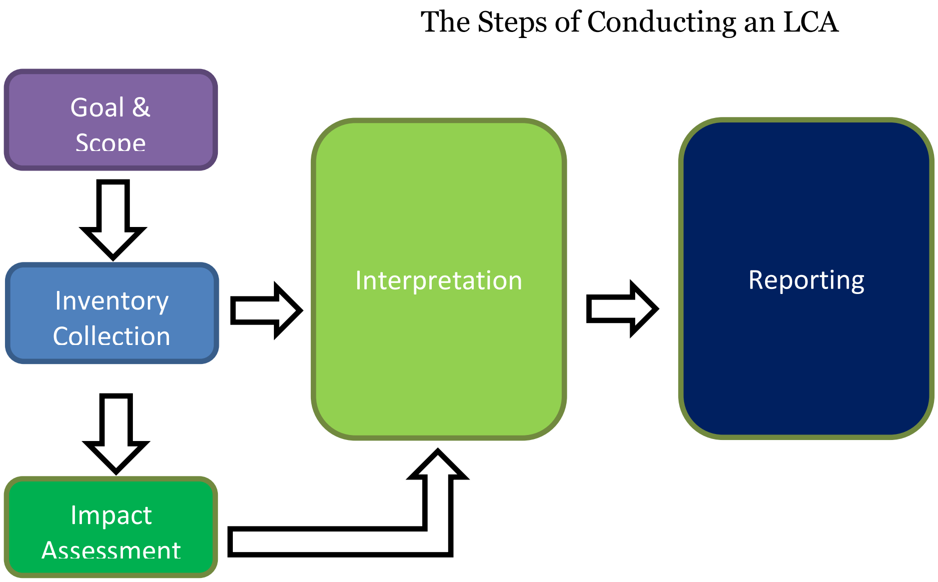

Figure 2 – **The Steps of Conducting an LCA**. The process is according to ISO 14040 standards.

As the number of biofuel policies increase and higher volumes promoted, it is vital to consider all phases involved to ensure a sustainable course of biofuel development. Without a holistic view on the outcomes from altering biofuel feedstock, production processes, and consumption patterns, it is not possible to predict net sustainable impacts from the driving policy. Using LCA in connection with biofuel policies will enable policy-makers to focus efforts on key industries and areas that will be impacted such as the agriculture sector. For switchgrass to add to biofuel targets, assessing potential consequences through LCA is needed to prepare the industry and move forward from research phases.

The potential issues in commercial scale production of switchgrass-derived biofuels can also create environmental ethical dilemmas. Environmental ethics centers around the challenges related between human advancement and environmental preservation, the basis for principles used to interact with nature (Minteer, 2009) Personal views on the value of nature shape how societies respond to new technologies that will change environmental conditions. Callicott (2012) says environmental ethics can be described as the combination of ecology and science to determine a value based system of constraints on behaviors necessary for both environmental and human benefit. For example, individuals may voice their personal ethical beliefs and start movements such as with Rachel Carson and *Silent Spring* in the 1960's (Carson, 2008). The views involved in biofuel production and use vary drastically, covering the entire spectrum of beliefs about the relationship between humans and the environment. Some dilemmas around biofuels include food supply impact, land use change, and water distribution. Policymakers have the responsibility to evaluate all sides of the dilemmas before instituting new laws. The dilemmas can be discussed using earth systems engineering management (ESEM) principles, topics for consideration before interacting in natural systems (Allenby, 2007).

Considering the missing research gaps of connecting policy, environmental impacts, and environmental ethical dilemmas, the following objectives are set for this thesis work and covered in the following chapters.

- Objective 1: Perform an LCA on switchgrass produced for cellulosic ethanol and drop in fuels, focusing on the cradle-to-gate agriculture phase.
- Objective 2: Use U.S. RFS2 2022 goals and CA's Low Carbon Fuel Standard GHG baseline scenarios to address the role switchgrass have to meet biofuel policies.

- Objective 3: Connect environmental ethical dilemmas of ecosystem altering, land use change, and water rights to the biofuel production for environmental improvements discussion using ESEM principles.

Organization of Thesis

The thesis consists of 3 chapters to present the findings from the research. The introductory chapter continues with background information necessary to understand U.S. biofuel policy, use of LCA in connection with biofuels, and the interest in switchgrass for biofuels. Chapter 2 is the methods and results of the LCA study focused on the agriculture phase of switchgrass-derived biofuels. The chapter also includes a policy analysis of the Renewable Fuel Standards (RFS2) and California's Low Carbon Fuel Standard (CA LCFS). The last chapter brings in more discussion on environmental ethics involved in biofuel policies and provides final conclusions and suggested future work. Chapters 1 and 2 were prepared in conjunction with research conducted for a United States Department of Agriculture project awarded to Arizona State University and the University of Pittsburgh. .

Background

U.S. Biofuels Policy

The development of U.S. biofuel policy can be seen as a progression from environmentally-focused policies in the 1950's and 60's. Beginning in 1955, the country saw the need to monitor air quality by enacting the Air Pollution Control Act. Air quality concerns continued by the enactment of the Clean Air Act in 1963, which was later amended to include biofuel-specific regulations in regards to air and water quality and pollution control ("Air Pollution Control Act," 1955; "Air Quality Act of 1967," 1967; "Clean Air Act Amendments," 1963; "Clean Air Act Amendments of 1970," 1970; "Clean Air Act Amendments of 1977," 1977; "Resource Conservation and Recovery Act ", 1976;

"Safe Drinking Water Act," 1974; "Surface Transportation Assistance & Highway Revenue Act," 1982; "Toxic Substance Control Act," 1976). Biofuels were eventually addressed in the 1970's by the addition of a tax exemption for ethanol in the Energy Tax Act of 1978 (Tyner, 2008). In 1990, the Clean Air Act amendment provided specific standards on renewable fuels, incorporating biofuels in future industry to be heavily incorporated in future environmental policy making ("Clean Air Act Amendments of 1990," 1990).

There also exists a connection between biofuels policy and energy regulations. In the 1980's and 90's, environmental policies started to include energy regulations such as the Alternative Motor Fuels Act of 1988 and Energy Policy Act in 1992 ("Alternative Motor Fuels Act," 1988; "Energy Policy Act of 1992," 1992). Each of these policies included terms for alternative fuels, including biofuels. The policies of this time began to consider energy quantity and sourcing. This also marks the start of using policy to push for energy independence and security. Similar regulations on quantity and sourcing can be seen in the 2005 Energy Policy Act as well as EISA.

The present biofuels policies use different means to meet a combination of environmental and energy purposes. As mentioned, EISA is an example of biofuel policy that is set to increase the volume of biofuels as well as improve the environment through GHG reductions. Other biofuel policies set regulations on the industry as a whole, promoting green jobs and biorefinery development such as Executive Order 13423 of 2007. Other pieces to biofuel policy are put in place to ensure the availability of feedstock cultivation. All of these policies require an incentive for compliance. A major incentive for biofuel production and use comes from economic benefits. Tax exemptions, subsidies, and refunds encourage the development and use of next generation biofuels (Sims et al., 2010).

Biofuel volume targets created by policies can push the alternative energy industry forward (innovate). EISA and others also encourages the investment beyond first-generation biofuels (corn ethanol), into 2nd and 3rd generation biofuels, those from non-food sources and residues of agriculture. In 2009, the RFS program was revised commonly referred to RFS2. Under the RFS2, the EPA set the renewable fuel standard projection up to the year 2022 and indicated that out of the 36 billion gallons biofuel produced only 15 can be from conventional corn ethanol. The remainder needs to come from biodiesel (50% life cycle GHG threshold reduction) such as from soybean oil, non-cellulosic advanced biofuels (50% life cycle GHG threshold reduction) such as grain sorghum, and majority from cellulosic ethanol (60% life cycle GHG threshold reduction) such that can be created from switchgrass. In order to use next generation biofuels, new technologies in production and in the transportation sector need to continue to develop.

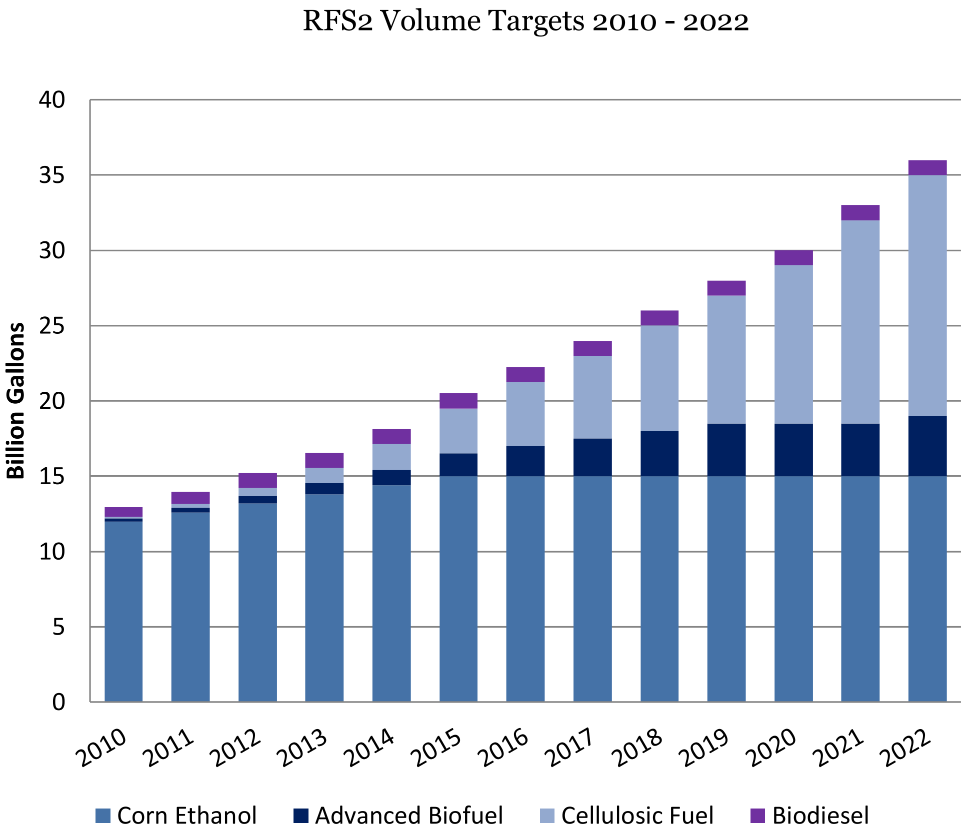

Figure 3 - **RFS2 volume targets 2010- 2022**. The volumes are for corn, advanced fuels, cellulosic fuel, and biodiesel (EPA, 2010)

CA LCFS is an example of setting state GHG reduction policy on life cycle impacts. The CA LCFS was passed in 2007 as part of the Executive Order S-01-07. The standard requires a 10% reduction in carbon intensity of fuel in the transport sector by 2020 for the whole state. The program does not require specific alternative fuel targets like RFS2, but uses a credit and deficits system to encourage reducing life cycle carbon intensity (mass CO_2 eq. per MJ of fuel) of transportation fuels. CA LCFS has been regulated by the California Air Resources Board (CARB) since 2009.

The Interest in Switchgrass

Research indicates many feedstocks and alternatives for biofuel production in the U.S. beyond current first generation biofuels. The major contributors for ethanol in motor vehicles are corn and sugarcane, but both have been criticized for impacting food supply and low energy return on investment (EROI) values for production(Stein, 2007; P. B. Thompson, 2012). Other agricultural feedstocks such as switchgrass are of new interest because of their availability, lack of direct influence on the food supply, and ability to produce fuel that will comply with biofuel regulations while feasibly meeting the demands for the U.S. In connection to RFS2 goals, next generation biofuels are necessary to reach the 36 billion gallon biofuel target by 2022. Table 2 shows the EPAs estimations for biofuels in 2022, capping first generation corn ethanol at 15 billion gallons (USDA, 2010).

Table 2- The values of the predictions represent the desired volumes according the RFS2 36 billion gallon target for 2022 set in 2009. Switchgrass and other perennial grasses are predicted to be the next largest contributor to biofuels compared to conventional corn ethanol.

EPA Feedstock Assumptions and Gallons by 2022	
Switchgrass (perennial grass)	7.9 bg
Soy biodiesel and corn oil	1.34 bg
Crop residues (corn stover, includes bagasse)	5.5 bg
Woody biomass (forestry residue)	0.1 bg
Corn ethanol	15.0 bg
Other (municipal solid waste (MSW))	2.6 bg
Animal fats and yellow grease	0.38 bg
Algae	0.1 bg
Imports	2.2 bg

Switchgrass (*Panicum Virgatum L.*) is an energy crop of interest, estimated to account for close to 40% by volume of U.S. biofuels in 2022. Some of the agriculture characteristics that make switchgrass appealing included its lack of required maintenance, and ability to adapt to multiple weather conditions and grow on marginal lands. It is found in most of the continental US, but heavily in the plains of the Midwest (Fike et al., 2006a; Vogel et al., 2002). Currently switchgrass is commonly used for erosion control, filling marginal empty lots of land, and can be found in animal feed. Since switchgrass is perennial, the initial preparation on land only needs to occur every 9 to 15 years (McDonald et al., 2006). Studies show that switchgrass can be harvested for biomass 2 to 3 times a year, yet the biomass yield is reduced compared to a single harvest (Douglas et al., 2009; Fike et al., 2006b; Sanderson et al., 1996; Vogel et al., 2002). The cultivars of switchgrass are commonly classified as either lowland or upland depending on the native geographical location. The lowland switchgrass cultivars take longer to mature than upland strands (Lewandowski et al., 2003), while upland switchgrass tends to be more adaptive to dry conditions and lowland species adapt to flood conditions (Stroup et al., 2003).

LCA results of switchgrass for biofuel have shown a wide range of benefits and tradeoffs compared to fossil fuels. LCAs on switchgrass indicate a net zero or negative GHG value due to the high carbon storage in the grasses' roots. As much as 94% lower GHG emissions from the cellulosic ethanol derived from switchgrass compared to gasoline are recorded in LCA literature (Schmer et al., 2008). Energy models have indicated that switchgrass could produce greater than 700% output energy compared the input energy.

Table 3 provides a summary of switchgrass LCAs published and the focus of the studies.

Table 3 - Literature review summary table of switchgrass biofuel LCAs available in the literature. The system boundary and indication of discussing total biomass yield, impact categories, application to policy or specific agriculture impacts were recorded for each LCA paper.

Yr	Author	F.U.	System	Biomass Yield	GWP	Other Impacts	Policy	Ag. Details
2010	Bai, Luo, van der Voet	power for 1-km driving of midsize car	Cradle to Grave	X	X			
2010	Cherubini, Jungmeir	amount of biomass treated per year	Cradle to Gate	X	X	X		X
2008	Schmer, Vogel, Mitchell, Perrin	1 ha of land	Agriculture phase	X	X			X
2006	Wu, Wu, Wang	kg dry biomass	Well to Wheel	X	X	X	X	
2010	Spatari, Bagley, MacLean	1 L of Ethanol	Well to Gate	X	X	X		
2005	Spatari, Zhang, MacLean	1 L of Ethanol	Cradle to Gate	X	X	X		X
2011	Wang, Han, Haq, Tyner, Wu, Elgowainy	1 MJ of Fuel	Well to Wheel	X	X			
2009	MacLean, Spatari	1 MJ of Fuel	Well to Gate	X	X			
2010	Harto, Robert Meyers, Eric Williams	Gallons of water /1 gal fuel	Cradle to Grave		X	X		X

In order to contribute to the current research and make applications for environmental ethical issues, an LCA on switchgrass was needed. The following chapter presents a peer-reviewed style paper focusing on LCA results and the benefits of utilizing more than GHG reductions for policy makers.

CHAPTER 2

2 LCA and POLICY ANALYSIS AND RESULTS

METHODS

The research consisted of LCA of switchgrass for cellulosic ethanol and drop-in biofuel, and policy assessment based on the LCA results. The LCA was conducted on switchgrass agriculture and fuel production. Results were used to evaluate California's Low Carbon Fuel Standard and the U.S. RFS2 targets. The overall work was driven by objectives within a proposal with the University of Pittsburgh and the U.S. Department of Agriculture. The objectives of the USDA project are in Appendix A

Goal and Scope Definition:

The LCA was performed following ISO 14040 process (Organization, 2006). The goal of the attributional LCA was to determine environmental impacts of the agriculture phase of switchgrass as the crop grows in popularity for biofuel production. The audience of the study includes both biofuel / energy policy makers and members of the agriculture industry. The functional unit for the LCA is 1 kg of dry biomass for biofuel production. **Figure 4** shows the system boundary of the LCA study. The LCA system boundary includes the land preparation, cultivation, harvesting and upstream production impacts for switchgrass agriculture. Impacts from production of switchgrass-derived biofuel through pyrolysis were assessed in collaboration with the University of Pittsburgh and considered in order to scale the biomass yields to projected cellulosic fuel volumes.

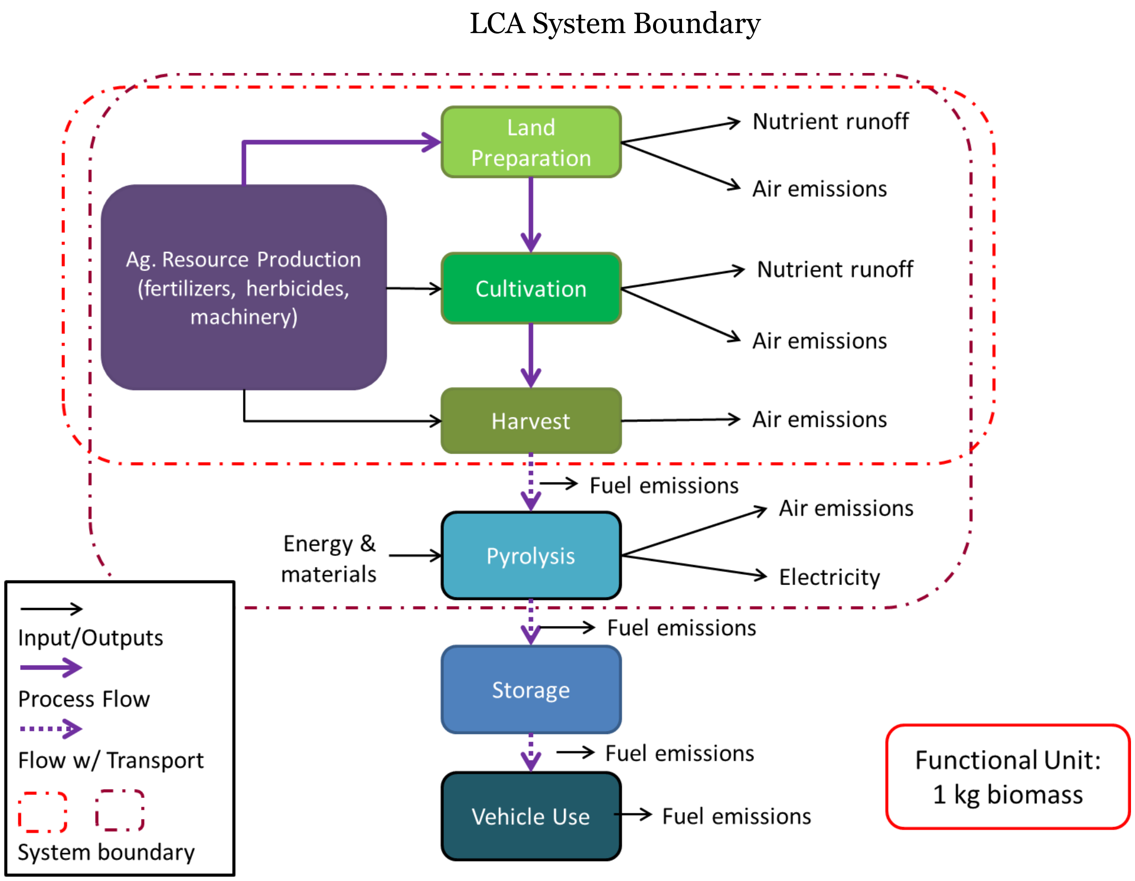

Figure 4 -**LCA system boundary**. The dark dashed line represents the system including pyrolysis for assess impacts associated with volume targets.

Life Cycle Inventory:

Inventories were collected from existing peer-reviewed publications on LCA and agriculture studies, best practices throughout the country, and databases such as Ecoinvent. Ecoinvent datasets for agricultural processes were used for sowing the seed, fertilizing, and harvesting. Sowing and fertilizing were assessed on a per meter squared basis. Harvesting through baling was assessed based on 1 harvest bale per hectare and 163 kg biomass per bale (Sokhansanj et al., 2009). Energy mixes represented those of Switzerland and were not updated to reflect U.S. energy consumption. GHG emissions from pyrolysis are estimated to be 0.03 kg CO2 eq. per MJ of renewable fuel produced.

Pyrolysis information for the University of Pittsburgh can be found in the appendix. Table provides values used from the inventory collection to perform the LCA. Average values of collected data were used to represent average national inputs. Detailed inventory data can be found in Appendix B.

Table 4 - Input table from inventory and source reference

Input	Value (unit)	Source(s)
	Conversion Factors	
Average yield	5.2 (Mg biomass/ ha)	(Spatari et al., 2010)
Ethanol Conversion	0.38 (L ethanol / kg biomass)	(Schmer et al., 2008)
Drop-in fuel conversion	0.097 (kg biomass / MJ)	
	Land Preparation	
Nitrogen Fertilizer	55 (kg/ ha)	(Spatari et al., 2005)
Lime	3000 (kg/ha)	(Bai et al., 2010)
	Cultivation	
Seeding rate	10 (kg/ ha)	(Bai et al., 2010; Cherubini et al., 2010; Pimentel et al., 2005; Schmer et al., 2008; Spatari et al., 2005)
Nitrogen fertilizer	86 (kg / ha / year)	(Bai et al., 2010; Schmer et al., 2008; T Searchinger et al., 2008; Spatari et al., 2010; Spatari et al., 2005; Vogel et al., 2002; Wu et al., 2006)
Phosphorus fertilizer	24.6 (kg / ha / year)	(Bai et al., 2010;T Searchinger et al., 2008; Spatari et al., 2010; Spatari et al., 2005; Wu et al., 2006)
Potassium fertilizer	67.6 (kg / ha/ year)	(Bai et al., 2010;T Searchinger et al., 2008; Spatari et al., 2010; Spatari et al., 2005; Wu et al., 2006)
Nitrogen runoff	4.79 (kg N eq. / ha/ year)	(Nearing et al., 2005; Nyakatawa et al., 2006; Sarkar et al., 2011)
Phosphorus runoff	15.3 (kg N eq. / ha / year)	(Nyakatawa et al., 2006)
Lime	150 (kg/ ha/ year)	Bai et al., 2010)
Atrazine	2.97 (kg / ha / year)	(Spatari et al., 2010; Spatari et al., 2005; Vogel et al., 2002)

Metolachlor	2.24 (kg / ha/ year)	(Pimentel et al., 2005)
	Harvesting	
Tractors & other agriculture machinery for baling	1 baling process	Ecoinvent - 1 p Baling/CH U (of project Ecoinvent unit processes)

Life Cycle Impact Assessment:

The impact assessment based on 1 kg of biomass was determined for the categories of global warming potential (GWP), acidification, eutrophication, ecotoxicity, and fossil fuel depletion. Impact factor values for agriculture were determined using Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) version 2.1. Eutrophication was adjusted based on runoff from nitrogen and phosphorus fertilizers. Additional impact in eutrophication was determined using average recorded nutrient runoff data and TRACI conversion of phosphorus to nitrogen equivalent (7.29 kg N per kg P) (Norris, 2002). GWP reduction over time was analyzed by altering the lifespan of a switchgrass field before re-establishment. Land use change is not explicitly included in the analysis. Pyrolysis impact assessment was only used to compare GHG emissions associated with well-to-tank switchgrass biofuels to expected U.S. GHG targets and reductions.

Policy Analysis:

The goal of the policy analysis was to assess the role switchgrass-derived biofuels can have in attaining RFS2 and CA LCFS GHG reductions. Previously published studies from research institutions, government agencies and private firms were used to apply the study's LCA results to national RFS2 cellulosic biofuel volumes 2014 – 2022 and CA LCFS 2020 GHG reduction goals. CA LCFS was assessed on a volume basis from a study conducted by ICF International to give annual cellulosic biofuel targets(International, 2013). The total GWP for annual targets for RFS2 and CA LCFS were determined for all cellulosic biofuel targets being produced by switchgrass-derived fuels. The LHV for switchgrass biofuel is assumed to be 35.8 MJ/L. The pyrolysis impacts based on kg of dry biomass were added to agriculture impacts from this study for comparisons.

RESULTS:

LCA Agriculture Results:

Normalized impact results of the agriculture phase for switchgrass are presented in Figure 5; the original results are presented in Appendix C. The agriculture phase can be divided into on-farm and upstream activities. The on-farm activities include events that take place during land preparation, cultivation, or harvesting on the switchgrass field. Impacts from on-farm activities include seed sowing, application of fertilizers and chemicals, nutrient runoff, and harvesting through a bailing process. The upstream activities represent the production of fertilizers and chemicals used during cultivation. The impacts from on-farm activities are much lower compared to the upstream production of agricultural chemicals in 4 of the 5 impact categories, contributing more than 60% of the impacts to these categories besides eutrophication. In the exception, nutrient runoff from the fertilizers causes eutrophication influence from on-farm activities to be high, over 83% of the total (20% from nitrogen and 63% phosphorus runoff).

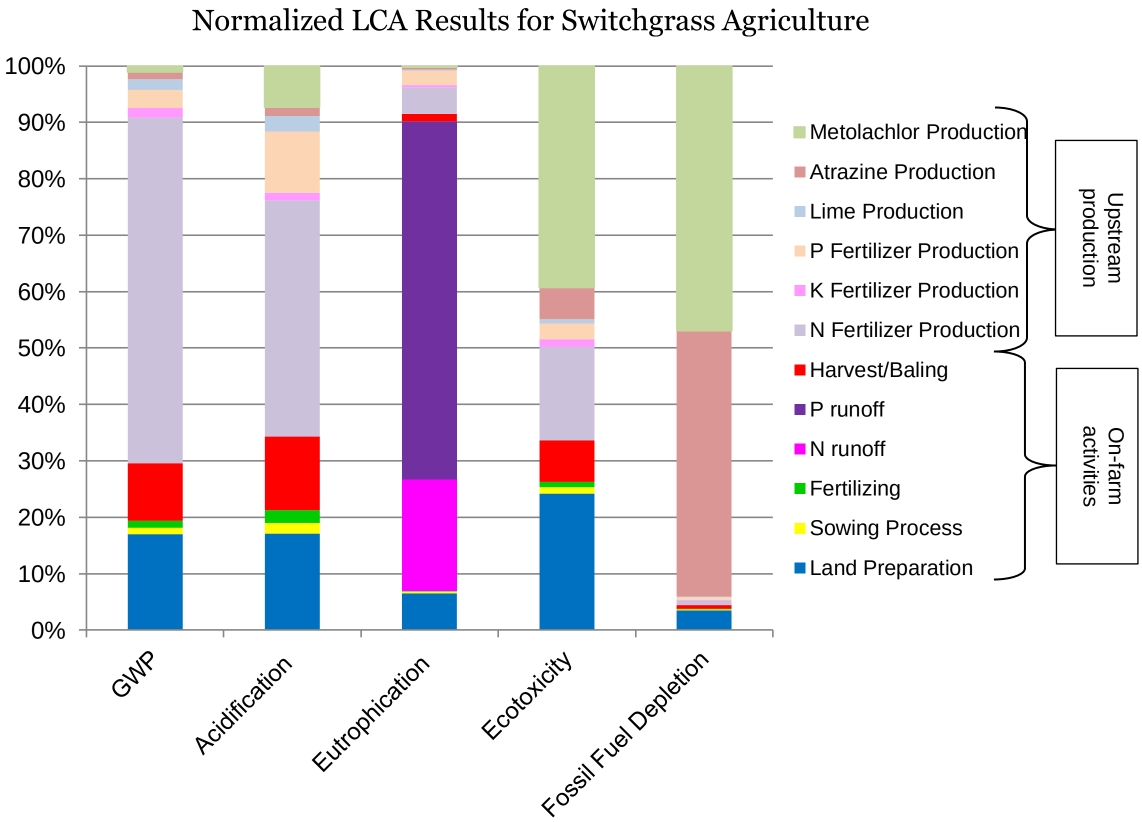

Figure 5 - **Normalized LCA Results for Switchgrass Agriculture**. The bright colors are on-farm impacts and the pale colors are from upstream production.

Of on-farm activities, the land preparation is a combination of events needed before the switchgrass seeds can be sown. Included in land preparation is the application of nitrogen fertilizer and lime and installation of irrigation on the land. Both of these activities may not be necessary in all regions of the U.S. for switchgrass agriculture. Switchgrass is known for its ability to grow on marginal lands; some farmers might decide not to include these steps to save time and money. The additional land preparation varies in its contribution to environmental impacts from 3.5% of fossil fuel depletion to 24.2% of ecotoxicity impacts. The low influence on fossil fuel depletion could encourage the agriculture industry to use irrigation and improve the soil conditions for switchgrass to ensure high yields. The GWP portion of on-farm activities comes from machinery needed for installation and application and transportation of materials and emissions to the air from fertilizers. On-farm activities include natural carbon reduction through the cultivation of the switchgrass. For GWP, the on-farm activities contribute less than 30% to the overall impact.

The runoff of nutrients from fertilizer application is the highest contributor to the eutrophication impact from switchgrass agriculture. Limited information is available for nutrient runoff from switchgrass agriculture in the literature. Research indicates that as switchgrass matures the runoff from fertilizers decreases (Lee et al., 1998; Lemus et al., 2009). This study that phosphorous runoff is the highest contribution to eutrophication impacts. The amount of fertilizer and rate of runoff for phosphorus is lower than those of nitrogen; however, the potency of phosphorus is high in nitrogen equivalent. The TRACI conversion factor for nutrient runoff indicates that each kg of phosphorus is equivalent to 7.29 kg nitrogen (Norris, 2002). Also, runoff rates depend on application rates, soil physical properties, micro-organism activity, sediment yields and rainfall volumes. (Nyakatawa et al., 2006; Sarkar et al., 2011).

Of the upstream activities, the production of fertilizer and lime are major contributors in GWP and acidification. Nitrogen production has the highest impact in all 5 categories of the fertilizers and lime application, even though the annual lime application quantity is more than 22 times greater than that of nitrogen. Nitrogen fertilizer production is the highest contributor to GWP and acidification with 61% and 42% of the impacts, respectively. The production of herbicides atrazine and metolachlor contribute heavily to fossil fuel depletion (94% total). The high impact is due to production of the herbicides being based on coal, natural gas, and crude oil. Offsets from co-products in biofuel production could reduce the impact of fossil fuel depletion for the whole lifecycle of switchgrass-derived biofuel. In general, upstream production of resources needed for agriculture require more electricity and time for operation than the farm machinery and equipment for on-farm activities.

While there have been a handful of LCAs of switchgrass for biofuels (Bai et al., 2010; Timothy Searchinger et al., 2008; Wu et al., 2006), only three previously published studies (Cherubini et al., 2010; Schmer et al., 2008; Spatari et al., 2005) separate the agricultural LCA results for comparison to GWP estimated in this study, shown in Figure **6**. Figure **6** shows that the previous LCAs range from 0.15 kg CO_2 to 0.05 kg CO_2 equivalent per kg biomass switchgrass; their results are 62 to 87% lower than the GWP estimated in this study. The highest recorded GWP from previous work is less than the impacts from the land preparation alone reported in this study. The difference in GWP shown in Figure **6** can be traced to variations in fertilizer application rates, differences in scale and region, and the estimation of soil carbon capture by the plant biomass.

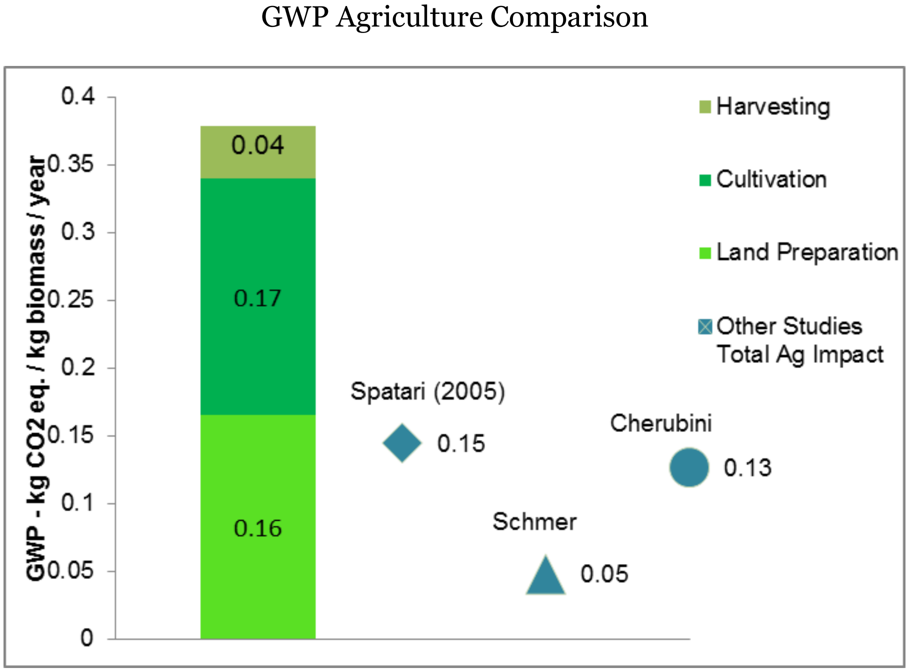

Figure 6 – **GWP Agriculture Comparison.** GWP results compared to the agricultural impacts of other switchgrass LCAs

Fertilizer is a major contributor to GHGs in the agriculture phase for biofuels, especially nitrogen fertilizer causing nitrous oxide (N_2O) emissions during cultivation. N_2O is reported to have 310 times more of an impact on global warming than CO_2 (IPCC, 2007). Increasing nitrogen fertilizer promotes high yields and will help ensure biomass for the biofuel industry to use. Adjustments in fertilizer composition and application processing can help reduce the impacts from nitrous oxide. In order to promote high yields and reduce N_2O emissions, an optimal nitrogen fertilizer application rate needs to be combined with improved application processes in the future. Spatari estimated 2.1 kg per hectare annually for N_2O emissions. Cherubini estimates 0.042 g N2O per g N fertilizer applied and also varies N_2O emissions in the sensitivity analysis of the study. Schmer does not specify N_2O emissions.

Previous LCAs have also differed from this study by focusing on regional conditions for switchgrass production, rather than estimating national agriculture impacts, which was the goal of this study. Many factors can influence impacts at the regional scale; for example the addition of lime and other nutrients is dependent on the regional condition of the soil before beginning cultivation. Regions with low soil acidity will not require lime during land preparations (Bullard et al., 2001). The literature for switchgrass agriculture covers small-scale switchgrass-for-biofuel research data for the Midwest, Southeast, and single states such as Michigan (Fike et al., 2006b; Love et al., 2011; Vogel et al., 2002). In Figure **6**, the study by Schmer et al. (2008) was unique in using 10 farms to obtain large-scale switchgrass agriculture production data, but targeted the prairie lands of Minnesota, Nebraska, North Dakota and South Dakota. Spatari and Cherubini do not provide details on the location of their studies. Using average agriculture inputs for soil preparation and seeding rates was assumed to display national averages for switchgrass cultivation.

Irrigation rates can also vary based on regional differences; assumptions around irrigation can cause the differences shown in Figure **6**. Irrigation accounts for a small amount of the GWP in this study, 0.06 kg CO_2 equivalent per kg biomass produced. The cited LCAs in Figure **6** did not include any impacts from irrigation (e.g. installation, electricity, additional runoff, etc.). Switchgrass is marketed as being an ideal biofuel crop since it can grow on marginal lands in the U.S., not requiring irrigation. However, if dependency on switchgrass derived fuels is increased, irrigation will help ensure an annual yield and reduce the risk of not meeting annual fuel targets. For example, one study showed an increase in switchgrass biomass yield cultivated in Kansas, Oklahoma, and Texas by adding irrigation to simulate a precipitation increase of 25% (Hartman et al., 2012).

Modeling accurate soil carbon capture is also a challenge for determining GWP. The previous studies based soil carbon capture on varying rates over time. From the soil carbon capture rates reviewed for this research, the maximum reduction in GWP would be 0.211 kg CO_2 equivalent, 50% of the GHG emissions based on the conservative yield of 5.2 kg biomass per hectare and the high carbon capture rate of 1,100 kg of carbon captured per hectare per year (McLaughlin et al., 1998). Spatari includes soil carbon capture as 4 kg CO2 eq. per liter ethanol. The GWP value from Schmer in includes soil carbon capture as 138.1 kg CO2 per Mg of biomass produced annually. The specific carbon capture by soil in Cherubini is not represented in Figure **6**. Additional field research including different switchgrass cultivars and soil conditions will provide important information for the agriculture industry and policy makers to determine realistic benefits from soil carbon capture from switchgrass.

Switchgrass can be cultivated without re-establishment for years, reported up to 20 years (Barry, 2008; Douglas et al., 2009). The yield of switchgrass varies annually, but is said to take 2 – 3 years to reach full maturity for a consistent yield. Figure 7compares the GWP impact of switchgrass per kg of biomass over a 15 year time period. The first bar shows the impacts associated with re-establishing the land every 3 years for 15 years total and the second bar represents the impact associated with no re-establishment for 15 years. The total GWP for the agriculture of switchgrass over 15 years is calculated to be 7.9 and 10 kg CO_2 equivalent per kg of biomass for re-establishment every 3 years and continuous for 15 years respectively. Energy use and loss are not included in the analysis.

Total GHG Emission Comparison of Re-establishing vs. Continuous Growth

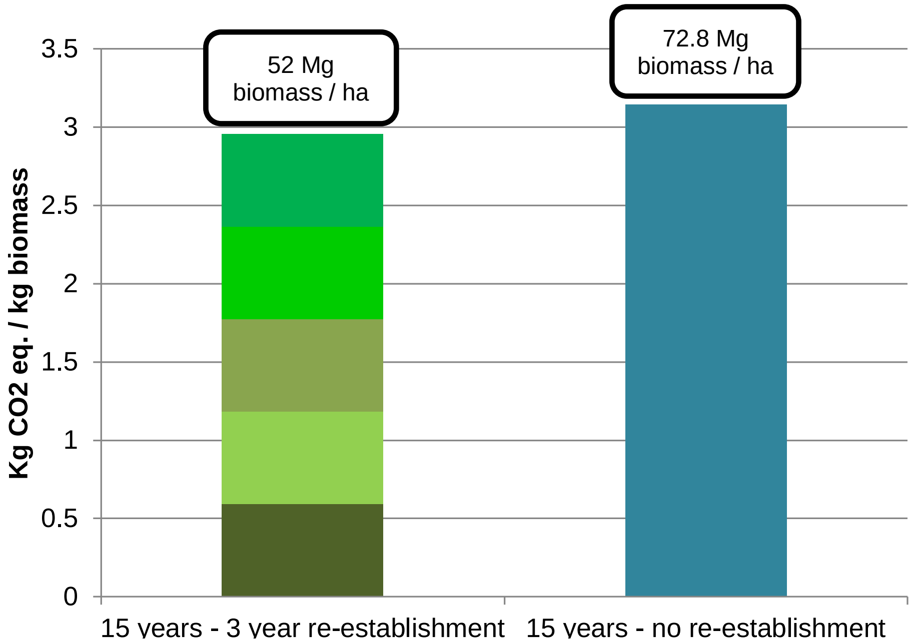

Figure 7 - **Total GHG Emission Comparison of Re-establishing vs. Continuous Growth**. The first bar represents the decision to re-establish the switchgrass every 3 years. The second bar represents allowing the switchgrass field to produce switchgrass for 15 years before re-establishment. Both bars include a year of preparation with no harvest. The textbox above gives the total biomass harvest during the 15 year time period.

The overall GWP impact over 15 years is slightly lower by re-establishing the switchgrass. The 3 re-establishment model is based on a year of preparation – initial irrigation set up, nitrogen fertilizer and lime application and sowing of the seeds, followed by 2 years of cultivation and harvest. Land preparation years do not require the additional fertilizer and application of herbicides involved in cultivation years. This causes an overall reduction in GHG emissions during those years. Year 2 and 3 are identical, including the impacts from cultivation and harvest based on the LCIA results. The total GWP for the 3 years is compounded 5 times for overall 15 year GHG emissions impact value. The 15 year model has one year of preparation and 14 of cultivation and harvest.

Before considering constant re-establishment of switchgrass as a means to reduce environmental impacts, it is important to consider the losses involved. The cost of re-establishing switchgrass frequently is loss of yield for years of re-establishment as well as limiting peak yields of switchgrass at maturity. Re-establishing switchgrass every 3 years causes a loss of 4 years of biomass over 15 years. Using the conservative biomass production yield of 5.2 Mg per hectare per year, the difference in average yield per hectare of cultivation over 15 years is 20.8 Mg between the two examples. Comparing the GWP impact per year of output shows a higher value for the re-established switchgrass strategy. The impacts from each re-establishment year are necessary for the years of cultivation that follow. By re-establishing the switchgrass every 3 years and losing a year of yield, the impacts per year of output is 0.46 kg CO_2 equivalent per output year. Allowing for 14 years of cultivation after land preparation, the GWP impact per output year is decreased to 0.39 kg CO_2 equivalent. In addition to the lower return on investment (lower GWP impact per biomass yield), the longer cultivation period before re-establishment will allow for higher yields from mature switchgrass, 3 years and later, to reduce GWP impacts per kg of biomass.

RFS2 & CA LCFS Analysis:

Switchgrass is expected to be a major contributor to targeted cellulosic biofuel volumes to meet RFS2 requirements. Figure 8 represents the GWP of using only switchgrass as a feedstock to meet RFS2 total cellulosic biofuel volumes. The agriculture emissions are calculated from this study, while the pyrolysis data is taken from research at the University of Pittsburgh on drop-in fuel production from fast pyrolysis of switchgrass. The CO_2 uptake during agriculture from the switchgrass plant and emissions from the tailpipe during biofuel use are not included in the analysis. The RFS2

60% GHG emission reduction baseline for cellulosic biofuels is based on well-to-wheel emissions from motor gasoline in 2005 (EPA, 2010). The 60% reduction baseline represents 40% of the gasoline well–to-wheel emissions for the 21.5 billion gallons of motor gasoline refined in 2005 (EIA, 2014). The figure shows a linear increase in GWP from switchgrass-derived biofuel over time. As the scale of production increases, it becomes more difficult to reach targets. The benefits from carbon capture in soil will improve the chance of switchgrass biofuels maintaining compliance with RFS2 GHG reduction targets for cellulosic biofuels.

RFS2 GHG Impacts from Switchgrass Biofuel for Cellulosic Volumes

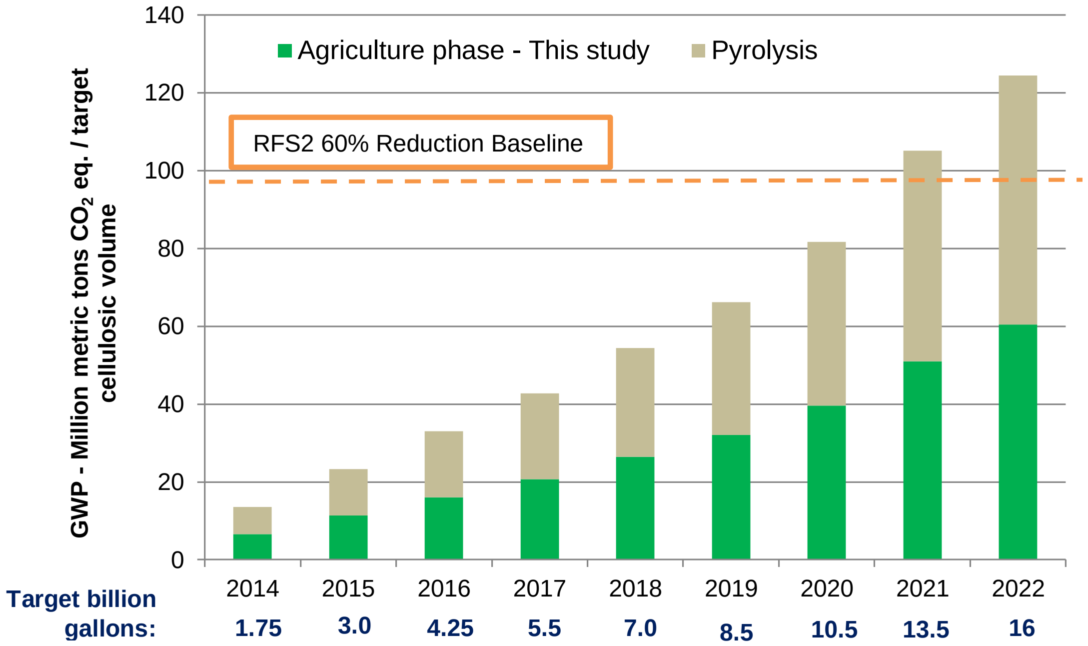

Figure 8 - **GWP of switchgrass biofuel production to meet the RFS2 target volumes for cellulosic fuel 2014-2022**. The RFS2 calls for cellulosic fuels to have a 60% reduction in lifecycle GHGs compared to gasoline emissions in 2005, represented by the 60% reduction baseline. Impacts from pyrolysis are taken from research in connection to this work at the University of Pittsburgh.

GHG impacts from agriculture are similar in quantity to impacts from pyrolysis. Switchgrass agriculture contributes 3.7 kg CO_2 equivalent per gallon of cellulosic fuel in this study. The pyrolysis data indicates that production of the switchgrass fuel contributes 4.0 kg CO_2 equivalent per gallon of fuel. The target of 1.75 billion gallons of cellulosic fuel for 2014 would produce 6.6 million metric tons of CO_2 equivalent emissions if the total volume was from switchgrass agriculture. As the volume increases to the 2022 goal of 16 billion gallons of cellulosic biofuel, the switchgrass agriculture GWP impact reaches 60.4 million metric tons of CO_2 eq. For 16 billion gallons of biofuel, the pyrolysis produces 64.1 million metric tons of CO_2 eq. Compared to pyrolysis emissions, the agriculture phase contributes 48% of the GWP total.

According to Figure 8, switchgrass-only cellulosic biofuel cannot be used to meet RFS2 GHG reduction goals. The switchgrass-only biofuel production remains under the 60% GHG reduction baseline (98.1 million metric tons of CO_2 equivalence) through the year 2020. The target volume of 10.5 billion gallons will produce 39.6 and 42.1 million metric tons of CO_2 eq. from agriculture and pyrolysis, respectively. Increasing production in 2021 to 13.5 billion gallons causes the total impact to increase 7 million metric tons over the baseline. Co-product allocation is an option to reduce total impacts from switchgrass. Through pyrolysis, co-products such as biochar and electricity offsets can be used to offset impacts for a more sustainable production of biofuel (Gaunt et al., 2008; Roberts et al., 2009). Including offsets may not be enough to allow for switchgrass-only cellulosic fuel to meet reductions. Technology improvements in any phase of the lifecycle of the fuel can also provide benefits to reduce environmental impacts. Methods of reducing tilling in agriculture and energy offsetting are examples of technology advancements that can lead to reduced lifecycle GHG emissions. (Smith et al., 2008) Other feedstock such as corn stover and woody residues will be required to contribute to cellulosic fuel volumes as well (International, 2013). These feedstocks vary in land use and conversion processing which can lead to overall reduced impacts (Njakou Djomo et al., 2012).

Similar to the RFS2, CA LCFS mandates a GHG reduction goal for the transportation sector. The goal is to reduce the average fuel carbon intensity (AFCI), mass of CO_2 eq. per MJ of fuel, from gasoline emissions by 10% by the year 2020. CA LCFS does not include projected biofuel or alternative energy volumetric or consumption targets to comply with the GHG reduction goal. A study conducted by ICF estimated the volumes of corn ethanol, sugarcane ethanol, and cellulosic biofuel to comply with CA LCFS (International, 2013). Figure **9** shows total GHG emissions from the agriculture phase and pyrolysis to meet ICF's estimated cellulosic biofuel volumes with only switchgrass-derived biofuel. Other studies provided 2020 AFCI targets from varying baseline years. Figure **10** compares the AFCI of switchgrass from this study to other 2020 baseline targets (CARB, 2009; Farrell et al., 2007; International, 2013). Due to unknown contribution from alternative fuels (electric, hydrogen, and natural gas), biofuel feedstock composition and carbon intensity (mass of GHGs per MJ of fuel), the baselines from Farrell and CARB cannot accurately be represented in total mass of GHG emissions.

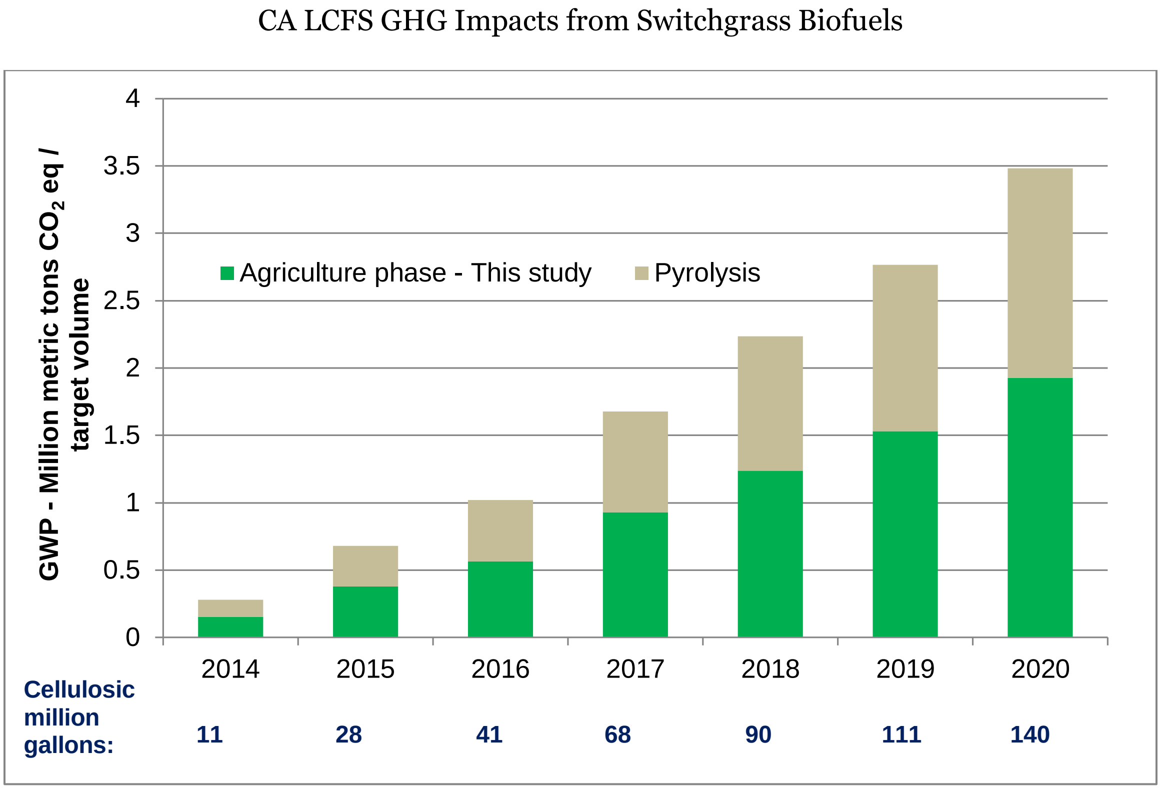

Figure 9 - **CA LCFS GHG Impacts from Switchgrass Biofuels**. The total GWP emissions associated with targeted cellulosic biofuel volumes for CA LCFS from ICF Internationals. The volume is assumed to only be met with switchgrass derived biofuel.

Alternative Fuel Carbon Intensity in 2020

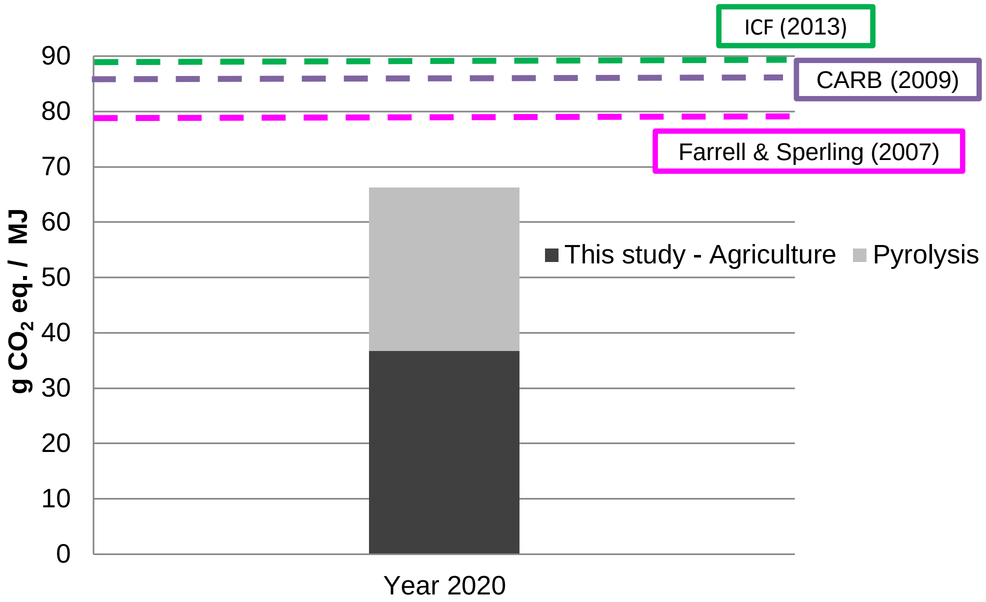

Figure 10 – **Alternative Fuel Carbon Intensity in 2020**. Average fuel carbon intensity of switchgrass cellulosic fuel compared to CA LCFS target reductions for 2020. The targets vary due to different baseline years and definition of transportation gasoline AFCI.

Unlike RFS2, the CA LCFS makes it challenging to determine the baseline to assess a 10% reduction. The program was passed in 2007, but did not begin until 2010.The studies in (CARB (2009); Farrell et al. (2007); International (2013))represent 2020 targets based on transportation AFCI in 2005, 2010, and 2013. Farrell & Sperling used 2005 data to prevent estimations in 2007 and set the 2020 compliance to 79.1 g CO2 eq. per MJ. The California Air Resource Board (CARB) estimated carbon intensities for 2010 to comply with the set CA LCFS baseline year; the CARB 2020 compliance is 86.3 g CO2 eq. per MJ. The report from ICF International used 2013 data because of an increase in carbon intensity from 96 to 98 g CO2 eq. per MJ from 2010. The ICF International baseline is the highest of the three studies at 89 g CO2 eq. per MJ. All targets are above the calculated AFCI for switchgrass-derived biofuel from pyrolysis.

According to the estimates for life-cycle GHGs in this study, switchgrass-derived cellulosic fuels could be used to meet CA LCFS. The switchgrass carbon intensity for agriculture and pyrolysis is roughly 66 g CO2 eq. per MJ, which is a 16% reduction compared to the lowest baseline from Farrell & Sperling. Final assessment of compliance for switchgrass ethanol will depend on the complete lifecycle GHG emissions for the fuel from cradle to grave with as well as using actual 2010 GHG emissions as the baseline year.

Objectives 1 & 2 are addressed from the LCA results and assessment of two current biofuel policies in place. The LCA results indicate that switchgrass agriculture has a significant influence in GHG emissions as well as environmental categories such as eutrophication. The runoff from fertilizers can have a high influence on water eutrophication. Also production of fertilizers and herbicides contribute to GHG emissions and fossil fuel depletion. The impacts from production of fertilizers and herbicides need to be considered when addressing policies such as RFS2 and CA LCFS. Switchgrass biofuels can play a role in meeting both RFS2 and CA LCFS. The RFS2 reduction target could be met with only switchgrass biofuels, but it will be a challenge as volumes increase towards 16 billion gallons. The CA LCFS has more flexibility in the volume of cellulosic fuels desired by 2020, allowing for switchgrass biofuels to be explored for compliance.

CHAPTER 3

3 ENVIRONMENTAL ETHICAL DILEMMAS AND FUTURE WORK

The goal of this chapter is to connect biofuel policy and life cycle assessment to environmental ethical dilemmas in biofuel production. The assessment is focused on common areas of concern for biofuels 1) food supply impacts, 2) water use changes and 3) land conservations. These three ethical areas are selected due to presence in the literature and media around these environmental concerns. Also, the various views on food, water, and land can be discussed on an ethical level as well as a scientific basis. The topics are assessed as value-laden issues, recognizing the areas are based on personal ethical views. Research as well personal viewpoints will need to be discussed for these areas for advancement in biofuel production. Switchgrass cellulosic biofuels are used as an example of how environmental ethical dilemmas can affect the biofuel industry and need to be incorporated in U.S. policy. The discussion on how to approach these potential problems focuses on the use of primary earth systems engineering management (ESEM) principles.

All three areas of policy, LCA and environmental ethics are interdisciplinary, complex and important for sustainable biofuel production. Biofuels seem like the clear solution to problems of energy sourcing and dependency, yet issues of food supply, land use changes / ecosystem alteration, and water use require additional thought. Using switchgrass biofuel as an example for the U.S., the chapter highlights potential dilemmas that will require the combination of policy and life cycle impact assessments for a sustainable solution.

Environmental ethics are moral principles used to determine the role and extent of interaction between humans and the natural world (Taylor, 2011). Chapter 1 discussed how environmental ethics has become a Western set of ethics placing humans above the rest of living organisms, an anthropocentric outlook on the relationship between mankind and nature. Environmental ethics has expanded, incorporating ecology, engineering, and philosophy ideals in creating systematic principles to guide actions involving nature (Minteer, 2009). The areas discussed for environmental ethics can be seen more as value-laden issues compared to current understanding in the environmental ethics research community.

Dilemmas in Biofuel Production:

Food vs. fuel

The idea that first –generation biofuels will hinder the food supply has been around since the start of corn ethanol in the 1930's (Escobar et al., 2009). The skepticism has advanced due to some believing that supporting liquid ethanol is also supporting world hunger (P. B. Thompson, 2012). Some in the U.S. believe that this argument is based on a fixed, limited crop yield; the more agriculture used for biofuel production means less for food distribution. The scientific data collected on biofuels can be distorted to appeal to the emotional ties to hunger. For example, a study reported that in 2004, the US used 32 million tons of corn to convert to fuel that equaled only 12% of the national fuel supply. That same tonnage of corn was estimated to have the ability to feed 100 million people using average world consumption levels (Stein, 2007). Number comparisons like these support the idea of biofuel production contributing to world hunger. Food supply impacts and world hunger are part of the reason for advancing to 2nd and 3rd generation biofuels to meet energy demands.

In addition to hunger, economic impacts on food is a dilemma still around for biofuels. A general rise in the price of food in 2006 - 2007 strengthens a link between biofuels and food supply. Models simulating the growth of biofuels predict that as biofuel demand increases, higher global prices for biofuel feedstock and food crops will occur due to competition for land (Koh et al., 2008). However, shifts in food prices have many factors such as extreme seasons, pestilence, and political interference (P. B. Thompson, 2012). The increase in prices on food cannot solely be placed on the development of biofuel. Also, this cost adjustment largely affects those living in developed countries where most purchase their food vs. those who live an agrarian lifestyle in developing land. The United Nations reports that nearly 80% of people living below the extreme poverty standard across the world are in rural areas and food entitlement comes from personal agricultural development (P. B. Thompson, 2012).

The food vs. fuel debate has been misrepresented. It paints an image of the food being snatched out of the hands of starving individuals in order to support those in high socio-economic standing. Food supplies and production have not reached their limits. Currently there is tons of excess food wasted every year ("Food Wasted," 2013). Proper allocation would contribute highly to reducing world hunger. Also, the market drivers for biofuel production skewing the consumption rates and costs of agriculture are not solely dependent on biofuels. Politics, weather, alternative uses for crops, and other factors play a role as well. The concerns for biofuels' impacts on food supply seem to be addressed towards the scientists and policy makers for supporting biofuel production. The debate is lacking an overall view of who should be involved and what type of framework/programs can be put in place to strategically work on biofuels and ensuring that benefits reach all levels, including the small & poor farmers (P. B. Thompson, 2012).

Switchgrass will play a role in the food vs. fuel debate even as a 2nd generation biofuel. The adjustments in animal feed will contribute to displacing other crops, possibility corn and soybean, for feed. The additional land and water needed for production will also contribute to a change in agriculture production. The influence might not be as direct as with corn, soybeans, and sugar, but due to the complexity of the system, the connection will still be present.

Water Use

Water use may be a major ethical dilemma as biofuel production continues to grow. Access to clean water is still a major global problem that has not been solved. The water used for the cultivation and production of biofuels will generally need to be clean, fresh water to ensure proper crop yields and composition. There may be some areas for reuse and recycling, but the majority of water is consumed as first use water. In 2007, it was reported that 42% of all U.S. freshwater withdrawals are for agricultural use, but 85% of the total U.S. freshwater consumption ends up being used for agriculture irrigation (Wu et al., 2009). The global annual water withdraws for agriculture use is 85% (Gomiero et al., 2010). Increases in cultivation of biofuel feedstocks may require additional irrigation infrastructure and additional volumes of water. The crops may have to compete for water with other uses in water-limited regions. For example the Southwest U.S. has limited fresh water availability, depending heavily on groundwater pumping.

Biofuel cultivation is not the sole process that requires water. Refineries and distilleries can require up to 4 gallons of water to produce a single gallon of ethanol (Mattison et al., 2005). At this rate, the volume of water used to produce 100 million gallons of ethanol is enough to support a town of 5,000 people for a year (Koh et al., 2008). Other studies have shown that to produce 1 liter of ethanol, it can take between 1.9 and 9.8 liters of water depending on the chemical conversion processes (Wu et al., 2009). Switchgrass is reported to require higher water use overall compared to corn (VanLoocke et al., 2012).

Increasing the cultivation of switchgrass or another feedstock will change the water consumption proportions and create stress between government, residents, and industry. Schaible et al. (2012) made the connection between location and standard use of regional water. Depending on the location of the cropland and addition of irrigation, government policy such as Native American water-right claims may be involved. Of the 57 million acres of irrigated cropland & pasture land in 2007, roughly 75% falls on 17 Western states, home of numerous reservations. These states applied nearly 74 million acre feet (or 24 trillion gallons) of water to crops. Additional water irrigation could become restricted in these areas and lead to more policies required to secure water rights. Native American water-right claims are estimated to account for nearly 46 million acre feet annually in 2008 and are not expected to decrease. Ethical viewpoints would affect how to proceed with attaining additional water for feedstock irrigation. Stress could then be created between other sectors due to the need to redirect water volumes and enact additional policies.

Studies on water use for switchgrass development have indicated that proper precipitation is directly related with biomass yield (Hartman et al., 2012; VanLoocke et al., 2012). These studies did not consider additional water application through irrigation, but their results support the benefits of irrigation. Mimicking the precipitation patterns of responsive regions such as the northern plains can alter water distribution in other agriculture regions. Regions will see the benefits from additional water on the switchgrass and may need to reevaluate current agriculture water use. One study comparing biomass yield variability of switchgrass in Oklahoma, Kansas, and Texas showed an increase in biomass yield in all three states by simulating a 25% increase in annual precipitation (Hartman et al., 2012). The water shifts were meant to resemble possible climate change results, but can still be used to support the additional water irrigation for higher biomass yield.

Water use in switchgrass agriculture and biofuel production may cause shifts in water allotment and issues for states and the entire country. Recycling water or improved efficiency of water delivery could reduce the impacts of irrigated water for agriculture use. The waste water from the refineries can be used for cooling/heating the facility to reduce the needed volumes. Runoff capture improvements and onsite water treatment on farmlands can contribute to the additional water desired for optimal biomass yield.

Land conversion

In the category of land conversion, biocentric and anthropocentric ethical views can be seen in biofuel production. Those focused on increasing biofuels for fuel improvements and energy options will encourage the increase in biofuel crop production. Deforestation, biodiversity, and ecosystem alternations will be the concern of biocentric individuals. Policy will be a major influence on regulation and management of land use for biofuel production.

Switchgrass and other crops such as miscanthus and canary reed grass are popular for biofuel production because they are known for their ability to grow in wide weather conditions and on marginal lands. The U.S. has over 230 million hectares of marginal land, 68 million hectares noted as being suitable for crops and vegetation (Cai et al., 2010). One research paper calculated that if switchgrass was used to fuel the San Francisco Bay area vehicles for one year, it would require near 7 million acres of agricultural land, roughly 80% of the irrigated lands for crops in California (Patzek, 2010). Utilizing this land for biofuel production can lead to high volumes of biofuel, but also environmental impacts associated with land use change and policies to regulate the cultivation of the energy crops.

Biofuel agriculture expansion will lead to land use conversion and possibly conflict. Transport of biofuel crops to new regions for cultivation may prove negative on native species. Because the upland cultivars of switchgrass tend to yield higher cellulose content, there may be a transition of upland cultivars to new regions. Many strands of switchgrass place their roots deep into soil for high stability; this root establishment could contribute to its invasiveness in new regions. Introduction of these ecotypes on marginal lands across the country could aid in increasing cellulosic volumes, but also lead to switchgrass becoming invasive in certain ecosystems (Nageswara-Rao et al., 2013).

How to Manage Dilemmas using Ethics, Policy, and LCA:

The Role of Research & Policy

Policies are seen as means to regulate and keep a process or market operational and beneficial. For the biofuel industry in the U.S., policies can stifle production or require advancements. With alternative fuels in the U.S., national and state specific initiatives have supported continuous development of biofuel options without explicitly addressing areas of concern or uncertainty such as impacts on the food supply, land use change, and environmental impacts outside of GHGs.

National policies such as the Energy Independence and Security Act (EISA) set the standards for the objectives of biofuel policies and methods of assessing effectiveness. Sustainable policies for biofuels will need to not only consider biofuel environmental impacts and economic stability, but also include consideration of the environmental ethical concerns discussed.

Policies such as EISA support interest in switchgrass biofuel production research, but commonly are not installed until after research and motivation for alternative fuels is present. Small scale research provides insight on theoretical ideal conditions for large scale production. After determining feasibility of large scale production, technology and industrial support allows for large scale production. This can lead to changes in resource availability and national environmental conditions, in which most biofuel policy does not consider. The result will likely be preparing for a policy to counteract the unintended consequences or a return to research to find solutions for the consequences Figure **11** shows a current option for the progression of biofuel policy, highlighting that the current set up revisits experimental research only after unintended consequences are seen and policy is not involved until after large scale production is available.

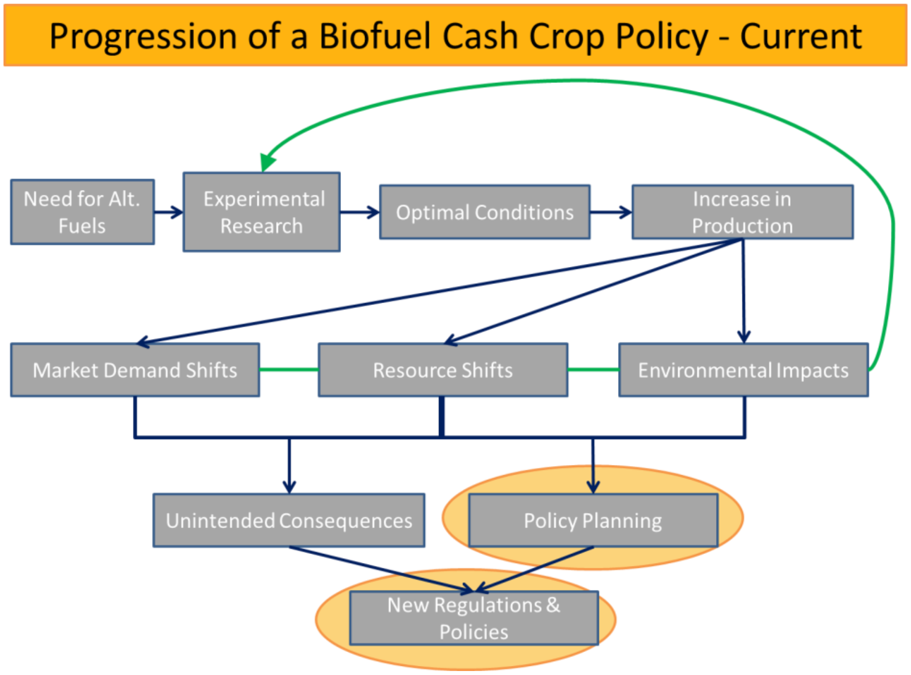

Figure 11 – **Progression of a Biofuel Cash Crop Policy Current.** This is a sample process flow diagram of producing policies for biofuel. The green loop indicates the review of research after increased production causes unintended consequences. The orange ovals indicate areas where policy is included in the process.

The current progression of biofuel policy supports a retrospective approach to evaluating conditions. It is not until the overstressing of the system that policies are reviewed. Incorporating life cycle thinking into policy design can enable a prospective outlook, incorporating the impacts of policies prior to their installment and foreseeing potential benefits and issues. Also, by including policy, directly and indirectly related topics, will allow for a holistic assessment of the change in fuel sources. Figure **12** shows an adjusted approach to the policy making process including life cycle thinking and policy planning during research and a re-evaluation of progress of the policy. The adjustment now has three areas where policy is involved in the creation of the new biofuel specific legislation. This will help include policy makers in the progression of the biofuel development, to keep them informed for the decision making process. The process adds policy review to the experimental phase of alternative energy development. This review includes other energy policy as well as any that relate to other environmental fields such as water use, land conservation, and biodiversity in the region. New techniques such as LCA make it easy for all sectors involved in the production and use of the biofuel to be accounted for. LCA is generally geared at environmental impacts of a product or service, but research using life cycle thinking can review any impacts within a designated system boundary. By using comparative and characteristic life cycle thinking during the research phases, policy makers can anticipate consequences of large scale implementation. Policy makers can also benefit from beginning with a pilot incentive as a test of a policy. It is important to pilot or test the policy; which can be accomplished via computational approaches, voluntary test markets, or other pilots of the policy.

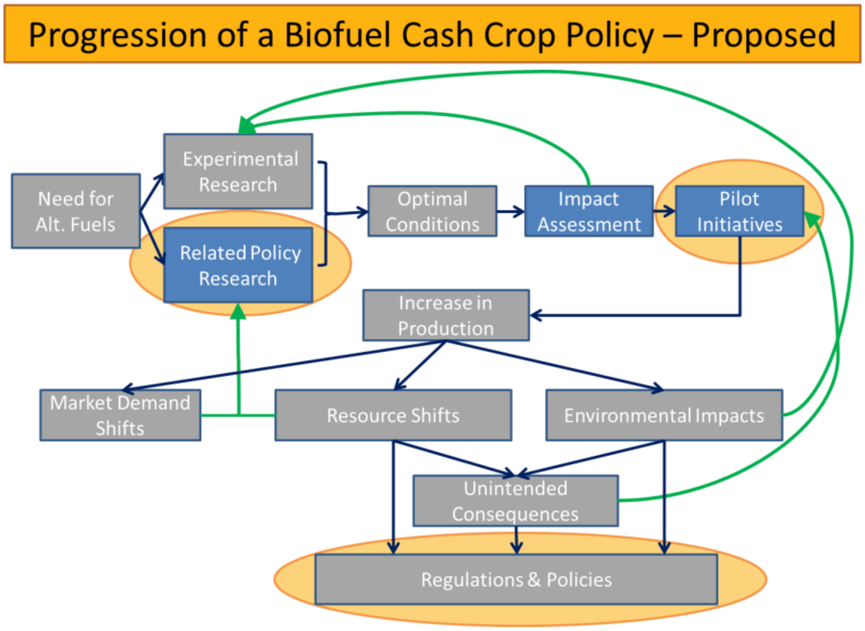

Figure 12 – **Progression of a Biofuel Cash Crop Policy Proposed.** The updated flow of creating biofuel policies incorporates life cycle thinking and related environmental policies throughout the process. Relative fields and markets are reviewed while experimental research is occurring to foreshadow unintended consequences. Additional proposed steps are highlighted in blue.

Taking the ethical dilemma of water use as an example, the proposed process would require that along with the research conducted on producing cellulosic ethanol from switchgrass under different irrigation conditions, review and research on water policy and water use in agriculture in different regions should be performed. During this step, engineers and environmental researchers can work together to understand and model expected water use outcomes in various regions of the country. Using the results from both areas of research, optimal growth and production conditions can be agreed upon and explored for large scale implementation. Next a prospective LCA can be performed including the restraints of both biofuel and water policies when collecting inventory data. Impact assessment values may indicate that the current arrangement would not be beneficial, helping to prevent unexpected negative environmental impacts and indicating the need for more research. Once impact assessment results are estimated for reasonable outcomes, an initiative or incentive can introduce the ideal production of switchgrass. For example, there may be an incentive for farmers of Alamo switchgrass to reduce water use by 15% by using tax credits for saving a certain number of gallons annually. Growth in switchgrass production, water use or other unintended consequences can be observed from participants and used to move forward with any policy development. The shifts in resources and markets could potentially lead to areas of weakness in current policies or indicate policies missing from consideration. Returning to the research phase of the program could be required to prevent a new policy installment to counteract the indirect shifts. If the environmental impacts from the prospective LCAs are not as expected, additional research may be needed in order to prevent extreme negative impacts. If the preliminary initiative results in the extreme stress on a system, then it will not be successful as a required policy. Once a voluntary initiative is seen as successful in resource use and environmental impacts, a designated policy or regulation can be place for all members of the industry to follow. Policies will be different based on regional needs, but should all work together for federal concerns.

Policies not only need to be used for the biofuel industry, but also to protect all parties and industries involved. There needs to be consideration given to food security, environmental impacts, and the rights of the farmers and landowners. The UK Nuffield Council on Bioethics report provides insight into where policy may be needed to prevent unethical actions (Buyx et al., 2011; P. Thompson, 2012). The report can be broken into 1) common good of mitigating climate change, 2) respect human rights and vulnerable populations and 3) increasing stewardship, sustainability, and intergenerational justice. Five principles make up the framework proposed by Nuffield in order to be applied to biofuel production.

1) Biofuels development should not be at the expense of people's essential rights
2) Biofuels should be environmentally sustainable

3) Biofuels should contribute to net reduction of total GHG emissions and not exacerbate global climate change
4) Biofuels should recognize the rights of people to just reward
5) Costs and benefits of biofuels should be distributed in an equitable way (Buyx et al., 2011)

Similar to the Nuffield principles, earth systems engineering management (ESEM) provides principles to guide human involvement in natural processes and systems. ESEM principles make discussion for ethical dilemmas possible with statements that require thought. The next section uses ESEM principles to discuss the progression of switchgrass-derived biofuels.

Involvement and Handling Environmental Ethics – Earth System Engineering Management:

An approach to consider ethical dilemmas tied to biofuel production is to use ESEM principles to guide the discussion. The three ESEM principles used for the discussion are 1) limit involvement 2) be aware of boundaries and expect failure outside the boundary and 3) evaluate technology's role. These three categories are briefly discussed because of their obvious connection to biofuel production and ability to support all sides of the environmental ethical dilemmas discussed in this thesis.

ESEM Principle - Limit involvement

The ethical dilemmas discussed in this thesis incorporate an element of human involvement. With involvement in natural systems brings more concerns and possibilities of unintended consequences. A principle of ESEM says to *"Only Intervene when necessary and only to a required extent.*" (Allenby, 2007). Inputs of land and water for switchgrass are limited and currently used as resources for other products or industries. The extended growth of switchgrass can lead to exploitation of our resources and creates a need for continuous intervention to address unintended consequences.

Take for example the initial growth of corn ethanol. The increase in business for Midwest farms and environmental benefits made corn ethanol very appealing. (Akinci et al., 2008; Sorda et al., 2010). Research was conducted continuously to develop higher ethanol blended gasoline and vehicles for intervention in the fuel industry. The required extent of use of corn ethanol was not understood. As popularity grew, corn markets began to feel the stress from a new heavy purchaser. Restrictions and policies began to be put in place to balance the industry and counteract intervention. That is one of the reasons why corn ethanol is capped in the RFS2. Also, this began the search for alternative sources of fuel and second generation biofuels such as switchgrass (Buyx et al., 2011).

ESEM Principle - Be aware of boundaries & alert to other areas of failure

The complexity of the system of switchgrass-derived biofuel can be seen from the various potential ethical dilemmas discussed. Another earth system engineering management principle discusses the importance of being honest about complex systems, not over simplifying to remove real world links and connections (Allenby, 2007). This ESEM principle says *"it is critical to be aware of the particular boundaries within which one is working and to be alert to the possibility of logical failure when one's analysis goes beyond the boundaries."* The popularity of switchgrass as a biofuel feedstock includes its perceived a) reduction on demand on human food supply b) provision of a more sustainable and environmentally-friendly means to meet fueling demands, and c) enhancement of energy efficiency compared to corn. Simplifying the issue of switchgrass vs. corn to any of these areas could cause a misunderstanding and present a false view of the situation. For example, there is research that supports the conclusion that switchgrass is not the right change from corn for biofuel production (Patzek, 2010). Patzek presents a study comparing the use of switchgrass with corn, highlighting the importance of recognizing the system boundaries are not just based on agriculture, energy, or environmental impacts but rather the combination of these areas.

Boundary definition is very important to be understood because anthropocentric and biocentric individuals might envision different systems. The anthropocentric viewpoint on switchgrass biofuels might focus on the fact that switchgrass is not included in the human diet. A biocentric view might reach to include the animals that have switchgrass as feed. This viewpoint might also be more sensitive to the adjustments in biodiversity than economic markets for increased switchgrass. Incorporating this ESEM principle in policy creation ensures that the complex boundary can be made clear to all involved.

ESEM Principle – Evaluate technology

There are technology improvements in ethanol production efficiency and reductions of GHGs due to the shift in fuel use that will accompany the increased biomass production and ethanol yield, but it is still only relative. The ESEM principle focusing on technology also incorporates the importance of evaluation prior to large scale development (Allenby, 2007). This ESEM principle states: *"the capability to model and dialogue with major shifts in technological systems should be developed before, rather than after, policies and initiatives encouraging such shifts."* The prospective thinking of the impacts from the technology with small scale evaluation will allow for scenarios to be created, researched, and predict economic and social outcomes. Similarly, we would not want to invest in a switchgrass biofuel monopoly until the technology involved is fully understood. A review of ethical obligations by policy makers and scientists brings up the following point:

> "At present, it is almost impossible to predict exactly whether a technology will emerge as a successful biofuels pathway that avoids causing harmful consequences. What can be said with confidence is that the lessons learned from

> the problems of established biofuels must be integral in the development of new ones in order not to repeat the mistakes of the past. Meanwhile, it is clear that established biofuels will continue to play a role while new products emerge, but mechanisms to mitigate their negative effects are imperative."(Buyx et al., 2011)

The technology around biofuel production is not at its limit and will continue to grow. In order to account for the constant development, techniques such as LCA will allow for prospective insight before large scale implantation. The combination of LCA in research and policy around technology will help stability in the complex system. The view on the state of biofuel production, from switchgrass or other feedstock is still a personal matter as technology changes. This ESEM principle enables conversations about the role of technology from anthropocentric and biocentric individuals involved.

Conclusions & Future Work:

The optimal conditions to produce switchgrass biomass will be researched in order meet alternative fuel goals and take advantage of incentives. The inputs for cultivation are the first factors that can lead to increasing the odds of having high biomass yield. Nutrients are vital to the growth process. Nitrogen fertilizer along with other nutrients may need to be supplied to the fields regularly to increase the odds of high yield. Additional water use through irrigation will most likely be involved in best agriculture solutions. Research will need to consider the combination of fertilizers, irrigation, land use, and environmental concerns from anthropocentric and biocentric members in the biofuel industry.

The future work on switchgrass derived biofuels will need to reduce the amount of uncertainty currently present. The data available for agriculture is regionalized. Switchgrass has the potential to grow in the majority of the continental U.S., but there is a lack of data from some regions, making country-wide estimates unrealistic. Also, agriculture inputs in general will need more data. Water use and irrigation is one large area of uncertainty that future work should focus on. For total environmental impacts to be accurately represented, land use changes will also need to be agreed upon in future research. Current literature does not agree on how to consider the tradeoffs associated with the conversion of lands for agriculture or production needed for the biofuel industry. Greater understanding on these uncertainties will be useful for the progression of the biofuel industry.

Additional research combining policy, environmental impact assessment tools, and potential ethical dilemmas will allow for assessment of overall sustainable influence of switchgrass biofuel. As seen with the RFS2 goals and CA LCFS policies, switchgrass derived ethanol and replacement fuels can meet environmental goals of reducing GHGs, but still impact eutrophication, water use, and land use. LCA only enables policies to evaluate environmental impacts; other aspects of sustainability such as economics and social implications are not quantified with LCA tools. Finding ways to use LCA and other means of considering unintended consequences is still important for policies. ESEM principles on intervention, boundary definition, and technology involvement can help shape the involvement of policy and technology in switchgrass derived biofuel production.

Research on the restructuring of policy fulfilment will need to be conducted for future advancement of biofuels policy. For switchgrass biofuels to meet national and state specific energy targets, the current process of using policy for biofuel feedstock and production should include life cycle thinking early to avoid large scale unintended consequences. Also, policy will need to be assessed on how to account for shifts in other industries.

A discussion of environmental ethics and the biofuel industry is necessary to understand the different views on biofuel production. Today, anthropocentrism and biocentrism (placing the best interests of individual living organisms first) can be seen in arguments for and against the biofuel industry. It is a challenge to incorporate these outlooks into biofuel policy and technology advancement. Switchgrass-derived biofuel serves as an example that next generation biofuels also have ethical dilemmas besides food vs. fuel. The focus on marginal lands for switchgrass agriculture causes concern for ecosystem invasion. Also, growth in popularity and dependency on switchgrass as a biofuel feedstock will encourage additional nutrient treatment and irrigation for higher yields. Farmers who consider converting their land for switchgrass production will need to consider the additional costs and impacts associated with consistent high biomass production. Policy makers need to consider the life cycle of switchgrass biofuel impacts as well as the social concerns of industries involved such as farmers and local governments. The policies encourage high volumes of advanced fuels without addressing the unintended consequences from increasing human involvement in natural systems. As switchgrass grows in popularity, additional research on the relationships between policy, new technology, and environmental impacts will benefit the country as the government works towards sustainable energy policies.

REFERENCES

Air Pollution Control Act, Pub. L. No. P.L. 84-159 (1955).

Air Quality Act of 1967, Pub. L. No. P.L. 90-148 (1967).

Akinci, B., Kassebaum, P. G., Fitch, J. V., & Thompson, R. W. (2008). "The role of bio-fuels in satisfying US transportation fuel demands". *Energy Policy, 36*(9), 3485-3491.

Allenby, B. (2007). "Earth Systems Engineering and Management: A Manifesto". *Environmental Science & Technology, 41*(23), 7960-7965.

Alternative Motor Fuels Act (1988).

Bai, Y., Luo, L., & Voet, E. (2010). "Life cycle assessment of switchgrass-derived ethanol as transport fuel". *The International Journal of Life Cycle Assessment, 15*(5), 468-477.

Barry, P. (2008). Switchgrass may yield biofuel bounty. *Science News, 173,* 46-46.

Bullard, M., & Metcalfe, P. (2001). "Estimating the energy requirements and CO2 emissions from production of the perennial grasses miscanthus, switchgrass and reed canary grass". *London, England: ADAS Consulting Ltd.*

Buyx, A. M., & Tait, J. (2011). "Biofuels: ethics and policy-making". *Biofuels, Bioproducts and Biorefining, 5*(6), 631-639.

Cai, X., Zhang, X., & Wang, D. (2010). "Land Availability for Biofuel Production". *Environmental Science & Technology, 45*(1), 334-339.

Callicott, J. (2012). "Ecology: An Ethical Perspective".

CARB. (2009). Staff Report: Initial Statement of Reasons (C. E. P. Agency, Trans.) *Proposed Regulation to Implement the Low Carbon Fuel Standard* (Vol. 1). Sacramento, CA: California Air Resource Board.

Carson, R. (2008). *Silent Spring (1962)*.

Charles, M. B., Ryan, R., Ryan, N., & Oloruntoba, R. (2007). "Public policy and biofuels: The way forward?". *Energy Policy, 35*(11), 5737-5746.

Cherubini, F., & Jungmeier, G. (2010). "LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass". *The International Journal of Life Cycle Assessment, 15*(1), 53-66.

Clean Air Act Amendments, Pub. L. No. P.L. 88-206 (1963).

Clean Air Act Amendments of 1970, Pub. L. No. P.L. 91-604 (1970).

Clean Air Act Amendments of 1977, Pub. L. No. P.L. 95-95 (1977).

Clean Air Act Amendments of 1990, Pub. L. No. P.L. 101-549 (1990).

Demirbas, A. (2009). "Political, economic and environmental impacts of biofuels: A review". *Applied Energy, 86, Supplement 1*(0), S108-S117.

Dixon, R. K., McGowan, E., Onysko, G., & Scheer, R. M. (2010). "US energy conservation and efficiency policies: Challenges and opportunities". *Energy Policy, 38*(11), 6398-6408.

Douglas, J., Lemunyon, J., Wynia, R., & Salon, P. (2009). *Planting and Managing Switchgrass as a Biomass Energy Crop*.

EIA. (2014). *U.S. Total Gasoline Retail Sales by Refiners*. Retrieved from: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=A103600001&f=A

Energy Policy Act of 1992 (1992).

EPA, U. S. (2010). Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis (O. o. T. a. A. Quality, Trans.).

Escobar, J. C., Lora, E. S., Venturini, O. J., Yáñez, E. E., Castillo, E. F., & Almazan, O. (2009). "Biofuels: Environment, technology and food security". *Renewable and Sustainable Energy Reviews, 13*(6–7), 1275-1287.

Farrell, A. E., & Sperling, D. (2007). A Low-Carbon Fuel Standard for California, Part 1: Technical Analysis.

Fike, J. H., Parrish, D. J., Wolf, D. D., Balasko, J. A., Green Jr, J. T., Rasnake, M., & Reynolds, J. H. (2006a). "Long-term yield potential of switchgrass-for-biofuel systems". *Biomass and Bioenergy, 30*(3), 198-206.

Fike, J. H., Parrish, D. J., Wolf, D. D., Balasko, J. A., Green Jr, J. T., Rasnake, M., & Reynolds, J. H. (2006b). "Switchgrass production for the upper southeastern USA: Influence of cultivar and cutting frequency on biomass yields". *Biomass and Bioenergy, 30*(3), 207-213.

Food Wasted. (2013). 53 words, *World Today,* p. NEWS; Pg. 12.

Gaunt, J. L., & Lehmann, J. (2008). "Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production". *Environmental Science & Technology, 42*(11), 4152-4158.

Gomiero, T., Paoletti, M., & Pimentel, D. (2010). "Biofuels: Efficiency, Ethics, and Limits to Human Appropriation of Ecosystem Services". *Journal of Agricultural and Environmental Ethics, 23*(5), 403-434.

Hartman, J. C., Nippert, J. B., & Springer, C. J. (2012). "Ecotypic responses of switchgrass to altered precipitation". *Functional Plant Biology, 39*(2), 126-136.

International, I. (2013). California's Low Carbon Fuel Standard: Compliance Outlook for 2020.

IPCC. (2007). *The physical science (Fourth Assessment Report).* Cambridge, UK: Cambridge University Press Retrieved from http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html.

Koh, L. P., & Ghazoul, J. (2008). "Biofuels, biodiversity, and people: Understanding the conflicts and finding opportunities". *Biological Conservation, 141*(10), 2450-2460.

Lee, K. H., Isenhart, T. M., Schultz, R. C., & Mickelson, S. K. (1998). "Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA". *Agroforestry Systems, 44*(2-3), 121-132.

Lemus, R., Parrish, D. J., & Wolf, D. D. (2009). "Nutrient Uptake by 'Alamo' Switchgrass Used as an Energy Crop". *BioEnergy Research, 2*(1-2), 37-50.

Lewandowski, I., Scurlock, J. M. O., Lindvall, E., & Christou, M. (2003). "The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe". *Biomass and Bioenergy, 25*(4), 335-361.

Love, B. J., & Nejadhashemi, A. P. (2011). "Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan". *Biomass and Bioenergy, 35*(5), 2200-2216.

Mattison, E. H. A., & Norris, K. (2005). "Bridging the gaps between agricultural policy, land-use and biodiversity". *Trends in Ecology & Evolution, 20*(11), 610-616.

McDonald, S., Robinson, S., & Thierfelder, K. (2006). "Impact of switching production to bioenergy crops: The switchgrass example". *Energy Economics, 28*(2), 243-265.

McGee, C., & Chan Hilton, A. B. (2011). "Analysis of federal and state policies and environmental issues for bioethanol production facilities". *Environ Sci Technol, 45*(5), 1780-1791.

McLaughlin, S. B., de la Torre Ugarte, D. G., Garten, C. T., Lynd, L. R., Sanderson, M. A., Tolbert, V. R., & Wolf, D. D. (2002). "High-Value Renewable Energy from Prairie Grasses". *Environmental Science & Technology, 36*(10), 2122-2129.

McLaughlin, S. B., & Walsh, M. E. (1998). "Evaluating environmental consequences of producing herbaceous crops for bioenergy". *Biomass and Bioenergy, 14*(4), 317-324.

Minteer, B. A. (2009). *Nature in common?: environmental ethics and the contested foundations of environmental policy*: Temple University Press Philadelphia, PA.

Nageswara-Rao, M., Stewart, C. N., Jr., & Kwit, C. (2013). "Genetic diversity and structure of natural and agronomic switchgrass (Panicum virgatum L.) populations". *Genetic Resources and Crop Evolution, 60*(3), 1057-1068.

Nearing, M., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., . . . Renschler, C. (2005). "Modeling response of soil erosion and runoff to changes in precipitation and cover". *Catena, 61*(2), 131-154.

Njakou Djomo, S., & Ceulemans, R. (2012). "A comparative analysis of the carbon intensity of biofuels caused by land use changes". *GCB Bioenergy, 4*(4), 392-407.

Norris, G. A. (2002). "Impact Characterization in the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts". *Journal of Industrial Ecology, 6*(3-4), 79-101.

Nyakatawa, E. Z., Mays, D. A., Tolbert, V. R., Green, T. H., & Bingham, L. (2006). "Runoff, sediment, nitrogen, and phosphorus losses from agricultural land converted to sweetgum and switchgrass bioenergy feedstock production in north Alabama". *Biomass and Bioenergy, 30*(7), 655-664.

Organization, I. (2006). "ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework".

Patzek, T. (2010). "A Probabilistic Analysis of the Switchgrass Ethanol Cycle". *Sustainability, 2*(10), 3158-3194.

Pimentel, D., & Patzek, T. (2005). "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower". *Natural Resources Research, 14*(1), 65-76.

Resource Conservation and Recovery Act (1976).

Roberts, K. G., Gloy, B. A., Joseph, S., Scott, N. R., & Lehmann, J. (2009). "Life cycle assessment of biochar systems: Estimating the energetic, economic, and climate change potential". *Environmental Science & Technology, 44*(2), 827-833.

Safe Drinking Water Act (1974).

Sanderson, M. A., Reed, R. L., McLaughlin, S. B., Wullschleger, S. D., Conger, B. V., Parrish, D. J., . . . Tischler, C. R. (1996). "Switchgrass as a sustainable bioenergy crop". *Bioresource Technology, 56*(1), 83-93.

Sarkar, S., Miller, S. A., Frederick, J. R., & Chamberlain, J. F. (2011). "Modeling nitrogen loss from switchgrass agricultural systems". *Biomass and Bioenergy, 35*(10), 4381-4389.

Schaible, G. D., & Aillery, M. P. (2012). Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands (E. R. Service, Trans.) *Economic Information Bulletin* (pp. 67): U.S. Department of Agriculture.

Schmer, M. R., Vogel, K. P., Mitchell, R. B., & Perrin, R. K. (2008). "Net energy of cellulosic ethanol from switchgrass". *Proceedings of the National Academy of Sciences, 105*(2), 464-469.

Searchinger, T., Heimlich, R., Houghton, R., Dong, F., Elobeid, A., Fabiosa, J., . . . Yu, T.-H. (2008). "Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change". *Science, 319*, 1238 - 1240.

Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., . . . Yu, T.-H. (2008). "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change". *Science, 319*(5867), 1238-1240.

Sims, R. E. H., Mabee, W., Saddler, J. N., & Taylor, M. (2010). "An overview of second generation biofuel technologies". *Bioresource Technology, 101*(6), 1570-1580.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., . . . Smith, J. (2008). "Greenhouse gas mitigation in agriculture". *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*(1492), 789-813.

Sokhansanj, S., Mani, S., Turhollow, A., Kumar, A., Bransby, D., Lynd, L., & Laser, M. (2009). "Large-scale production, harvest and logistics of switchgrass (Panicum virgatum L.) – current technology and envisioning a mature technology". *Biofuels, Bioproducts and Biorefining, 3*(2), 124-141.

Sorda, G., Banse, M., & Kemfert, C. (2010). "An overview of biofuel policies across the world". *Energy Policy, 38*(11), 6977-6988.

Spatari, S., Bagley, D. M., & MacLean, H. L. (2010). "Life cycle evaluation of emerging lignocellulosic ethanol conversion technologies". *Bioresource Technology, 101*(2), 654-667.

Spatari, S., Zhang, Y., & MacLean, H. L. (2005). "Life Cycle Assessment of Switchgrass- and Corn Stover-Derived Ethanol-Fueled Automobiles". *Environmental Science & Technology, 39*(24), 9750-9758.

Stein, K. (2007). "Food vs Biofuel". *Journal of the American Dietetic Association, 107*(11), 1870-1878.

Stroup, J. A., Sanderson, M. A., Muir, J. P., McFarland, M. J., & Reed, R. L. (2003). "Comparison of growth and performance in upland and lowland switchgrass types to water and nitrogen stress". *Bioresource Technology, 86*(1), 65-72.

Surface Transportation Assistance & Highway Revenue Act (1982).

Taylor, P. W. (2011). *Respect for nature: A theory of environmental ethics*: Princeton University Press.

Thompson, P. (2012). "The agricultural ethics of biofuels: climate ethics and mitigation arguments". *Poiesis & Praxis, 8*(4), 169-189.

Thompson, P. B. (2012). "The Agricultural Ethics of Biofuels: The Food vs. Fuel Debate". *Agriculture*, 19.

Toxic Substance Control Act (1976).

Tyner, W. E. (2008). "The US Ethanol and Biofuels Boom: Its Origins, Current Status, and Future Prospects". *BioScience, 58*(7), 646-653.

USDA. (2010). A USDA Regional Roadmap to Meeting the Biofuel Goals of the Renewable Fuel Standard by 2022 *USDA Biofuels Strategic Production Report*.

VanLoocke, A., Twine, T. E., Zeri, M., & Bernacchi, C. J. (2012). "A regional comparison of water use efficiency for miscanthus, switchgrass and maize". *Agricultural and Forest Meteorology, 164*(0), 82-95.

Vogel, K. P., Brejda, J. J., Walters, D. T., & Buxton, D. R. (2002). "Switchgrass Biomass Production in the Midwest USA This research was funded in part by the U.S. Dep. of Energy's Biomass Fuels program via Oak Ridge Natl. Lab., USDA-ARS, and the Univ. of Nebraska. Contract no. DE-A105-900R21954. Joint contrib. of the USDA-ARS and the Univ. of Nebraska Agric. Exp. Stn. as Journal Article 13263". *Agron. J., 94*(3), 413-420.

Wu, M., Mintz, M., Wang, M., & Arora, S. (2009). "Water Consumption in the Production of Ethanol and Petroleum Gasoline". *Environmental Management, 44*(5), 981-997.

Wu, M., Wu, Y., & Wang, M. (2006). "Energy and Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment". *Biotechnology Progress, 22*(4), 1012-1024.

APPENDIX A

USDA PROPSAL GOAL AND OBJECTIVES

The goal of the proposed research is to quantify the policy implications of increased biofuel production. We will evaluate the environmental impacts associated with 2nd and 3rd generation biofuels, specifically focusing on **perennial grasses, sorghum, and oil seeds** for the production and commercialization of drop-in biofuels in each of the four US Census Bureau defined regions of the US. We propose to evaluate the feasibility of meeting the EISA Renewable Fuel Standards (EISA RFS) as well as local policies such as the Penn Security Initiative and California's Low Carbon Fuel Standard (LCFS). Finally, we aim to evaluate strategies for avoiding or mitigating any unintended consequences. The specific objectives include:

1. Develop life cycle inventory (LCI) and LCA modules for several biomass to drop-in replacement biofuel pathways. The modules will contain essential information about the processes for the LCA of a variety of advanced drop-in replacement biofuels. Feedstocks will include **perennial grasses, sorghum, and oil seeds;** they will be modeled in each of the four US Census Bureau defined regions of the US.
2. Identify implications of existing and future renewable fuel policies, biomass feedstocks, processing methods, upgrading pathways, final fuel and coproduct mixes, and emissions in the U.S.
3. Assess the policy ramifications and unintended consequences of using several different biomass feedstocks and conversion pathways for producing low biofuels and other useful bioproducts in the U.S. context.

   Disseminate the data, LCA modules, and findings via the USDA Commons

APPENDIX B

INVENTORY COLLECTION

Year	Author	Title	Functional Unit / Focus of Paper	Seeding		Carbon Sequestration		Fertilizer/Nutrients		Water	
2005	Sabrina Spatari, Yimin Zhang and Heather L. MacLean	Life Cycle Assessment of Switchgrass and Corn Stover-Derived Ethanol Fueled Automobiles	8 Mg/ha/year switchgrass yield	8.3	kg/ha			55	kg N/ ha prep		
		Sup. Info	1 Km of driving					7.5	kg N/Mg switchgrass		
								80	kg N/ ha		
								2.1	Kg P/ Mg switchgrass		
								18.8	kg P/ha		
								8.8	kg K/Mg switchgrass		
								88.8	kg K/ha		
2010	Yu Bai, Lin Luo, Ester van der Voet	Life Cycle Assessment of switchgrass derived ethanol as transport fuel	power for 1-km driving of midsize car	10	kg/ha			100	kg N./ha		
								40	kg P/ha		
								80	kg K/ha		
								3000	kg Lime/ha		
2010	Francesco Cherubini, Gerfried Jungmeir	LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass	amount of biomass treated per year, 477 kt(dry)/a of switchgrass	15	kg/ha	0.2 - 1.1	t C/ha per year (Paustian 2006)	112	kg N/ha (Smeets 2009)		
						0.53	t C/ha per year (McLaughlin 2002)	17	kg P/ha (Smeets 2009)		
						0.102	kg CO2 eq / kg switchgrass (assuming 5.2 Mg bio/ha	54	kg K/ha (Smeets 2009)		
						0.212	high range Kg CO2 /kg switchgrass	150	kg Lime/ha (Bullard & Metcalfe 2001)		
2008	M.R. Schmer, K.P. Vogel, R.B. Mitchell, R.K. Perrin	Net Energy of Cellulosic Ethanol from Switchgrass	5.2 to 11.1 Mg/ha biomass yield	10	kg/ha	138.1	kg C/Mg of biomass per year (estimated)	10	kg N/Mg expected yield per ha		
		Supporting Tables (http://www.pnas.org/content/suppl/2007/12/21/0704767105.DC1#T1)				4.42	Mg C/ ha per year (Northern Plains)	74	kg N/ha per year (average)		
						0.138	kg CO2 eq / kg biomass				
	May Wu, Ye Wu, Michael Wang	Energy and Emission Benefits from alternative liquid fuel derived from switchgrass				48500	g/dry ton (Andress 2002)	10635	g N/dry ton		
						0.0485	kg CO2 eq / kg biomass	142	g P / dry ton		
								228	g K/ dry ton		
	Timothy Searchinger, Ralph Heimlich, R.A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, Tun-Hsiang Yu	Use of U.S. Croplands for Biofuels INCREASES Greenhouse Gases Through Emissions from Land Change									
2010	Sabrina Spatari, David M. Bagley, Heather MacLean	Life cycle evaluation of emerging lignocellulosic ethanol conversion technologies	1 L of Ethanol			53500	g CO2 / dry metric ton SG	11.7	g N/dry Kg SG		
						0.0636	Kg CO2 / kg switchgrass biomass	0.16	g P/dry Kg SG		
								0.25	g K/dry Kg SG		
	NOT From LCA Studies										
2009	Rocky Lemus, David J. Parrish, Dale D. Wolf	Nutrient Uptake by Alamo Switchgrass Used as an Energy Crop	Average biomass yield of 15.9 Mg/ha per year					50	kg N/ha		
								Moderate levels as relative to corn P and K			
2002	Kenneth Vogel, John Brejda, Daniel Walters, Dwayne Buxton	Switchgrass Biomass Production in the Midwest USA Harvest and Nitrogen Management	10.6 - 12.6 Mg / ha biomass yield	430	PLS / m2			0	kg N per ha tested		
								60			
								120	* Found as optimal rate		
								180			
								240			
								300			
	David Pimentel, Tad Patzek	Ethanol Pro. Using corn, SW, and wood; Biodiesel pro. Using soybean and Sunflower	10,000 kg yield, 40 million kcal yield	1.6	kg / ha per year			50	kg /ha per year		
	S.B. McLaughlin, D.G. De La Torre Ugarte, C.T. Garten Jr., L.R. Lynd, M.A. Sanderson, V.R. Tolbert, D.D. Wolf	High-Value Renewable Energy from Prairie Grasses	Social & environmental costs of production of Switchgrass				*See paper figure 2				
						0.76	Mg C/ha/year for 10 yrs				
						130	Tg C over 10 yrs				
						0.53	Mg C/ha/year for 30 yrs				
						0.16	kg CO2 / kg biomass (assuming 5.2 Mg bio/ha)				
1998	S.B. McLaughlin, D.G. De La Torre Ugarte, C.T. Garten Jr., L.R. Lynd, M.A. Sanderson, V.R. Tolbert, D.D. Wolf	Evaluating Environmental Consequences of Producing herbaceous crops for bioenergy	10 Mg/ha/year (unirrigated)			1.1	Mg C/ha/year for 5 years				
			13.5 Mg/ha/year used in energy calc			0.212	kg CO2 / kg biomass (assuming 5.2 Mg bio/ha)				
			37 Mg/ha maximum								
	Carla A. Gunderson, Ethan B. Davis	Exploring Potential U.S. Switchgrass Production for Lignocellulos	10-12 Mg/ha dry mass per year								

Chemicals		Land		Crop Yield		Energy		Machines		Notes
4.15	kg atrazine/ha					59	MJ/kg N fertilizer	7.7	L/tonne grass Tractors	Emissions per MJ of diesel fuel from equipment from Wang
						7.8	MJ/kg K fertilizer			
						190	MJ/kg			
2.5	kg herbicides /ha (Smeets 20	29.8	kha							
		3 to 9	ha per field			43.8	Seed energy MJ/kg			
		220	kg/ha seed yield			1365	MJ/ha (not including fertilizer)			
28	g herbicide/ dry ton	5.5	sqmi							Used GREET in modeling
		3520	acres							
		1424.5	ha							
0.031	g Atrazine/dry Kg SG			11.2	dry metric ton/ha/year			280	MJ/dry metric ton	Dry weight comp = 37.4% Glucan, 24.9% xylan, 3.4% arabinan, 1.1% galactan, .3% mannan, 23.6% lignin
										N2o emissions = 1.5% of fertilizer applied
										See Wang (2007) and Laser et al (2009)
										Used plots in KY, NC, TN, VA and WV
2.24	kg Atrazine kg a.i. per ha									
2.24	kg Metolachlor a.i. per ha									
1.1	kg 2,4-D a.i. per ha									
3	kg / ha per year									
		16.9	Mha	9.4	Mg/ha				*Same as hay	Table 3 compares corn and switchgrass GHG reduction to gasoline. Economic gain expressed throughout the paper
				158	dry Tg					
						17.8	GJ/ha/year in crop production			Information on Carbon Emissions & costs
						220.2	Gj/ha/year in biomass energy			
						10.2	GJ/ha/year in ethanol production			
						104.4	GJ/ha/year in ethanol energy			
										Information on references for precipitation, compared 30 papers for yield values

APPENDIX C

NUTRIENT RUNOFF CALCULATIONS

Nutrient Runoff Averages

Author	Title	N	P	Notes
Nyakatawa, Mays, Tolbert, Green, Bingham	Runoff, sediment, nitrogen, and phosphorus losses from agricultural land converted to sweetgum and switchgrass bioenergy feedstock production in north Alabama	nitrate loss - 1 -8 kg/ha	Average P runoff 2.1 kg/ha	>200 kg/ha sediment yield. Factors include- soil physical properties, micro-fauna activity, soil infiltration rates, rainfall volume, sediment yields
Sarkar, Miller, Fredrick, Chamberlain	Modeling nitrogen loss from switchgrass agricultural systems	7.5 - 4.9 kg/ha for 67 kg N, 10 - 7 kg/ha for 90 kg N		approximately 50-67% less loss than that from cotton. Fertilization rate of 67 kg/ha. For 90 kg/ha, esimated to have lose range 10-7 kg/ha. Study focused on the SE
Kikiema, Rothstein, Min, Kapp	Nitrogen fertilization of switchgrass increases biomass yield and improves net ghg balance in north Michigan			Nitrogen stimulated CO2 uptake increasing biomass yield. The IPCC methodology provides a N20 emission factor as a function (12.5 g /kg) of the amount of applied fertilizer N. No run off data provided
Nearing	Modeling response of soil erosin and runoff to changes in precipitation and cover	28.2 - 13.5 %		
		0.24 kg N / kg NO3	7.29 kg N / kg P	Norris 2002 TRACI Impact factors
		Average N (kg N equ / ha) **4.79**	**Average P (kg N equ/ ha)** **15.31**	

APPENDIX D

PYROLYSIS INFORMATION

TRACI IMPACTS For Fast Pyro - Normalized to 1 MJ of Output Renewable Fuel			TRACI 2 v4	
TRACI Impacts (w/Bioelectricity Offset)	**Ozone depletion**	**Global warming**	**Smog**	**Acidification**
Units	kg CFC-11 eq	kg CO2 eq	kg O3 eq	mol H+ eq
Total	1.18535E-09	0.029575831	0.001334195	0.009571944
TRACI Impacts (w/Biochar Offset)	**Ozone depletion**	**Global warming**	**Smog**	**Acidification**
Units	kg CFC-11 eq	kg CO2 eq	kg O3 eq	mol H+ eq
Total	1.34409E-09	0.026439095	0.001498292	0.010806272
Normalized to 1 kg dry biomass				
Units	kg CFC-11 eq	kg CO2 eq	kg O3 eq	mol H+ eq
w/bioeletricity offsets	1.22285E-08	0.305113241	0.013763962	0.098747081
w/biochar offsets	1.38661E-08	0.272753726	0.015456836	0.111480775

Assume Dry basis

0.38	L ethanol / kg biomass (Schmer & Vogel 2008)
0.288	L fuel / kg biomass (This study)
0.076	Gal fuel / kg biomass (This study)

Input Biomass*	
Wet Basis (kg/day)	2000000
Dry Basis (kg/day)	1500000
Output Renewable Fuel	
Density (kg/L)	0.836
LVH (MJ/L)	35.8
Fuel Volume (L/day)	432247.343
Fuel Volume (Gallon/day)	114187.6451
Fuel Mass (kg/day)	350251.6318
Fuel energy (MJ/day)	15474454.88

Useful relationships for normalizing impact categories	
kg Biomass (Wet Basis)/MJ-Renewable Fuel	0.12925
kg Biomass (Dry Basis)/MJ-Renewable Fuel	0.09693

*Assumes 25% Moisture Content

Eutrophication	**Carcinogenics**	**Non carcinogenics**	**Respiratory effects**	**Ecotoxicity**
kg N eq	CTUh	CTUh	kg PM10 eq	CTUe
9.98166E-05	1.45449E-09	3.22903E-09	2.95751E-05	0.025714076
Eutrophication	**Carcinogenics**	**Non carcinogenics**	**Respiratory effects**	**Ecotoxicity**
kg N eq	CTUh	CTUh	kg PM10 eq	CTUe
0.000113112	1.64047E-09	3.65101E-09	3.33281E-05	0.028807635
kg N eq	CTUh	CTUh	kg PM10 eq	CTUe
0.001029738	1.50049E-08	3.33116E-08	0.000305106	0.265274201
0.001166901	1.69236E-08	3.7665E-08	0.000343823	0.297188298

APPENDIX E

RFS2 AND CALCFS INFORMATION

			Agriculture Impact for Switchgrass Cellulosic Fuel					Pyrolysis Impact
Year	Total RFS2 Target (billion gallons)	Cellulosic biofuel (billion gallons)	GWP (million metric tons CO2 eq.)	Acidification (thousand metric tons SO2 eq.)	Eutrophication (thousand metric tons N eq.)	Ecotoxicity (billion CTUe)	Fossil Fuel Depletion (billion MJ surplus)	GWP (million metric tons CO2 eq.)
2014	18.15	1.75	6.6022	31.2781	80.9388	12.3385	0.2974	7.0141
2015	20.5	3	11.3180	53.6196	138.7522	21.1516	0.5098	12.0242
2016	22.25	4.25	16.0338	75.9612	196.5655	29.9648	0.7222	17.0342
2017	24	5.5	20.7496	98.3027	254.3789	38.7780	0.9346	22.0443
2018	26	7	26.4086	125.1125	323.7550	49.3538	1.1895	28.0564
2019	28	8.5	32.0676	151.9223	393.1311	59.9297	1.4444	34.0684
2020	30	10.5	39.6130	187.6687	485.6325	74.0308	1.7842	42.0845
2021	33	13.5	50.9309	241.2884	624.3847	95.1824	2.2940	54.1087
2022	36	16	60.3626	285.9714	740.0115	112.8088	2.7188	64.1288

2005 CO2 emissions from transport motor gasoline = 1,186.1 metric tons
2005 gasoline well to tank GHG emissions = 19.2 kg CO2 equ / mmbtu of fuel
well to wheel = 98.2 kg CO2 equ / mmbtu of fuel
diesel = 18 kg CO2 eq / mmbtu fuel
US EPA. Office of Transportation and Air Quality. Assessment and Standard
Division. Renewable Fuel Standard Program (RFS2) Regulatory Impact
Analysis. Washington, DC, USA; 2010. p. 467
LHV (Lowest heating value) energy content = 116090 btu / gal gasoline
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, version 1.7. 2007. Input Fuel Specifications. Argonne National Laboratory. Chicago, IL

	ICF International Study			GWP (kg CO2 eq.)				Acidification	Eutrophication	Ecotoxicity	Fossil Fuel Depletion
Year	MG Cellulose	L	kg biomass (0.38 L per kg)	Ag	Pyrolysis	Total	Total (million metric tons CO2 eq.)	kg SO2 eq	kg N eq	CTUe	MJ surplus
2013	5	18927063	49808060	18863312	15197098	34060411	0.0341	33959.1	14719.6	13396042.9	322862.0
2014	41	155201914	408426089	154679161	124616208	279295369	0.2793	278464.7	120700.9	109847552.1	2647468.8
2015	100	378541253	996161193	377266248	303941970	681208217	0.6812	679182.1	294392.5	267920858.8	6457241.0
2016	150	567811880	1494241790	565899371	455912955	1021812326	1.0218	1018773.1	441588.8	401881288.1	9685861.5
2017	246	931211483	2450556535	928074969	747697246	1675772215	1.6758	1670787.9	724205.6	659085312.5	15884812.8
2018	328	1241615311	3267408714	1237433292	996929661	2234362953	2.2344	2227717.2	965607.5	878780416.7	21179750.4
2019	406	1536877489	4044414444	1531700965	1234004397	2765705362	2.7657	2757479.3	1195233.6	1087758686.6	26216398.3
2020	511	1934345805	5090383697	1927830525	1553143466	3480973990	3.4810	3470620.5	1504345.8	1369075588.3	32996501.3

Carbon Intensity Values for Fuels that Substitute Gas

	Carbond Intensity (gCO2eq/MJ)
Cellulosic	21.3

Baselines	Year	Value (gCO2/MJ)	10% target
ICF	2013	98	89
CARB	2010	95.9	86.3
Farrell & Sperling	2005	87.9	79.1