SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

CESEM

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Life Cycle Assessment of Switchgrass Ethanol for Arizona

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Executive Summary

An increase in population and need to protect the planet has created many initiatives and research goals in developing alternatives methods of fueling. Federal and state policies have provided a push for industries to find ways to of reducing their impact on the environment while maintaining competitiveness. In the sector of alternative fuels, large policies such as the Renewable Fuel Standards (RFS) in the United States are making goals to reduce vehicular fuel from coal and oil, and focus on alternative fuels such as ethanol and biodiesel. Along with the RFS and other federal policies, states are introducing independent initiatives to promote the use of alternative fuels.

Research has shown that other crops besides corn can feasibly be used to produce ethanol for fuel use. One of the major crops of interest currently is switchgrass (*Panicum Virgatum L.*) because of its ability to grow under a variety of weather conditions and soil types. Switchgrass does not require as much maintenance as corn and is a perennial grass that can have high yielding fields for up to 9 years.

This report focuses on the impacts from using switchgrass-derived ethanol to meet the state of Arizona's policy to have government fleet vehicles operating on alternative fuels. The study uses a life cycle assessment (LCA) approach to evaluate 22 million gallons of ethanol produced in Arizona and stored at fueling stations for use. Impacts in land use, global warming, and water quality are evaluated using software tools and databases in Ecoinvent and Simapro.

The results of the study indicate that the cultivation and harvest phase of the process will contribute the most to negative environmental impacts. According to the study, application of heavy nutrient fertilizer and the machinery needed for the additional agriculture have the potential to contribute over 36 million moles of hydrogen and 89 million CTU eq. to the air, soil, and water.

The study provides preliminary insight into the cultivation of switchgrass for biofuels in Arizona, but does require additional research. The results do not provide values for global warming impacts comparable to that of previously published LCA work. The geographic locations are different; however the cultivation and harvest phase is expected to provide a carbon negative or carbon neutral process. Also, information on water irrigation was not assessed due to switchgrass being marketed as a crop not requiring large moisture content

in the soil. The dry, arid conditions of the southwest will most likely need for occasional watering to ensure that the soil is moist and the switchgrass will survive the warmer seasons. Another LCA with accurate global warming impacts and Arizona-specific water requirements would be needed before any assessments on the feasibility of switchgrass ethanol being used to meet fleet vehicles needs could be made.

INTRODUCTION

I. Project Background

The search to fulfill alternative energy initiatives and policies in the US has been geared heavily towards biomass feedstock for fuels. Ethanol from corn has been a large push in the past and infrastructure has become more common across the country to accommodate high-percent ethanol operational automobiles. Other agricultural feedstock is being researched for their ability to comply with biofuel regulations. Perennial grasses such as switchgrass are appealing because of their lack of required maintenance, and ability to adapt to multiple weather conditions and grow on marginal lands.

This study looks into the impacts from producing switchgrass-derived ethanol in order to meet some state policies. There are many policies and mandates that encourage the production of alternative fuels, but there is a lack of review in what that will take as far as land, energy, and other resources. Geographical and logistical differences will alter the impacts and should be considered prior to making decisions on what type of alternative fuel source to invest in. For example, the southwest United States needs to be conscious of water used for irrigation and land nutrient levels when deciding on what feedstock to grow for fuel.

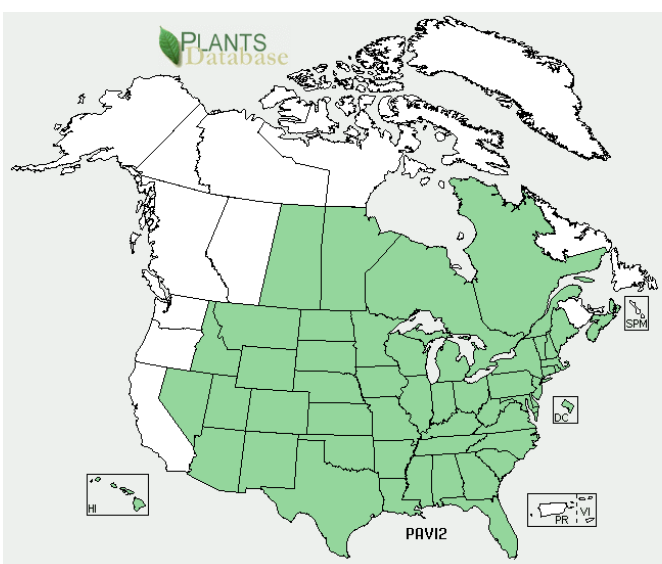

Figure 1 - Native locations of switchgrass cultivars (Source: USDA National PLANTS Database)

Since some switchgrass cultivars are native to the state of Arizona, this study attempts to consider the impacts from producing switchgrass locally in order to produce ethanol for a state policy on alternative energy. The state has set the goal to convert all government fleet vehicles to be hybrid electrical (HEVs), alternative fuel (AFVs) or meet low emission standards according to Arizona Statute 41-803. Along with this statute, Arizona Revised Statute 49-573 requires 90% of federal fleets in counties larger than 1.2 million people to operate on alternative fuel. Since Maricopa County holds more than half of the citizens in the state, both regulations need to be met. The set up allows life cycle thinking to explore the consequences involve with the area being completely dependent on regional switchgrass for biofuel production.

II. Research Goal & Purpose

The purpose of the study is to begin the thought process of considering the impacts associated with fulfilling biofuel policies across the country. The preliminary results from this study provide 1) insight into the large scale use of switchgrass-derived ethanol, 2) indications of what processes will contribute the most to environmental concerns, and 3) what areas of study need more diligent records and research. The information in this report should be sought after by policy makers, energy & agriculture organizations, local farmers, and the biofuel production industry.

METHODOLOGY

I. Functional Unit Selection & Reference Flows

The functional unit (FU) needs to capture the characteristics of vehicle operation feasibility, improve the quality of air emissions from vehicles, and apply to state laws or incentives regarding alternative energy options. Some positioning (not necessary but are appealing to consumers) properties for the FU include ease of production, storage needs, and costs. The FU chosen for the study is the volume of fuel (gal) needed in Maricopa County, AZ to accommodate one year of vehicular operation for all government fleet vehicles. The LCA will be footprint-ing the use of switchgrass biofuel in order to assess the likelihood of adoption in Arizona and then can be compared to other cellulosic agriculture crops such as corn and soybeans to produce ethanol for fuel blending as well as pure use. Some other alternatives could be renewable energy sources converted to power vehicles such as electricity and fuel cells, but are not large options in engine operation.

The reference flows used to evaluate the FU of the study need to also determine the impact switchgrass biofuel will have on land use, water quality, and infrastructure needs in the study area for one year. Reference flows of energy, water, and switchgrass will provide the details needed to assess the changes of interest. These flows will also be used to calculate the environmental indicators of 1) land occupation, 2) global warming, and 3) water/soil/air quality through acidification, ecotoxicity and eutrophication during the life cycle impact assessment of the study.

II. System Boundary

The figure below shows the system of interest for the study. Flows of materials as well as energy and emissions are recorded through the cradle to gate process of switchgrass biofuel production. The boundary begins with switchgrass growth and cultivation because an increase in land, fertilizer, and water use will be needed to produce additional biofuel. The boundary stops at fuel dispensing stations and does not evaluate the use phase vehicle operation. The impacts of using switchgrass-derived ethanol in vehicles over gasoline or corn ethanol have been previously studied and recorded (Bai et al, 2010, Kim, S., & Dale, B. E., 2005, and Spatari, S., Zhang, Y., & MacLean, H. L., 2005). Switchgrass ethanol has been seen to reduce GHG emissions from gasoline and impact on environmental indicators of global warming and resource depletion compared to gasoline. Co-products, such as the switchgrass stover after lipid extraction, are not evaluated in the study.

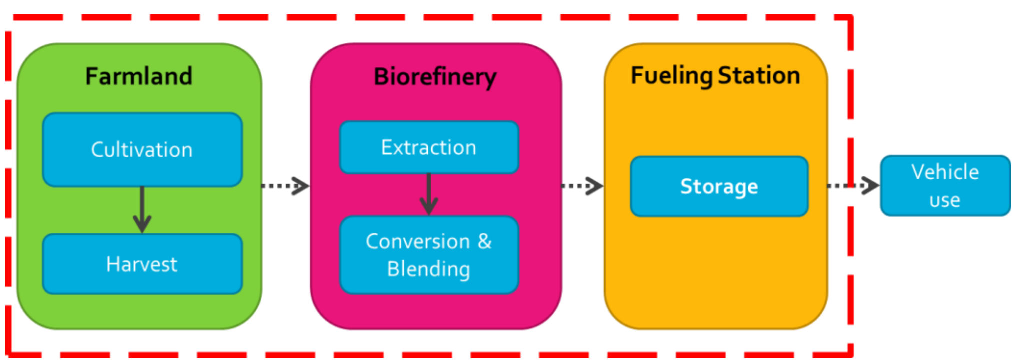

Figure 2 - The production and use of switchgrass ethanol. The study system boundary is inside the red dashed line.

III. Data Collection and Life Cycle Inventory

Data for inputs and outputs are gathered from previous switchgrass studies and community databases on biofuel production. Cultivation quantities and yields for switchgrass are taken from the United States

Department of Agriculture (USDA) Agricultural Research Services (ARS) database. The database provides annual planting and harvest information based on geographic location. The fertilizer/ nutrient mix is taken from Bai et al. (2010) and other USDA fact sheets. Simapro 7.3 is used to determine information on harvesting and cultivation machinery as well as for ethanol conversion processes. Further conversion data is taken from published papers such as Kim and Dale (2005) and Schmer (2008).

Between each process in the system is a transportation component. Switchgrass is highly adaptable and can be grown on marginal lands of a variety of geographical conditions, but it is most common to the northern prairies of the United States east of the Rocky Mountains and into the Midwest. Sladden, Bransby, and Aiken (1991) provides details of the switchgrass availability in the southeast U.S., but recent research has shown that upland switchgrass, found in the northern states, produces more biomass than lowland species such as Alamo and Kanlow in the south (Fike et al, 2006). Switchgrass material from the plains before or after extraction would have to travel across the country to provide Arizona with biofuel. This study will assume that the switchgrass is grown local to Arizona and all biorefineries and blending stations will be in the state. The travel estimations will be similar to Bai et al. (2010) and use data from the Ecoinvent database (www.ecoinvent.org).

IV. Means of Assessment

The U.S. Energy Information Administration (EIA) as well as the Arizona Department of Transportation (AzDOT) provides details on vehicle-miles of travel, motor fuel consumption, state government fleet vehicle registration numbers, and the average fuel economy for use in determining fuel needs for a year in the study area. A linear increase in fleet vehicles and equal allocation of state fuel consumption was assumed for 2013. Inventory of process flow elements was conducted using the recent peer reviewed publications, switchgrass agriculture best practice information from the United States Department of Agriculture, as well as processes found in Ecoinvent. After the collection of inventory, Simapro 7.3 was used for modeling and impact assessment.

INVENTORY

I. Volume of Fuel Needed

The functional unit is based on all state government fleet vehicles operating in accordance to Arizona Statues 41-803 and 49-573 and beyond. Instead of having 90% of the vehicles operating on alternative fuels, the study is using a volume of fuel that will support all the vehicles in the fleet as of 2013 for an entire year. Records from US Census Bureau reported over 3.9 million people living in Maricopa County in 2012, over half of the entire state population. AzDOT records reported 138,667,600 gallons of diesel and 1,551,997,191 gallons of gasoline used in 2011-2012 fiscal year. The county's vehicle registrations totaled 3,761,859 for 2011, of which 50,714 were government vehicles (1.35% of the total).

Assumptions need to be made about the increase in vehicles over time and allocation of fuel. A direct proportion and equal distribution of fuel use is taken for ease of calculations. In reality, there will be different demands of fuel between industrial, commercial, and personal vehicles. Volumes of fuel use in Maricopa County from 2001 to 2012 have fluctuated without a trend. An increase in vehicle fuel is predicted to continue at the same increase rate (1.8%) as from 2010-2011 to this past year. The number of vehicles is increased by this same rate for simplicity. Therefore, a government vehicle count of 51,700 is predicted for 2012-2013, with 90% = 46,530. If total fuel for 2012-2013 is predicted to equal 1,720,587,757 gallons (141,163,617 gallons diesel & 1,579,424,140 gallons gasoline), 1.35% is assumed to go to government fleets for a total of 23,227,935 (average 458 per vehicle annually). Since switchgrass is primarily sought after for ethanol and gasoline substitutes, the functional unit studied for government fleets using gasoline to operate on switchgrass ethanol is rounded down to 22 million gallons.

II. Cultivation & Harvest Stage

Studies suggest a range of ethanol production per area of field used. One study conducted listed an average biomass yield of both upland and lowland biomass to be 14.2 Mg per ha (Fike et al. (2006)). Another study lists a range of 5.2 to 11.1 Mg per ha of annual biomass yield from established fields (Schmer, Vogel, Mitchell, and Perrin (2008)). Lowland switchgrass has a lower yield than upland and is not likely to produce as much biomass. It is estimated that for 5.2 Mg per ha of biomass yield, a field will need to produce 8 Mg of switchgrass yield per ha. A conversion factor from biomass to ethanol is estimated to be 0.38 L ethanol per kg of biomass harvested. Using this conversion factor, a range of 1,976 – 5,396 L ethanol per ha (211.2 – 576.7 gal per acre) is estimated. From this information, a conservative take on cultivation and harvest would be to use the low end of the range, and make 42,200 hectares (104,200 acres or 163 sq. miles) available for switchgrass bioenergy cultivation, less than 0.5% of the total agriculture farm land recorded for Arizona in 2011.

For cultivation to begin there is a preparation year for the fields that requires seedlings and nutrient inputs. The land is conditioned and there is no harvesting during the preparation year. Using data from published articles, the preparation year requires 100 kg of nitrogen, 40 kg phosphorous, and 80 kg potassium in the fertilizer per hectare of field (Bai, Luo, and Voet (2010)). The preparation would call for a total of 4,220,000 kg N, 1,688,000 kg P, and 3,376,000 kg K. There is also a need to add lime and moisture to some soils, but these amounts vary based on location and soil conditions. A range of lime was found from 3000 kg/ha to 150 kg/ha to increase pH levels near 6.0 to 6.5 (Bai et al. (2010),Cherubini and Jungmeier (2010)). Water and lime additions are not considered due to the individual need of the fields used.

Seeding of the switchgrass is done on a pure live seed (PLS) basis. The National Resource Conservation Services suggests that switchgrass seeding be done between 6 and 12 lbs. PLS per acre (6.7 – 13.5 kg PLS per ha) (Jimmy Carter Plant Materials Center (2011)). When more seeds are used, the risk of dormancy is not a large factor for failure of biomass production. A value of 10 kg per ha is used, calling for a total of 422,000 kg of PLS switchgrass seed. Inventory on creating the PLS state of the seeds was not considered. The switchgrass seeds are planted using drills in row formations allowing the equipment to move through the field.

Following the preparation year, one year of additional growth is taken before the first harvest. Throughout this year, fertilizers, herbicides and other chemicals are continually added to the crops. An average of the fertilizer nutrients reported in the literature and best practices reports was used in the inventory. For nitrogen application, the average value from reviewed LCAs on switchgrass is 86.5 kg/ha annually after preparation year (Bai et al. (2010),Cherubini and Jungmeier (2010), Schmer et al. (2008), (Spatari, Zhang, & MacLean, 2005)). Other nutrients such as phosphorous and potassium application was not always seen as a vital contribution after the preparation year. However for this study, values of 40 kg P/ha, and 80 kg K/ha were used to improve Arizona's soil conditions based from the Bai et al. experiment design. Herbicide application during production years was found in the literature ranging in quantities of 3 to 5.5 kg per ha annually (Pimentel and Patzek (2005), Vogel, Brejda, Walters, and Buxton (2002), Wu, Wu, and Wang (2006), Cherubini and Jungmeier (2010), Spatari et al. (2005)). Atrazine was a common herbicide cited. An estimated value of 3 kg atrazine per ha is used, totaling 126,600 kg (279,105 lbs.) needed for one year of switchgrass production.

Carbon Sequestering is huge factor for that appeal of switchgrass cultivation for biofuel. It is estimated that 200 to 1100 kg of CO2 are sequestered through a hectare of switchgrass annually (Cherubini and Jungmeier (2010), Schmer et al. (2008)). An average value of 650 kg CO2 per hectare is used for estimation purposes, providing 27,430,000 kg captured annually by the switchgrass fields needed for the study.

Harvest occurs only once a year. The harvest is suggested to take place soon after the first killing frost (Douglas, Lemunyon, Wynia, and Salon (2009)). For Arizona, this would probably be in late November, early December. Each tractor use for harvesting and baling is reported to need 7.7 L of fuel per Mg of grass (Spatari et al. (2005)). Using this number, a total of 61.6 L per ha and close to 2,600,000 L (686,842 gal) of fuel for the tractors is needed to cultivate the switchgrass fields for the year. Multiple tractors would be needed in order to conduct the harvest in a short period of time.

III. Bio refinery – Ethanol production

A past LCA of switchgrass bio refinery processes provides the information on the processes of converting switchgrass to ethanol (Cherubini and Jungmeier (2010). The biomass needs to be dried, which is recorded as requiring 11.6 kWh per ton. Using the yield of 5.2 Mg per ha, the total amount of biomass that would need processing is 241,888 tons, equaling 2,805,910 kWh. After drying, processes of hydrolysis, fermentation, and distillation. All of these processes require electricity, chemicals, and machinery that all have environmental impacts. The electricity demand is recorded as 0.83 GJ per ton biomass and would need 200,767 GJ for the entire production. Information on the chemicals and machines are not provided.

Ecoinvent provides inventory data on the impacts of constructing and operating a new refinery plant of 90,000 ton annual capacity. Depending on the ability to transform local Arizona fuel plants to operate for switchgrass, multiple refineries may need to be built to meet the demands associated with the state policies on alternative fuel. For this study, three biorefineries were modeling using Ecoinvent inventory data.

IV. Transportation & Storage

Transportation distances were estimated in the reviewed studies and range from 20 km to 100 km between the farms, refineries, and fueling storage stations (Bai et al. (2010), Cherubini and Jungmeier (2010), Spatari et al. (2005)). For this study, distance traveled by tractor trailers for transport is 200 km total, 100 km from the farm to the refinery and another 100 km from the refinery to the fueling stations. The diesel required for the trucks and impact associated with their travel was taken from Ecoinvent.

Fuel storage tanks are assumed to be included in the Ecoinvent process of operating a fueling station. The study does not consider the production of additional fueling stations, only converting stations to hold enough ethanol to support the fleet vehicles. An estimate of 800 fueling stations in the county, each with a storage capacity of 20,000 gallons for ethanol was used to consider impacts from this stage of the process.

V. Uncertainty

Assumptions are made in each stage of ethanol production and use. The study is set for future use therefore volumes of fuel, number of vehicles needing to operate on ethanol, feasibility of producing switchgrass ethanol, and the ability to convert and store all the ethanol for the year are a few. Switchgrass ethanol has only been produced on small, research scales. The state of Arizona would have to have the funds, time, and space to accommodate all that would be involved in taking on using solely ethanol from switchgrass. Water irrigation is not a necessity for switchgrass, but studies have shown the biomass yield increases when cultivated on well-irrigated fields compared to marginal lands (Stroup, Sanderson, Muir, McFarland, and Reed (2003)). There is uncertainty in the performance of the switchgrass fields located in

Arizona due to water restrictions and limitations. Water data is minimal on switchgrass ethanol production, none for the southwest US, but additional irrigation would definitely be necessary for large scale production in the state.

Uncertainty is also increased by geographical differences in the literature and database values. Energy inputs are different and can make a large difference in results. The electrical mixes from the literature and databases do not match that of Arizona. From the Energy Information Administration, Arizona's 2012 electricity mix was 0.02% petroleum, 11.2% natural gas, 45.4% coal, 36.1% nuclear, 5.8% hydro, and 1.4% other. The majority of the previous switchgrass studies are based in the Midwest and prairie states where

IMPACT ASSESSMENT

Impact assessment was performed using the American method of TRACI 4.0 in Simapro 7.3. The TRACI impact factors recorded in this report are global warming, acidification, ecotoxicity, and eutrophication. Land occupation was taken from another LCI assessment method in Simapro in order to track the shifts in land use. The figures and table below show the findings after running the analysis.

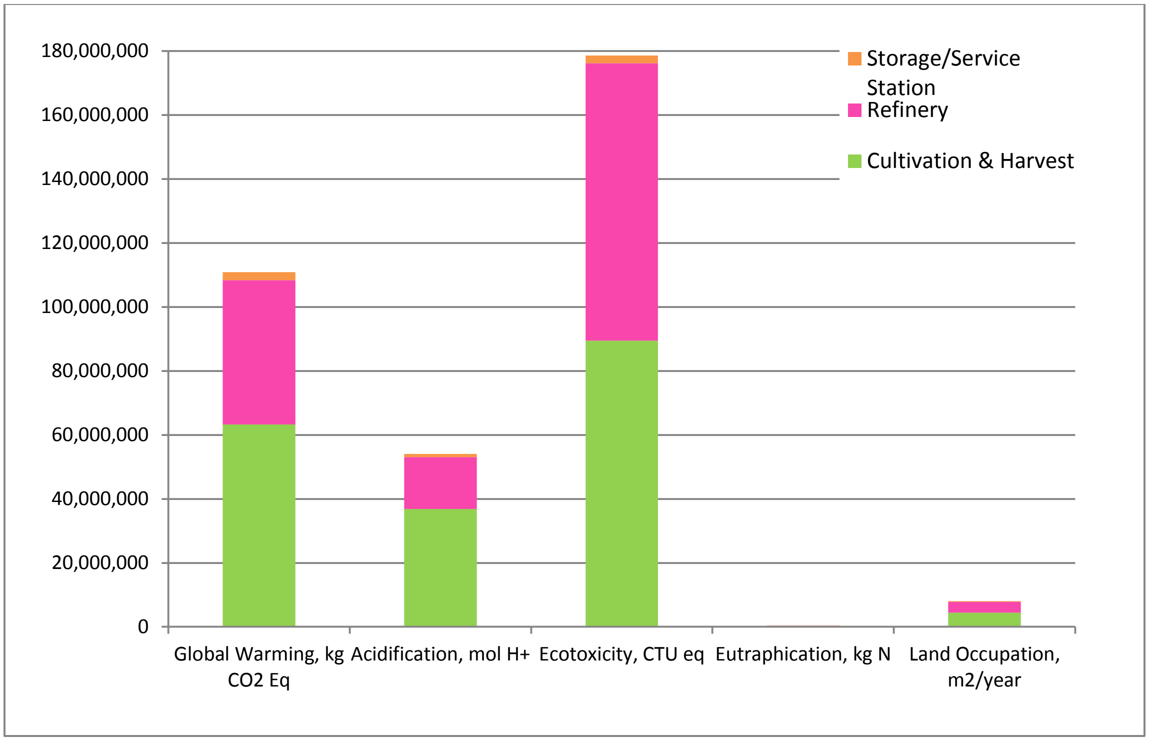

Figure 3 - Impact assessment results according to quantity readings for each phase of the system.

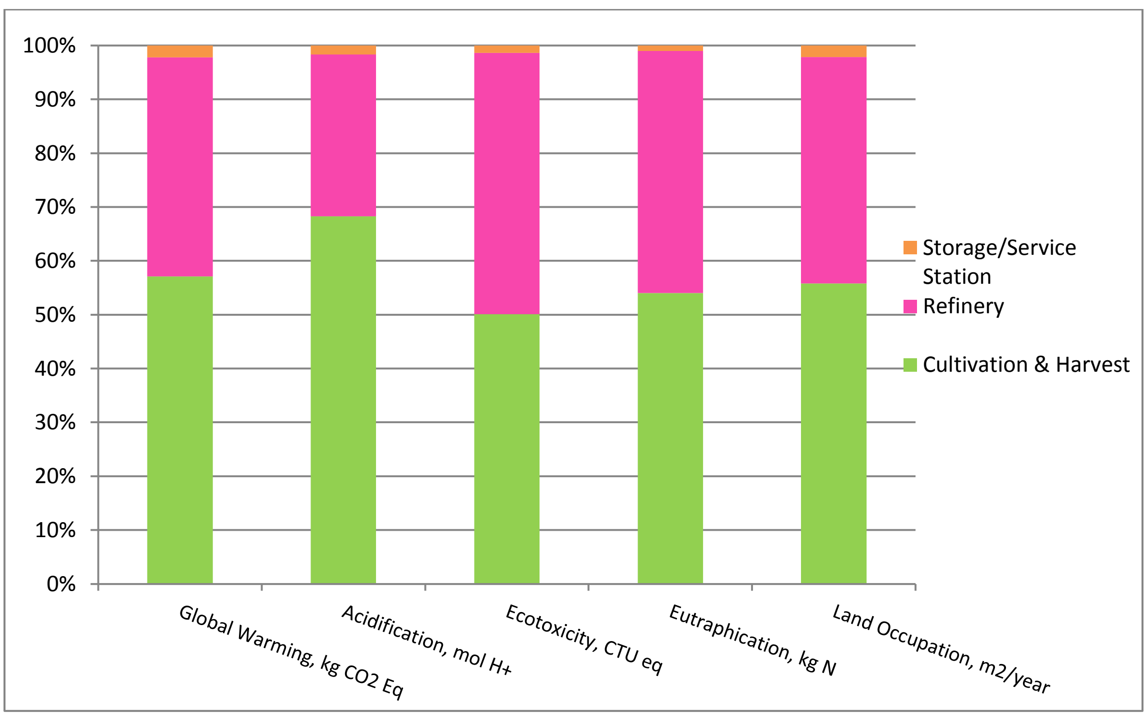

Figure 4 - Impact assessment results according to percent contribution for each phase of the system.

SimaPro Analysis	Global Warming (kg CO2 Eq)	% Contr.	Acidification (mol H+)	% Contr.	Ecotoxicity (CTU eq)	% Contr.	Eutrophication (kg N)	% Contr.	Land Use (m2/year)	% Contr.
Cultivation & Harvest	63,300,000	57%	36,882,800	68%	89,464,000	50%	206,358	54%	4,473,200	56%
Refinery	45,141,182	41%	16,229,799	30%	86,734,148	49%	171,497	45%	3,370,804	42%
Storage/Service Station	2,424,614	2%	913,337	2%	2,444,326	1%	4,008	1%	170,183	2%
TOTAL	110,865,796		54,025,936		178,642,474		381,863		8,014,187	

Figure 5 - Table of environmental impacts according to the analysis through Simapro using inventory values.

The percent contributions in all the categories except for global warming seem acceptable. The results indicate that for the production of the amount of ethanol from switchgrass needed to support the vehicles for a year, the majority of environmental impacts occur during the cultivation and harvest phase. This is logical for some of the categories because of the impacts from fertilizer application in emissions and runoff. The high-assumed value of nutrient fertilizer is valid and necessary because of the sandy soil in Arizona. The emissions come from the machinery needed for planting, tilling, fertilizer application, and harvesting. Runoff will be impacted also by that additional nitrogen and phosphorous applied to the fields, as indicated in the high acidification, ecotoxicity, and eutrophication contributions. The small contribution to environmental impacts from the storage phase also seems acceptable. This phase in the cycle would include minor adjustments in fuel pumping by switching to hold ethanol. If properly installed, contamination from leaks and fume releases will be minimal.

Land use shifts are substantial as well. The 4,473,200 square meters a year shift for cultivation and harvest is just under 450 hectares or 1,105 acres. This is about the same as 1,100 football fields. The additional land for cultivation will come from needed storage of any new equipment, expansion of factories to produce the equipment and fertilizers, and additional infrastructure. This additional land use needs to be heavily considered, especially since the study was only focused on one policy.

The global warming values are questionable because of the previous research on switchgrass ethanol. The cultivation and harvest phases should be carbon negative or neutral due to the capture that takes place as the switchgrass grows. Simapro allows for carbon capture to be assessed by indicating the kg of carbon sequestered for each kg of seed planted. An error may have occurred when entering the information for the carbon capture and fertilizer application to cause such as large impact on global warming.

CONCLUSIONS & FUTURE RESEARCH

Using only switchgrass ethanol to meet the needs of Arizona's government fleet vehicles is seen as having heavy environmental impacts. The cultivation and harvest of the crop are seen as being the most impactful and contributing to GHGs emissions, acidification, ecotoxicity, eutrophication, and land use. Finding ways to reducing the amount of land needed or fertilizers applied for optimal yield would be a hotspot for reduction. Storage and production of the ethanol should be looked into for improvements once proper cultivation and harvest conditions are found.

The study is a start to the consideration of switchgrass ethanol use in the southwest but there are areas that still need future consideration. For example, water use is a big factor that was not properly considered due to lack of information. Previous studies on switchgrass ethanol have been conducted in regions where rainfall provides enough water to the switchgrass and additional irrigation is not involved. Also, due to switchgrass harvesting taking place only once a year, additional land use will need to be considered to store the biomass while conversion is taking place and to hold the excess ethanol before being transported to the fueling stations when necessary.

The results of the study do require verification and additional assessment before critiquing the feasibility of an Arizona switchgrass ethanol-powered government fleet. First technology will need to progress to allow for efficient, cost effective, large scale cellulosic ethanol production from switchgrass. Currently the production is limited and would not be logical to provide for entire state annual needs. Also, for future assessments, the switchgrass will likely not fully be cultivated instate. The additional transportation impacts will be considered with the tradeoffs from not requiring the higher nutrients and water volume that Arizona native soil needs. Once more details about the production process are known, life cycle thinking towards switchgrass ethanol can provide more insight for policy makers and agriculture industry players to make well-supported decisions for the use of this up and coming alternative fuel.

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SUPPLEMENTAL INFORMATION

Arizona's Fuel (Diesel) Use by County (http://www.azdot.gov/Inside_ADOT/FMS/PDF/diesgals12.pdf)

ARIZONA USE FUEL GALLONS
FY 1990 - 2012

COUNTY	FY 1989-90	FY 1990-91	FY 1991-92	FY 1992-93	FY 1993-94	FY 1994-95	FY 1995-96	FY 1996-97	FY 1997-98	FY 1998-99	FY 1999-00	FY 2000-01
APACHE	17,034,687	22,269,841	21,468,116	25,165,770	33,622,917	30,083,999	31,683,170	33,863,881	37,748,467	39,500,546	38,652,839	40,724,308
COCHISE	29,257,417	34,923,714	27,672,220	31,719,721	38,032,358	36,049,353	38,019,801	41,472,536	46,383,308	47,610,018	47,160,023	49,846,523
COCONINO	16,173,849	19,367,035	18,452,051	20,888,132	22,216,459	24,944,511	26,633,663	28,666,420	34,451,375	37,248,958	36,868,499	39,166,085
GILA	7,091,611	8,489,826	8,075,588	9,360,480	11,335,532	10,718,995	11,386,139	12,109,552	13,886,210	14,464,266	14,598,753	15,235,640
GRAHAM	6,622,363	7,945,586	7,930,916	9,445,727	13,880,245	10,715,263	11,336,634	12,216,716	13,974,116	14,927,366	14,366,053	15,188,364
GREENLEE	3,390,288	4,053,177	3,824,872	4,717,646	7,043,259	5,316,624	5,693,070	6,161,941	7,001,873	7,268,915	7,181,100	7,564,895
LA PAZ	12,246,720	14,509,781	13,434,018	15,652,602	19,980,091	18,315,500	19,455,445	21,111,345	23,606,066	24,544,109	24,291,190	25,603,601
MARICOPA	61,493,461	72,045,767	65,421,995	73,465,398	76,415,043	87,552,780	93,366,342	100,252,092	111,952,026	116,463,520	114,971,859	120,593,064
MOHAVE	22,666,413	26,627,884	22,693,296	30,887,618	44,597,864	34,304,514	36,485,150	39,704,329	43,768,760	45,609,381	45,289,591	47,994,311
NAVAJO	12,342,725	14,691,224	13,843,201	15,333,678	14,181,618	18,617,617	21,188,119	22,343,732	25,383,454	26,869,509	26,614,108	28,226,326
PIMA	47,300,428	56,546,631	53,960,171	60,826,100	61,982,920	73,071,848	77,574,261	82,891,496	94,478,431	98,238,373	96,912,251	101,912,170
PINAL	25,590,401	29,786,572	28,633,864	33,687,490	41,780,110	39,348,979	41,980,198	46,348,508	51,910,596	54,151,730	55,854,797	58,581,479
SANTA CRUZ	7,747,479	9,380,497	9,437,175	11,415,051	17,643,318	10,333,050	10,247,526	11,037,911	12,294,861	12,543,952	12,456,283	13,466,959
YAVAPAI	20,217,311	24,265,521	23,531,780	27,362,336	34,716,396	31,914,583	33,217,822	37,775,376	42,224,025	44,019,518	43,144,636	45,500,347
YUMA	21,860,412	26,191,106	25,564,596	30,117,453	40,550,133	34,755,629	36,782,179	39,865,076	44,741,327	46,597,061	46,033,631	48,022,790
TOTAL	311,035,565	371,094,162	343,943,859	400,045,202	477,978,263	466,043,245	495,049,519	535,820,911	603,804,894	630,057,222	624,395,613	657,626,862

COUNTY	FY 2001-02	FY 2002-03	FY 2003-04	FY 2004-05	FY 2005-06	FY 2006-07	FY 2007-08	FY 2008-09	FY 2009-10	FY 2010-11	FY 2011-12
APACHE	42,422,496	43,664,692	46,464,717	50,290,043	54,385,096	54,001,344	53,673,706	45,476,862	44,407,777	46,062,961	45,612,704
COCHISE	51,904,369	53,425,367	56,773,772	61,512,296	67,199,190	66,966,594	66,518,436	56,459,467	55,756,666	57,786,867	57,747,322
COCONINO	41,124,793	42,334,013	43,210,417	46,966,037	51,250,830	50,050,733	49,286,739	41,794,667	41,215,588	42,030,504	41,426,922
GILA	15,848,963	16,314,981	16,561,464	17,970,451	22,333,759	21,567,429	22,380,236	18,820,656	18,655,853	19,890,733	19,602,388
GRAHAM	15,917,723	16,385,759	17,569,934	19,023,870	20,714,664	20,619,118	20,241,307	17,141,638	16,907,128	16,849,068	16,855,349
GREENLEE	7,866,036	8,097,326	8,666,588	9,318,505	10,172,703	10,160,728	10,101,893	8,556,597	8,578,407	8,890,953	8,838,249
LA PAZ	26,726,645	27,512,507	29,529,555	31,962,734	34,892,549	34,890,608	34,583,876	29,320,233	28,946,370	29,996,085	29,992,385
MARICOPA	125,619,317	129,167,926	136,475,605	147,447,645	160,777,443	159,992,476	158,854,998	133,525,270	131,662,877	136,179,036	138,667,600
MOHAVE	50,840,446	52,335,344	55,593,757	60,289,570	64,677,410	65,181,437	64,804,054	55,394,517	54,754,700	56,744,209	57,451,859
NAVAJO	29,846,465	30,718,877	32,966,405	35,665,938	38,990,152	38,946,822	38,865,042	33,020,031	32,393,207	33,558,742	32,868,809
PIMA	104,329,464	107,381,591	114,423,386	124,200,241	135,633,577	135,396,122	135,190,818	114,907,350	113,536,146	117,612,015	116,549,206
PINAL	61,968,296	63,971,711	68,228,178	74,999,908	81,998,926	84,663,320	82,540,515	70,073,457	69,023,802	71,946,043	75,888,265
SANTA CRUZ	14,198,745	14,616,239	15,678,149	16,986,115	18,604,579	18,907,520	18,797,158	15,925,807	15,561,251	16,227,835	16,767,288
YAVAPAI	48,282,610	49,702,294	52,861,267	57,227,963	61,994,621	61,204,001	60,624,464	51,130,146	50,343,877	52,136,566	52,072,505
YUMA	50,694,211	52,179,626	55,958,544	60,754,010	66,374,702	66,282,370	65,927,805	55,798,657	55,062,359	56,703,110	55,367,187

Arizona's Gasoline Use by County (http://www.azdot.gov/Inside_ADOT/FMS/PDF/gasgals12.pdf)

ARIZONA GASOLINE GALLONS
FY 1990 - 2012

COUNTY	FY 1989-90	FY 1990-91	FY 1991-92	FY 1992-93	FY 1993-94	FY 1994-95	FY 1995-96	FY 1996-97	FY 1997-98	FY 1998-99	FY 1999-00	FY 2000-01
APACHE	26,573,844	25,634,576	26,113,151	27,229,834	27,229,999	29,752,786	27,063,937	21,713,973	15,259,137	26,253,269	28,053,443	28,261,659
COCHISE	42,908,705	42,722,042	46,012,084	42,907,644	44,391,256	44,578,149	48,637,741	45,608,881	49,387,533	62,349,381	63,583,911	49,701,730
COCONINO	86,509,103	86,826,755	86,536,680	86,313,637	87,866,942	91,263,617	90,272,043	91,274,955	89,767,966	105,704,799	123,797,415	131,335,993
GILA	21,173,269	21,852,778	24,376,385	24,227,897	24,303,592	26,075,015	25,677,813	25,230,846	25,417,952	29,518,883	31,515,458	28,050,301
GRAHAM	8,904,377	9,046,088	9,316,253	10,286,249	10,470,438	10,910,970	11,650,240	11,497,362	11,204,678	11,927,191	12,668,027	10,807,747
GREENLEE	3,174,313	2,941,485	3,418,928	3,749,622	4,004,407	3,118,554	3,834,974	3,071,844	3,560,056	4,248,749	3,998,347	3,714,050
LA PAZ	16,160,034	17,202,373	21,078,860	31,615,962	20,250,319	20,670,765	24,539,951	25,960,792	22,591,558	26,668,579	29,178,196	29,479,148
MARICOPA	992,687,253	979,339,842	963,371,312	1,003,863,735	1,025,106,206	1,067,840,554	1,134,726,469	1,185,905,805	1,219,200,100	1,310,502,755	1,338,111,695	1,392,390,421
MOHAVE	76,969,674	83,237,105	82,989,105	89,423,372	92,361,755	91,794,394	95,734,382	92,829,936	94,096,430	96,885,724	103,067,687	103,201,634
NAVAJO	53,754,692	51,976,366	53,226,270	53,645,529	56,000,428	58,162,012	58,453,861	55,416,098	52,091,801	56,571,102	65,075,537	63,948,997
PIMA	287,032,122	298,259,207	316,876,139	331,039,969	338,127,695	332,801,501	346,333,132	352,408,883	344,628,492	366,790,995	410,588,887	399,417,225
PINAL	50,198,789	50,332,876	48,828,927	50,827,423	55,793,502	58,289,954	60,885,927	65,475,418	65,492,115	71,704,488	73,038,420	70,229,117
SANTA CRUZ	12,527,717	14,155,034	13,522,495	16,368,002	19,597,002	20,015,138	17,576,425	18,741,826	20,127,681	22,419,303	23,437,330	24,811,733
YAVAPAI	57,398,772	57,079,243	60,142,315	60,429,316	59,059,765	67,176,748	71,431,028	72,366,429	73,103,774	78,000,506	80,239,390	79,184,742
YUMA	61,864,887	60,882,762	59,852,696	64,382,085	65,524,869	65,415,556	66,568,781	69,322,855	72,201,901	83,640,014	91,354,800	85,538,800
TOTAL	1,797,837,551	1,801,488,532	1,815,661,600	1,896,310,276	1,930,088,175	1,987,865,713	2,083,386,704	2,136,825,903	2,158,131,174	2,353,185,738	2,477,708,543	2,500,073,297

COUNTY	FY 2001-02	FY 2002-03	FY 2003-04	FY 2004-05	FY 2005-06	FY 2006-07	FY 2007-08	FY 2008-09	FY 2009-10	FY 2010-11	FY 2011-12
APACHE	31,809,628	32,021,881	31,548,566	30,382,536	30,353,709	27,121,873	26,466,346	27,478,322	26,669,503	27,358,248	26,673,601
COCHISE	54,231,661	54,904,384	56,306,187	58,200,662	59,842,797	61,280,182	57,112,351	51,772,212	56,692,843	53,927,825	48,979,994
COCONINO	132,991,488	125,897,762	109,262,146	108,012,184	103,211,966	103,165,038	101,104,461	92,439,564	93,152,706	92,920,154	90,113,228
GILA	27,303,835	26,299,476	30,556,440	34,524,661	32,879,444	33,687,614	31,530,805	27,583,201	29,284,937	29,414,175	29,942,628
GRAHAM	11,206,254	11,909,275	10,606,049	11,602,453	10,528,338	12,699,871	13,310,878	9,820,352	12,713,794	12,850,487	11,428,353
GREENLEE	2,452,414	2,372,819	2,721,621	2,920,583	3,577,801	3,369,995	3,274,659	3,325,186	2,643,329	3,184,067	3,609,877
LA PAZ	29,782,126	29,728,920	31,616,935	34,599,286	32,123,970	35,761,707	34,057,950	31,684,368	32,501,450	33,815,845	33,754,767
MARICOPA	1,435,375,342	1,490,129,655	1,526,283,642	1,536,136,249	1,596,332,274	1,696,777,678	1,680,283,509	1,574,810,563	1,505,131,152	1,534,426,339	1,551,997,191
MOHAVE	104,290,151	108,946,159	113,336,400	132,264,555	121,243,224	118,731,966	111,106,533	104,955,761	108,441,384	106,029,035	104,161,173
NAVAJO	57,367,157	60,973,836	66,879,250	69,364,603	62,232,604	63,159,282	61,322,038	61,263,003	58,439,980	59,984,493	55,740,305
PIMA	398,316,125	404,501,629	395,330,549	389,341,578	371,309,146	384,600,547	394,428,155	356,454,764	386,963,156	383,694,806	382,781,749
PINAL	71,176,660	74,661,275	85,753,405	99,858,478	101,597,300	109,236,724	119,685,805	112,917,712	114,026,315	111,623,454	109,702,763
SANTA CRUZ	26,358,752	27,280,949	32,206,452	31,434,627	28,409,612	27,914,475	24,926,338	21,098,973	22,489,733	20,783,567	17,826,868
YAVAPAI	83,362,324	86,021,861	90,689,132	91,779,506	94,289,890	95,388,241	88,692,923	83,984,020	90,349,800	90,325,605	88,579,743
YUMA	91,659,624	95,630,542	95,077,644	97,593,661	98,262,938	97,739,564	102,114,242	91,932,388	93,426,284	88,803,381	88,593,327