CELLULOSIC ETHANOL POTENTIAL: AN IOWA CASE STUDY

by

Trevor Cutsinger
Dr. Norman Christensen, Advisor
May 2009

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

2009

Abstract

The many arguments against corn ethanol in recent years coupled with rising energy prices and concern over greenhouse gas emissions have sparked a surge of interest in cellulosic ethanol. The popularity of cellulosic ethanol as a viable energy alternative is not difficult to understand. From a simplistic point of view, cellulosic ethanol can be derived from anything containing cellulose. A wide variety of biomass residues and dedicated energy crops are the most likely source of large quantities of feedstock. While none of the feedstocks for cellulosic ethanol contribute directly to the so-called "food versus fuel" debate, the obstacles to the large-scale production of this energy source are significant. Not only are there numerous social acceptance factors that need to be considered, but the demands imposed by harvest, storage, and transportation of the vast quantities of feedstock that are likely to be generated are immense. Many technologies are being explored for the conversion of the various feedstocks into cellulosic ethanol, with the jury still out on which processes are the most energy and cost efficient. Regional differences are another factor that will ultimately play a large role in determining the makeup of a cellulosic ethanol market. The Midwestern United States, for example, is heavily agricultural, making it a prime candidate for perennial grass feedstocks while the southern United States is much more heavily forested and is likely to utilize more wood products. Clearly, there is much potential to be tapped into in this emerging market, and the purpose of this Masters project is to explore some aspects of its future.

The state of Iowa is analyzed as a case study, in order to understand the relationship between marginal agricultural lands, the Conservation Reserve Program (CRP), and potential cellulosic ethanol feedstock production. The sample counties were chosen based on their 2007 CRP enrollment acreage. The ten counties with the highest CRP acreage and the ten counties with the lowest CRP acreage were included in the analysis. The logic behind this decision is based on the fact that higher CRP acreage is generally indicative of poorer quality farmland, including steeply sloping land, highly erodible soils, rocky soils, and riparian areas. The next step was to identify marginal agricultural lands in these counties, which was done using the Land Capability Classification system. This system ranks land on a scale of 1 to 8, with 1 being the best farmland and 8 being the most limited. In this case study, all land in category 4 and higher is considered marginal. The land cover on these marginal lands was then analyzed, with particular attention paid to corn. The primary conclusion reached in this project is that a substantial amount of marginal land in Iowa is planted in corn and other row crops. These lands could be better utilized, both environmentally and economically, by instead planting them in switchgrass or other perennial grasses for cellulosic ethanol production.

Acknowledgements

I would like to thank my Masters Project advisor, Dr. Norman Christensen, and my academic advisor, Dr. Daniel Richter. Without their suggestions and guidance, this project would not be nearly as complete. I would also like to thank my family, friends, and Emily for support and confidence in me during this process.

Table of Contents **Page**

List of Figures **Page**

List of Tables

Introduction

In 2007, Congress mandated the production of 36 billion gallons of biofuels by the year 2022 as part of the Energy Independence and Security Act. Sixteen billion of these gallons are to be from cellulosic ethanol. This mandate updated the Renewable Fuel Standard of 2005 (RFA 2008). The Department of Energy has invested heavily in cellulosic ethanol projects. In recent years, they have invested well over $300 million in 6 Cellulosic ethanol projects, utilizing both thermochemical and biochemical methods of conversion (DOE 2007). Despite heavy government subsidies in research and development projects for cellulosic ethanol, there is legitimate concern that the Congressional mandate is unrealistic.

Table 1. Renewable Fuel Mandate

Year	Cellulosic Biofuel (Billion Gallons)
2009	0
2010	0.1
2011	0.25
2012	0.5
2013	1
2014	1.75
2015	3
2016	4.25
2017	5.5
2018	7
2019	8.5
2020	10.5
2021	13.5
2022	16

Source: Renewable Fuels Association

By way of general introduction to the topic of cellulosic ethanol, it is useful to briefly summarize a 2005 joint study by the U.S. Department of Energy and the U.S. Department of Agriculture that has come to be known as the "Billion Ton Study." This detailed report analyzes how much biomass can be sustainably produced from land in the United States to be used for bioenergy and bioproducts. In short, the study found that "the combined forest and agriculture land resources have the potential of sustainably

supplying much more than one-third of the nation's current petroleum consumption." The report concludes that close to 1 billion dry tons of biomass can be supplied by agricultural lands in the U.S., with 377 million dry tons coming from perennial crops (i.e. grasses). The study also estimates that 370 million dry tons of biomass can be supplied annually from forest lands in the U.S. (Perlack 2005). See Figure 1 below for the study's estimated breakdown of biomass sources.

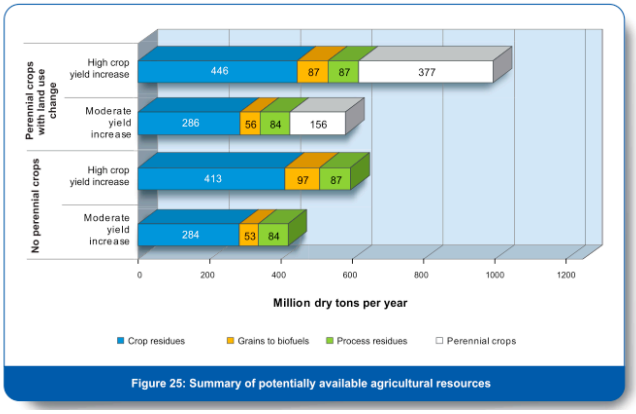


Figure 1. Billion Ton Study Estimates

Source: Billion Ton Study (DOE, USDA 2005)

Not surprisingly there are critics of the report's estimates. David Pimentel believes that harvestable biomass in the U.S. is actually more like half of Billion Ton Study estimates. Regardless of which estimate is used, it is clear that the removal of large quantities of biomass from agricultural lands and forests will alter ecosystem functions and wildlife patterns (Tenenbaum 2005).

The goal of this project is to provide a basic understanding of the enormity of the task ahead and to present an analysis of one state's cellulosic ethanol production potential. Ideally, other regions and states can duplicate the thought processes and techniques outlined here in order to best utilize their own natural resources and environmental settings to contribute their own piece of the whole cellulosic ethanol pie. Since Congress has presented us with such a massive undertaking, two particular case studies will be utilized throughout to provide concrete examples and allow for a meaningful analysis. The first case study is switchgrass as the primary feedstock for cellulosic ethanol. Though many feedstocks could be discussed, the perennial crop

switchgrass has been researched in depth and has many promising characteristics for large-scale ethanol production. The second case study, which piggybacks on the first, is a detailed analysis of potential cellulosic ethanol production in the state of Iowa, where switchgrass is native. Iowa was chosen for several reasons, including the fact that it is the second largest corn producing state and the leader in corn ethanol refining capacity. Iowa also has close to two million acres of land enrolled in the Conservation Reserve Program. Since much of the acreage enrolled is already covered in perennial grasses, these marginal agricultural lands are of special interest for switchgrass production.

What's Wrong With Corn Ethanol?

The primary feedstock for ethanol production in the United States today is corn. Numerous sources in the scientific literature have reported on corn ethanol's massive carbon footprint and associated environmental degradation. In terms of water quality alone, every gallon of ethanol produced from corn results in approximately 17.3 grams of Nitrogen, 6.3 grams of Phosphorous, and 1.3 kilograms of soil being released into our nation's waterways (Mubako and Lant 2008)[1]. If we then consider the amount of corn ethanol produced in the United States over the past decade, these pollution statistics become astronomically large (see Table 2 below). The percentage of U.S. corn produced has been steadily increasing since the late 1990s, meaning that the demand for corn for ethanol production is increasingly to blame for the continued and growing environmental degradation associated with its production. In 2008, 86 million acres of land in the U.S. were planted in corn, a 7 percent decrease from 2007 (USDA-NASS 2008).

[1] The original article contains these numbers in terms of liters of ethanol. The conversions associated with gallons are mine for consistency.

Table 2. U.S. Corn Ethanol Production

Year	Millions of Gallons	Millions of Bushels of Corn Utilized	Millions of Bushels Produced in the U.S.	Percent of U.S. Corn Used for Ethanol
1999	1,470	565	9430	5.99%
2000	1,630	627	9920	6.32%
2001	1,770	681	9500	7.17%
2002	2,130	819	8970	9.13%
2003	2,800	1077	10090	10.67%
2004	3,400	1260	11810	10.67%
2005	3,904	1430	11110	12.87%
2006	4,855	1800	10530	17.09%
2007	6,500	2300	13170	17.46%

Source: National Agriculture Statistics Service and
http://www.ethanolrfa.org/industry/statistics/, accessed 1.13.09

Experts on both sides of the ethanol debate argue vehemently for their own studies, statistics, and opinions. Those in the industry argue that corn ethanol decreases greenhouse gas emissions (GHGs) and is highly energy efficient, yielding much more energy than is required to produce it. For example, the Renewable Fuels Association proudly announces on its website that replacing gasoline with ethanol helps to reduce GHGs by 29 percent (RFA 2008). A study in 2004 by the U.S. Department of Agriculture determined that ethanol has a positive energy balance, yielding 67 percent more fossil energy than is required to produce it (Shapouri 2004). On the other side of this debate, researchers like Timothy Searchinger have highlighted net greenhouse gas emissions from corn ethanol production, citing land conversions in a life-cycle analysis (Searchinger, Heimlich et al. 2008). David Pimentel, another prominent scientist, argues that 29 percent more fossil energy is required to produce a liter of ethanol from corn than it contains (Pimentel 2005). My purpose is not to determine which side is "right," but merely to point out that the answer often depends on what type of question one is asking and the associated assumptions.

A 2005 article by Pimentel and Patzek cites twelve authors going back to 1989, giving just a glimpse of the array of literature warnings against the so-called benefits of corn ethanol.

They caution policymakers of dramatic air, water, and soil pollution and significant contributions to global climate change if corn ethanol continues to be subsidized by the government and pursued as the future of United States energy policy (Pimentel 2005). It is important to be realistic, however, regarding the direction of ethanol policies in this country. Billions of dollars have been invested in the corn ethanol industry, and it will not simply disappear quietly as new energy technologies slowly ramp up production capability. A recurring theme throughout this project will be the importance of diversifying our energy sources; in much the same way as a financial consultant might advise us to diversify our portfolios. Those who advocate for the rapid demise of a significant contributor to the energy needs of the country seem to lack a basic understanding of energy economics.

This brief introduction demonstrates why many environmentalists and some policymakers want to move the United States' energy policies in a new direction. Cellulosic ethanol is one such new direction, although it may have its own set of environmental, economic, social, and political complications.

What is Cellulosic Ethanol?

Cellulosic ethanol is a variety of ethanol that is produced through biological or thermochemical processes from any biomass containing cellulose or hemicellulose. It is these polymers that determine the structure of tree trunks, plant stalks, and the majority of plant matter in general (DOE 2009). The most common sources of biomass are municipal waste, herbaceous crops including several perennial grasses, and woody residues (Wyman 2007). Every feedstock will have somewhat different characteristics in terms of energy potential, cost-effectiveness, conversion feasibility, and environmental impact. Since the analysis of the feedstocks alone could be the subject of several reports, the focus here will be placed on herbaceous crops,

particularly switchgrass (*Panicum virgatum*). Switchgrass has been heavily researched and has demonstrated potential for conversion into ethanol, but it is only one of several potential sources for satisfying the cellulosic ethanol component of the Renewable Fuels Mandate.

Two arguments favoring cellulosic ethanol over corn ethanol are that the net energy balance is much better and the Greenhouse gas emission (GHG) figures are substantially lower. The net energy balance is determined simply by comparing the energy inputs required for production to the energy potential of the harvested biomass. A study published in 2007 analyzing the energy balance of switchgrass in the mid-Continental United States on marginal cropland concluded that the switchgrass in the study plots produced 540 percent more renewable energy than non-renewable energy it consumed. It also was responsible for 94 percent lower GHG emissions than gasoline (Schmer, Vogel et al. 2007). The findings from Searchinger's study of GHGs associated with corn should be considered in the context of cellulosic ethanol as well, however, particularly if there is any conversion from idle land for large-scale switchgrass production involved.

There are a couple of research initiatives focused predominantly on producing ethanol from perennial grasses. One excellent example is the Great Plains Institute's Native Grass Energy Initiative. According to the Institute, biomass including perennial grasses has the potential of displacing over a third of our current petroleum consumption. The focus of their research is on the perennial grasses switchgrass, indiangrass, and big bluestem (Great Plains Institute 2007). They argue that the large-scale production of perennial grasses will revitalize rural economies, produce a much needed energy alternative (for transportation fuel as well as electricity production), and dramatically improve ecosystem services. They emphasize

advantages like increased farm income, expanded wildlife habitat, and a potential market niche for carbon sequestration payments associated with grass for energy production.

Another research project, lead by David Tilman, professor of ecology at the University of Minnesota, is focused on studying the differences between prairie grass monocultures and mixtures of many grass species. The major finding related to energy production from grasses, is that diverse mixtures of different grass species has the potential of producing as much as 238 percent more energy than grass monocultures, including switchgrass (Tilman, Hill et al. 2006). This finding is related to another important discovery that the energy potential of these grass polycultures on degraded agricultural land is as much as 51 percent greater than the energy obtained from ethanol from corn on prime farmland. These findings, along with promising indications regarding enhanced carbon storage and other environmental benefits associated with increased diversity of grass species in energy production, should be given careful consideration in the cellulosic ethanol feedstock debate.

Despite the potential of cellulosic ethanol, the industry is still very much in its infancy. Several prominent companies like Archer Daniels Midland, BP, DuPont, Genencor, and Novozymes have been investing heavily in research and development activities associated with cellulosic biofuels, effectively supplementing ongoing government funded research. Critics continue to argue an "I'll believe it when I see it" approach, but there are already some small-scale production facilities operating. For example, Range Fuels in Georgia has been successful in using wood from pine beetle kills in Colorado as well as pine and hardwoods from in state to produce cellulosic ethanol (Range Fuels 2009). Large-scale commercial production of cellulosic ethanol as called for in the Renewable Fuel Mandate is likely just around the corner, with

DuPont and other companies estimating production beginning in 2010 (Bryner, D'Amico et al. 2008).

Why Choose Switchgrass?

There are many reasons to be optimistic about switchgrass aside from President Bush's 2006 speech mentioning the grass. It is native to the North American tall-grass prairie, spanning 14 states from Texas to Minnesota. It has also been found as far west as the Rocky Mountains and as far east as the Atlantic coast (Rinehart 2006). There are several different varieties of switchgrass, each adapted to its native habitat. It can grow in cold, dry climates, but maximum yields are found in warmer, wetter climates with a long growing season. There are two major types of switchgrass, upland and lowland varieties. The upland types fare better in drier soils and semi-arid climates and grow usually 5 to 6 feet tall. The lowland types grow best in heavy soils and wetter climates and can reach heights of 7 to 10 feet. Cave-in-rock and Shawnee are the highest yielding varieties of switchgrass adapted to Iowa's climate. In preliminary studies, Alamo and Kanlow showed higher yields, but there is concern of winterkill for these varieties (Garland 2005).

Switchgrass yields vary widely, depending primarily on the climate and the variety. Numerous studies show a range of as little as 1 ton per acre to as many as 10 tons per acre, but the majority of research demonstrates that 5 tons per acre is a reasonable expectation in many areas (ORNL 1996). The ethanol production from the feedstock itself is another important consideration, and switchgrass yields between 80 and 100 gallons of ethanol per ton using current technologies (Moore 2007). Aside from these high production numbers, switchgrass is also an appealing alternative because of its ability to grow on marginal lands, steep slopes, and in river bottoms (Biello 2008). Initial studies indicate that the energy inputs of fertilizers and

pesticides to maintain production levels would be much lower than corn (Clanton 2008). The lifespan of most switchgrass varieties is between 10 and 20 years, meaning that once established it can continue to provide feedstock for many years without new planting (Garland 2005).

Environmental Benefits of Switchgrass

As with corn ethanol, there are experts both for and against cellulosic ethanol. The main difference, however, is that the negative environmental impacts of corn ethanol are well established and are visible for anyone to see. Since cellulosic ethanol has yet to be produced on a commercial scale, its environmental impacts are mostly theoretical. Perhaps the most important consideration regarding cellulosic ethanol is that the feedstocks necessary to produce it grow naturally. Prairie grasses like switchgrass are native to many states, forests grow across the country naturally producing tons of wood residues every year, and municipal yard waste is constantly taken to land fills that could instead be headed to refineries. Corn requires intensive management with the addition of petroleum-based fertilizers, pesticides, and in drier states large amounts of irrigation. This is not to suggest that cellulosic ethanol feedstocks in the quantity required by the Renewable Fuels Mandate will simply spring out of the ground, offering themselves for conversion into ethanol with no environmental impact whatsoever. On the contrary, there will likely be substantial land management and manipulation, including possibly some irrigation as well as fertilizer input to increase production. In the final analysis, the life cycle of cellulosic ethanol feedstocks has not yet been established, and there is a great deal of room to design a system whereby cellulosic ethanol can be commercially produced and environmental degradation can be avoided.

There are numerous documented environmental benefits of switchgrass. Switchgrass root systems are nearly as extensive as their aboveground biomass, effectively holding soil in place

and preventing erosion. If harvested carefully, these root systems will remain in place through years of harvesting. Related to the soil holding capacity of switchgrass is the carbon sequestration potential. The root systems themselves store carbon while helping preserve the largest carbon sink on the planet, the soil, from erosion. A joint report by Worldwatch Institute and Sierra Club showed that converting an average corn farm to switchgrass would save 66 truckloads of soil, reduce sediment flows by 84 percent, and reduce nitrogen runoff by 53 percent and phosphorous runoff by 83 percent (Widenoja 2007).

Switchgrass also has substantial wildlife habitat benefits. In a study conducted by the University of Wisconsin, different species of grassland birds fared well in both harvested and unharvested stands of switchgrass, suggesting that habitat benefits would even be observed in heavily managed stands of herbaceous crops. Some of the species studied were the American goldfinch, the ring-necked pheasant, the song sparrow, the bobolink, and the eastern and western meadowlark. The study also found that harvesting in August benefited 6 species that required diverse vegetative structure in their habitats (Undersander 2001). There are those who have voiced concerns about what a dramatic shift toward cellulosic feedstocks might mean for wildlife habitat, however. One main concern is that cellulosic feedstocks will be grown on currently idle land or lands enrolled in the Conservation Reserve Program (Bies 2006). It is likely beyond debate that herbaceous crops far surpass corn in terms of environmental desirability, but if land currently planted in corn continues in corn, additional lands will have to be planted in perennial grasses. Even though there is a wildlife habitat benefit to switching from corn to perennial grasses, the same cannot be said for a shift from idle lands with an array of diverse native species to lands that would be managed and harvested for cellulosic ethanol production. This is an excellent example of why the land chosen should be selected carefully.

Obstacles to the Establishment of Switchgrass

Though there are clearly many environmental, wildlife, and energy benefits to this native species, it is not without its problems. First, establishment of switchgrass can be quite tricky. It often takes two or three growing seasons before the young grasses are well established, and there is a good chance that a significant percentage of the seeds will not germinate (Duffy 2007). Seeds require very good soil contact to germinate, but seed dormancy, weed competition, and poor seedling vigor are some other causes often blamed for poor establishment rates. It grows best in areas that receive at least 15 inches of rain per year (Rinehart 2006). The more rain the region receives, the higher the productivity of the grass. As previously mentioned, the fertilizer requirements are lower for switchgrass than for corn, but depending on the results of a soil test, lime, phosphorous or potassium amendments may be needed to reach optimum yields. It will grow in a variety of different soil types, but thrives in moderately well to well drained soil with a pH between 5.5 and 7.0. Pesticides are not usually required, as many strains of switchgrass have shown good resistance to pests and disease (Garland 2005).

Planting Considerations

Switchgrass should be planted between late April and early June. In order to maximize the soil holding capacity of this grass, it is best to use no-till planting methods. However, tilling has been shown to be effective in controlling weed competition early in the plant's development. Herbicides have been effectively used to eliminate competition as well (Garland 2005). Switchgrass will grow throughout the warm months, stopping in the fall after the first frost.

Harvest Considerations

Switchgrass can be harvested once or twice a year. At this juncture, the majority of research indicates that the one cut system produces higher and more sustainable yields (Chariton Valley 2008). Under the one harvest per year scenario, the switchgrass would be harvested two to three weeks after the first frost in the fall. Some research has shown that harvesting four to six weeks after the first killing frost removes fewer nutrients from the soil and decreases the overall fertility needs of the crop. Waiting this length of time may reduce biomass yield by 10 to 20 percent, but it is likely better for long-term sustainability (Gibson and Barnhardt 2007). Ecologists also warn that leaving a 6-inch stubble is critical not only for the health of the switchgrass itself, but also for wildlife cover.

Conventional harvesting equipment can be used to harvest switchgrass. Round or rectangular bales can be collected and transported for storage. Round bales are difficult to store, so rectangular bales are typically preferred. There has been a great deal of research into single-pass harvesters and other innovative equipment that would increase efficiency and reduce harvesting costs.

Moisture is the final important harvesting consideration. A feedstock with greater than 15 percent moisture cannot be stored for a lengthy period, but drying the feedstock is not economically feasible either. Some research has been conducted looking into bulk systems that will grind the biomass into flowable forms. This strategy would increase harvesting efficiency and solve the problem of low energy density by grinding the grass into a smaller unit (Greer 2008).

Storage Considerations

Current perennial grass production is low enough that transportation and storage has not become a major economic or logistical obstacle. However, if production is to increase enough to accommodate a large ramping up of cellulosic ethanol creation, storage will be one of the major question marks. There are several different storage options, including in an open field, in an open field on crushed rock and covered by tarps, in an enclosed structure, or under a pole building with open sides. The most expensive is obviously in an enclosed structure, but this is also the best option in the sense that the quality of the switchgrass is maintained (Duffy 2007). A study conducted in Pennsylvania concluded that high water concentrations in fall harvests could prevent stable storage as the chemical composition might change (Adler, Sanderson et al. 2006). A research project at Iowa State University's Bioeconomy Institute has just begun in 2008 attempting to develop a cost effective system for the harvest, storage, and transportation of biomass (HST Consortium 2008).

Transportation Considerations

Transportation creates similar logistical and economic problems as storage does. While storage options on farms could be developed, the existing transportation options will not accommodate potentially massive amounts of biomass. Currently, trucking is the primary method by which biomass is transported, but there are those who believe that for switchgrass and other biomass crops to be economically competitive, the use of short-line railroads will be critical (Greer 2007). A report by the Natural Resources Defense Council suggests the need for large investments in freight, rail, and barge transport systems to facilitate the transport of feedstocks to cellulosic ethanol production facilities (Greene 2004).

Economics of Cellulosic Ethanol from Switchgrass

The multitude of variables that must be considered makes effectively judging the economic feasibility of converting switchgrass and other perennial grasses into ethanol on a large scale difficult, at best. Since there is no commercial scale production example to look to, economists and biofuel proponents have had to make some educated estimates regarding potential costs. The first and most obvious is the feedstock cost. For switchgrass to be grown in the first place, farmers must receive a competitive price. If they could make a larger profit sticking with traditional row crops, there is no incentive to shift to switchgrass.

Another important consideration is the scale of production. Massive refineries hauling feedstock from hundreds of miles away are not likely to be a cost-effective option. An ethanol refinery will have to purchase the feedstock and determine how far away from the plant they are willing to go to get it. In a document prepared by Mike Duffy of Iowa State University, the costs of production, storage, and transportation of switchgrass are estimated.

Conversion Processes

Pretreatment is required to break down the biomass to provide for efficient hydrolysis of the sugars. The primary goal of the pretreatment is to get higher yields of the "good sugars" that are used to make ethanol without degrading the biomass. There are several ways that this can be done, including dilute acid and the use of organic solvents (Greer 2005). These are used to break up the lignin sheath that surrounds the cellulose.

The two primary methods by which biomass can then be converted into ethanol are biological and thermochemical processes (Hess and al. 2007). Thermochemical conversion is a chemical process that breaks long-chain organic compounds that make up biomass into short-chain hydrocarbons. It is done in a heated, highly pressurized, oxygen-deprived environment.

The term encompasses several methods including Fisher-Tropsch (gasification), liquefaction (hydrothermal), and pyrolysis (anaerobic burning) (Zhang 2008). The thermochemical process can break the lignocellulose much faster than the biological method that utilizes enzymes.

Biological processes seem to be the most likely methods pursued at least at the outset. The biggest obstacle to the biological conversion process, seen in Figure 1 below, has been the cost of enzymes to facilitate the biological breakdown of the biomass. To counter this impediment, the Department of Energy funded Genencor International and Novozymes Biotech, with the goal of reducing costs of enzyme production. In 2004, Genencor said it had achieved a 30-fold reduction in the cost of enzymes, down to $0.10 - $0.20 per gallon of ethanol produced. Novozymes achieved a reduction from $5.00 to $0.30 per gallon (Greer 2005).

Social Obstacles to Cellulosic Ethanol from Switchgrass

Aside from the logistical issues associated with establishing large tracts of land planted in switchgrass for ethanol production, there is the social dimension. Large transitions and changes are often difficult for people to understand and accept, and this one might really present some challenges. A study was conducted in Tennessee to determine farmer willingness to grow switchgrass. The survey found that the majority of farmers in Tennessee had not heard of the possibility of growing switchgrass for energy production, while approximately half of the survey respondents were uncertain as to whether or not they would be willing to plant switchgrass. Some factors that increased the likelihood that a farmer would convert more of his or her land to switchgrass included lower age, higher levels of education, and higher off-farm incomes. Unsurprisingly, the farmers that had high net farm income per acre were more unwilling to convert their already profitable land to something so new and potentially risky (Jenson, Clark et al. 2007).

Another survey was conducted in the Chariton Valley of Iowa regarding the benefits and obstacles associated with switchgrass production (Brummer, Burras et al. 2002). The farmers surveyed knew many of the benefits of planting switchgrass, including its potential as a bioenergy crop, soil holding capacity, and improved water quality. Many expressed concerns regarding increased training, information, and complexity associated with a new crop and a new method of farming. Farmers across the board have expressed hesitation to jump into the switchgrass business due to the current lack of reliable markets (Jenson, Clark et al. 2007).

Political Complications: Special Interests and Subsidies

Corn ethanol has been subsidized by the United States government for many years, much to the dismay of numerous environmental organizations. Every five years when the Farm Bill comes back up in Congress there are bitter battles between corn lobbyists and those who believe the corn industry has been unfairly propped up by tax dollars. Interestingly, many environmentalists are not opposed to subsidies for other renewable energies that are perceived to be less environmentally destructive. Tax credits have been given for wind and solar energy in the past, and all types of biofuels have jumped on the bandwagon as well. Prior to the 2007 Farm Bill passing (in mid-2008), all biofuels received a 51-cent per gallon tax credit for blenders. The new bill gave up to $1.01 per gallon tax credit for producers and lowered the blenders' credit to 45 cents (Philpott 2008). The increased demand for petroleum and the ensuing price increases have created the need for a shift to renewable energy regardless of the subsidy levels, however.

The Conservation Reserve Program

According to a publication by the U.S. Department of Agriculture's Economic Research Service, the Conservation Reserve Program (CRP) is the largest agricultural land conservation

program in the country. The Food and Security Act created the CRP in 1985. The overarching purpose of the program is to take environmental susceptible croplands and pasture out of agricultural production. A CRP contract between a landowner and the government will typically last between 10 and 15 years. Under the terms of the contracts, the government pays the landowner a per acre amount and in exchange the land is planted in grasses or trees, which promotes ecosystem services like water quality protection, erosion reduction, and wildlife habitat. Another purpose of the program, throughout its existence, has been to reduce agricultural commodity supplies thereby impacting prices. The focus of this analysis will be on the environmental impacts of the CRP, but it is important to keep in mind that price control is a critical motivation the government has to continue payments. The amount of land enrolled in the program has fluctuated substantially since its inception, but a great deal of money continues to flow into it. In 2004, the USDA spent $1.6 billion to remove 34.7 million acres of cropland from production compared to about $1.8 billion in 2008 to remove 33.6 million acres. The amount spent per acre varies depending on a series of criteria called the environmental benefits index (EBI). This index ranks contract offers based on things like soil erosion, air quality, and water quality impacts (Hellerstein 2006). Examples of acreage and payment maps for the CRP are below in Figures 2 and 3.

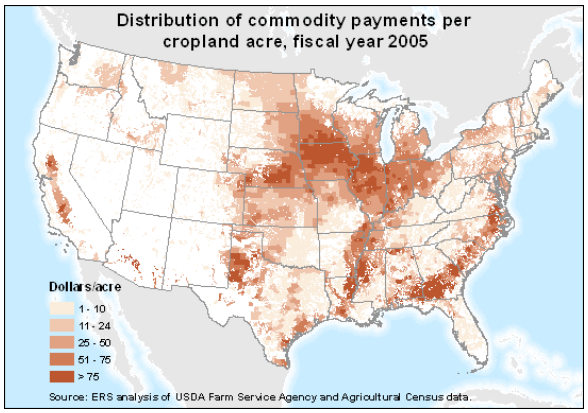


Figure 2. CRP Payments per Acre 2007

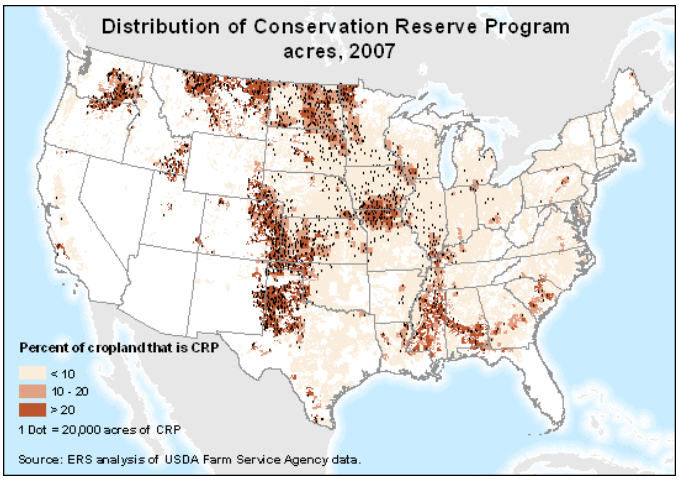


Figure 3. 2007 CRP Acreage

For the purposes of this analysis, it is important to understand the acreage fluctuation trends in the CRP in recent years. The much-debated 2008 Farm Bill reauthorized the CRP, but reduced the maximum allowable acreage from 39.2 million acres (the 2002 Farm Bill cap) to 32 million acres. Between 2007 and 2010, 27.8 million acres of CRP lands are set to expire, but 83 percent (~23 million acres) of these lands have already either had their contracts renewed or extended (Cowan 2008). The reasons for these enrollment fluctuations vary widely. During the summer of 2008, floods decimated much of the Midwest and disrupted crop planting accompanying high energy and food prices, causing some landowners to petition for penalty free early release from their CRP contracts. After some serious concern on the part of the environmental groups that millions of acres of CRP land would be lost to agriculture once again, the Department of Agriculture secretary Ed Schafer declared that no early release would be granted at the end of July 2008 (Judge 2008). Despite the sigh of relief from the CRP proponents, the number of acres will gradually decline to the new cap over the next couple of years. Whether a reduction in CRP acres, and thus an increase in planted acres, really impacts food prices or not remains to be seen.

Table 3. Conservation Reserve Program Acreage

Year	CRP Acres	Iowa CRP Acres	Percent of CRP Land in Iowa
2001	33,603,344	1,802,169	5.36%
2002	33,964,386	1,865,301	5.49%
2003	34,110,536	1,882,553	5.52%
2004	34,707,287	1,894,587	5.46%
2005	34,902,300	1,917,574	5.49%
2006	36,003,300	1,958,902	5.44%
2007	36,770,984	1,970,561	5.36%
2008	33,620,626	1,677,487	4.99%
Source: USDA Farm Service Agency			

There have been efforts to quantify the environmental benefits of the CRP. The Farm Service Agency has estimated that soil erosion has been reduced by approximately 454 million tons per year compared to the 1982 erosion rates. From the program's inception in 1985 through April of 2006, 2 million acres of wetlands along with an additional 2.5 million acres of riparian buffers had been restored. The Natural Resource Conservation Service estimates that more than 48 million metric tons of carbon have been sequestered annually and more than 3.2 million acres of wildlife habitat have been created on CRP lands. Other numbers that sing the praises of the CRP are reduction in fertilizer applications: Nitrogen reduced by 681,000 tons and Phosphorous reduced by 104,000 tons annually (Cowan 2008).

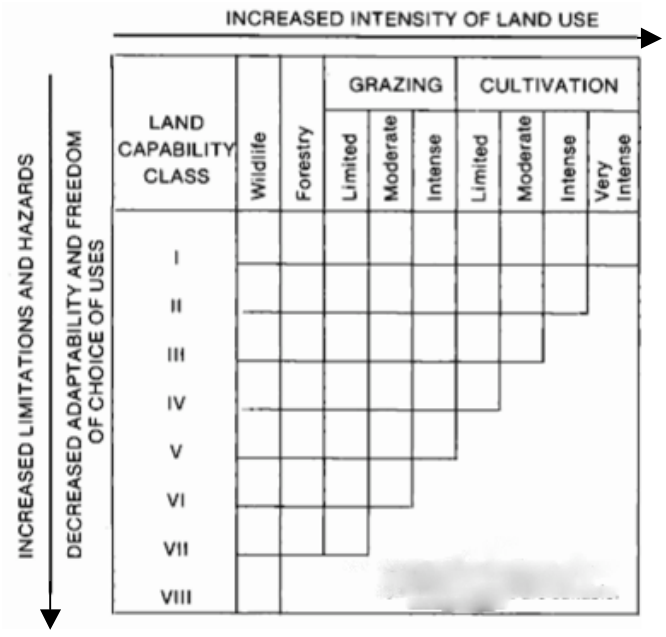
The Conservation Reserve Program and Cellulosic Ethanol

So what does cellulosic ethanol have to do with the Conservation Reserve Program? Currently, harvesting and grazing on the CRP lands are prohibited by the contracts. Some believe that perennial grasses and other biomass crops on CRP lands should be managed for harvest and ethanol production, but this would seriously damage the environmental benefits the land provides. Millions of acres currently under contract with the CRP are due to expire in the next

few years. Many farmers are feeling pressure to let their CRP acres expire and go back to row crops due to the high prices that can be fetched. Though the ideal from an environmental perspective might be to have all CRP land contracts renewed, it might make more economic sense for farmers to pursue a conversion of these lands into perennial grass production. Whatever land use choices are made in the future, it is clear that counties with high CRP acreage on the whole have a better environmental and economic incentive for energy crop production.

The Land Capability Classification System

The Land Capability Classification (LCC) system has been in use since the 1950s when the U.S. Department of Agriculture created it to "assess the appropriate uses of various types of land" (Brady and Weil 2002). Since the 1985 Farm Bill, its primary function has been to identify highly erodible landscapes that ought to be removed from commodity crop production (Helms 1992). Eight different capability classes are defined by the LCC, with each class indicating a greater limitation in terms of potential land uses. Figure 4 shows the potential uses for each class.



Source: Brady and Weil, 2002

Figure 4. Land Capability Class Uses

Class 1 is the best agricultural land with the least limitations. It is generally deep, well-drained, flat land that can easily be continually cropped. Class 2 lands are also good cropland, with a few small limitations that will require simple conservation practices to reduce the potential for erosion. Class 3 lands have significant limitations that require good planning to reduce erosion. The same crops can be planted on Class 1, 2, and 3, but cover crops must be mixed into the rotations on Class 3 land. Class 4 land can be used in a very limited fashion for cultivation, but typically only for crops that grow close together and provide good ground cover. Examples of crops that can be safely grown on Class 4 land are wheat, barley, sod, and hay crops. If a farmer wishes to plant row crops, no-till methods are best, but terracing can be used if necessary. Terracing limits erosion by layering the rows of crops down a slope. Lands in Class 5 typically have rocky soils, poor drainage, or short growing seasons that prohibit them from being cultivated. They can be used for grazing, however. Class 6 land is usually steeply sloped with substantial erosion problems and should not be cultivated. Class 7 and 8 both have major restrictions on their use, with Class 8 being essentially useless for any sort of commercial production (Brady and Weil 2002). There are three general subclasses to each category as well. Subclass “e” indicates that the main issue is erosion, subclass “w” indicates that water on or near the soil surface inhibits plant growth, and subclass “s” means that the soil is too shallow or rocky to accommodate intensive row crop management (Helms 1992).

The LCC is the basis for much of the analysis conducted in the Iowa Case Study. Though there are some debates and questions over the validity of certain aspects of the LCC, it is a well-established system by which to measure the general capability of a landscape to withstand different types of land use. For the purposes of the following case study, land classes 4 and above are assumed to be poor choices for intensive crop management.

Iowa Case Study

Iowa is one of the most productive states in terms of agricultural output in the United States. According to the National Agricultural Statistics Service of the USDA, Iowa harvested 13,850,000 acres of corn and 8,550,000 acres of soybeans in 2007. This yielded 2,368,350,000 bushels of corn and 438,780,000 bushels of soybeans. These numbers put Iowa at number one in the U.S. for corn acres and number two in the country for soybean acreage (USDA-NASS 2008).

With all of the corn produced in the state, Iowa also leads the nation in ethanol production from corn. As of November 2008, the ethanol production capacity in the state of Iowa, including capacity under construction, was 3,484 million gallons. The total ethanol production capacity in the U.S. on the same date, including capacity under construction, was 13,287 million gallons (RFA 2008). Despite the exponentially increasing ethanol production capacity in this country, if we are to meet the renewable fuel mandate, particularly regarding cellulosic ethanol, there is a long way to go.

These statistics, demonstrating agricultural proficiency, are the first reasons why Iowa is an ideal case study for potential feedstock production for cellulosic ethanol. The second important reason is that Iowa has several species of perennial grasses that are native to the state that can be used for energy production. Finally, there are close to two million acres of land enrolled in the Conservation Reserve Program. The goal of this research is not to demonstrate that CRP lands should be used to grow energy crops, but merely to show that there are millions of acres of land in the state, currently planted in row crops like corn, that have steep slopes, rocky soils, and poor drainage. CRP should continue to be promoted, but will ultimately fail to provide farmers with much needed income on all marginal agricultural land. Currently, farmers have no other meaningful financial incentive to do anything but continue to plant these poor

lands in corn or soybeans. If a viable market for perennial grasses comes online, however, a significantly more environmentally friendly and business savvy decision could be made on land use patterns.

There is a geographic pattern that emerges when looking at the state of Iowa in terms of production potential. A look at Figure 5 below, showing corn suitability ratings (CSR) in Iowa, gives a quick glimpse into what this production gradient looks like (Secchi and Babcock 2007). In theory, this image suggests that the darker blue areas are best for corn production and the lighter areas have poorer corn production. If this is the case, the lighter areas should end up being the focus of both conservation programs and energy crop production.

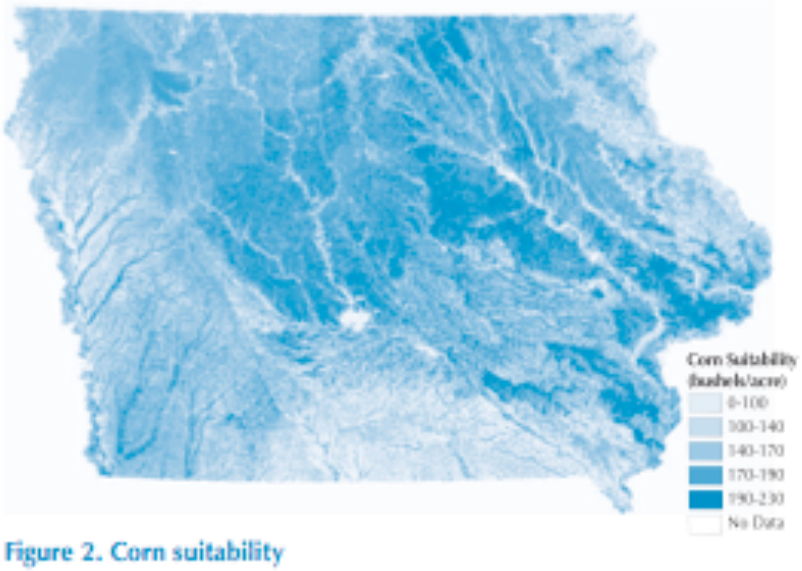


Figure 2. Corn suitability

Figure 5. Iowa Corn Suitability Rating

Figure 6 shows that the counties with generally low CSR do in fact have a higher percentage of land dedicated to the CRP (Tiffany 2007). This case study utilizes the ten counties with the highest CRP acreage enrolled and the ten counties with the lowest CRP acreage enrolled. The goal is to show that land capability class 4 and higher dominates the counties with high CRP acreage, and classes 1, 2, and 3 dominate the counties with low CRP

acreage. Counties that have a predominance of lands that are class 4 and higher could then prioritize a greater shift toward energy crop production on these marginal agricultural lands.

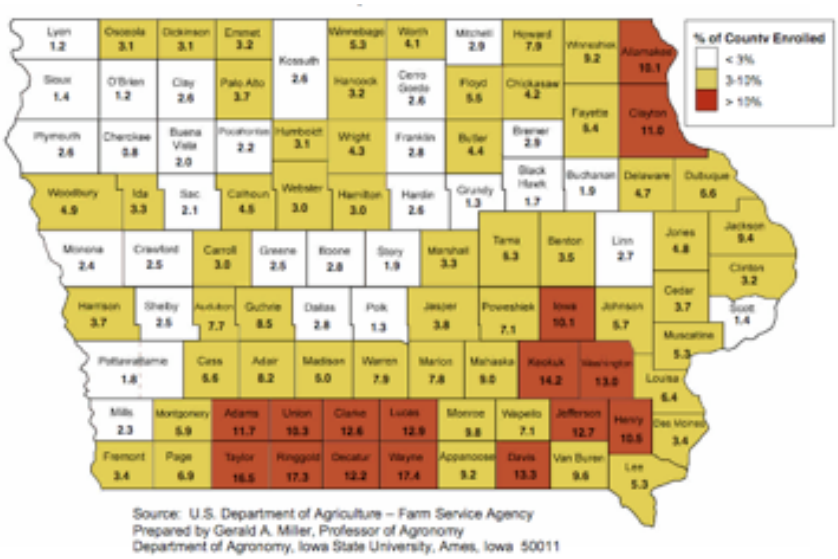


Figure 6. Iowa CRP Enrollment Percentage by County (April, 2007)

Methods

In this case study, soils data published in 2002 containing the Land Capability Classification of each soil unit was used alongside land cover satellite images from 2002 and 2007 in order to determine what the land cover in each county and on each Land Capability Classification unit has been. From this information, it can be determined where potentially poor land management decisions have been. The goal was to isolate units of land that are planted in commodity crops, dominated unsurprisingly by corn and soybeans, that are also classified as marginal or poor agricultural land according to the LCC. This analysis was performed using ArcGIS software.[2]

[2] The GIS data used in this analysis was obtained from the GIS Section of the Iowa Department of Natural Resources and from the National Agricultural Statistics Service.

I compared soils data from the Iowa Department of Natural Resources for the ten counties with the highest total CRP acreage and for the ten counties with the lowest total CRP acreage as of 2007. The sample counties were chosen on the basis of CRP acreage based on the hypothesis that marginal land classifications would dominate the counties with a high percentage of land enrolled in the program. I also downloaded the land cover images of the state from 2002 and 2007, developed from satellite photos, in order to quantify any meaningful changes in land uses over that five-year period (Iowa DNR 2008). The 2007 image I used is the Midwestern cropland data layer (USDA-NASS 2008). Throughout my analysis I attempted to use the most up to date information, and with a couple of exceptions the most recent available data were from 2007. Figure 7 shows a map of the counties in Iowa used for this case study.

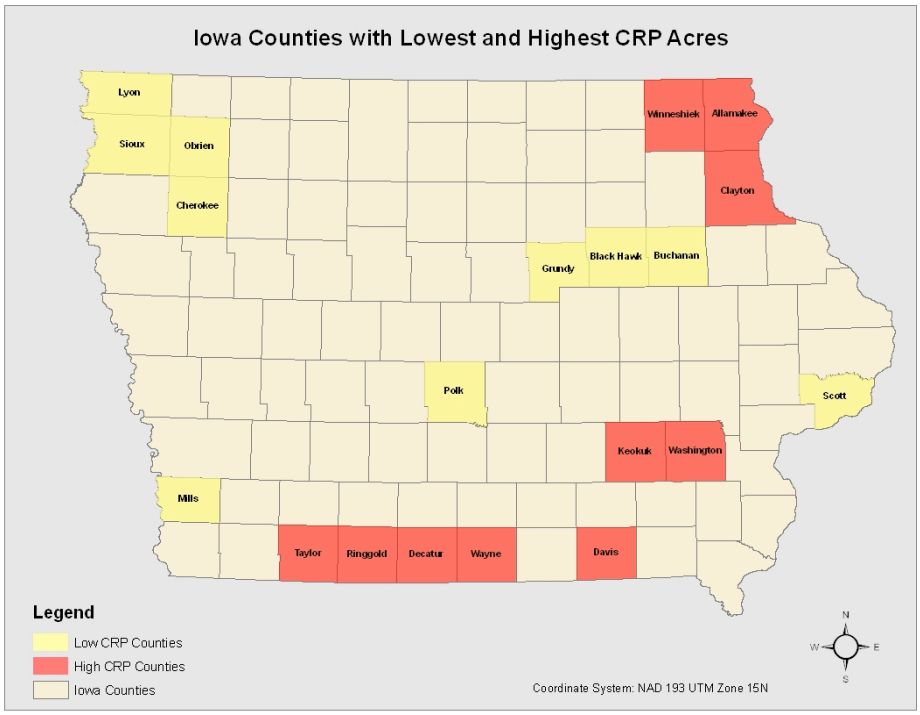


Figure 7. Iowa Case Study Counties

Analysis

Tables 4 and 5 below compare the two groups of counties based on cropland and CRP acreages. A review of these tables shows large differences in not only CRP acreage but also

percent of cropland harvested between the two categories of counties in Iowa. In essence, CRP acreage is a good indicator of counties in which commodity crop production potential is substantially lower. This suggests that there are large tracts of land that are idle, being used as grazed or ungrazed grasslands, or in conservation programs. Whatever the use is, these counties have much greater environmental and economic incentives to pursue energy crop production.

Table 4. Highest Acreage CRP Counties in Iowa

County	Area (acres)	Land in Farms (acres)	Total Cropland	Harvested Cropland	Percent Cropland Harvested	2002 CRP	2007 CRP	% of County in CRP 2007
RINGGOLD	344,109	299,426	215,860	119,277	55.3%	61,969	59,019	17.2%
WAYNE	336,384	304,983	235,265	144,768	61.5%	59,266	58,611	17.4%
TAYLOR	341,728	308,340	239,277	159,970	66.9%	58,440	56,703	16.6%
CLAYTON	498,438	432,724	314,957	248,030	78.8%	54,144	54,410	10.9%
KEOKUK	370,682	343,858	279,904	211,257	75.5%	56,098	52,779	14.2%
WASHINGTON	363,974	334,564	284,218	236,858	83.3%	41,162	47,169	13.0%
DAVIS	322,074	290,887	204,480	128,895	63.0%	44,123	43,089	13.4%
ALLAMAKEE	409,318	326,122	191,600	144,612	75.5%	41,438	42,303	10.3%
DECATUR	340,352	277,928	172,074	96,216	55.9%	43,187	41,747	12.3%
WINNESHIEK	441,350	380,034	303,258	251,757	83.0%	35,897	40,112	9.1%

Table 5. Low Acreage CRP Counties in Iowa

COUNTY	Area (acres)	Land in Farms (acres)	Total Cropland	Harvested Cropland	Percent Cropland Harvested	2002 CRP	2007 CRP	% of County in CRP 2007
CHEROKEE	369,376	335,410	289,810	271,900	93.8%	2,519	3,144	0.9%
SCOTT	293,075	228,692	210,317	201,417	95.8%	3,936	4,080	1.4%
GRUNDY	321,606	324,139	305,643	295,797	96.8%	3,681	4,148	1.3%
OBRIEN	366,771	362,365	332,191	321,700	96.8%	3,740	4,364	1.2%
LYON	376,000	341,534	304,913	294,141	96.5%	3,973	4,525	1.2%
POLK	364,384	227,069	204,203	190,229	93.2%	4,374	4,845	1.3%
BLACK HAWK	362,950	275,014	252,577	241,295	95.5%	6,209	6,345	1.7%
MILLS	279,379	247,254	220,178	203,926	92.6%	4,577	6,435	2.3%
BUCHANON	365,606	340,422	311,313	298,590	95.9%	5,330	6,802	1.9%
SIOUX	491,443	505,175	462,587	447,482	96.7%	4,999	6,931	1.4%

Source: 2002 Census of Agriculture (USDA-NASS 2002), 2000 U.S. Census (Census 2000)

A further analysis, looking at the soils data, breaks down each county into their respective land capability classifications. Table 6 below summarizes the number of acres each of the sample counties has in each land capability class. The most important conclusion that can be drawn from these data is that the high CRP counties, unsurprisingly, have a much higher percentage of their land areas in class 3 and above. The low CRP counties have the vast majority of their areas in classes 1 or 2. Unfortunately, spatial data for land enrolled in the CRP are unavailable due to privacy restrictions, but it is reasonable to assume from all of the qualitative information that the majority of CRP contracts are for land above LCC 3.

Table 6. Land Capability Classification of Counties (Acres)

County	Class 1-2	Class 3	Class 4	Class 5-7	Total Area
High CRP					
DECATUR	70,794	91,896	92,540	81,589	336,819
RINGGOLD	53,016	171,194	80,328	37,597	342,136
CLAYTON	79,812	174,753	72,016	129,998	456,579
TAYLOR	94,704	167,359	69,463	7,281	338,807
DAVIS	26,389	155,235	86,851	49,465	317,941
WASHINGTON	194,800	84,376	51,691	30,636	361,503
KEOKUK	169,308	105,863	49,110	36,842	361,122
WAYNE	65,686	145,261	90,765	34,241	335,953
WINNESHIEK	151,879	172,724	45,503	69,644	439,751
ALLAMAKEE	59,068	148,979	51,176	140,591	399,814
Total	**965,457**	**1,417,639**	**689,444**	**617,885**	**3,690,426**
Low CRP					
OBRIEN	349,402	8,192	850	7,022	365,465
SIOUX	412,259	56,605	3,125	3,355	475,345
LYON	302,228	57,573	5,322	6,258	371,381
BUCHANAN	302,036	17,065	26,695	17,513	363,309
BLACK HAWK	272,639	25,759	25,189	22,268	345,856
MILLS	144,218	102,530	18,876	13,210	278,834
POLK	201,908	58,010	8,926	27,571	296,415
SCOTT	143,129	77,521	19,173	29,199	269,022
GRUNDY	286,162	27,464	2,084	4,657	320,367
CHEROKEE	254,556	81,522	3,001	26,573	365,652
Total	**2,668,536**	**512,240**	**113,242**	**157,628**	**3,451,646**

Figures 8 and 9 below provide a visual example of the differences in land capability classification between Cherokee County (lowest CRP acres in Iowa) and Ringgold County (highest CRP acres in Iowa). It is not difficult to imagine that most of Cherokee County will be planted in commodity row crops since there is such a low percentage of Class 4 and such a high percentage of Class 1 and 2 land. Similarly, we would expect Ringgold County to have much less acreage in row crops.

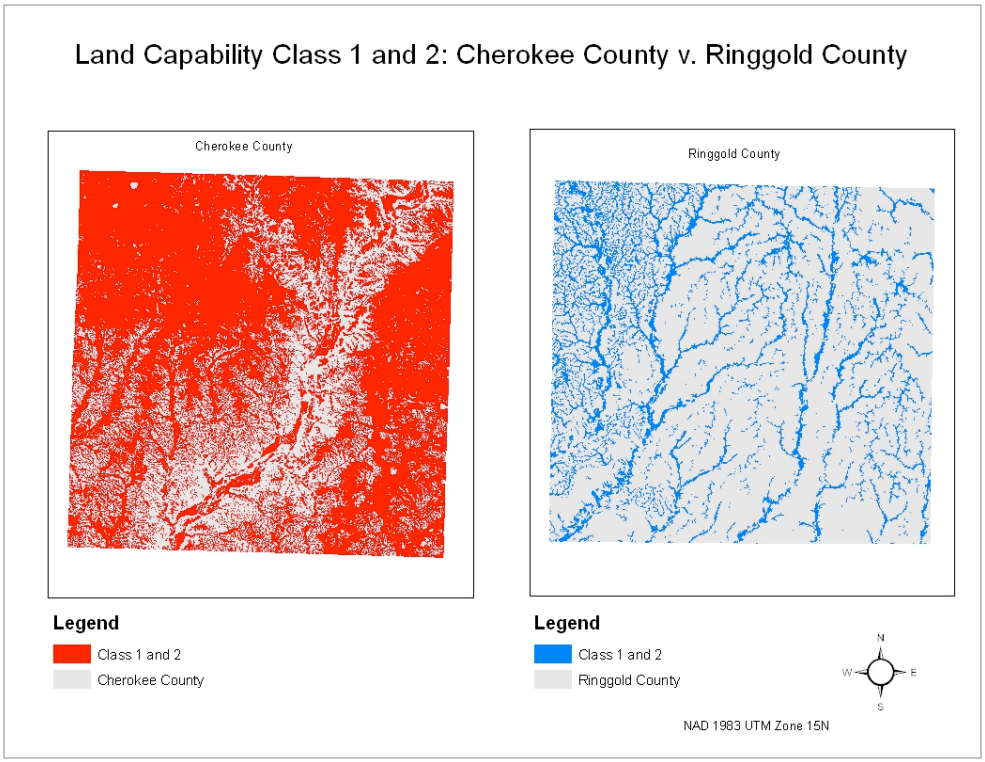


Figure 8. LCC 1 and 2 in Low v. High CRP Counties

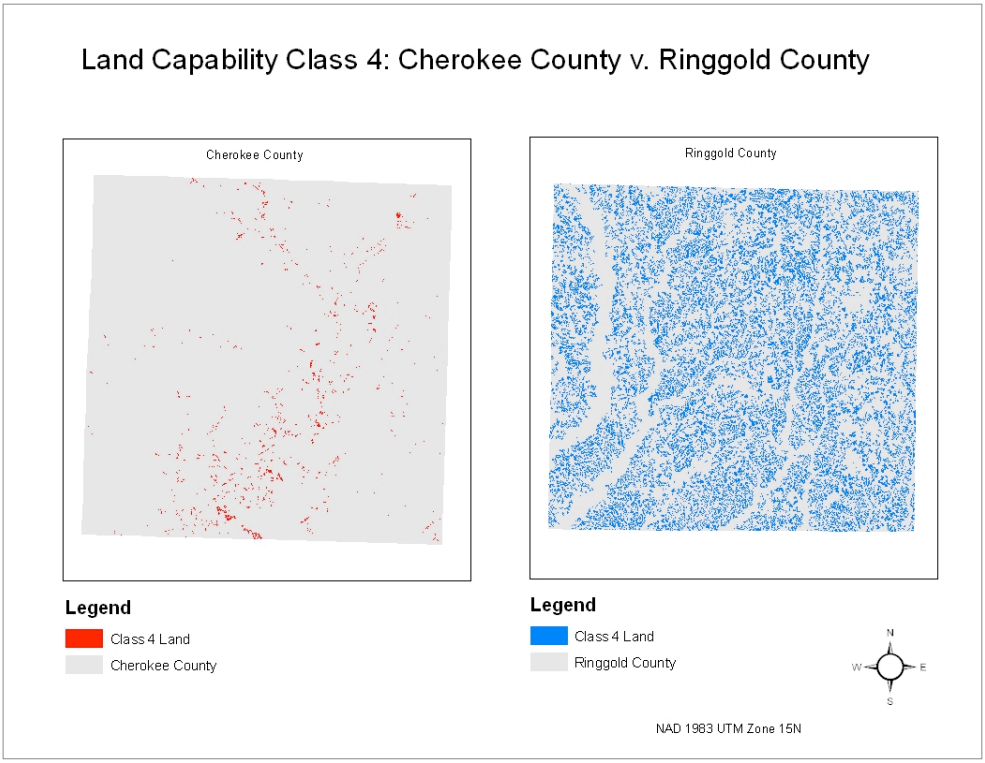


Figure 9. LCC 4 in Low v. High CRP Counties

2002 versus 2007 Land Cover

The focus of this section is to identify areas in the case study counties that are planted in corn and also have land capability classifications at 4 and above. It is these areas that should be the focus of energy crop production. This analysis was performed by overlaying the land cover images from 2002 and 2007 to quantify the acreage of the respective land uses on each LCC. Interestingly, corn and CRP acreage in the case study counties both increased between 2002 and 2007. One obvious reason for the dramatic increase in corn acres planted has been the increasing demand for corn ethanol. Table 7 shows the changes in corn and CRP in the case study counties.

Table 7. Changes in Corn and CRP Acreages between 2002 and 2007

County	2002 Corn Acreage	2007 Corn Acreage	Percent Change	2002 CRP Acreage	2007 CRP Acreage	Percent Change
HIGH CRP						
Ringgold	32,813	33,784	2.96%	61,969	59,019	-4.76%
Wayne	35,167	36,745	4.49%	59,266	58,611	-1.11%
Taylor	76,028	56,981	-25.05%	58,440	56,703	-2.97%
Clayton	103,986	108,578	4.42%	54,144	54,410	0.49%
Keokuk	97,050	103,774	6.93%	56,098	52,779	-5.92%
Washington	121,840	110,733	-9.12%	41,162	47,169	14.60%
Davis	31,231	30,688	-1.74%	44,123	43,089	-2.34%
Allamakee	47,757	39,468	-17.36%	41,438	42,303	2.09%
Decatur	23,459	26,064	11.10%	43,187	41,747	-3.34%
Winneshiek	106,680	113,215	6.13%	35,897	40,112	11.74%
LOW CRP						
Cherokee	129,977	143,376	10.31%	2,519	3,144	24.80%
Scott	98,503	117,818	19.61%	3,936	4,080	3.66%
Grundy	136,312	158,836	16.52%	3,681	4,148	12.68%
Obrien	146,932	161,498	9.91%	3,740	4,364	16.67%
Lyon	134,972	166,954	23.70%	3,973	4,525	13.88%
Polk	77,528	88,346	13.95%	4,374	4,845	10.77%
Black Hawk	127,254	142,700	12.14%	6,209	6,345	2.19%
Mills	95,175	96,971	1.89%	4,577	6,435	40.58%
Buchanon	148,927	191,703	28.72%	5,330	6,802	27.60%
Sioux	203,537	242,607	19.20%	4,999	6,931	38.66%
Total	**1,975,129**	**2,170,839**	**9.91%**	**539,064**	**547,561**	**1.58%**

Source: 2002 and 2007 land cover images and GIS analysis

Figure 10 below depicts an example of the differences that can be observed from the land cover images between the two categories of CRP counties. Corn and soybeans dominate Cherokee county, with very low CRP acreage, while grasslands are the predominant land cover in Ringgold County with high CRP acreage.

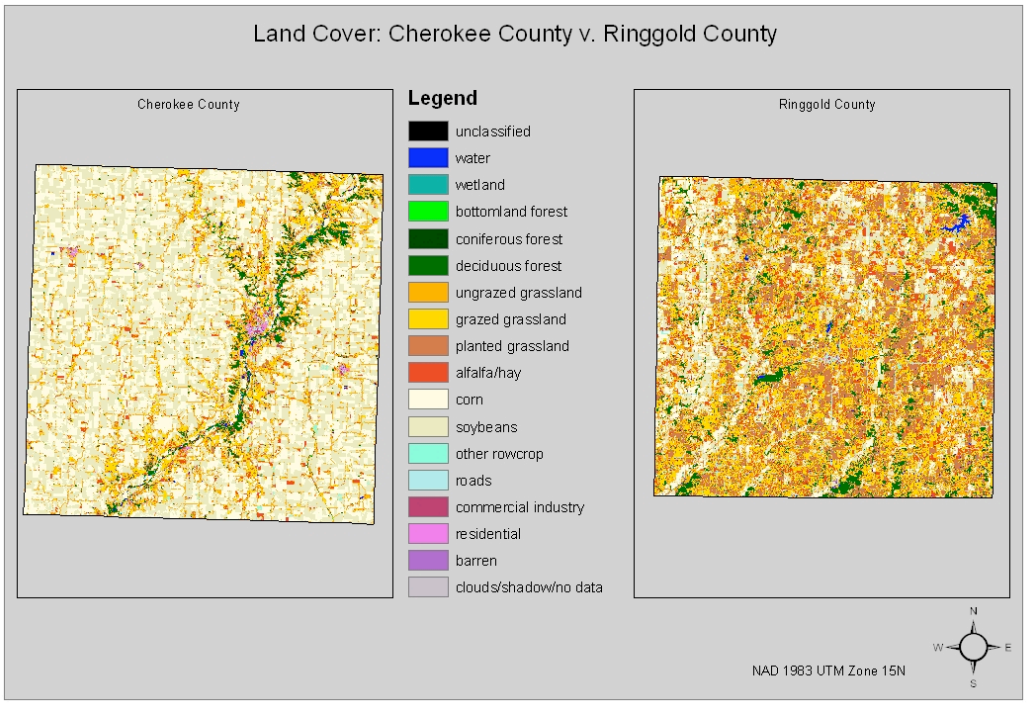


Figure 10. 2002 Land Cover Image Comparison

Results

The focus of this output is on corn planted in LCC 4 and above. Further research could follow the model outlined here, but shift the focus to soybeans, grasslands, or another dominant land use. Tables 8 and 9 below demonstrate one of the key findings of this analysis; namely, land classifications 4, 5, 6, and 7 in both high and low CRP counties have substantial amounts of corn.

Table 8. Corn Planted on LCC 4 and Above (2002)

County	LCC 4 with Corn	LCC 5 with Corn	LCC 6 and 7 with Corn	Total
HIGH CRP				
Ringgold	4,695	80	612	5,387
Wayne	7,410	0	703	8,113
Taylor	11,161	22	180	11,363
Clayton	11,714	588	7,328	19,631
Keokuk	9,411	202	2,638	12,251
Washington	13,930	359	2,850	17,139
Davis	5,197	0	303	5,500
Allamakee	3,008	29	1,653	4,691
Decatur	2,945	392	399	3,736
Winneshiek	7,578	222	4,154	11,953
Total	**77,050**	**1,895**	**20,820**	**99,765**
LOW CRP				
Cherokee	467	450	358	1,275
Scott	6,400	35	4,303	10,738
Grundy	745	584	0	1,329
Obrien	83	20	81	184
Lyon	734	0	105	839
Polk	674	75	104	853
Black Hawk	6,409	388	78	6,875
Mills	3,312	0	152	3,464
Buchanon	9,900	593	164	10,656
Sioux	586	138	27	751
Total	**29,309**	**2,283**	**5,371**	**36,964**

Table 9. Corn Planted on LCC 4 and Above (2007)

County	LCC 4 with Corn	LCC 5 with Corn	LCC 6 and 7 with Corn	Total
HIGH CRP				
Ringgold	5,132	25	515	5,672
Wayne	7,708	0	765	8,473
Taylor	7,266	22	50	7,338
Clayton	10,479	604	5,731	16,814
Keokuk	10,334	287	2,607	13,227
Washington	10,762	159	1,809	12,730
Davis	4,601	0	150	4,752
Allamakee	1,685	51	756	2,492
Decatur	3,982	290	234	4,506
Winneshiek	7,503	212	3,979	11,694
Total	**69,453**	**1,650**	**16,594**	**87,697**

LOW CRP				
Cherokee	630	436	645	1,710
Scott	7,084	26	4,536	11,645
Grundy	1,025	1,019	0	2,044
Obrien	181	23	219	422
Lyon	1,150	0	213	1,363
Polk	839	148	153	1,141
Black Hawk	6,099	429	99	6,626
Mills	3,743	0	147	3,890
Buchanon	10,827	778	189	11,794
Sioux	984	160	70	1,214
Total	**32,561**	**3,018**	**6,271**	**41,850**

Tables 10 and 11 below show the total proportions of each of these LCCs planted in corn. Though the high CRP counties have more acres of corn in the class 4 and above land areas, the low CRP counties have a higher proportion of each classification's area planted in corn. LCC 4 is the most compelling. In 2002, an average of 12.4 percent of the land in category 4 in the high CRP counties and 21.5 percent of category 4 lands in low CRP counties was planted in corn. These percentages were much lower for categories 5, 6, and 7. 2007 saw a large increase from 2002 in the low CRP counties to an average of 27.6 percent of category 4 land planted in corn. The percentage of land in corn in the high CRP counties remained about the same.

The hypothesis was that the high CRP counties would have a different proportion of marginal cropland planted in corn than the low CRP counties. A simple two-tailed student's T test comparing the mean proportions for each LCC for both low and high CRP counties yields statistically significant differences in class 4 lands in 2002 and each of the three categories in 2007 (statistical analysis included in Tables 10 and 11 below). The significantly different categories are highlighted in red in the tables.

Table 10. 2002 Proportion of Marginal Land Planted in Corn

County	Proportion 4	Proportion 5	Proportion 6-7
HIGH CRP			
Ringgold	5.85%	4.95%	1.70%
Wayne	8.16%	-	2.05%
Taylor	16.07%	4.31%	2.66%
Clayton	16.27%	4.56%	6.26%
Keokuk	19.16%	6.92%	7.78%
Washington	26.95%	7.38%	11.06%
Davis	5.98%	-	0.61%
Allamakee	5.88%	0.23%	1.29%
Decatur	3.18%	3.84%	0.56%
Winneshiek	16.65%	6.07%	6.29%
Average	**12.42%**	**4.78%**	**4.03%**
Std Dev	7.70%	2.23%	3.59%
Std error	2.43%	0.71%	1.14%
95% CI	4.46%	1.29%	2.08%
LOW CRP			
Cherokee	15.56%	6.65%	1.81%
Scott	33.38%	0.48%	19.67%
Grundy	35.73%	12.54%	-
Obrien	9.81%	1.69%	1.39%
Lyon	13.79%	-	1.68%
Polk	7.55%	0.50%	0.82%
Black Hawk	25.44%	1.83%	7.23%
Mills	17.54%	-	1.15%
Buchanon	37.08%	3.87%	7.40%
Sioux	18.75%	19.88%	1.01%
Average	**21.46%**	**5.93%**	**4.68%**
Std Dev	10.81%	6.94%	6.20%
Std error	3.42%	2.19%	1.96%
95% CI	6.25%	4.01%	3.59%

*Red Highlight indicates statistically significant category

Table 11. 2007 Proportion of Marginal Land Planted in Corn

County	Proportion 4	Proportion 5	Proportion 6-7
HIGH CRP			
Ringgold	6.37%	1.55%	1.43%
Wayne	8.50%	-	2.24%
Taylor	10.48%	4.39%	0.73%
Clayton	14.57%	4.80%	4.89%
Keokuk	21.08%	9.79%	7.68%
Washington	20.89%	3.26%	7.01%
Davis	5.30%	-	0.30%
Allamakee	3.30%	0.40%	0.59%
Decatur	4.31%	2.83%	0.33%
Winneshiek	16.46%	5.74%	6.04%
Average	**11.13%**	**4.10%**	**3.12%**
Std dev	6.72%	2.88%	2.96%
Std error	2.12%	0.91%	0.94%
95% CI	3.89%	1.67%	1.71%
LOW CRP			
Cherokee	21.00%	6.42%	3.25%
Scott	36.94%	0.35%	20.74%
Grundy	49.72%	22.03%	-
Obrien	21.26%	1.98%	3.73%
Lyon	21.56%	-	3.42%
Polk	9.44%	0.99%	1.22%
Black Hawk	24.24%	2.02%	9.41%
Mills	19.80%	-	1.11%
Buchanon	40.63%	5.09%	17.06%
Sioux	31.13%	23.00%	2.66%
Average	**27.57%**	**7.74%**	**6.96%**
Std dev	11.93%	9.35%	7.25%
Std error	3.77%	2.96%	2.29%
95% CI	6.90%	5.41%	4.20%

*Red Highlight indicates statistically significant category

The message that should be taken away from these data is that marginal cropland has seen an increase in corn over the five-year period between 2002 and 2007. This trend is likely to slow, however. Corn ethanol production is growing at a faster rate than required by the Renewable Fuel Mandate and the demand for cellulosic ethanol feedstocks is increasing. Though the proportion of marginal lands planted in corn is lower in the high CRP counties, it is clear that there is a great deal of land available for energy crop production. In order to effectively meet this

new demand, an innovative approach to land management will be needed in the low CRP counties that are producing massive amounts of corn. These are clearly the counties that are best suited for intensive row crop production, but there are some marginal lands should be utilized for energy crops. The high proportion of marginal lands planted in corn suggests that the prime farmland dominating much of the region has caused some farmers to cover even the most sensitive lands with corn and other crops as well.

Making the Numbers Speak

A brief thought experiment will help bring this analysis closer to home. Let us assume that in order to achieve 16 billion gallons of cellulosic ethanol by 2022, there will need to be 160 regional plants in different areas of the country with a capacity of 100 million gallons per year. Imagine that an entrepreneur in southern Iowa wants to focus on cellulosic ethanol production from switchgrass. He or she wants to find marginal agricultural land that has less economic competition from corn and other intensively managed crops, but cannot afford to be shipping feedstocks from all over the state. He or she could take a look at four adjacent counties that have been discussed in this analysis that have among the highest CRP acreages in the state. Taylor, Ringgold, Decatur, and Wayne counties' high CRP enrollment suggests that there is a great deal of sensitive land that needs to enter the energy production mix in an environmentally sound manner.

Assuming a modest 4 tons of switchgrass harvested per acre and 100 gallons of ethanol produced per ton, 250,000 acres would need to be dedicated to energy crop production in order to supply 1 million tons to produce 100 million gallons of ethanol.[3] These four counties have a

[3] These assumptions are based on an extensive literature review and considering numerous estimates of tons of switchgrass per acre and gallons of ethanol per ton.

combined 493,804 acres in land classes 4 and above, meaning that there is almost twice the needed acreage to supply this imaginary facility. Obviously harvest, transportation, storage, conversion, and social opposition obstacles need to be considered, but the land requirements can clearly be met.

Conclusion

The fundamental point that needs to be emphasized from this analysis is that there is a great deal of land in these sample counties that is planted in row crops like corn and soybeans that would be better off planted in native prairie grasses or put into conservation programs like the CRP. Not only would a change in practices on these marginal lands be better for the soil, water quality, and wildlife, but there is also a quickly growing market for biomass feedstocks for cellulosic ethanol production that can be tapped into. As the technology becomes more affordable and reliable and production facilities are created or retrofitted, the demand for land dedicated to energy crops will soar. Landowners and farmers who recognize the benefits now will realize a significant financial and environmental improvement over the status quo of corn.

The Conservation Reserve Program is an integral part of this story. There are those who would recommend that energy crops be harvested from lands enrolled in the program, but this may be risky from an ecosystem service perspective. The more important function of the CRP in this conversation is as a barometer of good land for energy crop production. Since the cap is now at 32 million acres for CRP land, similar land that farmers might otherwise attempt to plant in row crops could instead be used for energy crops. This approach would preserve some significant ecosystem services over intensive agriculture but also provide farmers some much-needed income as well. This is perhaps not exactly a win-win scenario, but it is a start.

For the provision of ecosystem services and wildlife habitat, having as much land as possible in conservation is the ideal. However, there is a finite amount of land that must be shared between conservation, agriculture, and energy interests. In an ideal world, the best farmland would be reserved for row crops while the marginal cropland could be used for energy crop production and the most sensitive land could be permanently retired in conservation programs. The reality is that competing interests, political power, and bottom-line economics will likely determine the actual allocation of land among these uses. Cellulosic ethanol production requirements can provide the needed economic incentives for perennial crop production on marginal lands.

Literary Citations

Adler, P., M. Sanderson, et al. (2006). "Biomass Yield and Biofuel Quality of Switchgrass Harvest in Fall or Spring." Agronomy Journal **98**: 1518-1525.

Biello, D. (2008). "Grass Makes Better Ethanol than Corn Does." Scientific American.

Bies, L. (2006). The Biofuels Explosion: Is Green Energy Good for Wildlife. Wildlife Society Bulletin. Bethesda, MD. **34:** 1203-1205.

Brady, N. and R. Weil (2002). The Nature and Properties of Soil. Upper Saddle River, New Jersey, Prentice Hall.

Brummer, E. C., C. L. Burras, et al. (2002). "Switchgrass Production in Iowa: Economic Analysis, soil suitability, and varietal performance." from http://www.biomass.ecria.com/__docs/pdf/Switchgrass%20in%20Iowa%202002.pdf.

Bryner, M., E. D'Amico, et al. (2008). "Biofuels; New Obstacles Emerge on the Road to Sustainability." Chemical Week.

Census. (2000). "U.S. Census Bureau State and County Quickfacts." Retrieved 11.2.08, from http://quickfacts.census.gov/qfd/states/19000.html.

Chariton Valley. (2008). "Harvesting Switchgrass." Retrieved 6.2.08, from http://www.iowaswitchgrass.com/cofiringcycle~harvesting.html.

Clanton, B. (2008). "Switchgrass ethanol study shows promise." Retrieved 6.16.08, from http://www.biodieselnow.com/forums/t/19495.aspx.

Cowan, T. (2008). Conservation Reserve Program: Status and Current Issues, USDA Economic Research Service.

DOE. (2007). "DOE Selects Six Cellulosic Ethanol Plants for Up to $385 Million in Federal Funding." Retrieved 8.20.08, from http://www.doe.gov/news/4827.htm.

DOE. (2009, 2.4.09). "Cellulosic Ethanol Feedstocks." Retrieved 3.11.09, from http://www.afdc.energy.gov/afdc/ethanol/feedstocks_cellulosic.html.

Duffy, M. (2007). Estimated Costs for Production, Storage, and Transportation of Switchgrass, Iowa State Extension. Retrieved 6.3.08, from http://www.extension.iastate.edu/agdm/crops/html/a1-22.html.

Garland, C. (2005). Growing and Harvesting Switchgrass for Ethanol Production in Tennessee, University of Tennessee Biofuels Initiative. Retrieved 6.3.08, from http://utextension.tennessee.edu/publications/spfiles/SP701-A.pdf.

Gibson, L. and S. Barnhardt (2007). Switchgrass, Iowa State Extension. Retrieved 6.12.08, from http:// www.extension.iastate.edu/Publications/AG200.pdf.

Great Plains Institute (2007). Home Grown Energy Security: The Potential for Chemicals, Fuels, and Power from Prairie Grass. Retrieved 7.18.08, from http:// www.gpisd.net/.

Greene, N. (2004). Growing Energy: How Biofuels Can Help End America's Oil Dependence, Natural Resources Defense Council. Retrieved 6.15.08, from http://www.bio.org/ind/GrowingEnergy.pdf.

Greer, D. (2005). Creating Cellulosic Ethanol: Spinning Straw into Fuel, Biocycle. Retrieved 6.2.08, from http://www.harvestcleanenergy.org/enews/enews_0505/enews_0505_Cellulosic_Ethanol.htm.

Greer, D. (2007). Realities, Opportunities for Cellulosic Ethanol, Biocycle. Retrieved 6.2.08, from http://www.jgpress.com/archives/_free/001220.html#more.

Greer, D. (2008). "COMMERCIALIZING CELLULOSIC ETHANOL." BioCycle **49**(11): 47-51.

Hellerstein, D. (2006). Agricultural Resources and Environmental Indicators. USDA Land Retirement Programs, USDA Economic Research Service.

Helms, D. (1992). "The Development of the Land Capability Classification." from http://www.nrcs.usda.gov/about/history/articles/LandClassification.html.

Hess, R. and e. al. (2007). Cellulosic Biomass Feedstocks and Logistics for ETOH, Oak Ridge National Laboratory.

HST Consortium. (2008). "Harvest, Storage, and Transportation." Retrieved 7.17.08, from http://www.biorenew.iastate.edu/research/harvest-storage-and-transportation-of-biomass.html.

Iowa DNR. (2008). "Natural Resources Geographic Information Systems Library." Retrieved 9.5.08, from http://www.igsb.uiowa.edu/nrgislibx/gishome.htm.

Jenson, K., C. Clark, et al. (2007). "Farmer willingness to grow switchgrass for energy production." Biomass and Bioenergy **31**: 773-781.

Judge, D. (2008). "USDA nixes CRP 'early-out' proposal." Retrieved 1.16.08, from http://iowaindependent.com/3155/usda-nixes-crp-early-out-proposal.

Moore, B. (2007). "Is Switchgrass Viable?" Retrieved 6.16.08, from http://bioenergy.ornl.gov/reports/tvareg/supply3.html.

Mubako, S. and C. Lant (2008). "Water resource requirements of corn-based ethanol." WATER RESOURCES RESEARCH **44**.

ORNL (1996). Potential Supply and Cost of Biomass from Energy Crops in the TVA Region: Results, Discussion, Conclusions, Oak Ridge National Laboratory.

Perlack, B. (2005). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, U.S. Department of Energy and U.S. Department of Agriculture.

Philpott, T. (2008). "The farm bill ups the cellulosic ethanol ante." Retrieved 2.12.09, from http://gristmill.grist.org/story/2008/5/23/14755/6585.

Pimentel, D. a. T. P. (2005). "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." Natural Resources Research **14**(1).

Range Fuels. (2009). "Biomass to Energy: Inventing the New Oil." Retrieved 2.12.09, from www.rangefuels.com.

RFA. (2008). "Ethanol Facts: Environment." Retrieved 1.13.09, from http://www.ethanolrfa.org/resource/facts/environment/.

RFA. (2008). "Ethanol Production by State." Retrieved 1.19.09, from http://www.neo.ne.gov/statshtml/121.htm.

RFA. (2008). "Renewable Fuels Standard." Retrieved 8.20.08, from http://www.ethanolrfa.org/resource/standard/.

Rinehart, L. (2006). Switchgrass as a Bioenergy Crop, National Sustainable Agriculture Information Service. Retrieved 7.5.08, from http://www1.eere.energy.gov/biomass/pdfs/ornl_switchgrass.pdf.

Schmer, M. R., K. P. Vogel, et al. (2007). "Net energy of cellulosic ethanol from switchgrass." Proceedings of the National Academy of Sciences **105**(2): 464-469.

Searchinger, T., R. Heimlich, et al. (2008). "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." Science **319**(5867): 1238-1240.

Secchi, S. and B. Babcock. (2007). "Impact of High Corn Prices on Conservation Reserve Program Acreage." Iowa Ag Review Online. Retrieved 8.21.08, from http://www.card.iastate.edu/iowa_ag_review/spring_07/article2.aspx.

Shapouri, H. a. D. (2004). The 2001 Net Energy Balance of Corn-Ethanol. Proceedings of the Conference on Agriculture as a Producer and Consumer of Energy.

Tenenbaum, D. (2005). "Harvesting the Potentail of Biomass." Environmental Health Perspectives **113**(11): 750-753.

Tiffany, B. (2007). "CRP Enrollment Maps." Retrieved 1.13.09, from http://extension.agron.iastate.edu/soils/CLU_maps.html.

Tilman, D., J. Hill, et al. (2006). "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass." Science **314**(5805): 1598-1600.

Undersander, D. (2001). "Switchgrass production for biomass." Retrieved 8.12.08, from http://www.cias.wisc.edu/crops-and-livestock/switchgrass-production-for-biomass/.

USDA-NASS (2002). 2002 Census of Agriculture, United States Department of Agriculture.

USDA-NASS. (2008). "Cropland Data Layer." Retrieved 9.5.08, from http://www.nass.usda.govresearch/Cropland/SARS1a.htm.

USDA-NASS. (2008). "Iowa Statistics." Retrieved 1.19.09, from http://www.nass.usda.gov/Statistics_by_State/Iowa/index.asp#.html.

USDA-NASS. (2008). "USDA Expects Corn Acres to Drop in 2008." Retrieved 1.15.09, from http://www.nass.usda.gov/Newsroom/2008/03_31_2008.asp.

Widenoja, R. (2007). Destination Iowa: Getting to a Sustainable Biofuels Future, Worldwatch Institute. Retrieved 7.19.08, from http:// www.worldwatch.org/node/5396**.**

Wyman, C. E. (2007). "What is (and is not) vital to advancing cellulosic ethanol?" Trends in Biotechnology **25**(4): 153-157.

Zhang, Y. (2008). "Rethinking Thermochemical Conversion of Biomass into Biofuel." Resource: Engineering and Technology for a Sustainable World. April 2008.