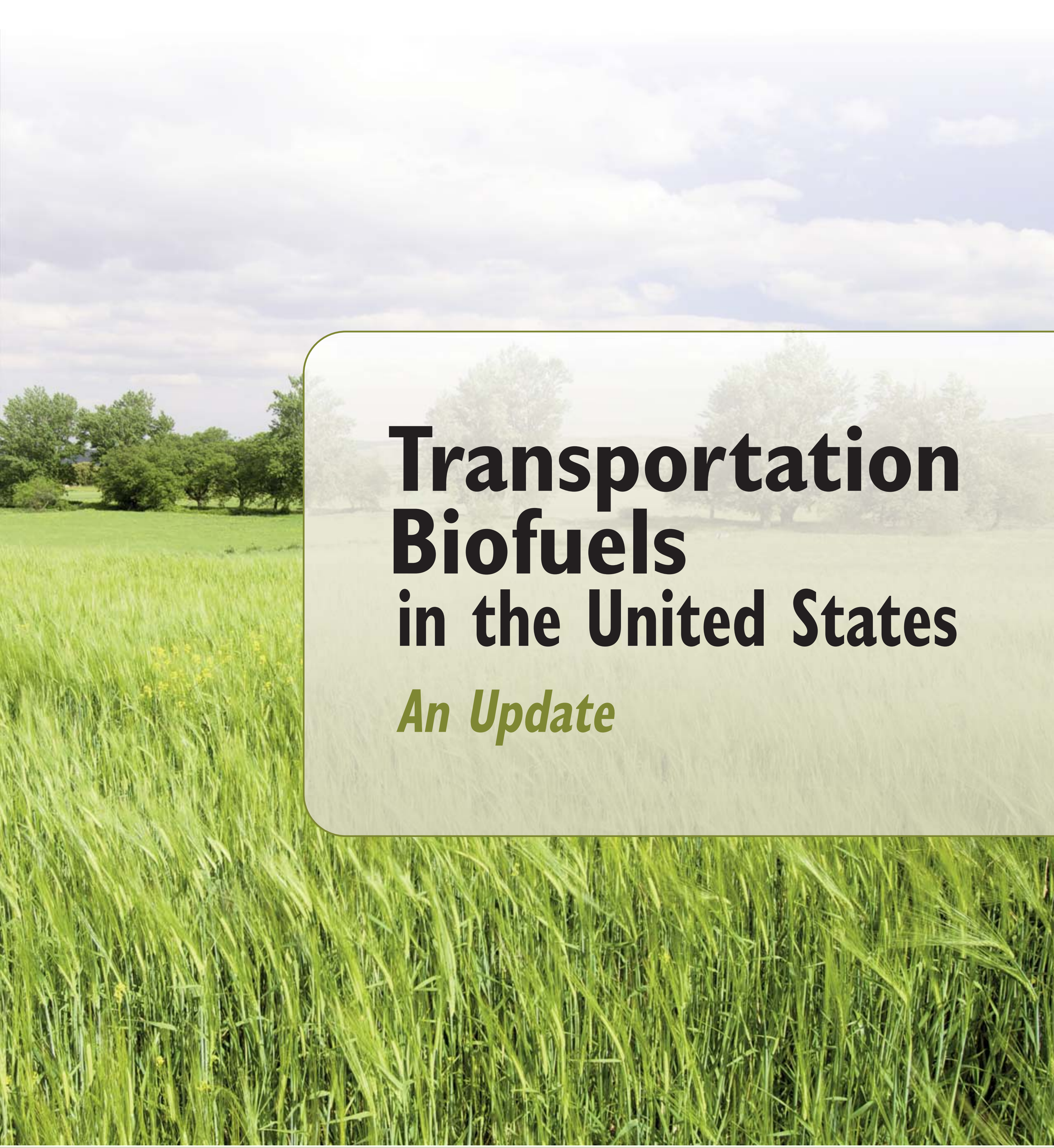


Transportation Biofuels in the United States

An Update

the MINNESOTA PROJECT

AUGUST 2009

ABOUT THE MINNESOTA PROJECT

The Minnesota Project is a nonprofit organization that champions the sustainable production and equitable distribution of energy and food in communities across Minnesota.

Our programs are focused on the development, conservation and efficient use of renewable energy; farm practice and policy that promote profitable farms that protect and replenish the environment; and the production and consumption of local, sustainably grown foods.

Through collaborative leadership we demonstrate practical solutions as a basis for future policy. For over thirty years we have fostered local empowerment, bridged diverse interests, encouraged shared values, and initiated working dialogues that create positive action and effective policies.

Visit us on the web at www.mnproject.org, and check out our new blog, Centered on Sustainability, at www.mnproject.org/blog.

ACKNOWLEDGEMENTS

Thanks are due first and foremost to the individuals interviewed for this paper and to all of the other organizations working to advance and study the biofuels industry.

This report also would not have been possible without the collaborative work of several individuals at The Minnesota Project. Luke Ekelund and Molly Ciaccio conducted most of the research, interviews, and data collection. Dr. Ryan Stockwell is the report's key author. Dan Thiede provided editing and layout expertise.

This report is made possible by a grant from the Energy Foundation.

FOR MORE INFORMATION

Dr. Ryan Stockwell
Director of Energy & Agriculture
The Minnesota Project
651.789.3330
rstockwell@mnproject.org
www.mnproject.org

PHOTO CREDITS

All photos in this report, unless otherwise noted, are generously provided by the Natural Resources Conservation Service (NRCS) Photo Gallery and the National Renewable Energy Laboratory (NREL) Photographic Information eXchange (PIX). A small number of images, such as the one at left, are supplied by The Minnesota Project.

CONTENTS

Introduction iii

Section I: Technology 1

Cellulosic Ethanol 1

Algae Biodiesel 4

Corn Ethanol 5

Section II: Policy 7

Biomass Crop Assistance Program 8

Renewable Fuel Standard 9

Section III: Issues 11

Food versus Fuel 11

Indirect Land Use Change 12

Soil and Water 13

Invasive Species versus Native Species 14

Monoculture versus Polyculture 15

Conclusion 16

References 17

TABLES AND FIGURES

Tables

Table 1: U.S. Cellulosic Ethanol Commercial Projects 2

Table 2: Four Biomass Feedstocks Under Research 3

Figures

Figure 1: Consolidated Bio-Processing 1

Figure 2: Fossil Energy Btu Requirements to Produce 1 Btu of Fuel Energy 6

INTRODUCTION

These days you cannot turn around without hearing and reading about new developments in the biofuels sector—it can be nearly impossible to follow all of the news. These updates come in many forms: Researchers continue to make advancements in the biofuels production process and in feedstocks; New state and federal policies and research and development efforts are announced on a weekly basis; Innovative collaborations and coalitions form to overcome information and political barriers; Start-up pilot, demonstration, and commercial biofuels production facilities are regularly announced by developers. To even the most engaged observers, it seems the biofuels wave continues to gain strength.

Yet, quiet announcements occur just as regularly about canceled or bankrupted biofuels facilities, research that yields bad news, and new concerns about the implications of ramping up biofuels production (Smith 2008, SustainableBusiness.com 2009). These updates have led to one major question about the future of the industry: Will the uncertainty of biofuels goals, impacts, and results act as a rocky shore to the biofuels wave, breaking up the growing momentum and scattering the industry in several directions, perhaps delaying for years the growth of a stable, formidable, and sustainable biofuels sector that could truly begin to reduce greenhouse gas emissions and our reliance on fossil fuels?

While you can't expect to find an answer to that question here, we do intend for *Transportation Biofuels in the United States* to act as a tool to provide an overview of the current status of major developments in the biofuels industry. We will highlight recent changes in biofuels production processes, biomass development, and federal level policies such as the Biomass Crop Assistance Program. We will also review unavoidable issues including the food versus fuel debate and the difficult indirect land use change debate. Our intention is not to criticize, cheerlead, or otherwise deny or approve particular results or arguments. Instead, our purpose will be to provide information, pose questions, and seek objective analysis of the information that is currently available. Only through an open discussion may we most effectively find root problems and appropriate solutions. We believe that through honest evaluation and analysis, this wave of biofuels will not only stay together, but carry us all in the right direction.

Section 1

Technology

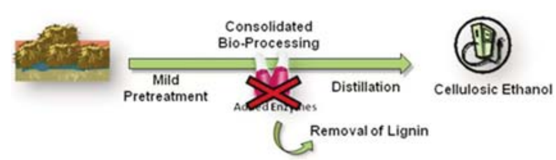
Cellulosic Ethanol

Support for the advancement of cellulosic biofuels is catching up to support for corn ethanol. In January 2009, an $80 million loan guarantee from the USDA Rural Development program was awarded to Range Fuels, a cellulosic ethanol technology company, to develop a commercial-scale cellulosic ethanol facility in Soperton, Georgia. Former USDA Secretary Ed Schafer said, "The investment in this facility, which will make cellulosic ethanol from wood chips, has the potential to significantly advance the timetable for second-generation ethanol production in this country" (Christiansen 2009). The Department of Energy will invest up to $385 million for six biorefinery projects: Abengoa Bioenergy Biomass, ALICO, Inc., BlueFire Ethanol, Inc., POET Biorefining (formerly Broin Companies), Iogen Biorefinery Partners, LLC, and Range Fuels (formerly Kergy Inc.). The expected annual capacity of these plants will total more than 130 million gallons (Stevens 2007). See *Table 1* on the next page for more information on cellulosic ethanol research, development, and demonstration facilities.

Many new technologies are emerging as more funding becomes available to support research and new products. Blue Fire Ethanol Company has developed a technology called concentrated acid hydrolysis. It enables a wide array of cellulosic materials to be converted into sugar, providing raw material for fermentation to produce renewable fuels or for chemical conversion into any of a hundred different specialty and/or commodity chemicals.

Another emerging technology is called Consolidated Bio-Processing (CBP)—–see *Figure 1*. Mascoma Corporation has focused on the commercial development of this new processing method. Researchers at Mascoma consider it the simplest, lowest cost configuration for producing cellulosic ethanol, as it allows nature to do most of the work by introducing genetically modified bacteria and microbes that hydrolyze and ferment the sugars into ethanol. Mascoma's new facility in Rome, New York is now producing cellulosic ethanol with CBP.

Figure 1: Consolidated Bio-Processing



Source: Mascoma, www.mascoma.com/images/technology/cbp2.jpg

Range Fuels has invented a two-step thermo-chemical process to produce low-carbon biofuels. The two steps are summed up as solid to gas and gas to liquid. The feedstock is first converted to synthesis gas (syngas) using heat, pressure, and steam in a converter. The syngas is passed over Range Fuels' proprietary catalyst as it is changed to alcohol. This alcohol can then be processed into ethanol. This two-step thermo-chemical process has potential to be cost effective because it uses natural chemical reactions and conversions rather than enzymes and yeasts which require considerably more inputs. Range Fuels' technology has been tested and proven in pilot-scale facilities for over eight years.

Table 1: U.S. Cellulosic Ethanol Commercial Projects

Company	Location	Technology	Capacity	Feedstock	By-Products
Abengoa	York, NE and Hugoton, KS	thermochemical, bio-chemical processing	23.2 million gallons per year (mg/y)	corn stover, wheat straw, milo stubble, switchgrass, other	electricity
Blue Fire Ethanol	Los Angeles Cty, CA	concentrated acid hydrolysis	19 mg/y	green, wood and other cellulosic urban wastes sorted from MSW	none
California Ethanol Power, LLC	Brawley, CA	undisclosed	55 mg/y	sugarcane	renewable energy, fertilizer, biomass, and biomethane
Ecofin, LLC	Washington Cty, KY	solid-state fermentation process	1.3 mg/y	corn cobs	none
Flambeau River Biofuels, LLC	Park Falls, WI	biomass gasification with Fischer-Tropsch catalytic conversion into liquid fuels	6 mg/y	wood and wood residues	pulp for paper manufacturing on site
Iogen Biorefinery Partners	Shelley, ID	enzymes	18 mg/y	wheat, rice & barley straw, corn stover, and switchgrass	unspecified
Mascoma	Rome, NY and Chippewa Cty, MI	genetically modified bacteria to break down and ferment wood chips	45 mg/y	woody biomass	unspecified
New Page Corp.	Wisconsin Rapids, WI	biomass gasification with Fischer-Tropsch catalytic conversion into liquid fuels	5.5 mg/y	woody biomass, mill residue	unspecified
New Planet Energy	Vero Beach, FL	gasification of wood and fermentation of syngas into ethanol	129 mg/y	wood, vegetative wastes and energy crops	unspecified
Pacific Ethanol	Boardman, OR	undisclosed	2.7mg/y	wheat straw, corn stover and poplar residuals	unspecified
POET Biorefining	Emmetsburg, IA	corn	31 mg/y	corn stover and fiber	methane
Range Fuels, Inc.	Soperton, GA	two-step thermo-chemical process	20 mg/y	wood and wood residues	methanol
ZeaChem	Boardman, OR	biochemical processing	1.5 mg/y	poplar trees, sugar, wood chips	unspecified

On June 10th, 2009, a Canadian Shell service station became the first in the world to sell gasoline blended with cellulosic biofuel (from wheat straw). The blend consists of 90 percent petroleum and 10 percent cellulosic ethanol. The biofuel is produced locally from non-food raw materials at Iogen Energy Corporation's demonstration plant. Iogen and Shell are partners in the plant, which now produces 40,000 liters of fuel per month (Burnham 2009).

Cellulosic ethanol feedstocks under research include corn stover, miscanthus, switchgrass, and fast-growing trees like poplar and willow. See *Table 2* for a review of key four feedstocks.

Table 2: Four Biomass Feedstocks Under Research

Cellulosic Crop	Positives	Negatives
Corn Stover	▪ Most readily available feedstock for ethanol ▪ Along with being a direct feedstock for ethanol, corn stover can also be used to fuel regular corn ethanol production ▪ Nutrient replacement and harvesting activities are the only costs for collecting corn stover	▪ Removing corn stover from fields after harvest may harm soil productivity, structure, fertility, crop yields and increase erosion ▪ Stover moisture content greater than 30% decreases baling efficiency and storability due to risk of molding & rotting
Miscanthus	▪ Sterility prevents invasiveness ▪ Rhizomes (root pieces) can be broken up, collected and planted using existing agricultural equipment (e.g. potato harvesters and planters) ▪ Excellent for carbon sequestration and soil building, and can be grown on less fertile land ▪ Low input ▪ Has higher per-acre production potential than corn or switchgrass	▪ Little or no experience with this crop in the US, so long-term performance under US conditions unknown ▪ Long-term investment discourages adoption ▪ Miscanthus rhizomes have a low tolerance to frost
Switchgrass	▪ Grown on land considered unsuitable for row crop production; hearty crop ▪ Multi-use: a substitute for wheat straw in livestock bedding, straw bale housing, and a substrate for growing mushrooms ▪ Native to the United States ▪ Requires little pesticides or fertilizers ▪ Low soil erosion rate as a perennial plant with a deep root structure	▪ No current operating market making farm-level implementation difficult ▪ Farmers unfamiliar with raising the plant ▪ Long-term investment requirement and current lack of crop insurance discourages adoption
Wood (Poplar, Willow)	▪ Lower capital-intensive conversion costs ▪ Good energy balance for fossil energy consumed in production ▪ Low maintenance	▪ Highly variable costs ▪ Longer harvesting period relative to other energy crops

Algae Biodiesel

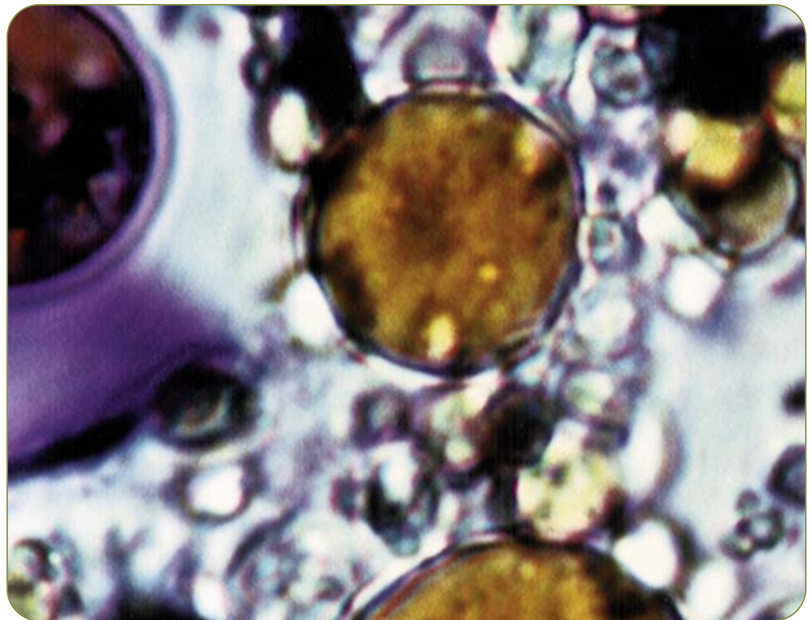
Algae has excited scientists and environmentalists for years with the oil production potential it presents. Current estimates for the oil yield of algae are around 10,000 gallons per acre (Oilgae 2008). This potential compares quite favorably to other plant-oil crops including soybean (48 gallons per acre), safflower (83 gallons per acre), sunflower (102 gallons per acre), rapeseed (127 gallons per acre), castor bean (151 gallons per acre), coconut (287 gallons per acre), and oil palm (636 gallons per acre) (Addison 2008). This high production potential, if achieved, could drastically reduce acreage demands to produce biofuels and increase biofuels' ability to meet demand. "If we were to replace all of the diesel that we use in the United States with an algae derivative," says Solix Biofuels CEO Douglas Henston, "we could do it on an area of land that's about one-half of one percent of the current farm land that we use now" (Haag 2007). Researchers and environmentalists are also excited about the potential algae presents for avoiding the food versus fuel debate that plagues land-based fuel crops. Not only could algae-derived biodiesel considerably reduce the overall surface area necessary to produce the fuel, it may be grown in fresh or salt water and survives in less than ideal conditions.

Research is still required on establishing effective growing and management systems—a task complicated by researchers' relative unfamiliarity with aquaculture, or water-based agriculture. Researchers are focusing on developing technologies and systems for establishing and maintaining the ideal water temperature, sunlight, and nutrient mix, including carbon dioxide. At their southwestern Colorado facility, Solix Biofuels grows algae in closed "photobioreactors", which are chambers made of polyethylene plastic. Carbon dioxide is bubbled through the triangular chambers. To increase efficiency, Solix Biofuels plans to capture carbon dioxide from the exhaust of power plants and feed it into their photobioreactors.

Algenol Biofuels Inc. has a technology that can produce ethanol from algae through natural processes. The technology links photosynthesis with natural enzymes to produce ethanol inside each algae cell. The ratio of energy output to fossil fuel input is 8:1. Algenol produces over 6,000 gallons of ethanol per acre per year, and this result is expected to rise to 10,000 gallons by the end of this year (Algenol Biofuels Inc. 2009).

AlgaeVenture Systems announced in March of 2009 a breakthrough on their liquid separation and dewatering microalgae process. The technology uses processes that exist in nature including capillary effect, cohesion, absorption and transpiration pull. This reduces the cost of removing, harvesting and dewatering by more than 99 percent—from $875 per ton to $1.92 per ton, according to AlgaeVenture Systems, making algae-based biodiesel fuel economically feasible. Another new technology, called Light Immersion Technology, solves the problem of "self-shading" that has previously prevented algae from growing more than 3-5 cm deep. The Light Immersion Technology, discovered by Bionavitas Inc., helps distribute light below the shade layer, enabling algae to grow denser—up to a meter deep. This is an excellent step towards increasing yields in the mass production of algae.

The positives of algae as a feedstock are clear: potential yields are high; it grows rapidly; it grows in salt water, freshwater, contaminated water, on land not suitable for food production, and at sea or in ponds, leaving land open for food production; and it grows better when fed extra carbon dioxide and organic material like sewage, providing the opportunity to clean up other problems during its production. Obviously research and development are still needed to increase the cost-effectiveness of algae biofuels for large-scale production. The main concern with algae is that some are invasive species—a concern held with some cellulosic ethanol crops, such as miscanthus. Algae biodiesel remains a horizon technology with great potential, essentially requiring more scientific advancements before it can be considered for commercial production.



Corn Ethanol

Corn ethanol experienced rapid implementation in the 1990s before analysis of corn ethanol created considerable push back from scientists, politicians, and the general public. Much of this technology became locked in place. On average, existing corn ethanol facilities can produce 2.75 gallons of ethanol per bushel of corn. In other words, corn ethanol facilities can produce about 400 gallons of ethanol per acre of corn. There have been efforts in recent years to extract more ethanol per bushel of corn to improve the per-acre production and reduce the food versus fuel image corn ethanol has received of late.

Arisdyne Systems Inc., an ethanol producing company, has partnered with ethanol technology firm Delta-T Corp. to develop a process called controlled-flow hydrodynamic cavitation, which has potential to increase ethanol yields from corn by increasing the heat and pressure applied in the process to extract more ethanol. Project partners hope to confirm research by September 2009 and set up a full scale trial by the end of the year (Christiansen 2009).

EdeniQ, an ethanol technology company, has their latest idea on trial: Corn3 Yield Enhancement Program. It combines three different technologies to increase ethanol fuel yield. These three include improved yeast production, a propriety milling and mixing device, and improved enzymes. EdeniQ's Corn3 program has been proven at a large-scale pilot plant in Visalia, CA to increase yields by 10 percent. It is currently in commercial-scale trials (Christiansen 2009).

Research is also advancing on processes to create multiple fuels from the corn already used in the ethanol process. In particular, oil may be extracted from corn kernels and processed like soybean oil to create biodiesel. In December of 2008, Greenshift Corporation announced a large investment to build twelve corn oil extraction facilities. This technology is currently used in four ethanol facilities in the Midwest (Davis 2008). By extracting and converting the corn oil into biodiesel, ethanol facilities may increase per-bushel fuel production by up to 8 percent.

Much news has been made in recent years about the energy ratio of corn-based ethanol. Depending on the extent of the factors considered in the lifecycle assessment and the refining process used, corn ethanol has been shown to have anywhere from a slightly negative energy balance (meaning it takes more energy to produce a gallon of ethanol than the energy contained in that gallon of ethanol) to a fairly positive ratio (meaning there is more energy in a gallon of ethanol that the energy required to produce it).

Figure 2: Fossil Energy Btu Requirements to Produce 1 Btu of Fuel Energy

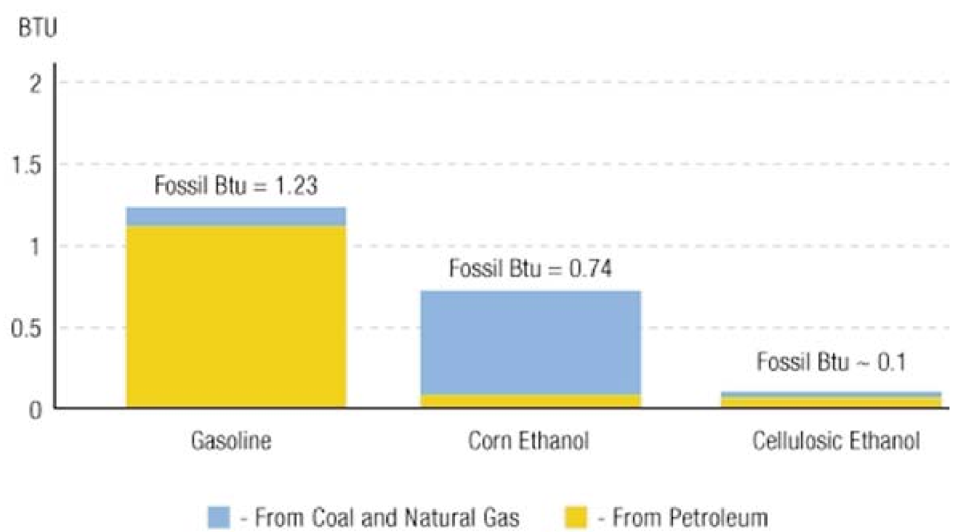


Figure 2 shows how much fossil energy is required to provide 1 BTU of each fuel at the pump. The graph does not reflect energy derived from solar or other renewable sources used in the production of ethanol (EERE 2009).

Recently, the University of Nebraska Lincoln (UNL) conducted research on the energy ratio of ethanol. They found that corn ethanol has a positive energy ratio. For every unit of fossil fuel energy input, 1.5 to 1.8 units of energy in the form of ethanol are created. Researchers used the UNL-developed Biofuel Energy Systems Simulator (BESS) to make their calculations. BESS considers the energy used in crop production, the ethanol production process, the use or production of co-products, and transportation (UNL 2009).

By most analysis, the production process accounts for the largest portion of the energy required to produce corn ethanol. It stands to reason that reducing energy demand at the production phase has the biggest potential to improve the energy ratio of corn ethanol. Most corn ethanol plants burn natural gas to provide heat for the cooking, distilling, and drying processes.

Replacing natural gas with biomass and combined heat and power facilities dramatically improves the energy ratio of corn ethanol. Both the Central Minnesota Ethanol Cooperative located in Little Falls, Minnesota, and the Chippewa Valley Ethanol Cooperative, located in Benson, Minnesota, have begun exploring the option of obtaining a large portion of their process energy supply from biomass sources such as wood waste and agricultural crop residues. Both organizations are also planning combined heat and power facilities. Combined heat and power maximizes the energy captured from the sources by co-locating electricity production and thermal energy production. Alone, each process is able to capture no more than 50 percent of the available energy. The uncaptured energy simply flies out the smokestack. But stacked together, these systems can effectively use 90 percent of the energy found in the energy source—in these cases, biomass. Taken together, combined heat and power and biomass can considerably improve the fossil fuel energy ratio of corn ethanol.

Section II

Policy

Federal and, to a lesser extent, state government policies play considerable roles in shaping the direction and path of biofuels development. More so than any other individual player or industry, the federal government, through its numerous agencies with various responsibilities, has the ability to impact the path of biofuels development. Often this authority stems from the federal government's responsibility to care for the public good, such as public health and safety, environmental protection, public education, national and domestic security, and infrastructure development and protection.

Translating those responsibilities into the field of biofuels, the federal government has taken on the responsibility of addressing barriers to a robust biofuels sector that meets its larger responsibilities to the public good. A number of barriers currently exist, requiring action on several fronts. These barriers can be broadly categorized as knowledge and infrastructure. Further knowledge is needed on technologies, agricultural practices, environmental impacts, and economics, while infrastructure is needed in processing and capacity, product testing, and market regulation and certainty. A number of research funding efforts are underway through the Department of Energy, Environmental Protection Agency, and Department of Agriculture to address planting, growing, and harvesting techniques, energy input to output ratios, biomass processing and fuel production technologies, and environmental impacts. Many of these funding opportunities have been initiated or expanded through the American Relief and Recovery Act, better known as the Stimulus Bill. Through ARRA, the Department of Energy is offering almost $800 billion in grants, loans, and or other assistance to research and pilot, demonstration, or commercial-scale biorefinery projects (US DOE 2009). Such research is vital to establishing dependable, replicable, and cost-effective biofuels production and processing systems.

However, two other issues persist that research or technology may not necessarily address, requiring unique government policies. The first issue is establishing stable markets for biomass growers and biofuel processors so that they may enter the market with more certainty. As market conditions stand now, both biomass growers and biofuels producers have reason to hesitate without a dependable market for biomass crops or a dependable supply to produce biofuels. The second issue is establishing standards regarding the emissions produced by biofuels. What emissions level is acceptable to achieve our desired greenhouse gas reductions? Two federal policy developments are working to address these issues: the Biomass Crop Assistance Program for market creation and the Renewable Fuel Standard for emissions requirements.

Biomass Crop Assistance Program

The Food, Conservation and Energy Act of 2008 (2008 Farm Bill) established a number of renewable energy promotion and advancement programs, one of which is the Biomass Crop Assistance Program (BCAP). Under section 9011 of Title IX of the 2008 Farm Bill, BCAP was designed to "promote the cultivation of perennial bioenergy crops and annual bioenergy crops that show exceptional promise for producing highly energy-efficient bioenergy, that preserve natural resources, and that are not primarily grown for food or animal feed" (Harte 2009). BCAP will provide support in every step of the biomass energy process from land preparation and planting to harvesting and transportation to a processing facility. Through BCAP, the nation will reduce its dependency on commodity crops as an energy source and shift to more renewable, less strained biomass material for a better fuel source into the future (Radloff 2009).

The Biomass Crop Assistance Program developed with the purpose of establishing biomass or non-food crops for conversion to bioenergy. Unlike existing traditional research efforts, BCAP seeks to confront the uncertainty of establishing new markets based on biomass crops that often take a few years to reach initial harvest. Farmers have little reason to take on the considerable risk of growing a new crop such as switchgrass or hybrid poplars when there is little certainty of demand for the crop. Traditional crops such as corn and wheat have the advantage of long-established markets, known production methods, and a short (less than 1 year) turn around from planting (expense) to harvest (income). However, the problem is not simply one for biomass growers. The long delay in establishing biofuel facilities, coupled with the uncertainty in biomass supply creates uncertainty for biofuel producers as well. Essentially it becomes a Catch-22 when establishing a new biofuels market: farmers need certainty of demand before they can grow the crops and processors need certainty of supply before they can establish plans for a facility.

BCAP will address this double-sided problem by establishing certainty for both biomass grower and biofuel producer. The program proposes to establish annual risk-offsetting payments to biomass growers as well as cost-sharing to cover most of the cost of preparing the land and planting the initial crop. Annual payment rates will be based on the opportunity cost of removing acreage from existing crop production. Essentially, participating farmers can dedicate a portion of their agricultural land to biomass production but still receive an income. With certainty in income, farmers can feel more confident in a biomass market. Similarly, participating biomass processors can receive matching support through BCAP for covering the costs of collection, harvest, storage, and transportation of biomass. BCAP will also add a level of coordination to the early planning stages of both biomass growing and biofuel conversion facilities. All applications to BCAP will require coordination between biomass growers and processing facilities. This process will help establish market and supply chain connections necessary for biofuel projects to fully develop.

As a recently created program born in 2008 Farm Bill, BCAP has yet to go through many of the stages between creation and full program roll out. The USDA must yet establish many of the program details. A number of issues must be addressed regarding not only effective implementation and ease of participation, but also larger program goals as well. For instance, how and to what extent will BCAP address the food versus fuel issue? The program is designed to push development of biofuels from non-food crops, but the food versus fuel debate is not entirely avoided. There are, after all, only so many acres available for crops. Also, considering the larger goal of establishing environmentally-friendly alternatives to fossil fuels, how will BCAP rules get written to address environmental issues such as soil erosion and nutrient runoff that are not directly tied to greenhouse gas emissions?

The Commodity Credit Corporation and Farm Service Agency recently announced a Notice of Funds Availability for the Collection, Harvest, Storage, and Transportation portion of BCAP. This notice provides proposed program details for the CHST portion as well as an opportunity to provide comments. See http://edocket.access.gpo.gov/2009/pdf/E9-13724.pdf. Further program details and opportunities for comment will occur in the future. For those who want to stay up to date on BCAP developments, USDA Farm Service Agency, the agency administering the Biomass Crop Assistance Program, offers a website where BCAP information and updates will be posted:
http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap.

Renewable Fuel Standard

The Renewable Fuel Standard (RFS) was initially established under the Energy Policy Act of 2005. This law requires fuel distributors to blend increasing levels of biofuels into their fuel supply. The RFS was amended by the Energy Independence and Security Act (EISA) of 2007 and established a new fuel standard, starting with 9 billion gallons of renewable fuels required in 2008 and rising to 36 billion gallons by 2022, or roughly 25 percent of expected fuel volume. The EISA shifted much of that requirement toward cellulosic biofuel. Of the 36 billion gallons of biofuels required by 2022, 16 billion gallons must be fulfilled by cellulosic fuels (Environmental Protection Agency 2009).

Fuel blenders or distributors are held accountable through a Renewable Identification Number program. Renewable Identification Numbers, or RINs, are essentially identification numbers assigned to each individual gallon of biofuel as it is produced. When distributors or blenders purchase the fuel, they purchase the RINs associated with that fuel. The distributor then turns in the RINS to the EPA as record of purchase or possession of the adequate volume of biofuels. If fuel distributors cannot meet the requirements, they will face penalties and fines. However, the intent of the RFS is not to place the burden of building the biofuels industry squarely on the backs of distributors. If conditions, such as limited biomass supply or processing facilities, hinder distributors' efforts of meeting the requirement, the Environmental Protection Agency (EPA), the federal agency overseeing the program, may wave the requirement and amend the mandated levels for subsequent years.

The Energy Independence and Security Act established the first mandatory greenhouse gas (GHG) emissions reduction thresholds for renewable fuels. In order to qualify as a renewable fuel and for the distributor or blender to be able to use the fuel toward the renewable fuel standard, renewable fuels must meet minimum lifecycle greenhouse gas emissions reductions compared to the emissions of standard petroleum gasoline. Corn-based ethanol must obtain a reduction of 20 percent in lifecycle greenhouse gas emissions, biomass-based diesel must achieve a 50 percent reduction, and cellulosic ethanol must have greenhouse gas emissions 60 percent below petroleum gas emissions. Lifecycle emissions for all biofuels include not only direct emissions associated with the planting, harvesting, transportation, and processing of the biomass into biofuels, but also indirect land use changes resulting from increased acres dedicated to growing biomass, pushing the production of food crops onto uncultivated lands (EPA 2009).

Measurements for indirect land use change have recently been projected by the Environmental Protection Agency in its effort to establish lifecycle greenhouse gas emission scores for the various biomass sources and processing technologies (EPA 2009). The lifecycle analysis scoring takes into account both direct emissions as well as significant indirect emissions resulting from land use change. According to the analysis by the EPA, corn ethanol meets the lifecycle greenhouse gas thresholds specified in the Energy Independence and Security Act only when a best-case natural-gas dry mill is used. Biomass-fired dry-mill ethanol plants qualify as advanced biofuels and must meet a 50 percent GHG reduction standard. When outfitted as a combined heat and power plant, such ethanol falls just short of the threshold requirement. The EPA, however, has the authority to reduce the threshold to 40 percent. According to the EPA study, soy-based biodiesel also fails to meet the GHG reduction threshold while cellulosic ethanol from switchgrass or corn stover both meet established lifecycle GHG thresholds (EPA 2009).

The final analysis will have a big impact in the resulting carbon scores for the various renewable fuel crops. Key to establishing the final lifecycle analysis will be establishing the timeline for analysis. Any analysis includes indirect land use change. The major impact with land use change is the opening of grasslands and forests for crop production either to produce bioenergy crops or to produce crops displaced by bioenergy crops. The opening of such lands creates a large initial release of carbon from the soil. However, the carbon balance is regained over increasing years of subsequent biofuel production from those lands to replace petroleum transportation fuels. A short timeline for analyzing lifecycle GHG emissions will give less time for biofuels to overcome the initial carbon debt associated with the indirect opening of new lands. A longer time horizon would allow biofuels more time to produce low carbon crops to replace petroleum fuels and essentially pay off that initial carbon debt.

The EPA provides extensive information regarding the Renewable Fuel Standard at http://www.epa.gov/OMS/renewablefuels.

Section III

Issues

Despite the considerable advancements in technology and policy in recent years, a number of issues have developed to create considerable drag on advancement of the biofuels industry. The major impending issues facing the industry in fact have developed only recently in light of research or as a response to growing pains to a burgeoning biofuels industry. In two of the issues explored here, food versus fuel and indirect land use change (ILUC), considerable debate has developed and will continue to rage for quite some time due to the uncertainty associated with each. The other issues addressed here, Measurement and Certification and Other Non-carbon Environmental Impacts have had less exposure time, but just like food versus fuel and ILUC developed in light of growth in biofuels, these issues will arise after further expansion in the biofuels sector and increased awareness of previously unmeasured impacts and benefits.

Food versus Fuel

The 2008 food inflation scare created a difficult time for the biofuels industry. At a time of record high gas prices, but with rising commodity prices, namely corn, corn ethanol and soy biodiesel took considerable public relations hits. Corn rose from around $2.50 per bushel in late 2006 to over $7.50 per bushel in mid 2008. The consumer price index increased 5.5 percent annually between 2007 and 2008, the highest annual increase since 1990, angering and frustrating many consumers. Many consumers blamed the rapid growth of the biofuels industry for the food price jump. Many corn ethanol plants, after all, were justified as new market opportunities for farmers that would raise farm income. The rapid rise in corn used for ethanol production provided direct evidence. From 2006 to 2008, the number of bushels of corn consumed in ethanol production almost doubled from 2.1 billion bushels to 3.6 billion bushels (Oak Ridge National Laboratory 2009). This translated into higher corn prices. A recent Congressional Budget Office (CBO) report credited ethanol demand with 35 percent of the corn price rise. Between April 2007 and April 2008, corn prices rose from $3.39 per bushel to $5.14 per bushel, or a 52 percent increase (CBO 2009).

Throughout that time numerous media outlets drew an immediate correlation between rising food prices and rising corn prices. The obvious culprit became ethanol (Barrionuevo 2007, Goldman 2008). The logic seemed simple. Ethanol took an increasing portion of the corn supply, corn prices were going up due to rising demand, rising prices for basic ingredients pushed up retail food prices as food processors passed along to the consumer rising costs. Ethanol gained a black eye despite the attempts of farmers and renewable fuel proponents to defend the first-generation biofuel.

Subsequent studies conducted by universities and the Congressional Budget Office provided a much different explanation for the food price rise experienced in 2007 and 2008. The non-partisan Congressional Budget Office concluded that between April 2007 and April 2008, the rise in the price of corn resulting from expanded ethanol production contributed between 0.5 and 0.8 percentage points of the 5.1 percent increase in food prices over that time (CBO 2009).

Many people ignored the fact that most corn goes to feeding livestock for dairy and meat production and that dried distillers grains, a by-product of the ethanol process, could still be used for animal feeding purposes. The CBO study also concluded higher energy input costs had a more significant role in increasing food prices. Regardless of the more recent analysis, the public relations damage had been done. Ethanol lost its luster. Not only that, but subsequent consideration for biofuels has become conditioned on the food versus fuel debate. The Energy Independence and Security Act of 2007 established new renewable fuel mandates with considerable emphasis placed on expanding renewable fuel production from non-fuel crops. The Food, Conservation, and Energy Security Act of 2008 (2008 Farm Bill) reduced the corn ethanol tax credit and redirected incentives toward cellulosic fuel development. These efforts will certainly reduce the chance of immediate competition for food crops. However, considerable potential still exists for competition between food and fuel crops for fertile land.

Indirect Land Use Change

Biofuels face an additional issue that has created uncertainty for the future of the industry. And much like the food versus fuel debate, indirect land use change (ILUC) is mostly driven not by technology barriers but by attempts to create comprehensive measures to address the larger issues driving biofuels growth—climate change caused by greenhouse gas emissions.

For many proponents, biofuels represent a viable alternative to petroleum transportation fuels. Biofuels emissions, after all, can be negated by the carbon sequestration that occurred by the plants before they were processed into fuel. However, indirect land use change poses serious questions about the full lifecycle impact, or total carbon balance, of biofuels. Under the theory of ILUC, agricultural land taken out of traditional crop production to grow biofuels would cause a ripple effect felt throughout the world. Regardless of biofuel development, the world needs a set amount of food production. The world also has a set or finite amount of agricultural land on which to grow the crops necessary to meet existing food and fiber demands. As farmers switch to growing biomass crops for a biofuels industry, other lands—non-productive marginal, virgin forest, grassland, or otherwise—must be converted to crop production in order to provide for food and fiber needs.

Opening new lands has the potential to release years of carbon sequestered into the soil by plants and trees. This could negate any carbon emission reductions experienced by biofuels. Biofuels proponents note ILUC creates an unfair standard. They note that petroleum is not held to a standard that charges it with the emissions from indirect effects. Yet environmentalists argue a solid solution will nonetheless have to account for all impacts associated with biofuels since all emissions, in the end, have the same effect of contributing to global warming.

While attributing carbon emissions from indirect land use change to expanded production of biofuels is debatable, it is clear that ILUC has the potential to have both good and bad consequences for the biofuels sector. On the one hand, accounting for ILUC may offer a bigger push to research designed to reduce both direct and indirect emissions associated with biofuels. With the standard clearly established for biofuels, research may become focused on crops with considerable production potential. Through high biomass production, fewer acres are needed, and thus fewer acres of traditional crops may be displaced. On the other hand, attributing carbon emissions from indirect land use change to biofuels has the potential to effectively delay the full implementation of the biofuels sector for a number of years until researchers establish crops capable of producing enough biomass per acre to minimize ILUC to acceptable levels. Within that time, our dependence on petroleum to fuel our transportation sector would only continue, further contributing to global warming. This would be a particularly sad result considering that the cause could be simply an inaccurate accounting of the carbon impact of indirect land use change attributed to biofuels.

For the sake of effectively addressing global warming we must have accurate analysis of the total carbon impact of biofuels. Just as ignoring some components' contributions to carbon emissions would limit the effectiveness of biofuels in reducing greenhouse gas emissions, so too would overestimating the carbon impact of biofuels production by inhibiting the growth of replacement fuels for petroleum transportation fuels.

Soil and Water

Using corn, corn stover, or other agricultural crops or residues for the production of ethanol may negatively impact soil erosion and water quality. The harvesting of corn stover holds the greatest potential for negatively impacting soil erosion and water quality. Current corn harvesting practice puts corn stover back onto the field after the corn has been separated, where it provides organic matter to farmland, a vital component to maintaining soil health. Stover also helps prevent soil erosion by slowing surface water runoff and increasing water retention. Removing stover from farmland has the potential to harm soil productivity and increase erosion which can then reduce water quality through increased sedimentation and nutrient runoff.

According to the March–April 2009 issue of *Soil Science Society of America Journal*, Humberto Blanco and Rattan Lal, researchers at The Ohio State University, conducted a study of the four-year impacts of systematic removal of corn stover from long-term no-till systems in Ohio. The results of the study showed that stover removal degrades the soil structure, reduces soil fertility, reduces soil organic carbon concentration, and reduces crop yields while also increasing soil erosion. Study authors concluded that only about 25 percent of the total corn stover may be removed without having significant negative impacts in the soil organic and carbon content or unduly increasing erosion (Blanco & Lal 2009). Negative impacts resulting from corn stover removal may be higher on traditionally-tilled corn fields, and may therefore require higher amounts of corn stover to remain in the field to maintain soil health and stability.

Another concern gaining more attention is the water used in the biofuels production processes. This concern has become acute in regions that have historically experienced prolonged periods of drought and saw a boom in construction of corn ethanol plants over the last decade. In 2005, it took an average of 4.2 gallons of water to produce 1 gallon of corn ethanol. (Keeney & Muller 2006) Most of this water is lost during the cooling process. Corn ethanol facilities have made water efficiency advancements in recent years to cut water usage by 20 percent or more. New technologies that make use of gray water for cooling purposes or recycle water for reuse could dramatically cut the water demand of corn ethanol facilities to below the average 2.25 gallons of water that petroleum refineries consume to produce 1 gallon of gasoline.

Cellulosic biofuels, in comparison, have lower estimated water demands. Many technologies extract water from biomass material as part of the process of extracting the cellulose. This water can then be collected for use in the production process. Some technologies have even shown promise to produce a net excess of water.

Invasive Species versus Native Species

Some invasive species have the potential to become biomass feedstocks and could aid the biofuel industry through their rapid growth rates and large biomass production rates. The potential also exists for invasive species to cause problems in many ecosystems. Many ecologists and agronomists insist more research must be done to adequately predict environmental impacts and long-term ecological consequences. Invasive species such as cattails, European milfoil, and miscanthus must be assessed for the likeliness of invasion and the potential for growers to easily control invasive species before widespread implementation may occur.

As with any invasive species, the plants discussed here have the potential, once introduced to an area, to spread on their own, often despite the efforts of landowners to control the species. Even with the risk of invasion, cattails, European milfoil, and miscanthus are receiving consideration as potential biofuel crops because of their ability to rapidly produce biomass. Cattails grow in every U.S. state and are easy to plant. They grow in one-half inch of water, and one seed can produce 98 shoots in two weeks. Cattails also reduce water pollution by revitalizing groundwater (Schrupp 2008). Milfoil, another water plant, invades and overtakes lakes and streams. Hundreds of thousands of dollars are spent each year by property owners trying to get rid of it, but it keeps returning.

On the University of Illinois–Urbana farms, 320 acres is dedicated to biofuel research. Ongoing studies look at positives and negatives of new feedstocks and test to see if other native plants will work as well. The miscanthus grass has, so far, been the most successful; producing twice as much biomass as corn stover. The grass is sterile, so it does not produce seeds. In order to grow more, it has to be dug up and the rhizomes have to be replanted somewhere else. Even though it is very labor intensive, its sterility is a benefit because the plant is prevented from becoming invasive through air pollination. Researchers at the farm are working on find machinery able to plant and harvest this crop cost-effectively (Mies 2009). If there is a way to easily manage enough acres to provide the demanded fuel, this might be the new main biofuel feedstock.

Monoculture versus Polyculture

Monoculture is the practice of planting and growing one kind of crop over a large area. Examples of this include large corn and wheat fields. This practice can yield a large amount of crops on a large amount of land with minimal effort because the planting, care, and harvesting processes can be standardized. There is also no pressure or competition for nutrients from other plants in the area. This makes it easier for the farmer to reduce costs while producing a large amount of product. Problems exist, however, with a monoculture system. The entire crop can become susceptible to complete destruction by one agent such as a disease or insect. Also, monocultures require relatively large amounts of inputs to prevent the incursion of naturally occurring plants. Finally, monocultures reduce the overall health of the land and take entire areas out of ecosystem balance.

Polyculture is the agricultural practice of growing multiple species of crops in the same space. It mimics natural ecosystem functions such as the recycling of biomass, the balance of biodiversity, naturally maintained soil health and a more eco-efficient use of a variety of soil conditions. The diversity of polyculture improves its ability to fight disease, survive harsh weather such as droughts, and makes plant species less susceptible to pests. Polycultures also typically produce higher amounts of vegetative cover which reduces the rate of evaporation and allows for greater infiltration of water into the soil for plant use (Fears 2008).

David Tilman, a leader in polyculture research, has conducted a number of experiments on biodiversity. In May 2006, Tilman and others published the results of a 12 year experiment, showing that an acre planted with multiple species of crops yields more biomass than an acre planted in monoculture (Tilman, Hill & Lehman 2006). The biodiversity representative of polyculture happens naturally without replanting or fertilizer. It not only produced more mass but more reliable and predictable annual yields. Yield reliability will be important to growing the biofuels industry. Researchers in Germany and the Netherlands are conducting experiments similar to those conducted by Tilman and others and are showing comparable biomass results with entirely different polyculture plant species (Morrison 2006).

The planting and harvesting of polyculture is a much more complicated, uncertain, and labor-intensive task than planting and harvesting monoculture crops. The multiple seed varieties often rule out traditional agricultural planting methods or require considerable modifications to equipment and methods. Harvesting is similarly complicated by plants species reaching full growth at different times. Moreover, many current cellulosic ethanol technologies require a “clean” singular fuel source. These current technologies depend upon processes that can convert only one plant type. As some current cellulosic technology stands, polyculture-produced biomass would require sorting of plant species before entering the conversion process.

Conclusion

The biofuels sector has experienced considerable change in recent months mainly as a result of the contracting economy. Tightening credit has also made it more difficult for planned projects to break ground. Many investors are waiting for technological winners to emerge from the research, development, and demonstration phases and for more stability in federal energy policy before pursuing new projects.

Recently enacted policies such as the Biomass Crop Assistance Program and the Renewable Fuel Standard will help overcome two barriers to a robust biofuels sector: uncertainty in demand and unstable supply chains. Further advancements in biomass processing technology will reduce direct greenhouse gas emissions, while improvements in biomass crop production have the potential to ameliorate both indirect land use change issues as well as the food versus fuel debate by reducing the number of acres necessary to supply a fully operational biofuel industry.

Further policy development must occur in the area of environmental protection. Many biomass crops have lower fertilizer needs and provide better soil protection than traditional crops. However, that is no guarantee such crops become the biomass crop of choice for many farmers. Without proper incentives, biomass producers will be rewarded not necessarily for carbon-constrained production, but for maximum biomass production.

Policies and programs must be established that simplify the carbon accounting for biomass production as well as the valuation of biomass, taking into account variable inputs and natural resource impacts. In essence, programs must be established to easily and clearly differentiate between (1) the value of a ton of biomass produced from marginal lands using fewer carbon-intense inputs and having little negative impact on the natural resources, and (2) the value of a ton of biomass produced from highly productive agricultural lands using a large amount of carbon-based inputs and having mixed natural resource impacts. Such a system would go a long way in creating clear market demand for sustainably-produced biomass. This system would also provide assurance to policy leaders and the general public that biofuels are meeting the larger goals of reducing greenhouse gas emissions while avoiding direct food price increases or sacrificing natural resources like healthy soil, clean water, and wildlife habitat.

References

Addison, Keith. 2008. *Oil yields and characteristics.* Journey to Forever. http://journeytoforever.org/biodiesel_yield.html (accessed June 23, 2009).

Aden, Andy. October 2007. *Water Usage for Current and Future Ethanol Production.* National Renewable Energy Laboratory. http://www.swhydro.arizona.edu/archive/V6_N5/feature4.pdf (accessed June 25, 2009).

AlgaeVenture Systems. http://www.algaevs.com (accessed June 30, 2009).

Algenol Biofuels Inc. http://www.algenolbiofuels.com (accessed June 30, 2009).

Barrionuevo, Alexei. January 2007. *Rise in Ethanol Raises Concerns About Corn as a Food.* The New York Times. http://www.nytimes.com/2007/01/05/business/05ethanol.html (accessed June 28, 2009).

Bionavitas, Inc. February 2009. B*ionavitas Announces Breakthrough Algae Growth Technology for Biofuels Production.* Bionavitas Press. http://www.bionavitas.com/pressrelease_02.24.09.html (accessed June 24, 2009).

Blanco-Canqui, H., R. Lal. 2009. *Corn stover removal for expanded uses reduces soil fertility and structural stability.* Soil Science Society of America Journal 73, no. 2: 418–426. https://www.crops.org/story/2009/mar/tue/corn-stover-removal-reduces-soil-fertility (accessed June 23, 2009).

Blue Fire Ethanol. http://bluefireethanol.com (accessed June 29, 2009).

Bourne, Joel K. Jr. October 2008. *Green Dreams.* National Geographic. July 8, 2009. http://ngm.nationalgeographic.com/ngm/2007-10/biofuels/biofuels-p6.html (accessed June 30, 2009).

Briggs, Michael. August 2004. *Widescale Biodiesel Production from Algae.* University of New Hampshire Biodiesel Group. http://www.unh.edu/p2/biodiesel/article_alge.html (accessed June 30, 2009).

Burnham, Micheal. June 2009. *Shell Sells Cellulosic Ethanol Blend in Canada.* The New York Times. http://www.nytimes.com/gwire/2009/06/10/10greenwire-shell-sells-cellulosic-ethanol-blend-in-canada-10074.html (accessed June 20, 2009).

Cannon, Brevy. August 2008. *Algae: Biofuel of the Future?* University of Virginia Today. http://www.virginia.edu/uvatoday/newsRelease.php?id=5985 (accessed June 30, 2009).

Christensen, Pia Hallenberg. October 2008. *Milfoil to be studied as biofuel.* Herald Net. http://www.heraldnet.com/article/20081006/BIZ/710069955/1005 (accessed June 20, 2009).

Christiansen, Ryan C. July 2009. *A Triple Play for Higher Yields.* Ethanol Producer Magazine. http://www.ethanolproducer.com/article.jsp?article_id=5734&q=A%20Triple%20Play%20for%20Higher%20Yields&category_id=46 (accessed June 18, 2009).

Christiansen, Ryan C. January 2009. *Range Fuels receives $80 million USDA loan.* Ethanol Producer Magazine. http://www.ethanolproducer.com/article.jsp?article_id=5295 (accessed June 28, 2009).

Christiansen, Ryan C. July 2009. *Tiny Bubbles to Make You Happy.* Ethanol Producer Magazine. http://www.ethanolproducer.com/article.jsp?article_id=5732&q=tiny%20bubbles%20make%20you%20happy&category_id=46 (accessed June 28, 2009).

Comis, Don. April 2009. *In Producing Ethanol, Some Cornstalks Should be Left in the Field.* U.S. Department of Agriculture. http://www.ars.usda.gov/is/pr/2007/070425.htm (accessed June 30, 2009).

Congressional Budget Office (CBO). April 2009. *A CBO Paper: The Impact of Ethanol Use on Food Prices and Greenhouse-Gas Emissions.* Congress of the United States, Congressional Budget Office. http://www.cbo.gov/ftpdocs/100xx/doc10057/04-08-Ethanol.pdf (accessed June 29, 2009).

Davis, John. December 2008. *Big Investment for Corn-Oil Biodiesel.* DomesticFuel.com. http://domestic fuel.com/2008/12/18/big-investment-for-corn-oil-biodiesel (accessed June 29, 2009).

Energy Efficiency and Renewable Energy (EERE) – Alternative Fuels and Advanced Vehicles Data Center. *Ethanol Energy Balance.* United State Department of Energy. http://www.afdc.energy.gov/afdc/ethanol/balance.html (accessed June 17, 2009).

Environment News Service. July 2008. *Biofuel from Corn, Switchgrass and Miscanthus.* Environment News Service. http://www.ens-newswire.com/ens/jul2008/2008-07-31-091.asp (accessed June 30, 2009).

Environmental Protection Agency. May 2009. *EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels.* Environmental Protection Agency, Office of Transportation and Air Quality. http://www.epa.gov/OMS/renewablefuels/420f09024.pdf (accessed June 30, 2009).

Environmental Protection Agency. May 2009. *EPA Proposes New Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond.* Environmental Protection Agency, Office of Transportation and Air Quality. http://www.epa.gov/OMS/renewablefuels/420f09023.pdf (accessed June 30, 2009).

Environmental Protection Agency. May 2009. *RFS2: 4 Separate Stds.* Environmental Protection Agency. http://www.epa.gov/OMS/renewablefuels/rfs2-4standards.pdf (accessed June 30, 2009).

Ethanol Renewable Fuels Association. January 2009. *U.S. Cellulosic Ethanol Projects Under Development and Construction.* Ethanol Renewable Fuels Association. http://www.ethanolrfa.org/resource/cellulosic/documents/CurrentCellulosicEthanolProjects-January2009.pdf (accessed June 28, 2009).

Farnham, Dale. September 2001. *Corn Planting.* Iowa State University Extension. http://www.extension.iastate.edu/Publications/PM1885.pdf (accessed June 30, 2009).

Fears, Sean. August 2008. *Monoculture vs. Polyculture Farming Methods.* True Progress. www.true-progress.com/monoculture-vs-polyculture-farming-methods-84.htm (accessed June 19, 2009).

Goldman, David. June 2008. *Food Price Spike: Is Ethanol to Blame?* CNNMoney.com. http://money.cnn.com/2008/06/27/news/economy/ethanol_food_prices (accessed June 28, 2009).

Green Car Congress. April 2007. *USDA Research Suggests the Amount of Corn Stover Available for Ethanol Production Must be Reduced to Preserve Soil Quality.* Green Car Congress. http://www.greencarcongress.com/2007/04/usda_research_s.html (accessed June 30, 2009).

Haag, Amanda Leigh. March 2007. *Pond-Powered Biofuels: Turning Algae into America's Newest Alternative Energy Source.* Popular Mechanics. http://www.popularmechanics.com/science/earth/4213775.html (accessed June 19, 2009).

Harte, Paul. June 2009. Interview by Luke Ekelund.

Hipple, P., M. Duffy. 2002. *Farmers' Motivations for Adoption of Switchgrass.* Purdue University News. http://www.hort.purdue.edu/newcrop/ncnu02/v5-252.html (accessed June 30, 2009).

Joyce, Christopher. January 2008. *Study Boosts Switchgrass as New Alternative Fuel.* National Public Radio. http://www.npr.org/templates/story/story.php?storyId=17910749 (accessed June 29, 2009).

Keeney, D., M. Muller. October 2006. *Water Use by Ethanol Plants: Potential Challenges.* Institute for Agriculture and Trade Policy (IATP). http://www.iatp.org/iatp/publications.cfm?accountID=258&refID=89449 (accessed June 27, 2009).

Kimball, Joe. June 2009. *Biomass plant provides energy by burning renewable materials, including Cheerios waste.* MinnPost.com. http://www.minnpost.com/politicalagenda/2009/06/22/9694/biomass_plant_provides_energy_by_burning_renewable_materials_including_cheerios_waste (accessed June 27, 2009).

Klotz, Irene. May 2009. *NASA Grows Algae for Biofuel, Treats Waste.* Discovery Channel News. http://dsc.discovery.com/news/2009/05/14/nasa-algae-biofuel.html (accessed June 15, 2009).

Mascoma Corporation. 2008. *Consolidated Bio-Processing.* http://www.mascoma.com/technology/cbp.html (accessed June 20, 2009).

McAuliffe, Peter. *A Condensed Guide to Poplar Management: Why, Where, When, and How.* Scott Paper Limited. http://www.for.gov.bc.ca/nursery/fnabc/Proceedings/Poplar.htm (accessed June 30, 2009).

Mies, Tim. March 2009. *Miscanthus, Switchgrass and Restored Prairie Tested as a Potential Energy Crops.* University of Illinois Urbana-Champaign. http://www.aces.uiuc.edu/news/stories/news4705.html (accessed June 22, 2009).

Morrison, Deanne. May 2006. *Natural Prairie Holds Key to Sustainable Fuels.* University of Minnesota News. http://www1.umn.edu/umnnews/Feature_Stories/Natural_prairie_holds_key_to_sustainable_fuels.html (accessed June 17, 2009).

National Renewable Energy Laboratory (NREL). May 2008. *NREL Industry Partners Move Cellulosic Ethanol Technology Forward.* http://www.nrel.gov/news/press/2008/600.html (accessed June 22, 2009).

Oak Ridge National Laboratory. July 2009. *Biofuels from Switchgrass: Greener Energy Pastures.* http://bioenergy.ornl.gov/papers/misc/switgrs.html (accessed June 30, 2009).

Oak Ridge National Laboratory. 2009. *Corn Used for Ethanol Production.* http://cta.ornl.gov/bedb/feedstocks/Grains/Corn_used_for_Ethanol_Production_US-Figure.xls (accessed June 29, 2009).

Oilgae.com. *Algal Oil Yields.* http://www.oilgae.com/algae/oil/yield/yield.html (accessed June 27, 2009).

Pyter, R., T. Voigt, E. Heaton, F. Dohleman, S. Long. June 2009. *Growing Giant Miscanthus in Illinois.* University of Illinois. http://miscanthus.illinois.edu/wp-content/uploads/growersguide.pdf (accessed June 30, 2009).

Radloff, Gary. June 2009. Interview by Luke Ekelund.

Range Fuels. http://www.rangefuels.com/range-fuels-technology.html (accessed June 28, 2009).

Reubold, Todd. March 2009. *University of Minnesota Study Reveals New Energy and Economic Benefits of Corn Stover.* University of Minnesota News. http://www1.umn.edu/urelate/newsservice/NS_details.php?release=090302_3944&page=NS (accessed June 30, 2009).

Schrupp, Chelsey. February 2008. *Out with the corn, in with the cattails.* Minnesota State University, Mankato Reporter. http://media.www.msureporter.com/media/storage/paper937/news/2008/02/12/NationalAndWorldNews/Out-With.The.Corn.In.With.The.Cattails-3203652.shtml (accessed June 23, 2009).

Shapouri, H., J. Duffield, M. Wang. July 2002. *The Energy Balance of Corn Ethanol: An Update.* U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses. Agricultural Economic Report Number 813. http://www.transportation.anl.gov/pdfs/AF/265.pdf (accessed June 30, 2009).

Smith, Sarah. March 2008. *Ethanol Start-Ups and the Bankruptcy Bogeyman.* Ethanol Producer Magazine. http://www.ethanolproducer.com/article.jsp?article_id=3729 (accessed June 30, 2009).

Steeves, Susan A. August 2006. *Fast-Growing Trees Could Take Root as Future Energy Source.* Purdue University News. http://news.uns.purdue.edu/html4ever/2006/060823.Chapple.poplar.html (accessed June 30, 2009).

Stillman, Charles. June 2006. *Cellulosic Ethanol: A Greener Alternative.* Clean Energy. http://www.cleanhouston.org/energy/features/ethanol2.htm (accessed June 30, 2009).

SustainableBusiness.com. April 2009. *Another Ethanol Bankruptcy.* http://www.sustainablebusiness.com/index.cfm/go/news.display/id/17965 (accessed June 26, 2009).

Tilman, D., J. Hill, C. Lehman. 2006. *Carbon-negative biofuels from low-input high-diversity grassland biomass.* Science 314:1598-1600.

Tseng, Nin-Hai. June 2008. *Kudzu could be the next biofuel. Cox News Service.* http://www.ajc.com/news/content/news/stories/2008/06/19/KUDZU_biofuel_ethanol.html (accessed June 29, 2009).

U.S. Department of Energy. February 2007. *DOE Selects Six Cellulosic Ethanol Plants for Up to $385 Million in Federal Funding.* http://www.energy.gov/news/4827.htm (accessed June 23, 2009).

U.S. Department of Energy. May 2009. *Secretary Chu Announces Recovery Act Funds to Accelerate Biofuels Research and Commercialization.* http://www.energy.gov/news2009/7375.htm (accessed June 30, 2009).

University of Minnesota Morris. May 2009. *Technology behind Biomass Gasification.* University of Minnesota Morris. http://renewables.morris.umn.edu/biomass/technology (accessed June 14, 2009).

University of Nebraska-Lincoln. January 2009. *UNL Research: Corn Ethanol Emits 51 Percent Less Greenhouse Gas Than Gasoline.* Cattle Network. http://www.cattlenetwork.com/Content.asp?ContentID=284922 (accessed June 29, 2009).

Wald, Matthew L. June 2009. *Algae Farm Aims to Turn Carbon Dioxide into Fuel.* The New York Times. http://www.nytimes.com/2009/06/29/business/energy-environment/29biofuel.html?_r=1 (accessed June 30, 2009).

University of Illinois. 2007. *Miscanthus.* University of Illinois. http://miscanthus.illinois.edu (accessed June 30, 2009).