What is the Viability of Cellulosic Ethanol as an Alternative to Fossil Fuels in today's Economy?

Sarah Whiteside, Timothy Balmorez, Michael Kaiser

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In the midst of today's energy crisis and increased environmental awareness emerges a need for more sources of renewable, green energy around the world. The consequences from anthropogenic burning of fossil fuels experienced over the last few decades forecast a global warming unlike anything ever witnessed on earth. Computer modeling of the warming caused by anthropogenic and natural sources predicts a minimum 8°C increase of the average global temperature by year 2300 (19). Although the effects of these drastic temperature changes cannot be absolutely determined, signs of melting ice masses in the polar regions do not bode well for the future generations of all life on earth. In addition, high oil prices in the US have also sparked an interest in research toward reducing our dependence on foreign oil. The emergence of biofuels provides a renewable source of energy whose lifecycle introduces far less CO_2 and GHGs into the atmosphere. Cellulosic ethanol in particular has garnered much attention due to the fact that its feedstocks can be grown virtually anywhere or provided in the form of agricultural waste residues.

In 2007, the U.S. Renewable Fuel Standard was expanded to include specific mandates for cellulosic ethanol production, spurring an increase in bioethanol companies looking to profit from this large, guaranteed market. However, today, in light of recent economic downturns and an increased interest in domestic natural gas, many of these companies have struggled to reach commercialization stages despite financial assistance from numerous government agencies and private investors. Assessing the viability of cellulosic ethanol as an alternative to fossil fuels in today's and future economies requires a consideration of various factors. Primarily, cellulosic ethanol must be "greener", both environmentally and ethically, than current fossil-fuel based options. Secondly, the conversion technology from biomass to ethanol must be able to maximize the energy available within the lignocellulose in a cost-effective manner. Finally, the policies governing cellulosic ethanol production must have an enormous impact on its commercial markets and potentially hold the greatest power over the future of this biofuel. By investigating these markets and the funding available to companies, we hope to assess the current state of the cellulosic ethanol industry and provide insight on promising strategies for future success and implementation.

ENVIRONMENTAL IMPACT

The side by side comparison of the chemicals used in the feedstock production pretreatment processes of both corn ethanol synthesis and cellulosic ethanol synthesis.

Summation

Although global warming has yet to be proven among society, there is substantial evidence that greenhouse gases produce a global warming fingerprint to which mankind is responsible (10). Antagonists of global warming who usually have ties to big oil companies try to sway the general public from global warming by saying that the sun is getting warmer or that this is a normal fluctuation that has been witnessed in the past. But the evidence for global warming is indisputable when you look at the atmospheric data from polar ice drilling, the molecular effects of GHG's, and the 3D climate models (11). The temperature fluctuation witnessed in the past is primarily due to natural factors such as volcanic eruptions that introduce large amounts of gases, ash, and debris into the atmosphere. Present day introduction of GHG's into the atmosphere because of anthropogenic factors such as the burning of fossil fuels to fuel industry and transportation have been increasing nonstop as the population increases. This demand for energy does not have a foreseeable end or plateau so mankind must find an alternative energy source that does not produce GHG's for the sake of future generations. Renewable energy is a step in the right direction because it allows us to utilize energy from nature that we take for granted such as the wind and sunlight. But since current technology requires liquid fuels, we look to biofuels to fill that niche. Biofuels are theoretically much cleaner than fossil fuels since their feedstock growth reduces CO_2 in the atmosphere therefore their lifecycle is much greener than fossil fuels. The public should be properly informed of the risks on the environment and life on earth that our current means of energy pose so that more policies and resources can be used to increase our dependence on biofuels, namely cellulosic ethanol.

Our biofuel of choice is cellulosic ethanol, which is a greener alternative to corn ethanol. While corn ethanol represents a promising renewable energy source, the food versus fuel debate has researchers searching for biofuel feedstocks that don't take advantage of food meant for human consumption. Here we looked at the chemical hazards resulting from two different processes in the production of cellulosic ethanol, feedstock production and biomass pretreatment, and compared them to chemical hazards from the analogous steps in corn ethanol production. The feedstocks we considered in our hazard analysis were corn stover, woody biomass, and corn (fruit).

Pesticides

On the basis of feedstock production, the corn-based sources used the most hazardous herbicides and pesticides. Pesticides in particular tend to be especially toxic to humans and the ecosystem - presumably as an inherent result of their use to kill insects that feed on the fruit. While corn stover effectively uses no additional herbicides or pesticides, its production still involves the use of the common corn chemicals and, for this reason, it is more favorable for human and environmental health to consider grasses like Miscanthus or Switchgrass. The growth of these grasses require far fewer herbicides than corn due to their rapid growth and ability to easily sprout over vast stretches of land. The production of woody biomass from the lumber industry can also forgo use of massive amounts of pesticides and thus reduce hazards from agricultural chemicals.

The method of herbicide application can also have a large effect on the potential environmental effects of a chemical. In general, crop dusting by plane is the least efficient mode of application, and can contribute significantly to chemical drift onto nearby ecosystems and water sources. Application by sprayers or seed treatment (where seeds are coated with chemicals before planting) are the preferred methods of herbicide delivery, but more costly. On average, crop dusting costs between $15 to $25 per acre[1], while hiring workers to spray chemicals raises prices so much that the option is foregone by most farmers. The pesticides used for corn ethanol production are more ecotoxic and harmful to humans compared to the herbicides used for growing switchgrass and other cellulose sources. In terms of green chemistry, the use of cellulose as a source for ethanol production is less dangerous to both the environment and people - the large amounts of herbicides and pesticides use make it unattractive compared to Miscanthus and Switchgrass.

Corn Fruit Treatment Chemicals

The pretreatment steps of the corn (fruit) ethanol production involve either dry milling or wet milling. In terms of pretreatment, corn fruit uses the least number of toxic chemicals compared to corn stover and woody biomass: in dry milling, the corn is ground up and combined with water - enzymes are then added to digest this "meal" down to simple sugars. Ammonia is then added to keep the pH under control, and as a nutrient for the yeast. Compared to the water and enzymes, Ammonia poses the largest hazard to human health - it can irritate the skin and eyes, and when mixed with household oxidants such as bleach it can produce toxic "chloramines."[9] Even with that said, ammonia is still a commonly used household chemical and both humans and other animals have an innate ability to prevent biological buildup of it alone (converting it to carbamoyl phosphate using the enzyme carbamoyl phosphate synthetase). The other pretreatment process is wet milling. Here, the corn grain is steeped in dilute sulfuric acid to separate it into parts. Strainers can then be used to segregate out different components, such as corn oil, glutenous protein, corn gluten feed, and the steeped water. The starch can then be fermented into ethanol using the dry milling process - the reason that wet milling is attractive is due to the multitude of other products it can produce, such as corn starch, corn syrup, gluten meals, and other fibrous products. Thus, the treatment of corn is less energy intensive than that of cellulosic sources (which need to separate lignin from cellulose, *explored in the Technology Section*).

In summary, the use of other cellulosic sources can be used in lieu of corn fruit as a feedstock for the production of bioethanol. This is environmentally favorably because the herbicides used to grow cellulosic ethanol (along with the chemicals used in its pretreatment) are less harmful compared to the pesticides used in growing corn fruit. Armed with this fact, we plan to continue researching into the political and economic landscapes surrounding the production of both corn ethanol and cellulosic ethanol in order to better understand the businesses developing it and help make predictions for future impacts from both processes.

TECHNOLOGICAL IMPACT

What is the most environmentally friendly way to produce cellulosic ethanol, considering feedstock, pretreatment, and general process design?

A thorough understanding of cellulosic ethanol production involves taking a look at the technological barriers in the production process and the methods used to overcome them. The transformation of cellulosic feedstock into ethanol generally involves three main steps: pretreatment, enzymatic hydrolysis, and fermentation. The microorganisms used in fermentation can only metabolize six-carbon (and sometimes five-carbon) sugars, so enzymes are used to hydrolyze the cellulose into monomeric sugars before fermentation. However, the cellulose and hemicellulose in the dried biomass are initially bound tightly by lignin residues that make them inaccessible to hydrolysis enzymes. Cellulosic ethanol producers prep the lignocellulose for hydrolysis by first processing with a pretreatment method. This pretreatment step is one of the most expensive parts of the entire production process and is critical for effective conversion at later steps (2). The lignin can be disrupted by physical, chemical, or biological means, each of which presents its own difficulties in terms of effectiveness and environmental toxicity (7).

Dilute acid pretreatment has been favored by the National Renewable Energy Laboratory (NREL) and is one of the most researched pretreatment methods (1)(6). The acid, in combination with high temperatures, softens and hydrolyzes a portion of the lignin component, making the cellulose and hemicellulose accessible for hydrolysis into a variety of products, including glucose, xylose, and furfural (3). Furfural, though an inhibitor in the fermentation step, can be transformed into high-value co-products to maximize profits (4). The xylose can also metabolized by special bacteria into ethanol if furfural is an undesired product. Although dilute acid pretreatment bypasses the need for a separate enzymatic hydrolysis step, the high cost of corrosive-resistant equipment as well as waste disposal of neutralized acid (gypsum) can be barriers to implementation (10).

Ammonia Fiber Expansion (AFEX) is another popular pretreatment. This method is attractive due to its ability to delignify herbaceous and agricultural residues, making for high yields at low enzyme loadings. The process works by soaking biomass in liquid ammonia under vapor pressure of liquid ammonia, allowing the chemicals to thoroughly wet the lignocelluloses, and then rapidly reducing the pressure to atmospheric, and keeping the temperature at the boiling point of ammonia (-33.3 °C) (5). This rapid expansion from within, along with the accompanied freezing of biomass, depolymerizes and significantly disrupts the lignin such that cellulose is accessible to hydrolytic enzymes. Some downsides to this pretreatment include the high cost of ammonia and its ineffectiveness on certain feedstocks, especially softwoods (1).

Uncatalyzed steam explosion involves a very similar process to that of APEX. Biomass is soaked in water and heated under high steam pressure, which is then rapidly released, causing a kind of explosion that physically disrupts the lignocelluloses. The release of acetic acid during this explosion along with the acidic nature of water at high temperatures further catalyzes hydrolysis within the lignocellulose. A major benefit of uncatalyzed steam explosion is the cheapness of water and avoidance of chemicals potentially hazardous to human health and the environment, though a major downside involves its low yield of hemicelluloses sugars (7).

A biological pretreatment approach uses white-rot fungi as a means to decompose softwood feedstock into a more cellulase-accessible form. These fungi, which are responsible for natural degradation of woody biomass in forests, release lignin-degrading enzymes such as peroxidases and laccases (8). Favored for its low energy and environmental cost, fungal pretreatment methods have found success in laboratories but so far, have been too time consuming for implementation at a larger scale. Some additional problems stem from the fungi's tendency to consume some cellulose and hemicelluloses in the process, lowering the effective yield (9).

Determining the most advisable technology pathway requires a consideration of both economic and environmental consequences. An ideal pretreatment method would accept multiple different types of feedstocks, would use minimally hazardous chemicals, and would efficiently transform lignocelluloses into sugars accessible for fermentation without producing inhibitors. The process might also combine steps, for example, using bacteria for fermentation that also produce the cellulases necessary for hydrolysis. Combining steps can save money on bioreactors as well as reduce complications associated with the additional movement of materials. However, with the case of genetically engineered microorganisms, the additional regulations from policies such as TSCA could potentially present an obstacle to fledgling companies. A process amenable to the production of high-value co-products would also be a feature of the ideal cellulosic ethanol technology, allowing companies to increase their often razor-thin profit margins. The xylose monomers from the hemicelluloses fraction, although inhibitory to the fermentation process, can be converted into platform chemicals like furfural and levulinic, which can be used to produce typically petroleum-based substances like fuels, fuel additives, and polymers (4).

Political Impact

How are the various policies concerning cellulosic ethanol affecting its commercial markets?

There is much debate over biofuel in today's scientific community. Much of it is attributed to the global warming effect of the greenhouse gases (GHG) produced by the increased burning of fossil fuels. Fossil fuel combustion produces gaseous carbon dioxide, which can concentrate in the atmosphere and absorb infrared light according to its absorption spectra thus trapping more IR in the atmosphere and amplifying the green house effect. Glacial formation studies that reveal atmospheric composition over millions of years show that current atmospheric levels of CO_2 is on a historic rise and is correlated to the increase in global temperature (11). In the last ten years, the main driving factor for biofuel production concerns America's energy independence since oil prices have recently skyrocketed due the nonrenewable, limited amounts of fossil fuels. Recently, success with fracking has uncovered large volumes of natural gas in America and Britain which could drastically reduce the price of oil (12). Although this dissolves the financial woe's of adopting alternative fuels, the environmental consequences of pumping more GHGs into the atmosphere is far more devastating than high gas prices. Together these reasons have brought forth government officials to provide mandates and incentives in order to motivate scientists to develop a green and sustainable energy plan for the future.

Cellulosic ethanol is a promising green energy alternative that utilizes cellulosic feedstocks from plant material. This feedstock has the intrinsic benefit of being virtually carbon neutral since its growth consumes CO_2. Ethanol is commonly used as a gasoline additive in an effort to reduce the reliance on fossil fuels. The ideal type of ethanol is a bioethanol, with the most popular feedstocks being corn and sugar cane. But since these feedstocks conflict directly with their availability for human consumption, local economies are seeing a price increase for foods. Cellulosic ethanol can be produced in virtually any environment that is rich in plants or foliage. An ideal cellulosic ethanol facility would ideally be located in an area where its cellulosic feedstock is harvested. Corn stover, switch grass, and woody biomass are among the most popular due to their abundance. The short proximity between feedstock to the facility will reduce the transportation costs and emissions since the final product, cellulosic ethanol, is much lighter than the original biomass. The location would also have access to a water source since common pretreatment methods as well as hydrolysis steps involve boilers. It is important that the water source is plentiful since competition for access to clean water is a common issue in areas where there are unmet demands for agriculture, livestock, and humans (1). According to the Safe Drinking Water Act enforced by the U.S. Environmental Protection Agency a new plant is required to obtain a Water Use Permit in order to use water from a surface or underground source for the pretreatment and hydrolysis steps (3). The plant will also be subject policies and regulations from the county in which it resides. Most of the common pretreatment methods involve large amounts of weak acids and nonhazardous chemicals that would be best handled by discharging them to the facilities own wastewater treatment system. The construction of a wastewater facility National Pollutant Discharge Elimination Permit (NPDEP) covered by the Clean Water Act (CWA) (3). Additional benefits to obtaining the NPDEP include the ability to construct holding/collection systems in case our facility has the ability to produce specialty chemicals besides ethanol. Common pretreatment and fermentation methods also produce regulated substances such as anhydrous ammonia a facility would require the facility to obtain an Air Operating Permit as stated under the Clean Air Act (3). This permit would also benefit facilities that use boilers the lignin separated during hydrolysis can undergo combustion in order to generate electricity or heat that can be used to self-support the whole process. Unlike the construction permits that last for the lifetime of the facility, this permit must be renewed after a certain period of time in the case that the threshold quantity for regulated substances changes.

When considering only ethanol as a product, our technology is already included among the list of acceptable chemicals covered by the Toxic Substances and Control Act inventory (TSCA) so we will not have to submit a premanufacturing notice to make ethanol. TSCA is not a list of acceptable chemicals, it is merely a list of already manufactured chemicals – most of which have never been studied for toxicity. The known toxicity of ethanol include a lethal oral dose 50 (LD50) of 6200 mg/kg, animal carcinogenicity, negative reproductive and fetal effects, promotion of tumor development, development of liver and heart disease, central nervous system depression, impairment of testosterone secretion, and an irritant risk to the eyes, throat, and lungs. TSCA does not address wastes produced as byproducts, but if our facility plans of producing specialty chemicals from the byproducts or to export our chemicals to Europe further studies on these byproducts is required. The European Community Regulation developed REACH, which deals with the Regulation, Evaluation, Authorisation, and Restriction of Chemical substances. REACH requires chemical manufacturers and importers to identify and manage the risks linked to all their manufactured and marketed chemicals (14). In regards to the microorganisms we will be using for fermentation, our process is using standard yeast and bacterial strains, which are also not regulated by TSCA since they don't contain recombinant DNA. Research efforts are being focused to genetically modify strains that are specific to the different conditions determined by the biomass composition and pretreatment processes, but these methods are not yet popular since they are in early stages of development. Advancements in newly bioengineered microorganisms that lead to their large-scale use would be required by TSCA to acquire more data such as their effect on health and environment (15,18).

Although the requirements for constructing and running a cellulosic ethanol are extensive, there are also many policies in place that incentivize this economy and make its production worthwhile. According to the Renewable Fuel Standard, as amended by the Energy Independence and Security Act of 2007, the US must produce at least 21 billion gallons of advanced biofuels annually by 2022, 16 billion gallons of which must specifically come from cellulosic feedstock (4). These advanced biofuels must emit at least 60% less of the baseline GHG emissions from reformulated gasoline. The RFS sets quotas on the amount of cellulosic ethanol blended into gasoline each year, providing a guaranteed market for cellulosic ethanol producers. In fact, blenders are already being penalized millions of dollars for not using cellulosic ethanol regardless of the fact that there are still no large-scale cellulosic ethanol biorefineries producing fuel at this time (16).

Cellulosic ethanol is also addressed indirectly in the California Low Carbon Fuel Standard, which puts a maximum on the amount of greenhouse emissions a fuel producer is allowed to emit each year and allows companies with low GHG emissions to trade with companies going over the limit (5). The carbon limit is set at a certain percentage of baseline gasoline emissions and progressively lowered each year to encourage production of low carbon fuels. This program doesn't provide a direct market for cellulosic ethanol, but instead allows the market to determine which low-carbon fuel option succeeds. Cellulosic ethanol companies, with their typically low-emission fuels stand to profit not only from the market created by the LCFS, but also from the selling of carbon credits. For reference, credits were averaging around $27 per metric ton of carbon dioxide equivalent during the first two months of 2013 (17).

In evaluating whether fuels meet the LCFS standards, regulators use life cycle assessments from fuel production to end-use, aka "well-to-wheels.". For cellulosic ethanol from forest residues, the California GREET model estimates that fuel production will release 21.4 g CO_2/MJ energy produced, a 77.7% decrease from gasoline's 95.9g CO_2/MJ (6). Assigning a life cycle assessment (LCA) for ethanol from corn stover is difficult due to the variety of assumptions one can make about which processes of the life cycle to consider. For example, if just looking at the additional carbon impact of harvesting stover from a corn field and refining it into ethanol, the net carbon impact is -9.5 g CO_2/MJ, most of which is coming from the additional electricity and process heat produced by burning residual distillation solids (7). However, this approach is not realistic since it neglects the emissions due to the production of the corn crop, which is necessary for stover harvest. The most conservative estimate of carbon intensity for ethanol from corn stover was 40 g CO_2/MJ, or a 59% decrease compared to emissions from gasoline. This estimate uses an energy-based approach for crop production, assigning 33% of corn-growing emissions to the stover, and assigned appropriate emissions for the subsequent refining process.

The comparably low carbon intensities of both of these processes demonstrate a preference for cellulosic ethanol production under the RFS and LCFS, since in most models they produce the required (for the RFS) 60% decrease from gasoline life cycle emissions. Although these models do not consider indirect land use change in the production of our considered residual waste feedstocks, such change is likely to be minimal, since no additional land is required for production of these feedstocks. Soil fertility could be undermined by the removal of crop residues that are typically recycled into the soil.. In addition, Cellulosic ethanol does not qualify for carbon credits under the Renewable Energy portfolio standards since it is not typically used in the large-scale production of electricity.

Policy Changes to Promote Adoption:

Under the basis of commercialization, these recent policies have allowed companies to increase their production capabilities. The scale of current cellulosic ethanol production began a large increase in 2008 when the United States began developing new commercial-grade plants. Total production of 12-million liters/ year became operational, with another 80-million liters/ year under construction (a total of 26 plants) (7). The projected scale of this production – in 2022 – is mandated by the Renewable Fuel Standard to be 136-liters/ year (8). As is can be seen, a large driver of the cellulosic biofuel production is the government mandate to continue to produce the ethanol. Thus, the current landscape of companies in this industry has been influenced by this policy.

Changes in the policies regarding the production of cellulosic biofuels can greatly influence the adoption of the technology, with differing effects at various scales of operation. At smaller scales, the current mandate actually creates a market for companies. However, the fact that this market is government mandated allows for a considerable amount of uncertainty. The RFS gives companies the assurance that they will be able to sell their products at this point in time, and because of this there will be more companies entering the market to compete for the government centered market share.

However, the companies who build their businesses off of this government-centered demand may be unable to sell their products directly to consumers if the government mandate is removed. Thus, a guaranteed and unchanging mandate would remove this uncertainty and allow smaller companies to take the risk of increasing their production. This also holds true for the larger-scale production of cellulosic biofuels. Since the constraints of REACH and TSCA do not impede companies from reaching their full capabilities in producing cellulosic ethanol, and the RFS creates a market for companies to sell to, it can be said that current policies are, for the most part, favor companies who produce cellulosic ethanol. Be that as it may, this does not account for the reason that cellulosic ethanol hasn't superseded fossil fuels in commercial use.

While increasing this mandate would, in theory, increase the production of cellulosic ethanol and profits of firms who produce it with a profit margin greater than zero, this is not the case for most firms. Pretreatment methods remain too costly, and many companies in the market have yet to reach sustained profitability. Thus, this aforementioned mandate is not being met. To this end, a major political driver of cellulosic ethanol would facilitate production (to meet the market that has been created). While, pretreatment methods of the cellulosic ethanol have driven up the end cost of the fuel, compared to fossil fuel companies who literally pump profit from the ground, scientific funding to create new pretreatment methods have remained marginal - leaving a key area for policy implementation that would allow cellulosic ethanol production to make itself more sustainable. This would be best achieved in funding at interdisciplinary institutions, like universities and national laboratories, which tend to be more open to innovative ideas that could drive significant technology changes without being restricted by a company's resources or business plan.

Alongside this, there is room for political changes resulting in increased companies and competition. Under the Food, Conservation, and Energy Act of 2008 any company can apply for a grant covering up to 30% of the cost of producing a plant the specializes in the production of advanced biofuels (9). This policy creates an incentivized motivation for companies to enter the cellulosic biofuel production sector. However, once they do, the high costs still pull them away from reaching profitability (unless the company also simultaneously produces other products, such as DuPont). In addition to assisting in more efficient production methods, future policies assisting in the production of manufacturing plants would also help to strengthen cellulosic ethanol industry as a whole. For example, the first plant of every company could be guaranteed a 20% cost-matching of the capital expenditure. While subsidies do exist for companies wanting to enter this space, increased subsidization would incentivize more players to enter - with more players competition would motivate cheaper production and more efficient manufacturing. Finally, a subsidization of the end product would help benefit companies who sell to the end consumer. The government's main help comes from cost subsidization. For cellulosic companies to benefit, across the board subsidies would not only strengthen competition but also incentive more efficient production methods.

Since cellulosic ethanol facilities are expensive, the amount of research and development that will go into this industry must be driven by governments in order for keep them afloat. The government needs to develop a way to balance the pros and cons when it comes to using biofuels as opposed to fossil fuels in order to give biofuels an advantage in today's market. While many of the cellulosic ethanol processes may not be completely clean, they pose far less long-term danger to humanity and provide us with a step of being more energetically self-sufficient.

BUSINESS IMPACT

What are the profitability of current cellulosic ethanol companies in the market and how are they affected by economic and policy obstacles?

CURRENT COMMERCIALIZATION

The current market for cellulosic ethanol contains a large number of cellulosic ethanol research labs, a handful of pilot companies, and demonstration facilities. Unfortunately, reaching fruition into a full-scale commercialization plant has yet to be seen primarily due to inadequate technology and funding. Funding for cellulosics has decreased in recent years due to low returns compared to gasoline, fear from investors who've witnessed millions dollar investments go down the drain, and the advent of fracking – which continues to lower the cost and increase availability of gasoline (20).

There are potentially hundreds of different cellulosic feedstocks to go along with the many different conversion techniques, but technology has not yet proposed either a cost-effective way to extract the sugars in cellulosic biomass and convert them into usable ethanol or a profitable solution for the separated lignin (21). Research labs and energy companies across the world are working to advance current technologies and as of 2011 there are 21 pilot or demonstration-scale cellulosic ethanol plants that are new or are under construction (22). But as virtually all potentially great facilities have experienced, their growth usually ends here in the "Valley of Death" (23). The problems arise when funding for the research and development of a technology begins to dwindle away before the financial returns of that company sees a significant return. Investors who are looking to make the most gains grow tired of the relatively low cash flow and choose to invest towards more proven and profitable companies rather than waiting for the technology to be developed. This results in the closure of the pilot and demo-scale that even the closure of the first and only commercial plant (24). Perhaps due to competition and fruitful thinking, many of these companies overestimate the volume that they can produce and returns their technology can achieve given that they'll have more time and money to spend on refining their methods while a commercial site gets built. This was seen with Range Fuels in 2011 when they closed their commercial facility due to inadequate funding after not meeting their initial estimates despite the over $300 million funding from state, federal, and private funding (1-2).

The main problem with the process lies in the pretreatment method in which the sugars are separated from the lignocellulose abundant in plant materials. Lignocellulose is naturally very difficult to breakdown due to its rigid, crystalline structure and consequently even more difficult to do so in a green, cost-effective manner (3). This is a serious problem since return rates dictate investor support and most of the time and energy focused on this part of the process. Cellulosic companies need to develop higher efficiency and turnover of biomass to ethanol in order to make higher returns for investors and improve the green chemistry. Another indirect economic problem is seen with the current price of oil. Oil is highly subsidized by the government compared to cellulosic ethanol and is therefore a lot cheaper to manufacture (23). The onset of fracking within the continental US has led to more accessible oil that's relatively easy to collect. It has exacerbated the problem with fossil fuels by driving oil fuel prices lower and lower as fracking efforts are increased (4). The incentives of a cheaper, independent energy are hugely impacted thus creating more of an obstacle when it comes to commercialization. In a time where money rules all, it's difficult for investors to invest in a technology whose returns are three times smaller than that of an existing and proven method (5).

FUNDING

While many promising cellulosic ethanol companies are able to acquire enough funding from Angel investors, venture capitalists, and government grants for initial research and pilot facilities, they face an enormous barriers in financing on the road to commercialization . One of the largest issues for companies seeking private investors lies in the difficulty of promising any short-term returns. Plants can take two or three years to construct and if any problems arise in the scale-up technology, they can take even longer. In order to provide a kind of safety net for these potential roadblocks, companies ideally look for investors willing to provide large loan guarantees or private equity on a long time scale. Below is a table of available information on private investment in cellulosic ethanol companies.

Cellulosic Ethanol Producer	Amount of Private Funding Received (32)
Iogen	$425 mil total investment from Dutch/Shell Groups Goldmann Sachs, Volkswagon, Petrol Canada
Enerkem	$136 mil in three rounds of financing since 2008
Mascoma	$120 mil in four rounds of financing
Fulcrum Bioenergy	$93 mil in private equity in 2011
Zeachem	$65 mil in three rounds of financing
Fiberight	$15 mil in 2012 from confidential private equity fund

The US government has been a critical funder of many cellulosic ethanol companies, with the most significant amounts of capital coming from US Department of Energy grants. In 2007, the DoE announced $385 million in funding to six cellulosic ethanol companies planning to build commercial scale plants(9). Of the six, half have since abandoned construction plans (Iogen, Alico, Range Fuels) leaving the other three (POET, Abengoa, and BlueFire) still in the running for commercializing production

(25-30). Of the three failures, one (RangeFuels) was due to a technical defect in the plant construction, resulting in the production of methanol instead of ethanol. They announced their foreclosure in late 2011. Another, Iogen, was able to secure a $500 million loan guarantee from the Canadian governement and thus canceled U.S. construction plans, where money was more limited. Alico did not end up going ahead with construction after vaguely stating that "the risks outweighed any potential benefits"(26).

Government programs also provide long term loans to struggling biofuel companies, which are generally risky clients for many other lenders. USDA Biorefinery Assistance Program-provides loan guarantees up to $250 million for non-corn renewable biomass-derived biofuels. It awarded $250 million to Coskata in 2011, $132.4 million to Abengoa in 2011, and $232 million loan guarantees to ZeaChem in 2012, all for construction of commercial-scale cellulosic ethanol plants. Another program from the USDA, the Advanced Biofuels Payment Program, provides payments in the tens of thousands of dollars for renewable-biomass (non-corn) biofuel companies that are already actively producing a biofuel. However, cellulosic ethanol companies have had trouble accessing this money since most are not producing commercially yet. One of the few, Abengoa, received $155,922 in 2012 (8). Although these companies are receiving considerable sums of money from the government, the cost of a commercial-scale cellulosic ethanol plant hovers around $400 million, and reliable, long-term contributions from private investors are not enough to fill the funding gap (31).

States looking to attract jobs and stimulate their economy are also potential funders for cellulosic companies trying to commercialize. POET-DSM has benefitted from a $15 million grant from the Iowa Power Fund and Mascoma received $12.1 million from the Michigan Strategic Fund, both of which companies are planning to build commercial facilities within their respective states. Other states, such as Minnesota and Colorado focus funding on early stage research toward more general renewable energy solutions, which could potentially be useful for less developed start-ups.

Cellulosic ethanol companies would benefit most substantially from large DoE grants and loans, which put good faith in the company's future and encourage investment by additional backers. However, the fiscal cliff is making funding less and less available for cellulosic companies, especially those in the commercialization stages, making alternative sources of funding increasingly important(6). There are substantially more funding opportunities for basic biofuels research, mostly for academic laboratories. For example, the Joint BioEnergy Institute (Lawerence Berkeley Labs), Great Lakes BioEnergy Research Center(University of Wisconsin-Madison in partnership with Michigan State University), and BioEnergy Research Center (Oak Ridge National Laboratory)(7) all received a continuation of DoE funding for $125million over the next 5 years. In addition, cellulosic ethanol research could fall under the umbrella of groups like the National Science Foundation, which support broad-based research on a variety of important, relevant projects. Small start-up cellulosic ethanol companies might benefit from this funding by partnering with local academic institutions that can keep them up to date on the latest updates in technology with minimal cost to themselves .

Corporate funding presents a different alternative to cellulosic ethanol companies struggling to finance commercial plants, though recent developments have been bleak. Both BP and Chevron have pulled funding from their cellulosic ethanol divisions in the past several years due to inability to raise profit margins to acceptable levels(10). In 2011, Mascoma announced a tentative investment of $50 million from Valero toward their commercial-scale plant in Michigan, but confirmation of this deal is unknown. Also in 2011, Chrysler formed a Memorandum of Understanding with ZeaChem to build awareness of cellulosic ethanol, although the specific terms have not been released (11).

STRATEGIES FOR COMMERCIALIZATION

Our main strategies for removing obstacles for commercialization are rooted in circumventing the two largest problems that our technology is facing on its path to commercializing: (1) the market, and (2) the science behind converting our inputs into our deliverables.

The first main roadblock to commercializing involves the technology, and for biofuels this involves building a production plant. This huge capital cost (on the scale of the $250 loan guarantee granted to Coskata) is largely mitigated by new biofuel firms through investment (because new firms don't have the cash flows to fund it). To illustrate this point, the smallest capital investment made by an emerging biofuel firm was over $180 million (12). However, this is not the sole driver of the roadblock - this large capital expenditure is paired together with increased costs in converting the feedstock to ethanol seen by current technology. In 2012, the cost of producing cellulosic ethanol was 40% higher than that of producing corn ethanol, at $3.55 per gallon (13). Compare this to the cost of producing gasoline at $2.66 per gallon (14). Together, the cost of creating production plants and the high costs of producing cellulosic ethanol, these two costs drive down the cellulosic ethanol profitability. And thus, the government mandate by the RFS goes unmet every year.

To remove this obstacle to commercialization, manufacturers of cellulosic need to either (1) develop more cost-effective processes of producing their product, or (2) get the government to subsidize the price disparity between fossil fuel prices and their own. Obviously, the former is more sustainable.

Politically, the best changes would allow cellulosic ethanol to obtain more funding, and more room to develop themselves in order to decrease this cost efficiency gap. One venue could involve academia, through government grants or funding, that would allow more research to be done in efficient conversion processes. The largest obstacles all involve improving the technology (both pretreatment, and fermentation), and the best ways for the government to influence this is through offering venues (organizations) and money for growth.

In addition to the technological barriers impeding the development of cellulosic ethanol as a comparable alternative to fossil fuels, the market also plays an important role in this decision. In the SEC filing that Mascoma filed to retract its $100 million Initial Public Offering, the management sited "unfavorable market conditions" as the reason they pulled back. This theme has recently rung true for many other firms in this industry. In the market, stakeholders care about getting their returns. For cellulosic ethanol companies specifically, this involves both ensuring that the company doesn't default, and, further than this, making the company profitable to get investors their return.

Currently the market is dominated by vehicles that run almost solely on fossil fuels. There are currently 254,212,610 vehicles in america (17), of which 618,504 are powered by ethanol (18). This means that 0.24% of the vehicle market is open to sell ethanol to. With such little market share even available for ethanol, the profitability of companies in this market are much lower than those of fossil fuel companies. Thus, although counter-intuitive, a main way for cellulosic companies to become more profitable may be to enter the vehicular manufacturing market in developing more cars to run off of their fuel. Partnering with an already profitable auto-manufacturer to develop these vehicles would be the best way to accomplish this; the auto-maker would create vehicles to run off larger quantities of ethanol, and the ethanol producer would benefit from an increased market. In an even more creative approach, bringing in non-profits to partner with may allow cellulosic ethanol companies to better market themselves - the NPO would benefit from being offered products from the cellulosic ethanol company, and from being able to attach its name to the company, while the cellulosic ethanol company would benefit from the NPO's marketing and name a well. For example, a non-profit pushing against global warming such as stopglobalwarming.org (20), could link to the website of a cellulosic ethanol producer marketing their product. This would both help the NPO's cause and help the profitbality of the cellulosic ethanol company. Repeat this marketing scheme for many more NPO's of the same nature, and the ethanol producer would receive a large benefit. In a sense, both companies would help each other.

To conclude, the current commercialization of cellulosic ethanol has made a lot of progress compared its market in past years. While companies are receiving funding, the obstacles to commercialization have proved to be quite formidable. The largest challenge is the road to profitability and sustainability. This can be obtained through either developed technology, or gaining larger market share.

Conclusion:

The main two drivers behind cellulosic ethanol are that (1) global warming is rapidly affecting our current environment adversely, and (2) cellulosic ethanol is more sustainable than corn ethanol because it does not reduce the food supply. Thus, cellulosic sources of ethanol, such as Miscanthus and Switchgrass, provide a sustainable solution to the ethical and environmental dangers of continued fossil fuel use. Government mandates have created a market for companies to sell their products to, however this mandate has frequently been unmet. This reason is largely due to the large costs also associated with producing cellulosic ethanol, and this lack of profitability is why we haven't already switched to this sustainable fuel source.

Environmentally, there is a large argument for cellulosic sources of ethanol. The chemicals used to produce the feedstocks are much more benign than the pesticides needed to produce corn ethanol. Thus, not only does cellulosic ethanol mitigate the food vs. fuel argument, it is also a more environmentally friendly alternative.

Technology benefits, however, lean towards the side of corn ethanol. The processes of producing ethanol from corn, wet and dry milling, involve very little energy and extra chemicals. The process strips the sugar from the raw source either mechanically or via a dilute acid. Cellulosic sources of ethanol must deal with the problem of lignin, which is frequently energy-intensive to remove. The largest area for future improvement in getting cellulosic ethanol to the market lies in these pretreatment methods; government funding to make these processes more cost/ energy efficient would allow cellulosic companies to more directly compete with fossil fuels.

The political environment surrounding cellulosic ethanol has been, for the most part, beneficial to companies already in the space. The Renewable Fuel Standard has created a government-mandated market for companies to sell ethanol. However, the underlying problem costs associated with producing the product must be addressed in more detail. More funding for pretreatment research (either academic or private) is best the direction for the government to promote. Afterwards, subsidizations for companies building manufacturing plants would continue to help cellulosic ethanol penetrate the fuel market.

On a final note, businesses producing cellulosic ethanol continue to meet roadblocks on the path to directly competing against fossil fuels. The two largest aforementioned costs are the development of a commercial manufacturing plant (which requires a very large initial capital expenditure for companies who haven't even begun to make profits), and the cost disparity between cellulosic ethanol and fossil fuels (due to the energy intensive pretreatments). Because recently funded cellulosic companies have failed to attain profitability, the current investing landscape has become apprehensive to further funding of cellulosic ethanol. Government grants can go part of the ways, but funding of research into making more efficient pretreatments is the best current option. To compound this fact, the current society has built up 100 years of infrastructure around fossil fuels - public vehicles cannot run on a more than 15% ethanol to gasoline blend of fuel, and there aren't very many cars that actually do run on ethanol.

The path to replacing fossil fuels is long and cost intensive. While companies are emerging to produce cellulosic ethanol (which is much more environmentally sustainable), the technological barriers have kept companies from attaining profitability. Without profits, companies in the cellulosic market frequently aren't able to continue their operations, and thus funding for these companies have recently decreased. The first step is for the government to fund research into pretreatments, and then companies can begin to undo the years upon years of societal infrastructure created around using fossil fuels.

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