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Feedstock loss from drought is a major economic risk for biofuel producers

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ABSTRACT

High cost of technology is seen as the primary barrier to full commercialization of cellulosic biofuels. There is broad expectation that once conversion technology breakthroughs occur, policy support is only needed to accelerate cost reductions through "learning by doing" effects. In this study, we show that droughts pose a significant economic risk to biofuel producers and consumers regardless of the rate at which technology costs fall. We model a future switchgrass derived cellulosic biorefinery industry in Kansas based on spatially resolute historic (1996–2005) weather data, representing a rainfall regime that could reflect drought events predicted to occur throughout the U.S. Midwest by climatologists (Karl et al. (2009) U.S. Global Change Research Program USA). We find that droughts reduced modeled biorefinery capacity factors, on average, by 47%, raising biofuel production costs by 35% between a modeled dry and wet year. Interestingly, we find that two logical strategies to plan for drought; (1) building large biorefineries to source feedstock from a larger area and, (2) Storing switchgrass in good production years for use in drought years; are not very effective in reducing drought risks. Our findings should be of particular concern to low carbon fuel policies like California's Low Carbon Fuel Standard and the U.S. Second Renewable Fuel Standards (RFS2) whose costs of compliance may be much higher than expected.

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1. Introduction

Research has shown that most vehicle technology and clean fuel options to reduce greenhouse gas (GHG) emissions from transportation come at a high carbon abatement cost when compared to other energy sectors like power [1–4]. However, estimates show that second generation biofuels have the potential to displace a substantial share of petroleum use in transport [5–8]. There is also broad agreement that the primary barrier to full commercialization of cellulosic biofuels is the high technology cost [9–11] and cost reductions after commercialization could be rapid [12]. Finally, although the carbon mitigation potential of biofuels have been questioned vigorously [13–16], both biofuel critics and proponents agree that cellulosic biofuels offer significant carbon reductions over

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petroleum especially if the feedstock is grown on lands that have low opportunity costs and limited potential for cascading indirect land use change effects [17]. Lifecycle environmental impacts are further reduced for non-irrigated feedstocks [18].

Each of these widely held views have played some role in the design and enactment of low carbon fuel policies like the US Second Renewable Fuel Standard (RFS2) [19], the California Low Carbon Fuel Standard (LCFS) and the European Union's Renewable Energy Directives (EU RED) for transportation [20]. All of these policies set their targets under the implicit assumption that cost-effective biofuels would play a key role in meeting them [3]. While each of these transportation fuel policies are designed for some level of planned or forced flexibility (e.g., EPA has waive mandated volumes due to a lack of capacity) each is expecting biofuels to fulfill the majority of the targets because vehicles that use other alternative fuels like electricity or hydrogen are not expected to be a significant part of the fleet by 2020 [20,21]. Hence, these Governments may have enacted fuel policies with less ambitious targets had expert opinion on the potential and projected production cost trends for cellulosic biofuels not been so optimistic.

In this paper, we study the effects of drought on the production costs of cellulosic biofuels and find that it poses a substantial risk to farmers and biofuel producers regardless of assumptions on biofuel technology development. The effects of drought are ignored in studies of biofuel supply chain economics [9,22], although climate studies predict that extreme weather events, including drought events, will become more frequent in the U.S. Midwest [23–28], where most of the nation's biofuel crops are likely to be grown [29,30]. Our research suggests that the ethanol price spikes caused by the 2012 drought [31] could recur in future droughts when demand for low carbon biofuels could be substantially higher and necessary to achieve deep greenhouse gas emission reduction targets [19,32].

Most US biofuel experts expect that switchgrass and miscanthus will be the two major purpose grown crops for a sustainable US biofuel industry, with switchgrass being better suited to the Midwest [29]. Switchgrass is chosen as the feedstock in this study because its response to drought conditions is better understood than miscanthus, although both are understudied. Our results are not likely to change qualitatively for Miscanthus, the other promising biofuel crop for the U.S. Midwest [30], because it is less drought tolerant than switchgrass [33]. Using historic weather data from 1996 to 2005 we develop a methodology for estimating dry periods that will affect switchgrass yields. We then derive annual biofuel cost curves for rain fed switchgrass derived cellulosic biorefineries located in Kansas (see the Methods section for an explanation of why we chose Kansas). We model three scenarios, one with no drought planning and two more where biorefineries take measures to mitigate drought risks:

1. In Scenario 1, we model switchgrass production on existing Conservation Reserve Program (CRP) lands,[1] which we use as a proxy for marginal lands, and a biorefinery in each county supplied exclusively from switchgrass production within that county. Biorefineries are sized under the assumption that there will be no drought induced feedstock loss and the production cost of ethanol is estimated using the biorefinery economic model described in the Supplementary Material.
2. In Scenario 2, an "aggregated" scenario, roughly six to eight counties are aggregated together to supply larger biorefineries, with the goal of spreading drought risk across a larger regions. As in Scenario 1, CRP lands are used and biorefinery are sized using the same methodology as in Scenario 1. A maximum capacity of 757 million liters per year (200 million gallons) is modeled with some regions having multiple biorefineries at this maximum size.
3. In Scenario 3, a "storage" scenario, biorefineries are sited and sized as in Scenario 1 but plan for drought by a) under-sizing biorefinery capacity by 10%, b) contracting for the same switchgrass supply as in the previous scenarios, and c) having available storage for the additional annual switchgrass supply. We apply a storage capital cost adder (described in the biorefinery supply chain economics below) [34–36].

We present results on a "relative costs" basis with 100% being the lowest production cost result across the three scenarios which is $0.74/gle ($2.82/gge)[2] for mature cellulosic ethanol technology. If we assume current cellulosic ethanol technology the costs are $1.28/gle ($4.85/gge) which is consistent with current cellulosic ethanol costs estimates [9,11]. We chose to present results on a relative basis to draw attention to the drought effects rather than speculations of future cellulosic ethanol process maturity and costs (see Supplementary Material for cellulosic ethanol processes and cost estimation methodology). Our costs include a farm-gate price for switchgrass, transportation cost between farms and biorefineries, and the long-term marginal cost for biorefineries (this includes capital costs, depreciation, and return on investments). In Fig. 4 through Fig. 6 "relative costs" are the normalized cost results from the scenarios (i.e., the estimated costs divided by the lowest production cost result across the three scenarios).

2. Methods

Forecasts of U.S. switchgrass production potential and rain water availability indicate that Kansas is an ideal state for estimating the effect of future climate change driven drought conditions on ethanol production and costs. U.S. Midwestern states east of Kansas historically have had greater and more consistent precipitation rates than those further west and have thus faced fewer drought years [37]. Performing the same analysis using historic data for these states would not likely reveal future cellulosic biofuel risks from drought. However, studies indicate that climate change will produce more frequent and longer lasting extreme weather events with

[1] CRP lands are lands voluntarily taken out of agricultural production by farmers and are commonly used as a proxy for marginal lands.

[2] gle is gasoline liter equivalent & gge is "gasoline gallon equivalent" which is the energy equivalent of a liter (or gallon) of gasoline.

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