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Land and Food Risks of Cellulosic Biofuels

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Thank you to Jonathan Lewis, Rachel Smolker, Chris Coxon and Marci Lavine Bloch.

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1. Executive Summary

While the majority of biofuels consumed in the United States to date have been first-generation, food-based biofuels (primarily corn ethanol, soy biodiesel, and imported sugarcane ethanol), the Renewable Fuel Standard (RFS) also requires consumption of 16 billion gallons (BG) of cellulosic biofuels annually by 2022. Cellulosic biofuels, sometimes called "next-generation" biofuels, must reach a greenhouse gas (GHG) emissions savings threshold of 60%. They are intended to be sourced from non-food feedstocks produced on "marginal" land to avoid further competition with the food supply and move beyond the food versus fuel dynamic. This, in addition to 5 BG of other advanced biofuels (at least 1 BG of biodiesel, as well as biofuels such as sugarcane ethanol), is where the majority of the United States' growth in biofuels consumption is expected to come from, as corn ethanol consumption is already nearing the conventional ethanol 15 BG mandate (around 10% of the gasoline supply, or the current blend wall). While meeting the full RFS cellulosic mandate by 2022 is highly unlikely, cellulosic biofuels may pose some of the same risks as first-generation biofuels, such as large land requirements,[1] higher feed and food prices,[2] and negative impacts on food security,[3] land rights,[4] and the environment.[5] We must carefully evaluate these risks and learn the lessons from first-generation biofuels expansion to ensure that the same mistakes (particularly the contribution to 2008 and 2012 food price spikes) are not repeated.

Cellulosic biofuels consumption has thus far failed to reach RFS-mandated levels. This is unlikely to change in the near future due to various economic, technological, logistical, infrastructure, and other challenges. The U.S. Environmental Protection Agency (EPA) waived cellulosic mandates down more than 95% in 2015 and 2016.[6] Revised volumes are just 123 and 230 *million* gallons (MG), compared to statutory mandates in the *billions* of gallons, and the gap has only grown in EPA's 2017 proposed rule.[7] The U.S. Energy Information Administration (EIA) estimates that trends of low cellulosic biofuel consumption are likely to continue through 2040.* EIA expects just 56 MG of cellulosic ethanol to be blended into the U.S. fuel supply in 2022, not even 1% of the 16 BG RFS mandate.[8] While EIA does not include other sources of cellulosic biofuel – namely compressed or liquefied natural gas (CNG/LNG) derived from municipal solid waste (MSW) for use in natural gas vehicles – in its projections, adding in likely consumption would still reach only 2.5% of the 16 BG mandate by 2022.

Overall impacts of cellulosic biofuels on food security and land use will be dependent on feedstock choices, land use, scale, and location. Some feedstocks will have a greater impact on food security and land rights than others. The number of necessary inputs, such as land and water, can also, of course, significantly change the likelihood of negative impacts. Location is an important factor, as where feedstocks are grown

* EIA's Annual Energy Outlook for 2016, released in May 2016, was used for calculations in this report. http://www.eia.gov/forecasts/aeo/er/excel/aeotab_17.xlsx

can have an outsized impact on the food security in local areas. This research focuses primarily on the risks of different feedstock choices and questions of scale.

While agricultural and forest residues and MSW with negligible land requirements have dominated cellulosic biofuel consumption to date, cellulosic ethanol is also being produced from food/feed sources such as corn kernel fiber. For 2016 and 2017, EPA projected that 90-91% of cellulosic biofuel consumption would be produced from MSW (for CNG/LNG use).[9] The remaining 10% – made up of cellulosic ethanol – is expected to be produced from corn kernel fiber, wood waste, and corn stover.[10] Corn kernel fiber's share of overall cellulosic ethanol consumption is expected to grow from just 3-4% in 2016 to 22% in 2017, according to EPA.[11] Future feedstocks could also include more land-intensive perennial grasses and woody crops. Though not food crops, they may be planted on acres currently used for food and forage production. The RFS was intended to spur development of non-food-based biofuels and liquid fuel alternatives, but major growth right now is in CNG/LNG for use in natural gas vehicles, with corn fiber a potentially significant part of future cellulosic ethanol's growth.[12]

This report, based largely on a literature review of past studies, analyzes the likely food and land impacts of three U.S. cellulosic biofuel consumption scenarios. The scenarios include basic projections of future cellulosic biofuel consumption based on historic volume mandates set by EPA and consumption projections from both EIA and EPA. While the focus is on U.S. consumption, certain food security, land rights, and land use impacts may be international in nature. The first scenario projects the impacts of a lower but more likely consumption level – 400 MG by 2022 – while the mid-consumption 2.5 BG scenario is unlikely without policy changes. The third high-consumption scenario projects the impacts of meeting the full 16 BG cellulosic mandate by 2022, which is currently required by law, but highly unlikely even with policy changes. As long as the mandate remains law, the EPA is obligated to at least try to fulfill it. Even though they are expected to fall very short in in the near future, efforts to meet the 16 BG mandate will continue and therefore the possible risks and impacts must be carefully evaluated.

Of the three, the low-consumption scenario is less likely to impact land use and food security, because production would be at a small scale and biofuels could be sourced from cheaper, low-risk feedstocks such as MSW, with smaller amounts of corn stover, corn kernel fiber, and wood residues. However, using significant amounts of corn fiber to meet the mid-consumption 2.5 BG scenario (or other scenarios) could divert feed to fuel, increasing land required to grow livestock feed and pushing feed and food prices higher; as corn is already used as a corn ethanol feedstock, it would be readily available and corn fiber cellulosic ethanol could be scaled up quickly if the technology is deployed at more corn ethanol facilities. To meet the full 16 BG cellulosic mandate, 30-60 million additional acres would likely be required to produce greater volumes of higher-risk, land-intensive feedstocks such as perennial grasses, woody crops, etc., displacing food and feed production and exerting upward pressure on crop and food prices.

Fully implementing the RFS cellulosic mandate would increase risks of higher crop and food prices, land rights disputes, and negative environmental impacts. Higher food prices negatively impact food security and increase hunger, particularly for families in developing countries spending a large portion of their income on food. Land rights disputes already tied to biofuels mandates would only worsen with greater land requirements for cellulosic biofuels. Utilizing a small amount of lower-risk feedstocks such as wastes and residues (which could be scaled up more quickly as the technologies have reached small commercial scale) would pose less risk to food and land, but avoiding these risks would be nearly impossible if the U.S. requires the 16 BG cellulosic mandate to be met. The EPA's 2011 triennial report to Congress estimated that certain cellulosic feedstocks will also negatively impact the environment.[13] Algal biofuels could also pose additional, unique environmental and food risks.

To limit land and food risks of second-generation biofuels, in the short term, federal mandates and other subsidies should support only a small amount of low-risk cellulosic biofuels derived from sustainably harvested residues and wastes, coupled with effectively implemented sustainability measures. The RFS also needs to be reformed to address its current harmful and unrealistic volume mandates. As part of that conversation, consideration should be given to other policy mechanisms that would better accomplish the goals of reducing GHG emissions in transportation and supporting sustainable cellulosic biofuel development. Some options include policy tools to promote alternative transportation methods and electric vehicles powered by wind and solar, and policies that focus on truly sustainable cellulosic biofuels, used where they would be most effective, such as aviation.

The following sections provide more information on the potential and risks of cellulosic biofuels, including background on cellulosic biofuels production/consumption (section 2), descriptions of cellulosic pathways and feedstocks (section 3), feasibility of future cellulosic biofuel consumption levels, including production and consumption challenges (section 4), land and food risks of three consumption scenarios (section 5), and policy recommendations to help reduce the food and land risks of cellulosic biofuels (section 6).

2. Background

2.1 What Are Cellulosic Biofuels?

The RFS and other policies to support biofuels were enacted to improve U.S. energy security and reduce GHG emissions from the transportation sector. More specifically, unlike first-generation biofuels, cellulosic biofuels were to be derived from non-food crops planted on marginal or less-productive land to limit competition with food and farmland. Cellulosic feedstocks include cellulose, hemicellulose, and lignin non-food portions of existing food crops (such as agricultural residues), in addition to forest residues, MSW, and "energy crops" (such as perennial grasses, woody crops, and genetically engineered sorghum and energy cane). Cellulosic biofuels can be produced from biochemical conversion to create cellulosic ethanol, thermochemical conversion to create ethanol or biomass-to-liquid fuels (such as renewable diesel), and CNG/LNG derived from biogas.

In the United States, cellulosic biofuels are primarily incentivized through the federal RFS mandate, but also through tax incentives and various programs at the U.S. Department of Agriculture (USDA) and U.S. Department of Energy (DOE). The RFS, greatly expanded in the *Energy Independence and Security Act of 2007*, requires 36 BG of biofuels to be used in U.S. transportation fuel by 2022. The mandate for 16 BG cellulosic biofuels mandate is nested within both the total renewables and advanced mandates. In the RFS, cellulosic biofuels are defined as "renewable fuel derived from any cellulose, hemicellulose, or lignin … derived from renewable biomass" with GHG emission reductions of at least 60%.[14] Generally, cellulosic biofuels are thought of and promoted as cellulosic ethanol to be blended with gasoline. However, the broader term "cellulosic biofuel" is generally used here because the majority of cellulosic gallons consumed to date have not been ethanol, but rather CNG/LNG derived from biogas. This pathway was approved by EPA in 2014 after the producers proved that its feedstock – MSW – comprises mostly cellulosic waste.

2.2 History of Cellulosic Biofuels in the RFS and Future Production/Consumption Levels

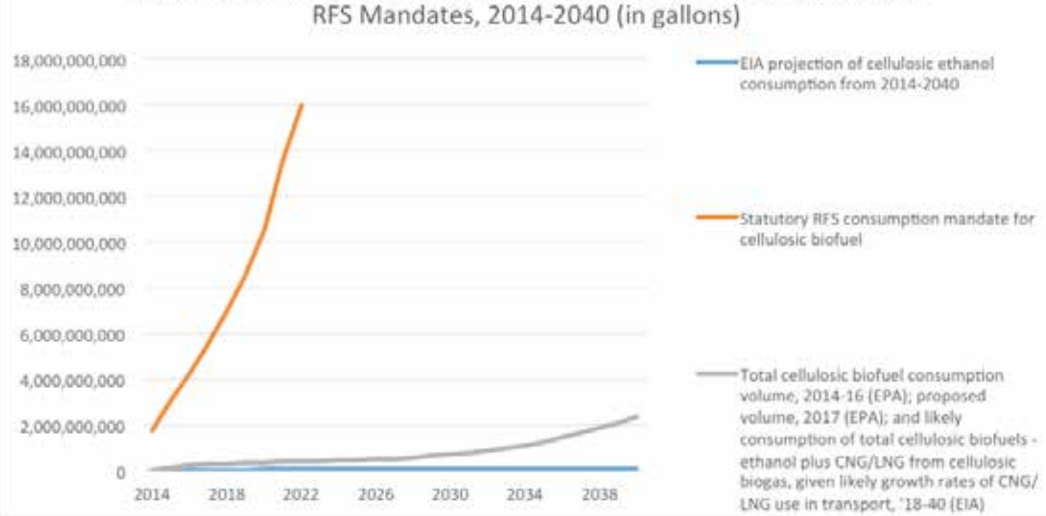
The RFS and other federal biofuel incentives have failed to promote cellulosic biofuel consumption to the level required by law, resulting in EPA waiving down cellulosic mandates every year a rule has been issued, recently by more than 95%.[15] Revised EPA cellulosic volumes for 2015 and 2016 are just 123 and 230 million gallons, compared to statutory mandates in the billions of gallons (see Figure 1).[16] The ability of the industry to even meet these low requirements in 2016 is an open question.[17]

As EIA and others predict, trends of low cellulosic biofuel consumption are likely to continue not only through 2022, but through 2040 due to economic, technical, logistical, and other barriers. Hence, cellulosic biofuels are extremely unlikely to reach their 16 BG mandate by 2022. For cellulosic ethanol, EIA expects just 56 million gallons of consumption in 2022, not even 1% of the 16 BG RFS mandate (as demonstrated below in Figure 1, where cellulosic ethanol is almost non-existent).[18] Though EPA expects cellulosic ethanol consumption to increase 40% between 2016 and 2017, the Agency actually expects fewer companies to produce cellulosic ethanol in 2017 than in 2016, meaning growth in the industry is currently limited. The EIA excludes the CNG/LNG biogas pathway from its future cellulosic projections (because it does not directly displace liquid petroleum fuels[19]) and assumes the cellulosic production tax credit will expire. Still, the EIA's projection of negligible cellulosic ethanol growth until 2040 is significant.

Even with future use of CNG/LNG added to EIA projections for cellulosic ethanol, total cellulosic consumption levels increase to only 400 MG by 2022 (in gray) and still fall significantly below RFS mandates (in orange).[20] Today, CNG/LNG use dominates cellulosic consumption, making up a likely 90% of the EPA's total 2016-17 cellulosic requirements[21] – with cellulosic ethanol (produced from corn stover, corn kernel fiber, sugarcane bagasse, and wood residues) filling the remaining 10%.[22] However, EIA's future annual growth rates of CNG/LNG use in natural gas vehicles are lower than large recent annual increases, and this pathway will be unable to compensate for the lack of cellulosic ethanol development.[23] Therefore, EIA's projected consumption for 2022, even with the CNG/LNG pathway added, would be only 400 MG, marginally higher than the 312 MG of cellulosic biofuel proposed by EPA to be used in 2017.

Imports of cellulosic biofuels produced and processed outside of the U.S. from feedstocks such as sugarcane bagasse are also limited as only 37 million gallons of cellulosic ethanol were produced globally in 2012.[24] While the International Energy Agency's (IEA) projections are more optimistic than EIA's (by assuming the continuation and implementation of certain policy measures to reduce global GHG emissions), IEA still assumes the 16 BG cellulosic mandate would not likely be met until 2050.[25] The National Academies of Sciences (NAS) projects that cellulosic biofuels will become cost-competitive with petroleum-based fuels only in an environment with high oil prices, a carbon tax, and significant technological breakthroughs.[26]

Figure 1: Actual and Projected U.S. Cellulosic Biofuel Consumption vs. RFS Mandates, 2014-2040 (in gallons)



2.3 Cellulosic Technologies

Technological and economic hurdles have been the two primary challenges facing cellulosic biofuel producers. Cellulosic biofuels, on average, are more costly and capital-intensive than their first-generation counterparts. Cellulosic technologies – primarily for corn stover ethanol and biogas from MSW for use in CNG/LNG vehicles – have only just reached early commercial scale, while others are still largely in the demonstration or R&D/pilot phase.[27] Aside from biogas, the two primary technologies used to produce cellulosic ethanol are biochemical and thermochemical conversion. Most current cellulosic ethanol facilities use biochemical processes because they are generally cheaper than thermochemical technologies.[28] Of the two, biochemical and thermochemical fast pyrolysis are expected to have lower water requirements.[29] Thermochemical processes are also expected to be able to utilize a wider range of feedstocks and create several different fuels, including ethanol, biomass-to-liquids (such as renewable diesel, which contains more energy than biodiesel), and other drop-in fuels.[30] Other RFS-eligible "fuels" derived from cellulosic feedstocks include renewable heating oil and electricity (used for transportation) and naphtha (used to make high-octane gasoline[31]); however, these are not covered below because they are sparsely used.

Biochemical conversion: Biochemical conversion uses "a physical and chemical process to liberate tightly bound cellulose and hemicellulose from lignin,"[32] the latter of which is burned to generate electricity.[33] Then, strong acid or enzymes are used to break up the cellulose and hemicellulose (known as hydrolysis) into simple sugars for fermentation.[34] Fermenting, the final step in the cellulosic ethanol production process, is one of the most difficult, so synthetic biology is often considered as a way to improve the technology.[35]

Thermochemical conversion: Thermochemical conversion creates biofuels by using gasification or pyrolysis processes.[36]

- **Gasification (Fischer-Tropsch):** Biomass is heated with oxygen at high temperatures and high pressure to decompose cellulosic biomass, resulting in a mixture of carbon monoxide and hydrogen called syngas.[37] "After cleaning, the syngas is catalytically converted through Fischer-Tropsch (FT) synthesis into a broad range of hydrocarbon" liquid fuels.[38] FT technology has been used to produce coal- and gas-to-liquid fuels,[39] in addition to renewable jet fuel.[40]

- **Pyrolysis:** Biomass is heated without oxygen at lower temperatures, creating bio-oil/bio-char "that can be used subsequently as a feedstock for a petroleum refinery."[41] Pyrolysis can be used to produce drop-in biofuels that do not face E10 blend wall constraints.[42] Pyrolysis technology faces greater hurdles than FT, but may use equipment common in the petroleum industry, which could reduce capital costs.[43]

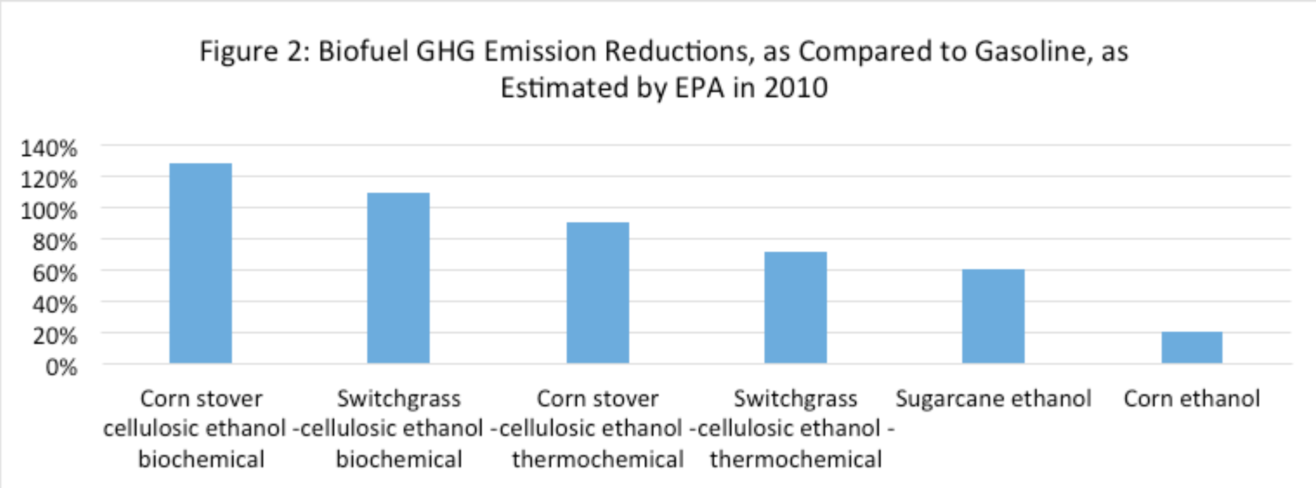
Corn kernel fiber conversion: Fewer steps are needed to convert corn kernel fiber into cellulosic ethanol than, for example, the biochemical conversion processes for corn stover-to-ethanol, because only the glucose from the cellulose – not the hemicellulose – is fermented. Corn kernel fiber contains little lignin, making the production process simpler, as cellulose is difficult to separate from lignin.[44]

Biogas: Derived from MSW, biogas can be used to generate renewable electricity or CNG/LNG for use in natural gas vehicles. The latter uses biogas that is "upgraded to biomethane by removing CO2 and hydrogen sulfide (H2S), and injected into the natural gas grid" for use in the transportation sector.[45] While EPA did not expect biogas/CNG-LNG to contribute to the RFS mandate in 2010, it approved the technology as a new cellulosic biofuel pathway in 2014.[46] While natural gas vehicles are primarily used in larger vehicle fleets in the United States, they are commonly used in other countries.[47]

2.4 Greenhouse Gas Reduction Potential of Cellulosic Biofuels and Impact on Land Use

One of the primary goals of the RFS is to reduce GHG emissions, with cellulosic biofuels required to reduce life-cycle GHG emissions by 60%. One of the major sources of emissions for first-generation biofuels are the GHG emissions from land-use change. The Congressional Budget Office (CBO) states, "the RFS can cause the release of stored carbon directly, when crops for renewable fuels are grown on previously unfarmed land, or indirectly, when those crops compete for land that had been used to grow other commodities, leading to higher commodity prices, which encourage[s]"[48] domestic and international land use expansion.[49] Hence, NAS concluded the "RFS may be an ineffective policy for reducing global [GHG] emissions."[50] This is a risk for not only first-generation feedstocks, but also cellulosic feedstocks that require land for production.

When EPA analyzed GHG reductions of biofuels for the RFS in 2010, it calculated life-cycle reductions over a 30-year period that would occur for biofuels produced in 2022.[51] EPA estimated corn stover and switchgrass cellulosic ethanol produced through a biochemical process would reduce GHG emissions by the greatest amount compared to gasoline (129% and 110%, respectively).[52] Thermochemical technologies would result in smaller reductions.[53] As seen in Figure 2, while these reductions are greater than those for corn or sugarcane ethanol, they would be lower if EPA analyzed current biofuels production instead of biofuels produced in 2022, which discounts some emissions from land-use change. Emissions reductions may also be lower if EPA did not give cellulosic ethanol credit for combusting leftover lignin after the biochemical production process,[54] which reduces GHG emissions, because the lignin replaces some fossil fuel use to power the biofuels facility.[55] Generally, residue- and waste-based biofuels are more likely to reduce GHG emissions given their limited land use,[56] but some studies calculate that corn stover ethanol (and switchgrass ethanol) may not even meet the required 60% reduction.[57]



3. Cellulosic Biofuel Pathways and Feedstocks

3.1 Approved and Pending Pathways for Cellulosic Biofuel in the RFS

While the majority of cellulosic gallons to date have been derived from wastes, other cellulosic "pathways" are approved by EPA. Table 1, adapted from EPA, lists the pathway-approved ways companies may produce biofuel to meet the RFS cellulosic mandate (by producing D3 RINs).[58]

Table 1: Approved and Pending RFS Pathways for Cellulosic Biofuels

CELLULOSIC BIOFUEL	FEEDSTOCKS	PRODUCTION PROCESS
Ethanol (D3 RIN); cellulosic diesel, jet fuel, and heating oil (D7 RIN for cellulosic biofuel or biomass-based diesel)	Crop residue, slash, pre-commercial thinnings and tree residue, switchgrass, miscanthus, energy cane, giant reed (Arundo donax), napier grass (Pennisetum purpureum), and separated yard waste; separated MSW; separated food waste and cover crops	Any
Renewable gasoline and renewable gasoline blend-stock (D3 RIN)	Crop residue, slash, pre-commercial thinnings, tree residue, and separated yard waste; biogenic components of separated MSW; cellulosic components of separated food waste and annual cover crops	Pyrolysis, gasification, thermo-catalytic hydrodeoxygenation, biological conversion, biogas, among others
Naphtha (D3 RIN)	Switchgrass, miscanthus, giant reed, energy cane, and napier grass	Gasification and upgrading processes converting cellulosic biomass to fuel
Renewable CNG/LNG, renewable electricity (D3 RIN)	Biogas from landfills, municipal wastewater treatment digesters, agricultural digesters, and separated MSW digesters; and biogas from the cellulosic components of biomass processed in other waste digesters	Any

3.2 Descriptions of Cellulosic Feedstocks

3.2.1 Agricultural Residues

The agricultural residues likely to be used for cellulosic ethanol production in the short term include those from corn and sugarcane production, given their widespread availability in the United States and Brazil, respectively. Other residues – from wheat, soybeans, barley, oats – could also be used.[59] Several U.S. companies are beginning to produce cellulosic ethanol from corn stover (the non-edible leaves, stalks, and cobs, instead of the corn kernel, which is used for corn ethanol production). In addition to being left on the ground after harvest to provide soil nutrients, reduce soil erosion, and retain soil moisture,[60] corn stover and other agricultural residues are currently used as bedding and fodder for livestock.[61] Because excessive residue removal can increase soil erosion, studies generally assume only 10-50% of corn stover residues in particular would be harvested out of a total of 3-4 dry tons* per acre, depending on tillage methods.[62] Greater amounts of corn stover are available from higher-yielding acres (such as productive irrigated land). Another residue used for cellulosic ethanol production is sugarcane bagasse, which has historically been burned to generate electricity and heat.[63] In 2010, EPA assumed all bagasse ethanol consumed in the United States would be sourced from a doubling of U.S. sugar acres from 2007-2022 (with all residues used for ethanol).[64] However, EPA now expects GranBio, a Brazilian sugar bagasse ethanol producer, to export to the United States.

Agriculture residues can be used as a feedstock with relatively low risk to food security, assuming there is no over-removal. Small-scale agricultural residue removal would not require direct land for production (such as the very low levels currently being used to supply two corn stover ethanol facilities), but large-scale use could increase the profitability of growing certain first-generation biofuel crops, as agricultural producers would receive additional income from selling agricultural residues to biofuel refineries.[65] Farmers may then be incentivized to forgo certain crop rotations and avoid switching to non-biofuel crops (such as wheat), instead planting biofuel crops that yield the most income per acre. This would only further incentivize biofuel crop planting at the expense of food and feed crops. Over-harvesting residues would eventually affect productivity as a result of depleted nutrients and cause soil erosion, hurting both the environment and food security. Therefore, though crop residues would not directly require dedicated land, a 2011 NAS report concluded that large-scale use of crop residue-based biofuel would still increase overall demand for land and land prices.[66] Scale, then, is key to determining the impact of agricultural residues as a feedstock.

* Note that in this report (and in other major reports on cellulosic biofuels), cellulosic feedstocks are measured in dry tons per acre. Each dry ton of cellulosic biomass may yield 70-95 gallons of biofuel (the 2011 NAS report used the 70-gallon figure while EPA's RFS implementation rule in 2010 assumed each dry ton would produce 90-94 gallons of cellulosic biofuel).

3.2.2 Corn Kernel Fiber

When implementing the expanded RFS in 2010, EPA did not expect cellulosic ethanol to be produced from parts of corn kernels ("corn kernel fiber")[67] because the RFS prohibits corn starch-based biofuels from qualifying as "cellulosic biofuels."[68] However, in a 2014 rule, EPA allowed the cell walls of the corn kernel ("fiber") to qualify as a cellulosic biofuel, a move supported by the corn ethanol lobby.[69] Corn fiber, which makes up 8-9% of the kernel, has been described as a low-hanging feedstock because corn is already used for first-generation ethanol production.[70] The fiber/cell wall contains a small amount of starch in addition to cellulose, hemicellulose, and lignin,[71] and is categorized by EPA as an agricultural residue (specifically a "crop residue," shown in Table 1 above).[72]

Corn kernel fiber is undeniably a food-based biofuel, as it comes directly from the edible part of the feedstock, even if it is not the whole kernel. Facilities that are adding this cellulosic ethanol technology to existing corn ethanol facilities are able to produce not only corn ethanol (from corn kernels), but also smaller amounts of corn fiber-based cellulosic ethanol to receive the $1.01 cellulosic producer tax credit and qualify for cellulosic RINs in the RFS. Therefore, the cellulosic production is directly supporting traditional corn ethanol, which has food price and land-use impacts. Additionally, because corn kernel fiber entering corn ethanol facilities has historically become distillers grains, which are used as livestock feed[73], using this portion of the kernel for biofuel instead will slightly reduce the amount of available feed, possibly increasing feed prices.

3.2.3 Perennial Grasses

Perennial grasses (plants that grow each year from the same roots) that may be used for cellulosic biofuel production include switchgrass and miscanthus. Other "energy crops" that could be used (which are not covered in depth here but may still pose food and land risks) include Arundo donax (giant reed, which may become invasive in the United States) and genetically engineered sorghum[74] and energy cane. The latter two are engineered to yield more biomass for use in biofuel production (such as inedible stalks[75]) rather than sorghum or sugar to be eaten as food.[76] Switchgrass "is a perennial grass native to North America, where it is dominant in tall grass prairies."[77] It may be planted with other diverse grasses, but yields are typically lower.[78] The EPA's 2010 RFS implementation rule assumed an average yield of 4-8 dry tons per acre for switchgrass plantings,[79] while other estimates range from 3-88 tons per acre.[80] Irrigation may be required in dry areas such as Oklahoma and Texas.[81] Miscanthus, on the other hand, is a sterile perennial grass native to Asia and Africa.[82] Miscanthus yields an average of 13-33 tons per acre on poor land and 18-110 tons on productive land.[83] While EPA assumes land use change GHG emissions tied to switchgrass production would be lower than soy biodiesel or corn ethanol, they would still be greater than sugarcane ethanol.[84] Miscanthus, because it is higher yielding, is expected to result in less land use change than switchgrass.[85]

Perennial grasses require dedicated land, and are therefore a risk to food security and land rights. While perennial grasses were expected to be produced on marginal land when the RFS was enacted, yields in test plots are highest on existing productive cropland,[86] and fertilizer may be required to avoid long-term soil nutrient losses. Hence, DOE and other experts now assume perennial grasses would be planted on existing cropland and pasture.[87] When cropland and pasture acres are diverted from food and feed production to perennial grasses for cellulosic biofuel production, increased demand for land raises the risk of land grabs; there is also a risk of food prices increases to compensate for that lost food/feed production, particularly in local areas. A UN Committee on World Food Security's (CFS) High Level Panel of Experts (HLPE) 2013 report also states that since perennial grasses are typically planted in 10- to 12-year rotations, they are a "less easily reversible option than annual crops if land has to be reverted quickly to food production."[88] Mandating the use of large-scale cellulosic biofuels that are at least somewhat made up of perennial grass crops (if mandates are enforced in practice) would not only increase the amount of land dedicated to biofuel crops and increase demand for land, but perennial grasses (unlike sugar or corn, for instance) cannot be quickly diverted to food or feed.

3.2.4 Forest Residues and Woody Crops

Potential woody biomass RFS feedstocks include lower-risk forest residues, as well as higher-risk monocultures of short-rotation woody biomass crops requiring dedicated land.[89] The RFS currently restricts forest residues to "slash, pre-commercial thinnings and tree residue from non-federal forestlands."[90] Forest residues are currently used to generate electricity, among other uses, so their availability for biofuels may be limited. Both EPA and DOE assume woody feedstocks would contribute a limited amount (up to 25%) toward meeting the full 16 BG cellulosic mandate. Certain whole planted trees are also eligible as feedstocks for the RFS ("from actively managed tree plantations on non-federal land"),[91] but a pending application with EPA has not yet been approved.[92] The primary types of short-rotation woody crops include poplar, willow, and eucalyptus (all of which may require irrigation or large amounts of water).[93]

Other risks of using whole trees for biofuels include questionable GHG reduction (deforestation is a major driver of GHG emissions) and a loss of biodiversity and ecosystems.[94] Using whole trees as a dedicated energy crop raises concerns about land-grabs and deforestation, as they would require dedicated land. Dedicated land presents the same risk to food security; the feedstock grown on the dedicated land can increase the risk (in the case of corn), but it cannot negate the risk from using land. Even harvesting thinnings brings a risk that forest land could be seized and local communities denied access to traditional land and communal forests. Many people around the world depend on access to forests for food and energy.

Some authors have suggested that land-intensive dedicated energy crops such as short-rotation trees could be planted on marginal (less productive) land so they do not compete with land currently used to produce food. However, the availability of marginal land for future cellulosic feedstock production is limited. Searchinger and Heimlich (2015) suggested that "Indonesia's cleared forests that are overrun by alang-alang grasses could be a candidate for biofuel crop production, … [but they] provide a low-opportunity-cost way of meeting rapidly growing demand for palm oil for food. Using these grasslands instead for biofuels could push growers to convert forests to meet food product demands for palm oil."[95] IEA also warns that "[u]sing residues and surplus forest growth, and establishing energy crop plantations on currently unused land, may prove more expensive than creating large-scale energy plantations on arable land."[96] Using marginal land to avoid competition with food production is an often-repeated strategy. In practice, however, it is not usually the most economical or practical option and is therefore unlikely to happen. It is also important to remember that what looks like marginal land may be in use by local communities who have a right to that land.

3.2.5 Municipal Solid Waste

MSW, or more specifically biogenic components of separated MSW, is generally used as the term for the feedstock used to produce biogas to power CNG/LNG vehicles; note that other waste-based feedstocks are also eligible for the RFS, including "separated yard waste and cellulosic components of separated food waste."[97] These waste-based feedstocks can be used to generate biogas at separated MSW digesters and landfills, in addition to various other digesters.[98] Using MSW for biofuel production has less risk of competing with land currently used for food production. However, the supply of MSW and other wastes is limited because they are also used for electricity generation in the United States and in other countries.

3.2.6 Algae

Algae can be used to produce biodiesel, and possibly also cellulosic ethanol.[99] Several companies are developing genetically modified, synthetic forms[100] of algae to be cultivated in either open ponds or in outdoor or indoor closed photoreactors (or a combination of the two).[101] NAS states that algae "would not necessarily compete with food for agricultural land or fresh water, and … would use CO2 as a feedstock."[102] After algae is harvested, oil is extracted "through chemical, mechanical, or electrical processes," and algal oil is used in the biofuel production process.[103] While NAS estimates algal biofuels could be produced at large scale at competitive prices,[104] the technology is still in the R&D/pilot phase, water requirements could be significant, and algae could escape and pollute nearby waterways.[105] If produced at a large scale, land requirements could also be significant, as photoreactors would need dedicated land. However, the algal facilities could be located in areas that would not be suitable for farming and is not environmentally sensitive.

Algae-based cellulosic biofuel could be wholly created from synthetic biology. Synthetic DNA is used to create algae that produce lipids. The lipids are then directly converted into biofuel with inputs such as sunlight, water, sugar, and fertilizer.[106] Feedstocks using synthetic biology such as algae may require large amounts of sugar, which could increase demand for sugar.[107] Synthetic biology is also being used for another purpose in cellulosic biofuel production: creating genetically engineered yeasts and enzymes to help "break down [cellulosic feedstocks such as woody biomass and corn stover] into sugars for fuel."[108] Several companies have developed yeasts and enzymes to improve the efficiency of corn ethanol and cellulosic biofuel production. Synthetic biology may pose risks to public health, the environment, and biodiversity if synthetic organisms escape into the environment and pollute water, damage ecosystems, or become invasive.[109] Therefore, in 2012, more than 100 global organizations signed on to a set of principles recommending the use of the precautionary principle in regard to the use of future synthetic biology technologies.[110] The UN Convention on Biological Diversity (CBD) also "agreed at their 10th Conference in 2010 that the release of synthetic biology's products requires precaution."[111]

4. Feasibility of Future Cellulosic Biofuel Production

Certain cellulosic technologies and feedstocks are more likely to be scalable – especially in the short term – while others will face significant challenges. In the short term, cellulosic biogas from MSW (used in CNG/LNG vehicles) will likely dominate the market, with smaller volumes of agricultural residue and corn kernel fiber cellulosic ethanol.[112] These readily available feedstocks face fewer economic and technological challenges (they are already being produced at a small commercial scale and can be located next to landfills or existing ethanol facilities, reducing transportation, energy, and other costs) than woody crops and perennial grasses requiring dedicated land (with less-developed technologies):

- EPA expects the **CNG-LNG/MSW pathway** to "increase at a rapid pace due to the fact that many [existing] U.S.-based [MSW] entities currently capture or produce biogas."[113] If all MSW generated in the United States each year that is not already used for recycling (85 million dry tons) or electricity generation (another 32 million dry tons) was instead used to produce biofuels (a net availability of 136 million tons), approximately 11 BG of biofuels could be produced.[114] However, using 100% of these wastes would be unrealistic, and MSW's use fueling CNG/LNG vehicles is also limited by the relatively small size of the natural gas fleet. EIA expects U.S. CNG/LNG consumption to grow 23% between 2017 and 2022 and 800% between 2017 and 2040, but still only reaching 2.3 BG by 2040 if annual increases of natural gas consumption in the transportation sector are realized.[115] In its 2010 RFS implementation rule, EPA estimated 0.6-2.2 BG of cellulosic biofuel could be produced from MSW in 2022, which is consistent with EIA's estimates, in addition to those in this report.[116]

- **Agricultural residues** will face logistical and economic challenges before they can be produced at a large scale because they are currently much more expensive than gasoline. If these challenges are overcome, corn stover ethanol production could reach 5-8 BG. Larger volumes could negatively impact the environment (particularly soil and water quality) by promoting unsustainable removal of residues, particularly in areas with highly erodible land, for instance.[117] Even a production volume of 5-8 BG could increase the profitability of growing biofuel crops such as corn and increase land prices, creating incentives for farmers to expand biofuel crop production even further, at the expense of food production.

- **Corn kernel fiber** ethanol (and potentially DDG-based ethanol[118]) could be scaled quickly as the technology can be bolted onto existing corn ethanol facilities and the feedstock – corn – is the largest crop in the United States. The corn ethanol industry estimated 2 BG of corn kernel fiber- and DDG-based ethanol could be produced from the current corn supply.[119] However, a more conservative 1 BG estimate is used for the mid-consumption scenario in this report to reflect the fact that bolting this technology onto each existing corn ethanol facility (with a 6.5% conversion ratio*) would yield only 1 BG.[120]

- Production of land-intensive biofuels such as **perennial grasses and woody crops** will face greater hurdles to reach large commercial-scale production by 2022, given technological and economic challenges and the lack of a readily available feedstock.

5. Risk Analysis of Cellulosic Biofuel Production on Land and Food

While Congress may have intended cellulosic fuels to move beyond food versus fuel, nothing in the RFS promotes low-risk cellulosic biofuels over high-risk ones. Small-scale production of low-risk cellulosic biofuels derived from wastes and residues may not put large pressure on land or food prices, but consuming food-based cellulosic biofuels (derived from corn starch, for instance) and/or a large amount of cellulosic biofuels to meet the RFS will likely increase food and land prices, with negative impacts on the poor in developing countries in particular. Economics could also change over time, potentially incentivizing riskier fuels, even at lower consumption levels.

As Popp et al. (2014) noted, food security can be affected by biofuels production

* While 8-9% of each corn kernel consists of the outer cell lining (fiber), production processes may not be able to produce cellulosic ethanol from this full volume, so a more conservative 6.5% figure is used here, consistent with current industry conversion ratios.

either “directly, if food commodities are used as the energy source, or indirectly, if bioenergy crops are cultivated on soil that would otherwise be used for food production.”[121] As previously noted, determining the risk to food security should focus on what feedstocks are being used, how much land is required, scale of use, and where production is likely to take place.

5.1 Likely Location of Cellulosic Feedstock and Biofuels Production

While the majority of cellulosic biofuels fulfilling the RFS will likely be produced in the United States, both feedstocks and biofuels may also be imported. Facilities located in Canada and Brazil currently export cellulosic biofuels to the United States.[122] Cellulosic biofuel facilities are located (or likely to be located[123]) near feedstock availability, including biogas facilities near landfills and corn stover and corn fiber facilities in the U.S. Corn Belt.[124] If full RFS mandates are met, EPA expects sugarcane bagasse facilities to be located in the South, switchgrass facilities in Oklahoma, and forest residue facilities in the Southeast, Northwest, and Northeast. Internationally, land-rich countries such as Brazil, Mexico, Thailand, and India may also attract cellulosic investment, though biorefineries are less likely in developing countries given large cellulosic investment and technology requirements.[125] However, biofuel feedstocks could be produced in sub-Saharan Africa, the Caribbean, and Latin America (IEA, 2010).[126] Producing biofuels feedstocks outside the United States (particularly in developing countries where land tenure rights can be vulnerable) carries higher food security risks.

Historic land grab cases have been tied to both EU and U.S. biofuels mandates, but, especially since the EU reformed its mandate in 2015, the U.S. mandate is expected to drive the most growth globally.[127] If large-scale future cellulosic mandates are met with land-intensive biofuels, the risk of land rights disputes tied to biofuels would only increase, with a disproportionately negative impact on the livelihoods and food security of poor families in developing countries.[128] IEA found that “[u]nclear land rights and poorly regulated land acquisition – conditions which often prevail in developing countries – lead to displacement of local farmers to non-arable regions or urban centres. These concerns are basically the same … for second-generation biofuel production.”[129] Some companies are already seeking to import second-generation feedstocks,[130] not to mention indirect land-use changes of increased U.S. biofuel feedstock production displacing food production elsewhere. While marginal land in certain developing countries has been suggested for cellulosic feedstock production, this land is often already used for firewood collection, food production, biodiversity,[131] etc.[132] Hence, unless effective sustainability measures are strictly enforced, cellulosic biofuels could negatively impact land rights in developing countries.

5.2 Projected Consumption Scenarios

The scale of cellulosic consumption is important for determining the impact on food security. High-consumption scenarios have different risks than low-consumption scenarios. The availability of cellulosic feedstocks will be much greater than their demand as biofuels given the numerous challenges outlined in Section 5.3. In other words, even in the high-consumption scenario described below, the limitation is not always the availability of cellulosic feedstocks (such as the large availability of agricultural residues, for instance) but rather their high cost, alternative uses in other industries and for environmental protection, and failure of cellulosic technologies to be deployed at a large scale.

Low-consumption scenario (most likely): The first low-consumption scenario of 400 million gallons is the most likely to be achieved by 2022, in addition to being the least risky for food and land. This scenario assumes that only 2.5% of the 16 BG RFS mandate would be met by 2022, given EIA estimates for future consumption of cellulosic ethanol combined with EPA projections for future consumption of cellulosic CNG/LNG (produced from MSW/biogas). EPA expects the latter – CNG/LNG – to account for at least 90% of cellulosic consumption in 2017,[133] so a similar ratio (85%) is projected in 2022. Given the current availability and lower price of MSW, agricultural and forest residues, and corn kernel fiber, these feedstocks would likely continue to be used in cellulosic production in 2022 (because the technologies are already developed at least at a small scale).[134] The scenario assumes EIA estimates of future annual increases (3-7%) in the amount of CNG/LNG used in natural gas vehicles[135] would be met (consistent with EPA's assumption for 2017[136] that one-third of vehicles fueling with CNG/LNG will use fuel derived from MSW), in addition to a doubling of cellulosic ethanol consumption by 2022.[137]

Meeting the low-consumption scenario of 400 MG would require the following feedstocks/technologies:

- 4 million dry tons of MSW to produce a 345-MG-equivalent of CNG/LNG, and
- 0.7 million dry tons of feedstock to produce 56 MG of cellulosic ethanol.* The latter would likely be made up of corn stover, corn kernel fiber, and wood waste. Note that corn kernel fiber ethanol could exceed EIA projections if scaled up quickly at current corn ethanol facilities expressing interest in the technology.[138] That would significantly increase risk for food security because of the feedstock used, but not necessarily the scale.

Mid-consumption scenario (unlikely without policy changes): The mid-consumption scenario assesses the impacts of producing and consuming 2.5 BG of cellulosic biofuels by 2022, which is unlikely according to EIA, but could be achievable

* This report assumes 95 gallons of cellulosic biofuel can be produced from each dry ton of MSW and 80 gallons for each dry ton of cellulosic ethanol feedstocks. These are consistent with other studies, ranging from 70 gallons per dry ton in the 2011 NAS study to 90-94 gallons in EPA's 2010 implementation of the expanded RFS. The higher the rate, the fewer feedstocks required to produce biofuels, but actual conversion rates will vary between feedstocks and technologies.

with additional incentives for cellulosic biofuel production/consumption between now and 2022. Though this scenario would require just 16% of the full 16 BG mandate, significant consumption increases of both cellulosic ethanol in the gasoline supply (beyond the E10 blend wall) and cellulosic biofuel – namely CNG/LNG derived from MSW – in natural gas vehicles would be necessary. The former would require a 50% annual growth rate in non-corn-fiber cellulosic ethanol consumption (to 240 MG), exceeding EIA projections by a factor of 4. However, an even faster growth rate for corn kernel fiber ethanol is assumed (from just a few million gallons to 1 BG by 2022). Blending a total of 1.2 BG more cellulosic ethanol into the U.S. gasoline supply would require greater use of higher ethanol blends since ethanol use is currently constrained by the E10 blend wall (assuming first-generation corn ethanol consumption does not decline commensurately). To meet the latter CNG/LNG consumption level, a 35% annual growth rate in the use of natural gas in the transportation sector would be necessary (consistent with EPA-projected increases from 2016-17), compared with EIA projections of only 3-7% annual increases from now until 2022.[139] This would require 100% of CNG-LNG vehicles to use fuel derived from cellulosic MSW biogas (up from 33% proposed in 2017).[140] This highlights the stark challenges of achieving just 2.5 BG of cellulosic consumption by 2022.

Meeting the mid-consumption scenario would require the following feedstocks/technologies:

- 14 million dry tons of MSW (representing 10% of current MSW that is generated annually but not already used for recycling or electricity generation) for a 1.3 BG-equivalent of CNG-LNG, and

- 15 million dry tons of other feedstocks (over 80% assumed to be corn kernel fiber, with the remainder from corn stover, forest residues, etc.) to produce 1.2 BG of cellulosic ethanol. Of the 1.2 BG, 1 BG would be corn kernel fiber-based ethanol with 240 MG of other cellulosic ethanol). The primary risk in this scenario is using corn kernels for biofuels, that would have instead ended up as DDG livestock feed (or potentially food if not diverted to corn ethanol production).

High-consumption scenario (highly unlikely): Meeting the full 16 BG cellulosic mandate by 2022 is highly unlikely even with policy changes, because of the significant economic and technological barriers.[141] However, this scenario is currently required by law and the assumed goal even after 2022, and therefore worth consideration. While authors have compiled various feedstock and land estimate needs to meet the 16 BG mandate, below we assess EPA's assumptions of feedstocks and biofuels that could meet the full mandate, as one example of the potential impacts on land and food. In 2010, EPA projected that switchgrass would be the only land-intensive feedstock used to meet the 16 BG mandate requiring 13 million acres, because the other half of the mandate – 8 BG – would be met with non-land-intensive feedstocks such as residues and wastes. EPA's optimism on non-land based fuel means that its overall land requirement estimate is lower than those from other authors. Other estimates generally range from 30-60 million acres depending on feedstock choices, oil prices, and other variables (see Figure 3 below). Though EPA expects large amounts of switchgrass ethanol, other agencies expect cheaper agricultural residues and wastes to be used, especially in the short-term, as compared to more expensive, land-intensive cellulosic feedstocks (with longer establishment timeframes).[142] However, meeting the full 16 BG mandate would likely promote more land-intensive biofuels consumption because it could not be met with wastes and residues alone without harming the environment.[143]

EPA expected the following feedstocks/biofuels to fulfill the 16 BG mandate (high-consumption scenario*):

- 80 million dry tons of switchgrass, planted on 13 million acres, to produce 8 BG of ethanol, and
- Less-land-intensive feedstocks, including (1) 53 million dry tons of corn stover (around 20% of current stover availability) for 5 BG of ethanol, (2) 26 million dry tons of MSW for 2 BG of biofuel, and (3) sugarcane bagasse, forest residues, and other feedstocks making up the remaining 1 BG.[144]

5.3 Cellulosic Biofuel Land Requirements and Related Risks

Cellulosic biofuels may either increase competition for land directly by spurring greater production of biofuel crops or indirectly by using crop residues. Residues do not necessarily require more land, however as the 2011 NAS report states, "new demand for surplus residue would increase the overall value of land."[145] Higher land prices can drive land grabs, negatively impacting rights, and promote particular types of crop expansion where there are energy needs, rather than supporting needed food production and access where there is hunger.

It is important to emphasize that globally there is no large area of available land that is suitable for crop growth and not in demand for other use. Even without biofuels, the world will already require 70% more food in 2050 than in 2000 to feed a growing world population, requiring at least 10% more land[146] (with estimates of 173-500 million additional acres based on different crop yield and pasture intensification assumptions).[147] In addition to increased demand for protein, demand for timber and pulp is also expected to put pressure on land resources.[148] On top of this, global first-generation biofuel mandates are likely to require 33-43 million additional acres by 2025,[149] and meeting the full 16 BG RFS cellulosic mandate (high-consumption scenario) could require another 30-60 million acres.** As IEA has concluded, "In

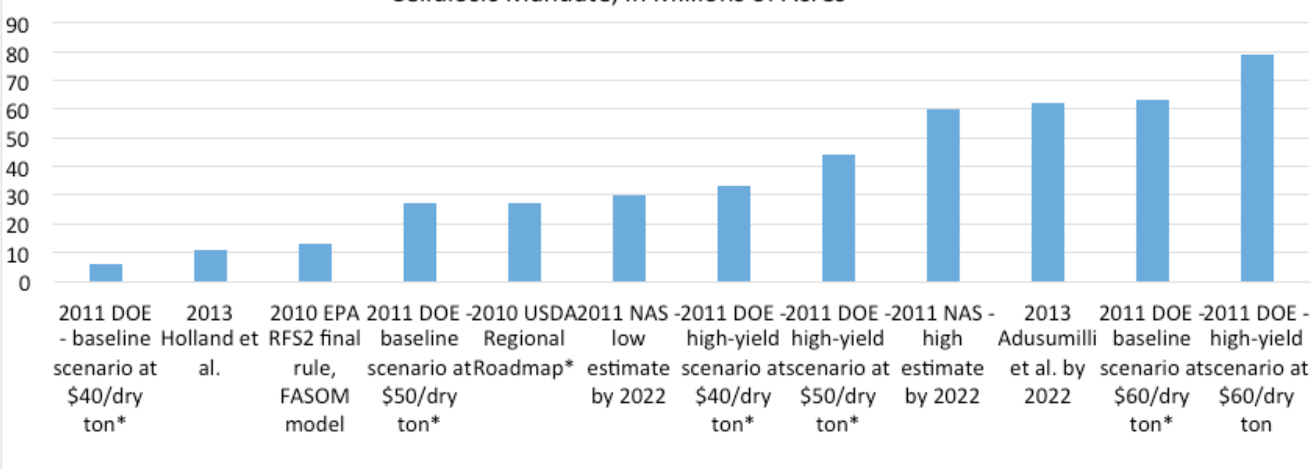
* Achieving the 16 BG mandate would require approximately 250 cellulosic biofuel facilities (similar to the number of existing corn ethanol facilities - 200) utilizing a total of 200 million dry tons of cellulosic feedstocks annually. To meet this level of production, current cellulosic ethanol facilities would need to double in size and produce at full capacity (which they have yet to do). Note also that EPA did not project corn fiber- or algae-based biofuels to fulfill the cellulosic mandate at the time of its 2010 assessment.

** Estimates of additional acres required to meet both first- and second-generation global biofuels mandates include an additional 150 million acres, which is in line with estimates of U.S. land requirements for cellulosic biofuels in this report (10-60 million acres, or even 80 million acres on the high end). Global land dedicated to biofuel crops would grow from 2.5% of arable land in 2014 to around 6% in 2050, as Popp et al. (2014) estimate.
http://www.sciencedirect.com/science/article/pii/S1364032114000677

countries where food supply is not secured, cultivating crops for biofuel production on arable land can further weaken food security and thus have serious social impacts,"[150] such as land grabbing as biofuel companies seek additional land to grow biofuel feedstocks in developing countries where input and land prices are generally lower.[151]

Of the three scenarios considered here, the low-consumption scenario of 400 MG is the least likely to impact land use since small-scale production would be sourced mostly from less-land-intensive wastes and residues (primarily MSW and corn stover). However, mid-level consumption of 2.5 BG may increase feed prices with at least 2 million acres of annual corn production (as corn fiber) being diverted from the current livestock feed market (as DDGs) to biofuels instead.[152] The high-consumption scenario of meeting the full 16 BG cellulosic mandate by 2022 could require significant amounts of land (6-79 million additional acres, with a more likely range of 30-60 million,[153] as seen in Figure 3). The 30-60 million-acre estimate is in line with projections from NAS and lies in the middle of projections from other authors, as well. High-end estimates (79 million acres) are comparable to the current number of U.S. corn acres. However, note that authors assume different feedstock conversion ratios, land use constraints, crop yields, etc.*

Figure 3: Projected Land Use Expansion Impacts of Meeting 16-Billion-Gallon RFS Cellulosic Mandate, in Millions of Acres



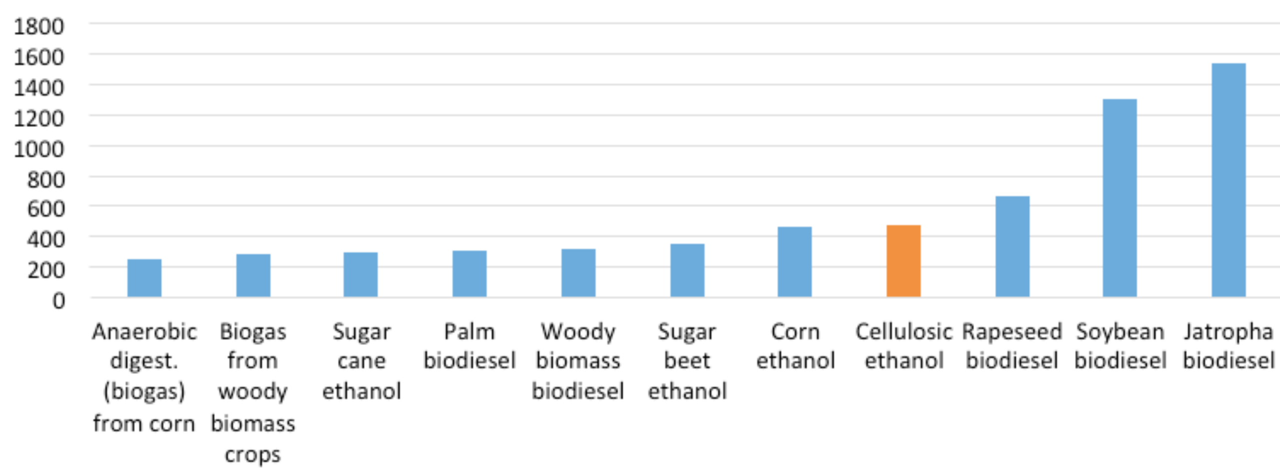
Current first-generation biofuels in the U.S. – corn ethanol[154] and soy biodiesel[155] – already require 53 million acres, the size of Kansas.[156] Meeting the low-consumption scenarios (400 MG) would require roughly the same amount of land, while the mid-consumption 2.5 BG scenario may increase land required to grow feed crops. To meet the full cellulosic mandate, total U.S. land dedicated to growing major biofuel crops (corn ethanol, soy biodiesel, and cellulosic ethanol in the U.S.) could grow to 60 million acres

* Note that estimates with an asterisk (*) also include land requirements to meet the 5-BG advanced biofuels mandate. Most authors estimate land use impacts through 2022, while the 2010 USDA analysis and the 2011 DOE billion ton update estimate impacts in 2020 and 2030, respectively. EPA's gross 13-million-acre estimate for switchgrass is used instead of a net increase of 8 million acres to be consistent with other studies.

on the low end (the size of Michigan), or to 83 or even 133 million acres on the high end (larger than New Mexico or California, respectively).

Though meeting the full cellulosic RFS mandate is unrealistic in the near future, understanding its potential large land footprint is important when considering future RFS reforms and because EPA will continue to administer the RFS (with wider discretion) after 2022. As the 2013 CFS HLPE report on biofuels concluded, "[T]he more surface is needed to produce a certain amount of energy, the more the impact on food security via pressure on land use is likely to be."[157] The report found (based on information from IEA and McDonald et al.) that cellulosic ethanol production could require *more land per liter* than sugarcane or corn ethanol (see Figure 4).[158] Searchinger and Heimlich (2015) project even greater land use intensities: cellulosic feedstock yields would need to increase 2-4 times to meet the current number of gallons per acre that corn ethanol yields.[159]

Figure 4: Land Use Intensity (in average hectares per million liters of gasoline equivalent) of Global Biofuels, FAO (2013)/IEA (2011)/McDonald et al. (2009)



5.4 Impact of Cellulosic Biofuels on Food Prices and Food Security

While researchers have tied the expansion of first-generation biofuels to higher food prices, studies on the likely impacts of cellulosic biofuels have been more limited. But, as Popp et al. (2014) estimate, "Large-scale cultivation of dedicated biomass is likely to affect … global food prices ..."[160] The 2013 HLPE report warned that the "expansion of the consumption of biofuels … [is] beginning to have an impact outside the frontiers of the major … [producing countries], either by reducing exports of food or by increasing imports, driving the increase of international prices, which can have a negative impact on food security, on poor importing countries, poor consumers."[161]

Of the three cellulosic biofuel consumption scenarios considered in this report, the low-consumption scenario has less risk of competing with the food supply since primarily residues and wastes would be used.[162] However, meeting the mid-consumption scenario of 2.5 BG would likely spur greater use of corn kernel fiber-based cellulosic ethanol (and also potentially DDG-based ethanol[163]), currently used as livestock feed, which could put upward pressure on feed and food prices. And even if a small amount of food-based or land-intensive biofuels is used to meet the full 16 BG cellulosic mandate by 2022, crop and food price increases are likely unavoidable because crop productivity has historically failed to keep up with increased biofuel demand.[164] Meeting the full cellulosic mandate would likely push feedstock production onto grassland, hay, and pasture acres, resulting in increased feed prices with forage productivity not keeping up with demand.[165] Food crops such as wheat, soybeans, rice, and corn may also be displaced by more acres of perennial grasses and trees, resulting in food price increases if yields do not increase commensurately.[166]

Many biofuel economic and GHG emission models actually depend on food prices increasing, and therefore consumption decreasing. As Searchinger and Heimlich (2015) explain, some biofuel policies, such as the RFS, are based on models that assume less global food consumption to account for increased biofuels production. They estimate that "phasing out the use of [global] crop-based biofuels instead of meeting an expanded 10% [biofuel] target is likely to mean the difference between a 90% crop calorie gap and a 60% gap."[167] To meet the full RFS mandate, EPA estimated that global consumption of food would drop by 2.5 million metric tons from 2007 to 2022, equivalent to the amount of food required to feed Rwanda's 12 million residents[168] for an entire year. EPA specifically projected that vegetable oil consumption would decline with prices increasing 38%.[169] While this lower food availability is primarily tied to expanded soy biodiesel production within the overall RFS, increased switchgrass production may also reduce U.S. exports of soybeans, corn, and wheat as switchgrass replaces food acres.[170] EPA thus expects food crop prices to increase, in addition to cropland expansion likely occurring in Latin America, China, and the Pacific Rim to make up for food acreage losses.[171]

However, global demand for food continues to grow.[172] As Searchinger and Heimlich stress, it is unrealistic for biofuel mandates' underlying economic models to assume people will eat less food because either this is unlikely to occur in reality, meaning models should account for more land to meet both food and fuel needs, or biofuel mandates directly contribute to food insecurity. Wealthy individuals, who could eat less but still consume enough nutritious calories to be healthy, are not likely to do so as they can afford more expensive food. Former International Food Policy Research Institute director general von Braun (2008) estimated "that worldwide calorie consumption would fall by 2% in most regions by 2020 if the trend toward [global] biofuels is 'moderate,'" with a decrease of over 8% in Latin America and sub-Saharan Africa with more "drastic" expansion.[173]

Higher food prices and less food availability impact food security not only for those who are already hungry but also for those at risk of becoming food insecure. According to FAO, 800 million people are undernourished globally,[174] and as Adusumilli et al. (2013) emphasize, "higher food prices resulting from biofuel mandates impact lower income society more severely than others."[175] Higher food prices stretch food aid budgets and negatively impact the poor in the United States and around the world. Families in developing countries such as Guatemala, Kenya, and Nigeria are disproportionately affected since they already devote an average of 40-60% of their consumer expenditures to food, compared to just 7% in the United States.[176] RFS mandates also increase food price volatility, as inflexible demand for large-scale biofuels mandates must be met regardless of whether supply shocks (such as droughts or floods) also increase food prices. If production of food-based and/or land-intensive cellulosic biofuels increased significantly, food price volatility would also worsen, disproportionately impacting low-income consumers. As IFPRI notes, "the overlap between biofuel production … and food security may therefore be a negative one."[177]

6. Policy Options and Recommendations

To help ensure that cellulosic biofuels achieve their stated goals of little to no competition with food or land and lower GHG emissions, biofuel mandates and subsidies should be significantly reformed to prioritize low-risk over high-risk cellulosic biofuels and set at more realistic levels. As noted at the beginning of this paper, the food security risks are determined by the type of feedstock, the land requirements, the scale of the production, and the location of the production. Biofuel policies therefore should be focused at lowering the risk as much as possible across all four factors in order to protect and promote food security.

Table 2 below shows the spectrum of risk for different feedstocks on food security and land use.[178] Low-risk feedstocks include sustainably harvested residues and MSW, if produced at a small scale. However, removing too much lower-risk agricultural or forest residues to meet more than half of the 16 BG cellulosic mandate could increase soil erosion, as EPA recognized in 2010.[179] Higher-risk feedstocks toward the middle and end of the table would either directly use food crops such as corn or use dedicated land (such as perennial grasses or short-rotation woody crops), which could displace land currently used to produce food. Using high-risk feedstocks at any scale would pose risks of higher food prices and greater competition with land given the limited availability of marginal land. Low-risk feedstocks such as forest residues could also move to the "high-risk" category if loopholes allowed whole trees to be cut down to create "residues," for instance. Algal biofuels could also pose unique risks to water, public health, etc., particularly related to synthetic biology.

The first step then must be to begin distinguishing among cellulosic feedstock types. Specific policies to achieve these goals include ensuring that federal supports such as tax incentives or mandates do not support high-risk feedstocks such as food/feed sources or dedicated energy crops. Instead, they should be focused on supporting (via mandates, subsidies, etc.) a small scale of cellulosic biofuels derived from socially and environmentally sustainable "low-risk" feedstocks[180] (such as residues and wastes) that are not food-based or land-intensive.[181] This will likely be more cost-effective as well, as residues are currently available in large quantities, technologies have reached small commercial scale, and new sustainability measures could help lessen negative environmental effects.

However, residue-removal limitations are not currently required by law, and the RFS does not promote low- over high-risk feedstocks. Technologies for algae and more land-intensive grasses and trees are still in their infancy with yields and land requirements less known,[182] making risk mitigation more difficult. While the RFS contains a provision to limit biofuel-induced land use change, EPA has failed to properly implement it in practice.[183] Therefore, limiting negative impacts of cellulosic biofuels production on food security, land use, and the environment will be difficult in practice and require reform, regardless of scale.

Table 2: Risks to Food & Land of Cellulosic Biofuel Feedstocks (lower-risk near top, higher risk at bottom)

	TYPE OF FEEDSTOCK	PROS	CONS
Lower Risk	Unused municipal organic waste, anaerobic digesters, and landfill gas	Would not compete with land used for food production	Waste should be significantly reduced before it arrives in the landfill; should avoid perverse incentives for new landfills and anaerobic digesters
	Sustainably harvested/collected agricultural residues (such as corn stover & sugarcane bagasse)	Does not require new dedicated acres of cropland	Large-scale residue removal may increase profits, impacting land use decisions,[184] in addition to increasing soil erosion and fertilizer applications and lowering soil carbon, which negates GHG savings[185]
	Post-harvest forest residues, unused sawdust, and urban wood waste	Generally would not compete with land used to produce food	Large-scale use may create competition; policies should avoid unintended consequences such as clear cutting to create "residues"
	Algae	Limited land competition[186]	May use synthetic biology and become invasive; potential for large water[187] and sugar requirements
	Perennial grasses (switchgrass & miscanthus)	Could improve water & soil quality	May be planted on land currently used for food production
	Pulpwood/woody crops	Low input requirements	May be planted on land currently used for food production; potential for disease, invasive species, pest damage, irrigation requirements, and greater GHG emissions; risk of deforestation with demand increases
Higher Risk	Corn kernel fiber and DDGs	Likely produced at existing facilities	Currently have alternate uses as livestock and/or poultry feed, so scaling up may increase feed and subsequently food prices

Consideration must also be given to how much cellulosic biofuels can be reasonably produced. Clearly the RFS cellulosic mandate will not be met by 2022, but pursuing consumption of 16 BG of cellulosic biofuels – whether by 2022 or 2040 – would require significant usage of riskier biofuels that would use dedicated land. Using large amounts of dedicated land presents a major risk to food security and right now there are no pathways to 16 BG of cellulosic biofuels that do not involve that risk or others such as degrading the environment. Policies to promote cellulosic biofuels should be refocused to promote low-risk, environmentally friendly fuels, rather than risking hunger by reaching for an arbitrary goal. Even the medium-scale scenario identified risks to food security due to the food-based feedstocks used. Therefore, the amount of cellulosic biofuels supported by federal policies should be in the several hundred million gallons, not the 16 billion gallons currently required by the RFS.

There are particular risks related to where biofuels (including biofuels feedstocks) are produced. Biofuel feedstock production that relies on high fertilizer use and biofuel processing plants have both been found to use significant amounts of water. While any dedicated cropland presents a risk of the impact on food prices, the biggest risk of hunger comes from producing biofuel feedstocks in countries where land grabbing is common. Seizing 100,000 acres of land in Guatemala or Tanzania and forcing smallholder farmers off of their land is a human rights violation that has immediate, profound impacts on those families. Because of the extreme risk, at a minimum imported fuels and feedstocks should not receive federal incentives. Ideally, biofuel products would not be imported from countries that have a high risk of land grabs.

Any federal incentives for biofuels should also meet the following social and environmental sustainability standards (and if these conditions are not met or are unlikely to be met, the biofuel should not be supported by government mandates or financial incentives):[188]

- **Land use and land/human rights:** limit conversion of land;[189] any land acquisitions must adhere to the Voluntary Land Tenure Guidelines and the principle of free prior and informed consent (if these principles are likely to be abused, the pathway should not be approved); and there must be enforcement of land and worker rights.[190] Smallholder farmers who have control over their land tenure and practice agroecology are the best for food security and the climate.

- **Water:** "water usage for human needs, sanitation, ecosystem integrity, and for food security should take priority …" and policies should include "flow of 'virtual water' assessments from developing countries to developed ones" if feedstocks are imported to the United States.[191]

- **Environment:** ensure GHG models accurately reflect actual global food consumption and land use without assuming food consumption will decline to reduce GHGs; ensure crop residue removal rates do not increase soil erosion;[192] promote small-scale feedstock[193] harvesting that complements food systems;[194] protect biodiversity and wildlife habitat;[195] minimize unintended consequences of using waste-based and other feedstocks; and avoid risks of invasive species and synthetic biology.

More consideration also needs to be given to how we use what biofuels we have. Clearly there is limited potential for large-scale biofuel usage. Even without sustainability standards and protections for food security, biofuels alone will not be able to replace fossil fuels in our transportation system. Therefore, policies should be focused on reducing emissions through other means, such as using electric vehicles powered by wind and solar or even urban planning to promote mass transit, walking, and biking. What biofuels we can produce in a socially and environmentally sustainable way should be directed towards where they can achieve the most benefits. That may mean staying local, where waste residue is a byproduct of industrial products and can be used to replace fossil fuels in the short term. It may also mean focusing biofuel usage on transportation systems with limited alternatives to fossil fuels, such as airplanes and some heavy duty trucks.[196] What is clear, however, is that the RFS as currently structured is not going to accomplish any of these goals. It is unlikely to be able to promote sufficient biofuels to meet the 16 BG RFS mandate in 2022 or anytime in the foreseeable future. And if the RFS were able to significantly boost cellulosic biofuel consumption, it would likely involve high-risk feedstocks and large amounts of land that put food security and land rights at risk.

7. Conclusion

Because of the scale of production needed and the feedstock and land required to do so, meeting the full 16 BG RFS cellulosic biofuel mandate would risk food security, land use, and land rights, in addition to those experienced with first-generation, food-based biofuels. While cellulosic biofuels are intended to be derived from non-food crops produced on marginal land, corn kernel fiber is already being used for cellulosic ethanol. And the majority of cellulosic consumption to date has been CNG/LNG derived from MSW instead of liquid fuels that displace petroleum use directly. In addition, large-scale use of non-food agricultural residues could increase land and crop prices in the future, not to mention land-intensive perennial grasses and woody biomass crops. This will negatively impact food security, particularly for families in developing countries spending a larger portion of their income on food. Land rights disputes may also occur if land is set aside for biofuel feedstock production at the expense of local communities using the land for food, water, firewood collection, etc.

Of the three cellulosic biofuel consumption scenarios considered in this report, the low-consumption scenario of 400 MG by 2022 is least likely to lead to competition with food and land since primarily agricultural residues and wastes would be utilized. The mid-consumption scenario of 2.5 BG may increase feed prices, particularly if large amounts of corn kernel fiber currently used as livestock feed are instead diverted to fuel. Meeting the full 16 BG mandate by 2022 would likely divert significant amounts of current feed and food crop acres (30-60 million) to biofuel production, increasing food and land prices. While meeting the full RFS mandate by 2022 is highly unlikely, scaling up consumption of food- and feed-based cellulosic biofuels, particularly in the mid-consumption scenario, could also increase risks to food and land.

The United States is at a turning point. Biofuels policies must be reformed in the short term to ensure that the RFS's goals are met instead of additional food crops being diverted to fuel production, among other unintended consequences. If the RFS continues to fail to serve as a bridge between food-based, first-generation biofuels and more sustainable second-generation biofuels, it should be repealed. Otherwise, the expansion of food-based biofuels will continue, resulting in increased food prices, greater land competition, and ultimately lower food security for people already struggling to feed their families each day.

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