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CELLULOSIC ETHANOL FROM CORN STOVER: CAN WE GET IT RIGHT?

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Executive Summary

Low-carbon liquid fuels are an essential component of the effort to reduce fossil fuel use and achieve necessary reductions in greenhouse gas (GHG) emissions to avert catastrophic climate change. Second-generation biofuels must achieve a lower carbon impact than corn ethanol and avoid the negative environmental impacts of corn ethanol. Failure to deliver on these environmental promises could irreparably damage public policy support for biofuels.

Production of second-generation biofuels is now under way, with three major facilities on track to produce a combined 80 million gallons per year of ethanol from corn stover. Stover is the corn plant residues typically left in the field after corn grain harvest—the cobs, husks, leaves, and stalks. Stover has the advantage of not being a food source like corn itself, and as a by-product of corn production, it has lower production costs. However, corn stover is not "waste." Some amount of crop residues are essential to return organic matter to farm fields, maintain healthy soils, minimize erosion and water pollution, and sequester carbon. Research shows that a modest portion of stover can be sustainably harvested for biofuel production on flat and highly productive fields, if erosion is under control and harvest amounts are carefully limited. On the other hand, excessive stover removal (or any removal at all on many corn acres) harms the soil, increases erosion, leads to water pollution, increases nutrient applications and pollution, and can reduce the amount of carbon sequestered in soil organic matter.

The first three companies to launch stover-to-ethanol plants—owned by Abengoa, POET-DSM, and DuPont—either opened their doors in 2014 or are planning to open in 2015. Each has voluntarily adopted its own sustainability approaches for stover harvest.

This paper is an early response to this emerging industry. It explores the conditions under which stover harvest can be carried out without compromising soil health or contributing to water degradation—an issue that will grow more prominent as production of second-generation biofuels from stover expands. It then profiles the different approaches the three leading cellulosic ethanol plants are taking to limit stover removal to environmentally sustainable levels and ensure that stover sourcing practices do not harm the land. It details the information each company reports relying on to determine sustainable harvest levels and examines how each plans to monitor and enforce company standards to ensure implementation by supplying farmers.

The practices of these first three facilities are important and precedent setting, especially to the extent that they demonstrate leadership in setting a high bar for the industry as a whole. However, no public policies are in place today to guide or regulate stover harvest, and future facilities are currently under no obligation to take similar approaches. Further, if the technologies employed by these leading companies prove viable and more facilities are built that rely on stover, the value of stover—and thus the value of growing corn—will increase, contributing to demand for ever more corn production.

Production of corn at the scale currently seen in the United States is almost certainly inherently unsustainable, resulting in a broad spectrum of impacts to water quality and quantity, soil, wildlife habitat, and air quality. While the facilities described in this report have chosen locations where they believe they can collect corn stover without exacerbating soil erosion and nutrient loss, the other impacts of growing corn may still be intensified. At the same time, greater demand for stover will increase pressure on farmers to provide more of it, potentially threatening the types of measures being taken to limit the impacts of these facilities, even if these measures are ultimately made mandatory.

Thus, the race is on not just to identify the best soil conservation practices and stover harvest management systems—and to work to make these mandatory—but to do so in a way that continues to be effective even as the scale of the market grows. This requires more than discouraging practices that would make an environmentally unsustainable farming system worse; it means actually encouraging changes in farming practices that are better for the land. Measuring the impacts on the land of stover-fueled facilities and transparently reporting these impacts are likely insufficient to accomplish this goal, but they are certainly necessary steps.

Beyond voluntary corporate standards, this paper also examines government policies (or lack thereof) regarding stover-based cellulosic ethanol production and how the United States Department of Agriculture (USDA) and other agencies could be involved in ensuring sustainable stover harvest rates. It also looks at potential problems with stover-based biofuels that may have been overlooked thus far, and examines what conservation practices farmers should be using to accompany stover removal. Finally, it makes recommendations to support companies in ensuring sustainable stover harvest, and to equip policymakers to put in place guidelines for farmers as the new stover-based ethanol industry grows and we move toward an expected expansion of cellulosic ethanol feedstocks from agriculture.

These recommendations include, but are not limited to, the following:

- Cellulosic biofuels producers should be required to build stover sustainability requirements into their operations. This includes enforceable, site-specific conservation plans (or the equivalent) that set limits on stover harvest from every field or uniform region to ensure soil health and prevent erosion. The Natural Resources Conservation Service (NRCS)—or, given NRCS's capacity constraints, another conservation specialist—must be actively involved in the science and oversight of each facility's sustainability plan.
- Independent, third-party verification, compliance monitoring, and ongoing assessment of harvest practices and resulting soil quality are critical elements of corporate programs. Third-party certification, such as that offered by the Roundtable on Sustainable Biomaterials (RSB), can be sought by cellulosic ethanol facilities, using specific indicators for quantities of crop residues to be left on the field versus those harvested for bioenergy. As RSB provides, site-specific farm plans would be required.
- Federal subsidies (loans, grants, tax credits) to new biomass conversion facilities should be made contingent on company use of site-specific feedstock sustainability certification or other verification of environmental performance. Considerations of sustainability around residue removal should be expanded beyond soil erosion and soil carbon to include impacts on water and habitat.
- Cellulosic biofuel producers should work with conservation groups and technical advisers or farmers to develop best practices. Site-specific evaluation for stover harvest provides an excellent opportunity to educate corn farmers about opportunities for conservation on their land. The value of conservation tillage or no-till, cover crops, crop rotations, nutrient management, and other soil health practices should be part of conservation planning. These practices are vastly underutilized and can be combined to maximize carbon sequestration and water quality and quantity issues, possibly alongside modest stover harvest. Cellulosic biofuel producers should also explain and expedite plans to incorporate perennial energy crops, including grasses, prairie mixes, and hay, into their facilities.

With future cellulosic biofuels development, it is important to identify the real decision makers in ensuring sustainable harvests. Who should decide the extent of the stover harvest? Is it the farmer, the harvester, the stover aggregator, or the biofuel producer? The first three facilities, profiled here, chose to direct third-party harvesters and advise farmers according to their own guidelines. In the future, biofuel companies may not have a direct relationship with farmers or harvesters, instead buying from an aggregator company.

Moreover, as residues and cellulose become more commercialized, cellulose could emerge as a commodity like corn, with volumes bought and sold on the open market with no differentiation or connection to farm-level sustainability performance. Currently, neither landowners nor farmers nor any other entities monitor actual impacts on the land. If stover harvest were to worsen the net environmental impact of corn acres, there is currently no accountability.

Policies are urgently needed to ensure that corn stover for biofuel production is harvested only when it is expected to be sustainable for each farm field. Policymakers and industry leaders must safeguard against excessive harvests that worsen impacts on the environment by depleting soil carbon or contributing to erosion or polluted runoff. Policies are also needed to encourage the further transition to perennial energy crops, like grasses and willows that regrow from the roots every year, thus allowing ongoing harvests without disturbing the soil or requiring much irrigation or application of chemicals.

In addition, the approach to environmental sustainability that cellulosic biofuels producers and ultimately our policies converge on should work not just when there are a few facilities but also when there are many and they are competing with one another for stover or other cellulosic feedstocks. Furthermore, the approach should also work if and when farms move away from corn-on-corn rotations or, better yet, move to much more diversified farming systems. Transparent reporting on the actual performance of the farms supplying a given facility across a broad spectrum of indicators would limit the ability of facilities to compete with one another by over-collecting stover or otherwise encouraging poor management practices.

Part 1:
Beyond Corn; Challenges in Ensuring Sustainable Stover Harvest for Ethanol

INTRODUCTION

Cellulosic ethanol is becoming a reality, as three large-scale commercial facilities complete construction and begin converting corn stover to ethanol. POET-DSM and Abengoa began operations in 2014, and DuPont plans to open in 2015.[1,2,3] These companies have designed innovative cellulosic facilities and feedstock business models. They are diversifying the existing corn ethanol industry with new production processes to manufacture ethanol using a nonfood agricultural product, harvesting a portion of corn farmers' crop residues typically left in the field after corn grain harvest. This residue—cobs, husks, leaves, and stalks—is called stover.

> ***Using cellulosic biomass for biofuels has the potential to have a smaller carbon footprint than using corn does, as long as the feedstocks are harvested from existing production systems that do not displace natural forests or food production.***

Corn is the leading crop grown in the United States, both in acreage and cash value. Corn also exceeds all other cereal crops in biomass production—i.e., as a feedstock for producing fuel.[4] Though livestock farmers sometimes remove stover for silage, feed, and bedding, intensive corn production regions where stover biofuel facilities are likely to locate are not typically the same regions where dairy production is located, with its mixed corn, hay, and pasture acreage. Overall, corn is harvested for silage on 8 percent of corn acres; it is not clear how many corn acres remove stover for bedding, feed, and grazing after the grain is harvested.[5] What is clear is that stover harvest on a continuous basis and at a larger scale for biofuel production is something new.

While other nonfood energy crops, such as perennials like switchgrass, may one day also be grown for commercial-scale biofuel production, it is not surprising that corn stover is the kickoff cellulosic feedstock. Farmers are already producing it in vast quantities concentrated in particular regions, with little competing market demand for it. However, while stover production is incidental to the corn production system, it cannot be treated as a waste product. Since the advent of farming, crop residues have generally been retained on the land to build fertility, soil quality, and productivity. Corn stover has an essential role in replenishing the soil with organic matter. However, with removal limits and other safeguards in place, it is possible to sustainably harvest a portion of the stover produced on qualifying fields.

The coming of the second generation of biofuels has been greatly anticipated and encouraged as part of federal and state energy goals to cut oil use and limit reliance on food-based feedstocks for first-generation biofuels—most notably, corn ethanol—while also producing low-carbon liquid fuels. Using cellulosic biomass for biofuels has the potential to have a smaller carbon footprint than using corn does, as long as the feedstocks are harvested from existing production systems that do not displace natural forests or food production. It is also widely hoped that cellulosic biomass for biofuels will have substantially less deleterious impacts on soil, water, and wildlife habitat than corn production does. However, if stover removal is excessive and not managed responsibly, it could deplete soils of organic matter, cause water and wind erosion, and reduce crop productivity.

A number of factors affect the sustainability of stover removals, including removal rates and practices, farm location, and the combination of stover removal with the farmer's tillage practices. However, no public policies—or even guidelines—exist today to regulate removal of stover, mitigate potential negative environmental impacts, or guide farmers. Instead, the challenge of ensuring sustainable removals is currently left up to individual biofuel companies.

DuPont, POET-DSM, and Abengoa are each attempting, in different ways, to ensure their new businesses grow despite the potential risk that feedstocks will be insufficient or unsustainable. They know that if farmers stop supplying stover due to concerns about soil quality, or if the public objects to stover-based ethanol that depletes the land or creates other negative environmental impacts, the outlook for growth may be significantly hampered.

LACK OF POLICY GUIDANCE

Varying amounts of stover should be retained on every field to maintain soil quality and productivity, depending on the particular site and farming practices. However, no laws, requirements, recommendations, or public oversight mechanisms are in place to guide the emerging stover harvesting industry. Cropping practices are almost entirely unregulated, and agriculture groups resist regulations. Further, there are few programs or policies in place at this time where biomass harvest safeguards could easily be inserted.

Renewable Fuel Standard

The RFS was enacted in 2005 with the objective of replacing a portion of transportation fossil fuels with renewable fuel by mandating that transportation fuel contain a minimum volume of renewable fuel. This mandate was met largely by corn ethanol. The RFS2 went further in 2007 amendments, reducing the life-cycle GHG emissions allowed in renewable fuels to meet the mandate, relative to gasoline. It provided incentives to shift further growth in biofuels production away from food-based biofuels (corn ethanol) and toward cellulosic and other advanced biofuels made from cellulosic crop residues, perennial grass energy crops, forestry residues, solid wastes, and algae. The goal by 2022 is to reach 21 billion gallons of advanced biofuels with GHG emissions 60 percent lower than gasoline. The U.S. Environmental Protection Agency (EPA) has developed complex models to ascertain the conditions under which advanced biofuels will achieve this GHG reduction goal. Most corn ethanol plants have been grandfathered in, while new plants must meet at least a 20 percent GHG reduction.[6]

The existing market potential for ethanol blending is already being met using corn ethanol. The advanced biofuels mandate now has the potential to be fulfilled largely with a corn by-product, using stover instead of corn. However, while the RFS created the opening for stover ethanol production, how stover collection is carried out by farmers is outside the sphere of public regulation or oversight, and virtually no public policy is in place to deter those who combine excessive stover harvest with unsustainable farming practices.

Meanwhile, much slower progress is being made toward perennial crops. For example, DuPont and the University of Tennessee (Genera Energy) constructed a pilot-scale biorefinery that is fueled with harvests of native switchgrass, miscanthus, and biomass sorghum.[7] BP started developing a 20,000-acre farm in Florida to grow a type of biomass sugarcane for a new ethanol plant but later backed out.[8]

Clean Water Act

Agriculture nonpoint source pollution is the largest source of water pollution today. However, with the exception of large livestock feedlots, it is exempted from the Clean Water Act. This exemption has been called "one of the last, great intractable problems of environmental law," as it prevents the EPA from achieving the goal of fishable and swimmable waters due to cropland pollution runoff.[9] The agency encourages the USDA and states to use voluntary management practices and incentives to reduce farm pollution, but there remains a lack of enforceable pollution benchmarks for agriculture. Agribusiness has been successful thus far in its fight to resist government regulation. As a result, any excessive removal of corn stover that results in erosion and pollution is unmonitored and unregulated.

Conservation Compliance Program

The USDA has numerous voluntary conservation incentive programs for agriculture, aimed at those individual farmers who choose to improve their operations, but only one requirement that can be enforced. Conservation Compliance is a Farm Bill provision dating from 1985 that seeks to prevent erosion on previously designated, highly erodible fields, and to prevent conversion of wetlands to cropland. This provision applies only if farmers choose to receive benefits from USDA farm programs, including crop insurance subsidies, loans, disaster assistance, conservation programs, and commodity payments.

Most corn acres are enrolled in crop insurance programs (81 percent in 2012) and thus are covered by the law if they have highly erodible acres.[10] Those farmers must have on file, and must implement, a conservation plan for highly erodible acres that has been approved by the Natural Resources Conservation Service (NRCS). Unfortunately, monitoring is highly uneven across the country, and is too often plagued by compliance loopholes, lengthy compliance times, lax enforcement, and minuscule reductions in commodity benefits for those who fail to comply. Even so, a key policy challenge as stover becomes a new crop is to incorporate any planned stover removal from highly erodible fields into the required conservation compliance plans for every corn producer who receives subsidized crop insurance or other benefits. Such plans should specify required stover retention amounts and the combination of reduced tillage, cover crops, and other practices that will meet the required erosion goal.

Biomass Crop Assistance Program

The Biomass Crop Assistance Program (BCAP), administered by the Farm Service Agency (FSA) of the USDA, is authorized to provide matching payments for collection, harvest, storage, and transport of stover and certain other types of biomass delivered to a biomass conversion facility.[11] BCAP payments essentially double what industry pays for its stover, up to $20 per dry ton, and may be collected by producers for up to two years. BCAP is currently the only program that aims to ensure sustainability of stover and other biomass harvest. The law requires a full conservation plan to be implemented for each farm or field, taking into account the timing and amount of the planned biomass harvest, in order for landowners to qualify for BCAP matching payments.

To administer the program, FSA uses farmer self-certification without formal follow-up, verification, or enforcement. The primary conservation practice involved in BCAP stover evaluation is residue management, which includes no-till, mulch till, and seasonal residue management. If indicated, grassed waterways and other erosion structures may be included. The 2014 farm bill limited spending on this element of BCAP to 10–50 percent of total BCAP funding, which was set at $25 million per year. In 2014, funding totaled $12.5 million for biomass deliveries.

The NRCS is designated and funded by the FSA to provide the conservation plans for farmers, looking at the crop rotation used, residue harvest levels, and site-specific information to predict impacts on all resources. The plan indicates needed conservation practices to achieve sustainability. Achieving a tolerable soil loss level, (NRCS's term for sustainable levels of erosion) is the primary goal for stover harvest, but plans are written to meet soil and water quality criteria and also address all other resource concerns pertinent to the field, using the established NRCS process of full conservation planning to the Resource Management System level of sustainability. Local NRCS technical advisers will meet with each farmer, specifying the amount of stover to be harvested (or, conversely, the amount to be retained on the field) and calculating the combination of conservation practices that are necessary to bring that field to sustainability.[12]

While BCAP contains a promising policy for sustainability, the intention has not yet been fully realized. Though Abengoa was an approved facility in 2014 for matching payments, the timing imposed by the USDA that year prevented NRCS from completing any conservation plans in time, and no matching payments for stover were actually made. Many farmers are unfamiliar with NRCS conservation plans, and it takes time to develop them, which has left farmers and bioenergy companies frustrated and unable to access BCAP matching payments in a timely way thus far.[13]

In addition, verification and enforcement of BCAP conservation plan implementation for stover have yet to be fully demonstrated. The FSA reported that $4 million was committed in 2014 for conservation planning and compliance, primarily for NRCS.[14] Participants must self-certify that they will comply with their conservation plan under threat of penalty, including contract termination. However, it is not clear what outside verification will take place throughout the matching payment process to ensure that farm practices in the conservation plan were used and that ultimate impacts on the fields are acceptable.

Voluntary Stewardship Certification

Biofuel companies may choose to use a third-party certification program to ensure that their stover suppliers are using sustainable practices. At least one voluntary certification program may be capable of verifying sustainable stover removal. The Roundtable on Sustainable Biomaterials (RSB) certifies farmers and processing companies wishing to prove that they meet explicit, internationally agreed-upon sustainability requirements.[15] Practices to maintain or enhance soil physical, chemical, and biological conditions (including crop residue retention) are specifically required by the RSB Principles and Criteria, and their evaluation is part of the normal audit process. In order to comply with this criterion of the RSB standard, feedstock producers are requested to show that their practices minimize soil erosion and maintain soil organic matter. RSB auditors evaluate farmers' soil management plans, based on experience and input from NRCS experts.

If corn feedstock for ethanol were to be RSB certified, then sustainable stover removal would be considered part of crop residue retention practices and would be automatically included among the multiple criteria audited by RSB auditors, including emissions, conservation, soil, and water. Wherever available, auditor training would incorporate relevant tools to guide auditors with information regarding stover production in the United States and specific indicators such as NRCS data on retention rates for specific soil types, slopes, and practices. To date, no U.S. corn crops have been RSB-certified.

Another possibility is that RSB could certify only the stover removal rather than the whole corn crop under its standard for residues and by-products, and thus narrow the focus to the soil impacts caused directly by stover removal. In this case, auditors would verify that the stover removal does not reduce long-term soil stability and organic matter content. NRCS computations for tolerable erosion and stable soil organic matter may be optimal targets for site-specific certification of stover harvest. RSB also has procedures that may be used for certifying groups of farmers.

The starting point for third-party stewardship certification (such as RSB's) would be the stated intention of a biofuel producer to ensure and promote the fact that its entire process from the farm field to the pump is sustainable according to international standards.

Corporate Stewardship Policies

Today, voluntary self-regulation via corporate stewardship policies dominates the industry. The three companies profiled in this report, POET-DSM, DuPont, and Abengoa, have each developed their own sustainability requirements for stover harvest that could provide a model for others. These companies are contracting with farmers within a defined radius of their facilities to buy stover. Unlike the corn crop itself, which is usually harvested directly by the grower, third-party harvesters will typically collect stover. At least two third-party companies, Pacific Ag and Genera Energy, are aiming to create dedicated biomass supply chains for a whole new generation of cellulosic biorefineries.

FIRST-GENERATION FEEDSTOCK: IMPACTS OF CORN PRODUCTION

The history of renewable fuels is a story of success, as well as unintended consequences. The first generation of corn biofuels grew over the past two decades to become a key component of gasoline blending, accounting for one-tenth of the nation's gasoline fuel mix. Begun at a time of corn surpluses and low prices, the corn ethanol industry added value to a raw commodity and grew quickly, bolstered by supportive policies. However, few policy safeguards were in place to mitigate the environmental footprint of corn farming, resulting in significant negative environmental impacts.

The past two decades of increased corn production have led to increasing environmental problems, including water pollution, soil degradation, and loss of habitat.[16] The problem is most apparent in the large Mississippi River Basin, where corn farming is the leading cause of water pollution. Corn is the nation's largest crop, both by acreage and by dollar value, and about 30 percent of all corn ends up as ethanol (after removing the distillers grains sold as livestock feed).[17,18] Eight states produce more than three quarters of the nation's corn crop, and they are all located in the Mississippi watershed.[19]

Fertilizer runoff from cornfields leads to high levels of nitrates and phosphorus in the nation's waterways and groundwater. Excess fertilizer from chemical applications and livestock manure is picked up by precipitation and washed away into drainage tiles, creeks, lakes, and rivers. As a result, many rural communities face drinking water pollution problems from high nitrates. Polluted water reaching the Gulf of Mexico causes large and harmful algal blooms as an annual occurrence. As algae die and decompose, oxygen in the water is consumed, leading to severe oxygen depletion, or hypoxia, which kills fish and other marine life. The result is a dead zone that peaks in size each summer, averaging 6,000 square miles. Other concerns from corn production include soil erosion from wind and air, soil compaction, loss of soil carbon, pesticide drift and runoff, loss of biological diversity, and loss of wildlife and aquatic habitat.[20]

Ethanol production increased by 9 billion gallons between 2000 and 2009. Over the same period, U.S. farmers reacted to the rising price of corn by planting an additional 7.2 million acres, bringing total U.S. corn acres to 80 million.[21] Most of that 10 percent increase in corn acreage came from soybean fields being shifted to continuous corn production from the traditional corn-soybean rotation (while other crops, such as cotton, were shifted to soybeans). However, one-third of the total shift to corn acreage came from converting hay fields, pastures, and former Conservation Reserve Program lands that provide perennial cover for critical wildlife habitat.[22] These lands, covered by perennial plants, were replaced by annual crops that leave no living cover to protect the soil between fall harvest and early summer. Between 2006 and 2011, 1.3 million acres of grassland and wetland were converted to cropland in the Dakotas, Nebraska, and parts of Minnesota and Iowa.[23] By 2014, total corn acreage was roughly 92 million acres.[24]

Many of the environmental impacts from the corn boom can be mitigated by well-known but underutilized conservation practices. Too often, corn farmers use antiquated practices like moldboard plowing, over-application of fertilizer with unrealistic yield expectations, and acceptance of visible erosion. Alternatives like no-tillage, nutrient management, cover crops, irrigation management, and basic soil conservation practices like grassed waterways and contour planting are widely available but not yet the norm.[25,26]

Introducing stover harvest for ethanol on a large scale could intensify the negative impact of corn, if the same underutilized conservation practices continue to be ignored.

Agricultural nutrients are the largest cause of the Gulf of Mexico's dead zone, including those from corn production.[27] While corn ethanol is not the only driver of corn production, nor is it the primary cause of the environmental impacts detailed here, the expansion of corn production without necessary conservation practices is leaving a legacy of increasingly polluted water and loss of

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habitat. Introducing stover harvest for ethanol on a large scale could intensify the negative impact of corn, if the same underutilized conservation practices continue to be ignored. Since these practices are not widely used by corn farmers today, it is unlikely they will be employed when sale of stover is added, unless policies require it. Even more significant is the need to halt the expansion of corn production into grasslands, wetlands, buffers, waterways, steep slopes, and inappropriate soil and climate regions. As cellulosic biofuel production expands, the combination of environmentally harmful farming practices and stover removal could further exacerbate the impacts of corn production systems.

SECOND-GENERATION FEEDSTOCKS: SOIL BENEFITS OF STOVER VS. DAMAGE FROM OVERHARVEST

Residues

Crop residues like stover are sometimes left on fields to provide a physical buffer from rain, wind, and sunlight. This moderates soil temperature, reduces evaporation, increases moisture infiltration, and reduces runoff and erosion. Residues contribute some carbon to soil (although not as much as the plant roots), which improves soil organic matter, water retention, nutrient levels, and soil life activity—all of which promotes plant growth and yield, soil productivity, and a reduced carbon footprint for agriculture. Residues also return some nutrients back to the soil. Corn stover is currently harvested on a modest scale for silage, bedding, and livestock feed, with similar potential losses of residue benefits as stover harvest for biofuels.

Tillage

A critical determinant of environmental impact is how much tillage is used—whether stover is all retained on the field or harvested in part for stover feedstocks. Farmers manage residues primarily by their choice of tillage. No-till leaves 100 percent of stover on top of the soil and is generally most beneficial to the soil. Reduced tillage such as chisel plowing or ridge tillage retain at least 30 percent of the residue on top of the ground while mixing the rest into the soil, as defined by NRCS conservation practice standards.[28]

Conventional tillage with a moldboard plow turns all residues under. If done in the fall, it leaves bare soil vulnerable to erosion and water runoff, which carries soil and associated nutrients and pesticides into water bodies. Organic matter exposed to the air by tillage quickly breaks down; this results in a release of carbon into the atmosphere and a loss of soil organic matter, a prime determinant of soil health. One reason farmers stick with plowing is to save time when they are farming large acreages. If they prepare fields in the fall, the soil warms sooner in the spring and they can start planting earlier and cover more acres.

Unfortunately, no-till was used on only 30 percent of corn acreage in the U.S. as of 2009. In other words, less than one-third of all cornfields used the tillage method preferred for partial stover harvest.[29]

Other Conservation Practices

In addition to reduced tillage, the primary conservation practices relevant to sustainable corn and stover production systems include cover crops, diversified crop rotations with high-residue crops and perennials, pesticide and fertilizer management, drainage management, and irrigation management.

Each of these practices is scientifically prescribed and evaluated by NRCS programs, and all can be integrated with partial stover harvest. Some exciting new combination practices are being demonstrated that could enable partial stover harvest on fields that otherwise might not support it, such as combining stover harvest with cover crops or incorporating strips of prairie or perennial grasses in cornfields.[30,31]

Yet today, significant acreage in the Corn Belt is farmed for corn with none of these practices in place. Cover crops are a hot topic these days, but adoption rates remain low.[32] Relatively few farmers do regular soil tests to determine nutrient needs before purchasing fertilizer, and even fewer use integrated pest management systems before applying pesticides for weeds and diseases.[33,34] The USDA estimates that 25 percent, 34 percent, and 37 percent, respectively, of corn acreage does not achieve recommended nitrogen rates, timing, and application methods.[35]

Fertilizer runoff is a major concern with corn production. Some 40 to 60 percent of the nitrogen fertilizer applied to cornfields is lost as it leaks into surface waters and groundwater or dissipates in the air as nitrous oxide.[36] Even agronomically optimal fertilizer applications, which aim for the most crop yield at the lowest cost, do not take into account the fact that the farm system is inherently "leaky," releasing nutrients into tile drainage systems, runoff, and groundwater. Stover harvest could exacerbate nutrient loss, because stover contains some nitrogen, phosphorus, and potassium. This requires farmers to increase their applications of these nutrients the next year, some of which is subject to migration to the environment. Moreover, overharvest of residues could reduce soil organic matter, accelerating fertilizer losses to runoff and infiltration.

Crop Rotation

The sequence of crops grown plays a major role in how stover removal may affect the environment. Long-term crop rotations, including several years of small grains or perennial hay, will build up soil organic matter and soil quality, making stover removal in the corn year less of a concern. The typical corn-soybean two-year rotation has fewer benefits but retains the advantages of a legume (nitrogen fixing) crop, as well as a cycle that also mitigates some pest and weed problems, thus potentially reducing pesticide application.[37]

An emerging concern is the increasingly common practice of monoculture corn, referred to as corn-on-corn planting, where rotations are eliminated at least for several years at a time. Monoculture can bring a greater threat of pest problems (such as corn rootworm), and a need for increased pesticide and fertilizer applications.[38] In such systems, extremely high levels of stover can build up, which leads some farmers to increase tillage, or even to plow, to allow earlier spring planting.[39] Greater market demand for stover threatens to push higher harvest and ultimately more monoculture corn-on-corn planting. Stover harvest is being promoted by some (DuPont, in particular) as a practice that can solve the challenges of, or even enable, monoculture no-till corn by reducing problems of excess residue. With the erosion benefits of no-till on the one hand and pest and disease costs on the other, this raises concerns that stover harvest may have an unintentional consequence of promoting monoculture corn.

Stover and the Carbon Footprint of Biomass Harvest

Most conservation practices that reduce the carbon footprint of agricultural biomass harvest are also vital to protecting soil, water quality and availability, and wildlife habitat. These practices can also help farmers adapt to climate change already occurring by making soils more resilient to chaotic weather. Biologically diverse agricultural systems simultaneously mitigate climate change and are more resilient to climate change, while providing co-benefits that help the environment.[40]

It is important to distinguish the climate benefits of a cellulosic ethanol system, as measured from feedstock to the gas tank, and the climate benefits of individual steps in the process. For example, DuPont's facility is scored to reduce greenhouse gas emissions by 100 percent compared with gasoline, according to EPA models, and POET-DSM is scored at 85 to 95 percent relative to gasoline.[41] The EPA accounting system used by the RFS includes many factors, including the use of cellulose and by-product material to displace fossil fuel in the ethanol production process or by other energy users. Average estimates are now used to calculate the carbon impact of corn feedstock production itself, ignoring how better or worse conservation practices on individual fields or differing stover removal rates would impact the carbon result.

Discussions of the carbon emissions impacts of various agricultural activities are often fraught. Certain agricultural practices can affect climate change by reducing GHG emissions and sequestering atmospheric carbon in the soil—or, conversely, by increasing GHG emissions and releasing carbon from the soil. In the case of stover collection, the carbon footprint reflects the extra fuel burned to harvest and transport the cellulose, the additional fertilizer applied to make up for removed nutrients, and whether soil carbon sequestration is increased or decreased. Unfortunately, the answer here is not an easy one because of the site-specific nature of farms and the changing state of the science regarding soil carbon sequestration. Nevertheless, avoiding unintended consequences requires proceeding cautiously based on existing science.

Calculating Stover Removal Rates

It is important to note the two different ways crop residue is measured. Bioenergy companies usually measure removal based on dry tons of biomass removed at harvest, while conservation programs tend to look at the percentage of soil covered by residue after planting the next crop. Therefore, harvesting two tons out of four tons of available biomass is 50 percent removal of biomass, but retaining enough residue to keep 50 percent of the soil covered may allow anything from zero harvest to several tons' harvest per acre—depending on the stover productivity of the crop.

There is generally a linear relationship between corn grain yield and the amount of stover produced. As corn yields go up, crop residues also increase by a similar amount of dry weight. Because the leaves and stems are the chlorophyll factories that enable heavier production of corn kernels, it

makes sense that they rise in tandem. This is an important relationship since corn yields are closely measured, while unharvested stover is not typically monitored. The grain yield for any particular field provides a proxy for how much residue is produced.[42]

The future of stover production levels is difficult to predict. National corn yields climbed steadily since the 1930's, with some major swings due largely to weather.[43] Whether climate change will reduce productivity, or whether better growing methods will continue the historic increase in yields, are open to question.

Even those who support removal of stover are careful to point out that only a portion should ever be removed. According to Iowa State University Extension, "Sustainable partial residue removal rates depend on several factors, which include soil erodibility, surface slope, cultural practices, and climate conditions. Recent research suggests that partial residue removal should be approached carefully and based on ground cover requirements to control soil erosion and maintain soil quality and soil organic matter."[44] The amount to remove varies widely, from none on fields that require all of the residue for soil quality and health, to some on fields that are relatively level and have necessary conservation practices in place. The majority of studies recommend a limit of between 25 and 50 percent harvest levels over time (although keeping sufficient stover on the ground on a given farm may be better addressed by a requirement for minimum tons of stover retained per acre, with the ideal retention amount depending on a number of factors and possibly higher, but not lower, than that minimum).[45]

The question is not so much how much residue to harvest, but how much to keep on the field to retain soil organic carbon in the soil. The answer depends on many factors related to the particular site, especially the type of tillage used. Iowa State Extension clearly states in its series of fact sheets that continuous removal of corn residue while using intensive tillage will result in compromised soil health and productivity.[46] This is true across all rotations, but even more so with continuous corn, which results in a 64 percent reduction in soil organic matter, as demonstrated by their tillage studies established in the late 1800s and continuing to the present in the Midwest.[47]

Even retaining all residues is not sufficient to counteract moldboard plowing's impact on soil organic matter. With conservation tillage methods such as chisel plowing or no tillage, studies show a decline in soil total organic carbon as residue removal rates increase. The same is true of soil microbial life: Studies have shown a steady decline in microbial biomass carbon with increasing residue removal and increasing tillage.[48] Iowa State concludes, "Residue removal for any use needs to be determined by the actual amount of crop residue produced, type of tillage system, and nutrient management program, as well as field slope and erosion potential...The use of no-tillage can sustain soil organic carbon in the short term, when at least 2.7–30 tons per acre of reside is kept on the soil surface."[49]

The USDA Agriculture Research Service (ARS) acknowledges that the potential negative impacts of excessive residue removal on soil health are wide ranging, including wind and water erosion, soil compaction, reduced soil organic matter, and reduced surface aggregation.[50] These are not abstract environmental concerns but will have real impacts on productivity and profitability. Some removal is acceptable to the ARS when corn is under complete no-till, when too much residue can lead to delayed availability of soil nutrients and delays in soil warming and drying. However, no-till is used on less than 25 percent of corn acreage. The other 75 percent use some tillage, such as chisel plowing or intensive tillage with a moldboard plow. Brian Wienhold of the ARS said during a recent Web seminar that tillage removes organic matter (by exposing it to air) just as stover harvest removes organic matter. The clear implication is that every farmer selling corn stover should be changing to no-till.[51] Stover also contains nitrogen, phosphorus, and potassium, so that whatever is removed from the field must be replaced. Other concerns are geographically dependent, such as the effect of stover on soil warming in the North and moisture retention in the South.

On the most productive cornfields, there is a growing sense among some farmers that there is too much stover—that it keeps soils too wet and cold in the spring, or that it is more difficult for farming machinery to deal with. These concerns go along with larger operations where time is of the essence in a late spring, or where farmers need to plant corn early to cover all of their acres. A certain amount of stover harvest is therefore perceived as possibly helping their operations.

The Science of Crop Residues and Soil Organic Matter

The science of how carbon is captured from the atmosphere and stored in soil organic matter—or, alternatively, released from the soil when organic matter is oxidized due to erosion and tillage—is a quickly evolving area of study. There is still too much uncertainty to offer clear agronomic advice to landowners and biomass companies. For instance, research suggests scientists have for years not measured soils deeply enough to track carbon and have failed to take baseline measurements when comparing different farming systems' effects on carbon.[52,53] The physical model of how organic matter works is changing, with new understandings of roots, rhizosphere and microbial life, and the importance of deep-soil carbon sequestration.

In addition to the tillage question, ARS states that acceptable residue removal will always be a site-specific harvest decision, even to the point of treating different parts of each field differently, according to slope and soil type.[54] Blanket guidelines may not be appropriate, but flexible guidelines could still be effective.

For NRCS, site-specific stover removal recommendations are based on evaluating the entire cropping system and its specific soils, slopes, and climate. The agency uses two predictive tools: One predicts whether erosion will be controlled, defined as achieving a tolerable level of soil erosion ("T"), using the Revised Universal Soil Loss Equation 2 (RUSLE2). The other estimates whether soil carbon will be maintained, defined as achieving a positive score on the Soil Conditioning Index (SCI.) Every local field office of NRCS, located in nearly every county in the nation, can provide technical assistance to farmers to run these models for their fields and determine what level of stover removal is sustainable, and which additional conservation practices would make it sustainable.

Part 2: Case Studies
Three Corn Stover Ethanol Facilities

Company	Location	Production Capacity	Feedstock
DuPont Cellulosic Biofuel Solutions	Nevada, Iowa Starting in 2015	30 million gallons/year	Corn stover
POET-DSM Advanced Biofuels	Emmetsburg, Iowa Started in 2014	20–25 million gallons/year	Corn stover
Abengoa Bioenergy Biomass of Kansas	Hugoton, Kansas Started in 2014	25 million gallons/year	Corn stover, wheat and milo residues, prairie grasses

Case Study 1:
DUPONT CELLULOSIC ETHANOL FACILITY, NEVADA, IOWA

DuPont's 30-million-gallon-a-year cellulosic facility near the town of Nevada, Iowa, was completed in early 2014 and is set to produce fuel by the end of 2015. The company has been demonstrating stover collection and storage since 2010, with third-party harvesters who come immediately after the corn harvest and pick up stover from contracted farms. DuPont plans to eventually contract with 450 to 600 farmers within a 35-mile radius of the facility, on 200,000 acres. The facility is located next door to a corn ethanol plant owned by Lincolnway Energy, sharing farmer suppliers and transportation systems, and DuPont reports it will sell Lincolnway its leftover lignin to replace coal for energy at the corn grain facility.[55]

DuPont has spent more than a decade developing both a conversion process for cellulosic ethanol and the supply chain for its chosen biomass feedstock—corn crop residues—and reports that it launched an effort to ensure that corn residue harvest will not cause erosion or damage soil health on the Iowa farms projected to supply the feedstock. According to the company, the agronomic expertise brought in-house in 1999 when DuPont bought out Pioneer Hi-Bred—the nation's leading GMO corn seed company, with an extensive system of research and education and close connections to farmers—has been fully applied to exploring how to persuade farmers to sell their stover and what level of removal is environmentally sustainable.[56]

DuPont reports that it realized early on that most farmers are focused on and invested in harvesting corn grain during the critical harvest period and would likely be resistant to adding the additional step and expense of harvesting their own stover or even managing third-party stover harvesters. Payments for stover—now at $15 a ton or $30 an acre for DuPont—pale in comparison with corn revenues. DuPont selected a business model in which it will manage third-party stover harvesters to visit each contracted farm within a few days of the corn harvest to shred, pile, bale, and stack the specified amount of stover. Farmers will be asked to turn off the shredding attachments typically used on combines to distribute stover on the soil. Large bales of clean stover will eventually be transported from the farms for interim storage at 20 to 30 staging locations within a 30-mile radius of the ethanol facility, and then trucked as needed to the facility. Full facility operation requires about 1 bale per minute.[57]

According to DuPont, the big question for the company is how to ensure that stover harvest is sustainable. The company cites two reasons for its focus on soils and sustainability. First, construction of a $200 million ethanol facility demands that future feedstocks be available for the life of the plant. Any decline in stover productivity or resistance from farmers worried about their land would threaten their feedstock supply chain. Second, DuPont has adopted environmental protection and sustainability as one of its core company values.[58]

Yet there is no public policy or scientific consensus on recommended levels of stover removal for DuPont to rely on. Even though stover removal is sometimes used on a small scale by livestock farmers for silage, feed, and bedding, biomass harvest on a continuous basis or larger scale is something new. Moreover, there is no transparent system for ensuring that sustainable removal is enforced at the field level across all the acres the company will source from, or for ensuring that stover harvest is not used in conjunction with bad practices.

In March 2013, the USDA announced the first federal-private joint agreement on sustainable cellulose feedstocks, working with DuPont to safeguard natural resources on private lands used to supply feedstocks for cellulosic ethanol production.[59] The aim is for DuPont to voluntarily set (and then meet) standards for sustainable harvesting of agricultural residues for biofuels. NRCS will partner with DuPont to tailor corn stover collection to each individual farm. A memorandum of understanding specified that individualized conservation planning assistance would be provided for farmers who supply feedstocks to DuPont to ensure sustainable residue removal.

DuPont pledged to develop a process using NRCS conservation planning tools and its own personnel to work with the stover-contracting farms to prevent soil erosion, promote healthier soils, and use nutrients efficiently. NRCS pledged to use its expertise so each farm could control water and wind erosion and maintain soil organic matter. The Iowa NRCS expects many farmers will have to reduce tillage, maybe to no-till, and possibly add cover crops to meet this standard.[60] DuPont hopes to be able to present certification from NRCS to each farm affirming that its conservation plan meets the standards and is being implemented, as audited by NRCS. The Iowa NRCS reports that it doesn't typically see many corn farmers coming in for voluntary conservation help, so it welcomes the opportunity to help them develop conservation practices to meet the standards. There is some concern as to whether the nine or so county NRCS offices in the DuPont region have sufficient staff to provide the technical assistance that could be needed by some 500 stover farms, so NRCS has worked with DuPont staff to verify that company conservation planning tools meet NRCS conservation standards.[61]

In April 2014, the Iowa NRCS signed an operational memorandum of understanding that specifies DuPont will provide information to producers on their soil health under current management, taking feedback in the first round of consultations.[62] DuPont created its own tool, using NRCS models, to use with farmers who do not already have an NRCS conservation plan. DuPont will tell farmers what their erosion is in an average year and will report their Soil Conditioning Index score, which predicts soil organic matter based on current practices and the level of residue removal. One-year contracts, to start, will allow both farmers and DuPont to evaluate results annually. By 2018, multiyear contracts will accompany individual soil health plans that specify practices to meet "sustained soil health," defined as meeting the erosion standard and a positive SCI score. In the end, farmers will have to balance residue removal with changes to tillage, use of cover crops, or other practices in order to meet the erosion and soil organic matter goal.[63]

How DuPont Set Its Standards

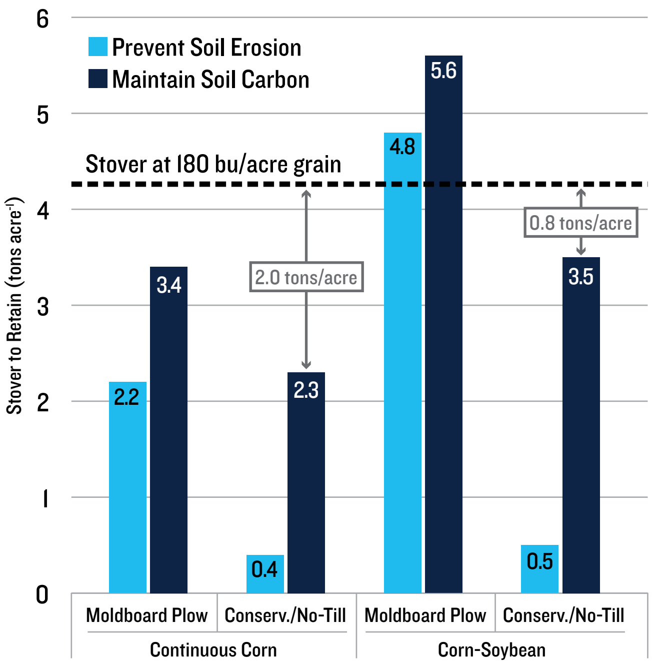
According to DuPont, the company decided to come at the question of sustainable harvest with an innovative, three-track approach into which they have built multiple layers of protection. First, DuPont will screen out land most likely to fail. Second, the company will self-limit its stover harvest to 2 tons dry stover per acre and harvest in only three out of every four years. Third, and most significant, DuPont's agreement with the NRCS helps every contracted farmer develop a conservation plan with verified implementation of practices that achieve zero erosion and preservation of soil organic matter. Each of these three layers of protection is described below.[64]

1. SCREENING OUT VULNERABLE LANDS. DuPont will accept stover only from relatively flat fields, with slopes under 4 percent (class A and B farmland). Further, according to the company, it will contract only from fields with average yields of more than 180 bushels of corn per acre, and only from farms that use no-till or conservation tillage. As corn yields go up, stover production also goes up. Scientists have concluded that when corn yields exceed 180 bushels per acre using conservation tillage or no-till, more stover may be produced than is needed to sustain soil quality, and thus some portion of it can be sustainably removed.[65] These requirements are not hard to meet in central Iowa, with its flat land and high yields, and they ensure that highly erodible acres and fields not producing sufficient residues are not contracted for stover. Thus fields with moldboard plowing, well known to accelerate erosion and loss of soil organic matter, will not receive contracts to sell corn residues to DuPont. How the company will ensure that its stover contracts do not include sloped lands is not clear.

2. LIMITING STOVER HARVEST. DuPont decided on a 2-ton-per-acre harvest rate. DuPont wanted to make the decision of how much to harvest, rather than leaving it to the farmer or contracted stover harvester. Since technology is not yet available to measure available stover while driving a harvester over the field, DuPont decided to use research that looked at the question from another angle: how much stover is needed for soil sustainability? The remainder is what can safely be harvested.[66]

In 2007, USDA Agriculture Research Service scientists led by W. W. Wilhelm determined that the amount of stover needed to control erosion was significantly less than that needed to maintain soil organic carbon, and thus soil carbon is the limiting factor on which to focus.[67] These scientists further looked at tillage as a driving force in retaining soil carbon and found that moldboard plowing required substantially more stover to be left on the field than no-till or conservation tillage.

Figure 1: Comparison of Stover Needed to Maintain Soil Carbon vs. to Prevent Soil Erosion



Source: Wilhelm et al. 2007. Corn Stover to Sustain Soil Organic Carbon Constrains Biomass Supple. *Agronomy Journal*. 99: 1665-1667

Figure 1, above, adapted from the Wilhelm study, shows that continuous corn with conservation or no tillage requires 2.3 tons of stover per acre for soil health, leaving 2 tons per acre to be safely harvested. A corn-soybean rotation with conservation or no tillage requires retaining 3.5 tons per acre for soil health, so at a yield of 180 bushels per acre, 0.8 ton per acre can be safely removed.

DuPont also said it added a measure of safety by pledging to harvest only 75 percent of qualified acres from land planted to continuous corn, or take stover off those fields in three out of every four years. If the land is in a corn-soybean rotation, it will harvest only 40 percent of qualified acres each year, or two years out of five.[68]

The Pitch to Farmers

Even though excessive harvest is a potential harm to cropland, DuPont is openly reaching out to farmers with a message that removing "excess residue" for biomass will be a service to them.[69] Indeed, highly productive lands using conservation tillage or no-till can experience difficulty with stover shading soils in the spring, keeping them wet and cold. Heavy stover layers can interfere with crop establishment and early growth, as well as immobilize nitrogen and harbor pathogens. Too many farmers now respond with aggressive tillage that harms soil organic matter, increases susceptibility to erosion, and raises GHG emissions. DuPont's message is that partially harvesting residue for biomass, while ensuring tolerable erosion and no decline in soil carbon, will actually lead to greater adoption of conservation tillage or no-till.

DuPont points out that removing some of that stover can help with faster emergence of plants and higher plant populations, leading to an average gain of 5.2 bushels of corn per acre, according to field trials. That amounts to $20 per acre. In addition, some can eliminate the stalk chopper pass, and 40 percent of past participants report reducing their tillage. Altogether, DuPont says farmers receive a net profit of $32 per acre when stover is harvested as a residue management tool. The company's own surveys show that 40 percent of farmers do reduce tillage after selling stover; however, there is still little evidence of use of no-till practices. As DuPont tried to attract corn growers to contract to sell stover, it paid a minimal price, $24 per acre in 2014.[70]

3. A CONSERVATION PLAN FOR EACH FARMER. DuPont is working with NRCS to develop and verify a conservation plan for each participating farmer. Company staff will help contracted farmers calculate water and wind erosion and soil organic matter levels, using user-friendly software based on venerable and validated NRCS tools. The Revised Universal Soil Loss Equation 2 predicts whether water erosion is at the tolerable level (T) for soil loss and is used in combination with the Wind Erosion Prediction System. The Soil Conditioning Index predicts whether organic matter is declining, holding constant, or increasing. Use of these indices with a specific performance requirement of achieving T for erosion and no loss of soil organic matter gives clear guidance as to whether the stover removal is sustainable, or if it should reduced or eliminated, or if additional conservation practices are needed.[71]

Case Study 2:
ABENGOA BIOENERGY BIOMASS, HUGOTON, KANSAS

Abengoa opened its new, 25-million-gallon-per-year cellulosic ethanol plant in Hugoton, Kansas, in October 2014.[72] Abengoa is an international technology company headquartered in Spain and is the second-largest ethanol company in the world. Its operations include six ethanol plants in the United States. The Hugoton facility commercialized Abengoa's proprietary technology that enables diverse cellulosic feedstocks to be used, including multiple crop residues and perennial energy crops.

In addition to producing ethanol, the same stover cellulosic feedstocks and the lignin that remains after ethanol fermentation are fed into a biomass-fired boiler. This produces the steam and electricity needed for the facility and up to 21 megawatts per year of renewable electricity that is sold to the grid.[73] In the future, Abengoa also hopes to replace petroleum beyond ethanol, by making renewable bioplastics, biochemicals, and drop-in jet fuel.[74] Much of the ethanol produced in Kansas will be sold to California with its strong low carbon fuels standard (LCFS), as well as potentially Oregon and Washington as they look to adopt similar standards.[75]

Abengoa buys and stores agriculture waste, primarily irrigated corn stover, but also accepts up to 20 percent additional crop residues from wheat and milo as well as perennial switchgrass, to provide some diversity in case of a crop failure.[76] Abengoa predicts it will need about 350,000 dry tons of biomass a year; it will buy up to 15 percent of available biomass within a 50-mile radius of the plant, encouraging a free market where farmers can decide how often and how much stover to harvest and sell.[77]

Abengoa conducts the collection as a service to farmers through a contract with Pacific Ag, an agricultural residue and hay harvesting business operating in seven states. Individuals can also deliver it themselves if they prefer. Payment options include a flat $15 per dry ton, a payment tied to the price of ethanol, or a smaller payment plus nutrient replacement in the form of an ash by-product from the Hugoton plant. Abengoa estimates that removing 1.5 to 2.5 tons of stover will result in a payment of $22.50 to 37.50 per acre.[78]

Abengoa assumed responsibility for harvest in accordance with guidelines developed with NRCS, focused primarily on minimizing soil erosion from wind in this arid region of Kansas. Managing stubble height is the most important practice. A spokesman for Abengoa stated that "to maintain sustainable farming practices in the project area, we have worked with NRCS to evaluate residue removal rates with respect to limiting soil erosion."[79]

NRCS recommended that Abengoa consider climate, which in the Hugoton area ranges from arid to very arid. Yearly precipitation averages under 16 inches, which results in most corn being irrigated. The type of soil and the particular crop rotation determine wind erosion potential and maximum residue removal. (The supply region for Abengoa has stopped using conventional tillage; the company states that almost all of its suppliers use no-till or strip-till, which is not the case in the POET-DSM and DuPont supply regions.) NRCS mapped the three soil types in the supply area and prepared wind erosion calculations for typical crop rotations and agriculture practices, resulting in a simple worksheet that predicts what stover harvest levels will result in "tolerable" soil loss (NRCS's term for sustainable levels of erosion) due to wind erosion.[80]

A one-page list of residue removal guidelines used by the company indicates that in irrigated fields with continuous corn, up to 75 percent of residue can be sustainably harvested, with the exception of sandy-soil fields, which can sustain 50 percent removal. In the somewhat less dry region, up to 50 percent of crop residues for wheat and wheat-sorghum rotations with fallow in one soil type may be harvested.

Using the information for each contracted field, harvesters are trained to windrow and harvest only the recommended amount of stover. In reality, the company reports that it harvests almost exclusively at the 50 percent level, because more aggressive removal tends to pick up an unacceptable amount of dirt contamination.[81]

According to the company, because this arid Kansas region has already eliminated most tillage, the impact of stover removal on soil organic matter is not much of a concern, as root systems that remain untilled contribute the most to soil organic matter.[82] In Iowa, scientists generally conclude that maintenance of soil carbon levels remains a concern with stover removal because no-till is not the typical tillage practice.

Abengoa reports that it tried to participate in the NRCS BCAP matching-payments program in 2014, but the short deadline early in the harvest period made it extremely difficult to get any participants.[83] NRCS was willing to provide conservation plans, but the agency had very limited staff and did not have enough time to train additional technical service personnel to assist interested farmers.[84] Note that BCAP conservation plans would go much further than just addressing wind erosion, as the Abengoa company harvest guidelines cover, because BCAP plans address all conservation issues on the land.

Case Study 3: POET-DSM ADVANCED BIOFUELS, EMMETSBURG, IOWA

In September 2014, POET-DSM Advanced Biofuels opened its $275 million Project Liberty, a "bolt-on" facility that will make 25 million gallons a year of ethanol from stover. It is co-located at POET-DSM's existing Emmetsburg, Iowa, corn grain ethanol plant. POET's partner, Royal DSM, is a Dutch maker of the enzymes required to break down cellulose. POET stockpiles corn stover purchased from area farmers, focusing on cobs and leaves harvested at a conservative rate of 1 ton per acre. The partners expect to pay $20 million annually to buy feedstock from farmers within a 45-mile radius of the plant.[85] POET will also produce renewable process steam for both the cellulosic facility and the adjacent corn grain facility, using a solid fuel boiler to burn renewable solid waste streams and an anaerobic digester for liquid waste streams.[86]

According to POET, the company decided to avoid much of the site-specific planning required for higher levels of stover removal by simply using a conservative 1-ton-per-acre removal limit in every field. "We're starting low to make sure we're doing the right thing," said a POET official.[87] One ton represents about a fourth of the stover on each acre. POET cooperated with Iowa State University and the USDA Agriculture Research Service to document with multiyear research that with good soil and crop management practices, corn yields should be sufficient to support a sustainable corn stover harvest of 1 ton per acre "from this and similar fields" (like those around the POET plant). [88],[89] The Iowa NRCS is not directly involved with POET as it is with DuPont, but NRCS says that the 1-ton-per-acre removal rate is probably acceptable because of the location, an area of very flat fields and high crop and residue productivity.[90] However, an NRCS official noted that even 1 ton could be too much in other regions of Iowa or the rest of the country, especially where there are steep slopes. In such cases, it may not be appropriate to remove any stover.[91]

POET-DSM hired a group called POET Biomass to do outreach to farmers over the past seven years to implement collection procedures and achieve increasing harvests of stover. POET's Project Liberty is projected to purchase 285,000 dry tons of biomass annually from 285,000 acres within a 45-mile radius of the plant. Approximately 25 percent of available stover per acre, or one ton, will be removed. About $20 million annually will be paid to area farmers.[92]

Unlike DuPont, POET reports that it is not managing stover harvest practices other than to require that farmers report grain yields (as a proxy for stover production), and that the private stover harvesters weigh and track total stover harvested per acre, in order to prevent accepting or paying for more than 1 ton per acre. By conservatively aiming for only half the generally accepted rate of stover harvest, POET avoids the need for detailed, site-specific planning. The company expects some individual farmers to harvest and deliver, but mainly newly developing baling companies will deliver stover to the facility.[93]

Part 3:
Analysis, Concerns, and Critical Elements for Sustainability

As the first commercial cellulosic biofuel plants open their doors, the three profiled companies have each developed a voluntary approach to ensure sustainable stover harvest, out of concern for both the land and future feedstock reliability. All three companies have a strong public stance on sustainable stover removal, though each approaches the issue independently and somewhat differently:

- DuPont takes a more aggressive approach, sourcing up to 2 tons of stover per acre, with the potential to harvest even more in the future if soil organic matter sustainability proves out. The company is using a very hands-on, conservation benchmark approach with each farmer, backed by NRCS expertise and oversight.
- Abengoa is following NRCS guidelines directing their stover harvesters to take only the amount of stover recommended for their specific local climate, soils and cropping conditions, using no-till and correct stubble height to prevent wind erosion, which is the top concern in its arid region.
- POET takes a reasonably conservative 1-ton-per-acre approach, avoiding concerns about excessive stover removal on the flat, productive farmlands surrounding Project Liberty, where retained residues should be sufficient to protect the land. However, some of its 26 other ethanol facilities slated for stover biofuels are located in hilly areas where even 1-ton removal may be too much.

Each company has worked with researchers and NRCS to identify appropriate responses to ensure that corn stover removal, when added to corn production, does not increase erosion or decrease soil carbon levels on every field. However, even with good cooperation between these private entities and NRCS, concern remains regarding monitoring and verification. Who will check that crop yields are high enough to maintain the recommended stover harvest? Who is checking for proper harvest rates—or, more important, proper retention of stover on the field? Who does the field checks in spring before planting to make sure residues are there? Who checks for excessive erosion or declining soil organic matter?

In DuPont's case, NRCS is committed to helping the company with a quality assurance system. DuPont will do spot checks of contracted farms to check practices, residue levels after planting, and the presence of ephemeral gully erosion, which forms in low spots when it rains heavily, and take soil samples. NRCS will then spot-check a portion of DuPont's spot checks. The effectiveness of this system of enforcement, as well as public transparency in enforcement efforts, will be critical to the overall success of DuPont's voluntary approach as the company moves forward with stover harvest.

As with DuPont, the Abengoa stover sustainability program is well planned and grounded in NRCS science, but little verification or monitoring is built in. It is important that there be checks to determine whether the stated crop rotation and tillage methods are being used. Stover harvesters should be monitored to verify how much residue is being retained on fields. Longer-term monitoring should be conducted to verify that ongoing stover removal at company-approved rates is indeed not degrading the soil or leading to wind erosion.

Likewise, even with POET's reasonably conservative approach in deciding to apply a minimal level of stover removal, no formal monitoring or verification systems will be put in place for this project outside of POET records, and therefore no public accountability built in to ensure that harvest rates are as planned and that soil and erosion conditions remain stable.

For its part, DuPont says it went beyond maintaining field conditions prior to stover removal by requiring a higher baseline level of conservation. The company reports that it aspires to require every cornfield to maintain soil carbon levels and prevent erosion after residue harvest, according to NRCS conservation measurement tools, which should raise the sustainability of corn ethanol feedstocks as well.[94] However, while these may be corporate goals, transparent verification of this standard is still necessary and lacking.

Of equal concern is that DuPont is actively touting the advantages of continuous corn, a noticeable trend where farmers abandon the traditional corn-soybean rotation in favor of planting corn for several years in a row. Iowa already has about 10 percent of its corn acres in continuous corn; this is generally occurring in areas close to ethanol plants or with high volumes of livestock waste to apply. Monoculture corn-on-corn produces copious amounts of stover, but it also brings increased risk of pests and diseases, as well as poor soil health, poor water quality, and a host of other economic and environmental concerns.[95]

DuPont's website tells farmers, "Managing residues through partial stover harvest allows you to increase your percentage of corn after corn, generally providing higher profit potential for your farming operation."[96] DuPont also encourages stover farmers to reduce their tillage operations to compensate for the loss of stover and to take advantage of easier field operations and earlier soil warming. In some cases, use of a cover crop with continuous corn can compensate for stover removal and provide fertility and healthier soil biota.[97] However, encouraging the right amount of stover removal in order to enable the further intensification of corn farming brings significant concerns about environmental impacts.

With the voluntary sustainability measures being taken by the three early movers in this industry, cellulosic biofuels in the U.S. may be off to a good start. However, the lack of public policy to ensure feedstock sustainability raises a number of important concerns. Because of the many variables involved, it is not possible to set generic national guidelines for stover removal or residue retention across all agricultural lands. Instead, site-specific conservation plans are needed for each field, taking into account all the site and farming system characteristics. When a local region is shown to have certain uniform characteristics, specific regional requirements might be set relating to tillage, yields, and residue retention. However, areas with diverse topography, soils, or farming systems will always require site-specific analysis.

KEY AREAS OF CONCERN

Corporate Oversight

The obvious problem with relying solely on corporate sustainability policy is that there is no public oversight of their systems. If procedures fail to maintain soil organic carbon levels or prevent erosion, will the company revise its procedures? Monitoring and oversight are necessary, both of individual growers and of the company's procedures. If the market for cellulosic ethanol takes a downturn (as happens frequently in the corn ethanol industry), will the sustainability programs be the first to go? Corporate sustainability policies are commendable and can be effective, but independent, third-party review and verification of actual performance must be added.

Future Facilities and Scale of Resulting Stover Harvests

All three of these companies or their technology partners are openly planning to replicate their biomass facilities and feedstock operations in the future, either for other developers who will license the technologies (as in the case of Abengoa and DuPont) or for their own corn ethanol facilities (POET).[98,99,100] Clearly, many more cellulosic facilities could be built if these early efforts prove successful. Vastly more residues and energy crops will be harvested, but with different approaches to sustainability likely to be taken by each facility. There are no public policies in place to ensure that the next wave of cellulosic ethanol plants operate and source their feedstocks in an environmentally sustainable manner.

Near-Term Challenges

While commercial-scale, second-generation biofuels production is finally under way, the industry still faces important challenges. The first cellulosic facility to open, Kior, which thermochemically processed wood waste, halted operations and needs an influx of investment to improve the technology before continuing.[101] In addition, serious concerns remain about the sustainability of its feedstock, purported to be wood waste but also including whole trees.

At the same time, the 10 percent "blend wall" limits the market for ethanol, and increasing transportation efficiency is reducing the market for all liquid fuels.[102] Further, the EPA has proposed reducing the RFS requirements for both corn ethanol and cellulosic ethanol from the statutory goal to reflect current realities. On top of that, the new cellulosic technology is currently more expensive per gallon than ethanol or gasoline, and like all new technologies it will predictably require a period of some years to achieve its full promise and competitive prices. This may give policymakers time to develop sustainability safeguards for cellulosic biomass ahead of the next ethanol boom.

Corporate sustainability policies are commendable and can be effective, but independent, third-party review and verification of actual performance must be added.

Use of Unsuitable Acres

The three cellulosic facilities profiled in this report chose locations that minimize risks with stover removal because the farm fields for miles around are nearly flat and highly productive for corn. Avoiding fields with slopes or with low yields (and accompanying low residues) is key to stover sustainability. As future facilities locate in riskier areas, it will be ever more critical to have policies to guide ethanol plant siting so that residue harvesting will not take place on unsuitable acres. An even bigger burden will fall on the biorefinery to aggressively refuse to buy stover from unsustainable fields.

In terms of sustainability, the three facilities examined in this report focus only on soil erosion and soil organic matter. Other important potential environmental impacts of stover harvest, such as nutrient pollution, pesticide runoff, groundwater depletion, and effects on wildlife habitat, are not being addressed at all. These concerns are critical to overall environmental sustainability and must be considered when evaluating whether the addition of stover harvest will exacerbate the impacts of corn production and create additional environmental harm.

Lack of Accountability

With future cellulosic biofuels development, it is important to identify the real decision makers in ensuring sustainable harvests. Who should decide the extent of the stover harvest? Is it the farmer, the harvester, the stover aggregator, or the ethanol producer? The first three facilities, profiled here, chose to direct third-party harvesters and advise farmers according to their own guidelines. In the future, biofuel companies may not have a direct relationship with farmers or harvesters, instead buying from an aggregator company. As residues and cellulose become more commercialized, cellulose could emerge as a commodity like corn, with volumes bought and sold on the open market with no differentiation or connection to farm-level sustainability performance. Currently neither landowners nor farmers nor any other entities monitor actual impacts on the land. If stover harvest were to have a negative net impact on corn acres, there is currently no accountability.

Continuous Corn Planting

There are strong indications that stover harvesting is being sold to farmers as a means to aid and possibly increase the use of monoculture corn. Where farmers grow corn on corn, thus eliminating crop rotations, it is true that partial stover removal can promote earlier planting, easier tillage management, and often better yields in the next year. However, this move away from even the most basic annual rotation between corn and soybeans raises the likelihood of pest and disease problems, encourages greater pesticide use, and can potentially increase pest resistance to pesticides. The positive impact of rotation on yield, referred to as the rotation effect, is still being studied, as are the possible benefits to soil biota. A recent Iowa study on nitrate loss in drainage water found that continuous corn systems had 37 percent higher nitrate-N concentration in drainage water, compared with corn-soybean rotations. While the study also found that residue removal itself had little impact on nitrate-N concentration, it is conceivable that stover harvest encourages elimination of crop rotations, indirectly leading to greater nutrient pollution.[103] If stover removal is the enabler of more continuous corn, will stover ethanol serve to indirectly exacerbate corn-related environmental problems? In the case of DuPont, the seed and fertilizer aspects of its business may be in conflict with the sustainability objectives in its biomass operations.

Limits of the NRCS Soil Conditioning Index

The soil conditioning index is an important tool that predicts whether organic matter is increasing or decreasing in a particular field, but its meaning is limited because it does not specify whether a field is starting from—and staying at—very low levels. Requiring a positive score for stover removal could in some cases merely mean that an extremely degraded cornfield is not being degraded further by stover removal.

Limits of the Erosion Index

The current soil-loss equation model predicts overland water erosion but ignores ephemeral gully erosion. This is the form of erosion that is most typical on farms. Additional tools are needed to predict heavy erosion from rain events, and NRCS is working on this challenge.

Ignoring Water Quality and Habitat

In terms of sustainability, the three facilities examined in this report focus only on soil erosion and soil organic matter. Other important potential environmental impacts of stover harvest, such as nutrient pollution, pesticide runoff, groundwater depletion, and effects on wildlife habitat, are not being addressed at all. These concerns are critical to overall environmental sustainability and must be considered when evaluating whether the addition of stover harvest will exacerbate the impacts of corn production and create additional environmental harm.

For instance, nutrients must be replaced to account for stover that is removed, meaning higher fertilizer application rates in the following year; how much will this add to already unacceptable nutrient runoff rates? The seed side of DuPont recently signed agreements with eight midwestern universities to improve nitrogen management practices using detailed field mapping.[104]

DuPont agronomists say that farmers in the Corn Belt currently lose $50 to $60 per acre because of nitrogen waste, with even bigger losses during heavy rainstorms.[105] The new research is intended to give farmers tools to plan, monitor, and adapt nitrogen practices to save money and improve the environment, especially in the face of climatic uncertainty. It is important that water quality and habitat concerns be included in feedstock sustainability policy.

Anticipating Perennial Feedstocks

Industry has promised inclusion of perennial feedstocks like switchgrass in the biomass feedstock supply, but when will this shift move from promise to reality? Abengoa's technology is touted for its ability to interchange feedstocks, but how is the harvest of grass from Conservation Reserve Program lands and other acres going to be enabled? A Biochemtex facility in Clinton, North Carolina, may be the next plant to open; plans call for a 2016 startup to process perennial grass feedstocks into ethanol.[106] However, at the time of publication of this report, the future of the company remains unclear.[107]

Other crops of interest, including the giant reed Arundo donax, have raised serious concerns about invasiveness, while some, like miscanthus, must be carefully managed to control invasiveness, according to NRCS. The international Mossi Ghisolfi Group owns Beta Renewables and with partner Novozymes already makes ethanol from wheat straw, rice straw, and Arundo donax at a facility in Crescentino, Italy, producing 20 million gallons of ethanol a year by late 2013.[108] An innovative cropping system could incorporate perennial grasses into buffers and sensitive areas within and around annual crop production systems for the purpose of cellulose harvest, replacing stover removal and cleaning up corn runoff at the same time.

Ensuring NRCS Capacity

Large stover conversion facilities may trigger many farmers to request a conservation plan from their local NRCS office. While such technical assistance is at the heart of the NRCS mission, actual staff capacity to deliver that assistance depends on adequate funding. Adding a role for NRCS to verify or certify compliance with the plan would require additional agency funding.

RECOMMENDATIONS TO ENSURE STOVER BIOFUEL SUSTAINABILITY

If the policies promoting cellulosic biofuels—and the first cellulosic ethanol plants—are successful, we could eventually see hundreds of plants like the three profiled here. Now is the time to ensure that the sourcing of crop residues and the production of new energy crops avoid negative environmental impacts.

For every field or uniform region, any facility engaged in stover removal for biofuels production must have a site-specific conservation plan (or the equivalent) for limiting stover removal to sustainable levels, taking into account the actual farming practices being used on that field, to ensure soil health and erosion prevention. Alternatively, carefully developed regional plans could be developed, with specific requirements about slopes, farming practices, and stover harvest levels. Plants must have independent, third-party verification of the harvest practices of their suppliers, such as certification by the RSB. Sustainability outcomes on the land must be made transparent to the public.

Cellulosic ethanol plants should seek early involvement of the USDA in facility development to ensure that sustainable biomass supplies will be available for the proposed facility, and under what conditions. They should also seek the involvement of the NRCS to approve or deny each field's site-specific conservation plan and its planned level of stover removal, and to conduct spot checks to verify performance. Diminished stover yields in times of drought or other circumstances should result in decreased or eliminated stover removal.

DOE, USDA, and other federal subsidies (loans, grants, tax credits) to new biomass conversion facilities should be made contingent on company use of site-specific feedstock sustainability certification or other means of verifying environmental performance—not just for corn stover but for all biomass. Ultimately, the RFS and LCFS should likewise be revised to recognize and reward biomass biofuel facilities that achieve environmental sustainability through certification or other performance verification.

Considerations of environmental sustainability around residue removal should be expanded beyond soil erosion and soil carbon to include impacts on water and habitat. For example, stubble height after harvest can be a key determinant of habitat value to birds and other wildlife.

Finally, biofuel producers should work with conservation groups and technical advisers or farmers to develop best practices. Site-specific evaluation for stover harvest provides an excellent opportunity to educate corn farmers about opportunities for conservation on their land. The value of conservation tillage or no-till, cover crops, crop rotations, and other soil health practices should be part of conservation planning. No-till, cover cropping, and nutrient management are a trio of vastly underutilized practices that can be combined to maximize carbon sequestration and address water quality and quantity issues, possibly alongside modest stover harvest.[109] Perennial cover crops are being evaluated to see if they provide enough soil carbon to offset the loss of carbon when greater amounts of corn stover (or all of it) are harvested.[110] It is also possible that cover crops themselves could be harvested for biomass, grown at the same time as a main crop.[111] Biofuel producers should also explain and expedite plans to incorporate perennial energy crops, including grasses, prairie mixes, and hay, into their facilities. Our policies should encourage diversity in both our biofuel feedstocks and our crops more generally.

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