cenusa bioenergy

EMERGING MARKETS FOR SWITCHGRASS IN THE US MIDWEST:

CHALLENGES AND OPPORTUNITIES

Contents

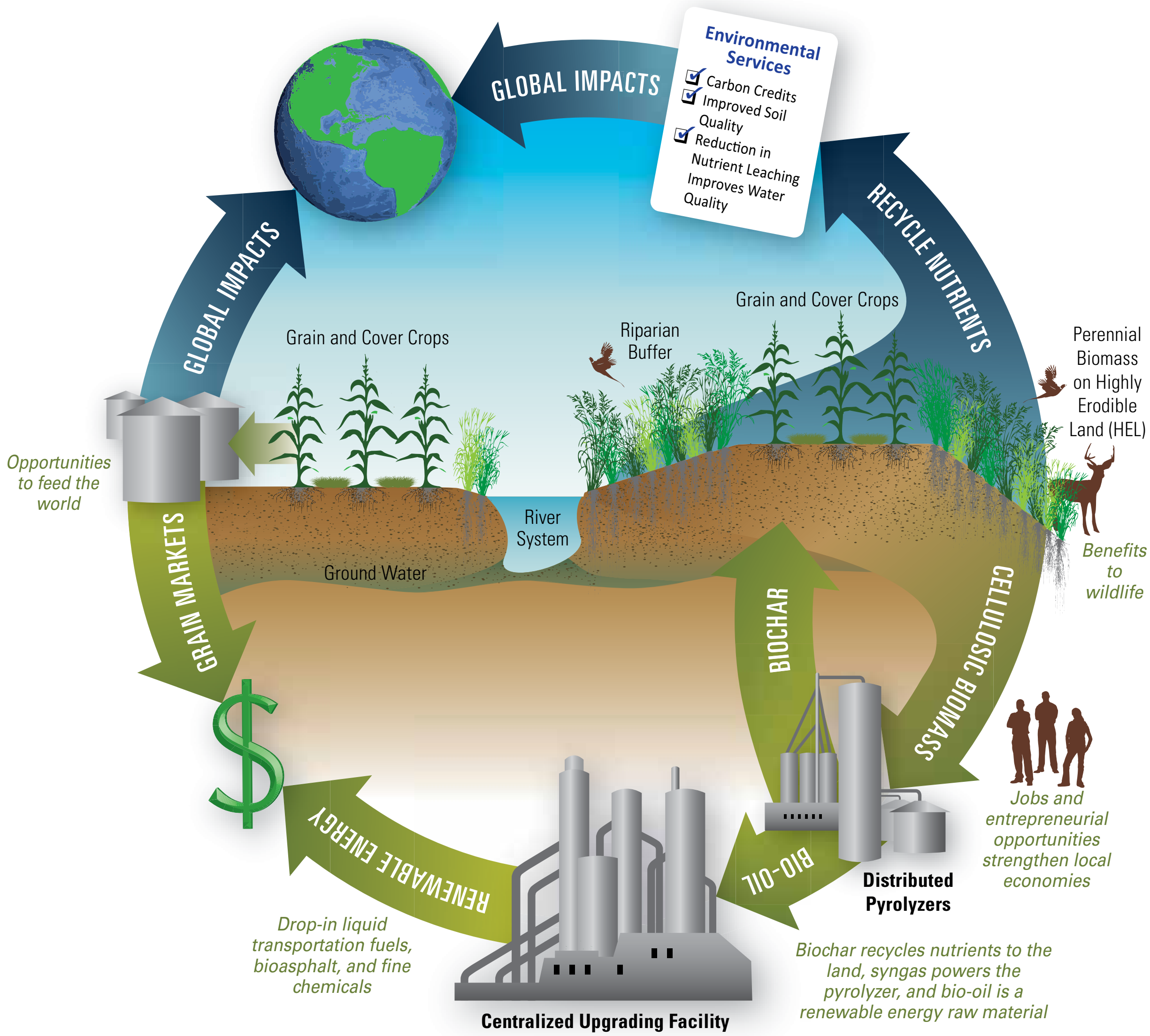


Figure 1. CenUSA Vision

Introduction

In the early 21st century, the United States set ambitious goals for biofuel production. The Energy Independence and Security Act of 2007 altered the Renewable Fuels Standard to mandate 16 billion gallons of cellulosic biofuel be produced in the United States by 2022 (EPA, 2017). To achieve this goal, the country would need to produce immense quantities – on the order of 100 – 200 million tons – of cellulosic biomass. In 2011, the USDA NIFA CAP program funded a project, *Sustainable Production and Distribution of Bioenergy for the Central USA* (hereafter CenUSA) whose focus was investigating the creation of a Midwestern biofuels and bioproducts system derived from perennial grasses. CenUSA's research focused on five stages involved in developing switchgrass as a viable cellulosic bioenergy crop: Germplasm to Harvest, Post-Harvest, Education, Outreach and Extension, and Commercialization.

FARMERS HAVE LITTLE INCENTIVE TO PLANT PERENNIALS WITHOUT A VIABLE MARKET,

and energy companies won't build cellulosic biorefineries

without a reliable feedstock supply already in place.

Switchgrass and other perennial grasses have the potential to be environmentally-beneficial, high-yielding sources of cellulosic feedstock. However, despite the help of grants, subsidies, and tax breaks for cellulosic ethanol producers, corn grain ethanol still accounts for more than 95% of domestic ethanol production, reflecting the challenges of this bulky, and harder-to-process feedstock, and suggesting that widespread commercialization may yet be many years away (RFA, 2018). Even if the cellulosic ethanol market grows rapidly, corn stover is likely to be a cheaper feedstock; to date, corn stover has been the feedstock of choice for companies that have pursued cellulosic ethanol production in the Midwest (Schill, 2017). However, excessive stover removal from fields can increase erosion and water pollution and reduce nutrient concentration in soil (Blanco-Canqui et al, 2017; Halvorson and Stuart, 2015). For this reason, if switchgrass yield, selling price, and logistic efficiency continue to improve, switchgrass may be able to outcompete stover and contribute significantly to the long-term feedstock supply chain for cellulosic biofuels.

Be that as it may, no nationwide market for cellulosic biofuels currently exists. This has created an impasse for the cellulosic feedstock market: farmers have little incentive to plant perennials without a viable market, and energy companies won't build cellulosic biorefineries without a reliable feedstock supply already in place. Despite the barriers, there are reasons to continue pursuing widespread switchgrass commercialization. Switchgrass is drought tolerant and can be grown on marginal land, making it successful in areas where row crops might struggle to turn a profit. Switchgrass also offers environmental benefits when farmed in place of row crops. These include nutrient and pollution reduction in agricultural runoff, flood control, carbon sequestration, and overall improvement of soil health (Blanco-Canqui et al, 2017). The competitive advantages of switchgrass have not been sufficient to cause it to be widely cultivated in the US Midwest. Reasons for this include the difficulty in valuing non-market ecosystem services, as well as the technological lock-in that occurs when a particular approach (e.g., corn/soybean rotation) is used so widely that alternatives are difficult to establish. For these reasons, we seek here to explore possible alternative niche markets for switchgrass. Niche markets are smaller-scale, localized commercialization opportunities that farmers could supply while waiting for the much larger cellulosic biofuels market to develop. These existing and emerging markets could help generate a profit for producers and bridge the gap between the current state of switchgrass commercialization and the future state of the market as envisioned by proponents of the RFS.

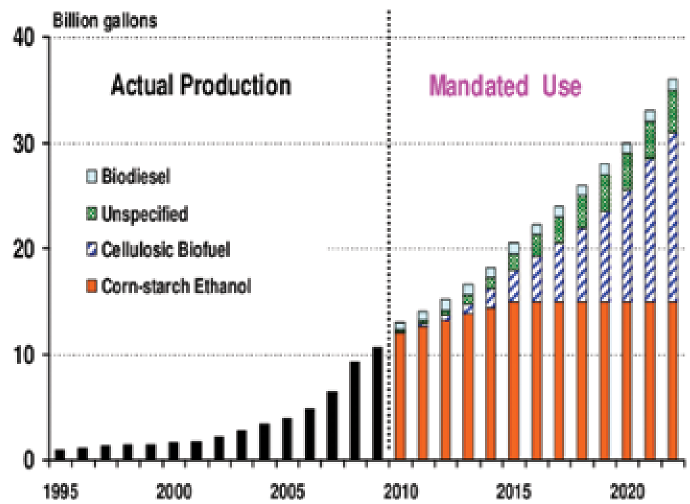
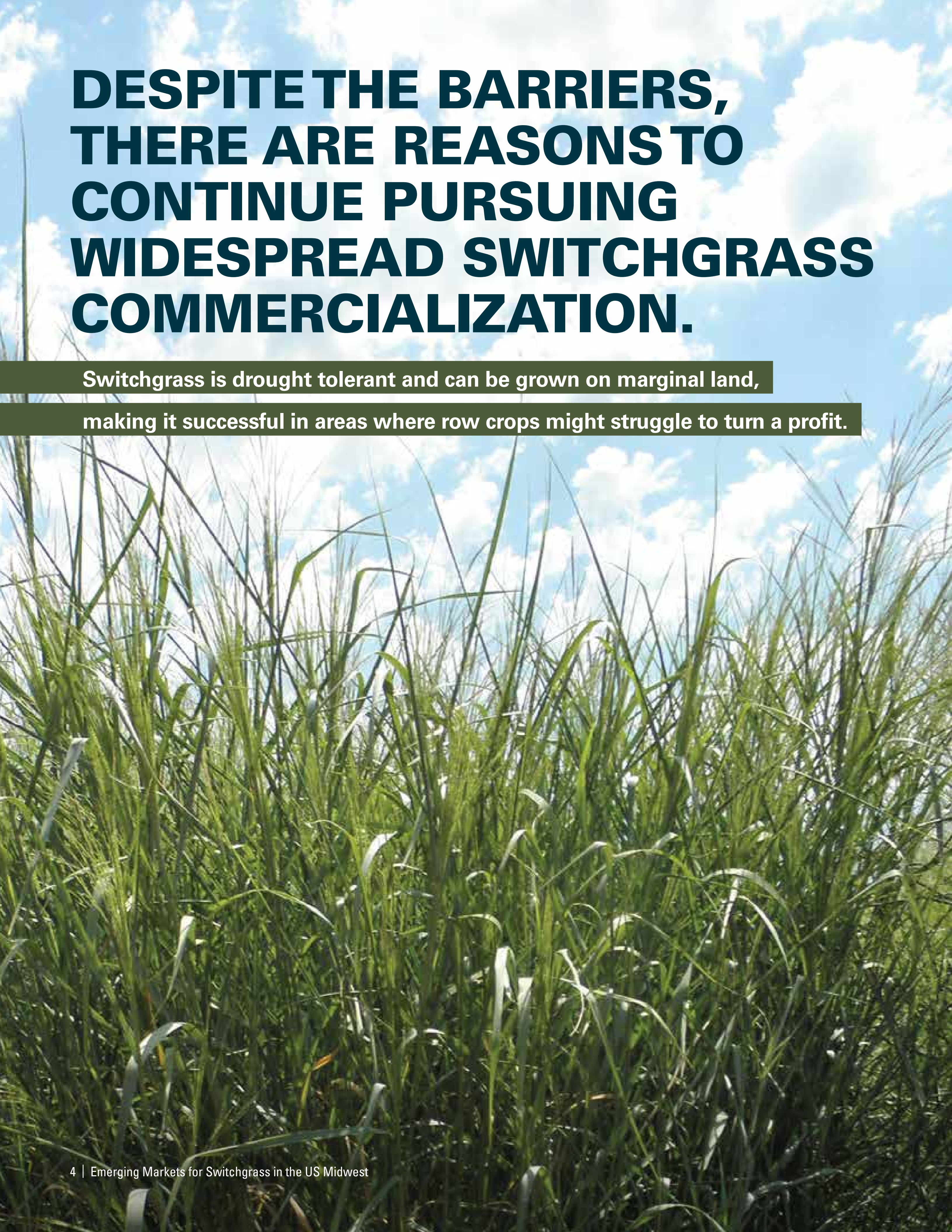


Figure 2: RFS Mandated Biofuels Production vs. Actual Production (Schnepf, 2010)

In the remainder of this article, we will outline the methods of switchgrass establishment and production, describe the costs associated with this production, provide a more detailed comparison between switchgrass and corn stover as feedstocks for lignocellulosic biorefineries, and then describe twelve niche markets into which switchgrass can be sold. In so doing, we hope the reader will gain an understanding of the opportunities and challenges facing this emerging feedstock.

SWITCHGRASS AND OTHER PERENNIAL GRASSES HAVE THE POTENTIAL TO BE ENVIRONMENTALLY-BENEFICIAL, HIGH-YIELDING SOURCES OF CELLULOSIC FEEDSTOCK.



DESPITE THE BARRIERS, THERE ARE REASONS TO CONTINUE PURSUING WIDESPREAD SWITCHGRASS COMMERCIALIZATION.

Switchgrass is drought tolerant and can be grown on marginal land, making it successful in areas where row crops might struggle to turn a profit.

Production — Switchgrass Management and Costs

Switchgrass (*Panicum virgatum* L.) is one of several perennial warm season grasses that grow naturally in North America (Vogel et al., 2014). CenUSA's 'Germplasm to Harvest' objectives centered around the development of new and improved switchgrass cultivars, optimizing the production systems of these feedstocks, and developing sustainable harvest, transportation, storage strategies for switchgrass, and analyzing feedstock production options. This initiative involved collaboration by researchers at universities across the Midwest.

A large part of CenUSA's feedstock development effort involved the development and release of 'Liberty' switchgrass, a new high-yielding cultivar designed to be grown in the US Great Plains and Midwest (Vogel et al., 2014). Trials in Nebraska found that Liberty switchgrass produced 40 percent more biomass than other cultivars of switchgrass. Rob Mitchell, Ken Vogel, and Mike Casler are CenUSA Co-Project Directors on Feedstock Development, who have conducted years of research on switchgrass. They explain that the higher yields are a result of three generations of cross-breeding, which produced a grass with a later flowering period and resilience to winter weather. They go on to explain that the later flowering provides valuable time for the plant to grow, leading to the higher yield. For this reason, Liberty production costs are lower than that of other cultivars (Mitchell & Vogel 2016). Given the current average Liberty yield of six tons/acre, the production cost of Liberty falls in the range of $46 to $74 per ton (Hoque et al., 2015).

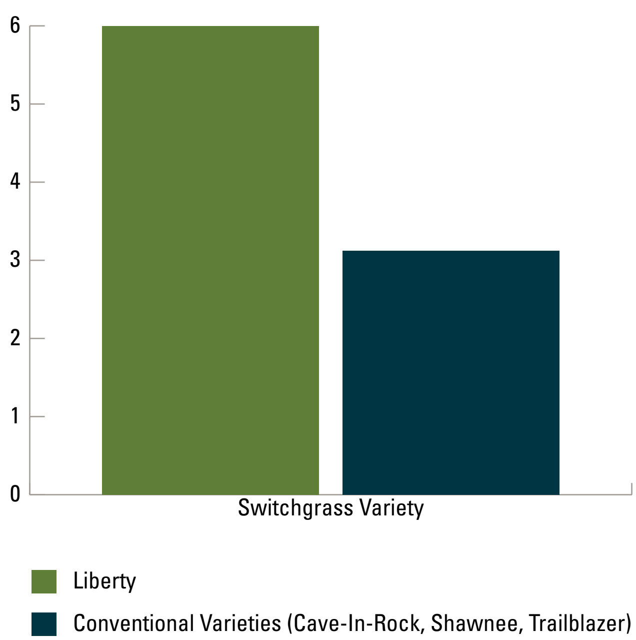


Figure 3: Switchgrass Cultivar Yield Comparison

An Iowa State research team led by Mainul Hoque and including CenUSA collaborator in Outreach & Extension, Chad Hart, concluded that the Liberty has a simpler and more efficient establishment period than traditional switchgrass varieties (Hoque et al., 2015). While other switchgrass cultivars take three years to establish, with Liberty, it's possible to produce a harvestable crop the year after seeding. Moreover, if the area where the switchgrass is to be grown has been used for crop production, not as much site preparation is necessary compared to pasture or brushland. Hoque's group also recommends planting soybeans on land that will seeded with perennial grasses the following year. Doing so lessens weed pressure, provides an income source to the farmers while the field is being seasoned for switchgrass production, and the subsequent soybean stubble provides cover for switchgrass establishment (Hoque et al., 2015).

While switchgrass can grow on marginal land that is currently not being used to grow crops, there are additional costs to consider when determining switchgrass profit margins. The main factors that contribute to the cost of producing switchgrass are seeds and planting, fertilizing, weed control, harvesting and renting the land.

Planting switchgrass in late spring, a few weeks after the corn planting period, is recommended. According to Michael Jacobson, a Penn State bioenergy researcher, soil tests are recommended to determine the soil fertility. These tests should be done before sowing the seeds to determine what type and what amount of fertilizer to use if the fields need fertilizing (Jacobson, 2015). As the grass begins to grow, it is important to provide timely management to ensure good yield. Weeds are the most common reason for stand failure, but will stop being an issue once the stand is well-established (Mitchell & Harlow, 2014). A stand may produce two to three tons of dry matter in its establishment year, (Hoque

et al., 2015) and a yield of five to seven tons per acre in the following years (Jacobson, 2015).

There are tradeoffs to harvesting before versus after the first frost of the season. By harvesting before the first frost, a higher yield of switchgrass will be collected (Serapiglia et al., 2017). However, by waiting to harvest the switchgrass until after the first frost, there is time for the nutrients in the plant to translocate to the roots, making them available for the next year's crop (Na, 2013). Appropriate harvest time also depends on the intended market use of the switchgrass. If the crop is being used for cellulosic ethanol production, harvesting later will give the grass time to dry out, making it better suited to combustion and storage (Na, 2013).

One of the most comprehensive commercial-scale studies analyzing the cost of switchgrass production in the Upper Midwest comes from Richard Perrin, who is a researcher at the University of Nebraska Lincoln, as well as a CenUSA collaborator on Markets & Distribution and Sustainable Feedstock Production Systems. Perrin and his team monitored the growth of common switchgrass cultivars such as 'Cave-In-Rock', 'Shawnee', and 'Trailblazer' (Schmer et al., 2006) at ten switchgrass production sites across North Dakota, South Dakota, and Nebraska (Perrin et al., 2008).). After five years, the team concluded the average switchgrass production cost to be $65.86 per Mg ($59.87 per dry ton) with a yield of 5.0 Mg/ha (2.23 tons/acre). When the data was projected out to a 10-year period, switchgrass production cost fell to $46.26 per Mg ($41.97 per ton) and yield was projected to increase to 7.0 Mg/ha (3.12 tons/acre) (Perrin et al., 2008).

A 2015 analysis by Penn State Extension found that farm-gate price for switchgrass hovers around $55 per dry ton (Jacobson, 2015). However, according to a 2015 survey of 1134 farmers in the North-Central United States, growers would need $230 per acre or $82 per dry ton to be motivated to grow switchgrass as a biofuel feedstock on their marginal land, which is roughly its value for livestock feed (Perrin et al., 2017).

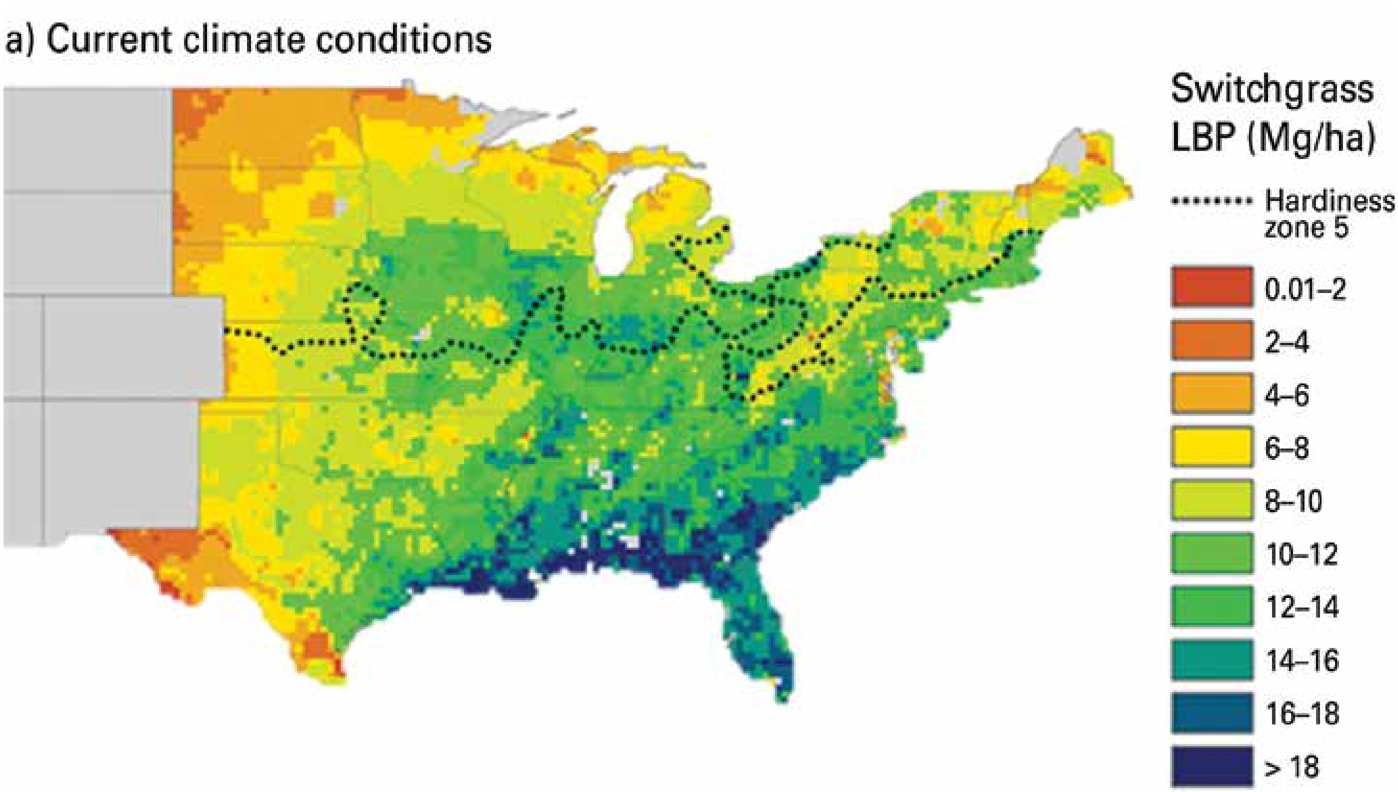


Figure 4: Other potential switchgrass production picture: Local Biomass Potential in different regions (Mg/ha)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Switchgrass vs. Stover for Cellulosic Ethanol

A significant potential market for switchgrass is large-scale commercialization as a cellulosic biofuel feedstock. A surge in cellulosic ethanol commercialization could lead to a significant decrease in the nation's carbon output – life cycle emissions of greenhouse gasses for cellulosic ethanol are estimated to be 86% lower than those from petroleum-based fuel sources (Wang et al., 2007).

However, creating an industrial-scale technology for conversion of cellulosic biomass to biofuels has proved to be challenging. In recent years, companies like DuPont and Abengoa spent hundreds of millions of dollars building cellulosic ethanol plants in the Midwest, and subsequently shut their doors without ever reaching commercial production (Stolark, 2017). These high-profile setbacks have cast doubt on the feasibility of commercial cellulosic ethanol production, but there is evidence to the contrary. One such counterexample is POET, the nation's second largest ethanol producer, who opened a cellulosic ethanol plant in Emmetsburg, Iowa in 2014, and was able to overcome a major pretreatment bottleneck in 2017. The company plans to ramp up production to its full plant capacity of 20 million gallons annually. VERBIO, a company with two cellulosic biogas production facilities in Germany, has acquired the Nevada, Iowa DuPont cellulosic facility with the intention of generating renewable natural gas from cellulosic feedstock (VERBIO, 2018). Although cellulosic ethanol production nationwide has not kept pace with the goals set by the RFS, commercial production went from zero gallons per year in 2013 to 10 million gallons per year in 2017, which indicates momentum for the industry (Schill, 2018).

The Abengoa, DuPont, and POET plants were designed to use corn stover, or the husks, stalks, leaves, and cobs left in fields after a corn crop is harvested (Kemp, 2015). At full capacity, the Emmetsburg POET plant is expected to require up to 850 tons of corn biomass per day (Gibson, 2011). Although stover is a good source of biomass, it is not technically a waste product – depending on the location and conditions of a field, leaving a layer of stover on a corn field can assist in maintaining soil health by preventing sediment erosion and replenishing carbon in the soil.

To ensure that feedstock would be available in the long term, DuPont chose to prioritize sustainable harvest of stover for its Nevada plant. The company approached this by first screening out vulnerable lands, which included any that produced less than 180 bushels per acre. Second, stover removal was limited to 2 tons per acre (Kemp, 2015). Even when taking precautions, a USDA study suggests that continuous partial stover removal significantly depletes soil organic carbon content, meaning continuous stover removal for cellulosic feedstock could be a detriment to corn grain yield (Halvorson and Stewart, 2015). The trade-off between soil health benefits and additional income forces producers to perform a balancing act. Those interested in selling their stover must make a careful analysis of their field conditions, upcoming weather patterns, and market trends before making the decision to harvest and sell a portion of their stover.

Alternatively, switchgrass has a myriad of environmental benefits and grows well on marginal land that may not produce a profitable row crop yield (Feng et al., 2016; Hartman et al., 2011). Switchgrass mitigates nutrient pollution from fertilizer, provides flood control, increases yield when used in a crop rotation, creates habitat for wildlife, and prevents soil erosion and sequesters carbon with its extensive root system (Blanco-Canqui et al., 2017). A survey of producers and others in the agricultural industry indicates that growers value the conservation and environmental benefits that switchgrass provides, but it is difficult to connect a monetary value to these benefits. It is unlikely that many farmers will be willing to convert the land they use for row crops to growing perennial grasses unless they can be certain that they will receive a competitive profit for doing so (Jacobs, 2015).

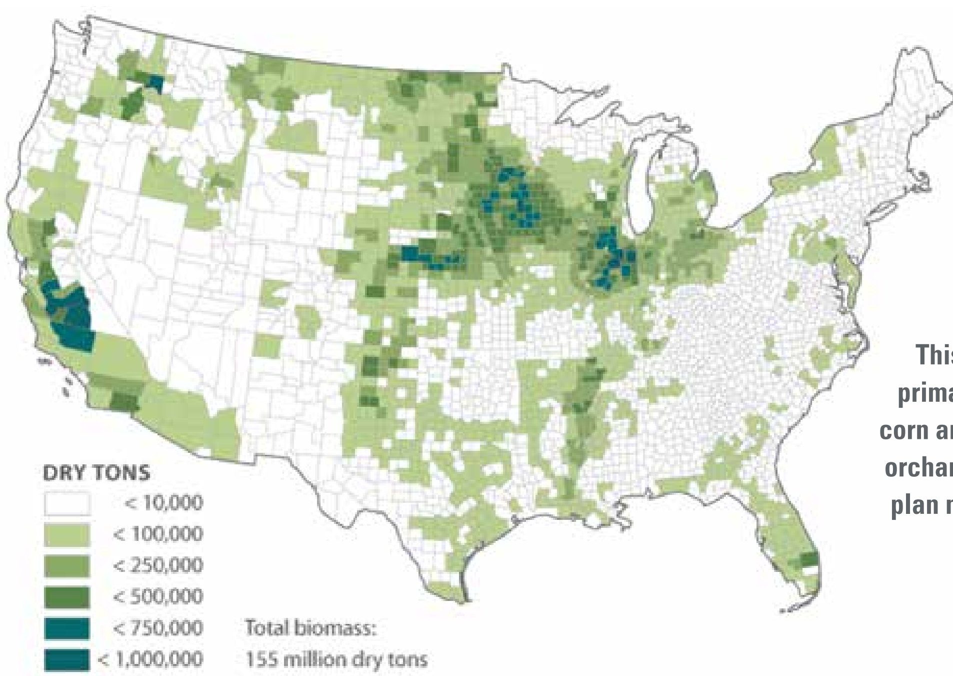
Both stover and switchgrass can produce approximately 80 gallons of ethanol per ton of dry yield, but stover has the advantage of being a byproduct of an already well-established crop, allowing producers to sell it for profit in addition to their corn grain (Fransen et al., 2010). The economic viability of harvesting stover depends on the price offered in comparison to the costs of harvest, collection, and storage of the biomass. The cost of additional fertilizer application must be factored in as well because if a field is stripped of a portion of its stover, fewer nutrients will be returned to the soil (Khanna and Paulson, 2016).


DANGER
HOT
SYNGAS

After accounting for these additional stover harvesting costs, a 2016 study from the University of Illinois determined that for high productivity farm land utilizing conventional tillage in a continuous corn rotation, stover would need to sell for $61.13 per dry ton to justify its harvest. For land with low productivity, this breakeven price jumped to $74.70 per dry ton of stover (Khanna and Paulson, 2016). A 2012 estimate from the University of Missouri placed prices for baled corn stover in the range of $60 to $100 per ton (University of Missouri, 2012). In other words, farmers may make a substantial profit from choosing to harvest their stover, or they may lose money, depending on their yield and the state of the market in any given year. This high volatility introduces another deterrent to corn growers interested in selling their stover.

At its current yield per acre and selling price, switchgrass is not an economically viable competitor for corn stover as an ethanol feedstock (Perrin et al., 2017). Switchgrass has the potential to be more profitable than corn on land that yields less than 60 bushels per acre (Perrin and Schmer, 2014), which is well below the average U.S. yield of 178 bushels per acre (Barrett, 2018). Although this may make switchgrass production seem impractical, repeated breeding of switchgrass strains, as with CenUSA's 'Liberty' cultivar, has resulted in consistent progress in increasing yield and biomass quality of the crop. If this progress continues, switchgrass will gradually become more profitable and thus more competitive against corn and corn stover (Mitchell, 2016). As manufacturers learn to overcome the technological challenges associated with this emerging industry, production will continue to grow, and increased production will require an increase in biomass feedstock. Additionally, as demand for feedstock increases, supply and logistic issues may drive up prices for corn stover, creating a gap in the market for switchgrass as a biofuel feedstock.

To reach the stage where mass quantities of switchgrass can be profitably sold to biorefineries, growers will need access to smaller "niche" markets for switchgrass as well. Niche markets are small, regional markets that farmers who are interested in growing switchgrass could start selling into. These alternative markets could provide immediate income for switchgrass growers, thus bridging the gap between the current state of the cellulosic biofuels industry, and the state when refineries are using switchgrass to produce biofuels on a commercial scale. In this paper, we discuss a variety niche markets into which switchgrass is currently being sold or might be sold to in the near future. Markets that are currently sourcing switchgrass from growers are placed first, followed by markets that could soon be sourcing switchgrass, with the most speculative markets placed last. While ideally, we would report the price switchgrass at which can be sold for into each individual market, information on this topic is extremely limited; therefore, we have summarized our price comparisons according to the cost of each switchgrass-derived product and the cost of its traditional competitor within each market.



This category is comprised of both primary and secondary residues from corn and small grains, as well as cotton, orchard prunings, and other parts of the plan not needed for food or other uses.

Figure 5: Potential Available Biomass from Agricultural Residues in the U.S. (Union of Concerned Scientists, 2012).

Individual Niche Markets

Absorbance

In Union Township, Pennsylvania, Ernst Conservation Seeds processes 10,000 tons of switchgrass into pellets each year. The 25,000 tons of pellets manufactured by Ernst seeds annually are shipped primarily to clients in Pennsylvania, Ohio, and West Virginia; a portion of the pellets go toward horse bedding, but most are used for liquid waste absorbance and disposal in drilling operations of nearby Marcellus Shale. Roughly 4,000 acres of land are used to grow the switchgrass, 2,000 of which are leased from local farmers who may have had marginal land where traditional row crops won't thrive. (Myers, 2015).

Switchgrass has other absorption applications in addition to drilling waste. MKB Stormwater Innovation, another Pennsylvania-based company, manufactures an erosion control sock for sediment and runoff control on construction sites. Switchgrass socks are more lightweight than traditional erosion socks filled with compost, making them easier and less costly to transport. In addition, spreading the switchgrass from the sock on-site after the sock has been used can aid in site restoration by promoting vegetative growth (MKB, 2018).

MKB is not the only switchgrass sock on the market. BEG Group, a biosecurity company based in Ohio, offers a USDA-certified switchgrass sock that can be used as a replacement for compost filter socks or for straw erosion wattles. Their 8" diameter switchgrass sock sells for $2.98 per linear foot (Biopreferred, 2019). Carter-Waters Construction Material, a construction supply company in the Midwest, sells a 9" diameter conventional straw wattle at a price of $50.50 for a 25' piece ($2.02 per linear foot) (Carter Waters Construction, 2018). Though the switchgrass variety is more expensive per linear foot, switchgrass socks have the advantage of being more lightweight and thus easier to transport than straw socks. Switchgrass producers in the Ontario area say that they've been offered contracts from U.S. based erosion control companies at a higher price than the current industry standard (Carter, 2018). This is evidence that there is a large enough market in place to support substantial production, but that growers in the region have not yet taken on the opportunity.

Cat Litter

Others have found a purpose for switchgrass in the pet industry. OurPets, a company based out Fairport Harbor, Ohio, manufactures a cat litter made from switchgrass and biochar. Conventional cat litter is made from clay; it is non-biodegradable, it creates dust, and is heavy. According to the company, a 10 lb bag of the switchgrass blend provides the same amount of litter box material as a 25 lb bag of conventional litter. A 10 lb bag of the OurPets litter sells for around $13.50, and while the price of conventional cat litter is highly variable depending on the brand, a 25 lb bag of conventional litter from one popular brand, Fresh Step, sells for $13.00 - $14.00 (chewy.com pricing). Not only is OurPets cost competitive, but market trends have also shown that consumers in the pet market have a growing interest in natural products. Sales growth of regular cat litter increases at a rate of about 2% annually, a rate proportional to the increase in cat ownership. The natural cat litter market, on the other hand, has seen a 15% annual expansion or higher in recent years (Caley, 2016).

Switchgrass, which OurPets sources from Pennsylvania, clumps well, traps and filters odors efficiently, and has antimicrobial properties (Kinzel, 2017). It requires minimal chemical application throughout its growth cycle, it's sustainable, environmentally friendly, and has a low price point, all of which translate to strong sales according to Steve Tsengas, the CEO of OurPets. Other natural materials have pierced the litter market – corn, wheat, and pine for example – but some of these are food sources, and have high demand in other markets as well, which makes them subject to price fluctuations. Corn also receives higher pesticide and fertilizer application than switchgrass, which is something that some consumers in the natural pet market may be leery of (Caley, 2016). The commercial success of OurPets as well as the rapid expansion of the natural litter sector may offer an exciting niche opportunity for switchgrass in the $2.5 billion cat litter industry (Kinzel, 2017).

Animal Bedding

Poultry Bedding

When switchgrass is chopped using a conventional Rotochopper, it produces a uniform material that can be sold and used as animal bedding. The poultry and dairy industries are the two animal production fields most in need of hygienic, affordable bedding options. Switchgrass has a few properties that allow it to perform well as an animal bedding: its low nitrogen content makes it biologically inert, and its high fiber strength enables moisture to evaporate quickly and distribute weight easily (Samson et al., 2018). Perdue Farms, one of the nation's largest chicken producers, has recently started to show interest in utilizing switchgrass as bedding in their production houses. They conducted a year-long study in four of their Delaware chicken houses, replacing their traditional pine shaving bedding with bedding processed from switchgrass (Wallfred, 2018). They found that chickens bedded with switchgrass were equal in weight, feed conversion, and mortality to those bedded with pine shavings, which is the industry standard. Pine shaving availability has recently been on the decline in some regions and thus is driving up prices (Moyle et al., 2016). Per poultry house, Perdue found that pine shavings cost $2,750 to mow, bale, and transport, while switchgrass cost $2,345 per house – a 15% savings (Porter, 2015). A modern poultry farm will have at least 6 production houses, which translates to a $2,430 savings if bedding is changed annually, a common practice in the industry (Fairchild et al, 2006). A large operation may have up to 24 production houses, which would translate to a $9,720 annual savings (Mastyl, 2016).

When a similar study was performed in 2015 by the University of Maryland on three commercial production houses, results comparable to the Perdue Farms study were witnessed: There was no significant difference in bird weight, feed conversion, livability, or footpad quality between birds bedded conventionally and those bedded with switchgrass (Moyle et al., 2016). With demand for antibiotic-free chickens on the rise, producers will require access to sanitary, disease-resistant bedding. Processed perennial grasses have efficient absorption and desorption processes due to their high surface area, which helps to keep barn moisture in the optimal range to prevent the spread of microbes, which can have adverse effects on bird health and ammonia formation. This property combined with their low nitrogen content helps prevent the occurrence of darkling beetles, one of the most prominent pests in the poultry industry. Combining the benefits of disease and pest reduction with the benefit of lower cost compared to wood shavings while having no significant difference in productivity could make switchgrass bedding an attractive prospect for chicken producers (Samson et al., 2018).

Additionally, the environmental benefits of switchgrass could help to offset poultry industry pollution. Broiler waste collected from production buildings is commonly spread on cropland. This waste is high in nutrients, and runoff from the farmland causes algae blooms in nearby water bodies and depletes them of their oxygen. The Chesapeake Bay, in particular, has seen an increasing issue with seasonal dead zones and loss of aquatic life due, in part, to the massive chicken industry in Maryland and Delaware (Reichert et al., 2011). Studies have demonstrated the potential of

Photo courtesy of Jordan Barstow, Grandview Farms, Manitoulin Island, Ontario CA

switchgrass to reduce nutrient loading in runoff (Wu and Zhang, 2007). Therefore, if switchgrass production became common near chicken production facilities in order to supply them with a readily-available bedding source, it could have the added benefit of helping to meet nutrient reduction goals in the Chesapeake Bay and other affected water bodies.

Dairy Bedding

Switchgrass is a promising alternative to conventional dairy barn bedding as well. The market for switchgrass as dairy bedding has recently taken off in Ontario, Canada where farmers turn to it as a low-cost replacement for cereal straw to use on dairy farms. In 2017, the Dairy Farmers of Canada financed a research project to compare conventional straw bedding to switchgrass bedding. The study involved two experiments, the first done with 9 dairy cows and the second with 24 cows, where the cows were housed in pens that contained three stalls – the first bedded with chopped switchgrass, the second with a switchgrass-carbonic magnesium lime combination, and the third with the industry standard bedding of straw on a rubber mat. Researchers discovered that given the option, cows preferred the untreated switchgrass over the other two options, and that the switchgrass showed equivalent results in lying time, injury, and teat-end bacteria to wheat-straw (Wolfe et al., 2017). Switchgrass has shown to be superior to wheat-straw in terms of pathogen accumulation in dairy barns due to its lower moisture and nitrogen content. In Ontario, where switchgrass has started to find a market in commercial dairy operations, the cost of delivered switchgrass bedding is $0.08 per pound, while the cost of wheat straw bedding is $0.07 per pound (Samson et al., 2018). The University of Madison-Wisconsin estimates that roughly 25 lb of straw bedding is added to the bedded area per cow per day (UW-M, 2019), which results in a $0.25 price difference per head per day.

In addition to wheat straw, other common types of dairy bedding include sawdust or sand. Sand allows very little bacterial growth and results in the lowest amount of hock injuries in cows, making it the preferred bedding choice for many. However, sand is easily compressed by cows, so it requires continual maintenance to re-form a looser bed, which adds to producer costs. It is also poor insulator, making it less comfortable in the winter months, and it tends to cause significant wear and tear on manure-handling equipment. Wood shavings and sawdust provide reasonable cow comfort, but don't absorb moisture as efficiently as grass bedding. They are also abrasive and tend to cause splinters and high amounts of hock injuries in cows (Samson et al., 2018).

It is also common for used dairy bedding to be applied to fields as a soil amendment, and switchgrass bedding has the advantage of having a high nutrient availability, effectively increasing soil organic matter when spread on land, as opposed to sand or wood shavings, which do not make effective soil amendments (Samson et al., 2018). There are more than 9 million dairy cows in the United States; if farmers are made aware of switchgrass as an affordable alternative to their current bedding practices, a prosperous localized market for switchgrass growers could develop.

Horse Bedding

Switchgrass can also be pelletized for use as horse bedding. Conventional horse bedding is primarily chopped or pelleted straw or wood shavings due to their low cost and high absorbency. However, horses find straw bedding palatable and tend to eat it, and wood shavings can lead to the inhalation of dust and particles by the horses, both of which create health concerns (Pfister, 2017). Pelletized switchgrass bedding is highly absorbent, not palatable to horses, and allows selective removal of waste-contaminated bedding. The switchgrass horse bedding market has been on the rise in recent years and is readily available in the Northeastern United States (Cherney, 2011). Pennsylvania's Ernst Conservation Seeds sells pelleted switchgrass for horse bedding at a unit price of $0.16/lb (Ernst Seeds). A comparable pine pellet horse bedding may sell for a unit price of $0.15/lb.

Mulch

Switchgrass has many properties that make it a promising source for mulch production. On a farm-scale operation, switchgrass has been shown to work best for crops that are grown in cool-to-warm conditions; these include strawberries, blueberries, and garlic. In 2008, Quebec strawberry farmers began looking to switchgrass as a source for mulch in a bid to increase the survival rate of their crops throughout the winter months, and have had success in the decade since. Due to its high cellulose content, switchgrass is an exceptional insulator. It keeps soil temperatures cool during the day and prevents heat loss at night. It also decomposes more slowly and has a higher structural strength than cereal straw, a more commonplace mulch component, which allows it to better resist snow loading. Switchgrass also has potential in nursery, home garden, and landscaping applications. Its low nitrogen content suppresses weed germination, and its moisture trapping capabilities allow any retained water to infiltrate slowly into the soil (Samson, 2018).

The booming mushroom market may provide a source of income for switchgrass growers as well. One of the primary components of the substrate used for mushroom farming is wheat straw, and farmers have seen an escalation in wheat straw demand in recent years which they credit in large part to the growing mushroom market. According to Bill Lozier of Pacific Ag, "A big mushroom farmer may buy more than 30,000 tons a year." However, it hurts farm production to bale and export straw many consecutive years in a row. This is because straw is a byproduct of grain in the same way stover is a byproduct of corn: when its left on the field, straw replenishes organic matter as well as nutrients to the soil. According to Stephen Guy, an agronomist at Washington State University, baling straw year after year will start to take a toll on grain yield (WashU Extension, 2015). Additionally, the wheat straw market is sensitive. An extended winter in 2018 led to a Midwest hay shortage creating a market for straw, which in turn left mushroom growers low on substrate and struggling to keep up with demand (Rajamanickam, 2018).

Switchgrass does not face the same price pressures as hay. What's more, a study done by Mushroom Canada determined that growers can replace up to 40% of their conventional substrate mix with switchgrass without sacrificing mushroom yield or quality (Schaer, 2016). The Sustainable Agriculture

Research and Education program found that in Wisconsin, baled switchgrass mulch could be purchased for prices ranging from $5 - $14. Comparatively, straw mulch may sell for $4 - $5 per bale and pine straw mulch may sell for $8.50 - $9.50, making supplementing with switchgrass economically feasible for Midwest growers (Ends, 2012). Kent, Pennsylvania alone produces more than 1 million pounds of mushrooms each day (Segal, 2017). The stretches of marginal land that have been left behind by strip mining in Pennsylvania provide ample area for switchgrass production without having to compete with food crop production, which could create a localized market for switchgrass (Duke, 2017).

Forage

In addition to bedding, another potential market for switchgrass within the livestock sector is as forage or roughage in cattle diets. Perennial grass growth aligns well with the summer grazing season, and switchgrass in its young, leafy stage produces forage high in yield and nutrient content. Switchgrass tends to produce higher quality hay for grazing than tall fescue grass, which is the pasture grass most commonly utilized in the Mid-South. This is because switchgrass is a warm-season crop; the bulk of its growth occurs when hay making conditions (dry, warm temperatures) are at their best. Switching from tall fescue to switchgrass for grazing operations could increase the performance of grazing cattle. The forage market also allows switchgrass to be grown as a “dual-purpose” crop. Early growth can be hayed or grazed, while the later growth can be allowed to mature and harvested after the first killing frost to be used as biofuel feed stock, or as roughage (Bates et al., 2018). Planting switchgrass for forage may allow cattle farmers to cut costs in areas such as Nebraska, where high pasture rental rates can put a financial strain on farmers (Clark, 2017).

Roughage

Roughage is a cattle feed component containing indigestible fibers to promote rumen health. Traditional cattle roughage is primarily hay, silage or cornstalks, but recent studies have demonstrated switchgrass’s potential as an effective roughage source. A study of 247 steers found that those that were fed switchgrass as roughage had comparable weight and carcass data to those that were fed corn stalks (Clark and Harlow, 2017). Furthermore, cows tend to nitpick and sort through their food when fed corn stalks, but have been shown to eat more consistently when switchgrass is used as their roughage ration (Peterson, 2014). The value of switchgrass as a livestock feed is expected to be roughly $95 per ton of dry matter. Because hay prices tend to be in the $80-per-ton range, switchgrass may have more value as a livestock feed than as a cellulosic feedstock in the current state of the market.

Energy Generation

Commercial Boilers

There are potential energy applications for switchgrass outside of the cellulosic ethanol industry as well. In the Southeastern United States, it’s common for facilities to

use biomass systems, fueled primarily with woodchips, as a cheaper alternative to heating oil (Porter, 2015). Piedmont Geriatric Hospital in Burkeville, Virginia had one such system, utilizing sawdust as a biomass source to heat its facility. However, the availability and quality of sawdust declines throughout the winter months, and thus is subject to price fluctuations. This motivated the hospital to start experimenting with using switchgrass as part of their feedstock mix in 2006. The staff saw a substantial increase in steam output as well as a cost reduction when compared to their prior system (Sarisky-Reed, 2017). When compared to fuel oil over the winter months, the hospital claims that the switch to perennial feedstock saves taxpayers $1300 a day in heating costs. Commercial boilers such as these have the largest likelihood to take off in rural areas; the hospital in Burkeville doesn't have access to natural gas due to its location. FDC Enterprises, the company that processes the grasses used in Piedmont Geriatric, sources its grass from nearby farmers. The company plans to begin supplying additional facilities in the coming years. Each of these facilities has the potential to create a profitable switchgrass market for local farmers in the same way the Burkeville hospital has (Porter, 2015 and Wilson, 2013).

Fuel Pellets

Pelletized switchgrass similar to that produced at Ernst Farms could partially replace home heating oil in the Northeast, where residential heating is largely fueled by heating oil. In 2013, Paul Adler of the Agricultural Research Service performed a study comparing the life cycle emissions and heating cost of switchgrass pellets for home heating to other traditional fuel sources: coal, natural gas, and petroleum-based home heating oil. Greenhouse gas emissions generated by switchgrass were determined by analyzing switchgrass production, densification into pellets or cubes, and conversion to heat and power. For every ton of switchgrass planted, harvested, and transported to a processing plant, 192 lb of CO2 equivalent were emitted, the majority being NOx due to switchgrass' high nitrogen content. Processing the material into pellets resulted in an addition 287 pounds of CO2 equivalent per ton of dry matter. When comparing these life cycle emissions to those of fuel oil for home heating, switchgrass emits 145 lb less of CO2 equivalent per gigajoule of residential heat generated. When compared to natural gas, switchgrass pellets generate 158 fewer pounds of CO2 equivalent than natural gas used for heating (Wilson et al., 2011).

Adler's team also analyzed fuel product prices, and found that after accounting for annual capital plus fuel costs, each gigajoule of heat generated by switchgrass pellets in a residential setting would cost $21.36. The same amount of heat produced by fuel oil would cost $28.22, based on 2010-2011 heating oil prices. When determining how replacing fuel oil with switchgrass could affect the Northeastern U.S., Adler referenced the U.S. Department of Energy's Billion Ton Report, which states that by 2022, there could be enough sustainable biomass in the region to completely replace fuel oil as a heating source. In this scenario, consumers would save between $2.3 and $3.9 billion per year in fuel costs and prevent roughly 885 million tons of CO2 equivalent emissions (Wilson et al., 2011).

Areas like Vermont, where using wood biomass in pellet stoves is the conventional form of home heating, also pose a market opportunity for switchgrass fuel pellets. Vermont has the highest concentration of advanced wood heating systems in the United States, and has set a goal to meet 90% of the state's energy needs with renewables (including wood) by 2050 (Juillerat and Sherman, 2017). Vermont also has 84,000 acres of idle cropland, with a large portion being marginal (VGEP, 2011).

In 2011, the Vermont Grass Energy Partnership set out to determine if pelletized grasses could effectively replace wood pellets as a heating source. In comparing three grass varieties to wood pellets, measured in BTUs/lb of pellets burned, switchgrass had a slightly higher energy value than the wood pellet control group and far outperformed the other two grasses. Although these results are promising, switchgrass pellets pose a challenge in boilers designed to burn wood pellets due to their higher ash content. There are few residential-sized boilers on the market compatible with pure grass fuel; grass pellet heating has seen more success in commercially-sized boilers, such as in greenhouses or grain dryers. Alternatively, a blend of switchgrass pellets and wood pellets can be used rather than relying purely on either – with Vermont's wood pellet market steadily increasing, a 20% switchgrass substitution would be more efficient than pure wood pellets and still create a sizable market for the crop (VGEP, 2011).

Paper Making

Research suggests that switchgrass has several potential applications in materials manufacturing as well. One of these applications is paper making. Traditional paper making involves using the Kraft Pulping Process to convert wood biomass into pulp. This pulp consists almost entirely of cellulose fibers, which are the main component of paper. Switchgrass has a high cellulose content, making it a candidate for a wood replacement in paper manufacturing (Madakadze et al., 2010). According to the Economist, despite the 'digital era' we're seemingly living in, worldwide paper consumption has increased by half since 1980 (The Economist, 2012). The United States imports most of its lumber from Canada, and in 2018, prices for this lumber hit record highs (Tobin, 2018). The combination of environmental concerns as well as a shortage of wood fiber has resulted in non-wood pulp production increasing faster than wood pulp production. A study done by the University of Pretoria, South Africa in partnership with the Pulp and Paper Research Institute of Quebec set out to find if two types of perennials, elephant grass and switchgrass, are suitable for pulp production, and found that both species could be pulped easily using the Kraft Pulping Process (Madakadze et al., 2010).

Resource Efficient Agricultural Production (REAP) Canada, an organization with a focus on exploring and encouraging the production of perennial bioenergy crops, also evaluated the pulping ability of switchgrass, and found that it had similar yields to wood. Perennials can be harvested annually, and produce more fiber per acre of land than hardwood trees,

the primary papermaking feedstock. Perennials also have the potential to be grown within a smaller radius of pulp mills. If plant breeding continues to produce higher perennial grass yields and pulp and paper making processes are adapted to be compatible with agri-fibers, pulping lines for perennials could be integrated into already existing pulp mills. In addition, paper companies could benefit from a fiber supply that would be available for years at a time; this could result in long-term switchgrass production contracts for local farmers, providing them a guaranteed revenue for the crop (Girouard and Samson, 2000).

Medium Density Fiberboard

Another application where switchgrass could serve as a substitute for wood is in the manufacturing of medium density fiberboard (MDF). MDF is a manufactured wood product made up of wood fibers mixed with resin and wax and pressed into flat panels. Unlike particle board, it cuts well and can be painted, and is used commonly for molding, laminate flooring, and cabinets, among other uses. The University of Sopron in Hungary was the first organization to conduct a study on the use of energy grasses to produce MDF. Their aim was to study the mechanical properties of MDF boards mixed with wood fibers at different concentrations when constructed with three types of adhesives. Energy grass fiber was evaluated at concentrations of 20%, 40%, 60%, 80%, and 100%, with the complementary amount being wood fiber. With one adhesive, Melamine Urea Formaldehyde (MUF), grass fiber performed similarly to boards made from 100% wood fiber for modulus of elasticity, modulus of rupture, and internal bond strength. Wood only performed better in thickness swelling – the swelling of the board due to a change in moisture content – which is likely due to the water adsorption of the grass being slightly higher than that of the wood fiber. Fiberboard has a standard thickness swelling requirement of 35% or lower; this requirement was met in mixtures of up to 60% energy grass, indicating that it may be more practical to utilize a mixture of grass and wood fiber (Alpár and Markó, 2017).

Bioplastics

Perhaps the most speculative market for switchgrass is in the bioplastics industry. Polyhydroxybutyrates (PHBs) are molecules that can be produced with properties that resemble non-renewable plastics, the major difference being that they are biodegradable – when disposed of, they will break down into CO2 and water. Metabolix Inc. has been using microbial fermentation to produce PHBs since 2001. Their PHB resins have been used in gift cards, pens, and biodegradable planting pots, but the biggest application has been in compost bags in Europe (Ebert, 2008; Howard, 2014). Though the molecules are currently produced commercially using microbes, Metabolix has long had the intent of using plants, particularly switchgrass, to produce these bioplastics (Yield10, 2015).

Metabolix has made progress producing PHBs in plants, but they have learned that as PHB levels increase in switchgrass, plant growth and yield is impaired. This result was not unexpected, as a fraction of the fixed carbon in plants is diverted to produce the PHB. After discovering this, the company went on to focus on developing new genetic and

informatic tools to enhance the photosynthetic capabilities of switchgrass in an attempt to utilize the remaining fixed carbon more efficiently. In 2015, they redeployed their crop science program under the name Yield10 Bioscience. Yield10 aims to improve crop productivity and seed yield in switchgrass by boosting CO2 fixation efficiency, as well as CO2 direction and conversion into plant matter. They have witnessed yield improvements in switchgrass and camelina oilseed, their two crops of interest. Although this switchgrass application is still in its experimental phase, if progress continues to be made, an exciting new niche market for switchgrass could develop (Yield10, 2015).

Renmatix

Another nascent but promising market for switchgrass is in the production of industrial sugars. Renmatix is a company working toward the use of biomass to derive cellulosic sugars that can be used to manufacture biofuels and chemicals. In 2014, CenUSA added a Commercialization objective to its portfolio, and partnered with Renmatix to seek expanded commercial opportunities for perennial grasses. Renmatix has developed their patented Plantrose® Process which uses water at a high temperature and pressure to break down biomass into industrial sugars. These sugars can then be used to manufacture a wide variety of products: for example, xylose and glucose extracted from the plant material can be used to make fibers or biofuels, while extracted lignin can be used as a substitute for fossil fuels in heat and electricity production.

The Plantrose® Process works on a variety of feedstocks, but Renmatix focuses exclusively on sources that don't compete with food: this includes wood residue, corn stover, and perennial grasses. Conventionally, biomass is converted into cellulosic sugars through the use of pricey enzymes and acids which require expensive equipment and produce small volumes of sugars. By using two of nature's most abundant resources, plants and water, Renmatix has made the process not only more affordable, but more sustainable too. At their Pennsylvania headquarters, Renmatix is looking into Liberty switchgrass, big bluestem, and indiangrass as biomass sources as they prepare to commercialize their process (Harlow, 2016).

Mine Reclamation

Although farmers may be reluctant to convert productive land used for row crops into land used for perennials, there are areas of the United States where stretches of marginal land sit unused. Surface coal mining in the Appalachian region has created a vast expanse of deteriorated land. An estimated 4.9 million hectares of land across West Virginia, Kentucky, Virginia, and Tennessee have been affected by surface mining (Brown et al., 2015). Although these lands have been reclaimed to regulatory standards, they remain in a condition that makes them marginal for cash crop production. Reclaimed mine soils tend to be nutrient deficient, contain toxic substances, and have poor moisture regimes and restricted rooting. Because of this, the primary land use for reclaimed mine lands in West Virginia tends to be cool-season grasses or legumes for pasture production. This creates a unique locality for switchgrass production – because it is robust, researchers believe that planting switchgrass rather

than the typical pasture crops grown in Appalachia may be better suited to the limited fertility that the land provides (Keene and Skousen, 2010).

A series of experiments performed by West Virginia University aimed to find out if switchgrass grown on reclaimed mine land could reach the same production potential that is seen on standard agricultural land in the surrounding area. When sludge consisting of sewage waste and paper mill pulp was applied to the mine soil before planting, switchgrass yields ranged from 5.7 Mg per hectare (2.5 tons per acre) to 19.0 Mg per hectare (8.5 tons per acre) after the sixth year of establishment. In comparison, the average switchgrass yield in the remainder of West Virginia ranges between 13.8 Mg per hectare and 16.6 Mg per hectare (Brown et al., 2015).

With evidence that switchgrass production in reclaimed mine soils has the potential to provide comparable biomass yield to switchgrass grown in the surrounding region, it is reasonable to believe that switchgrass production on these lands could become a more profitable crop than the current standard grass and legume production. Switchgrass could produce a profitable crop in Appalachia while continuing to offer the same benefits as the conventional grasses and legumes, such as erosion control, sedimentation and nutrient runoff reduction, and carbon sequestration. Large-scale production on reclaimed mine lands could increase soil fertility while also offering habitat space for wildlife that may have been previously driven out of the region (Keen and Skousen, 2010).

Because of its comparatively lower value to corn and soybeans, it is unlikely in the near future that switchgrass will be economically competitive with food crops on land that is agriculturally productive. Therefore, utilizing reclaimed mine area for switchgrass production could give the crop an advantage by providing an extensive land base to begin producing high amounts of biomass for the ethanol industry (Skousen and Gutta, 2013). Beginning large-scale switchgrass production in these regions could also spur other niche markets in the area. For example, Pennsylvania is facing a similar problem to that of West Virginia; thousands of acres of land that were previously used for strip mining sit un-reclaimed or unused. Marvin Hall, an agronomist at Penn State University, is in the process of conducting a study to determine if switchgrass can be grown profitably on these marginal lands. Pennsylvania has seen a variety of emerging switchgrass markets in recent years – these include switchgrass processed for mulch production, or for erosion control and absorption devices – if production on reclaimed strip mines is successful, these small, localized markets could be spurred into expansion by an increased availability of switchgrass biomass (Duke, 2017).

A summary of price comparisons according to the cost of each switchgrass-derived product and the cost of its traditional competitor within each market is shown on the next page.

MARKET	PRODUCT	COST	UNIT
Dairy Bedding	Switchgrass	0.08	lb
	Wheat Straw	0.07	lb
Poultry Bedding	Switchgrass	2,345.00	poultry house
	Pine Shavings	2,750.00	poultry house
Horse Bedding	Switchgrass Pellets	0.16	lb
	Pine Pellets	0.15	lb
	Alfalfa Pellets	0.35	lb
Roughage	Switchgrass	55.00	ton
	Grass Hay	160.00	ton
	Wheat Straw	75.00	ton
Cat Litter	OurPets Switchgrass Biochar Mix	13.49	10 lb bag*
	Fresh Step Clay Mix	12.99	25 lb bag
Home Heating	Switchgrass Pellets	21.36	gigajoule of heat
	Heating Oil	28.22	gigajoule of heat
Construction Absorbance Socks	Switchgrass Socks	2.98	linear foot 8” sock
	Straw Socks	2.02	linear foot 9” sock
Mulch	Switchgrass	5.00 - 14.00	bale
	Straw / Hay	4.00 - 5.00	bale
	Pine Straw	8.50 - 9.50	bale

**OurPets claims that a 10 lb bag is equivalent to 25 lbs conventional clay litter*

Figure 5. Switchgrass Product Cost Comparisons


EXIT
ALUM-LINE

WITH CONTINUED BREEDING AND IMPROVEMENT TO YIELD AND BIOMASS QUALITY, SWITCHGRASS COULD BECOME MORE COST COMPETITIVE AS A CELLULOSIC FEEDSTOCK, AS WELL AS A MATERIAL SOURCE FOR THE NICHE MARKETS IDENTIFIED IN THIS PAPER.

Conclusion

As the cellulosic ethanol industry continues to overcome hurdles and scale up production, ethanol manufacturers and corn producers may find that sustainable, affordable stover removal for cellulosic feedstock is less feasible than previously thought. As a result, the cellulosic industry may begin to look to switchgrass as a more reliable feedstock source. In the meantime, there is a myriad of potentially profitable opportunities in localized niche markets for switchgrass producers. The nutritional content of switchgrass gives it value as livestock forage and roughage; its absorbance and antimicrobial properties make it an effective component of livestock bedding, cat litter, and sediment control devices; its high cellulose content gives it potential in materials manufacturing, from particle board to bioplastics, and it can serve as a promising substitute for home heating oil or wood biomass boiler fuel.

Some of these markets have a higher likelihood of taking off than others - Canada has seen success developing fuel pellet, livestock bedding, and absorbance markets for switchgrass, indicating that these markets could find footholds in the United States as well. Some U.S. manufacturers, in the case of switchgrass absorbance socks, have even started sourcing their grass from Ontario due to lack of supply locally, revealing a production gap to be filled if U.S. growers begin to take interest (Brandau, 2018). Because it is robust and drought tolerant (Blanco-Canqui et al., 2017), producers can utilize switchgrass on their marginal land where they might struggle to get a reasonable yield of corn or soybeans. The vast expanses of reclaimed surface mine land in the United States also pose a considerable opportunity for switchgrass production.

With continued breeding and improvement to yield and biomass quality, switchgrass could become more cost competitive as a cellulosic feedstock, as well as a material source for the niche markets identified in this paper. With sufficient expansion of these niche markets, widespread switchgrass production could provide a supplemental income to farmers throughout the Midwest and beyond, as well as providing invaluable environmental services to farmland and the ecosystems that surround it. Ultimately, a well-established land base of switchgrass growth could result in a reliable feedstock source for a commercial-scale cellulosic ethanol industry.

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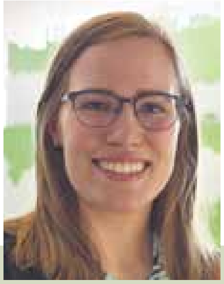
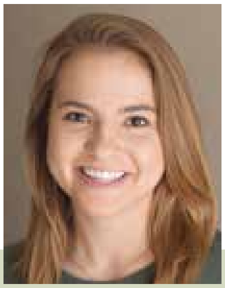


Breanna Dykstra

Bre Dykstra is a CenUSA Bioenergy Undergraduate Research Intern and a co-author of this paper. Bre is a Biological Systems Engineering major at Iowa State University. After graduation, she is interested in pursuing a career in product development and food quality.



Alyssa Iverson

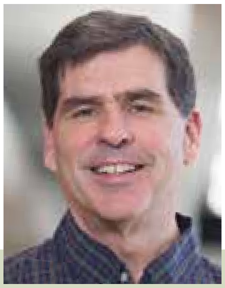
Alyssa Iverson is a CenUSA Bioenergy Undergraduate Research Intern and a co-author of this paper. Alyssa is studying biological systems engineering at Iowa State University and after graduation, she will be pursuing her Masters with a focus in water resources engineering.

Keri Jacobs

Dr. Keri Jacobs served as a faculty advisor for this publication. She is an associate professor of economics and extension economist at ISU. Dr. Jacobs is a Co-PI on the CenUSA project, primarily investigating the market barriers to production of dedicated biomass and exploring the conditions and incentives necessary to achieve commercial-scale production.

Anne Kinzel

Anne Kinzel supervised the development of this paper as is the CenUSA Bioenergy COO and Assistant Director of the Iowa State University Bioeconomy Institute.



Ken Moore

Ken Moore is the Project Director of CenUSA Bioenergy and a Charles F. Curtiss Distinguished Professor in Agriculture and Life Sciences at Iowa State University.

Raj Raman

D. Raj Raman served as a faculty advisor for this publication. He is a Morrill Professor of Agricultural and Biosystems Engineering (ABE) Department at Iowa State University. Dr. Raman is a Co-PI on the CenUSA project, directing the Education Objective.

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