cenusa bioenergy

Annual Progress Report

Executive Summary

Agro-ecosystem Approach to Sustainable Biofuels Production via the Pyrolysis-Biochar Platform

September 2016

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Agro-ecosystem Approach to Sustainable Biofuels Production via the Pyrolysis-Biochar Platform (AFRI-CAP 2010-05073)

Project and Objective Executive Summaries - August 1, 2015 – July 31, 2016

Executive Summary – Feedstock Development Objective

The Feedstock Development Objective continues to focus on developing perennial grass cultivars and hybrids that can be used on marginal cropland in the Central United States to produce biomass for energy. Year 4 focus is on selection and breeding of switchgrass.

Co-Project Directors

- Mike Casler, USDA-ARS, Madison, Wisconsin, michael.casler@ars.usda.gov, 608.890.0065.
- Rob Mitchell, USDA-ARS, Lincoln, Nebraska, Rob.Mitchell@ars.usda.gov, 402.472.1546.

Significant Accomplishments – Year 5

- Developed initial NIRS calibrations for biomass quality traits that include multiple species of warm-season energy grasses.
- Developed two new late-flowering switchgrass populations and two new late-flowering big bluestem populations with biomass yield estimates about 25-30% higher than for ‘Liberty’ switchgrass.
- Completed chemical compositional analysis of mixed grass species.
- Evaluated hydrolysate sugars that were prepared by industrial partner Renmatix from switchgrass for conversion to single cell oil.
- Measured extractable sugar yields from ‘Liberty’ and ‘Summer’ switchgrass planted in Arlington, Wisconsin on a per hectare basis using an integrated bioprocess.
- Completed evaluation of forage and new biofuel switchgrass populations for rust resistance across the North Central region. Found ‘Kanlow’ and Kanlow-derived populations to exhibit high rust resistance across North Central environments and the resistance was expressed against both species of rust pathogen *Puccinia emaculata* and *Uromyces graminicola*.
- Determine that the two rust fungi exhibit different temporal dynamics in causing rust disease in switchgrass. The onset of infection differs between the two species, this difference likely

to be due to differences in environmental requirements for switchgrass infection. In addition, *Uromyces graminicola* exhibits a shorter duration between from uredinial (infecting spore) formation and telial (resting spore) formation than *Puccinia emaculata*. This suggests that *P. emaculata* produces infectious spores over a longer period and could explain observations that rust disease caused by *P. emaculata* tends to be more severe than that of *Uromyces graminicola.*

Planned Activities, Outcomes, and Impacts - Year 6

- Establish seed multiplication fields of four new late-flowering candidate cultivars (two switchgrasses and two big bluestems) in central Illinois. Seed to be harvested in 2018 will be made available to NIFA CAP projects with interest in perennial energy grasses for the central USA.
- Complete all data analyses of 2012 and 2014 multi-location cultivar biomass trials. Prepare one manuscript summarizing results.
- Complete the remaining data analysis and prepare two manuscripts summarizing our efforts to optimize genomic prediction for biomass yield of switchgrass.
- Complete data analysis and manuscript preparation for optimizing selection methodology to increase biomass yield of switchgrass.
- Conduct compositional analysis on ‘Liberty’ switchgrass samples harvested at various heights.
- Analyze Liberty and Summer switchgrass samples grown in Arlington, Wisconsin for conversion to ethanol.
- Complete writing of paper describing differential resistance to rust disease among switchgrass populations and submit paper for publication in a refereed journal.

Executive Summary – Sustainable Feedstock Production Systems

This CenUSA Bioenergy objective focuses on conducting comparative analyses of the productivity potential and the environmental impacts of the most promising perennial grass bioenergy crops and management systems using a network of 14 fields strategically located across the Central United States. The goal is to produce a quantitative assessment of the net energy balance of candidate systems and optimize perennial feedstock production and ecosystem services on marginally productive cropland while maintaining food production on prime land.

Co-Project Directors

- Robert Mitchell, USDA-ARS, Rob.Mitchell@ars.usda.gov, 402.472.1546.
- David Laird, Iowa State University, dalaird@iastate.edu, 515.294.1581.
- Jeffrey Volenec, Purdue University, jvolenec@purdue.edu, 765.494.8071.

Significant Accomplishments – Year 5

Studies in this Objective aim to optimize biomass production by placing the best biomass production system (species, cultivar within a species) in its adapted environment and providing adequate, but not excessive inputs (nutrients, water,…) to minimize production costs while protecting the environment. The following brief vignettes illustrate the importance, and challenges, associated with these studies:

- On most sites studied in the upper Midwest, the switchgrass cultivar 'Liberty' developed in Task 1 explicitly for biomass production out-yielded the best "forage-type" switchgrass cultivars available.
- At locations with severe winters (Minnesota) some plots of 'Liberty' switchgrass were injured and biomass production was reduced.
- *Miscanthus x giganteus* also has high biomass yield at most locations in the Midwest, often double the yield of the best switchgrasses available. However, this species is clonally propagated making establishment costs high, and since all plants are genetically identical, predisposing this perennial to widespread disease and insect attack.
- Soils with nutrient levels (N, P, K) that would restrict growth and yield of maize, alfalfa, and most other agronomic crops support high yields of switchgrass and *Miscanthus x giganteus* for multiple years (>5) without supplemental P and K fertilization and only modest (50 kg/ha/yr) N inputs.
- Annual biomass systems (sorghum, maize, small grains, etc.) are production systems familiar to farmers, and this familiarity may accelerate biomass production integration into the Midwest landscape.
- Sorghum can out-yield perennials like switchgrass and *Miscanthus x giganteus*, and other annuals like maize in certain extremely marginal sites (drought, landfills, etc.) and requires fewer inputs (N, water, P, K, etc.) than maize.
- As compared to established perennial systems, annual biomass production systems (maize, sorghum, etc.) are vulnerable to weather events that interfere with farming operations (planting, N fertilization, herbicide applications, etc.) and have a different level of risk associated with production.

- Species differences in biomass composition (cellulose, hemicellulose, lignin, etc.) are large and are impacted by management, especially harvesting where disproportionate leaf:stem losses occur.

- Greenhouse gas emissions, especially N_2O, are generally lower for biomass production systems were modest rates of N fertilizer are applied as is the case with switchgrass and Miscanthus.

- Environmental modeling reveals that loss of N to surface waters is also reduced markedly when perennial grasses are grown in place of maize/soybean rotations.

- Other models have used plot data from Objective 2 and previously published results from the literature to predict biomass yields in the Midwest and US at scale. These studies have improved these models (APSIM, SWAT, others) but also identified critical biophysical research that is needed for further model improvement.

These are only a fraction of the findings that have emerged from Task 2 research. They do illustrate, however, progress to-date to understand genotype x environment x management interactions that control agronomic performance of biomass cropping systems. These results will permit strategic deployment of the right biomass systems in the appropriate location, and provide producers with management tools to mitigate and manage risks associate with growing these lesser known cropping systems.

Planned Activities, Outcomes, and Impacts - Year 6

We will complete one more year of harvesting and write three manuscripts on the switchgrass harvest date x nitrogen rate study.

Executive Summary – Feedstock Logistics

The Feedstock Logistics objective focuses on developing systems and strategies to enable sustainable and economic harvest, transportation and storage of feedstocks that meet agribusiness needs. The team also investigates novel harvest and transport systems and evaluates harvest and supply chain costs as well as technologies for efficient deconstruction and drying of feedstocks.

Co-Project Directors

- Kevin Shinners, University of Wisconsin, kjshinne@wisc.edu, 608.263.0756.

- Stuart Birrell, Iowa State University, sbirrell@iastate.edu, 515.294.2874.

Significant Accomplishments – Year 5

- **Iowa State University**

We have developed an empirical model to predict the influence of weather and swath density on in-field drying characteristics of biomass feedstock. Laboratory and field drying experiments were conducted and completed to estimate the impact of rainfall level and crop density on compositional and dry matter loses from switchgrass and corn stover for both day and night drying.

In the past quarter, experiments were conducted in the environmental chamber to calculate the equilibrium moisture content for switchgrass between the temperature range of 10 to 19˚C and varying relative humidity of 50 to 90%. A model has been developed to predict the equilibrium moisture content of switchgrass in the above-mentioned temperature and humidity range, which was lacking in the literature, and is necessary for development of drying rate models.

During day time conditions in both maturity stages, solar radiations and vapor pressure deficit (VPD) were positively correlated with drying rate whereas, wind speed and swath density were negatively correlated. During night conditions in both maturity stages, VPD was positively correlated and swath density was negatively correlated with drying rate. Effect of wind speed was however positive in seed developed stage and negative in seed shattering and seed shattered stage of maturity. Moisture content predicted by models were in good agreement with the moisture change observed in the experimental field drying studies. However, the models developed in the present study do not predict the moisture gain during rainfall events. Further experiments are required to estimate the gain in moisture and drying after a rainfall event.

The influence of rainfall amount and density on chemical composition change was also reevaluated and analyzed. The results after statistical analysis, shows a significant influence of swath density and rainfall amount on K and Mg content of switchgrass. Corn stover lost more K and Mg content in comparison to switchgrass as corn stover was more extensively conditioned during harvest. Fiber content containing cellulose and hemicellulose were least affected during the rainfall treatment. The leaching loss ranged from 0.2 to 2.8% for switchgrass, and losses ranged from 0.5 to 3.3% for corn stover, depending on the material density and rainfall. The total dry matter loss 48 hours after a rainfall event could be as high as 6.1 to 7.5% for switchgrass and corn stover, respectively. This level of total dry matter loss could significantly affect biomass harvest costs.

The moisture content of biomass materials such as corn stover and switchgrass, have a significant effect on dry matter losses during storage and biomass supply chain costs. Numerous instruments have been developed to measure grain moisture based on the high correlation between moisture content and electrical conductivity of a grains. However, these dielectric instruments have not yet been successfully utilized for sensing of the moisture content of biomass feedstocks such as corn stover and switchgrass.

Research has been conducted on predicting moisture content and bulk density of the biomass feedstocks based on the dielectric measurements. Dielectric variables were able to be used to predict moisture content and bulk density predictions for switchgrass and corn stover. For switchgrass, moisture content was predicted with R2 = 0.94 and RMSE = 0.052, while for density was predicted with R2 = 0.85 and RMSE = 0.0323. For corn stover, moisture content was predicted with R2 = 0.90 and RMSE = 0.0315, whereas, for bulk density, the prediction had a R2 =0.87 and RMSE = 0.0068. The results showed that dielectric measurements have good potential for predicting moisture content and bulk density although further investigation is required for a wider range of frequencies, moisture content, and bulk density levels. The development and design of the electronics for real-time biomass moisture sensor is continuing. At present research is being conducted on the control and operation of High Speed A/D convertors and D/A converters and the integration of these with FPGA filtering algorithms to determine signal attenuation and phase shift.

- **Journal Articles**
  - ✓ Khanchi, A. & S.J. Birrell, 2017. Estimating dry matter and composition change due to rainfall during field drying of switchgrass and corn stover. Journal of Biosystems Engineering 153:42-51.
  - ✓ Sharma, B., E. Brandes, A. Khanchi, S. Birrell, E. Heaton, & F. E. Miguez. 2015. Evaluation of Microalgae Biofuel Production Potential and Cultivation Sites Using Geographic Information Systems: A Review. BioEnergy Research 8(4):1714–1734.

▪ **University of Wisconsin**

- The large-square baler is the dominant package used to harvest and store biomass feedstocks. New "high-density" large square balers (HD-LSB) are now available and these were investigated for their ability to achieve densities that would insure weight-limited transport and at what energy cost. Bales of switchgrass, native grasses, reed canarygrass, sorghum, wheat straw and corn stover were created with a commercial HD-LSB producing maximum *dry basis* densities of 14.0, 14.2, 13.4, 14.1, 10.8, and 12.2 lb./ft^3, respectively. Density in excess of 14 lb./ft^3 would provide weight limited transport in most cases. Total specific energy requirements to operate and provide mobility for the baler increased as a quadratic function of density, which will increase baling costs due greater fuel use and increased capital costs from larger, more expensive tractors and equipment.
- Plastic twine is used to secure and limit re-expansion of large-square biomass bales. As

bale density increases, costlier twine with greater tensile strength is required to withstand the expansion forces, which adds to harvest costs. The cost of twine can exceed $3 per dry ton, which is almost 25% of the total cost of baling. Twine failure and broken bales anywhere in the logistics system adds considerably to the delivered costs due to the additional (inefficient) handling required to deal with broken bales. A system was developed to measure twine tension as high-density bales exit the bale chamber when twine stress is greatest. The system was used when harvesting reed canarygrass, switchgrass, native grasses, sorghum, and corn stover across a wide variety of bale densities. Models of twine tension as a function of bale density have been developed.

- An experimental baler which uses a unique, innovative auger compression system was acquired from an independent inventor. The auger baler is less complicated and lighter-weight than conventional plungerhead balers, so high-density bales could potentially be produced at less cost. The baler was tested in reed canarygrass, switchgrass, wheat straw, and corn stover. The baler was able to produce bales with density ranging from 15 to 20 lb./ft^3, considerably denser than conventional bales of similar crop material. However, performance issues related to feeding and crop flow currently challenge the steady-state operation of the baler. Additionally, the high-density bales are difficult to handle, requiring new handling tools and techniques.
- Two compression test fixtures were designed and fabricated so that either large-square or large-round bales could be re-compressed to “double density”. The round bale fixture was also used to reshape bales into a parallelepiped or cuboid shape to enhance transport efficiency. Densification characteristics of switchgrass, reed canarygrass, wheat straw and corn stover bales were then quantified. During these tests, force, energy and density data were collected and this data used to develop models of the recompression process for both bale types. The energy required to compress biomass bales over a relatively long period (~20 s) is about one-tenth that required to produce bales in a conventional plungerhead baler.
- A final drying rate trail was completed and the data collected from all eight trails was used to develop a model of the switchgrass drying rate. Major inputs to this model are solar insolation, vapor pressure differential, conditioning level, raking, and swath density. This drying rate model was then used to develop a model to predict the harvest progression of switchgrass across the fall harvest season in the Upper Midwest. The model uses historical weather data to predict the rate at which a harvest team of a windrower plus two-balers can complete harvest. The model was used to predict the machinery fleet and cost required to complete a substantial switchgrass harvest campaign in Wisconsin, Iowa and Nebraska. Delaying harvest until after a killing frost substantially reduced the acreage that can be harvested by one harvest team. A harvest that starts in

early September improved labor utilization and efficiency, and therefore reduced costs.

- A techno-economic analysis of grass feedstock logistics was completed. The model features modules for harvest; roadsiding; storage; transport; and grinding. A normalized supply curve model is used to estimate grass availability based on prices paid and producer costs. The combined model was used to estimate the economic impact of some of the harvest and storage options considered in this research, including bale size, bale density, bale accumulation, pre-cutting at baling, and storage options. The logistics cost of cutting, baling, storing, transporting and conducting a primary grind ranged from roughly $55 to 75 per dry ton. This cost did not include costs for land, amortized establishment, or fertilizer and weed control, nor did it include any profit for the producer.

Planned Activities, Outcomes and Impacts – Year 6

- **Iowa State University**

  - **Integration of feedstock supply chain cost analysis and machinery optimization model into a single decision support system for producers and refinery operators**. The system will be utilized to determine the feedstock supply chain costs for different feedstock supply chain configurations including multi-feedstock supply chains that include both perennial grasses and agricultural residues. An analysis system will be utilized to understand the interaction between scale of operations, producer demographics, type and spatial distribution of biomass production, and yield on feedstock supply costs. The expected outcome is the development of an integrated decision support tool that can be utilized by producers and the biorefinery industry to evaluate the feedstock supply costs for different supply chains, and determine the least cost machinery systems for harvest, storage and transportation of the biomass material.

  - **Field evaluation of the empirical model developed to predict the influence of weather and swath density on in-field drying characteristics of biomass feedstock**. The models can be used to improve management of field harvest operations under different projected weather conditions, and used to predict risk and the relative costs related to dry matter loss in the field during harvest operations.

  - **Development and evaluation of prototype real-time biomass moisture sensor for switchgrass and corn stover.** The moisture content of biomass materials such as corn stover and switchgrass, have a significant effect on dry matter losses during storage and biomass supply chain costs. Results showed that dielectric measurements have good potential for predicting moisture content and bulk density although further investigation is required for a wider range of frequencies, moisture content, and bulk density levels. The expected outcome is the development of instruments for predicting moisture content and bulk density that can be utilized in the feedstock supply management by producers and the bio-refinery industry.

- **University of Wisconsin**

Final year research activities planned include:

- Final evaluation of the high-density experimental large-square baler.
- Completion of the storage-study for large-square bales wrapped in breathable film.
- Completion and submission for publication of seven manuscripts.
  - ✓ Shinners, K.J. & J.C. Friede. (2017). Enhancing the drying rate of switchgrass.
  - ✓ Shinners; K.J., B. Sabrowsky, R. Nicholson. & C. Studer. 2017. Switchgrass harvest progression in the North-Central US.
  - ✓ Mcafee, J.M., K.J. Shinners, J.C. Friede & T.J. Kraus. 2017. Recompression of large-square biomass bales.
  - ✓ Mcafee, J.M., K.J. Shinners; J.C. Friede, C.P. Walters & D.E. Flick. 2017. Twine tension during harvest of large-square biomass bales.
  - ✓ Shinners, K.J. & J.C. Friede. (2017). Energy requirements to produce high-density large-square biomass bales.
  - ✓ Flick, D.E., K.J. Shinners, J.C. Friede & C.M. Nigon. 2018. Producing high-density biomass using an auger-baler concept.
  - ✓ Flick, D.E., K.J. Shinners & J.C. Friede. 2018. Outdoor storage of large-square biomass bales using breathable film wrap.

Executive Summary – System Performance Metrics, Data Collection, Modeling, Analysis and Tools

This objective provides detailed analyses of feedstock production options and an accompanying set of spatial models to enhance the ability of policymakers, farmers, and the bioenergy industry to make informed decisions about which bioenergy feedstocks to grow, where to produce them, what environmental impacts they will have, and how biomass production systems are likely to respond to and contribute to climate change or other environmental shifts.

Co-Project Directors

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Significant Accomplishments – Year 5

- **Iowa State University**

A comparative study of the water quality effects from planting perennial feedstocks and removing stover for biofuel production was completed. SWAT models were calibrated for three relatively small watersheds in the Corn Belt (St Joseph watershed, Indiana, Wildcat Creek watershed, Indiana and the Boone River watershed, Iowa) as well as a model of the entire Upper Mississippi and Ohio-Tennessee River Basins. Similar scenarios were developed related to stover removal and the placement of perennial grasses on cropland including the targeting of stover removal to non-environmentally sensitive land and the targeting of perennial grasses to environmentally sensitive areas. The results provide useful insights about how policy might be designed to incentivize these feedstocks.

All scenarios with perennial feedstocks generate large water quality improvements for nitrate, phosphorus, and sediment. Additionally, there was strong evidence that a significant share of the gains could be achieved for phosphorus and sediment reductions by targeting the environmentally most productive land. Results suggest that stover removal at rates up to 50% do not worsen phosphorus and sediment loads significantly.

- **University of Minnesota**

This year, we continued our investigations into the potential environmental effects of bioenergy. We finalized our switchgrass life cycle emission inventories and submitted a manuscript on the human health effects of changes in air quality resulting from switchgrass production. Our analyses identified the importance of fugitive dust and fertilizer production and use for overall impact. We also submitted a manuscript on the hydrologic and climate change effects of increased switchgrass and Miscanthus production in the central United States. Both manuscripts resulted from multi-year efforts in the development of the InMAP (Intervention Model for Air Pollution) and WRF-CLMcrop-Biofuels models. We also submitted manuscripts on the implications of increased perennial biomass production for ecosystem services and on the fuel market rebound effect of the Renewable Fuel Standard. Additionally, we continued investigating crop yield gaps and means of closing them.

Planned Activities, Outcomes and Impacts – Year 6

- **Iowa State University**

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We hope to get review comments back on the four submitted papers soon and begin revisions. Also, based on the findings of the scenarios undertaken in the three watershed studies additional scenarios are being developed to evaluate the water quality tradeoffs associated with the simultaneous use of stover and perennial feedstocks.

- **University of Minnesota**

  Planned activities for Year 6 include continued submission of manuscripts from output of previous quarters and continued outreach efforts to publicize the results of our work.

Executive Summary – Feedstock Conversion and Refining: Thermo-chemical Conversion of Biomass to Biofuels

The Feedstock Conversion and Refining Objective focuses on developing a detailed economic analysis of the performance of a refinery based on pyrolytic processing of biomass into liquid fuels. It also produces and provides biochar to other CenUSA researchers. The team concentrates on four primary goals:

- Develop a lignin catalytic (ZSM5) pyrolysis response model for various temperatures and catalyst to biomass ratios;
- Integrate the response data into a technoeconomic analysis model to assess the potential of converting perennial grasses, lignin and other biorefinery co-products to value-added fuels and identified chemicals via catalytic pyrolysis; and
- Provide technical and market targets to stakeholders of the commercialization objective; and
- Develop high value markets for the biochar co-product of biomass pyrolysis.

Co-Project Director

Robert Brown, Iowa State University. 515.294.7943

Significant Accomplishments – Year 5

- NaOH, Et_3N, and CaOH pretreatments were used with low temperature, low pressure hydrogenation to convert four industrial lignin streams, including those from ADM and Renmatix, to a soluble phenolic-rich oil that is flowable at room temperature and is more readily upgraded to fuels and chemicals than solid lignin.
- Total liquid yields from ADM and Renmatix lignin reached 98.4 and 87.9 wt% respectively, and include high-value compounds such as ferulic acid, coumaric acid, phenol, and guaiacol.

A patent application for the process has been submitted.

Planned Activities, Outcomes and Impacts – Year 6

Remaining work in Year 6 includes publishing a manuscript in a peer-reviewed journal.

Executive Summary – Markets and Distribution

The Markets and Distribution objective recognizes that a comprehensive strategy to address the impacts to and requirements of markets and distribution systems will be critical to the successful implementation and commercialization of a regional biofuels systems derived from perennial grasses grown on land unsuitable or marginal for the production of row crops. To develop this strategy, the team focuses on two unifying approaches:

- Evaluation of farm-level adoption decisions, exploring the effectiveness of policy, market and contract mechanisms to facilitate broad scale voluntary adoption by farmers; and
- Estimate threshold returns that make feasible biomass production for biofuels.

Co-Project Directors

- Dermot Hayes, Iowa State University, dhayes@iastate.edu, 515.294.6185.
- Keri Jacobs, Iowa State University, kljacobs@iastate.edu, 515.294.6780.

Significant Accomplishments – Year 5

To date, our objective has made progress on multiple fronts, including investigations into threshold returns of perennial grasses compared to alternative land uses, incorporating real option values into analyses of returns to switchgrass production, understanding producer-level support and frictions related to perennial grass adoption decisions, and modeling cellulosic supply under varying biomass collection schemes. The following are a few of the accomplishments and outputs from this objective in the past year.

- *To Grow or Not Grow: A Tool for Comparing Returns to Switchgrass for Bioenergy with Annual Crops and CRP*. We published a decision tool to aid producers in understanding the relative costs and returns to switchgrass production compared with traditional land uses in Iowa, including corn and soybean rotations, grazing, and CRP. The decision tool was jointly developed across objectives. https://cenusa.iastate.edu/switchgrass-production-tool.
- Chad Hart (Co-PD and Objective 9 collaborator) Presentation of the CenUSA decision tool by at the 2015 Integrated Crop Management conference.

- Submitted research for peer review to top agricultural economics field journal – in revision (revise and resubmit): "The Supply Curve for Cellulosic Ethanol." Authors Chao Li, Keri L. Jacobs and Dermot J. Hayes.
- Presentation at the CenUSA Annual Meeting to highlight our objective's accomplishment and current works.
- Supported graduate training of PhD student, Chao Li, who is incorporating project-related research into his dissertation.

Planned Activities, Outcomes and Impacts – Year 6

Our work during year 5 of this project suggests that less than 20 % of the available corn stover will be delivered to the plants. This is true because plants find it optimal to transport feedstocks as far as 50 miles rather than pay a premium that creates high participation. The intuition behind this result is that plants realize that if they offer a premium to incentivize new suppliers they must pay existing suppliers a similar premium. Our results show it less expensive for them to pay additional transportation costs than to pay every existing supplier an additional premium. Given this result, it is now clear that perennial grasses will be needed to meet the cellulosic mandate.

In Year 6 we plan to:

- Use simulation to predict the volume and value of the perennial grasses that will be needed to meet the mandate.
- Develop outputs that aid cellulosic processors in developing estimates for collection costs and availability of cellulosic biomass under varying assumptions relevant to the Midwest.
- Publish research in peer-reviewed journals.

Executive Summary – Health and Safety

The production of bioenergy feedstocks will have inherent differences from current agricultural processes. These differences could increase the potential for workforce injury or death if not properly understood and if effective protective counter measures are not in place.

The Health and Safety team addresses two key elements in the biofuel feedstock supply chain:

- The risks associated with producing feedstocks; and
- The risks of air/dust exposure.

Co-Project Directors

- Chuck Schwab, Iowa State University, cvschwab@iastate.edu, 515.294.4131.
- Mark Hanna, Iowa State University, hmhanna@iastate.edu, 515.294.0468.

Significant Accomplishments – Year 5

- Multiple risk model calculations were performed (using approximately 500,000 iterations) and those results were shared in the International Society for Agriculture Safety and Health international conference presentation.
- The probabilistic risk assessment model received additional refinements after examination of multiple runs and after model results were presented to safety professionals. The accuracy and precision in forecasting risk probability for different farming systems was increased.
- The risk results are that corn productions systems had a higher likelihood of human injury (99%) than biofuel switchgrass production systems (1%) over a 10-year life cycle.
- Focusing mitigation efforts on the greatest contributing factors would cause continued research on harvest operations of the corn production system due to the higher likelihood of injury.
- The preparation of a manuscript for a peer review journal article that shares the development and results of the model was begun.

Planned Activities, Outcomes and Impacts – Year 6

The finalization of the manuscript for a peer review journal article that shares the development and results of the probabilistic risk assessment model will be completed. This manuscript will be submitted to the *Journal of Agricultural Safety and Health*.

A different approach to collecting dust samples without human subjects is being explored. A series of pilot dust samples of potentially hazards activities will be measured and analyzed.

Executive Summary – Education

The Education Objective seeks to meet the future workforce demands of the emerging Bioeconomy through two distinct subtasks, as follows:

- Develop a shared bioenergy core curriculum for the Central Region of the United States.
- Provide interdisciplinary training and engagement opportunities for undergraduate and

and graduate students.

Co-Project Directors

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- Patrick Murphy, ptmurphy82@gmail.com

Significant Accomplishments – Year 5

- **Development of On-line Curriculum.** A CenUSA MOOC (massive open online course), *Introduction to Perennial Grasses for Biofuels* was created in collaboration with the Extension Objective using materials previously developed by both Objectives 8 and 9. Existing module content from the UNL PASSel platform was transferred to a learning management system at the Ohio State University Agricultural Technology Institute. Two peer-reviewed journal articles were published, elucidating the education team's experience organizing and delivering summer undergraduate research programs and developing online bioenergy educational materials.
- **Undergraduate Internship.** Eleven undergraduate students were successfully placed and mentored at CenUSA institutions: Iowa State University (4 interns); Purdue University (2 interns); University of Nebraska, Lincoln (3 interns); University of Wisconsin-Madison (2 interns) from June 2 – August 4, 2016.

  Two peer-reviewed journal articles were published, elucidating the education team's experience organizing and delivering summer undergraduate research programs and developing online bioenergy educational materials.

Planned Activities, Outcomes and Impacts – Year 6

- **On-line Curriculum Course Modules.** We will offer the CenUSA MOOC to the public on a self-serve basis and evaluate course feedback data to improve future course offerings. Edit existing module content base on outcomes from research objectives.
- **Undergraduate Internship.** This is not a planned activity for year six of the program.

Executive Summary – Extension and Outreach

The Outreach and Extension Objective serves as CenUSA's link to the larger community of agricultural and horticultural producers and the public-at-large. The team delivers science-based knowledge and informal education programs linked to CenUSA Objectives 1 - 8 and 10.

Co-Project Directors

- Jill Euken, jeuken@iastate.edu, 515.2946286
- Sorrel Brown (Retired July 2016)

Significant Accomplishments – Year 5

The CenUSA **Extension and Outreach Objective** engaged in significant public contact through a portfolio of educational events and programs, and virtual and social media outlets in Year 5 of the project.

- **Extension Staff Training/Materials Development/eXtension/Communications Team**

  In Year 5 the Extension Staff Training/Materials Development/eXtension/Communications Team produced:

  - *Making Business Decisions with Precision Data Can Encourage Perennial Grass Production*; a case study of AgSolver study authored by Susan Harlow and peer reviewed by Marty Schmer. http://articles.extension.org/pages/73918 (Exhibit 1).
  - *Renmatix Processes Biomass into Sugars for Industrial Use*. A case study authored by Susan Harlow and peer reviewed by Robert Brown. 4-05-2016. http://articles.extension.org/pages/73640.
  - *Biofuel Quality Improved by Delaying Harvest of Perennial Grass.* Revised (previously published) research summary http://articles.extension.org/pages/73615 (Exhibit 2).
  - *Guidelines to Growing Perennial Grasses for Biofuel and Bioproducts* - Rob Mitchell et. al. http://create.extension.org/sites/default/files/Cenusa_Guide_to_Perennials.pdf (Exhibit 3).
  - *CenUSA Biochar Research Flyer* - David Laird and Jill Euken. http://create.extension.org/sites/default/files/Cenusa_Biochar_Research_2016_flyer.pdf (Exhibit 4).
  - *Utilization of Mature Switchgrass as Roughage in Feedlot Diets* - Chris Clark and Dan Loy. http://create.extension.org/sites/default/files/CenUSA_Switchgrass_Beef_Feeding.pdf. (Exhibit 5).
  - *The CenUSA Legacy* (video) Pam Porter. http://farmenergymedia.extension.org/video/cenusa-legacy.

  Over the course of five years, the CenUSA Extension Products/Communications Team has produced 51 videos that are available on CenUSA's Vimeo and YouTube sites.

- **Vimeo Usage Data**

  In year 5, CenUSA videos and webinars on the Vimeo site were accessed as follows:

  ✓ Loads: 21,311.

  ✓ Plays/views: 1,113.

- **YouTube Usage Data**

  In Year 5, CenUSA videos and webinars were viewed 3,948 times on the YouTube site.

- **CenUSA eXtension Web Page Usage Data**

  In year 5, CenUSA videos and webinars on CenUSA eXtension page were accessed as follows:

  ✓ Visitors: 11,829 new users (New + returning users = 12,751).

  ✓ Page views: 18,284.

  ✓ Sessions: 12,751 new + returning users (79% new sessions/1st time visits).

- **CenUSA Web Site**

  ✓ Visitors: 4,973 unique visitors.

  ✓ Page views: 8,977.

- **CenUSA Twitter Account**

  CenUSA Twitter recorded 861 followers in Year 5.

- **BLADES' Newsletter**

  ✓ Quarter 1: 851 recipients with 298 unique opens.

  ✓ Quarter 2: 877 recipients with 282 unique opens.

  ✓ Quarter 3: 858 recipients with 281 unique opens.

  ✓ Quarter 4: 852 recipients with 278 unique opens.

▪ **Producer Research Plots/Perennial Grass/Producer and Industry Education Team**

In Year 5 the Producer Research Plots/Perennial Grass/Producer and Industry Education

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- **Producer Research Plots/Perennial Grass/Producer and Industry Education Team**

  In Year 5 the Producer Research Plots/Perennial Grass/Producer and Industry Education Team:

  - Worked with producers and farm managers to maintain nine on-farm demonstration plots in Iowa, Minnesota, Nebraska, and Indiana.
  - Collected data from the CenUSA on-farm demonstration plots to share with the CenUSA research team.
  - Held field days and tours at the CenUSA on-farm demonstration plots as well as informational meetings for producers, reaching a total of 1,635 producers and agricultural industry leaders.
  - Administered and analyzed surveys to document learning and behavior change (see quarterly reports for data).

- **Economics and Decision Tools Team**

  In Year 5, the Economics and Decision Tools Team continued fine-tuning the CenUSA Switchgrass Decision Tool and promoted the tool to producers and agricultural industry leaders. The Switchgrass Decision Tool was used as follows:

  - There were 363 individual downloads of the CenUSA Switchgrass Decision Tool pdf (http://www.extension.iastate.edu/AgDM/crops/pdf/a1-29.pdf).
  - There were 405 individual completions of the CenUSA Switchgrass Decision Tool (http://www.extension.iastate.edu/AgDM/crops/html/a1-29.html (click on xls file).

- **Public Awareness/4-H and Youth Team**

  In Year 5, the Public Awareness/4-H and Youth Team:

  - Continued development and pilot testing of CenUSA's youth curriculum and learning materials at Iowa State University and Purdue University.
  - Trained 208 adults to use the CenUSA Bioenergy youth educational materials.
  - Reached 3,259 youth in workshops, camps, classrooms, and field days using CenUSA youth curricula/materials.

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- **Public Education/Master Gardener Program**

  The Public Education/Master Gardener Program project was completed in Year 4 of the project. In year 5, the team has compiled all the research data generated by the biochar demonstration plots in Years 1-4; the data is currently being analyzed by a statistician. The final report should be finalized by the July 2017.

- **Extension Administration Team**

  - Taught two sessions at Extension National Association County Agricultural Agents Conference. The sessions, attended by more than 200 agricultural extension educators from throughout the United States focused on:
    - ✓ The potential for growing perennial grasses for biomass and bioenergy.
    - ✓ CenUSA's resources for agricultural producers/industry leaders.
  - Presented a session on CenUSA's "Citizen Science" work at the *National Energy Education* conference in Washington D.C. for 40 educators.
  - Negotiated budgets and deliverables with Nebraska, Indiana, Minnesota, Wisconsin CenUSA Extension program teams for the project's no-cost extension year.
  - Coordinated the efforts of the CenUSA Extension/outreach teams.
  - Developed, edited and published a brochure on bioenergy grasses.
  - Developed evaluation instruments for the CenUSA Extension teams and summarized survey results.
  - Hired and mentored a summer intern to do CenUSA C6 app updates.
  - Developed the CenUSA "Legacy" publication.
  - Developed CenUSA exhibit, handouts and secured staffing for the exhibit on CenUSA switchgrass feeding trials for the 2016 *Hay Expo*.
  - Developed exhibit and handout materials for the *International Biochar Initiative* conference (August 22-26, 2016).
  - Hired a graduate student in Agricultural Education (evaluation focus) to fill a vacancy caused by a team member's retirement.
  - Collected data from CenUSA Extension team members and wrote the Extension sections

quarterly and annual reports and provided a presentation covering CenUSA outreach initiatives at the Year 5 CenUSA Annual meeting.

Planned Activities, Outcomes and Impacts – Year 6

- **Develop, Produce and Post the Final CenUSA Fact Sheets, Research Summaries, Videos, and BLADES Newsletter Articles.**
  - Reach an additional 300 producers, industry leaders, educators, and agency personnel with information about perennial grasses, biochar and renewable energy.
  - Continue to share the Perennial Grass Decision Tool with producers and assist them with completing the tool.
  - Host event and share CenUSA information with congressional aides and federal agency staffers.
  - Finalize the CenUSA C6 curriculum, iBook, app and youth learning modules covering perennial grasses, carbon cycling, and biochar utilization.
  - Prepare and submit applications for teacher renewal credit and graduate credit for the C6 BioFarm teacher training program to be held in June, 2017.
  - Train 24 teachers/Extension Educators to use the C6 BioFarm Youth materials; video record the sessions and prepare an on-line teacher training program to be used for teachers to earn teacher renewal and graduate credit in the coming years.

Executive Summary – Commercialization

The Commercialization Objective was initiated in Year 4 to evaluate near and long-term commercialization prospects for products produced from perennial grasses grown on marginal land. It involves two commercial partners, ADM and Renmatix, who are evaluating CenUSA feedstocks in their conversion processes.

Co-Project Directors

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Objective 10A. ADM

- **Significant Accomplishments – Year 5**

  - NaOH, Et_3N, and CaOH pretreatments were used with low temperature, low pressure hydrogenation to convert four industrial lignin streams, including those from ADM and Renmatix, to a soluble phenolic-rich oil that is flowable at room temperature and is more readily upgraded to fuels and chemicals than solid lignin.
  - Total liquid yields from ADM and Renmatix lignin reached 98.4 and 87.9 wt% respectively, and include high-value compounds such as ferulic acid, coumaric acid, phenol, and guaiacol.
  - A patent application for the process has been submitted.

- **Planned Activities, Outcomes and Impacts – Year 6**

  Remaining work in Year 6 includes publishing a manuscript in a peer-reviewed journal.

- **Publications**

  Rover, M., P. Hall, R. Smith & R.C. Brown. 2016. Application of Low Temperature, Low Pressure Hydrogenation to Liquefy and Stabilize Lignin Streams. Presented at American Chemical Society National Meeting, San Diego, CA, 13 Mar.

Objective 10B. Renmatix

- **Significant Accomplishments – Year 5**

  These are the main activities that have been accomplished during Year 5 of the project:

  - Development of a conceptual manufacturing process and techno-economical evaluation for the commercial production of C5 and C6 sugars from switchgrass and corn stover.
  - Lignin production from switchgrass and corn stover for its conversion into value added products.
  - Conversion of switchgrass hydrolysates to single cell oils using oleaginous yeast strains and two-stage culture system (in collaboration with Bruce Dien at the USDA ARS).
  - Development of a conceptual manufacturing process and techno-economical evaluation for the commercial production of C5 and C6 sugars from switchgrass and corn stover.

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- **Task 10c-3. Development of a Conceptual Manufacturing Process and Techno-economical Evaluation for the Commercial Production of C5 and C6 Sugars from Switchgrass and Corn Stover.**

  A conceptual manufacturing process was developed to produce C5 and C6 monomeric sugars from switchgrass and corn stover. This conceptual process was then used to estimate high-level economics for capital and operating costs and the results were compared to those for processing woody biomass. The main economic implications from the analysis were as follows:

  ✓ Good amount of sugars is present in perennial grasses for conversion to product.

  ✓ Perennial grass sugar yields at pilot scale were close to those for woody biomass.

  ✓ Switchgrass had somewhat less lignin present to supply energy for the process vs. wood.

  ✓ Feedstock cost projected to be higher than woody biomass at this time. Further feedstock logistics optimization could reduce this.

  ✓ Estimated capital costs of a plant based on perennial grasses appear higher than that for one based on woody biomass due to need for added preprocessing units, and for removal of higher inorganic content.

  ✓ Estimated operating costs of a plant based on perennial grasses appear higher due to expenses for removal of higher levels of inorganics in grasses and supplementing energy needs due to no bark and less lignin vs. a plant based on woody biomass.

  ✓ Lignin valorization as a co-product could add significant benefit to economics and potentially offset additional costs.

- **Task 10c-4. Lignin Production from Switchgrass and Corn Stover.**

  Lignin samples from switchgrass and corn stover were produced successfully in Renmatix's Plantrose® pilot plant and shipped to Iowa State University. These samples will be tested for conversion into value added products by Robert Brown.

  In addition, lignin from switchgrass and corn stover that was produced in the pilot plant was tested at Renmatix's labs to check its performance as a partial replacement for adhesive for wood panel production. Results were encouraging as both lignins provided bond strength on veneer test samples that were similar to commercial resins used for wood panel production. Lignin produced by Renmatix's Plantrose® process could deliver significant co-product value for a biorefinery plant benefiting the overall economics if used as a partial replacement for adhesives in wood panel manufacturing.

A study was finished during Year 5 regarding structural characterization of native lignin in corn stover (CS), switchgrass (SG) and big blue stem (BBS). Lignin preparations were isolated from all 3 non-wood biomasses for their characterization by advanced NMR methods. First, the 2D NMR values were normalized per the sum of syringyl, guaiacyl, and *p*-hydroxyphenyl (S+G+H) units for relative comparison according to the current most popular methodology. The results were further translated into an absolute mode per 100 aromatics (Ar, aka mole %) using ^{13}C NMR as the reference. The ^{13}C NMR and ^{31}P NMR have also provided additional structural information. This information is relevant to understand lignin transformations through Renmatix's Plantrose® technology.

- **Conversion of Switchgrass Hydrolysates to Single Cell Oils using Oleaginous Yeast Strains and Two-stage Culture System in Collaboration with Bruce Dien (USDA ARS).**

  Samples of C5 and C6 sugar streams were sent for testing to CenUSA collaborator Bruce Dien. The goal was to produce neutral lipids and analyze them for suitability for conversion to biojet fuel, and biodiesel. *L. tetrasporus* achieved high lipid yields from Renmatix sugars and performed equally well on glucose and xylose enriched fractions. Results were found to be exciting. The results were better or comparable to most other reported results on different hydrolysates.

▪ **Future Directions**

There are several points that could be addressed to improve the economics for processing perennial grasses using Renmatix's Plantrose® technology.

- Develop lignin co-product applications to positively impact economics. Preliminary data suggests that lignin has potential in adhesive formulations for wood panel applications.
- Develop means to lower capital and operating costs through more efficient ways to deal with structural and non-structural inorganics. Perennial grasses have one order of magnitude higher amount of structural inorganics. Downstream processes may need to be changed/transformed to meet biorefinery feed specs.
- Conduct longer trial run in the demonstration plant with perennial grasses to better establish performance.
- Secure downstream partner for sugar and tailor sugar product to their needs.

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Also, lipid scouting tests were conducted at USDA-ARS with positive results towards the conversion of Renmatix sugars to neutral lipids as a precursor for biojet fuels. Based on these preliminary results the following activities are proposed as future ARS tasks to promote lipid yield through culture optimization:

- Medium development (C:N).
- Batch versus two-stage versus fed-batch

  Using 2-stage, NCAUR lab has reported lipid titers > 20g/l; the highest ever reported.
- Characterize different sources of sugars (e.g. crops) and sugar enrichments (e.g. xylose versus glucose).
- Extract lipids and characterize fatty acid profile to determine suitability to biofuel.