Executive Summaries

cenusa bioenergy

Annual Progress Report

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

September 2015

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LEGAL NOTICE

This report was prepared by Iowa State University and CenUSA Bioenergy research colleagues from Purdue University, United States Department of Agriculture-Agricultural Research Service, University of Illinois, University of Minnesota, University of Nebraska, Lincoln, University of Vermont, and the University of Wisconsin in the course of performing academic research supported by Agriculture and Food Research Initiative Competitive Grant No. 2011-68005-30411 from the United States Department of Agriculture National Institute of Food and Agriculture ("USDA-NIFA").

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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, 2014 – July 31, 2015

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 for the production of biomass for energy. Year 4 focus is on selection and breeding of switchgrass.

Co-Project Directors

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- Rob Mitchell, USDA-ARS, Lincoln, Nebraska, Rob.Mitchell@ars.usda.gov, 402.472.1546.

Significant Accomplishments – Year 4

- Completed the second year of harvest and data collection on 36 regional biomass trials of switchgrass, big bluestem, and indiangrass.
- Provided additional documentation of improved winter hardiness and survivorship of lowland-type switchgrass in USDA Hardiness Zone (HZ) 4, owing to two cycles of selection for survivorship within the cultivar Kanlow. These results provide documentation of range expansion for the lowland type that now includes USDA HZ 4 and possibly HZ 3.
- Created biomass samples of switchgrass and other warm-season grasses that will be used to expand the NIRS calibrations for biomass quality traits to include a broad range of warm-season energy grasses.
- Created biomass samples of switchgrass and big bluestem that can be used to address specific hypotheses regarding the role of plant traits such as lignin and ferulates in regulating conversion efficiency using either a fermentation or pyrolysis platform.
- Identified genetic variation for resistance to two rust pathogens of switchgrass, including sources of resistance to both pathogens.
- Developed a rapid and reliable RT-PCR method for detecting Panicum Mosaic Virus in switchgrass tissue samples.

- Identified genetic variation for antibiosis (resistance) of switchgrass to four species of aphids, including identification of adequate sources of resistance for breeding purposes and the development of an efficient and effective screening method.

Planned Activities, Outcomes, and Impacts - Year 5

- Complete third year of harvest on 2012 field trials.
- Complete first year of harvest on 2014 field trials.
- Select warm-season grass samples for hypothesis testing and NIRS calibration of biomass quality traits.
- Evaluate rust resistance of switchgrass and big bluestem cultivars in regional trials.
- Monitor arthropod abundance and diversity in warm-season grass trials in Nebraska and Wisconsin.
- Establish new switchgrass and big bluestem selection nurseries that will put the new selection index theory into practice.
- Begin the first cycle of genomic selection and the first cycle of phenotypic selection (as a control) within WS4U-C2 and *Liberty* switchgrass populations.

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.
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- Jeffrey Volenec, Purdue University, jvolenec@purdue.edu, 765.494.8071.

Significant Accomplishments – Year 4

- **Iowa State University**

- Work on development of a biochar module for the APSIM cropping system model was completed. A manuscript documenting this effort has been submitted GCB Bioenergy (Archontoulis et al., submitted). The biochar module within APSIM allows testing of hypotheses at a systems level as it accounts for biochar diversity and the multiple impacts of biochar on soil properties and processes and predicts both agronomic and environmental outcomes. Once fully calibrated and validated the new biochar module has the potential to be used to predict local, regional, and even global agronomic and environmental outcomes from the use biochar as a soil amendment.

- Rogovska et al. (2014) reported that biochar applications (5 rates 0 to 96 Mg ha^{-1}) on small plots significantly increased soil pH, readily available water content (water retained between −10 kPa and −100 kPa) and soil organic C and decreased soil bulk density. Biochar application had no consistent effect on water infiltration rates, soil CEC, or plant nutrient uptake. Biochar application increased grain yield during the first year by 11 to 55% following very high stover application rates (3.5× the typical amount), presumably because biochar mitigated adverse effects of allelochemicals released from decomposing residue. There was no detectable biochar effect on maize yield during the second year of the study.

- After three years of struggling to establish the perennial bioenergy crops on the Armstrong Farm system plots, due to drought (2012) and then weed completion (2013 and 2014), the switchgrass and low diversity biomass crops are finally in excellent condition. The *Liberty* switchgrass plots have virtually no weed competition in the 2015 growing season and are yielding ~6 t/ac at peak biomass (August). The low diversity perennial biomass crops have less than 20% weeds and are yielding ~3.5 t/ac at peak biomass (August). The high diversity plots are still struggling with weed competition and are yielding only ~1.5 t/ac. The results demonstrate that there are significant challenges in establishing perennial biomass crops for bioenergy production on marginal land in Western Iowa, but also that with persistence high-quality perennial biomass crops can be established.

- Rivka Fidel completed her research and is the final stages of writing her PhD dissertation. The dissertation integrates both field and laboratory incubation measurements of GHG emissions (both CO_2 and N_2O), and systematically documents the impacts of different amounts of biochar, different types of biochar, biochar*biomass cropping system interactions, and trade-offs between field and laboratory scale measurements of GHG emissions. The results demonstrate that short term increases in CO_2 emissions in biochar-amended soils are due to hydrolysis of carbonates and/or oxidation of labile organic compounds added with the biochar and that biochar amendments had no long-term effects on CO_2 emissions from soils in the studied agronomic systems. The results also demonstrate a reduction in N_2O emissions from biochar amended soils under maize production following N fertilization, but no apparent effect of biochar on N_2O emissions from soils under perennial biomass crops that received only small amounts of N fertilizer.

- **Purdue University**

  - Liberty switchgrass yields are superior to those of Shawnee switchgrass. Using identical management on adjacent fields at the Throckmorton Purdue Ag Center, biomass yields of Liberty switchgrass averaged 13517 kg/ha whereas Shawnee yields averaged 9898 kg/ha; a 37% improvement in yield.

  - High yield of switchgrass continues to be achieved with low fertilizer input. To date, soil test levels of phosphorus and potassium considered to be extremely low for profitable maize and alfalfa production have not reduced switchgrass biomass yield. High switchgrass yields continue to be obtained with relatively low rates of N fertilization (e.g., 50 kg N/ha).

  - Nutrient and water losses from switchgrass plots during rainfall is far less than maize, sorghum and other perennial biomass systems tested. During summer of 2014 only five rainfall events resulted in runoff and little nutrient left the plots. By comparison, runoff occurred nearly 20 times from maize, sorghum, and *Miscanthus* plots resulting in far greater losses of N and P from the fields to surface waters.

  - *Miscanthus* biomass production in excess of 30,000 kg/ha was obtained in fields adjacent to the *Liberty* and *Shawnee* switchgrass at the Throckmorton Purdue Ag Center, but in contrast to switchgrass, this species required high rates of N, P, and K fertilization to obtain these yields.

  - Perennial biomass and maize biomass systems continued to perform poorly at the Southeast Purdue Ag Center where they are located on a former landfill site. However, biomass yield of photoperiod-sensitive and sweet sorghums both exceed 11,200 kg/ha with as little as 50 kg N/ha as fertilizer. At this N rate maize biomass yields averaged 2776 kg/ha.

  - Large species-specific differences in concentrations of cellulose, hemicellulose, and lignin have been identified, and these do not vary substantially with location or fertility management.

  - We have developed modeling approaches that improve prediction of agronomic and environmental performance of specific biomass crops when deployed within watersheds.

- **University of Illinois**

- Two factor analysis plots with dedicated energy crops including biomass switchgrass, low diversity mixture, prairie cordgrass, and *Miscanthus x giganteus* were successfully established on wet marginal land at Urbana, Illinois. Biomass yield potentials of each species and mixture on wet marginal land have been evaluated based on harvest timing and frequency and soil N fertility management. The first full production of biomass was harvested in 2014. Biomass yields of all species and mixtures showed the potential of feedstock production on wet marginal land. The field plots will be continuously maintained for long-term evaluation.

- We have completed 4-years of a field comparison trial on wet marginal land. We compared biomass yield potential of a forage type switchgrass, big bluestem, *Miscanthus x giganteus*, and four natural populations of prairie cordgrass. *Kanlow* switchgrass was the highest biomass producer and was followed by prairie cordgrass and *Miscanthus x giganteus* under the precipitation conditions during 2011-2014 at Urbana, Illinois.

- We have completed a field evaluation of switchgrass and prairie cordgrass on salt-affected soil at Salem, Illinois. We evaluated two switchgrass cultivars (*Cave-In-Rock* and *Kanlow*) and two natural populations of prairie cordgrass during 2011-2014 on salt-affected soil (EC > 20 dS/m) caused by oil well activity. We were not able to establish *Cave-In-Rock* switchgrass because of its salt-intolerance. Both prairie cordgrass populations produced more biomass than *Kanlow* switchgrass and showed better potential for use as a dedicated energy crop on salt-affected marginal lands.

▪ **University of Minnesota**

- Collected and summarized yield data from both sites that show dramatic differences in tolerance to soil moisture stress and N fertility.

- Collected data indicating that *Liberty* switchgrass can suffer from winterkill, particularly under low soil moisture conditions.

- Presented results at the Annual Soil Science Society of America meetings, November 2014 (Anne Sawyer's dissertation research).

- Hosted a field day for U of MN Nutrient Management professionals, June 2015.

▪ **USDA-ARS-Lincoln Nebraska**

- Mitchell and Vogel (2015) reported switchgrass (*Panicum virgatum*) stands were invaded by big bluestem (*Andropogon gerardii*), smooth bromegrass (*Bromus inermis*) and other grasses during 10 years of management as a bioenergy feedstock. The greatest invasion by grasses occurred in plots to which no N fertilizer had been applied and with harvest at anthesis. In general, less grass encroachment occurred in plots receiving at least 60 kg of N ha^{-1} or in plots harvested after frost. There was no observable evidence of switchgrass from this study invading into border areas or adjacent fields after 10 years of management for biomass energy. Results indicate switchgrass is more likely to be invaded by other grasses than to encroach into native prairies or perennial grasslands seeded on marginally productive cropland in the Western Corn Belt of the USA.

- Perennial grass feedstocks were successfully established at the field scale in 2012, one of the driest and hottest summers on record, and have been managed as bioenergy feedstocks for three production years. Biomass production has been excellent for all three feedstocks. The *Liberty* switchgrass fields yielded 3.4 tons/acre when harvested and baled after frost in the planting year and averaged 4.8 tons/acre of transported yield in 2013 and 2014 when harvested and baled after frost. Big bluestem fields yielded 1.2 tons/acre when harvested and baled after frost in the planting year and averaged 4.4 tons/acre of transported yield in 2013 and 2014 when harvested and baled after frost.

- The low diversity mixture fields yielded 1.9 tons/acre when harvested and baled after frost in the planting year and averaged 5.4 tons/acre of transported yield in 2013 and 2014 when harvested and baled after frost. For comparison, corn yielded 103 bushels/acre in 2012 and averaged 144 bushels/acre in 2013 and 2014. Preliminary estimates indicate as much as 25% of the standing biomass is being lost during the harvest, baling, and transport process. The results demonstrate switchgrass, big bluestem, and low diversity mixtures can establish rapidly and be near full production 18 months after planting. Research is needed to develop technologies for transporting a greater percentage of the feedstock standing crop from the field to the biorefinery.

- In 2015, ARS Lincoln provided a variety of feedstocks to research collaborators such as ADM, Renmatix, Kimberly-Clark, Iowa State University, and the University of Illinois for numerous research projects.

- Sindelar et al. (2015) reported camelina (*Camelina sativa*) and field pennycress (*Thlaspi arvense*) are two winter oilseed crops that could potentially be integrated into the corn (*Zea mays*)-soybean (*Glycine max*) cropping system, which is the prominent cropping system in the U.S. Corn Belt. In addition to providing a feedstock for renewable aviation fuel, integrating these crops into corn-soybean cropping systems could provide ecosystem services like soil protection from wind and water erosion, soil carbon sequestration, water quality improvement through nitrate reduction, and a food source for pollinators. However, integration of these crops into corn-soybean cropping systems also carries possible limitations, such as potential yield reductions of the subsequent soybean crop.

Planned Activities, Outcomes and Impacts – Year 5

- **Iowa State University**

  - Field plot work will continue on the Armstrong Farm perennial bioenergy cropping system trials, the Boyd Farm biochar rate trials, the Sorenson Farm long-term bioenergy crop rotation trials, and the Agronomy Farm Field 70/71 biochar by residue harvesting trials.

  - Field and laboratory work investigating biochar impacts on nutrient cycling and nutrient bioavailability will continue. Results of these investigations will be used to calibrate and if necessary revise the new biochar module developed for the APSIM cropping systems model.

  - The new biochar module developed for the APSIM cropping system model will be both calibrated and validated using field plot data available in the literature and from the above mentioned field trials and laboratory research.

  - A new 2-year project will be initiated to determine mechanistic pathways of N_2O emission mitigation in biochar amended soils.

  - Five manuscripts from Ms. Fidel's PhD dissertation will be submitted for publication in refereed journals. The manuscripts are tentatively titled; (1) *Quantification of Structural, Carbonate and Other Alkalis in Eight Biochars*, (2) *Effect of Six Lignocellulosic Biochars on CO_2 and N_2O Emissions from Two Soils*, (3) *Impact of Biochar Fractions on Soil CO_2 and N_2O Emissions*, (4) *Effect of Biochar on Soil Greenhouse Gas Emissions at the Laboratory and Field Scales*, and (5) *Impact of Biochar on CO_2 and N_2O Emissions: Assessing Trade-Offs at the Greenhouse and Field Scales*. A sixth manuscript documenting perennial biomass crop establishment at the Armstrong system plots will be prepared for publication.

- **Purdue University**

  - Continue factor analysis research focused on species responses to N, P, and K fertilization. This includes analysis of biomass yield and composition, soil test P and K levels, and statistical analysis of results aimed at determining critical P and K concentration required for high biomass yield.

  - Continue to assess the environmental impacts and productivity potential of biomass systems at the Water Quality Field Station. This includes impacts on greenhouse gas production, loss of nutrients to surface waters, soil quality parameters, etc.

  - Calibrate and validate the APSIM crop growth model for switchgrass and miscanthus biomass production using CenUSA and published datasets.

- Accelerate efforts started in 2014 to move key CenUSA datasets into the National Agricultural Library (NAL). This includes piloting typical biomass yield and composition data, and datasets on environmental performance with the Ag Data Commons at NAL for metadata standards, interoperability among repositories, and creation of data dictionaries. This collaboration will extend to the Dairy CAP led by the University of Wisconsin and the wheat Climate Change CAP (REACCH) co-led by the University of Washington/University of Idaho.

- Continue to collaborate with the Iowa State University to evaluate impacts of various bioenergy crop production scenarios on hydrology and water quality. We will use the improved SWAT model to evaluate biomass production potential and associated hydrologic, water quality, and environmental impacts on marginal lands in the Mississippi River basin. This improved model accuracy will permit careful analysis of biomass productivity potential and environmental impacts as biomass systems are deployed at the landscape scale.

▪ **University of Illinois**

- Continue maintaining two factor analysis plots at Urbana, Illinois and collecting field data including biomass yield potential of native warm-season grasses on wet marginal land and their responses to harvest timing, frequency, and soil N fertility management.

- Evaluate and develop new energy crops that tolerate soil salt and flooding stress; we are planning to evaluate new lines of prairie cordgrass for salt and/or flooding stress.

▪ **University of Minnesota**

- Continue to collect and summarize yield data from both sites.

- Present results at the annual Soil Science Society of America meetings, November, 2015.

- Publish results: Extension bulletin regarding switchgrass fertility in MN; peer-reviewed article(s) summarizing establishment, biomass yield as function of cultivar and fertility, and fungal/bacterial community structure as a function of cultivar and fertility (Anne Sawyer's dissertation research).

▪ **USDA-ARS Lincoln Nebraska**

- Apply all field and plot scale treatments as indicated in research plans.

- Summarize the 4-years of system analysis plot biomass, composition, harvest height, visual obstruction measurements (VOM), elongated leaf height, greenhouse gas emissions, and soil quality data. Field work will continue on the system analysis plots in

2016 to increase our understanding of biomass production, economics, and long-term bioenergy crop system sustainability relative to corn production. We anticipate developing 6 manuscripts from the system analysis plot research.

- Laboratory work quantifying biomass compositional characteristics, nutrient cycling, and soil quality data will continue. Results will provide data for estimating transportation fuel yields per unit area, developing nutrient management plans, and providing background for the development of best management practices (BMPs).
- Summarize the factor analysis small-plot data to determine additional candidate feedstocks. We anticipate developing 2 manuscripts from the Factor Analysis plot research focusing on annual and perennial herbaceous feedstock options.
- A 2-year project evaluating the effects of Ryzup, a plant growth regulator, on switchgrass biomass yield and composition was initiated in 2015 and will continue in 2016.
- Year 5 of the warm-season grass grazing project will be conducted in 2016. We hope to graze the switchgrass, big bluestem, indiangrass, and mixed-species pastures with steers in 2016 to provide a better estimate of the beef production potential of the species.
- A 2-year project evaluating candidate feedstocks for wetland margins in North Dakota was initiated in 2015 and will continue in 2016.
- Establish a Crop/Livestock/Bioenergy Production System Demonstration site in eastern Nebraska to demonstrate how bioenergy feedstocks may be utilized on farm in preparation for the new bioeconomy.
- ARS Lincoln will continue to provide feedstock as needed to ARS, university, and industry collaborators.

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

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Significant Accomplishments – Year 4

- **Iowa State University**

  - An empirical model to predict the influence of weather and swath density on in-field drying characteristics of biomass feedstock has been developed. Laboratory and field drying experiments were conducted to estimate the impact of rainfall level and crop density on compositional and dry matter losses from switchgrass and corn stover were completed. 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, had 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 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 for moisture content and bulk density predictions of switchgrass and corn stover. For switchgrass, moisture content was predicted with a R^2 = 0.94 and RMSE = 0.052, while for density was predicted with a R^2 = 0.85 and RMSE = 0.0323. For corn stover, moisture content was predicted with a R^2 = 0.90 and RMSE = 0.0315, whereas, for bulk density, the prediction had a R^2 =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.

  - **Journal Articles**

    - ✓ Karlen, D.L., Kovar, J.L. & S.J. Birrell. (2015). Corn Stover Nutrient Removal Estimates for Central Iowa, U.S.A. *Sustainability*, 7, 8621-8634; doi:10.3390/su7078621

    - ✓ Moore, K.J., Birrell, S., Brown, R.C., Casler, M.D., Euken, J.E., Hanna, H.M., Hayes, D.J., Hill, J.D., Jacobs, K.L., Kling, C.L., Laird, D.A., Mitchell, R.B., Murphy, P.T., Raman, D.R., Schwab, C.V., Shinners, K.J., Vogel, K.P. & J.J. Volenec. (2015). Midwest vision for sustainable fuel production. Biofuels 2015:1-16. DOI:

10.1080/17597269.2015.1015312

- ✓ Emerson, R., Hoover, A., Ray, A., Lacey, J., Cortez, M., Payne, C., Karlen, D.L., Birrell, S.J., Laird, D., Kallenbach, R., Egenolf, J., Sousek, M. & T. Voigt. (2014). Drought effects on composition and yield for corn stover, mixed grasses, and Miscanthus as bioenergy feedstocks. Biofuels 5(3): 275-279.

- **Other Papers, Abstracts and presentations:**

  - ✓ De Souza, A., Birrell, S.J., Steward, B.L. & S. Ksketri. (2015). High frequency dielectric sensing system development for corn and switchgrass features measurement. ASABE Paper No. 2160026, Am. Soc. of Agric. Engineers, St. Joseph, MI.
  - ✓ Karkee, A. & S.J. Birrell. (2015). Profit and cost variation with the size variation of bio refinery. ASABE Poster No. 2188745, Am. Soc. of Agric. Engineers, St. Joseph, MI
  - ✓ Karkee, A. & S.J. Birrell. (2015). Least Cost Machinery Analysis for Two Different Biomass Collection Methods. ASABE Paper No. 2189917, Am. Soc. of Agric. Engineers, St. Joseph, MI.
  - ✓ Sharma, B., Birrell, S.J. & F.E. Miguez. (2015). An integrated GIS and mathematical model for optimal siting of bioethanol plants in the U.S. ASABE Paper No. 218705, Am. Soc. of Agric. Engineers, St. Joseph, MI.
  - ✓ Khanchi, A. & S.J. Birrell. (2015). Influence of rainfall level and crop density on dry matter loss from corn stover and switchgrass. ASABE Poster No. 2190787, Am. Soc. of Agric. Engineers, St. Joseph, MI.
  - ✓ Khanchi, A. & S.J. Birrell. (2015). Influence of weather and swath density on drying characteristics of corn stover. ASABE Paper No. 2190753, Am. Soc. of Agric. Engineers, St. Joseph, MI.

- **University of Wisconsin**

  - A study was undertaken to compare harvest and storage properties of perennial grasses with those of corn stover. Round bale density was not significantly different between these biomass crops. Switchgrass yield was more than twice that of corn stover, which helped dilute parasitic fuel use during harvest so switchgrass baling specific fuel consumption (gal/ton DM) was 36% less. Grass bales formed a better thatch, shed precipitation better and had lower aggregate moisture when removed from storage than stover bales. Losses during storage were 6.4 and 10.3% of DM for grass and stover bales, respectively. Grass bales were much more difficult to size-reduce by grinding than stover bales, so throughput and specific energy were considerably greater for grass bales than stover.

- High yielding grasses are tall at fall harvest and therefore susceptible to lodging. Lodged grass is more difficult to harvest and slows the harvest rate. Yield loss from long stubble that resulted from cutting lodged grasses were quantified and ranged from 0.5 to 0.8 ton DM/ac. This is a significant loss that needs to be addressed through better mower design.
- Single-pass baling of grain residue is now a commercial reality. These balers allow residue to be collected and packaged without stopping grain harvest and produces a clean, low-ash feedstock. However, special-purpose machines such as this have high costs because of limited annual use. A single-pass baler was modified to be able to harvest standing or windrowed switchgrass as a way to increase annual use and spread costs across all feedstocks. The modification was successful and the process produced a feedstock that was well size-reduced, possibly eliminating the need for primary bale grinding. However, productivity was much lower than conventional baling and unless this negative is overcome, the single-pass application would have limited utility for harvesting high-yielding grasses.
- We have developed a process that compacts a large round bale (LRB) and reshapes it into a parallelepiped or cuboid shape similar to a large square bale (LSB). The mechanism is able to reshape a round bale into a roughly square cross-section and increase the density from 9.5 to 13.5 lbs/ft^3 (dry basis). Power requirement for compaction is considerably less than with a LSB because densification occurs at much slower rate.
- A techno-economic analysis of grass feedstock logistics was begun. A model which features modules for harvest, road siding, storage; transport, and grinding has been developed. 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 $50 to 70 per dry ton. This cost does 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 5

- **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**

Bale density has a major impact on biomass cost, so work on increasing bale density will continue. High-density large square balers will be investigated, specifically in their ability to achieve weight-limited transport and at what cost. New approaches to large square baler designs will be investigated. Additionally, we will continue to develop a new approach where the round bale is re-shaped and re-compressed in the field to have greater density than a large-square bale plus have a parallelepiped or cuboid shape that better optimizes shipping volume. Data will also be collected on the force, energy and cost to increase large square bale density post-harvest. Bale size-reduction by grinding using conventional agricultural grinders is costly. Energy and operating costs of alternative grinding technologies from outside agriculture will be investigated. Alternative power sources for size-reduction (i.e. diesel versus electric) will also be considered. We have quantified significant losses that occur when perennial grasses lodge before cutting, so design changes to mowing equipment to reduce these losses will be considered. Finally, we will continue to develop our techno-economic analysis of some of the new harvest and transport approaches we have investigated in this work to determine the economic impact – either positive or negative – of these approaches. The model results will be integrated into the Integrated Biomass Supply Analysis and Logistics Model (IBSAL) so our results can serve as inputs to the simulation model. Simulations across different crops and weather conditions will provide a more global perspective of the true costs of grass feedstock logistics.

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 4

- **Iowa State University**
  - Completion of a baseline modeling system for the Upper Mississippi River Basin and Ohio Tennessee River Basin capable of evaluating the water quality impacts of dedicated biofuel crops.
  - Completion of a set water quality scenarios for the Boone River watershed comparing food, fuel, and energy tradeoffs for alternative land uses in the watershed.
- **University of Minnesota**

  One accomplishment this year was the publication of our analysis of the air quality and climate change impacts of transportation options in PNAS. This study received major media attention, has been downloaded over 30,000 times and is currently in the 99th percentile of articles tracked by Altmetric. The findings were presented before a hearing of the U.S. House Committee on Science, Space, and Technology. A second accomplishment was the successful graduation of two master's graduate students supported by CenUSA. The topics of their dissertation and theses included estimating land-use change associated with the Renewable Fuel Standard and quantifying yield gaps between field trials and commercial-scale production. Other accomplishments included preliminary results from detailed air quality modeling of switchgrass production and the preparation of a report on the rebound effect of increased biofuels production.

Planned Activities, Outcomes and Impacts – Year 5

- **Iowa State University**
  - Complete detailed water quality models for the Boone River Watershed and the Indian Creek Watershed in Iowa and Indiana respectively. Undertake comparisons between similar scenarios across the watersheds to assess environmental impacts and biofuel output associated with bioenergy crop placements.
  - Undertake large-scale assessments for bioenergy crop placement across the Upper Mississippi River Basin comparing optimized and market driven strategies with strategies limiting options to marginal land.
- **University of Minnesota**

  Planned activities for Year 5 include continued work on Task 1 (Adapt existing biophysical models to best represent data generated from field trials and other data sources), Task 2 (Adapt existing economic land-use models to best represent cropping system production costs and returns), Task 3 (Integrate physical and economic models to create spatially-explicit simulation models representing a wide variety of biomass production options), Task 4 (Evaluate the life cycle environmental consequences of various bioenergy landscapes), and Task 5 (Employ the modeling systems to study the design of policies to cost effectively supply ecosystem services from biomass feedstock production).

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 4

- Initial process models have been developed that will allow for detailed techno-economic comparison of product portfolios, which will include transportation fuel, chemicals, and other products such as sugars, bio-asphalt, bio-cement, and fuel for power generation.
- Determined that weathering (oxidation and hydrolysis) of biochars in soil environments has a large influence on biochar surface chemistry which influences nutrient and water retention capacity of biochars.
    - During weathering, cation exchange capacity (generally) increases for hardwood biochars but decreases for herbaceous biochars.
    - Biochar weathering results in formation of new oxygen containing organic functional groups on biochar surfaces (primarily carbonyl, hydroxyl, ether, aldehyde, and carboxyl groups).
    - Anion exchange capacity (AEC) of biochars is caused by oxonium functional groups, pyridinium functional groups, and the adsorption of proton by pi electrons in condensed aromatic C.
    - ~50% of biochar AEC is lost during biochar weathering, however, oxonium groups in bridging positions resist weathering and can provide stable pH independent AEC.
    - Weathered biochars retain more water than fresh biochars.
    - Lawrinenko, M. & D.A. Laird. 2015. Anion exchange Capacity of Biochar. *Green Chemistry*, 17 (9), 4628 – 4636. 2015, DOI: 10.1039/C5GC00828J. http://pubs.rsc.org/en/content/articlepdf/2014/GC/C5GC00828J?page=search

- Archontoulis, S.V., Huber, I. Miguez, F.E., Thorburn, P. J., Rogovska, N. & D.A. Laird. A model for mechanistic and system assessments of biochar effects on soils and crops and trade-offs. *GCB Bioenergy* (in press)

- Lawrinenko, M., Laird, D.A. Johnson, R.L. & D. Jing. Accelerated aging of biochars; impact on anion exchange capacity. Submitted to *Green Chemistry*.

- Lawrinenko, M.& D. A. Laird. Improved anion exchange capacity in biochar by aluminum and iron surface enhancement. In review.

- Bakshi, S., Aller, D. M., Laird, D. A. & R. Chintala. Comparison of the physical and chemical properties of laboratory- and field-aged biochars. In review.

- Evaluated the proximate analysis method for determining volatile matter (VM) and fixed carbon (FC) in biochars; specifically, we assessed the effect of the temperature used to separate VM and FC and compared proximate analyses of fresh versus weathered biochar.

- Determined that H:C and VM:FC ratios are correlated and provide independent methods of quantifying the labile fraction in biochars.

- Developed first prototype of biochar model within the APSIM cropping systems model.

- **Planned Activities, Outcomes and Impacts – Year 5**

  - Complete a literature review to expand the techno-economic analysis of potential pyrolysis products to include additional hydrocarbon chemicals and biochemicals such as food additives, pharmaceuticals, and other petro-chemical substitutes.

  - Complete market analysis to identify potential values of new pyrolysis product categories.

  - Complete economic and social (jobs and market impact) optimization of pyrolysis product portfolios by region.

  - Complete process model of the recovery of optimal pyrolysis product portfolios.

  - Complete manuscripts on pyrolysis economic and social optimization studies and techno-economic analysis of pyrolysis product portfolios.

  - Complete biochar aging study.

  - Complete manuscript on biochar aging.

- Complete manuscript on biochar AEC during oxidation.
- Complete manuscript on comparison of organic and inorganic alkalis in biochar.

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 4

To date, our objective has made progress on multiple fronts, including investigations into threshold returns of perennial grasses, incorporating real option values into analyses of returns to switchgrass production, and understanding producer-level support and frictions related to perennial grass adoption decisions. The following are a few of the accomplishments and outputs:

- Richard Perrin (CenUSA collaborator) and a graduate student completed a study of the potential impact of higher grain and hay prices on the allocation of crop acreage (Megeressa, (2013) *Impact of Biofuel Demand on Land and Water Use in the Great Plains*). The study finds that substantial incentives will need to be paid to grass biomass producers to divert significant acreages from current row crop rotations.
- Keri Jacobs (Co-PD) presented CenUSA project information and objective findings at the 2013 Integrated Crop Management conference and administered a survey to participants to elicit information about knowledge of perennial grasses and willingness to adopt practices. The survey findings were presented at the CenUSA annual meeting.

- Jacobs delivered three CenUSA webinars: *Competition for land use: Why would the rational producer grow switchgrass for biofuel?*
- Dermot Hayes (Co-PD) published project-related research in *Energy Policy*, *Economics Research International, and Biomass & Bioenergy*.
- Six PhD students in economics, two Masters students, and one undergraduate summer intern have been trained on this project in the last four years.
- The economics of perennial grass production have been updated based on outputs from collaborators and other objectives, providing a better understanding of prospects for making the system an economically viable choice for producers.

Planned Activities, Outcomes and Impacts – Year 5

In Year 5, we will continue to explore the market potential for perennial grass production using updated production costs and returns, land-competition factors, and potentially available incentives and programs designed to increase participation in the market. Two major projects are underway that will be completed in the next year:

- A stakeholder decision tool that incorporates perennial grass production costs and compares a perennial grass system with competing land uses (grazing, row-crop production); and
- A research paper that models the cellulosic biofuel producer as a single price monopsonist (single buyer of biomass). In the research project, assuming the biofuel producer is a monopsonist conforms to our current understanding of how a market for biomass will likely develop. We consider the role of perennial grasses when a mandate for cellulosic biofuel is large enough to exceed what can be produced with field residue (stover). The decision tool will be the first of its kind to integrate the most updated information on perennial grass production and synthesize its feasibility for a number of stakeholders, including cash renters, grazers, seed salespersons, and custom farmers.

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 4

- An injury and exposure database was populated with data from published sources and specific logic filters were crafted to created necessary values needed for probabilistic risk assessment model calculations.
- Multiple risk model calculations were performed and analyzed with results shared at the International Society for Agriculture Safety and Health international conference and then submitted to the Journal of Agricultural Safety and Health.
- The Master Gardeners' safety precautions for storing, handling and applying biochar publication was entered into the community of practice (CoP) with eXtension with the CoP being Ag Safety and Health.
- A continual effort to maintain the relationship with collaborators at Penn State University (another USDA NIFA bioenergy project) in the safety objective was accomplished.

Planned Activities, Outcomes and Impacts – Year 5

- Multiple risk model calculations will be performed (approximately 500,000 iterations) and analyzed with results shared in a professional conference presentation and possible journal paper.
- The probabilistic risk assessment model will continue to receive refinements after examination of multiple runs and output analysis for accuracy and precision in forecasting risk probability for different farming systems.
- Specific modifications to the human subjects study will be made and approval pursued. The necessary air sampling equipment will be placed into service. Human subjects to participate in the study will have been recruited. Identified locations where potential dust hazards will be measured.
- The relationship with collaborators at Penn State University (another USDA NIFA bioenergy project) in the safety objective will continued to be strengthened.

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 graduate students.

Co-Project Directors

- Raj Raman, rajraman@iastate.edu, 515.294.0465
- Patrick Murphy, ptmurphy82@gmail.com, 765.494.1175

Significant Accomplishments – Year 4

On-line Curriculum Development. We completed content development for modules in conversion feedstock development and sustainable production systems. We wrote a manuscript summarizing module evaluation data presented at an online education conference. We finalized plans to move all existing module content from the UNL PASSeL platform to a Moodle-based platform at The Ohio State University (OSU).

- **Undergraduate Internship.** Nineteen undergraduate students were successfully placed and mentored at the following CenUSA institutions: Iowa State University (7 interns); University of Nebraska, Lincoln (6 interns); Purdue University (2 interns); University of Wisconsin, Madison (2 interns); ARC NCAUR Laboratory in Peoria, IL (1 intern); and Archer Daniels Midland in Decatur, IL (1 intern) from May 28 – August 1, 2015.
    - The summer undergraduate program consisted of formal and informal activities that included an orientation session, lab work, a series of lectures by faculty, workshops, seminars, field trips, lab tours, weekly lunches with the program coordinators, and student team building social events.
    - A mentor training video (15-minute video created by Raj Raman) was shared during the middle of May with the internship mentors (faculty/grad student/post doc) giving them ample time to view the video. This was followed by a May 20, 2015 combined face-to-face (for ISU-based mentors) and virtual meeting to clarify any questions and concerns in preparation of the undergraduate students' arrival on May 28.
    - Faculty, scientists, and graduate students served as mentors to the participating students, supervising the students' individual research projects and guiding their research experiences in labs.

- In addition to the above program-wide group activities, the students participated in their individual lab teams' meetings, at which they shared their project progress and learning experiences.

- The students' poster session on July 31, 2015 was a culminating event of the students' participation in the program that provided the students with the opportunity to learn and experience presenting and communicating their projects' results succinctly and effectively to the community of CenUSA researchers, advisory board members, and partners.

- Each year, Iowa State University's Research Institute for Studies in Education (RISE) administers a pre-program survey to assess students. This provides a baseline for program evaluation. RISE also conducts a post-survey and focus groups at the close of the program, as well as a post program six-month survey.

- Through e-mail and social media (including LinkedIn) we contacted all 55 alumni of the CenUSA summer research internship. Of those who have completed their undergraduate studies, 40% have matriculated to graduate school.

- **Graduate Intensive Program.** Raj Raman collaborated with Feedstock Development co-Project director Michael Casler to offer a one-day condensed graduate intensive program add-on to the 2015 CenUSA annual meeting. This one-day event included an in-depth tour of the facilities and field research plots at the Great Lakes Bioenergy Research Center as well as a tour of the Wisconsin Energy Institute to include research profile presentations by Brian Fox (biochemical, catalytic, and spectroscopic studies of redox active enzymes; protein engineering) and Chin Wu (focuses on the development of innovative flow energy harvester and assessment of renewable wave energy in the Great Lakes). The graduate students, as well as the summer undergraduate research interns, who attended the tours and research presentations witnessed a range of biomass research that was quite different from that in CenUSA, all covering a range of topics from production/sustainability all the way to conversion processes.

- **Graduate Research Webinar Series.** In year four, the graduate research webinar series was revamped into a panel-based series entitled *Conversations About Critical Issues*. Raj Raman, co-project director of the Education Objective, restructured and refocused the delivery of the research webinar content. Two one-hour sessions were offered at the start of 2015. These sessions had several CenUSA objective leaders or collaborating faculty present on an issue meant to be mildly controversial so that multiple views could be presented. This revamp was essentially launched to stimulate intra-project conversations with a grad-student audience to illuminate the various approaches to critical issues within the project.

    - January 30: The seminar topic was "What is the most realistic scenario for the adoption of SG (or other perennial) on marginal lands, and what policy changes would be needed to make this happen?" with panelists Jason Hill, Raj Raman, and Ken Moore.

    - March 27: The seminar topic was "What are the most realistic approaches to reducing N and P exports from the Corn Belt?" with panelists Cathy Kling, Dermot Hayes, and Raj Raman.

Planned Activities, Outcomes and Impacts – Year 5

- **On-line curriculum course modules.** Content for modules in the sustainable production systems, feedstock development, feedstock logistics, markets and distribution and conversion objectives areas will be developed this year. A massive open online course (MOOC) will be hosted by OSU using the module content developed. Existing module content in UNL PASSeL will be moved to the OSU Moodle platform for long-term public accessibility.

    - Continue the summer internship program. In 2016, the program plans to host 13 undergraduate interns, a diverse group of students representing institutions from across the country. The placement locations will be driven by the faculty mentors who are actively conducting bench and field research during the last year of the program.

- ✓ To date, 55 undergraduate students were successfully placed and mentored at CenUSA institutions: Iowa State University, University of Nebraska - Lincoln, University of Wisconsin – Madison, University of Minnesota, Purdue University, Idaho National Laboratory, USDA NCAUR Laboratories in both Ardmore, PA and Peoria, IL, and Archer Daniels Midland.

- ✓ The undergraduate student poster sessions at each annual meeting continues to be a significant catalytic event that brings together CenUSA collaborators and Advisory Board members to engage with transdisciplinary issues.

- **Graduate Intensive Program.** This is not a planned activity for year five of the program.

- **Graduate Research Webinar Series.** This series will not be conducted; however, graduate students will be invited to participate in critical project meetings as objectives disseminate findings in this final year.

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, mailto:sorrel@iastate.edu, 515.294.8802

Significant Accomplishments – Year 4

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 4 of the project. The Extension Staff Training/eXtension/Communications Team produced the following materials.

- **Fact Sheets**
    - *Index of Recent Biochar Publications* (http://www.extension.org/pages/72947/recent-publications-about-biochar#.VgAjaPMo6M8).

- *Fast Pyrolysis Efficiently Turns Biomass into Renewable Fuels* (Robert Brown) (http://www.extension.org/pages/72722/fast-pyrolysis-efficiently-turns-biomass-into-renewable-fuels#.VgAjf_Mo6M8).

- *Storing Perennial Grasses Grown for Biofuel* (Kevin Shinners) (http://www.extension.org/pages/70635/storing-perennial-grasses-grown-for-biofuel#.VgAjmvMo6M8).

- *The Economics of Switchgrass for Biofuel* (Richard Perrin) (http://www.extension.org/pages/71073/the-economics-of-switchgrass-for-biofuel#.VgAjsvMo6M8).

- *Biochar: Prospects for Commercialization* (David Laird and Pamela Porter) (http://www.extension.org/pages/71760/biochar:-prospects-of-commercialization).

▪ **Research Summaries**

- *Competition for Land Use: Why Would a Rational Producer Grow Switchgrass for Biofuel? (Keri Jacobs)* (http://www.extension.org/pages/72596/research-summary:-competition-for-land-usewhy-would-a-rational-producer-grow-switchgrass-for-biofuel).

- Safety and Health Risks of Producing biomass on the Farm (Douglas Schaufler) (http://www.extension.org/pages/71921/research-summary:-safety-and-health-risks-of-producing-biomass-on-the-farm#.VgA2jvMo6M8).

- *Research Finds Strong Genetic Diversity in Switchgrass Gene Pools (Mike Casler)* (http://www.extension.org/pages/70383/research-summary:-research-finds-strong-genetic-diversity-in-switchgrass-gene-pools#.VgAkQvMo6M8).

- *Near Infrared NIR Analysis Provides Efficient Evaluation of Biomass Samples (Bruce Dien)* (http://www.extension.org/pages/70496/research-summary:-near-infrared-nir-analysis-provides-efficient-evaluation-of-biomass-samples#.VgA3XvMo6M8).

▪ **Extension Videos**

- University of Minnesota Extension Master Gardener Biochar Research Summary https://vimeo.com/111655127.

- Biochar: An Introduction to an Industry https://vimeo.com/111760435.

▪ **Report**

Extension Master Gardener Biochar Demonstration Gardens 2014 Annual Report (See Exhibit 1. Extension Master Gardener Biochar Demonstration Gardens 2014 Annual Report).

- **Webinars**
  - Introduction to Biochar Commercialization Opportunities https://vimeo.com/118376782.
  - Biochar 101: Intro to Biochar https://vimeo.com/114174570.
- **Outreach Data**
  - **Videos and Webinars**
    - ✓ **Vimeo Stats for all CenUSA videos (produced years 1-4)**
      - Loads**:** 10,211[1]
      - Plays/views: 1,147[2]
      - Finishes: 275
    - ✓ **YouTube Stats for all CenUSA Videos**
      - Views: 3,906
      - Estimated Minutes Watched: 12,436
      - YouTube**:** 57 subscribers
  - **eXtension CenUSA Site Views/Statistics**
    - ✓ 7,907 unique visitors, 11,798 pageviews of the CenUSA specific pages.
    - ✓ Average time on page is 4 min 24 seconds.
    - ✓ The top viewed page is, consistently and by-far-and-away, *Switchgrass (Panicum virgatum) for Biofuel Production*, featuring Rob Mitchell; with 3,847 views. See below for the top 10 pages.
    - ✓ Traffic sources remain relatively consistent. They are 81% search engines, 15% direct traffic, 4% referring sites, and a handful from Twitter.
    - ✓ The top 10 states accessing CenUSA publications were Texas, Illinois, Michigan, California, Pennsylvania, North Carolina, Virginia, Minnesota, Colorado, and Nebraska; with use from throughout the US and world. England and Quebec top the international use.

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[1] A "load" is counted each time the video player loads on any page, wherever a video is embedded.
[2] A "play" is counted each time someone pushes the play button on a video.

- ✓ **Top 10 eXtension Pages**
  - o *Switchgrass (Panicum virgatum) for Biofuel Production*
  - o *Biochar: Prospects of Commercialization*
  - o *The Economics of Switchgrass for Biofuel*
  - o *Research Summary: Safety and Health Risks of Producing Biomass on the Farm*
  - o *Control Weeds in Switchgrass (Panicum virgatum L.) Grown for Biomass*
  - o *Fast Pyrolysis Efficiently Turns Biomass into Renewable Fuels*
  - o *Successfully Harvest Switchgrass Grown for Biofuel*
  - o *Minnesota Watershed Nitrogen Reduction Planning Tool*
  - o *Research Summary: Management Practices Impact Greenhouse Gas Emissions in the Harvest of Corn Stover for Biofuels*
  - o *Switchgrass (Panicum virgatum L.) Stand Establishment: Key Factors for Success*

- **CenUSA Web Site**
  - ✓ 2,794 unique visitors, 5,868 pageviews.
  - ✓ Average time on page is 1 min 39 seconds.

- **Social Media**
  - ✓ **Facebook Followers**: 216 people "like" CenUSA Bioenergy; **Twitter Followers**: 634; **YouTube Subscribers**: 57.

- **BLADES E-Newsletter**

  Five BLADES e-newsletters were produced and emailed to 819 contacts. The newsletters included 26 e-news articles and 3 video shorts (video titles: *CenUSA Commercialization Objective from Rob Mitchell*; *CenUSA Looks for Next Batch of Summer Interns* and *Commercial Corner: LaVon Schiltz: Building Renewables*).

- **Producer Research Plots/Perennial Grass/Producer and Industry Education Team**
  - ✓ Worked with producers/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 CenUSA

research team.

- ✓ Held field days/tours of the CenUSA on-farm demonstration plots, and informational meetings for producers, reaching a total of 797 producers/ag industry leaders.
- ✓ Surveyed and analyzed surveys to document learning and behavior change (see quarterly reports for data).

- **Economics and Decision Tools Team**

  The team completed and vetted the *Perennial Grass Decision Tool* (http://www.extension.iastate.edu/agdm/crops/html/a1-29.html).

- **The Public Awareness/4-H and Youth Team**
  - ✓ Continued development and conducted pilot testing of CenUSA youth curriculum and learning materials at Iowa State University and Purdue.
  - ✓ Trained 248 adults to use the CenUSA Bioenergy materials.
  - ✓ 909 youth participated in events that used CenUSA curricula/materials during Year 4.

- **Public Education/Master Gardener Program**
  - ✓ Established and maintained five biochar demonstration gardens.
  - ✓ Collected data on various horticultural crops in the demonstration gardens and developed exhibits/blogs/fact sheets/research summaries with data.
  - ✓ Reached 2988 participants with garden tours, educational programs and exhibits about the CenUSA project and biochar utilization in horticultural applications during Year 4.

- **CenUSA Extension Administration Team**
  - ✓ Provided leadership at the national training summit for 79 Extension Educators (Extension Energy and Environment Summit – or E3 Summit) in September, 2014 (See Exhibit 2 E3 Conference Agenda). The Summit featured research and demonstration summaries from CenUSA and the other NIFA Bioenergy CAPS.
  - ✓ Renegotiated budgets and deliverables with CenUSA Extension program teams in Minnesota, Nebraska, Indiana and Wisconsin.
  - ✓ Conducted four new outreach components as recommended by the CenUSA Advisory Board in 2013 (feedlot trial with CenUSA switchgrass, evaluation of value

proposition for alternative uses of switchgrass, and national training summit for Extension Educators, and established/maintained/used CenUSA demonstration plots/outreach program at Vermeer Global Headquarters).

- ✓ Coordinated efforts of the various CenUSA Extension/outreach teams.
- ✓ Developed evaluation instruments for all the CenUSA Extension teams, summarized survey results and developed research reports and published results.
- ✓ Reached over 300 Extension Educators by teaching sessions about CenUSA outreach programs and materials at two national Extension meetings (National Extension Energy Summit in Seattle, Washington, April 7-9, 2015; and National Association of County Agricultural Agents in Sioux Falls, South Dakota, July 12-16, 2015).
- ✓ Collected data from CenUSA Extension team members and wrote Extension sections for CenUSA reapplication and quarterly and annual reports and provided presentation about CenUSA outreach initiatives at the CenUSA annual meeting.

Planned Activities, Outcomes and Impacts – Year 5

- Share information about CenUSA research and outreach programs with an additional 50 Extension educators at a national Extension sustainability conference in the spring of 2016.
- Develop, produce and post additional CenUSA Fact Sheets, Research Summaries, videos, newsletters, blog posts and maintain Twitter and Facebook accounts.
- Utilize "citizen science" program to promote shared learning about the impacts of perennial grass agriculture on ecosystems.
- Reach an additional 1,000 producers, industry leaders, educators, and agency personnel; and 500 horticultural producers and industry leaders, with CenUSA information about environmental, economic, and public relations impacts of transitioning marginal cropland to perennial grass and will understand the impacts of biochar as a soil amendment.
- Share the "Perennial Grass Decision Tool" with 500 producers and assist them with completing the tool.
- Finalize CenUSA C6 curriculum, iBook, app and youth learning modules re: perennial grasses, carbon cycling, and biochar utilization. Train 100 adults in use of the materials; and host events for an additional 1000 youth where they will utilize the materials and will demonstrate increased learning about renewable energy and STEM careers.

Objective 10. 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

- Tom Binder, Tom.Binder@adm.com, 217.451.4228
- Frank Lipiecki, Frank.Lipiecki@renmatix.com, 609.220.5370

Objective 10A. ADM

Significant Accomplishments – Year 4

- A proprietary pretreatment has been developed that enables continuous pyrolysis of industrial lignin streams by preventing char agglomeration in the reactor.
  - Multiple sources of lignin were successfully pyrolyzed using this pretreatment, including lignin streams from ADM and Renmatix. A lignin stream generated by enzymatic hydrolysis of corn stover was also successfully pyrolyzed.
  - Resulting bio-oil from lignin pyrolysis was catalytically cracked to produce aromatic hydrocarbons (primarily benzene, toluene, and xylene) and olefins (primarily propylene and ethylene). With hydrogen as a carrier gas, carbon conversion of the bio-oil to aromatics and olefins was 24.2% and 17.8% respectively.
  - Low-Temperature, Low-Pressure Hydrogenation (LTLP-H) was used to depolymerize Organosolv lignin from ADM, converting the lignin solid into a liquid that flows at room temperature. Lignin from Renmatix required an initial depolymerization step utilizing sodium hydroxide and other bases. This treatment took place at 125°C and atmospheric pressure. Base depolymerization of lignin has been reported in the literature, but at temperatures of 250°C and higher and under high pressure.
  - Zhou, S., Brown, R.C., & X. Bai. (2015) The use of calcium hydroxide pretreatment to overcome agglomeration of technical lignin during fast pyrolysis. *Green Chemistry*. DOI: 10.1039/c5gc01611h.
- **Plans for Year 5**
  - Continue to pyrolyze technical lignins provided by multiple industrial sources and production processes.

- Conduct continuous flow catalytic pyrolysis of pretreated lignin in 100 g/h fluidized bed reactor.
- Catalytically crack resulting pyrolysis oil from lignin to produce aromatic hydrocarbons and olefins.
- Enable 4-vinylguaiacol to vanillin reaction using the Cso2 enzyme.
- Optimize activity of the Cso2 enzyme in *E. coli* and S. cerevisiae using model 4-VG.
- Convert phenolic monomer mixtures that include 4-VG to vanillin.
- Complete manuscript on continuous flow catalytic pyrolysis of pretreated lignin.
- Complete manuscript on upgrading of lignin pyrolysis oil.
- Complete manuscript on converting phenolic monomers to vanillin.

Objective 10B. Renmatix

- **Significant Accomplishments – Year 4**

  - **Task 10c-1. Initial Physical and Chemical Characterization of Feedstocks Provided by CenUSA**

    Renmatix received nine biomass samples from the USDA-ARS (see Table 1) and conducted full chemical and physical characterization. The biomasses were found to contain a good amount of sugars that appeared to be suitable for recovery using the Plantrose® process. Xylan content was found to be between 19 and 22%, and glucan content between 31 to 34%. Lignin content was between 19 and 23%, while ash was typical of grassy biomass, around one order of magnitude higher than woody biomass. A complete report of biomass characterization was issued on April 16, 2015 (Exhibit 3. Renmatix Biomass Characterization Report).

    Preliminary characterization of native, switchgrass lignin using 2D-NMR was completed. Complementary characterization using 13C-NMR will be completed during the first quarter of year 5 and a report on lignin characterization will be issued.

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Table 1. Biomass Samples for Characterization			
No.	Biomass	Harvest	
		Month	Year
1	Switchgrass	August	2014
2	Switchgrass	November	2013
3	Low diversity mix	August	2014
4	Low diversity mix	November	2013
5	Big bluestem	August	2014
6	Big bluestem	November	2013
7	Corn stover	October	2014
8	Indiangrass	November	2014
9	Bio-energy big bluestem	November	2014

- **Task 10c-2. Bench scale: Determine Suitability for Processing Herbaceous Biomass with Plantrose® Process**

  The bench-scale screening study for hemicellulose removal from corn stover and from switchgrass by water under sub-critical conditions was completed. These biomasses will be further tested at a pilot scale using Renmatix's Plantrose® process. Results show good hemicellulose conversion and yield to xylose from both biomasses during hot water extractions. The hot water treatment of these biomasses generates sufficient hydrogen ions to catalyze and propagate auto-hydrolysis. A window of temperature and residence time conditions was found for optimal yield and conversion.

  The composition of the minor herbaceous perennials was found to be similar to switchgrass and corn stover. Therefore, it is expected that the piloting results from the latter two can be used to reasonably predict performance for the other perennials.

- **Task 10c-3. C5 sugar, C6 Sugar and Lignin Yield Compositional Data From Pilot Scale Tests**

  Two biomass samples were ground to the required particle size to be tested in Renmatix's pilot plant. Switchgrass was tested successfully with good xylan yield (>65%) and hemicellulose conversion (>75%) during the hemicellulose auto-hydrolysis process. Supercritical hydrolysis of cellulose also showed a good conversion level (>85%). Initial, small amounts of glucose and xylose solutions were produced in the pilot plant and will be refined and further tested along with lignin solids.

- **Planned Activities, Outcomes and Impacts – Year 5**

There are two main tasks that are to be completed during the course of year 5 of the project for the evaluation of the use of perennial grasses and corn stover as feedstocks in Renmatix's Plantrose® technology. Below is a brief description of each task.

- **Task 10c-3. Pilot-scale Testing**

  We will determine the potential economic feasibility of switchgrass and corn stover conversion into sugars and lignin via Renmatix's Plantrose® technology.

  The two biomass materials will be processed individually in Renmatix's Bioflex Conversion Unit in the Hemicellulose and the Supercritical Hydrolysis units. Xylose and glucose oligomer solutions will be refined to monomeric sugar solutions. Xylose and glucose sugars will be fermented to ethanol with common yeast or bacteria. Optimized process conditions will be established. Capital and operating costs will be estimated based on a conceptual manufacturing process for the two biomass materials.

- **Task 10c-4**

  Samples of lignin residue produced from each of two biomasses in the Plantrose® pilot plant will be provided to ISU for conversion to value-added products (Objective 10d).