cenusa bioenergy

Annual Progress Report

Executive Summaries

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

November 2017

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NOTICE

• Copies of this report are available for download at the CenUSA Bioenergy website (http://www.cenusa.iastate.edu/ResourceLibraryItems)

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

Annual Report Executive Summaries

August 1, 2016 – July 31, 2017

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.

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

- All data has been collected and received at central locations.
- Several manuscripts are in various stages of preparation, including:
  - A summary of biomass yield improvements across 13 field-trial locations.
  - Nitrogen demand associated with breeding for increased biomass yield.
  - Biomass quality associated with breeding for increased biomass yield.
  - Multi-location survey of insect populations in switchgrass and big bluestem trials.
  - Conversion efficiency of 'Liberty' switchgrass.
  - Epidemiology of switchgrass rust.

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

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

Significant Accomplishments

- **Iowa State University**

  Our CenUSA Objective 2 efforts have focused on writing and publishing during the last year. We have maintained the CenUSA system plots at Armstrong Research Station, but as we have spent our CenUSA funding we used funds from another project to support the plots and collect one last year of data.

- **Purdue University**

  - High switchgrass yields can be obtained on soils considered marginal for soil test phosphorus (P) and potassium (K). Levels of these nutrients known to reduce yield of alfalfa and maize have little influence on switchgrass yields. Thus, deploying switchgrass on low fertility sites in the landscape may be an excellent strategy for co-production of food/feed and biomass.
  - Annual application of modest amounts of nitrogen (N) fertilizer annually (~75 kg N/ha) results in higher yields of *Miscanthus* than does application of higher levels (~150 kg/ha) on alternate years and allowing internal N cycling to provide N to growing shoots.
  - After extensive analysis of cell walls and other compositional traits we can conclude that yield of cellulose, hemicellulose, lignin, sugar, and starch per hectare is largely determined by biomass yield and not by concentrations of these biomass constituents *per se*.

- **University of Illinois**

  - By the end of this project year, we completed three years biomass production of five energy crops on a wet marginal land with two environmental replications. The field biomass yield data demonstrated that perennial energy crops can be successfully grown for biomass production on wet marginal lands while improving ecosystem services such as water quality.

- Biomass samples collected from each plot during the growing season of 2016 were ground and sent to the U.S. Dairy Forage Research Center for laboratory analysis of biomass quality traits. Nutrients and minerals in biomass were measured to quantify the nutrient removal by energy crops grown on a wet marginal riparian buffer. The data indicated that harvest management and species had significant impacts on nutrient removal.

▪ **University of Minnesota**

- We completed near-anthesis and post-frost harvest activities and sample processing for the factor plots at Lamberton and Becker, Minnesota.

- **Anne Sawyer Dissertation**

  Anne Sawyer completed her dissertation using data collected from CenUSA. She defended her dissertation on June 15, 2017 and officially graduated July 31, 2017. Using her work, we are preparing three manuscripts for publication (See dissertation abstracts below).

  - **Chapter 1. Switchgrass and Mixed Perennial Biomass Production as Affected by Nitrogen Fertility and Harvest Management**

    Biofuel production using native perennials on marginal soils can reduce U.S. dependence on foreign oil and curtail greenhouse gas emissions without diminishing food crop production. In this research, we quantified biomass production and nitrogen (N) removal as a function of harvest regime (anthesis and post-frost) and N application rate (0, 56 and 112 kg N ha^{-1}) on two marginal sites in Minnesota. We examined three switchgrass (*Panicum virgatum* L.) monocultures, including 'Liberty,' a new bioenergy variety, and three polycultures: grass-only, grass-legume, and grass-legume-forb. At Becker, post-frost harvest yields totaling 11.0 Mg ha-1 over three years were achieved in 'Sunburst' and 'Shawnee,' while 'Liberty' produced 7.0 Mg ha-1 when fertilized at 112 kg N ha-1 yr-1. At Lamberton, post-frost harvest yields in 'Shawnee,' 'Sunburst' and 'Liberty' totaled 32.5, 29.9 and 21.2 Mg ha-1 respectively, over three years, when fertilized at 56 kg N ha-1 yr-1. Yields of the low-diversity (LD) grass mix were similar to 'Shawnee' switchgrass at both locations. Yield differences between harvest regimes varied by cultivar and location, although most feedstocks produced similar or greater yields in the post-frost harvest. Our results indicate that maximum biomass production can be achieved with either a well-adapted switchgrass variety or LD grass mix fertilized with 56 kg N ha-1 annually, post-establishment, on a moderately productive loam soil, and with 112 kg N ha-1 annually on an excessively drained sandy soil. While producers may have flexibility in harvest timing for some feedstocks in the first few years following establishment, a post-frost harvest regime will remove less N and promote stand longevity with fewer inputs over time.

- **Chapter 2. Rhizobacteria Community Structure as a Function of Cultivar and Nitrogen in Switchgrass Grown on Two Marginal Soils**

  Switchgrass is a native perennial grass and promising biofuel crop that can be used for production on marginal agricultural lands. As such, research into the switchgrass rhizosphere microbiome has been ongoing in an effort to identify patterns in microbial communities that may be beneficial for increasing sustainability in production. In this study, we examined the effects of cultivar and nitrogen (N) fertilization on rhizosphere bacterial community structure in switchgrass grown on two marginal soils. We selected two upland forage cultivars, 'Sunburst' and 'Shawnee,' as well as the first lowland bioenergy switchgrass adapted for production in USDA hardiness zones 4, 5, and 6, 'Liberty'. We found that that existing soil characteristics primarily shaped switchgrass rhizosphere communities, but both cultivar and N fertilization also influenced microbial selection in the rhizosphere. Only N fertilization resulted in consistent differences in bacterial orders across location, including orders containing genera involved in N dynamics in soil: Nitrosomonadales and Rhodocyclales. We also found that within-site spatial variability in soil properties influenced rhizosphere community structure, although differences were confined to minor taxa (< 0.1% of sequence reads). While our results provide insight into the effects of cultivar and N fertilization on the switchgrass rhizosphere bacterial community, they also indicate a need for future research addressing the influence of existing soil characteristics, including within-site spatial variability, on development of the rhizosphere microbiome in agricultural settings.

- **Chapter 3. Cultivar and Phosphorus Fertilization Effects on Switchgrass Biomass Yield, Phosphorus Removal, and Rhizosphere Microflora**

  Switchgrass (*Panicum virgatum* L.) is a native perennial grass identified as a promising biofuel crop for production on marginal agricultural lands. As such, research into switchgrass fertility and the switchgrass rhizosphere microbiome has been ongoing in an effort to increase sustainability in production. In this study, we examined the effects of cultivar and phosphorus (P) fertilization on biomass yield, phosphorus removal, and rhizosphere bacterial and fungal community structure in three switchgrass cultivars: 'Sunburst,' 'Shawnee' and 'Liberty' the first lowland bioenergy switchgrass adapted to USDA hardiness zones 4, 5, and 6. Biomass increased linearly in response to increasing P application on a low to medium soil test P clay loam soil. Applying 19.6 and 39.1 kg P ha-1, prior to establishment, provided average post-frost biomass yields of 10.1 and 10.3 Mg ha-1 yr-1, respectively, over three years. 'Shawnee' was more productive than 'Liberty' or 'Sunburst' (11.3, 10.2, and 8.6 Mg ha-1 yr-1, respectively). While cultivar was shown to influence both bacterial and fungal community structure in the rhizosphere, there were few consistent differences in taxa among cultivars. Phosphorus fertilization did not affect community structure among bacteria or fungi, despite a known switchgrass association with arbuscular mycorrhizal fungi for nutrient – particularly P – acquisition. The inability to detect fungal community differences as a function of P may be a result of known shortcomings in fungal sequencing, analyses, and taxonomy identification. Overall, our results indicate that while the rhizosphere effect does influence bacterial and fungal community structure, existing soil physiochemical parameters explain a greater proportion of variability in the rhizosphere community than do treatment effects.

- **Publications**

- Aller, D., R. Mazur, K. Moore, R. Hintz, D. Laird & R. Horton. 2017. Biochar Age and Crop Rotation Impacts on Soil Quality. Soil Sci. Soc. Am. J. (In press).

- Dokoohaki, H., F. Miguez, D.A. Laird, R. Horton & A. Basso. 2017. Assessing the biochar effects on selected physical properties of a sandy soil: An analytical approach. Commun. Soil Sci. Plant Anal. (In Press).

- Aller, D., S. Rathke, D. Laird, R. Cruse & J. Hatfield. 2017. Impacts of fresh and aged biochars on plant available water and water use efficiency. Geoderma, 307:114-121. http://dx.doi.org/10.1016/j.geoderma.2017.08.007.

- Archontoulis, S.V., I. Huber, F.E. Miguez, P.J. Thorburn & D.A. Laird. 2016. A model for mechanistic and system assessments of biochar effects on soils and crops and trade-offs. GCB Bioenergy. doi:10.1111/gcbb.12314.

- Fidel, R.B., D.A. Laird & T.B. Parkin. 2017. Impact of biochar organic and inorganic C on soil CO_2 and N_2O emissions. J. Environ. Quality, 46:505-513. doi:10.2134/jeq2016.09.0369. https://dl.sciencesocieties.org/publications/jeq/pdfs/46/3/505.

- Fidel, R.B. D.A. Laird & T.B. Parkin. 2017. Impact of six lignocellulosic biochars on C and N dynamics of two contrasting soils. GCB Bioenergy, 9:1279-1291. doi:10.1111/gcbb.12414.
- Laird, D.A., J.M. Novak, H.P. Collins, J.A. Ippolito, D.L. Karlen, R.D. Lentz, K.R. Sistani, K. Spokas & R.S. Van Pelt. 2017. Multi-year and multi-location soil quality and crop biomass yield responses to hardwood fast pyrolysis biochar. Geoderma, 289:46-53.
- Rogovska, N., D.A. Laird & D.L. Karlen. 2016. Corn and soil response to biochar application and stover harvest. Field Crops Res., 187:96-106. doi:10.1016/j.fcr.2015.12.013.

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

- Stuart Birrell, Iowa State University, sbirrell@iastate.edu, 515.294.2874.
- Kevin Shinners, University of Wisconsin, kjshinne@wisc.edu, 608.263.0756.

Significant Accomplishments

- **Iowa State University**
  - **Drying Rate Models**. Four drying rate models were finalized to predict the moisture change in switchgrass based on environmental conditions and swath densities. These models were developed for predicting moisture change in day conditions and for night conditions at different maturity stages. 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.

- **Biomass Drying Prediction Model**. An improved biomass drying prediction model has been developed. This model uses a random forest (RF) classification based algorithm, to predict moisture content (MC) of switchgrass (SW) and corn stover (CS). RF was able to predict the moisture content of switchgrass (SW) and corn stover (CS) with a coefficient of determination of 0.77 and 0.79, respectively. Hours after harvest, average solar radiation intensity, change in radiation intensity, rainfall, VPD were found to be the most important factors affecting the MC of CS. Drying CS in low density (LD) and medium density (MD) swaths facilitated quick drying even in moderate drying conditions and density were found to be higher in importance than other variables used for model development. Rainfall events ranging from 1.5 to 7.5 mm were experienced during the switchgrass drying period which delayed the crop drying by one day to several days depending on the weather conditions after rainfall. Several rewetting events were also observed due to dew at night and early morning which increased the MC in LD switchgrass and CS by 5 to 15%. The models developed in current study will help in decision making of switchgrass and CS collection after harvest based on forecasted weather conditions in lower Midwestern states.

- **Harvest Logistics Cost Analysis**. The results of the CenUSA harvest logistics cost analysis have been discussed with a number of US and international visitors, including industrial visitors from Brazil and China who are investigating the use of biomass for energy production.

- **Moisture Predicting Sensors**. Research on the development of sensors capable of predicting moisture content and bulk density of biomass feedstocks based on the dielectric measurements continued during this quarter. The development and design of the electronics for real-time biomass moisture sensor is continuing.

- **Publications**. Three journal articles have been published in 2017, with one more journal article in review and a second journal article to be submitted for review.

  A book chapter to be published in CRC Biomass Preprocessing Book, has been submitted and reviewed and is expected to be published, 2017. A journal article has been submitted to *Agricultural and Forest Meteorology* journal for review.

  ✓ Khanchi, A. & S.J. Birrell. 2017. Drying models to estimate moisture change in switchgrass and corn stover based on weather conditions and swath density. Agric. For. Meteorol., 1(8): 237-238. https://doi.org/10.1016/j.agrformet.2017.01.019.

  ✓ Khanchi, A.& S.J. Birrell. 2017. Effect of rainfall and swath density on dry matter and composition change during drying of switchgrass and corn stover. Biosystems Engineering, 153:42-51.

- ✓ Khanchi, A. & S.J. Birrell. 2017. Modeling the influence of crop density and weather conditions on field drying characteristics of switchgrass and corn stover using random forest. Biosystems Engineering (re-submission).
- ✓ Khanchi, A., B. Sharma, A.K. Sharma, A. Kumar, J.S. Tumuluru & S.J. Birrell. 2017. Effects of Biomass Preprocessing Technologies on Gasification Performance and Economic Value of Syngas. Book Chapter submitted to CRC Biomass Preprocessing Book Chapter. (Submitted, to be published 2017).
- ✓ Sharma, B. S. Birrell & F.E. Miguez. 2017. Spatial modeling framework for bioethanol plant siting and biofuel production potential in the U.S. Appl. Energ. 191:75-86.
- ✓ Karakee, A. & S.J. Birrell. 2018. Optimization and cost analysis of crop residue harvest systems. (In preparation).

▪ **University of Wisconsin**

Significant Accomplishments

- **Switchgrass Drying Rate Model**. We completed a model of the switchgrass drying rate as a function of 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 harvest can be completed. This work resulted in the publication of two peer-reviewed journal articles:
  - ✓ Shinners, K.J. & J.C. Friede. 2017. Enhancing the drying rate of switchgrass. BioEnergy Res., 10(3): 603-612.
  - ✓ Shinners, K.J., B.K. Sabrowsky, C.L. Studer & R.L. Nicholson. 2017. Switchgrass harvest progression in the North-Central US. BioEnergy Res. 10(3): 613-625
- **Twine Density Cost**. The cost of twine for high-density large-square bales can exceed $3 per dry ton, which is almost 25 percent 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. Work was completed developing relationships between twine tension and bale density for high-density bales. A manuscript was recently submitted based on this work:
  - ✓ McAfee, J.M., K.J. Shinners & J.C. Friede. 2017. Twine tension in high-density large-square biomass bales. Applied Eng. in Ag. (Submitted August 2017, in review.)

- **Auger Baler**. The experimental "auger" baler was evaluated when baling typical biomass crops. 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. Modifications were made to overcome performance issues related to feeding and crop flow, so baling can now take place at throughputs similar to conventional balers. Preliminary results of this work have been published in a conference proceeding and a peer-reviewed manuscript will be completed in the spring of 2018:

  - ✓ Shinners, K.J. J.C. Friede, J.R. McAfee, D.E. Flick, N.C. Lacy & C.M. Nigon. 2017. Conventional and novel approaches to creating high-density biomass bales. Proceedings of the Inter. Conference on Agricultural Engineering. Hanover, GE. Nov. 10 - 11.

  - ✓ Flick, D.E., K.J. Shinners, J.C. Friede & C. M. Nigon. 2018. Producing high-density biomass using an auger-baler concept. Transaction of the ASABE. (To be submitted in late-spring 2018).

- **High-Density Large Square Balers**. We investigated "high-density" large square balers to determine if these machines could produce bale densities which would reduce storage and transport costs by reducing required storage space and insuring weight-limited transport. Density in excess of 14 lb./ft^3 would provide weight limited transport in most cases. In only a few conditions was this goal reached and total baling energy requirements increased as a quadratic function of density. However, reduction in costs of aggregation, storage and transport more than offset the greater cost of harvesting high-density bales. A manuscript from this work is nearing completion:

  - ✓ Shinners, K.J. & J.C. Friede. 2017. Energy requirements to produce high-density large-square biomass bales. Energies. (To be submitted November 2017).

- **Densification Characteristics**. Densification characteristics of common biomass crops was investigated using test fixture intended to re-compress large-square bales to "double density". Models of recompression forces and energy as a function of attained density were developed. Forces in the straps that resist the bale resilient forces were determined. The results of this will be developed into a peer-reviewed manuscript will be completed in the spring of 2018:

  - ✓ McAfee, J.M., K.J. Shinners & J.C. Friede. 2018. Recompression of large-square biomass bales. Transaction of the ASABE. (To be submitted in spring 2018).

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

- Cathy Kling, Iowa State University, ckling@iastate.edu, 515.294.5767.
- Jason Hill, hill0408@umn.edu, 612.624.2692.

Significant Accomplishments

- **Iowa State University**

  Objective 4 collaborators focused on completing the review process of a set of four simulation-based studies submitted to the Journal of the American Water Resources Association (JAWRA) SWAT Special Series. This set of studies describes the impact of introducing biofuel cropping systems in specific watersheds representative of the eastern or western Corn Belt regions, as well as for the entire Upper Mississippi and Ohio River systems (representative of the entire Corn Belt). An overview study provides an assessment of the policy implications of the results of the watershed analyses. All four studies are now forthcoming in JAWRA; it is anticipated that those studies will be published in the final 2017 issue or first 2018 issue of JAWRA.

- **University of Minnesota**

  This year, the Objective 4 team in Minnesota continued preparing and submitting manuscripts from the research results of previous years. This resulted in four more publications, with two more in review and at least one more in preparation.

  - Harding, K., T. Twine, A. VanLoocke & J. Hill. 2016. Impacts of second-generation biofuel feedstock production in the central U.S. on the hydrologic cycle and global warming mitigation potential. Geophys. Res. Lett. 43:10773-10781. doi:10.1002/2016GL069981.
  - Keeler, B., J. Gourevitch, S. Polasky, F. Isbell, C. Tessum, J. Hill & J. Marshall. 2016. The social costs of nitrogen. Sci. Adv., 2:1-9. doi:10.1126/sciadv.1600219. (Open Access).

- Sun, J., T. Twine, J. Hill, R. Noe, J. Shi &M. Li. 2017. Effects of land use change for crops on water and carbon budgets in the Midwest USA. Sustainability, 9:1-. doi:10.3390/su9020225. (Open Access).

- Tessum, C.W., J.D. Hill & J.D. Marshall. 2017. InMAP: A model for air pollution interventions. *PLOS ONE* 12(4): 1-26. doi:10.1371/journal.pone.0176131. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0176131. (Open Access).

FEEDSTOCK CONVERSION AND REFINING

Co-Project Director

- Robert C. Brown, Iowa State University, 515.294.7934.

Significant Accomplishments

We focused on completing journal publications.

- Aller, D., S. Bakshi & D.A. Laird. 2017. Modified method for proximate analysis of biochars. J. of Analytical & Applied Pyrolysis. 124:335-342. doi.org/10.1016/j.jaap.2017.01.012.

- Bakshi, S., D.M. Aller, D.A. Laird & R. Chintala. 2016. Comparison of the Physical and Chemical Properties of Laboratory- and Field-Aged Biochars. J. Env. Quality, 45:1627-1634. doi:10.2134/jeq2016.02.0062.

- Bakshi, S., C. Banik, S.J. Rathke & D. A. Laird. 2017. Arsenic sorption on zero-valent iron-biochar complexes. (In preparation).

- Banik, C., M. Lawrinenko, S. Bakshi & DA. Laird. 2017. Functional groups in relation to biochar surface charges. (In preparation).

- Dang, Q., Wenzhen, L. & M. Mba Wright. 2017. Techno-economic analysis of a hybrid biomass thermochemical and electrochemical conversion system. Energy Technol. (Accepted).

- Fidel, R. S. Archontoulis, B. Babcock, R.C. Brown, H. Dokoohaki, D. Hayes, D.A. Laird, F. Miguez, & M. Mba Wright. 2017. Commentary on Current economic obstacles to biochar use in agriculture and climate change mitigation regarding uncertainty, context-specificity and alternative value sources. Carbon Manage. (Accepted).

- Fidel, R., D.A. Laird, & K. Spokas. 2017. Sorption of ammonium and nitrate to biochars is electrostatic and pH-dependent. Sci. Rep. (Reviewers requested "major revisions" before publication).

- Fidel, R.B., D.A. Laird, M.L. Thompson & M. Lawrinenko. 2017. Characterization and quantification of biochar alkalinity. Chemosphere, 167:367-373. doi.org/10.1016/j.chemosphere.2016.09.151.

- Lawrinenko, M., D. Jing, C. Banik & D.A. Laird. 2017. Aluminum and iron biomass pretreatment impacts on biochar anion exchange capacity. Carbon, 118: 422-430. http://dx.doi.org/10.1016/j.carbon.2017.03.056.

- Lawrinenko, M., D.A. Laird, R.L. Johnson & D. Jing. 2016. Accelerated aging of biochars; impact on anion exchange capacity. Carbon, 10: 217-227. doi:10.1016/j.carbon.2016.02.096.

- Lawrinenko, M., J. (Hans) van Leeuwen & D.A. Laird. 2017. Sustainable pyrolytic production of zerovalent iron. ACS Sustainable Chem. Eng., 5: 767-773. doi:10.1021/acssuschemeng.6b02105.

- Lawrinenko, M., Z. Wang, R. Horton, D. Mendivelso-Perez, E. Smith, T. Webster, D.A. Laird & J. (Hans) van Leeuwen. 2017. Macroporous carbon supported zerovalent iron for remediation of trichloroethylene. ACS Sustainable Chem. Eng., 5: 1586-1593. doi:10.1021/acssuschemeng.6b02375.

- Li, W., Q. Dang, R. Smith, R.C. Brown & M. Mba Wright. 2017. Techno-Economic Analysis of the Stabilization of Bio-Oil Fractions for Insertion into Petroleum Refineries. ACS Sustainable Chem. Eng., 2: 1528-1537.

- Li, W., Q. Dang, D. Laird, R.C. Brown, & M. Mba Wright. 2017. The impacts of biomass properties on pyrolysis yields, economic and environmental performance of the pyrolysis-bioenergy-biochar platform to carbon negative energy. Bioresour. Technol. (Accepted).

- Qi, F. & M. Mba Wright. 2016. A novel optimization approach to estimating kinetic parameters of the enzymatic hydrolysis of corn stover. AIMS ENERGY, 1(4): 52-67.

- Qi, F., T.J. Heindel, M. Mba Wright. 2017. Numerical study of particle mixing in a lab-scale screw mixer using the discrete element method. Powder Technol., 308: 334-345.

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

The primary goal of Objective 6 is to contribute new knowledge about how producers of dedicated biomass make decisions about participation and also about the contract mechanisms that might be effective as biomass processors work to procure feedstock from producers. In this final year, as a result of that research, we were invited to share our work in Washington, D.C. at a USDA C-FARE and Office of Chief Economist symposium, "American-Made Bioenergy from Field to Refinery: Feedstock Logistics."

The research and project support provided graduate student training in economics, and this year, a student earned his Ph.D., in part, as a result of a paper written through this support. The paper has been submitted for publication to *Energy Economics*, recognized as a premier field journal for work in the area of energy economics and finance. Additionally, this research will be summarized for publication in Iowa State University Center for Agricultural and Rural Development's *Ag Policy Review*, an in-print and online publication whose readership includes producers, policymakers, academics in the fields of agriculture and energy policy. Finally, our team's work in this area will be leveraged as Co-PD Jacobs begins work on a related competitive federal proposal to investigate sorghum as a feedstock for bioenergy.

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

We published a risk assessment model that measures the differences between two agricultural production systems forecasting the likelihood of worker injury. The published model provides a useful tool to produce logical results with limited agricultural injury data when comparing two agricultural productions systems. The ability to show the potential of where agricultural workers have the highest risk with newly developing systems like biofuel switchgrass production systems is valuable. A description of the model's approach and summary results for the public were made available on the E-extension web site Research Summary: Overview of Comparative Injury Risk Between Annual Corn and Perennial Switchgrass Production. 2017. http://articles.extension.org/pages/74211/research-summary:-overview-of-comparative-injury-risk-between-annual-corn-and-perennial-switchgrass.

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.

Significant Accomplishments

- **On-line Curriculum Course Modules.** We completed the design of a CenUSA Massive Open Online Course (MOOC) "Introduction to Perennial Grasses for Biofuels." The MOOC was offered to the public on a self-serve basis through The Ohio State University ATI Continuing Education program. Course feedback was evaluated to improve possible future course offerings. Existing modules were editing and brought online in the CenUSA Canvas-based learning management system at OSU ATI. New modules on plant breeding and warm-season grass pathology were also completed.

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 Director

- Jill Euken, jeuken@iastate.edu, 515.294.6286.

Significant Accomplishments

- **Extension Staff Training/eXtension Team - Publications, Proposals, Presentations**
  - **BLADES Newsletter**
    - ✓ CenUSA Bioenergy Engineers Cut Switchgrass Drying Time by 50%. http://blades-newsletter.blogspot.com/2017/01/cenusa-bioenergy-engineers-cut.html.
    - ✓ Plant Breeders Increase Switchgrass Yield by 40%. http://blades-newsletter.blogspot.com/2017/01/plant-breeders-increase-switchgrass.html.
    - ✓ New Market Place Opportunities for Biobased Products. http://blades-newsletter.blogspot.com/2017/01/new-market-place-opportunities-for.html.
  - **eXtension Articles**
    - ✓ The CenUSA Legacy: Creating a Sustainable Biofuels and Bioproducts System for the Midwest, which provides impact details of the project in concise format. http://articles.extension.org/sites/default/files/CenUSA-Legacy-Flyer.pdf.
    - ✓ What Would it Take to Convince Farmers to Grow Switchgrass for Biomass? Richard Perrin & Susan Harlow. http://articles.extension.org/pages/74212.

- ✓ Research Summary: Overview of Comparative Injury Risk Between Annual Corn and Perennial Switchgrass Production. Saxon Ryan, Charles Schwab, and Mark Hanna. http://articles.extension.org/pages/74211.

- **Team Overview Articles**

  - ✓ CenUSA Feedstock Development. Mike Casler & Susan Harlow http://articles.extension.org/pages/74210.
  - ✓ CenUSA Feedstock Logistics: Innovative Systems for Harvest, Transportation, and Storage of Perennial Grass Biomass. Kevin Shinners & Susan Harlow. http://articles.extension.org/pages/74073.
  - ✓ CenUSA Feedstock Conversion and Refining. Ryan Smith & Susan Harlow. http://articles.extension.org/pages/74206.
  - ✓ CenUSA Extension and Outreach: Perennial Grass Bioenergy Research and Knowhow for Producers, Students and Stakeholders. Jill Euken, Amy Kohmetcher & Susan Harlow. http://articles.extension.org/pages/74209.
  - ✓ CenUSA Models Predict Large Water Quality Improvements from Perennials. Pamela Porter. http://articles.extension.org/pages/74213.

- **Outreach (Social Media)**

  - ✓ **CenUSA Vimeo Channel**. The 54 CenUSA videos archived on Vimeo had 900 plays or views of the videos on our Vimeo site between August 1, 2016 and July 31, 2017.
  - ✓ **CenUSA YouTube Channel**. The 54 CenUSA videos were viewed 5468 times between August 1, 2016 and July 31, 2017.
  - ✓ **CenUSA Website**. 4,750 page views by 2,009 viewers between August 2016 and July 31, 2017.
  - ✓ **eXtension Website**. 10,622 page views by 7,630 viewers between August 2016 and January 31, 2017.

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

The team participated in events between August 2016 and July 2017 that reached 361 producers and agriculture industry leaders.

- **Publications, Presentations, Proposals Submitted**

Switchgrass and Mixed Perennial Biomass Production on Two Marginally Productive Soils as Affected by Nitrogen Fertility and Harvest Management. 2017. Presented at ASA, CSSA, SSSA International Annual Meetings, Phoenix, AZ. 9 Nov. https://scisoc.confex.com/scisoc/2016am/webprogram/Paper99966.html.

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

  - **Youth Development**

    - ✓ Conducted training for Vo-Ag and Science teachers in collaboration with Morningside College in Sioux City, IA for 15 Vo-Ag and STEM teachers on June 6, 14, 15 and 16. See Exhibit 1.

    - ✓ Conducted teacher training events in conjunction with the *National Ag in the Classroom* conference June 20-23 (https://naitcconference.usu.edu). CenUSA was a sponsor for the conference and provided overviews of the CenUSA C6 BioFarm program at both a plenary session and a breakout session, reaching over 350 teachers.

- **Economics and Decision Tools**

  - **CenUSA Switchgrass Decision Tool**. http://www.extension.iastate.edu/AgDM/crops/html/a1-29.html) was downloaded and completed by 809 users during the course of the CenUSA project, exceeding our project goal by 309!

- **Publications, Presentations, Proposals Submitted**

  Perrin, R.K.. L.E. Fulginiti & M. Alhassan. 2017. Biomass from marginal cropland: willingness of North Central US farmers to produce switchgrass on their least productive fields. Biofpr., 11(2) doi:10.1002/bbb.1741.

- **Evaluation and Administration**

  - **Actual Accomplishments**

    - ✓ Compiled reports from the CenUSA Extension team.

    - ✓ Received approval for CenUSA C6 teacher renewal credit for professional development course to be offered in June 2017 (see: https://staffdev.aea4.k12.ia.us/4DCGI/SC003599761801INV&*).

    - ✓ Selected for presentation at plenary session and breakout session at the National Agriculture in the Classroom Conference (http://naitcconference.usu.edu/index.cfm).

- ✓ C6 BioFarm: A Sustainability Game for Learning the Role of a Bio-Based Economy. Presented at National Extension Energy Summit (April 2017). https://ag.tennessee.edu/solar/nees2017/Pages/Agenda.aspx).
- ✓ Presented results from CenUSA and promoted use of CenUSA Decision Tool at Iowa Integrated Crop Advisor Conference. 1 Dec. 2016.
- ✓ Presented results from CenUSA and promoted use of CenUSA Decision Tool at SW Iowa Crop Advantage (112 participants). 17 Jan. 2017.
- ✓ Planned and conducted teacher training at Morningside College (June 2017) for 15 teachers and at the National Ag in the Classroom conference in Kansas City (July 2017) for 350 teachers.

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

- Tom Binder, Tom.Binder@adm.com, 217.451.4228.
- Fred Moesler, Renmatix, Fred.Moesler@renmatix.com 484.751.4018

Significant Accomplishments

- Provisional patent application submitted on “Methods of producing stable lignin phenolic oil.”
- Provisional patent application submitted on “Pyrolysis of lignin.”
- Demonstrated the use of microbial biocatalysts to produce vanillin from lignin-derived phenolic monomers. Specifically, conversion of 4-VG to vanillin was demonstrated.
- A variety of microbial species that were likely to naturally produce vanillin from 4-VG were identified in the scientific literature and characterized. These include *Pseudomonomas putida* KT2440, *Bacillus coagulans* DSM1 and *Lactobacillus coagulans* DSM 20174. Unfortunately, no production of vanillin from 4-VG was detected.

- The Cso2 enzyme from *Caulobacter segnis* was previously reported to enable the conversion of 4-VG to vanillin when expressed in Escherichia coli. Therefore, we cloned this enzyme into both *Saccharomyces cerevisiae* and *E. coli*, along with other genes intended to help with protein folding. Protein gels confirmed that the Cso2 gene product was expressed and soluble in the engineered E. coli strain.

- Despite verification of successful cloning of the Cso2 enzyme and supplementation of growth media with the iron chloride reported to increase enzyme activity, only very low levels of vanillin were detected. We have proposed that this low conversion is due to low solubility of 4-VG in aqueous fermentation media. However, the inclusion of emulsifiers did not improve vanillin production.

- **Publications**

  - Davis, K.M., M.R. Rover, R.C. Brown, X. Bai, Wen, Z. & L.R. Jarboe. 2016. Recovery and Utilization of Lignin as Monomers as Part of the Biorefinery Approach. Energies. 9(10): 808. doi:10.3390/en9100808.

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

  - Zhou, S., R.C. Brown & Bai. 2015. The use of calcium hydroxide pretreatment to overcome agglomeration of technical lignin during fast pyrolysis. Green Chemistry, Vol. 10.

- **Renmatix**

  At the 2016 annual meeting we reported that achieving high-value for lignin co-product from a biorefinery using the Renmatix Plantrose™ process to convert perennial grasses into sugars and lignin had the potential to make significant economic improvements to the biorefinery.

  The first opportunity evaluated and demonstrated in Year 6 for high-value lignin was as a partial replacement for phenol-formaldehyde adhesives for the production of OSB (oriented strand board) wood panels. Lignin from switchgrass was produced in Renmatix's Plantrose™ pilot plant, and was blended with a commercial, OSB resin at various partial replacement levels. The blends were tested for reactivity on maple veneer strips in our Automated Bonding Evaluation System and passed.

  Next the lignin was used to produce 3'x3' OSB panels at the University of Maine's Advanced Structures and Composites Center under industrially realistic OSB manufacturing conditions at up to 25% substitution rate in the panel face layers. The panels were tested against, and passed, US and Canadian commercial standards for internal bond strength, modulus of elasticity, modulus of rupture and thickness swell. The results of this work suggest that Plantrose™ biorefinery lignin could receive high values, possibly as much as $1,000/ton if used as a partial replacement for phenol-formaldehyde adhesives in OSB wood panel production, thereby significantly improving Plantrose™ biorefinery economics.

The second opportunity evaluated was the use of lignin in composite thermoplastic applications. Lignins from switchgrass were produced in Renmatix's Plantrose™ pilot plant. Each lignin was blended into polypropylene along with dispersing agents and commercial stabilizing agents using twin screw extrusion to homogenize the compositions that were prepared at various loading levels. Mold specimens with lignin and polypropylene were prepared and submitted for testing at Underwriters Laboratory (UL). In the event that lignin prepared from a Plantrose™ biorefinery can successfully be used in commercial applications in polypropylene thermoplastic applications, it may be possible to achieve value as high as $1,800-$3,000/ton, thereby significantly improving Plantrose™ biorefinery economics.

*   *   *   *

cenusa bioenergy

"Our vision is to create a regional system for producing advanced transportation fuels derived from perennial grasses grown on land that is either unsuitable or marginal for row crop production. In addition to producing advanced biofuels, the proposed system will improve the sustainability of existing cropping systems by reducing agricultural runoff of nutrients and soil and increasing carbon sequestration."

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