cenusa bioenergy

Annual Progress Report

Executive Summary

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

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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, 2013 – July 31, 2014

Executive Summary – CenUSA Bioenergy

We are pleased to highlight significant outcomes from Year 3 – a watershed year for CenUSA Bioenergy – and outline a vision and stakeholder-driven agenda going forward for Year 4.

USDA/ARS Announces Release of *Liberty*, a High-yielding switchgrass Cultivar. Producing excellent yields of biomass for bioenergy, the new switchgrass (*Panicum virgatum* L.) cultivar *Liberty* has pushed northward the agricultural zone where high-yielding switchgrass can be grown, and like the prairie grasses from which it was bred, Liberty prospers in marginal soils.

In multi-year trials made possible by CenUSA at Mead, NE and DeKalb, IL, both in USDA Plant Hardiness Zone 5, Liberty produced 8.2 and 7.3 tons/acre biomass, respectively, which was 1.6 to 2.5 tons/acre greater than the previously released upland cultivars adapted to the region. See Exhibit 1 for detailed information about release and availability of Liberty seed. CenUSA and ARS, Nebraska collaborated on the press release that states that Liberty 'promises to revolutionize biomass production' (Exhibit 2). An article on Liberty was the lead story in the inaugural edition of BLADES, CenUSA's new newsletter.

High Biomass Production on Marginal Soils. Design of management systems capable of achieving high biomass production on marginal soils, while minimizing system environmental footprint, is central to CenUSA's mission. In 2013 switchgrass biomass yields exceeded 11 metric tons/ha on marginal sites previously known to have low alfalfa and corn yields because of low potassium (K) and phosphorus (P) fertility. These biomass yields were achieved with no additional nitrogen (N) fertilization, but were comparable to stover yields from a high-yielding corn crop grown on excellent soils. Greenhouse gas emissions from the switchgrass stands were extremely low (similar to native vegetation) and very little N, P, or K left the field to contaminate ground or surface waters.

ISU Team Develops Process to Stabilize Phenolic Oligomers from Pyrolysis of Biomass. Researchers at Iowa State University have developed a proprietary process, low temperature, low pressure (LTLP) hydrogenation, to stabilize phenolic oligomers produced from pyrolysis of biomass. These compounds, derived from lignin in biomass, are extremely reactive even at room temperature, making them difficult to process into products. Once stabilized, these oligomers have potential as **heating oil**, and also as a **refinery blendstock**, as well as **starting material for synthetic polymers and carbon fibers**.

In Year 4 the LTLP hydrogenation process will be used with ADM's biorefinery processes to determine if high value products, including phenolic monomers, can be generated from ADM's lignin streams. Parallel experiments will be performed with the lignin stream from Renmatix.

Engaging Industry and the EPA. Beginning in 2012 and continuing into 2013 we have experienced considerable 'industrial pull.' This is attributable in part to two significant workshops we organized and held. The first, *Roadmap to Commercialize Thermochemical Biofuels Processing in the Midwest*, held in 2012, is still having impact. Our industrial partners ADM and Renmatix introduced the technologies they represent (acetic acid pulping and supercritical hydrolysis) at the 2012 workshop.

Our second significant workshop was *Enhancing Mississippi Watershed Ecosystems with Perennial Bioenergy Crops*, held in conjunction with University of Minnesota and the Mississippi River Gulf of Mexico Watershed Nutrient Task Force. It showcased our integrated modeling assessment of the Mississippi River Basin and the connection to the hypoxic zone in the Gulf of Mexico. This modeling system identifies the most cost-effective locations to target conservation investments, including the development of perennial feedstocks, to address the Gulf of Mexico hypoxic zone. An important outcome from this workshop was the appointment of Dr. Christopher Clark from EPA to our Advisory Board.

We used insight gained from these workshops for part of our strategic planning for the new initiative on Commercialization, which has been formalized as Objective 10.

Creating a Stakeholder-driven Agenda. We engaged an independent evaluator to perform unbiased and unvarnished in-depth telephone interviews with all members of our Advisory Board. The purpose was to gain stakeholder insight into the commercialization of biofuels and bioproducts and to chart a viable path forward. Because CenUSA's Advisory Board a) has representation for each of our key stakeholder groups, and b) knows us well, this analysis represents a strong validation of our path forward. Their points of highest priority (see Exhibit 3 for the full report) were:

- They were anxious to see real-world applications;
- They wanted an emphasis on looking broader than just switchgrass as a feedstock, and wanted to make sure that there were multiple markets for switchgrass.
- They suggested looking broader than just transportation fuels.

We used this input for part of our strategic planning for the new initiative on commercialization, ultimately leading to the formation of our new Commercialization Objective (Objective 10).

Developing Human Capital to Lead Tomorrow's Bioenergy Production. Wouldn't it be a major coup if a high school science fair project on switchgrass as a potential source of bioenergy was entered in the International Science Fair? One of CenUSA's summer students, Brian Prchal, now a high school junior, did just that when his project, *The Effects of Applying Wastewater Biosolids on Bioenergy Tests Plots and Various Varieties of Switchgrass*, performed under the mentorship of Carl Rosen of UMN, was rated so highly at the Regional Science Fair that it was advanced to the National Competition *AND* given automatic entry into the International Science Fair.

Transitioning from high school to university students: We routinely perform formative and summative evaluations on our CenUSA Summer Internship Program, and they are almost always positive. But until now we did not have in-depth analyses of the impact the summer experience had on students' personal and scientific growth, leadership development, and the ability to find a job. Nor did we have any information on the impact of the program to the mentor. We performed in-depth interviews on three representative students and parallel interviews with their mentors (see Exhibit 4). Results of these longitudinal surveys revealed the highly positive impact that CenUSA is having on developing tomorrow's leaders in bioenergy production.

The following are representative quotes from the students:

- *Thanks to CenUSA, I got a job in the plant biotech industry.*
- *The experience was the single most defining factor in my career plans for the future.*
- *I got to call the shots in my research project, which was an exciting experience most 20 year-olds don't get.*

Communicating Success. Among the dozens of this year's publications, presentations, videos, webinars and factsheets, the one of which we are most pleased is 'Midwest Vision for Sustainable Fuel Production,' which is at this writing under consideration as a cover article in *Biofuels* and co-authored by CenUSA's entire leadership team. The article charts the progress of CenUSA Bioenergy, and in the final section, *Future Perspectives*, sets forth a roadmap of additional research, technology development and education required to realize commercialization.

In addition, we have completely re-vamped our communications strategy, including our web site, added a newsletter (*BLADES*), and social media platforms. Since publishing our first issue of *BLADES*, traffic to our web site has increased 261% over baseline and traffic to our video/webinar sites has increased by 111% as well.

Assessing Overall Progress. We have employed the Fuel Readiness Level/Feedstock Readiness Level (FRL/FSRL) tool, with slight modifications, to track parallel progress in developing a fuel and conversion platform (purple bars) and a supporting feedstock system (green bars). The following tables (Fuel Readiness Level Tool) represent team consensus, and **illustrate** that the two systems are well synchronized.

Fuel Readiness Level Tool. Herbaceous perennials include switchgrass, big bluestem, and low diversity mixtures of big bluestem, Indiangrass and sideoats grama. However, switchgrass is the most advanced herbaceous perennial due to extensive and focused **bioenergy**-specific research conducted for more than 25 years at multiple locations.

Fig. 1 Fuel Readiness Level Tool

Fuel Readiness Level (FRL)

1	2	3	4.1	4.2	5.1	5.2	5.3	5.4	6.1	6.2	6.3	7	8	9

Biochar Product Readiness Level

1	2	3	4.1	4.2	5.1	5.2	5.3	5.4	6.1	6.2	6.3	7	8	9

ADM Acetosolv Pulping Readiness Level

1	2	3	4.1	4.2	5.1	5.2	5.3	5.4	6.1	6.2	6.3	7	8	9

Renmatix C5 and C6 Sugar Production Readiness Level

1	2	3	4.1	4.2	5.1	5.2	5.3	5.4	6.1	6.2	6.3	7	8	9

Corn Stover Feedstock Production[1]

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Herbaceous Perennial Feedstock Production

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Corn Stover Feedstock Market

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Herbaceous Perennial Feedstock Market

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Biochar Market

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

ADM Pulp Market

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Renmatix C5 and C6 Sugar Market

[1] Herbaceous perennials include switchgrass, big bluestem, and low diversity mixtures of big bluestem, indiangrass and sideoats grama. However, switchgrass is the most advanced herbaceous perennial due to extensive and focused bioenergy-specific research conducted for more than 25 years at multiple locations.

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Corn Stover Policy – Program Support and Regulatory Compliance

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Herbaceous Perennial Policy – Program Support and Regulatory Compliance

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Biochar Policy – Program Support and Regulatory Compliance

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

ADM Pulp Policy – Program Support and Regulatory Compliance

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Renmatix C5 and C6 Sugars Policy – Program Support and Regulatory Compliance

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Corn Stover Linkage to Fuel Conversion Process

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Herbaceous Perennials– Linkage to Fuel Conversion Process

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Biochar– Linkage to Fuel Conversion Process

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

ADM Pulp – Linkage of Switchgrass to Conversion Process

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Renmatix C5 and C6 Sugars – Linkage of Switchgrass to Conversion Process

1	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	5.1	5.2	5.3	5.4	6.1	6.2	7	8	9

Highlights of Year 4 Team Plan-of-Work

Going Forward into Year 4. With encouragement from NIFA's Bill Goldner and unanimous support of our Advisory Board, we have added Objective 10, Commercialization, to CenUSA's project portfolio. Archer Daniels Midland Company (ADM) and Renmatix will be formal collaborators and lead parts of Objective 10; all other Objectives will have elements of commercialization interwoven in them (See conceptual diagram, right, that shows Commercialization as a crosscutting Objective). For example, Vermeer, a farm equipment manufacturer, will collaborate with Objective 9 (Extension and Outreach), and Biochar Now, a purveyor of soil amendments, will collaborate on Objective 4 (Markets and Distribution) and Objective 2 (Biochar).

The addition of Objective 10, and particularly the development of additional bioproducts, addresses the stakeholder-identified need to develop additional markets for perennial grasses to reduce risk to farmers for planting them. Concomitantly, the ability to produce bioproducts such as lignin, hemicellulose, cellulose, stabilized phenolic oligomers and biochar, reduces risk to the biorefinery.

CenUSA Bioenergy is on the right course. Now at its project midpoint, CenUSA has already established that perennial grasses will be part of the U.S.'s biomass and renewable bioenergy portfolio. CenUSA is well positioned to continue its positive trajectory in Year 4. The project team has coalesced around Objective 10 (Commercialization) and looks forward to a year of discovery and implementation.

It is highly likely that a major outcome of Year 4 activities will be the development of additional markets for perennial grasses. This outcome is significant, as additional markets will reduce risk to both farmers and to biorefiners

CenUSA has played an important role in bringing together a large number of scientists, collaborators, and students to work together to evaluate options for developing a regional system for producing fuels and other valuable bio-based products from perennial grasses grown on marginal land. This large-scale interdisciplinary approach has not only led to new scientific discoveries and outcomes and educational materials and experiences, but it has fostered the emergence of a transdiscipline. All project participants have been actively engaged in spanning the multiple disciplines necessary to succeed in this endeavor. As a result, they have become conversant with each other's scientific language and have produced coordinated research and education outcomes that are exceptionally relevant to our collective goal.

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

- 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.

Accomplishments – Year 3

- Completed the first year of harvest and data collection on 36 regional biomass trials of switchgrass, big bluestem, and indiangrass.
- Planted an additional 26 regional biomass trials, including the newest and most elite breeding populations of switchgrass and big bluestem.
- Documented 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.
- Completed the most extensive and definitive study of heterosis in switchgrass to date. Documented the existence of heterosis within lowland x lowland hybrids and demonstrated the strong relationship between later flowering and higher biomass yields.
- 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.
- Created selection indices that can be used to simultaneously increase dry matter yield, ethanol yield, and high heating value content of switchgrass biomass. Documented the superiority of these selection indices compared to other breeding systems and selection criteria.
- Released 'Liberty' switchgrass, the first switchgrass cultivar to combine late flowering and high biomass yield of the lowland type with winter hardiness of the upland type. Expanded the range of late-flowering switchgrass to include USDA HZ 3 and 4.

Planned Activities, Outcomes, and Impacts - Year 4

- Conduct second year of harvest on 2012 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.
- David Laird, Iowa State University, dalaird@iastate.edu, 515.294.1581.
- Jeffrey Volenec, Purdue University, jvolenec@purdue.edu, 765.494.8071.

Accomplishments – Year 3

- Factor Analysis Plots and Systems Analysis Plots were harvested for biomass yield in Iowa, Illinois, Indiana, Minnesota, and Nebraska. Soil samples have been secured and analyzed.
- Biomass from key plots has been characterized for carbohydrate composition including total carbon, sugar, starch, neutral detergent fiber, acid detergent fiber, cellulose, and hemicellulose and the non-carbohydrate constituents, lignin and ash.
- Where soil fertility is a management factor being used to enhance productivity on marginal soils/sites, soils and biomass samples have been analyzed for the major plant nutrients nitrogen (plants only), phosphorus, and potassium.
- The impact of soil biochar amendments on yield, soil water cycling, soil carbon, greenhouse gas emissions and various soil quality parameters has been evaluated.
- Greenhouse gas emissions have been compared among various biomass production systems, with maize production for grain and native prairie sites serving as controls.

- Water movement and with it nutrient loss to surface waters via tile lines and erosion were determined at specific sites for several biomass production systems.
- In response to the CenUSA Advisory Board's recommendation in December 2013, the portfolio of biomass systems under evaluation was expanded (at no additional cost) from native perennial grasses (switchgrass, big bluestem, Indiangrass) to include additional perennial (Miscanthus x giganteus, hybrid poplar, prairie cordgrass) and annual (sweet sorghum, dual-purpose sorghum, photoperiod-sensitive sorghum, teff, oats, and winter wheat) systems.
- Extensive data analyses were conducted to compare system efficiencies including calculation of yield of carbohydrate fractions per hectare and system nutrient use.
- About 20 tons of switchgrass, big bluestem, and low diversity mixture bales were pelleted and numerous projects are underway such as comparing the composition of baled and pelleted material for biochemical and thermochemical conversion.
- Data were used to calibrate/validate the Soil Water Assessment Tool model and a new version with more robust algorithms for biomass systems was released.
- Statistical analyses were conducted to determine significant differences among system performance attributes (e.g., yield, N use, cellulose production and greenhouse gas production).

Planned Activities, Outcomes and Impacts – Year 4

- Measure yield and other agronomic production attributes of these biomass systems
- Monitor/document weed/insect/disease pressure and use control measures as necessary.
- Continue analysis of soils and plants for nutrients and carbon pools.
- Continue greenhouse gas and water quantity/quality measurements.
- Conduct statistical analysis of data.
- Prepare annual reports of data for GHG emissions, biomass production, surface soil characteristics, and management.
- Continue to improve biophysical models by calibrating SWAT and APEX with data from the biophysical measurements.

Executive Summary – Feedstock Logistics

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

Co-Project Directors

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

Accomplishments – Year 3

Although the large round bale (LRB) will likely be the dominant package for perennial grasses, as yield increases, so does the number of bales per unit area and the aggregation costs. We investigated a "giant round baler" (GRB) concept that created bales that weighed 3 to 4 times that produced from the largest commercially available round baler, with as much as 2 tons of DM per bale. The GRB handled as well as conventional LRB and in some cases maintained their shape and weathered better than conventional LRB.

Although the LRB will likely be the dominant package form for perennial grasses, round bales have some disadvantages compared to large square bales (LSB). Chief among these are lower density and less favorable cross-section –both of which lead to less than optimum transport weight. We have developed a process that compacts the LRB and reshapes it into a parallelepiped or cuboid shape similar to a LSB. We have collected force and pressure data to calculate the energy input and provide needed design data for future compression devices. 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. Power requirement for compaction is considerably less than with a LSB because densification occurs at a much slower rate.

A baler was modified to accumulate and strategically place bales at harvest. We have conducted additional data collection comparing alternative methods of handling bale-gathering logistics to aggregate bales. Different accumulation schemes were compared with regard to aggregation time and wheel traffic. Although bale accumulation and strategic bale placement significantly reduced time, distance, and fuel consumption compared to random bale placement, the benefits were reduced as crop yield and number of bales per acre increased.

Single-pass balers (SPB) are now commercially available to harvest crop residues from the rear of the combine harvester. These balers are substantially different from conventional balers, so they cannot be used to harvest windrowed crops like perennial grasses. Because crop residues like corn stover and perennial grasses will both be harvested in the late fall; modifications to the

SPB that facilitate either baling with the combine or baling windrowed crops would allow greater utilization and dilution of capital costs. Therefore, modifications to a SPB have been made so baling either with the combine or with windrowed crops like perennial grass can seamlessly occur.

Work continued on quantifying energy requirements for size reducing perennial grass biomass. Gross size-reduction at the baler and keeping bales dry prior to grinding significantly reduced the energy required for grinding. Comparison of grinding energy of different biomass materials (corn stover, wheat straw; soybean straw) with that for perennial grasses was also quantified.

Planned Activities, Outcomes and Impacts – Year 4

Storage characteristics of perennial grasses as affected by storage scheme, bale size-reduction at harvest, and storage duration will be investigated. Comparisons will be made with corn stover because considerable literature on stover storage exists. Storage effects will be quantified by losses, compositional changes and grinding effectiveness and energy requirements.

If the market for perennial grasses is weak because of excess supply, then an alternative market could be developed if ruminant fiber digestibility of very mature grasses could be increased by amendment application. Therefore, we will be conducting small-scale experiments to determine the feasibility of increasing ruminant fiber digestibility of mature grasses.

Work will continue on bale compaction and re-shaping to quantify power requirements, productivity, bale density, bale expansion rate, and, and storage characteristics. Work will also continue to quantify the performance of a SPB when harvesting either crop residues with the grain combine harvester or windrowed crops like perennial grasses.

Final work on bale-size and biomass size-reduction will be completed and techno-economic modeling of different bale size, pre-cut and storage schemes will be conducted for comparison purposes.

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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- Jason Hill, hill0408@umn.edu, 612.624.2692.

Accomplishments – Year 3

Our two most significant accomplishments this year were the publication of a featured policy piece "Federal agency models offer different visions for achieving Renewable Fuel Standard (RFS2) biofuel volumes" in Environmental Science and Technology (http://dx.doi.org/10.1021/es402181y) and the hosting of a workshop titled "Enhancing Mississippi Watershed Ecosystems with Perennial Bioenergy Crops," held jointly with the Mississippi River/Gulf of Mexico Nutrient (Hypoxia) Task Force" (https://www.biorenew.iastate.edu/watershedworkshop/).

Other major accomplishments include the successful defense of two doctoral students, the dissertations of whom covered ecosystem services related to water and a regional assessment of switchgrass production costs and returns. We also submitted for publication our research on regional changes in the biophysical exchange of carbon and water due to increased bioenergy production in the Midwest.

We also completed our first large scale scenario using the detailed SWAT model for the Upper Mississippi River Basin and the Ohio Tennessee River Basin with USGS 12-digit subwatersheds. The purpose of this modeling is to provide the ability to perform enhanced scenarios including greatly refined targeting scenarios to study placement of switchgrass and other biofuel crops in the landscape to evaluate to evaluate the water quality and carbon effects at the landscape level. This modeling system identifies the most cost-effective locations to target conservation investments, including the development of perennial feedstocks, to address the Gulf of Mexico hypoxic zone.

Planned Activities, Outcomes and Impacts – Year 4

We plan to continue our highly successful work on understanding the environmental impacts of the switchgrass-to-biofuel system both from a landscape perspective and from a life cycle perspective. We will (1) adapt existing biophysical models to best represent field trials and other data, and (2) adapt existing economic land-use models to best represent cropping system production costs and returns

Specifically, we are looking at the landscape level and wish to understand how placing switchgrass and other biofuel crops in the landscape affects environmental issues such as water quality and carbon flux. We will build on our recently completed large-scale scenario using the detailed SWAT model for the Upper Mississippi River Basin and the Ohio Tennessee River Basin with USGS 12-digit subwatersheds. The purpose of this modeling is to provide the ability to perform enhanced scenarios including greatly refined targeting scenarios. We will also continue our strong tradition of educating future bioenergy leaders in fields related to policy, water quality and the use of perennials in the landscape.

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.

Accomplishments – Year 3

- Mild catalytic pyrolysis experiments indicate potential for biofuel yield improvements by improving the conversion effectiveness of both biomass monomers and oligomers.
- Bio-oil co-firing fuel (BCF) could reduce coal-fired power plant GHG emissions below the Clean Power Plan requirements at a competitive minimum electricity-selling price.
- Titanium hydrides and zeolite catalysts could in combination improve hydrocarbon yields from lignin catalytic pyrolysis.
- Zeolite-based catalytic fast pyrolysis can yield aromatic hydrocarbons from lignin-derived monomers as effectively as carbohydrate-derived monomers.
- Transportation fuels derived from herbaceous biomass fast pyrolysis have a lower estimated biofuel cost ($2.70/gal) than woody biomass catalytic pyrolysis derived fuels ($3.65/gal).

- Inorganic phases including calcite and sylvite were found to be present in acid-washed biochars by X-ray diffraction. The evidence that these mineral phases were not removed from the biochar by the acid washing treatment suggests that some inorganic phases may become occluded inside of biochar. Such occluded mineral phases may slow or prevent the release of some (a small fraction) plant nutrients that are present in biochar.

- Anion exchange capacity (AEC) of various biochars was found to vary from 0.602 to 27.76 cmol kg^{-1}. The AEC generally increased with decreasing pH and increasing with pyrolysis temperature. High AEC biochars have the potential to be used for high value industrial and environmental applications; hence development of a capacity to produce high AEC biochar would add value to a pyrolysis plant.

- Research on the impact of oxidation treatments on the anion exchange capacity (AEC) of biochars was completed. Biochars produced at 700 °C exhibited a lower decline in AEC following the oxidation treatments in contrast to biochars produced at 500 °C. The AEC of an alfalfa meal biochar produced at 700 °C did not change significantly following oxidation. Stability of AEC in the high temperature alfalfa meal biochar is attributed to the highly condensed aromatic character of carbon in this biochar. Developing biochars with high AEC that is stable under harsh conditions is important for many potential industrial and environmental applications.

Planned Activities, Outcomes and Impacts – Year 4

- Conduct techno-economic analysis on scenarios including pyrolysis of perennials and biorefinery co-products.

- Micro-scale mass balance analysis to determine the monomeric and oligomeric composition of lignin fast pyrolysis bio-oil.

- Zeolite acid site characterization to analyze their effect on pyrolysis coking and depolymerization phenomena.

- Zeolite catalyst development to improve lignin conversion yields and selectivity. Characterization of aluminum moieties formed in pyrolysis. The aluminum-amended biochars have potential use as a Claus catalyst, which is industrially important for the removal of hydrogen sulfide from natural gas and various petroleum products.

- Investigation of potential high-value applications for high anion exchange capacity (AEC) biochars. High AEC biochars also have the potential to be utilized in potable water treatment for removal of various contaminants such as low molecular weight organic acids, which are known to contribute to the formation of toxic by-products in water distribution systems.

- Continuation of a cooperative study with the City of Des Moines, Iowa Water Works (DMWW). We have determined that acetate is a major downstream organic contaminant. We will investigate the use of high AEC biochars for removal of acetate from potable water.

Planned Research Impacts

- Determine economic feasibility of and highlight cost improvement opportunities for pyrolysis and catalytic pyrolysis biorefineries.
- Determine methods to convert lignin into biofuels and bio-based chemicals effectively using the catalytic pyrolysis pathway.
- Identify potential high value applications for the biochar co-product of bioenergy production.

Planned Research Outcomes – Publications on the following topics

- Applications of metal hydride as a lignin deoxygenating catalyst
- Effects of zeolite acid site morphology on the catalytic pyrolysis of lignin
- Lignin catalytic pyrolysis with zeolite catalysts modified with metal promoters
- Characterization of aluminum moieties formed in pyrolysis
- Potential high-value applications for high anion exchange capacity (AEC) biochars
- Stability of biochar anion exchange capacity in harsh oxidizing conditions

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

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Accomplishments – Year 3

In Year 3, we 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 continuation of survey efforts of producers to understand adoption decisions. Specifically, we had the following major outputs:

- Richard Perrin 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 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 the CenUSA webinars: *Competition for land use: Why would the rational producer grow switchgrass for biofuel?* to three separate audiences.
- Hayes (Co-PD) published project-related research in Energy Policy, Economics Research International, and Biomass & Bioenergy.

Planned Activities, Outcomes and Impacts – Year 4

In Year 4, we will continue to explore the market 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. In particular, we plan to exploit survey information from producers and existing federal conservation program data to estimate the biomass production potential under various pricing and contract scenarios in the central United States. In this analysis, we account for trade-offs in land use change and producers' potential willingness to accept lower returns from perennial grass production when environmental and conservation benefits are accounted for in the decision. Additionally, we will continue work with Rob Mitchell (Co-PD of Objective 2, Feedstock Production) to develop a decision tool that producers use to evaluate the potential for their land under perennial grass production when corn, soybean, and hay are alternative crops.

Executive Summary – Health & 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

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Accomplishments – Year 3

We have complied an extensive listing of actions that outlines the various steps to produce biofeedstock that will be the foundation of any risk assessment approach. While additional actions can always be added to the compiled list, we deemed our efforts complete enough to begin risk assessment modeling.

Saxon Ryan, a new graduate student joined the team replacing the existing Ph.D. student. He will be working primarily on the developing the risk model comparing differences between the two production operations, collecting the model data, and performing the risk calculations.

We adopted a standardized procedure of using three sources for injury data from risk assessment procedures by EPA. We have started validating the risk model terms and procedures to known standards was started.

The air sampling equipment was identified and the few sites for sampling have been identified. Human subject's approval for the second year was obtained.

Planned Activities, Outcomes and Impacts – Year 4

- Injury and exposure database will be populated with data from three sources and specific logic filters will be crafted to create necessary values needed for risk model calculations.

- Multiple risk model calculations will be performed and analyzed with results shared in a professional conference presentations and a possible paper.
- We will continue refinement of our baseline assessment of potential hazards.
- Specific modifications to the human subjects study will be made and approval pursued. The necessary air sampling equipment from vendor will be placed into service. Human subjects to participate in the study will have been recruited.
- The Master Gardeners' safety precautions for storing, handling and applying biochar publication will be integrated into one or more communities of practice (CoP) with eXtension with the target CoP being Ag Safety and Health and master gardeners second.
- We will continue to our develop relationship with NewBIO project collaborators from Penn State University (another USDA NIFA AFRI-CAP project) in the safety objective.

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

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Major Accomplishments – Year 3

- **On-line Curriculum Development.** We developed content for two modules in the markets and distribution objective area and two modules in the feedstock development objective area. We continued evaluation activities for existing modules, including analyzing data collected during Year 2.

- **Undergraduate Internship.** We successfully placed and mentored 16 undergraduate students at CenUSA institutions: Iowa State University (8 interns); University of Nebraska, Lincoln (4 interns); University of Minnesota (1 intern); Purdue University (2 interns); Archer Daniels Midland (1 intern) from May 28 – August 2, 2014.

- **Graduate Research Webinar Series.** The seminar series required students to explain how their research fits into the broader goals of the project, thereby creating a transdisciplinary-learning environment for graduate students involved in the project.

Planned Activities, Outcomes and Impacts – Year 4

- **On-line curriculum course modules.** Content for modules in the sustainable production systems, feedstock logistics and conversion objectives areas will be developed this year. Evaluation activities for the existing curriculum will be summarized in a case-studies article.

- **Continue the summer internship program.** In 2015, the program plans to host 20 undergraduate interns, with a diverse group of students representing institutions from throughout the country.

- **Graduate Intensive Program.** Working with objective leaders at the University of Wisconsin – Madison, offer a one-day condensed graduate intensive program add-on to the annual meeting. Plans include a proposed career-fair or similar activity with industry, tailored to grad students, plus other proposed high-value activities such as a tour of some GLBRC facilities and research plots. The graduate students will see a range of biomass research that is quite different from that in CenUSA, covering a range of topics from production/sustainability all the way to conversion processes.

- **Revamp the graduate research webinar series into a panel-based series entitled Conversations About Critical Issues.** Restructure and refocus the delivery of research webinar content. Consider four 1-h sessions spread over the academic year. Each session would have several CenUSA objective leaders or collaborating faculty discuss an issue meant to be mildly controversial so that multiple viewpoints can be presented. We are essentially hoping to stimulate intra-project conversations with a grad-student audience to illuminate the various approaches to critical issues within the project.

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

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Accomplishments – Year 3

The Extension Staff Training/eXtension/Communications Team produced the following from August 1, 2013 through July 31, 2014.

Fact Sheets

- Switchgrass (*Panicum virgatum*) for Biofuel Production
- Control Weeds in Switchgrass (*Panicum virgatum*) Grown for Biomass
- Plant Breeders Create New and Better Switchgrass Varieties for biofuels
- Successfully Harvest Switchgrass Grown for Biofuel
- The Economics of Switchgrass for Biofuel
- Competition for Land Use: Why would the rational producer grow switchgrass for biofuel?

Research Summaries

- Near Infrared (NIR) Analysis Provides Efficient Evaluation for Biomass Samples
- Research Find Strong Genetic Diversity in Switchgrass Gene Pools
- Minnesota Watershed Nitrogen Reduction Planning Tool
- Storing Perennial Grasses Grown for Biofuel
- Biofuel Quality Improved by Delaying Harvest of Perennial Grasses

Instructional Video

- Enhancing the Mississippi Watershed with Perennial Bioenergy Crops

Webinars

- The Renewable Fuel Standard and RINS Markets
- Anticipating Impacts of RFS 2014 Volumes on Corn and Soybean Prices

The team also produced three issues of BLADES newsletter (February, April, June).

During Year Three of the project, these materials, and those produced in Years 1 and 2, have had the following usage:

- CenUSA Fact Sheets and Research Summaries have had 3,492 views by 2,203 viewers
- Vimeo: CenUSA videos have had 693 plays and 9,335 loads
- YouTube: CenUSA videos have had 6,158 views
- CenUSA web site and Facebook: 3,047 visitors/followers

The **Producer Research Plots/Perennial Grass/Producer and Industry Education Team** has:

- Worked with producers/farm managers to maintain nine on-farm demonstration plots in Iowa, Minnesota, Nebraska, and Indiana.
- Collected data from the plots to share with CenUSA research team.
- Held field days/tours of the plots for a total of 277 participants.
- Hosted informational meetings for producers, reaching a total of 1,180 agricultural producers/consultants/industry leaders.

The **Economics and Decision Tools Team** has developed and released the *Watershed Nitrogen Reduction Planner Spreadsheet* and has the made significant progress on the web-based enterprise budget calculator.

The **Public Awareness/4-H and Youth Team** has:

- Developed an iPad app (C6) and piloted its use with over 350 youth/adults.
- Developed C6 curriculum/iBook/revised app and piloted with 330 youth/adults.
- Planned and executed 4-H science workshop and 4-H Round Up sessions.
- Developed and implemented switchgrass demonstration plots and learning materials at the Indiana FFA Center.
- Developed 4-H curriculum and school-based lessons and acquired licenses and software to host on-line youth education modules.

The **Public Education/Master Gardener Program** has:

- Established and maintained five biochar demonstration gardens.
- Collected data on various horticultural crops in the Extension Master Gardener demonstration gardens and developed exhibits/blogs/fact sheets/research summaries with data.
- Reached more than 5000 participants with garden tours, educational programs and exhibits about the CenUSA project and biochar.

The CenUSA Extension Administration team has:

- Provided leadership for the joint meeting held with the Mississippi River Hypoxia Task Force.
- Renegotiated budgets with each CenUSA Extension program in order to provide over $350K from the Extension line to support the CenUSA new commercialization objective.
- Developed four new outreach components as recommended by the CenUSA Advisory Board (feedlot trial with CenUSA switchgrass, evaluation of value proposition for alternative uses of switchgrass, and national training summit for Extension Educators, and 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.
- Wrote Extension sections for CenUSA reapplication and quarterly and annual reports.

Planned Activities, Outcomes and Impacts – Year 4

- 75 extension educators and industry professionals will gain awareness and knowledge in bioenergy topics at the Extension Energy and Environment Summit September 23-26, 2014.
- Develop, produce and post additional CenUSA fact sheets, research summaries, videos, newsletters, blog posts and maintain twitter and Facebook accounts.
- 1,000 producers, industry leaders, educators, and agency personnel and 500 horticultural producers and industry leaders will gain awareness and knowledge regarding environmental, economic, and public relations impacts of transitioning marginal cropland to perennial grass and will understand the impacts of biochar as a soil amendment.

- Hold 20 educational meetings, conferences, workshops, field days, media events, and networking activities regarding perennial biomass production BMPs, biomass logistics, safety, processing, economics and BMPs for using biochar as a horticultural soil amendment.
- Utilize "citizen science" program to promote shared learning about the impacts of perennial grass agriculture on ecosystems; promulgate best management practices (BMPs).
- Finalize C6 curriculum, iBook app and youth learning modules re: perennial grasses, carbon cycling, and biochar utilization. Train 100 adults in use of the materials; 1000 youth will utilize the materials and will demonstrate increased learning about renewable energy and STEM careers.

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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