V(A). Planned Program (Summary)

Program # 15

1. Name of the Planned Program

Sustainable Energy - Bio-Based Products Development

☑ Reporting on this Program

V(B). Program Knowledge Area(s)

1. Program Knowledge Areas and Percentage

KA Code	Knowledge Area	%1862 Extension	%1890 Extension	%1862 Research	%1890 Research
511	New and Improved Non-Food Products and Processes	100%		100%	
	Total	100%		100%	

V(C). Planned Program (Inputs)

1. Actual amount of FTE/SYs expended this Program

Year: 2012	Extension		Research	
	1862	1890	1862	1890
Plan	1.0	0.0	4.0	0.0
Actual Paid Professional	1.0	0.0	9.0	0.0
Actual Volunteer	0.0	0.0	0.0	0.0

2. Actual dollars expended in this Program (includes Carryover Funds from previous years)

Extension		Research	
Smith-Lever 3b & 3c	**1890 Extension**	**Hatch**	**Evans-Allen**
20000	0	369922	0
1862 Matching	**1890 Matching**	**1862 Matching**	**1890 Matching**
20000	0	369922	0
1862 All Other	**1890 All Other**	**1862 All Other**	**1890 All Other**
200000	0	2046236	0

V(D). Planned Program (Activity)

1. Brief description of the Activity

- Project proposals: **53**
- Technical presentations: **118**
- Technical papers: **10**
- Journal articles (indicate which are Extension or Research):
  - Research: **33**
  - Extension: **4**
- Patent Applications Submitted and/or Awarded (List complete citation of awarded patents.): **2 provisional patents submitted**
- Products taken to commercialization by industry: **0**
- Educating producers on production and harvesting practices: **50 educational videos**
- Educating producers on contracting crops for use in bioenergy: **0**

2. Brief description of the target audience

Other scientists, industry, agricultural producers, commercial developers

3. How was eXtension used?

eXtension was not used in this program

V(E). Planned Program (Outputs)

1. Standard output measures

2012	Direct Contacts Adults	Indirect Contacts Adults	Direct Contacts Youth	Indirect Contacts Youth
Actual	19	0	0	0

2. Number of Patent Applications Submitted (Standard Research Output)

Patent Applications Submitted

Year: 2012

Actual: 2

Patents listed

3. Publications (Standard General Output Measure)

Number of Peer Reviewed Publications

2012	Extension	Research	Total
Actual	4	33	37

V(F). State Defined Outputs

Output Target

Output #1

Output Measure

- Journal Articles

Year	Actual
2012	33

Output #2

Output Measure

- Technical papers and presentations

Year	Actual
2012	128

Output #3

Output Measure

- New processes developed

Year	Actual
2012	0

V(G). State Defined Outcomes

V. State Defined Outcomes Table of Content

O. No.	OUTCOME NAME
1	Products/processes taken to commercialization by industry
2	Harvesting and Logistics
3	Biochemical Conversion Technologies
4	Thermochemical Conversion Technologies
5	Modeling and Economics

Outcome #1

1. Outcome Measures

Products/processes taken to commercialization by industry

2. Associated Institution Types

- 1862 Extension
- 1862 Research

3a. Outcome Type:

Change in Condition Outcome Measure

3b. Quantitative Outcome

Year	Actual
2012	0

3c. Qualitative Outcome or Impact Statement

Issue (Who cares and Why)
The production of biofuels has increased due to rising energy prices, the desire for less dependence on foreign oil, and favorable government policies. Most current ethanol plants in the U.S. are corn-based, but in the state of Oklahoma corn production is not a major agricultural activity. However, perennial grasses and annual forages in this state have shown to be viable renewable biomass feedstocks. Switchgrass, a plant native to Oklahoma, has been deemed one of the best options as a sustainable feedstock to support a biorefinery.
An inventory of expressed genes in switchgrass tissues (expressed sequence tags or ESTs) will provide an important tool for assembling the complex switchgrass genome sequence. These ESTs also provide a source of markers for developing high density genetic maps. Such maps will be valuable for marker-assisted breeding to accelerate the pace of switchgrass cultivar development. Identifying expressed genes in particular tissues that contribute to key traits, like tillering, will provide the genomic tools for manipulating the trait for increasing biomass of switchgrass.
Improving biomass yield is a major target trait for biofuel plant species. However little progress has been made to date, because biomass production is a highly complex trait and the relevant genes/factors that control this trait have not been identified. Our research discovered that miR156 negatively regulates the expression of SPL transcription factors in plants and this regulation is required to promote vegetative phase transition to reproductive phase. By manipulating miR156 levels, such phase transition can be inhibited, thus plants will remain in a vegetative phase that, in turn, will contribute for biomass enhancement.

What has been done
Feedstock Development
Affymetrix gene chip analysis using a high and low tillering line has led to the identification of

nearly 2,000 genes that are differentially expressed in these tissues.
In collaboration with the Zengyu-Wang?s lab at the Noble Foundation, we engineered overexpression of miR156 in switchgrass.
We have been studying the mechanism of leaf blade outgrowth orchestrated by the homeobox transcription factor STF in the model plant Medicago truncatula. We are now one step ahead in identifying this gene as a repressor and revealing its repressor domain(s). This is a major step in defining the mechanism of STF function at the molecular level. WOX genes have been categorized into three clades: ancient, intermediate, and modern/WUS, based on phylogenetic analysis. A functional basis for this classification was not established. Using the classical bladeless lam1 mutant of Nicotiana sylvestris as a genetic tool, we examined the function of the Medicago truncatula WOX gene, STENOFOLIA (STF), in controlling leaf blade outgrowth. We found that fusion of either the WUS-box or an exogenous repressor domain to members of intermediate and ancient WOX clades results in a gain-of-function ability to complement lam1 blade outgrowth. These results suggest that modern clade WOX genes have evolved for repressor activity by acquisition of the WUS-box.
In an effort to determine how STF represses its target(s), we identified protein-protein interacting partners by yeast two-hybrid screens as we planned. One of these interactors is found to be TOPLESS (TPL). TPL is one of two co-repressors known in plants. We found that deletion of the WUS box and STF box of STF, which are required for repressive functions, abolishes interaction with TPL. We have narrowed down the interaction domains to single amino acid residues in each of these two domains. This finding suggests that the repressor domains are important perhaps for recruiting the co-repressors. To test if TPL is a critical factor that interacts with the repressor domains in determining the function of STF, we fused the full-length TPL to the truncated form of STF lacking the repressor domains and transformed it into the lam1 mutant. We found that this fusion construct complements lam1, suggesting that the function of the repressor domains indeed is to recruit TPL. Since TPL is known to interact with the auxin signaling machinery, this exciting discovery also discloses the connection of STF to the phytohormone auxin. In addition, we have also identified the actual STF target that is repressed by the STF/TPL repressor complex. This transcriptional repressor complex and its target clearly define how a meristem-like function is maintained for cell proliferation at the adaxial-abaxial junction of the leaf primordium.

Feedstock Production
To verify sweet sorghum yield potential under various environmental conditions, field trials have been conducted around the state. In addition, agronomic studies have been completed to determine the effects of fertilization, staggered planting dates, row spacing, and irrigation requirements on sweet sorghum quantity and quality.

Results
Feedstock Development
We have identified five key regulatory genes that can be useful for increasing tiller number in switchgrass.
By overexpressing miR156 in switchgrass, it was shown that tiller numbers are increased by 5-6 folds, which increases biomass production by 80-100%.
Transformation of STF into switchgrass using the maize ubiquitin promoter resulted in increased plant height, leaf size, and stem thickness, indicating that the pathway is functional in monocots as well. Interestingly, these switchgrass transgenic plants accumulate approximately two-fold (95-97% more) total biomass based on fresh weight and dry weight measurements at maturity, suggesting that STF-related master transcriptional regulators may hold the key to biomass feedstock improvement in C4 grasses. These transgenic plants also produce more soluble sugars per unit biomass compared to the controls. To our knowledge, this is the best success in switchgrass biotechnology to date. This demonstrates that our approach is valid and STF can be

used to manipulate biomass in annual and perennial dedicated biofuel crops. However, these transgenic lines have not been tested in the field due to regulatory hurdles.

The key results obtained from our STF research are:
-STF acts as a transcriptional repressor for its major function in leaf blade development.
-Two conserved domains at the C-terminal domain of STF protein, WUS-box and STF-box, mediate the repression function of STF.
-STF interacts with corepressor TOPLESS via its WUS-box and STF-box domains, and this interaction is critically required for leaf development.
-STF expression in switchgrass increases total biomass by approximately two-fold under greenhouse conditions. So, we have produced transgenic switchgrass plants that show 95% improvement in biomass yield over control transformed lines derived from the same callus.

Feedstock Production
Policy makers and researchers are concerned about the potential impacts of bioenergy crop production on water resources. This has been a focus of our field and modeling studies since 2010. Because bioenergy and water resources are typically studied by different science disciplines, dissemination of scientific information has been hindered. To address this problem, Ochsner organized a special symposium at the ASA, CSSA, and SSSA International Annual Meeting in Cincinnati, OH on Oct. 21-24, 2012. The symposium was entitled "Impacts of Bioenergy Crops on Water Quantity and Quality," and included invited keynote speakers from the disciplines of agronomy, hydrology, biosystems engineering, and climatology. This symposium resulted in increased awareness of research needs and activities related to the bioenergy-water nexus. Growing awareness of these needs is indicated by the fact that this topic area was one of two priority areas identified by USDA and DOE for the 2013 BRDI funding opportunity.

4. Associated Knowledge Areas

KA Code	Knowledge Area
511	New and Improved Non-Food Products and Processes

Outcome #2

1. Outcome Measures

Harvesting and Logistics

2. Associated Institution Types

- 1862 Extension
- 1862 Research

3a. Outcome Type:

Change in Condition Outcome Measure

3b. Quantitative Outcome

Year	Actual
2012	0

3c. Qualitative Outcome or Impact Statement

Issue (Who cares and Why)
Oklahoma State University was awarded a USDA Biomass Research and Development Initiative (BRDI) in 2009. The project objective was to develop practices and technologies necessary to ensure efficient, sustainable, and profitable production of cellulosic biomass. Using large-scale feedstock production research fields, the economic and environmental sustainability of switchgrass, mixed-species perennial grasses, and forage sorghum will be evaluated. Feedstock quality and logistical performance characteristics will be assessed under various harvest, handling, and storage scenarios. Production and logistic economic models will use the data produced from the large-scale experiments to determine if an integrated landscape vision of diversified species can provide a flow of feedstock throughout the year to a cellulosic biorefinery at a cost that will enable cellulosic biofuel to compete with gasoline.

What has been done
The harvesting field work on the BRDI project was completed in February 2013. Currently only basic and preliminary results are available. In 2010, the harvesting studies include a total of: 93 acres of forage sorghum; 638 acres of switchgrass; 492 acres of mixed grass. During the 2010 season, 618 bales of forage sorghum, 637 bales of mixed grasses, and 1,677 bales of switchgrass were produced.
The Oklahoma drought continued into 2012 and significantly impacted the total number of acres harvested. In the Panhandle the mixed grass and roughly half the switchgrass acres were a complete loss. In 2012, about 440 acres of switchgrass at four locations - 145 acres of sorghum at two locations, 116 acres of switchgrass in Chickasha, OK, 16 acres of mixed grass in Chickasha, OK, and 133 acres of mixed grass at two locations - were harvested. During the 2012 season, 754 bales of forage sorghum, 167 bales of mixed grasses, and 970 bales of switchgrass were put up as part of the project.

Results
The following are preliminary outcomes/observations for the BRDI harvesting, handling, and storage project:

Commercial equipment is available to harvest, package and provide in-field transportation and bale stacking, but there is room for improvement.

Forage sorghum can be naturally dried in the field and baled in Oklahoma with proper conditioning and cooperating weather conditions. Dry down times can be as little as five days under optimum conditions

Better bales are produced when forage sorghum is properly conditioned. Bales made from forage sorghum with minimal mechanical conditioning are difficult to construct, have a higher failure rate, and are often misshapen.

Older stands of high yielding switchgrass are extremely difficult on equipment tires.

In-bale moisture variability is a major issue, assuming biorefineries are going to purchase biomass based on dry weights.

Rotary disk blades dull faster when harvesting switchgrass after the first freeze as compared to before the first freeze.

Optimal harvesting would include three windrowers for every high density baler and four balers for every Stinger loader. The Stinger can handle between 100 to 150 bales per hour when moving the bales to the edge of the field.

Raking is not generally required for harvests after a freeze in switchgrass and mixed grass, unless it is economically feasible to combine windrows prior to baling.

4. Associated Knowledge Areas

KA Code	Knowledge Area
511	New and Improved Non-Food Products and Processes

Outcome #3

1. Outcome Measures

Biochemical Conversion Technologies

2. Associated Institution Types

- 1862 Extension
- 1862 Research

3a. Outcome Type:

Change in Condition Outcome Measure

3b. Quantitative Outcome

Year	Actual
2012	0

3c. Qualitative Outcome or Impact Statement

Issue (Who cares and Why)
Currently, high capital costs and technological obstacles are hindering the development of a viable biorefinery industry. Challenges in the biochemical conversion route include high cost of pretreatment and enzymes and lack of microorganisms that can efficiently co-ferment C5 and C6 sugars. In comparison, the major challenges for the hybrid conversion technology are mass transfer limitations due to low gas solubility in the medium, low cell productivity, enzyme inhibition

and the high cost of fermentation medium. As such, advancing the knowledge base in various aspects of the conversion processes to make them sustainable and profitable is essential, which are the goals of this research program.

Methods to capture and store renewable energy sources that cannot respond to power demand are needed. In addition, ways to capture and utilize CO2 from industrial processes will become more important to mitigate climate change. Our team is using a unique bacterium, Clostridium carboxidivorans, which feeds on H2 and CO2 to provide a solution to both of these challenges. C. carboxidivorans can produce ethanol, butanol, and hexanol from CO2 and H2. H2 can be generated from water by using renewable electricity (wind and/or solar power) and CO2 can be captured from power plants or other industrial sources. Ethanol is currently used as a biofuel, and butanol and hexanol are used in the chemical industry; butanol is a gasoline substitute and can be converted to jet fuel and hexanol is a jet fuel substitute.

Wind power is expanding throughout the world, including Oklahoma. Wind power has great potential for reducing our carbon footprint and providing rural landowners revenue, but a key problem is that it cannot provide baseline power. In other words, wind power production is not tied to power demand, so if more power is needed at certain times, one cannot increase power production by making the wind blow more. Also, if demand is reduced, one can't shut off the wind. In order to stabilize the peaks and valleys due to wind power's variability, a type of energy storage system is necessary to store energy when it is produced at a faster rate than it is consumed. A group of students and faculty at OSU have proposed using excess wind energy to generate H2 using water electrolysis. Anaerobic bacteria would consume the H2 and CO2 from and industrial source and produce ethanol. The team has named the process BioWinol.

Wheat, microalgae, and oilseeds present good potential for establishment of local biorefinery systems which would produce a number of bioproducts for local consumption and exports. Establishment of new and successful manufacturing sectors requires innovative product concepts and process development.

What has been done

Clostridium carboxidivorans has been identified as a bacterium that can effectively produce ethanol from CO2 and H2 in our studies. Also, a nutrient media was developed for the process. We have successfully used a hollow fiber membrane to diffuse gas into our medium. The membrane has been shown by other researchers to increase mass transfer rates by 20-fold over traditional stirred tank reactors. Also, we used a pH control to boost cell production. We successfully produced ethanol, n-butanol, and n-hexanol from CO2 and H2.

We are developing novel biocatalytic conversion processes for production of n-butanol and other chemicals. This technology has the potential to produce butanol with yields 20% higher than traditional ABE technology. We have submitted an invention disclosure on this technology to OSU Technology Development Center (TDC). The University Intellectual Property Screening Committee unanimously agreed and recommended that OSU retain rights to this invention. The TDC office is assessing our invention patentability and market potential.

Low cost wheat, microalgae, and oilseed processing techniques have been developed and optimized. These processes are environmentally benign and easy to operate. Hence, they can be adapted by small processors in the state. It might also be possible that these products could be commercialized by farmer's cooperatives.

Sweet sorghum activities this past year include the following:

Completed installation of a farm-scale dewatering/distillation system

Developed an economic feasibility template for use by potential sweet sorghum processors around the country

Assisted in establishing the Sweet Sorghum Ethanol Association for sharing knowledge and experience related to sweet sorghum ethanol

Results

For the biochemical conversion technology, the projected economic impact of the biorefineries to the local communities in Oklahoma can be over $1 billion per year and create over 400 direct jobs. To realize this benefit, the novel biocatalytic conversion process for butanol production should be implemented at significant levels. Ample opportunity exists for such undertaking. For example, it is estimated that 315 million gallons per year of butanol produced in 10 different facilities would be required to satisfy 25% of the 1.26 billion gallons of jet fuel used by the Navy each year.

We found that the hollow fiber membrane reactor (HFR) can provide sevenfold and twofold more gas transfer than the continuously stirred tank reactor (CSTR) and trickle-bed reactor (TBR), respectively. These findings are critical in designing reactors suitable for biofuels and chemicals production from syngas. We filed an invention disclosure on a novel method that significantly sustains culture activity, gas uptake and improves selectivity for ethanol production during synthesis gas (also called syngas) fermentation in CSTR. Syngas substrates such as carbon monoxide (CO), hydrogen (H2), and carbon dioxide (CO2) can be converted using microbial catalysts in our novel process to alcohols, organic acids, and other chemicals. Our process works with gases containing CO, H2, CO2 and N2 produced from various sources and can be applicable in various reactors.

The BioWinol process can effectively store wind energy while sequestering CO2. We envision industrial sources of CO2 using this process to sequester CO2 while producing valuable fuels and chemicals. This scenario would greatly benefit from any cap and trade system that might be implemented by governments.

Interest in sweet sorghum as a feedstock for biofuel production has grown exponentially in the past several years. Sorghums could provide an opportunity for this region of the country to become more involved in renewable fuel development and production, which would result in tremendous economic gains for rural America.

4. Associated Knowledge Areas

KA Code	Knowledge Area
511	New and Improved Non-Food Products and Processes

Outcome #4

1. Outcome Measures

Thermochemical Conversion Technologies

2. Associated Institution Types

- 1862 Extension
- 1862 Research

3a. Outcome Type:

Change in Condition Outcome Measure

3b. Quantitative Outcome

Year	Actual
2012	0

3c. Qualitative Outcome or Impact Statement

Issue (Who cares and Why)
Developing biomass conversion technologies for production of fuels that are compatible with petroleum infrastructure is crucial for reducing dependence on imported petroleum resources. These compatible fuels, also called "drop-in" fuels, can be produced using thermochemical conversion routes such as gasification. Biomass gasification technology is available to commercialize in near-term for converting biomass into fuels, chemical and power. Syngas, generated from biomass gasification, is a very well-known building block needed to produce many fuels and chemicals such as methanol, ethanol, ammonia, and hydrocarbons. However, Challenges in removal of contaminants, especially tars, from biomass-generated syngas continue to hinder commercialization efforts in biomass gasification.
Most combustion-based commercial systems such as burners, boilers, incinerators, furnaces, and combustors are designed for specific high energy imported fossil fuels. Generation of environmental pollutants, such as NOx, SOx, and dioxins, is linked with excessive use of these hydrocarbon fuels.

Thermochemical biomass gasification-based producer gas is considered as a viable renewable-type alternative to fossil fuels that allows for reducing energy costs and emissions in industrial systems and power plants. Biomass producer gas used in an integrated combined cycle process is one example offering great potential for enhancing the use of biomass in electricity generation, since it can substantially improve the efficiency of electricity production.

What has been done
We have focused on synthesizing and evaluating catalysts derived from biochar, a byproduct of biomass gasification. Three catalysts - original biochar, biochar-derived activated carbon, and biochar-derived activated carbon with acidic surface - were synthesized. Experiments were

carried out in a fixed bed tubular catalytic reactor at temperatures of 700 and 800°C using toluene as a model tar compound to measure effectiveness of the catalysts to remove tar. Steam was supplied to promote reforming reactions of tar.

Bench-top studies investigated natural gas co-firing with two model producer gas mixtures, one each representative of switchgrass and forage sorghum downdraft gasification, respectively, using a bench-scale air-swirled burner unit. Several tests have been conducted using our pilot-scale downdraft gasifier-burner setup to investigate technical and environmental performance.

Results

Results showed that all three catalysts (original biochar, activated carbon, and acidic surface activated carbon derived from biochar) were effective in toluene removal with removal efficiency of 69 to 92%. Activated carbon catalysts resulted in higher toluene removal because of their higher surface area, larger pore diameter, and larger pore volume. An increase in reactor temperature from 700 to 800°C resulted in a 3 to 10% increase in toluene removal efficiency. Activated carbons had higher toluene removal efficiency compared to biochar catalysts. Two manuscripts are developed for publication in refereed journals. Results from another project focusing on biochar production showed that biochar properties were significantly dependent on the type of biomass and gasification operating conditions, such as temperature and ratio of air-to-biomass, supplied into the gasifier.

Bench-top and a few pilot-scale producer gas-natural gas co-firing tests on air swirled type burner system indicated the potential for energy savings and emission reduction potential. The NOx level of 54 ppm at 100 % natural gas operation was reduced to 15 ppm for switchgrass model gas mixture and 11ppm for sorghum model gas mixture at 0% natural gas co-firing. With increase in equivalence ratio (ER), NOx and flame temperatures showed direct correlation with ER. It is anticipated that a typical biomass gasifier plant through producer gas co-firing with natural gas will have the potential to save 14,000 cubic feet of natural gas per ton of biomass gasified. A commercial steam boiler of a max of 400 MBH is purchased and efforts are being made to obtain funds for gasifier-boiler technology research.

After full development, the hybrid technology (gasification-syngas fermentation) can provide 35% more ethanol from the same amount of biomass compared to the biochemical conversion technology. If biofuel producers adopt this hybrid technology to produce 25% of the mandated 16 billion GPY renewable transportation fuels such as ethanol (i.e., 4 billion GPY), a projected savings of over $650 million per year can be achieved due to the use of 13.1 million tons less biomass with the hybrid technology. The improvements in the hybrid technology and the resolution of current bottlenecks (mass transfer and medium cost) associated with syngas fermentation will lead to greater opportunities to offset foreign oil needs within the U.S. and present economic opportunities to Oklahoma and the nation.

4. Associated Knowledge Areas

KA Code	Knowledge Area
511	New and Improved Non-Food Products and Processes

Outcome #5

1. Outcome Measures

Modeling and Economics

2. Associated Institution Types

- 1862 Extension
- 1862 Research

3a. Outcome Type:

Change in Condition Outcome Measure

3b. Quantitative Outcome

Year	Actual
2012	0

3c. Qualitative Outcome or Impact Statement

Issue (Who cares and Why)
The production of biofuels has increased due to rising energy prices, the desire for less dependence on foreign oil, and favorable government policies. Most current ethanol plants in the U.S. are corn-based, but in the state of Oklahoma corn production is not a major agricultural activity. However, perennial grasses and annual forages in this state have shown to be viable renewable biomass feedstocks. Switchgrass, a plant native to Oklahoma, has been deemed one of the best options as a sustainable feedstock to support a biorefinery. The optimal location for the state?s first biorefinery and most probable switchgrass production acres needs to be assessed.

What has been done
A comprehensive linear mathematical programming model was developed to determine the optimal location for the state's first biorefinery and most probable switchgrass production acres. IMPLAN® study area data and industry accounts were adjusted to show how the two activities will impact the study area. Also, given a large agricultural cooperative presence in Oklahoma, the model was modified to show how different ownership structures (i.e., varying levels of cooperative/private ownership) will affect the economic impacts of plant location decisions.

Results
In the case of the 100% privately-owned scenario, the combined industry output for switchgrass production and ethanol production was estimated at $70 million with a combined employment impact of 556 employees for the region. In the 100% cooperative-owned scenario, there is a combined industry output for switchgrass and ethanol production of $86.1 million, and a combined employment impact of 726 employees in the region. Because of the induced impacts that result from the cooperative membership model, industry output is $16.1 million higher than the privately-owned and employment has 170 more jobs. This information is being extended to community

leaders and will help support funding efforts for bio-refineries.

4. Associated Knowledge Areas

KA Code	Knowledge Area
511	New and Improved Non-Food Products and Processes

V(H). Planned Program (External Factors)

External factors which affected outcomes

- Natural Disasters (drought, weather extremes, etc.)
- Appropriations changes

Brief Explanation

Long-term drought conditions for Oklahoma persisted in 2012 and greatly impacted the feedstock production, harvesting, and storage components of this study. However, the severe drought and high temperatures provided an opportunity to understand feedstock production potential under severely limited conditions.

V(I). Planned Program (Evaluation Studies)

Evaluation Results

- 19 experimental cultivars are under evaluation in a regional trial for performance and adaptation.
- Numerous breeding lines were bred and evaluated for their potential in the development of new cultivars in switchgrass for the south central states.
- Proposals - submitted and awarded
- Journal articles published - number and quality
- Seminar and poster presentations

Key Items of Evaluation