Bio-feedstock Production and Development

A. Scope/audience

Agencies, corporations, and individuals wanting to understand the agronomic impacts of biomass production.

B. Overview & contribution in the past 5 years

From 1986 to 1992 we were involved in a U.S. Department of Energy-sponsored project focused on herbaceous biomass production on marginal soils. This research identified switchgrass (perennial system) and sorghum (annual system) as potential biomass species for agro-ecosystems where soil resources limit productivity of maize-soybean systems. In addition, past efforts using genetic selection of forages and cereals with improved digestibility have occurred primarily in the context of livestock production. These accomplishments can now be re-purposed in the context of improving crops for bioenergy use. With the renewed interest and availability of sponsored research funds in biofuels, Agronomy faculty have initiated research that focuses on several aspects of feedstock production and unintended environmental impacts.

C. Current challenges

Current U.S. plans for energy security rely on the diversion of feed grains to ethanol production and the conversion of large acreages of marginal land to the production of cellulosic biomass. To ensure the sustainable production of biofuels, studies are needed to conduct comparative analyses of the productivity potential and the environmental impacts of these biofuel crops and management systems.

D. Fundamental issues for the next 10 years

Long-term sustainable biofuels production with the concomitant protection and improvement of air, soil, and water resources requires a concerted effort by the scientific community to gain knowledge regarding the comparative production potentials and environmental impacts of biofuel cropping systems. U.S. agriculture has extensive experience with intensive maize production and both the grain and the stover can be used in energy production, but removing the majority of the aboveground biomass from a farm field may negatively impact air, soil, and water quality. Herbaceous perennials including novel species such as *Miscanthus* imported from Europe and low-input native systems represent alternatives that may offer discrete advantages over maize ethanol and soy biodiesel. However, at present, research on water, nitrogen (N) and carbon (C) cycling in these candidate biomass systems is fragmented and incomplete, a critical barrier to profitable, sustainable, and environmentally benign on-farm implementation of the U.S. biofuel agenda.

E. Projects that Purdue and especially Agronomy can develop to address these issues

1. ***Environmental Impact of Biomass Production:*** (Brouder, Turco, Volenec, D. Smith, Ejeta). Purdue has unique capabilities in the Water Quality Field Station (WQFS) with respect to the study of agro-ecology and the environmental costs and co-benefits of highly-productive, intensive agriculture. The WQFS is comprised of forty-eight 24-meter x 9-meter drainage lysimeters that permit a quantitative characterization of mass loss of soil constituents to surface water and also permits characterization of methane, carbon dioxide, and nitrous oxide emissions from the soil surface. Recently, WQFS treatments were modified to include low-input big bluestem, a facsimile for the native prairie community with no fertilizer inputs; maize grown in rotation with soybean and fertilized according to university recommendations; continuous maize fertilized according to university recommendations with or without residue removal; sorghum with grain and stover removal; *Miscanthus* production using best known management practices for establishment, production, and maintenance; and switchgrass production using best known management practices for establishment, production, and maintenance. Our goal is to quantify the N, C, and water balances for candidate biofuels cropping systems knowing that these will be critical drivers of biomass production sustainability.

2. ***Manipulate Wheat Metabolism to Increase Feed Stocks for the Bioenergy and Bio-products Industry:*** (Housley, Anderson, Carpita, Ohm, Scofield). To increase the use of wheat in feed stocks changes in stem fructan, starch and cellulose metabolism must be malleable to meet the demand of the biofuel and food industry. Fructans, the storage product of wheat stems, are not currently a source sought by industry to meet either the biofuel or food demand. If the carbon stored in fructan could be channeled into cellulose or starch, or if the fructan content could be increased markedly, then the value of wheat residue for the biofuel and food industry would be enhanced. Wheat is harvested in the summer when corn or soybean residue is unavailable. Furthermore, if value is added to the crop then the trend towards monoculture (continuous corn or soybeans), or two crop rotations (corn-soybeans), could be increased to a corn-soybean-wheat rotation, which would further enhance soil conservation. Planting and harvesting wheat might also lead to the development of double cropping with soybeans or another short season crop like buckwheat.

3. ***Impact of Agricultural Intensification on Regional Climate and Hydro-climatology: (Niyogi and cooperators).*** We are testing the hypothesis that, in a biofuel-driven economy, agricultural intensification will lead to increased agricultural land cover, which in subsequent decades, could lead to landscape fragmentation with urban-agricultural boundaries. The first project looks at assessing the current impacts of agriculture on regional weather and surface hydrology. The results are then compared to projected land use for 2030

assuming a range of possible agriculture intensification scenarios to assess the biofuel land use-climate change footprint. The second project in India where the 1960s green revolution and current sectorial bio-economic growth is serving as template for what might happen in Midwest U.S. with ag intensification. One outreach function associated with this project is the state climate office gets requests to provide presentations to numerous public venues concerning interactions among climate change and bioenergy.

4. ***DOE Energy Frontiers Research Center: (McCann-Biol, Agrawal-Chem Eng, Abu-Omar-Chem, Szymanski).*** A proposal is being developed that focuses on the interaction of biomass with catalysts during the process of chemical reduction of lignocellulosic materials to liquid fuel. A team of plant biologists focus on developing technologies needed to understand how catalysts interact with biomass and developing mechanistic knowledge about cell wall assembly that will enable engineering of next generation biomass for chemical feedstocks that are efficiently converted into liquid fuels or chemical feedstocks. We also are studying how plant cells partition carbon into vacuoles. This is relevant for biomass crops (grasses) because some species use vacuoles as a major storage compartment in the stem for sucrose. We would like to know about the dynamics of carbon partitioning at the whole plant, cellular, and molecular scales. It may be possible to alter the capacity of a sink, or the developmental period during which a tissue or organ can function as a sink. This technology has the potential to increase the energy content of biofuel crops.

5. ***Selection of Sorghum for Improved Biomass Potential:*** (Ejeta and collaborators). Several breeding and genetic approaches are being explored to improve yield and conversion efficiency of sorghum including breeding sweet sorghum hybrids, breeding sorghum hybrids with the *bmr* (low lignin) trait, breeding sweet and *bmr* (combination) hybrids of sorghum, breeding high biomass (high energy/dual purpose) hybrids of sorghum, characterizing the genetics of sweet sorghums, mapping of sweet sorghum QTL, mapping and cloning of different *bmr* genes, and inducing new mutations for tilling and genomics studies also discussed with faculty in Agronomy and other departments. We also are collaborating in studies aimed at understanding genetic variation in nitrogen use efficiency in different genetic combinations of sorghum in comparison with maize.

6. ***Analysis of Global Economic and Environmental Impacts of a Substantial Increase in Bioenergy Production:*** (Zhuang, Tyner-AgEc, Hertel-AgEc). The goal of this research is to develop realistic assessments of the economic and environmental impacts of regional and global policies designed to stimulate bioenergy production and use. We will build on the unique strengths of GTAP to analyze economic impacts of alternative bioenergy policies at regional and global levels. We will use the TEM model to help develop the land supply curves and to validate environmental consequences of

these policies and check their feasibility from the environmental and land use perspectives. The following outputs will be accomplished during the study period: build and incorporate an explicit biomass energy sector within the GTAP analytical framework and data base; examine changes in production, prices, consumption, trade, economic well being, etc. due to any policy or technical shock applied to the model; assess the trade effects of bioenergy policy scenarios at regional and global levels; and evaluate environmental impacts of alternative policies for bioenergy development. We will use the TEM model and its capabilities to: develop land supply curves for new lands, which will, in turn be used in the GTAP analysis; assess environmental consequences of policy scenarios; check feasibility of alternative ways of producing bioenergy; determine valid alternatives of producing bioenergy.

7. ***Cropping Systems for Biofuel Production:*** (Ohm, Snyder, Buckmaster-AgEng, Vyn, Johnson, Ejeta, Dobbins-AgEc, Valentin-AgEc). We will determine total biomass production potential and biomass utilization qualities from combinations of important Midwest U.S. grain/biomass crops. Winter wheat is harvested at three growth stages: flowering, mid grain fill. and grain maturity and immediately after each wheat harvest corn for grain/biomass, soybean for grain, sorghum for grain/biomass and sweet sorghum for grain/biomass is seeded in replicated plots. Biomass digestibility, crude protein and other quality measurements of utilization are determined.

8. ***In-field Corn and Sorghum Biomass Decay in Combustible Fuel-oriented Cropping Systems:*** (Vyn, Joern). The goals of this work include: to determine developmentally driven changes in chemical composition of stem and leaf components of maize and sorghum cultivars planted for grain versus whole-plant harvest, to evaluate the impact of low lignin biomass (bmr trait) in maize and sorghum as an improved source of combustible plant materials, and to assess the feasibility of using high plant density for corn and sorghum with the goal of harvesting these crops as a combustible fuel source. Other work focuses on quantifying of how harvest index changes as maize plant population density and fertility management changes.

9. ***Soy Biodiesel Breeding and Production:*** (LeRoy and others). We have been developing lines for soy biodiesel production that have greater than 25 percent oil concentration on a dry weight basis (20 to 22 percent is normal). In 2008, F3:5 lines from the first crosses are being evaluated for yield, oil, and protein. In addition, crosses are being made to high oil sources from southern U.S. germplasm and to high protein, low oil sources to develop mapping populations. We have a verbal agreement with industrial cooperators to map the high oil genes in the northern U.S. populations.

10. ***Biomass and Cell Wall Components of Switchgrass in Response to Water Deficit. (Jiang, Volenec and others):*** The project will determine biomass yield and synthesis of cell wall components of contrasting switchgrass

(lowland and upland) populations in response to water deficit. We expect to identify the effects of suboptimal growing conditions (e.g., chronic water deficit) on biomass and expression of key genes involved in cell wall composition. Optimizing plant biomass for more efficient ethanol processing requires an understanding of biomass development and cell wall composition under both optimum and stressed conditions. The information can be used by breeders to genetically enhance switchgrass for biofuels uses.

11. ***Development of maize traits useful for near-term feedstocks and as model systems:*** (Weil, Rocheford, Tuinstra, Johal-BTNY, Chapple-Biochem., Carpita-BTNY) For the immediate future, bioethanol and biobutanol feedstock is likely to be based on maize grain and stover. Using induced mutations and natural variation we are increasing starch digestion rate and starch extractability. In addition, we are examining genes controlling pericarp thickness to make grinding and processing more efficient and less energy intensive. We are also testing tropical varieties that accumulate high levels of stalk sugar, grow 6 to 7 m tall, and may require lower nitrogen inputs than conventional hybrids. We also are studying other lines with altered lignin concentration and composition in stalks, and genes that control cellulose formation. Our goal is to coordinate these efforts with parallel efforts in sorghum and use these two species together to help predict and guide improvements to other energy grasses.

F. The science team (expertise needed)

Teams will include Agronomy faculty and other faculty in the College of Agriculture and input will vary with the projects listed above.

G. Time frame

Indefinitely until funding expires (anticipate at least 10 years).

H. Evaluation of success

Discovery and dissemination of new knowledge in refereed journals and Extension publications.

Students educated in this area of science.

Improved public policy that is used to guide the development of the U.S. biofuels industry.

New products (germplasms, management strategies, technologies) that are used to enhance economic development of the U.S. biofuels industry.

I. Dissemination of information to decision makers/scientific community/public

Through traditional scientific and Extension education channels.

J. Resources needed

Money.

Graduate assistantships.

Support staff.

Field and laboratory equipment.

K. Conclusions/recommendations/vision for the future

The United States has a need and an opportunity to chart a new course in its energy future, one that includes plant biomass as energy feedstock. Estimates taken from the 25x’25 Action Plan show that the U.S. paid out an estimated $250 billion in 2006 for imported oil and suggests that the U.S. needs to produce 86 billion gallons of biofuels in order to reduce our dependence on imported oil 25 percent by 2025. In an analysis of actions needed to achieve the bold projections of the current, aggressive biofuel agenda (700 million tons/year), we will need to identify new high yielding crops possessing correct C composition, and improved cropping systems that enhance the capture of C on croplands, improve the use-efficiency of inputs including water and N, and that offer improved wildlife habitat and enhanced air and water quality.