Integrated Sustainable bioEnergy Pathways Project (ISEP)

Our ***vision*** is a future where sustainable, plant-based energy systems are a viable part of the U.S. energy portfolio. The production of bioenergy from lignocellulosic crops is one of the most promising pathways to develop sustainable energy from natural resources. However, diversity within plant resources and the environments in which they grow challenge the energetic and economic sustainability of these pathways. Investment in the commercial development of bioenergy has furthermore been tepid due to high uncertainty associated with energetics, economics and social viability of different conversion technologies.

Our ***objective*** in achieving this vision is to create a nation-wide framework for assessing tradeoffs associated with different bioenergy conversion pathways. We do so through a systems approach to Integrated Sustainable bio-Energy Pathways (ISEP, Fig. 1). We aim to characterize interactions between lignocellulosic energy resources and their growth environment. We further aim to characterize interdependence of the plant production system (including genetic resources), the harvest-storage-transport logistics and the conversion system, in the context of environmental services and socioeconomics. A strong emphasis on systems analysis will ultimately allow for the optimization of landscapes for the sustainable production of food, energy, and environmental benefits. To begin with, we will focus on an Iowa case study.

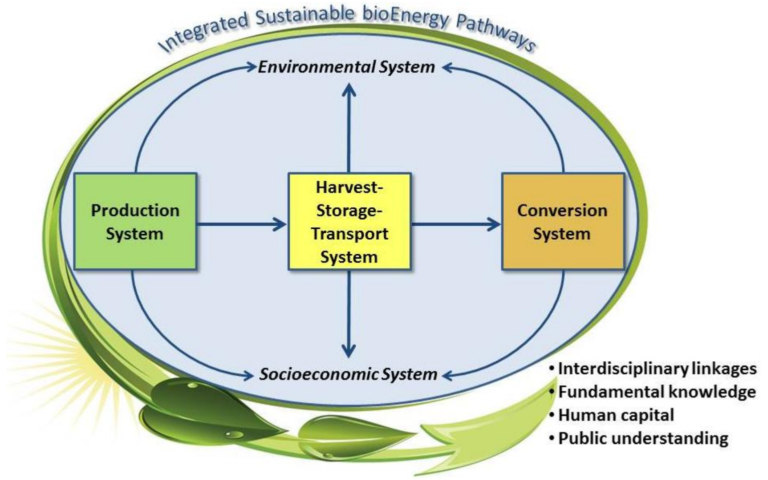

Fig. 1 *- Conceptual model of ISEP. Each discrete component reflects research areas, which presently are not well integrated and hence not able to holistically address grand societal challenges regarding food, energy and the environment. Our team has existing capacity to develop fully integrated and thus sustainable pathways.*

Outcomes of the ISEP Project include (1) robust interdisciplinary linkages across bioenergy pathways; (2) the creation of fundamental knowledge to understand the tradeoffs between and reduce uncertainty within production, harvest-storage-transport and conversion systems, including tradeoffs with food systems; (3) models to assess impacts on environmental and socioeconomic systems of a suite of previously untested bioenergy feedstocks; (4) an integrated plan of research and learning to develop the human capital required to implement our vision; and (5) changes in public understanding and support for ISEP (Fig.1).

Intellectual Merit – We will (a) develop new knowledge and capacity, including the use of new plant-based energy resource lines (i.e., native prairie, sorghum, miscanthus); (b) extend measurement of environmental impact to additional diverse plant-based energy resource systems and growth environments and develop full carbon, nitrogen, and water budgets for the plant-based energy resource systems; (c) quantify energetic, environmental, and economic impacts of diverse harvest-storage-transport systems and investigate the impact of seasonal and multi-year variability in weather, harvest timing, and feedstock quality on bioenergy conversion processes; (d) quantify the energetic, environmental, and economic impacts of converting diverse plant-based energy resources to useable forms of energy; and (e) integrate this fundamental new knowledge to develop human capital and improve public understanding. Intellectual merit lies in reducing key uncertainties in the ISEP through a holistic, integrated approach (Fig. 2).

Broader Impacts – The United Nations declared last year as the Year of Sustainable Energy for all, recognizing the importance of clean, safe energy sources in global welfare, particularly noting the role of biomass for electricity and liquid fuel generation. Balancing the increasing demands on agroecosystems to produce both food and fuel while sustaining the natural resource base on which a healthy society depends is a grand challenge with plant and environmental sciences and engineering at its core. The U.S. Midwest is at the heart of this "trilemma", leading the nation in maize and ethanol production as well as measures of soil and water degradation that could be improved or exacerbated under different scenarios of expected agricultural intensification. Finding solutions to these urgent and nuanced issues requires a transdisciplinary approach along a continuum from basic research to application, e.g. from sub-cell to ecosystem, from models of chemical transformation to models of human behavior, with heavy dependence on computation, communication and education.

Our project is interdisciplinary and translational in that we have well-established relationships with farmers, businesses, government and civil society organizations that enable the translation of gains in fundamental knowledge into new agricultural land management practices, commercial applications, and advancements in public policy. Example businesses and organizations we work with include DuPont-Pioneer, John Deere, Roeslein Industries, USDA Natural Resource Conservation Service, Iowa Soybean Association, and The Nature Conservancy.

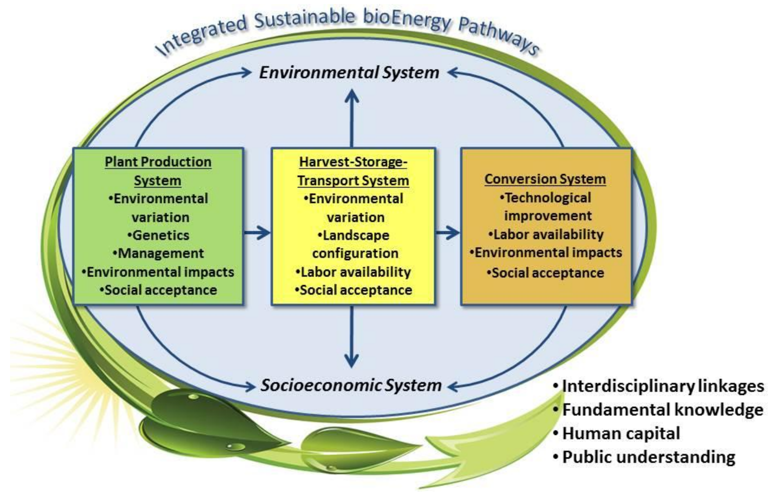

Fig. 2 *- Conceptual model of ISEP along with key areas of uncertainty within the Plant Production, Harvest-Storage-Transport, and Conversion systems thwarting investment in the pathways. We seek to reduce these uncertainties by integrating outputs from field-, lab-, and model-based experiments using systems analysis.*

Rationale– The vision of this proposal is aligned with the goal of supporting "*bold interdisciplinary projects in the areas of science, engineering, and education research"* in the following ways:

- ***Science***: We will address grand challenges in the plant and environmental sciences through research that reduces uncertainty and assesses tradeoffs associated with the food-fuel-environment trilemma (Fig. 2). Metrics to be evaluated under different pathways will include changes in air quality, water quality, and energy produced, and resiliency to weather extremes and policy and market fluctuation over annual, 5 yr, and 20 yr horizons.
- ***Engineering***: We will further analyze fundamental renewable fuel production mechanisms through techno-economic and life cycle models. Optimization models will be created to evaluate the effectiveness and efficiency of supply chain network design and operational planning. Environmental policies will be evaluated with engineering and economic models.
- ***Education***: Through existing programs associated with the BioEconomy Institute, BioCentury Research Farm, Iowa NSF EPSCoR, and Leopold Center for Sustainable Agriculture at Iowa State University, we are able to develop human capital and promote public understanding regarding ISEP, educating K-12 to adult populations.

While the U.S. possesses an outstanding capacity in discrete research areas relevant to the development of sustainable bioenergy pathways, investigators have struggled to integrate into functional teams capable of addressing the grand challenge posed by the food, energy, environment trilemma. In practical terms, we need to integrate plant, environmental, and social sciences with engineering. Union of these disciplines was historically challenged by differences of language and purpose, and is still commonly limited by focus and logistics.

Key Participants:

Dr. Lisa Schulte is an Associate Professor of Natural Resource Ecology and Management at Iowa State University (ISU). She studies the causes, consequences, and design of land-use change. Because humans are a major driver of change, she uses “coupled human and natural systems” as a lens to understand and anticipate change. Several current research projects address ecological, technological, and social innovations to enable agricultural landscapes to meet multifunctional societal goals. Expertise spans from local environmental and social monitoring to regional modeling and valuation of ecosystem service outputs. She was awarded ISU’s Early Career Award in Teaching in 2007. Schulte is a Fellow with Stanford University’s Leopold Leadership Program, a member of the “Rapid Response Team” of the Ecological Society of America, on the editorial board of *Landscape Ecology*, and on the board of trustees for the Iowa Chapter of The Nature Conservancy. For more information see: http://www.nrem.iastate.edu/landscape/.

Dr. Matt Darr is an Assistant Professor of Agricultural and Biosystems Engineering at Iowa State University. He has expertise and background in advanced machinery engineering, embedded data acquisition and instrumentation, and machinery logistical analysis. Dr. Darr’s current research emphasis includes equipment development for enhanced densification and logistics for cellulosic biomass feedstock, optimized storage and material upgrading for long term biomass feedstock stability, and machinery automation to support both biomass feedstock collection and optimal fertilizer placement. Dr Darr is a member of the American Society of Agricultural and Biological Engineers (ASABE), past officer of the ASABE Precision Agriculture Committee (PM-54) and member of the ASABE Automation (PM-58) and Student Design Competition (P-126) committees. For more information see: http://www.public.iastate.edu/~darr/.

Dr. Emily Heaton is an Assistant Professor of Agronomy focusing on the biomass crop production and physiology at Iowa State University. Her program aims to understand the growth and productivity of dedicated biomass crops in the Midwest, and how they can be managed to provide multiple ecosystem services. She specifically seeks to elucidate the reciprocal impact of environment on key physiological processes like photosynthesis, biomass accumulation, water use and nutrient cycling. Dr. Heaton is an editorial board member of *Global Change Biology Bioenergy*. She collaborates in the NIFA Coordinated Agriculture Project *CenUSA* and the DOE Regional Feedstock Partnership, and has also served as Bioenergy Systems Community Leader in the American Society of Agronomy since 2011. She was the 2013 recipient of ISU’s College of Agriculture and Life Sciences Early Career Award in Extension. For more information see: http://www.agron.iastate.edu/faculty/heaton/ .

Dr. Guiping Hu is an Assistant Professor in Industrial and Manufacturing Systems Engineering at Iowa State University (ISU), and a member of the Graduate Program for Sustainable Agriculture and Bioeconomy Institute (BEI). Her research interests include operations research and mathematical optimization models with applications on bioenergy production systems, sustainable agriculture and supply chain management. Her recent projects include technoeconomic and lifecycle assessment for advanced biofuels production systems, supply chain design and operational planning for thermochemical biofuel facilities. For more information see: http://www.imse.iastate.edu/directory/faculty/guiping-hu/.

Dr. Lizhi Wang is an Assistant Professor in the Industrial and Manufacturing Systems Engineering at Iowa State University, and a faculty member of the Graduate Program for Sustainable Agriculture. His research interests focus on optimization theory and applications in energy systems modeling, policy analysis, and decision making under uncertainty. Wang was a co-PI of an NSF project "21st century national energy and transportation infrastructures: balancing sustainability, costs, and resiliency (NETSCORE-21),” $2M, 08/2008 – 08/2012. The goal of the project was to identify optimal invest plans for the energy and transportation infrastructures for the next 40 years with respect to economic, environmental, and resiliency measures. For more information see: http://www.imse.iastate.edu/directory/faculty/lizhi-wang/.