1. **Project:** Investigating and Modeling Interactions among Bioenergy Stakeholders in Response to Water Availability and Climate Change
   Mentor: Emma Golub | **Faculty Member:** Ximing Cai
   Location: University of Illinois Urbana-Champaign
   Topic / Keyword: Crop science, Plant biology, Social science

This project explores the interdisciplinary relationships among stakeholders (i.e., bio-crop farmers, biorefineries, rural communities, and government agencies) in the cellulosic biofuel industry in response to water availability and climate change using survey, machine learning, and agent-based modeling techniques. Cellulosic biofuel is an emerging, advanced biofuel mandated by the 2005 US Renewable Fuel Standard that has already shown potential for reducing greenhouse gas emissions, mitigating agricultural runoff that pollutes downstream water quality and ecosystems, and helping mid-western farmers make more use of marginal lands otherwise unsuitable for growing food crops or traditional bioenergy crops like corn or soybeans. However, production levels and usage of cellulosic biofuels have failed to meet mandated targets. The goal of this project is to better understand why this is taking place, what stakeholder interactions are the most important in cellulosic biofuel production, and how we can help inform government agencies like the Department of Energy (DOE) to design more effective policies, programs, and synergies to bolster the emergence of the cellulosic bioeconomy. The student can learn all aspects of the project and improve a communication tool for all biofuel stakeholders through engaging in survey conduction and focus groups, helping build machine learning models to extract patterns in behavior from data, and exploring adjustments to existing agent-based models to simulate the bioeconomy. There are no prerequisite courses or experience needed to work on this project, but a background in social science with interests in environmental sustainability, bioenergy, and/or engineering would be helpful.

2. **Project:** Investigating the Role of Roots on Deep vs. Shallow Soil Carbon Cycling in Bioenergy Systems
   Mentor: Zoe Pagliaro | **Faculty Member:** Eddie Brzostek
   Location: West Virginia University
   Topic / Keyword: Crop science, Plant biology, Molecular biology

This project aims to address critical unknowns in how deep roots influence soil carbon stabilization. This will be achieved by burying labeled root litter down to 1 meter and then tracing the fate of that litter to determine if roots have a greater stabilizing or priming effect and how that changes with depth. The student will gain field and lab work experience from extracting soil samples, installing ingrowth cores, density fractionating soil, and extracting microbial DNA. Through this experience, they will learn about different ways we can investigate soil carbon dynamics and why this is crucial for enhancing the sustainability of bioenergy. There are no prerequisite courses or experience needed to work on this project, but students should possess the ability to perform extensive fieldwork, such as assisting with excavating deep soil pits down to 1 meter.

3. **Project:** Omics-Enhanced Isolation of Novel Microbes with Roles as Keystone Species in the Nitrogen Cycle of the Rhizosphere Ecosystem in Bioenergy Cropping Systems
   Mentor: Michael Millican | **Faculty Member:** Adina Howe
   Location: Iowa State University
   Topic / Keyword: Crop science, Plant biology, Molecular biology

Many microorganisms (i.e., bacteria) founding the soil remain difficult to grow in the laboratory. This limits our ability to understand the roles these organisms play in regulating nitrogen cycling within the root zone, or rhizosphere, of the plant, a critical component to building sustainable agricultural practices. This project aims to use genomic data from soil samples obtained from bioenergy crops to develop cultivation conditions targeting bacteria that are thought to have a critical role in regulating the nitrogen cycle. The student will learn about microbiology principles including bacteria physiology, ecology, and fungal biology, and they will get hand-on experiences in microbiology, such as isolating microorganisms from soil, and gain foundational skills in computational biology, such as using computational techniques to guide laboratory discoveries. There are no prerequisite courses or experience needed to work on this project, but experience with aseptic techniques as part of introductory biology and/or microbiology will be helpful (we are happy to teach students with limited experience).

4. **Project:** Effects of Extra Polymeric Substances (EPS) and Rhizodeposits on Soil Aggregate Stability and Water Holding Capacity under Miscanthus Plants
   Mentor: Toby Adjuik | **Faculty Members:** Marshall McDaniel and Andrew VanLoocke
   Location: Iowa State University
   Topic / Keyword: Crop science, Plant biology, Molecular biology

Extra polymeric substances (EPS) are thought to improve soil's physical properties, especially soil aggregation, which is important for improving soil water retention and soil fertility. This project aims to extract EPS from water treatment samples (i.e., aerobic granular sludge) and plant cells shed by the plant (i.e. rhizodeposits) from Miscanthus plants, which will then be tested for their effects on the aggregate stability and water-holding capacity of the soil under the plant. The student will assist in extracting EPS and rhizodeposits. The student will also be trained in soil physical measurements (aggregate stability analysis and water holding capacity) and data interpretation. There are no prerequisite courses or experience needed to work on this project, but introductory coursework in soil science and chemistry will be helpful.

5. **Project:** Improving Nitrogen Use Efficiency
   Mentor: Xueyi Xue | **Faculty Member:** Li-Qing Chen
   Location: University of Illinois Urbana-Champaign
   Topic / Keyword: Crop science, Plant biology, Molecular biology

The Chen lab aims to improve plant nitrogen use efficiency through mycorrhizal (fungi associated with plant roots) nitrogen acquisition or using signal molecules that the plant produces (low nitrogen-induced phloem long-distance signal molecules) for better growth performance. The student will learn how to measure and compare biomass and nitrogen content and gain molecular biology skills. There are no prerequisite courses or experience needed to work on this project.

6. **Project:** Characterization of Genetic Variants that Produce High-Value Carbon Compounds in Sorghum Stems
   Mentor: Maruti Nandan Rai | **Faculty Member:** Steve Moose
   Location: University of Illinois Urbana-Champaign
   Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

The Moose lab has created populations of sorghum that vary in how much sugar, oils, or cellulose are produced in their stems. These differences add value to sorghum for producing specialized bioproducts. The goal of this project is to characterize changes in gene expression that program the most valuable stem compositions. The student will gain an understanding of and experience with biotechnology and gene editing methods, exposure to computer software used in genomics research, and opportunities to link laboratory research to studies with impact in "real world" field applications. There are no prerequisite courses or experience needed to work on this project, but students who have taken at least one college-level biology course that covers genetics and/or molecular biology topics would be helpful.

7. **Project:** Understanding Chilling Tolerance in NADP-ME Type C_4 Bioenergy Crops
   Mentor: Cindy Chan | **Faculty Member:** Stephen Long
   Location: University of Illinois Urbana-Champaign
   Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

Bioenergy feedstock, such as Miscanthus, sorghum and sugarcane varieties are some of the NADP-ME type C_4 perennial grasses adapted to grow in marginal croplands which could be engineered to improve their photosynthetic efficiency to increase yield. This type of photosynthesis is co-limited by the enzyme pyruvate orthophosphate dikinase (PPDK), which is regulated by PPDK regulatory protein 1 (PDRP1), in the mesophyll cell, and by rubisco in the bundle sheath. Yet, when maize and Miscanthus are grown at 14°C, PPDK and rubisco continued to be expressed in Miscanthus while a reduction is observed in maize. This project aims to investigate the levels of PPDK and rubisco and their effect on photosynthesis under chilling conditions in these C4 bioenergy crops. This project involves the student growing NADP-ME type C_4 grasses under different temperatures then analyzing the protein expression of PPDK and rubisco, and the photosynthetic efficiency of the plants. The student will gain skills in plant maintenance, leaf sample collection, protein extraction, Western blot and basic photosynthetic measurement using LI-6800. Prerequisites include molecular biology, plant biology, and Excel, and experience in plant physiology and R is preferred.

8. **Project:** Hacking Sorghum Genetics for Increased Biofuel Production
   Mentor: Liz Dominguez and Mae Mercado | **Faculty Member:** Tony Studer
   Location: University of Illinois Urbana-Champaign
   Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

This project will focus on extracting RNA/DNA to study the expression rates for genes of interest. In addition to molecular characterization, field experiments will be done to investigate the physiology and agronomic performance of unique germplasm. The student will learn PCR/Gel electrophoresis, DNA/RNA extraction, using a Licor-6800 for measuring photosynthetic rates, microscopy and imaging of leaf surfaces, data Analysis in R, plant care in the greenhouse and field, and they will gain experience with maize for cross-crop comparisons. There are no prerequisite courses or experience needed to work on this project, but experience with basic genetics and molecular biology techniques would be helpful.

9. **Project:** Molecular Characterization of Genetically Modified (Transgenic) Sugarcane Plants
   Mentor: Baskaran Kannan | **Faculty Member:** Fredy Altpeter
   Location: University of Florida
   Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

Molecular characterization of genetically modified (or transgenic) plants includes confirming the presence of the genetically modified genes (or transgenes) in the transgenic plants after isolation and purification of genomic plant DNA, polymerase chain reaction (PCR), and gel electrophoresis. This project aims to correlate the expression of transgenes with the phenotype following RNA isolation, complementary DNA (cDNA) synthesis, and quantitative PCR (qPCR), and analyze the fatty acid content of the plants using time-domain nuclear magnetic resonance (TD-NMR). The student will learn skills in the isolation of DNA and RNA from plant samples, PCR, agarose gel electrophoresis, quantification of transgene expression by real-time PCR analysis, and total fatty acid analysis by TD-NMR. Prerequisites include courses related to plant science and/or biotechnology.

10. **Project:** Comparison of Remote Sensing and Traditional Phenotyping of Gene-Edited Sugarcane with Altered Leaf Angle
    Mentor: Eleanor Brant | **Faculty Member:** Fredy Altpeter
    Location: University of Florida
    Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

For this project, sugarcane lines containing a range of mutation frequencies in the LG1 gene will be assessed in a randomized field plot design. Both high and low planting densities will be utilized, and lines will be compared for a range of agronomic traits, including leaf inclination angle, plant height, and yield using remote sensing and traditional phenotyping methods. The student will gain experience in collecting and analyzing field data, field trial maintenance, and operating remote sensing technologies. There will also be opportunities to observe the sugarcane tissue culture process and the creation of gene-edited plants. Prerequisites include a course in plant science.

11. **Project:** Tissue Culture and Genetic Transformation of Sugarcane
    Mentor: Qasim Ali | **Faculty Member:** Fredy Altpeter
    Location: University of Florida
    Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

Plant tissue is a key step in transforming plants with new genes: plant cells are removed from the plant and grown in an artificial growth medium to make callus-undifferentiated cells, then formed calluses are bombarded with DNA-coated gold nanoparticles using a gene gun to introduce genetic modifications. The student will gain experience working in aseptic conditions, preparing tissue culture medium, sugarcane tissue culturing, and biolistic gene transfer (gene gun). There are no prerequisite courses or experience needed to work on this project, but an interest in biology or plant sciences research would be helpful.

12. **Project:** Engineering Improvements in Water Use Efficiency in C_4 Bioenergy Crops
    Mentor: Balasaheb Sonawane | **Faculty member:** Andrew Leakey
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

This project will investigate improving water use efficiency in crops by genetically engineering plants for lower stomatal density and how genetically engineering lower stomatal density impacts leaf hydraulics and photosynthesis. The student will be exposed to the overall structure of the scientific investigation and learn both physiological and molecular techniques, such as machine-learning-enabled tools developed for the automatic analysis of microscope images to count stomata on a leaf surface. The student will contribute to data collection, data handling and statistics, and scientific writing and presentation. Prerequisites include courses in basic biology and statistics.

13. **Project:** A Pattern from a Common Toolkit: Exploring a Central Model for Stomatal Patterning in Cereals
    Mentor: John G. Hodge | **Faculty member:** Andrew Leakey
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Crop science, Plant biology, Molecular biology, Computer Science

Stomata, or leaf pores, act as valves that regulate the exchange of water for carbon. Although their patterns on leaf surfaces have historically appeared dizzyingly variable, they appear to obey relatively simple geometric packing rules. Using a diverse range of natural varieties of warm-season grasses, the project will focus on studying the fundamental rules governing these packing arrangements to develop a model that can be applied across all cereal crops. The student will learn basic principles of plant anatomy and development while using optical tomography to image leaves for scoring stomatal patterning arrangements. The mentor will then work collaboratively with the student to apply geometric methods to their image data, providing practical experience in programming, data analysis, and data visualization. There are no prerequisite courses or experience needed to work on this project, but a basic introductory biology background would be helpful.

14. **Project:** Evaluating Transgenic Sorghum Engineered for Greater Water Use Efficiency
    Mentor: Sanbon Gosa | **Faculty member:** Andrew Leakey
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics, Computer Science

The project focuses on genetically modifying Sorghum plants for greater water use efficiency by reducing the density of stomata, or leaf pores. The student will use optical tomography to image and determine the number of stomata per unit area using machine learning. The student will also characterize the genetic makeup of these lines through genotyping by extracting DNA and amplifying it using PCR machines, measure photosynthesis and stomatal conductance using a Li-Cor machine, and analyze data. There are no prerequisite courses or experience needed to work on this project.

15. **Project:** Recombination of Miscanthus Chromosomes in Miscanes
    Mentor: Dessiree Zerpa Catanho | **Faculty Member:** Erik Sacks
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Crop science, Plant biology, Molecular biology, Genetics

The fate of parental chromosomes when backcrossing miscanes (the offspring of breeding sugarcane and miscanthus plants) back to sugarcane is unknown. This project will explore how parental chromosomes recombine in miscanes and provide insights into the fate of miscanthus chromosomes using a panel of 96 SNP-Type assays designed to differentiate between miscanthus and sugarcane chromosomes. The student will gain experience in DNA extraction and learn basic laboratory skills, including working with micropipettes, preparing buffers and solutions for DNA extraction, freeze-drying leaves, evaluating the quantity and quality of the DNA using Nanodrop, and normalizing DNA before genotyping. The student will also gain experience with data analysis using the Fluidigm SNP Genotyping software, writing scientific reports, and presenting their results. There are no prerequisite courses or experience needed to work on this project.

16. **Project:** Designing Novel Metrics to Characterize the Financial Viability and Environmental Sustainability of Integrated Biorefineries
    Mentor: Sarang Bhagwat | **Faculty member:** Jeremy Guest
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Industrial engineering, Civil engineering, Bioprocessing, Mathematics/Statistics

The goal of this project is to extend the existing library of metrics used to analyze the financial viability (using techno-economic analysis, TEA) and environmental sustainability (using life cycle assessment, LCA) of integrated biorefineries (i.e., refineries that produce high-value chemicals from renewable feedstocks) by designing novel metrics that yield targeted, comprehensive insights for the prioritization of research needs for researchers working on producing the renewable feedstocks and chemicals. This project will leverage two software packages in Python developed by the Guest group (BioSTEAM and AutoSynthesis), but a coding background is not required. The student will gain an understanding of chemical and environmental engineering principles used to analyze integrated biorefineries by reading key articles in the literature and working with the mentor and PI, then the student will help develop novel metrics in the analysis of biorefineries (i.e., metrics that yield insights beyond those from metrics commonly applied in studies that perform TEA and LCA of biorefineries). This opportunity will offer mentorship in science communication through reports, meetings, and poster presentations. There are no prerequisite courses or experience needed to work on this project, but prior experience in at least one project that involved numerical analysis is highly recommended.

17. **Project:** Recovery of Natural Colorants from Bioenergy Crops
    Mentor: Shivali Banerjee | **Faculty member:** Vijay Singh
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Industrial engineering, Bioprocessing, Chemistry

The increased awareness for eco-friendliness and sustainability has shifted the interest of stakeholders from synthetic colorants to natural plant-based colorants for industrial applications. Anthocyanins are common plant-derived colorants present in berries, grapes, purple tubers, purple leafy vegetables, and purple grains, but these sources have a well-established market and cannot be diverted completely for the recovery of anthocyanins. The project will focus on exploring bioenergy crops as alternative sources of anthocyanins and on anthocyanins as an additional product stream along with the production of biofuels. The student will review the literature to understand various methods for extracting natural colorants from plant tissues, be trained to run experiments on green extraction strategies for recovering natural colorants from bioenergy crops, and assist the mentor in estimating the yield of colorants recovered via the green extraction process. The student will develop skills in wet chemistry experiments (such as composition analysis and extractions), scientific analysis, and data presentation. There are no prerequisite courses or experience needed to work on this project, but students pursuing bioprocess, chemical, or environmental engineering studies are encouraged to apply.

18. **Project:** Analyze the C:N:O Ratio and Limiting Nutrients in the Lignocellulosic Hydrolysate under a Controlled Bioreactor System to Improve the Fermentation Efficiency of Genetically Modified Yeasts for the Production of Value-Added Bioproducts
    Mentor: Shraddha Maitra | **Faculty member:** Vijay Singh
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Industrial engineering, Bioprocessing, Chemistry, Microbiology

The optimum production of high-value chemicals produced during fermentation by genetically modified yeasts is controlled by the ratio of carbon (C), nitrogen (N), and oxygen (O) in the medium along with other specific nutrients required by genetically modified microbes. This project aims to systematically optimize the C:N:O ratio of the medium to improve the fermentation efficiency and maximize the yield of the high-value fermentation product in 3-liter bioreactor systems. The student will receive hands-on experience in yeast culturing, fermentation in bioreactor systems, and data analysis. Prerequisites include a basic understanding of fermentation and/or bioreactors.

19. **Project:** Preparation of Xylose-Rich Designer Hydrolysate from Lignocellulosic Biomass by Enzymatic Saccharification and Subsequent Fermentation
    Mentor: Shuchi Singh | **Faculty member:** Vijay Singh
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Industrial engineering, Bioprocessing, Chemistry, Microbiology

The project will focus on preparing a xylose-rich liquid and using it in yeast fermentation experiments. It will involve breaking down, or hydrolyzing, biomass from an agricultural crop (energy cane) with a xylanase enzyme to produce a xylose-rich liquid (hydrolysate). Then, an industrial yeast (*Saccharomyces cerevisiae* Ethanol Red®) will be used to convert glucose in the hydrolysate into ethanol. After separating out the yeast cells, the hydrolysate will be converted into ethanol or other commercially useful products, such as the artificial sweetener xylitol. The student will learn to develop an experimental plan, perform experiments, analyze data, and prepare reports, and they will get hands-on experience in performing enzyme-catalyzed reactions that break down plant biomass and culturing yeast cells for fermentation. There are no prerequisite courses or experience needed to work on this project.

20. **Project:** Deep Eutectic Solvents for the Valorization of Lignocellulosic Biomasses for Lipid and Sugar Recovery
    Mentor: Tirath Raj | **Faculty member:** Vijay Singh
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Industrial engineering, Chemical engineering, Bioprocessing, Chemistry

Petroleum-derived organic solvents are toxic, pollute the environment or are non-biodegradable, and have several health hazards. Alternatively, biologically derived chemicals such as sugars, amines, lactic acid, succinic acid, glycerol, choline chloride, etc. can be used to synthesize "new solvents" that are non-toxic, biodegradable, recyclable, and do not pollute the environment. Deep eutectic solvents are one of the new solvents that can be easily synthesized by simple mixing at low temperatures and can replace more hazardous petroleum-derived organic solvents in industrial-scale organic synthesis, bioenergy production, and extraction. The student will learn the basics of organic chemistry and build strong project management, time management, writing and communication skills for academic and professional career development. The student will also gain soft and functional skills, scientific aptitude, and would contribute to bioeconomic development for a safer environment. There are no prerequisite courses or experience needed to work on this project.

21. **Project:** Synergizing Photocatalysis and Biocatalysis for the New-to-Nature, Asymmetric Transformations
    Mentor: Wesley Harrison | **Faculty Member:** Huimin Zhao
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Microbiology, Chemistry, Biochemistry

Photobiocatalysis combines enzymes and photochemistry (the study of chemical reactions influenced by light) to achieve new-to-nature reactions to produce chemicals important to many industries. This project will focus on discovering and developing a novel chemical reaction by irradiating enzymes that contain vitamin B2 analogs with visible light to produce higher-value chemicals. The student will learn cell fermentation and protein expression and purification on the biology side and chemical synthesis, purification, and characterization on the chemistry side. In addition, the student will develop skills in project planning and management and learn how to use instrumentation such as High-performance liquid chromatography (HPLC), Gas chromatography–mass spectrometry (GCMS), Nuclear magnetic resonance (NMR), and Fast protein liquid chromatography (FPLC). Prerequisites include one year (two semesters) of organic chemistry lecture and experience in an organic chemistry undergraduate lab course. An interest in organic chemistry and biocatalysis would be helpful.

22. **Project:** Photoenzymatic Catalysis of Ene-Reductases
    Mentor: Zhengyi Zhang | **Faculty Member:** Huimin Zhao
    Location: University of Illinois Urbana-Champaign
    Topic / Keyword: Microbiology, Chemistry, Biochemistry

Photoenzymatic catalysis (using light to control the rate of a chemical reaction that uses enzymes to convert starting materials into products) combines the advantages of photocatalysis (using light to influence a chemical reaction) and enzymatic catalysis (using biological molecules as catalysts) to control the reactivity and selectivity of intermediate molecules in chemical reactions. This project aims to design novel photoenzymatic chemical reactions. The student will gain experience in protein engineering, synthesis of chemicals, and design and analysis of enzymatic reactions. There are no prerequisite courses or experience needed to work on this project, but courses in or related to biochemistry and organic chemistry are highly recommended.

23. **Project:** Catalytic Conversion of Triacetic Acid Lactone
    Mentor: Min Soo Kim | **Faculty member:** George Huber
    Location: University of Wisconsin-Madison
    Topic / Keyword: Chemistry

The Huber lab aims to transform triacetic acid lactone (TAL) into more valuable chemicals using a catalyst to perform the chemical reaction. The student will learn about working with batch reactors and continuous flow reactors, and how to analyze samples using gas chromatography (GC), high-performance liquid chromatography (HPLC), and nuclear magnetic resonance (NMR). Prerequisites include a course in organic chemistry and experience with catalysts and kinetics.

24. **Project:** High-Throughput Phenotyping of 170 *Issatchenkia orientalis* Yeast Strains under Complex Stress Environments
    Mentor: Ping-Hung Hsieh | **Faculty member:** Yasuo Yoshikuni
    Location: Lawrence Berkeley National Laboratory (Joint Genome Institute)
    Topic / Keyword: Microbiology, Genetics

This project aims to use a machine-learning-assisted genome-wide association study (GWAS) to discover which genes are involved in a yeast's physical traits (phenotype), such as tolerance to lignocellulosic hydrolysates (the liquid left over after breaking down biomass from an agricultural crop). The student will assist with the phenotyping (observing or measuring physical traits) of 170 *Issatchenkia orientalis* yeast strains when subject to different stress conditions. The student will learn yeast biology, basic microbiology lab skills, the usage of an automated liquid handling system, and the basic usage of imaging processing software. There are no prerequisite courses or experience needed to work on this project, but experience with microbiology lab work will be helpful.