Introduction to Renewable Energy – Biomass

Captured solar energy from biological systems currently plays a large role in human society through agriculture and small-scale domestic use. Expanding the use of biomass for large-scale energy services could help reduce the greenhouse gas intensity of the energy system. Because photosynthesis captures CO_2 from the air, the resulting carbon based feedstock can be processed and utilized in a similar manner to fossil fuels with lower net emissions of CO_2.

Biomass energy conversion could take advantage of many existing waste streams, but would also likely involve the cultivation and conversion of dedicated energy crops. The naturally low efficiency conversion of solar energy to biomass leads to large requirements of land, water and nutrients. Lifecycle cost, energy, and greenhouse gas emission considerations such as fertilizer production, harvesting, and feedstock transportation are barriers to the widespread use of energy crops. Increases in the yield of energy crops for given energy, water, and nutrient inputs would decrease the associated lifecycle costs. Research utilizing modern biotechnology could increase efficiency with respect to each of these inputs.

Research enabling more efficient and lower cost conversion methods could also benefit biomass energy. Thermochemical conversion systems designed for fossil fuels could be adapted to accommodate biomass feedstock, or new systems designed to take advantage of the unique properties of biomass could be explored. Biological conversion systems have the potential for higher efficiency and lower cost as our understanding and control of these organisms increase.

GCEP currently supports two research programs in the area of renewable energy/biomass.

Four PIs previously funded on separate GCEP projects in the lignin management area are collaborating in a combined project that targets an important and unsolved issue in plants with modified lignin content. This project led by Clint Chapple, Wout Boerjan, Claire Halpin, John Ralph, and Xu “Sirius” Li, entitled “Lignin Management: Optimizing Yield in Lignin-Modified Plants”, is aimed at overcoming the dwarfism and yield penalty associated with plants with modified lignin. Working independently with different lignin-deficient mutants, the partners have discovered novel genes that mitigate the growth defects [so-called lignin modification-induced dwarfism (LMID)] seen in severely lignin-depleted plants. Revealing the mechanism(s) by which this mitigation occurs is critical to fundamental understanding and useful manipulation of how plants partition carbon and may enable biomass manipulation for carbon sequestration in the future. The goal of these researchers is to determine the causes of, and to reduce the effects of, LMID. To date they have already found a strategy to lessen the effects of LMID in a particular mutant, and discovered novel genes involved in LMID. They have discovered a mutant that partially restores the growth defect of the original line, yet maintains saccharification efficiency. The gene responsible for this trait has been identified, and tests are underway to understand the mechanism behind the LMID reduction. Another mutant screen, in the highly dwarfed *ref8* (*c3h*) background, has identified more than 20 lines that suppress LMID, designated as *growth inhibition relieved (gir)*. Work is ongoing to characterize these and mutants from additional screens. The incorporation of alternative monolignols has also been investigated, as the inclusion of hydroxycinnamaldehydes leads to an increase in saccharification potential. Genes important for the high saccharification of mutants previously identified in *Arabidopsis* have been targeted for implementation in energy crops (barley, poplar). The new CRISPR/Cas9 technology will allow for targeted knock-outs of lignin biosynthesis genes in barley. This will allow for greater effects on plant lignin content and composition. This work has so far led to twelve publications in peer-reviewed journals as well as three currently *in press*.

Professors Spormann and Jaramillo have a project entitled "Integrated Electrochemical-biological Systems for the Production of Fuels and Chemicals from CO_2" that began in 2015. This ambitious project aims to bring together biological organisms and electrochemical devices to make fuels and chemicals from CO_2, water and electrical current. Electrochemical synthesis of small molecules, such as H_2 or formate, is becoming a promising route for converting electrical energy into chemical energy using catalytic materials based on transition metals, metal sulfides, and metal phosphides, among others. However, these processes are currently most efficient for 2-electron reduction steps rather than for producing multi-carbon transportation fuels and industrial chemicals, e.g. hydrocarbons, alcohols and ketones. On the other hand, certain microbial organisms have the capacity to synthesize C4-C6 and higher multifunctional organic compounds from simple C1 and H2 precursors at high selectivity, thus opening the unique opportunity for a novel combined microbial-electrochemical platform for sustainable fuels and chemical production. This research aims to explore the potential and limitations of operating microorganisms in a combined, efficient electrochemical system; design catalysts for compatibility with microbial systems; and engineer microbes for compatibility with selected electro-catalytic materials. Preliminary experiments using a gas transfer coupled system in a short-term experiment have shown that this coupling of electrochemical and microbiological system was generally successful and methane could be produced from electrochemically formed H_2. Future work will be focused on exploring the bottlenecks and benefits of different coupling methods of an electrochemical water-splitting and CO_2 reduction system with microbiological upgrading of the 2 electron reduction products obtained. The benefits and challenges of each system will be evaluated and the best system will be chosen for further improvement of the process. Special focus will be set on mass transfer limitations and on the various degrees of interactions of microbial growth media and microbial cells with the electrochemical catalysts.