Introduction to Carbon Negative Energy

Reducing carbon dioxide (CO_2) emissions may not be enough to curb global warming according to the Intergovernmental Panel on Climate Change. The solution will also require carbon-negative technologies that actually remove large amounts of CO_2 from the atmosphere. The concentration of CO_2 in the atmosphere has risen by roughly 70% since the industrial revolution, causing a 0.85^{o}C increase in global mean temperature. Currently, the energy sector is a major contributor to the increasing atmospheric CO_2. A growing global population and increased energy demand will cause an additional rise in atmospheric CO_2 unless we seek alternative energy resources. Renewables such as solar, wind, hydro, bioenergy, and direct emissions reductions technologies such as carbon capture and storage (CCS) could help curb CO_2 emissions. To augment these, technologies exist that remove atmospheric CO_2 and can potentially keep it out of the atmosphere. Among these are bioenergy with carbon capture and storage, direct air capture, and biochar. These technologies have benefits and downsides and vary drastically in predicted cost.

In the U.S., transportation is the second biggest human caused contributor to the carbon dioxide (CO_2) emissions, accounting for close to 30% of the total. Biofuels done in the right way could contribute to a net reduction in emissions from this sector. Well-managed biofuels crops could lead to increased soil carbon and coupled with carbon dioxide storage from the conversion process could lead to overall net negative CO_2 emission in the lifecycle of the biofuel.

GCEP currently funds two projects in this area.

One is led by Professors Laird and Brown and a consortium at Iowa State University in collaboration with Professor Zilberman and UC Berkeley. This project entitled "The Pyrolysis-Bioenergy-Biochar Pathway to Carbon-Negative Energy", aims to investigate the potential for an integrated pyrolysis-bioenergy-biochar industry to economically and sustainably produce carbon-negative renewable energy. During the first year of this project techno-economic analysis of two scenarios for deployment of the pyrolysis-bioenergy-biochar industry have been conducted. For the biochar & biofuel scenario, bio-oil is hydro-treated and then refined to produce both gasoline and diesel. In the biochar & bio-power scenario, bio-oil is mixed with crushed coal and then burned in existing coal-fired power plants to produce electricity. In addition this project is developing a biochar model that provides for the first time a means of systematically investigating complex soil-biochar-crop-climate systems, and critically a means of estimating the agronomic and environmental impacts of soil biochar applications for specific regions and agronomic systems. This capability is critical for determining the local value of the biochar co-product. So far the techno-economic analysis has shown that both the biochar & biofuel and biochar & bio-power scenarios are economically viable without considering environmental externalities or any income from the sale of biochar when the biofuel and electricity unit prices are greater than $3.09/gal and 10.17¢/kWh, respectively. However, given the current low prices for oil and other fossil fuels, it is apparent that some value from the sale of the biochar and/or carbon credits may be needed to make the pyrolysis-bioenergy-biochar industry economically viable. This project has already led to five peer-reviewed publications.

The second project led by Professors Larson and Williams at Princeton University and Professor Tillman at the University of Minnesota is entitled "Sustainable Transportation Energy with Net Negative Carbon Emissions: An Integrated Ecological and Engineering Systems Analysis". The Princeton and Minnesota researchers are collaborating on the science and technology of alternative negative GHG-emitting biomass energy systems that might be deployed commercially before mid-century to help meet U.S. transportation energy needs. One of the goals is to understand better system-wide implications of two mechanisms for achieving negative emissions: geologic storage of CO_2 captured during feedstock conversion (CCS) and storage of photosynthetic carbon in biomass roots and associated soil. The fundamental science being advanced is a new and comprehensive understanding of the ecological dynamics and root/soil (R/S) carbon storage potential for perennial grasses grown on the significant acres in the U.S. of degraded soils ill-suited for conventional agriculture. Minnesota researchers have collected extensive field data (currently being analyzed) from three experiments in the last growing season to quantify the potential for biomass energy production and concomitant R/S carbon storage. The first experiment, including collection of 320 above-ground samples, 4960 soil cores, and 2400 root cores, is evaluating the impact of perennial plant-species diversity on aboveground and belowground carbon. The Energy Systems Analysis Group (ESAG) at Princeton has been comparing prospective technical, greenhouse gas emissions, and economic performances of biomass energy with CCS (BECCS) systems for producing ground or air transportation fuels that can be "splash-blend" replacements for petroleum-derived fuels. Assessments carried out so far have focused on gasification and pyrolysis routes. Because BECCS plant scales are constrained by accessible biomass supplies, one ESAG focus has been on understanding prospects for improving economics at smaller scales.