Energy for the Developing World

The opportunity to provide low cost, high quality, and environmentally sustainable energy technologies for developing and emerging markets is enormous. Over the coming decades, billions of people will for the first time have access to modern energy technologies. Currently the world population is over 7 billion people of which approximately 1.4 billion people live without electricity and 3 billion people rely on solid biomass for heating and cooking. More than half the world population lacks modern access to energy and its services, either because it costs too much or is simply unavailable. Bearing in mind that energy and income poverty are tightly coupled, a major challenge is the need to find energy technologies that are extremely affordable without compromising the quality of the energy service or technology.

GCEP issued a request for proposals in 2014 for research that provides basic energy access for developing countries with a focus on innovative approaches for rural and poor communities with the potential to provide co-benefits, reduce carbon and/or black soot emissions, promote environmental sustainability, and improve socio-economic welfare. Through that solicitation, three projects were funded that represent a range of strategies; one project is housed at Stanford and the other two are at external institutions.

Professor Fan at Stanford University investigated thermal science in *Nighttime Radiative Cooling: Harvesting the Darkness of the Universe.* The concept utilizes the temperature difference between outer space and the Earth's surface for radiative cooling, which is the dominant mechanism by which the Earth's surface cools down at night. Radiative cooling is passive, requires no electricity input and has affordable applications for air-conditioning and refrigeration in developing countries. The group worked specifically on photonic and thermal design using experimental demonstrations and theoretical predictions. In the past year, the researchers have shown through theory that ultra large temperature reduction of as much as 60^oC from ambient is achievable and they have experimentally demonstrated a temperature reduction that far exceeds previous work. In an experiment performed at Stanford last year, they achieved an average temperature reduction of 37^oC from the ambient air temperature through a 24-hour day-night cycle, with a maximal reduction of 42^oC that occurs at peak solar irradiance. This result represents a record-breaking performance in radiative cooling. The results also suggest new functionalities of using radiative cooling and thermal radiation that can potentially be used in a wide range of applications for the thermal management of buildings, vehicles and textiles, as well as waste heat recovery. The researchers published this work in *Nature Communications*, two additional journals, and have filed a patent.

At the University of Texas, Austin, Professors Bard and Yu worked together with Professor Sadoway from MIT on *Low-cost Photovoltaics by Electrodeposition of Silicon PN Junctions.* This research was aimed at drastically reducing solar manufacturing costs to allow wide distribution of solar energy generation in the developing world. This research was focused on the design, synthesis, and characterization of electrodeposited silicon for solar energy. These researchers have for the first time, successfully demonstrated electrochemical deposition of Si films on carbon that show photo activity. They have developed a photoelectrochemical method for testing Si electrodeposits without producing a solid-state p-n junction and demonstrated the only Si synthesis process described that does not produce CO_2, i.e. $SiO_2 \longrightarrow Si + O_2$. They also report the first preparation of solid-state p-n junctions by electrodeposition. They have published five papers, have two under submission and an additional one that has been accepted to *Nature Communications*.

Professor Dismukes at Rutgers University worked with Jun Cheng at Zhejiang University, and Christoph Benning at Michigan State University, to examine *Robust Microalgal Production Strains for High Yield Growth on Fossil Fuel Gas: Toward Cost Effective Biofuels and CO_2 Mitigation.* The collaboration also involves cooperation with Yantai Hairong Co. to build a demonstration project of a coal-fired power plant that uses microalgae to capture and remove 2,000 tons of CO_2.

This project focused on the development of transgenic algal strains that can grow efficiently under mass cultivation conditions, while producing higher yields of oils (lipids) or biomass. *Nannochloropsis oceanica* CCMP1779 (*N. oceanica*), a highly oleaginous heterokont, was chosen for genetic manipulation by both random and targeted mutagenesis approaches. The researchers investigated the importance of photosynthetically assimilated carbon intermediates on the downstream steps of fatty acid biosynthesis and accumulation of triacylglycerols (TAG) was investigated. All three strategies used proved to be effective for enhancing neutral lipid production, increasing TAG accumulation by 2- to 3-fold. However, both the photosynthetic carbon fixation rate and biomass yield were slightly sacrificed in all mutants. Supplementing algal cultures with CO_2 from flue gas was investigated for increasing algal biomass productivity. A random mutation in two strains of algae led to an enhanced tolerance to low pH; one strain only benefits under low CO_2/DIC availability, while another additionally suppresses the toxicity of excess CO_2. On the whole, incremental improvement in photosynthetic growth rate and yield was achieved under various environmental stress conditions, or biomolecule composition could be shifted towards more desired products. However, no improvement in biomass yield under non-stressed optimal environmental conditions was achieved. The general conclusion reached is that it is very difficult to improve solar conversion efficiency of natural photosynthesis in any of the three branches of oxygenic photosynthesis. The researchers conclude that the fundamental limits of energy conversion and storage, thermodynamic limits associated with chemiosmotic gradients and redox energy differences, constrain the range of possible solutions using conventional cell biology. This project has led to two publications with four in preparation.