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 proposal 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 is investigating 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 is working 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 for as much as $60^{o}C$ 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 $37^{o}C$ from the ambient air temperature through a 24-hour day-night cycle, with a maximal reduction of $42^{o}C$ that occurs at peak solar irradiance. This result represents a record-breaking performance in radiative cooling. The researchers published this work in *Nature Communications* and have filed a provisional patent.

At the University of Texas, Austin, Professors Bard and Yu work with Professor Sadoway from MIT on *Low-cost Photovoltaics by Electrodeposition of Silicon PN Junctions.* The purpose of this research is to drastically reduce solar manufacturing costs and significantly lower the cost of solar production by advancing the technology for silicon electrodeposition. This research is concerned with design, synthesis, and characterization of electrodeposited silicon for solar energy. In the first year of the project, the team has successfully formed, on a small scale, a photoactive polycrystalline silicon film by electrodeposition from molten calcium chloride with silicon dioxide as the silicon source. In the second year of the project they have successfully produced high quality crystalline p-type silicon film from Si-O complex cations in $CaCl_2$-based molten salt. The inexpensive and abundantly available calcium silicates, calcium oxide and silica have been used as precursors for the production of Si films. The obtained p-type silicon film with thickness 30-50 μm shows good photoelectrochemical properties (photocurrent amounting to ~50% of a commercial p-type Si wafer). This progress represents the first move toward the ultimate goal of developing a cost-effective manufacturing process for Si solar cells.

Professor Dismukes at Rutgers University is working with Zhejiang University to examine *Robust Microalgal Production Straings 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. In their work, they hope to cultivate algal strains for advanced biomass and biofuels through random and targeted mutagenesis to select for mutant algal strains that can grow efficiently under mass cultivation conditions, while producing higher yields of algal oil (lipids). Progress so far includes the screening of 1200 random mutants for better growth. Four of these mutants were selected for further characterization. In addition five mutants that were able to tolerate lower pH were also selected. All of the selected mutants exhibited higher lipid content than the non-mutants. Further work and characterization of these and other mutants is underway.