Introduction to Completed Project Reports

Ten GCEP research programs have reached completion during the past year in six portfolio areas of Solar, Biomass, Carbon Capture and Separation, Carbon Storage, Advanced Combustion, and Advanced Materials and Catalysts. In some cases, GCEP receives portions of a final report as a result of different start times from the various sub-contracts in a multi-institutional team.

Solar

In the area of solar energy, four programs were completed this year. Last year Professors Gavin Conibeer and Martin Green of the University of New South Wales completed a long-standing program to develop a proof-of-concept device of a hot carrier solar cell using abundant and non-toxic nanostructured materials. This year Professor Jean-Francois Guillemoles has completed the final experiments for this effort. This final report concludes the work from the remaining institutions in the collaboration including the University of New South Wales, Insitut de Recherche et Developement sur l'Energie Photovoltaique (IDERP), Paris and the University of Sydney.

Professors Shanhui Fan from Stanford University in collaboration with Professor Paul Braun from University of Illinois at Urbana-Champaign is developing a thermo-photovoltaic (TPV) device capable of achieving solar-to-electric energy conversion efficiencies higher than the Shockley-Queisser limit for single junction solar cells. The main components of the system consist of photonic crystals designed to absorb electromagnetic energy over the entire solar spectrum and to re-emit light at energies close to and above the bandgap of a single junction photovoltaic cell. Achievements include: the first computational design of a realistic nanophotonic absorber and emitter structures that enable system efficiency beyond the Shockley-Queisser limit; experimental demonstrations of photonic crystal thermal emitters that operate at record high temperatures; and the establishment of an emissometer at Stanford that enables accurate and absolute characterization of emissivity at elevated temperatures.

Professors Alberto Salleo and Yi Cui are investigating a novel low cost concept for inorganic multi-junction solar cells. The proposed concept uses solution processable absorbers made of colloidal semiconductor nanocrystals and ZnO or Ag nanowire network-based transparent conductors as an alternative to established technologies based on brittle and high-cost transparent metal oxide films. The overall approach offers advantages such as large flexibility in the choice of active materials, easy control of subcell bandgap using quantum-confinement effects, and the practicability of realizing devices with a large number of junctions. No updates are reported for this year.

Professors Nicholas Melosh and Zhi-Xun Shen investigated a novel photon-enhanced thermionic concept that combines photon- and thermal-excitation in a semiconductor material to increase the efficiency of thermionic electron emission compared to current systems. The experimental results validated the concept and predicted physics for the PETE process and exhibited the need to improve carrier recombination and high temperature material stability. No updates are reported for this year.

Biomass

In the area of biolignin, one of the four programs that began in 2007 was completed. Professors John Ralph, Xuejun Pan and Sara Patterson at the University of Wisconsin-Madison have completed their project aimed at the delineation of a set of approaches for successfully altering lignin structure, in a way that allows plant cell wall breakdown to produce biofuels in a more energy-efficient manner, by providing alternative plant compatible monomers to the lignification process. This has been a highly productive project with 12 peer reviewed publications (two more submitted) and two patent applications. Overall, this fundamental project, coupled with the integral projects from other GCEP research in the lignin area (by the Boerjan, Chapple, and Halpin groups) has now identified several promising strategies and validated several specific examples of monolignol-replacement compounds that have the potential to significantly improve the energetics of biomass conversion. All of these strategies are aimed at making the lignin less of a recalcitrance factor and, in some cases, making it significantly easier to depolymerize. The ultimate GCEP goal of reducing greenhouse gas emissions at a global scale will depend on the ability to successfully engineer such traits into biomass crops, a goal of active research worldwide at present.

Another project in the bioenergy area of the portfolio will be ending this year. This project led by Professor Chris Field, with Professors David Lobell, Roz Naylor and Greg Asner, from the Carnegie Institution for Science and Stanford University was aimed at the assessment of biomass potential on a global scale. The original project plan emphasized four topic areas. Topic one used a new technology for interpreting remote-sensing data to quantify carbon and climate forcing from forested lands recently converted to biomass energy. Topic two extended this analysis to the global scale, using carbon-cycle modeling, combined with several kinds of observational data. Topic three focused on climate forcing from food-biomass interactions, with an emphasis on understanding indirect clearing that occurs as biomass for energy pushes food agriculture into other lands. Topic four looked at net climate forcing from biofuels-related direct and indirect conversions. It used climate models and satellite observations to quantify the component of climate forcing due to effects on albedo. Over the course of the project, the team published papers in all four of these areas. In addition, the team was able to devote substantial resources to some emerging areas. These included contrasting forest biomass in deforested and not deforested areas, the spatial velocity of climate change, consequences of alternative uses of biomass energy, and negative emissions energy technologies. The project was very successful and has led to 12 publications, including papers in Science, Nature, and PNAS. Post-docs supported on the project went on to jobs at UC Merced, the California Academy of Sciences, Arizona State University, and a Fulbright NEXUS Scholarship.

Carbon Capture and Separation

Shingo Kazama took over as the group leader around 2010, heading the team of scientists at The Research Institute of Innovative Technologies for the Earth (RITE) in developing CO_2-selective membranes. By engineering the chemistry and morphology of such membranes at the nanoscale, the group made significant improvements to membrane performance. The technology described in the report uses a novel and effective supercritical CO_2 directing method. This team has been funded by GCEP on various membrane separation technologies since 2006, and the project ended in the fall of 2012.

Carbon Storage

"Collaborative Research on Carbon Sequestration in Saline Aquifers in China" was carried out by a group of researchers at three institutions that include Professors Dongsxiao Zhang and Kristian Jessen of University of Southern California, Professors Qingdong Cai, Bin Gong, and Yi Zheng of Peking University, and Professors Yilian Li, Yanxin Wang, and Jianmei Cheng of China University of Geosciences. This project addressed fundamental issues associated with large-scale sequestration of CO_2 in saline formations with emphasis on developing the potential for CO_2 sequestration projects in China. This work involved: a comprehensive review of sedimentary basins in China in terms of basin characteristics and its proximity to CO_2 point sources; an experimental study to investigate the dynamic behavior of CO_2 migration in the context of storage insaline aquifers; and modeling and simulation for microscopic interactions and macroscopic long-term fate of injected CO_2 versus the host environment. The work has been highly recognized by the Shenhua Group, and the team will continue to work with Shenhua on China's first CO_2 sequestion project in a saline aquifer.

Advanced Combustion

Professor Chris Edwards' program pursued engines that reduce exergy loss by conducting combustion at states of extreme energy density. The team successfully constructed a free-piston device that can achieve compression ratios in excess of 100:1 and exhibited high efficiency. Follow-on work involved development of the methods needed to make direct measurements of combustion efficiency, emissions, and soot under these conditions. In the final year of the project, a new combustion approach based on use of an autoigniting, homogeneous mixture was developed.

Advanced Materials and Catalysts

Professors Thomas Jaramillo and Jens Norskov of Stanford University worked on a project aimed at the development of solid-state electrocatalysts based on design principles from nature that has come to an end this year. They explored catalyst materials for two energy conversion reactions of interest; the electrochemical reduction of CO_2 and the electro-oxidation of water. The goal was to develop efficient energy storage based on chemical fuels. Some of the notable achievements are: the development of new instrumentation and methodology to conduct CO_2-reduction studies (in particular, a custom CO_2 electrolysis reactor with on-stream head-space analysis by gas chromatography and ^{1}H-NMR and ^{13}C-NMR methods to detect liquid products in the liquid electrolyte post-reaction); and the study of CO_2 electroreduction on seven different metals: Cu, Ni, Pt, Fe, Au, Ag, and Zn, establishing their activity and selectivity for different gaseous and liquid products as a function of applied potential.