REU Site: Solar Energy Research for the Terawatt Challenge

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Jenefer Husman received a doctoral degree in Educational Psychology from the University of Texas at Austin, in 1998. She served as an Assistant Professor at the University of Alabama from 1998 to 2002, when she moved to Arizona State University. In 2008 she was promoted by ASU to Associate Professor. She is currently an Associate Professor in the Educational Studies Department at the University of Oregon. Dr. Husman served as the Director of Education for the Quantum Energy and Sustainable Solar Technology Center - an NSF-funded Engineering Research Center from 2011-2016. Dr. Husman is an assistant editor of the Journal of Engineering Education, and is a member of the editorial board of Learning and Instruction. In 2006 she was awarded the U.S. National Science Foundation CAREER grant award and received the Presidential Early Career Award for Scientists and Engineers from the President of the United States. She has conducted and advised on educational research projects and grants in both the public and private sectors, and served as an external reviewer for doctoral dissertations outside the U.S. She publishes regularly in peer-reviewed journals and books. Dr. Husman was a founding member and first President of the Southwest Consortium for Innovative Psychology in Education and has held both elected and appointed offices in the American Psychological Association (APA) and the Motivation Special Interest Group of the European Association for Research on Learning and Instruction.

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Nobel-Prize-winning chemist Richard Smalley recognized the need to produce abundant, clean, low-cost, energy as the greatest challenge of the 21st century. Coining this opportunity as the global "Terawatt Challenge,"[1] Smalley challenged scientists and engineers to develop sustainable technologies to meet the world's growing energy demands. The Quantum Energy and Sustainable Solar Technologies (QESST) Engineering Research Center is taking up this challenge. Funded by the National Science Foundation and the Department of Energy, QESST's mission is to generate innovative photovoltaic solutions for sustainable electricity generation. QESST's interdisciplinary team consists of faculty and students from eight universities, joined by leaders from world-renowned companies and leading photovoltaic entrepreneurs.

Education and outreach are critical to QESST's mission. The goals of the education program include

- increasing the size, experience, and diversity of the photovoltaic workforce,
- recruiting young people to photovoltaics, and
- providing learning experiences to ensure that QESST students are building the necessary skillsets to help meet the terawatt challenge.

The QESST summer research program is an important part of meeting those goals.

This summer, QESST hosted its sixth annual Research Experience for Undergraduates (REU), Teachers (RET) and Young Scholars (YS) program at Arizona State University's Ira A. Fulton Schools of Engineering. The cohort-focused program was significantly expanded from previous years (Pickett, et al. 2013), thanks to a three-year, $314,261, REU site grant awarded to QESST. The program, entitled, "Solar Energy Research for the Terawatt Challenge" allows nine undergraduate community college and university students to travel from around the country to work in ASU laboratories for nine weeks. The specific aim of the QESST REU site is for undergraduate students to be introduced to research and solar research specifically, experience how coursework they are studying can be put into practice in tackling the terawatt challenge, and practice how the principles of scientific research can be applied to any engineering challenge.

Expanding on the site grant, QESST partnered with Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) and the Center for Bio-mediated & Bio-inspired Geotechnics (CBBG) to create a diverse cohort of participants. Under the guidance of 10 graduate student mentors, the participants (14 undergraduate students, 3 high school students and 7 teachers) were provided a hands-on experience in solar cell manufacturing on a student-led pilot line from May 31 to July

29, 2016. Participants came from a range of backgrounds and varied educational levels. Participants joined from the states of Arizona, Mississippi, Ohio, Hawaii, South Carolina, California, and New Mexico. Young Scholars from high schools got their first taste of what it is like to do research in the university cleanroom, a controlled environment where contaminants such as dust are kept to a minimum to protect sensitive production processes. The majority of the program consisted of undergraduate students from community colleges and universities, as well as K-12 and community college STEM teachers. Teachers designed photovoltaic curriculum and shared their lessons with teachers from CBBG and with students in the ASU CompuGirls summer program. After receiving feedback and critiquing each other's lessons, the teachers applied what they learned over the summer to their classrooms.

The REU program's underlying approach to education through research was to provide a mix of hands-on training, creative freedom within a structured environment, and collaborative activities and presentations. Two important aspects of photovoltaic research that were repeatedly highlighted during the REU program are its multidisciplinary nature and its role in a sustainable future. Thus, the program leaders grouped students of complementary but different backgrounds into research teams, led projects that were multi-faceted, and ensured that each project was linked to the greater terawatt challenge through lectures and field trips. The ultimate goal was to build critical thinking and problem-solving skills through project and inquiry-based research experiences. The nine-week summer program was divided into two phases.

During Phase 1, structured learning activities included required safety and cleanroom training and an overview of solar cell processing, modeling, and characterization. To become acquainted with the laboratory environment, all the REUs, RETs, and YSs participated in two weeks of training at the ASU Solar Power Lab where they were required to fabricate solar cells from incoming wafer to IV measurement of single-cell modules ("Solar Cells 101").

During Phase 2, the REU participants broke into two- or three-member teams to investigate a fundamental materials, device, or life-cycle research question of relevance to a terawatt solar future. Each REU research team was supervised by a QESST graduate student mentor who guided them in designing and implementing experiments and analyzing the results for seven weeks. Each participant received in-depth, hands-on training in the tools and characterization equipment specific to their chosen project.

By design, the 2016 QESST REU participants experienced a range of research topics from across the PV value chain. Two teams focused on characterization of materials for heterojunction solar cells. They learned how to deposit transparent conductive oxide films and how to characterize their optical and electrical properties using spectrophotometry, ellipsometry, Hall Effect and sheet resistance measurements. One team demonstrated that the properties of RF sputtered indium zinc oxide films are determined by the oxygen partial pressure during deposition (rather than the oxygen/argon ratio), while the other group determined that the properties of indium tin oxide films are greatly affected by the underlying amorphous silicon layers. From this work, one paper is currently being prepared for publication in a peer-reviewed journal and another is expected when a new sputtering target arrives.

In a collaboration between QESST and NCI-SW, one REU team worked on a project that pertained to both nanofabrication and solar cells. The students developed a process for texturing silicon wafers with nano-sized pyramids for enhanced light trapping and reduced contact resistance to certain metallization schemes. This project was performed in conjunction with QESST partners at CalTech, and is also expected to result in a publication. Besides the projects pertaining to solar cells, two projects related to processes further down in the manufacturing chain were also successfully completed—one to develop a novel module lamination technique and one to determine the impact of recycling on the lifecycle of photovoltaic modules. The lamination project was part of a QESST associated project funded by ARPA-E. The aim of the project was to develop a hybrid photovoltaic/concentrated solar power trough collector which employed a polymer film within the laminate. The aim of this REU project was to determine if laminating the film to the substrate at only a few points could result in a laminate with sufficient adhesion to withstand field conditions. The students learned how to measure peel strength and designed an experiment to find the optimal size and density of the connection points. The students involved in the recycling project did almost the opposite. Their objective was to find a method to release laminated layers from the substrate using the minimum amount of energy possible. They tested chemical, ultraviolet, and thermal methods of delamination and found that thermal cycling was more effective than the current state of the art. They also determined the amount of energy required for the thermal delamination process.

Students' developed their engineering communication and team work skills, as well as their technical skills. On Fridays, each research team provided everyone associated with the program a presentation on their research goals and progress, fielding questions and garnering feedback. This activity created a sense of cohesion across the REU cohort, providing students with multiple opportunities to develop communication skills and for each member of the REU cohort to learn about the whole PV value chain. Concurrent with work on their research projects, all summer research participants attended lectures and workshops from QESST principle investigators and guest speakers from industry on topics such as the theory of solar cell operation, fabrication and characterization techniques, the present status of the photovoltaic market, sustainability, policy, economics of solar cells, entrepreneurship, career opportunities in photovoltaics, engineering ethics, communication skills, and team building. The lecture series was designed to demonstrate how participants' research projects fit into the bigger picture of the terawatt challenge.

QESST celebrated a successful end to the 2016 summer REU, RET, and YS programs on July 29th. Joined by participants from other QESST summer programs, students and teachers met at the ASU Engineering Research Center and shared their research during a poster presentation. This culminating event was attended by QESST faculty, post-doctoral scholars, graduate students, and industry members. The poster session was followed by a luncheon that included industry members from Ameresco, APS, First Solar, Soitec and NRG. The day ended with the presentation of certificates to the REU, RET, and YS participants in recognition of their outstanding efforts in the lab.

Six REU participants subsequently received travel funding to present their work at the Arizona Student Energy Conference in Flagstaff, AZ, September 15-16, 2016. Others presented at the Crystalline Silicon Solar Cells and Modules: Materials and Processes held in Vail, CO.

References

1. Smalley, R. E. (2005). Future global energy prosperity: The Terawatt Challenge. MRS Bulletin, 30, 412-417. Available at http://cohesion.rice.edu/NaturalSciences/Smalley/emplibrary/120204%20MRS%20Boston.pdf
2. Pickett, G., Bowden, S. Husman, J., Ross, K. Shell, D. F., and Nelson, K. G. (2013, June). Student-led solar cell fabrication pilot line: Engaging the next generation of PV engineers. In *IEEE 39th Photovoltaic Specialists Conference (PVSC)*, pp. 2389-2391. IEEE.

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