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Exploratory Research for New Solar Electric Technologies

R. McConnell and R. Matson

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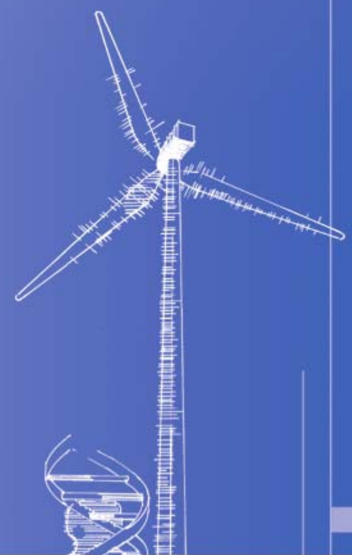

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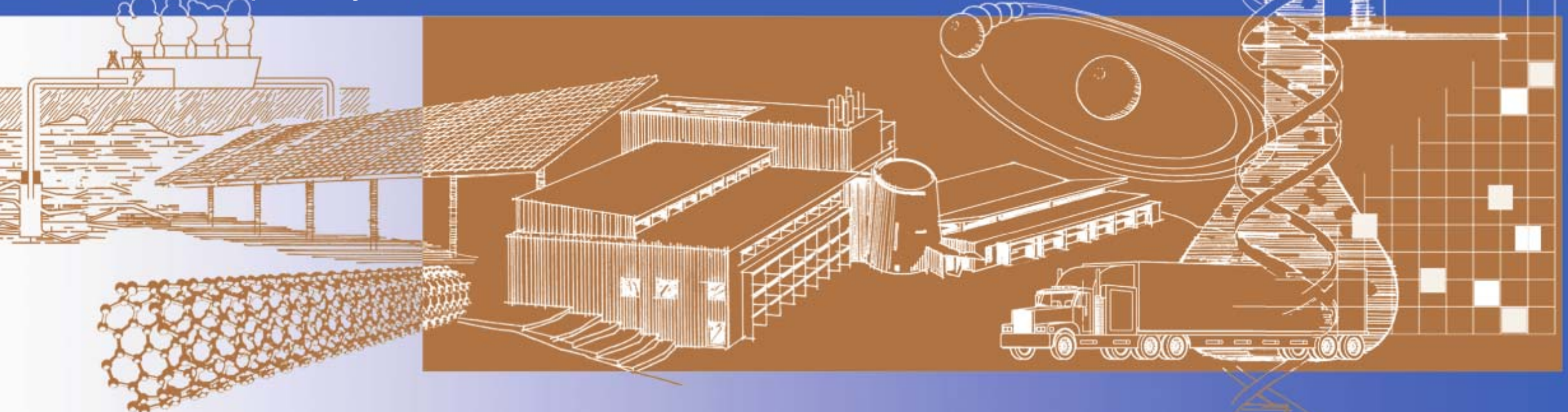

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Exploratory Research for New Solar Electric Technologies

Robert McConnell and Rick Matson
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd. Golden, CO 80401
robert_mcconnell@nrel.gov

ABSTRACT

We will review highlights of exploratory research for new PV technologies funded by the DOE Solar Energy Technologies Program through NREL and its Photovoltaic Exploratory Research Project. The goal for this effort is highlighted in the beginning of the Solar Program Multi-Year Technical Plan by Secretary of Energy Spencer Abraham's challenge to "leapfrog the status quo" by pursuing research having the potential to create breakthroughs. The ultimate goal is to create solar electric technologies for achieving electricity costs below 5 cents/kWh. Exploratory research includes work on advanced photovoltaic technologies (organic and ultra-high efficiency solar cells for solar concentrators) as well as innovative approaches to emerging and mature technologies (e.g., crystalline silicon).

1. Objectives

The strategy and objectives for the PV Exploratory Research Project are well stated in the Solar Program Multi-Year Technical Plan. The strategy is to establish a substantial program of fundamental materials, chemistry, physics, and electronics for the high-payoff, high-risk research that can yield great benefits to the nation. Creating substantial quantities of useful energy is the "holy grail" for renewable energy and this project is a prime example of research and development (R&D) worthy of Federal support.

The project's objectives are to develop next-generation technologies and systems with the potential to create new high-value applications of solar energy in producing hydrogen fuel, generating competitive bulk power at central stations, desalinating water, or creating other products that are beyond present capability. The project is expected to create both disruptive technology advances and multiple incremental improvements.

2. Technical Approach

The technical approach is to identify and support the best exploratory research groups since they are the most likely to create breakthroughs. Over the years, the project has been technology neutral and has supported leading-edge research in organic (plastic) solar cells, thin films, III-V solar cells, crystalline silicon and non-conventional PV concepts. In 1998, DOE, through this PV Exploratory Research Project, issued a request for proposals for next-generation PV concepts and conducted a rigorous competition leading to the selection of 18 university groups solely on the basis of the quality of the research proposed and the capabilities of the researchers. This set of projects—called Future-Generation PV—explored many PV ideas, including nanoparticles in polymers, new III-V materials for higher-efficiency multijunction solar cells, porous silicon, nanorod solar cells, new transparent conducting oxides and several studies of amorphous silicon. A second request for proposals—called Beyond the Horizon PV—yielded 15 new 3-year projects working on dye solar cells, molecular-chromophore cells, liquid-crystal cells, multijunction cells, nonvacuum processing for CIGS thin-film cells, rectenna cells, and a novel concentrator photovoltaic concept. These projects, led by 11 universities and 4 companies, finished in FY 2004. The most recent request for proposals asked for larger project efforts, funded at levels of 4 to 5 times higher than the earlier projects. NREL recently awarded three new PV Exploratory Research projects targeting higher efficiency organic solar cells and one exploring non-conventional photovoltaic conversion processes aiming for solar cell efficiencies above 60%.

The PV Exploratory Research Project also funds exploratory research into crystalline silicon solar cell technologies. While the emphasis has been on supporting the best crystalline silicon research at universities, the crystalline silicon solar cell industry was polled in 2000 and recommended the research topics in the last request for proposals issued in 2001 that led to awards to 7 universities. Three of these universities also participate in the National Science Foundation (NSF)-supported Silicon Wafer Engineering and Defect Science (SiWEDS) consortium. This consortium of integrated circuit (IC) companies (e.g. Intel, Texas Instruments, etc.) funds exploratory research of crystalline silicon materials and devices at highly qualified universities. By participating in the SiWEDS consortium, DOE and NREL are leveraging the crystalline silicon exploratory research interests of the multibillion dollar/year IC industry in order to accelerate and enhance the probability of photovoltaic breakthroughs—even in such a mature PV technology as crystalline silicon.

Because of limited funding for exploratory research, leveraging related R&D has become an integral strategy of the PV Exploratory Research Project. In the case of crystalline silicon, we are leveraging the interests of the IC industry. For organic solar cells, we are leveraging the research interests of universities and companies developing organic light emitting diodes for a myriad of display and lighting applications. In the case of high efficiency solar cells, we leverage the research accomplishments of the III-V industry developing high-speed IC devices used in most cellular phones—and especially the III-V solar cell industry supplying power for the nation's communications and defense satellites. It is not surprising, therefore, to receive the best research proposals from groups that have been able to explore technology areas in depth because the technologies have other very high value applications. Another example of leveraging is this project's support of PV exploratory research in NREL's Basic Sciences Center where each of the Principal Investigators has complementary funding from DOE's Office of Science mainly through programs in Materials Sciences or Chemical Sciences.

3. Results and Accomplishments

Detailed results and accomplishments are presented in the following papers at this DOE Solar Program Review Meeting.

Dye- and Semiconductor-Sensitized Nanoparticle Solar Cell Research at NREL, A. Frank, NREL.

Ultra-High Efficiency Excitonic Solar Cell. B. King, University of Nevada.

Interface and Electrode Engineering for Next-Generation Organic Photovoltaic Cells, T. Mason, Northwestern University.

Band Structures and Optical Properties of Transparent Conducting Oxides: Cd_2SnO_4, Zn_2SnO_4, and $CdIn_2O_4$, S. Wei, NREL.

Advances in III-V Heterostructures and Solar Cells on SiGe/Si Substrates, S. Ringel, Ohio State University. (This is an example of a "graduate" from the PV Exploratory Research Project as S. Ringel recently received a new award from the High-Performance Photovoltaic Project.)

Coadsorbent-Induced Band Edge Shift in Dye-Sensitized TiO_2 Solar Cells, N. Neale, NREL.

Effect of Nonideal Statistics on Electron Diffusion in Dye-Sensitized TiO_2 Solar Cells, J. van de Lagemaat, NREL.

Influence of the Electrolyte on the Performance of Dye-sensitized TiO_2 Solar Cells: Band Edge Movement and Surface Shielding, N. Kopidakis, NREL.

Toward a Unified Treatment of Electronic Processes in Organic Semiconductors. B. Gregg, NREL.

Correlation of Morphology and Device Performance in Inorganic-Organic TiO_2-Polythiophene Hybrid Solid-state Solar Cells, L. Robertson, Georgia Tech.

Fabrication, Characterization and Simulation of Solar Cells. G. Lush, University of Texas, El Paso.

Generating Hydrogen through Water Electrolysis using Concentrator Photovoltaics, R. McConnell, NREL.

DOE-NREL Minority University Research Associates Program, F. Posey-Eddy, NREL.

Modeling and Control of High-Concentrator Phtovoltaics for Hydrogen Production for Fuel Cells, R. Sowah, Howard University.

Energy Conversion and Storage Devices: Solar Energy Research and Education, K. Broussard, Southern University.

Development of Quantum Dot-sensitized ZnO and TiO_2 Nanorod Array Solar Cells, D. Jowhar, Fisk University.

Non-vacuum Processing of CIGS Solar Cells, C. Eberspacher, Unisun.

Lifetime Scanning using Microwave Reflection Spectroscopy, G. Rozgonyi, NC State

Wafer-Scale Fabrication of Ge/Si and InP/Si for Multijunction Solar Cell Applications, H. Atwater, Caltech. (This is another "graduate" of the PV Exploratory Research Project recently receiving a new award from the High-Performance Project.)

Tandem, Planar, Bulk and Mixed Heterojunction Solar Cells: Achieving High Efficiencies Using Small Molecular Weight Organic Photovoltaics, S. Forrest, Princeton University.

Next-Generation Photovoltaics, C. Honsberg, IEC, U. of Delaware.

Development of High-Efficiency Solar Cells on Low-Cost Silicon Materials, A. Rohatgi, Georgia Tech

The Impact of Metal Impurity Clusters on Solar Cell Performance in Multicrystalline Silicon, T. Buonassisi, UC Berkeley.

Effect of Grown-in Light Element Impurities on PV Silicon Mechancial Properties, A. Karoui, NC State,

Residual Stress Measurements as Related to Solar Cell Processing, S. Danyluk, Georgia Tech.

DOE Office of Science Funded Bbasic Research at NREL that Impacts Photovoltaic Technologies, S. Deb, NREL.

Quantum Dot Solar Cells: High Efficiency through Impact Ionization, M. Hanna, NREL

High Efficiency Solar Cell Concepts: Physics, Materials, and Devices, A. Mascarenhas, NREL.

Theory and Experimental Investigation of Approaches to >50% Solar Cells, C. Honsberg, U. of Delaware.

New Insights on Photovoltaic Materials from Solid State Theory, A. Zunger, NREL.

Amorphous and Nanocrystalline Silicon PV Technology, J. Yang, United Solar Ovonic.

Hot-Wire Chemical Vapor Deposition of Silicon Nitride for Photovltaic Applications, H. Atwater, Caltech.

Hydrogenation Methods & Passivation Mechanisms for c-Si Photovolaics, S. Estreicher, Texas Tech.

Hydrogen-Defect Interaction Phenomena in Si, S. Ashok, Penn State.

Nanocrystalline and Microcrystalline Silicon-simulations of Improved Material Properties. R. Biswas, Iowa State.

4. Conclusion

By enabling the nation's best researchers to explore advanced PV technologies, the PV Exploratory Research Project increases the chances for breakthroughs that can "leapfrog the status quo."

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