Pre-proposal to the PSU "Achieving Global Excellence" Program *March 16, 2009*

"Advanced Materials and Devices for Sustainable Energy"

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"Our future is with clean electrons." Thomas L. Friedman, *Hot, Flat, and Crowded*, cited at Portland State University, March 9, 2009

Summary

This proposal requests support to coordinate the many faculty members at PSU who work on the science and technology of sustainable energy. Although the primary focus is on novel photovoltaics, the full scope necessarily includes all the fundamental aspects involved in creating and characterizing new materials and devices. Faculty members from four departments in two schools are included so far. The existing expertise and prospective new directions include the synthesis of novel materials in novel configurations, characterization of the interrelated structural, optical, and electronic properties of materials, modeling of systems for optimization of energy conversion and utilization, and nanoscale fabrication of device prototypes and their testing. The proposed work will include new curricular initiatives to serve both graduate and undergraduate students, development of external grant proposals to support improved infrastructure for research in these areas, informative workshops and seminars to connect us with the current frontier research and researchers, and expanded collaborations in the local area and beyond to extend the scope of our work.

Background

The interrelated issues of energy and climate represent the most crucial long-term challenge facing the world today; the magnitude of the problems and the rapid changes underway require urgent and widespread responses. More than any other single response, the development of sustainable energy resources, combined with optimal usage and conservation of energy, addresses the solutions to these and other pressing issues. Recognition of the urgency of this work has led to increased attention worldwide to the fundamental science and technology of energy. Leadership in the United States is finally acknowledging the significance with targeted funding in the stimulus package and projected growth for funding agencies. In Oregon, we have become a leader in siting new solar technology companies, attracted by enthusiastic state support. Continued leadership in this area will require significant improvement in one area often cited by companies moving into a new area - a strong higher education system that provides an excellent workforce and connects the industry with state-of-the-art developments in the field. PSU has been making strides in meeting this need, focused on sustainability. This proposal aims to strengthen the fundamental science and technology research fields at PSU that directly connect to sustainable energy.

The ability to interconvert energy from one form to another is at the heart of how our society operates. Currently the US operates on 85% fossil fuel energy, importing much of it, burning it to release heat which is either used directly or converted to electricity or mechanical energy, mainly transportation. The overall operation epitomizes non-sustainability: the resources are finite and severely diminishing, the resources require transportation over great distances at

significant costs and occasional hazards, control of the resources are in the hands of a few with uncertain political and economic stability, and the byproducts of use are slowly suffocating the planet. Outside of that, the use of fossil fuels spawned the industrial revolution that completely transformed the way the world operated. It's time for new revolution, and it is the role of universities to lead the way. If PSU intends to be known for sustainability, it must be involved in this.

Of the potential sustainable resources, there are a few that can bring immediate cost-effective returns, including wind and nuclear. But their magnitude is limited. The global energy budget is about 14 TW (an average constant rate of power, as if the world were plugged into a meter). Wind might provide up to 2 TW. Nuclear power plants are sized in about the 1 GW range, but since it takes 1000 GW to make 1 TW, it would take construction of three 1 GW plants every day to get the first TW after about a year. Solar energy constantly bathes the earth in 120,000 TW of energy. There's just no avoiding it; solar is the only resource big enough to meet the long term energy needs of the world. The US could meet all the world's energy needs by collecting solar energy at 10% efficiency over an area that roughly correlates with the area of Arizona.

Underlying the ability to harvest and convert solar energy are advanced materials and devices, the explicit focus of this research group. If such large areas are needed, the materials must be inexpensive, reliable, and easy to deploy. The current technology utilizes silicon in either crystalline or amorphous (thin film) form. Although processing efficiencies and prices are slowly coming down, the inherent energy requirement of releasing silicon from silicon dioxide will always limit the cost effectiveness. New approaches to using even less silicon, e.g., nanowires, or new types of materials, e.g., inexpensive oxide semiconductors like TiO_2 or ZnO, or novel optical materials, e.g., solar concentrators, show the directions that will be needed for a truly revolutionary change in harvesting and converting energy.

Goals and Objectives

In the long term, this effort is designed to establish PSU as a major contributor to the understanding and development of new energy resources, energy interconversions, and energy utilizations that are consistent with and further enhance PSU's leadership in sustainability.

In the short term, the plan is to gather the diverse researchers on campus to develop a clear focus for our efforts, pursue external support to expand our infrastructure to address these issues, and establish mutually beneficial collaborations, both within PSU and externally, to extend our reach and our capabilities. It is important to point out that this group intends to work closely with the recently established RISE (Research Institute for Sustainable Energy); several faculty members cited here are already included as members of that group. We feel that there exists a fundamental need for a research-oriented group that focuses on the enabling science and technology that underlie the energy crisis, ultimately generating the solutions that will bring the world out of the crisis.

Undergraduate Education

There are numerous courses already available across campus that address key issues in sustainable energy. We will catalog and coordinate these various courses and assess where additional coursework would be beneficial to generate a cohesive energy curriculum. Where we find the greatest need for new coursework, we will apply to the NSF Course, Curriculum, and Laboratory Improvement (**CCLI**) program to support the curricular development. For example, we may find it most useful to develop an interdisciplinary course sequence that helps to bring together the many faculty with interests in the basic science and technology of energy. This would be similar to and complementary to the interdisciplinary course initiated by a group of faculty in the area of nanoscience, and complementary to any coursework that would be developed by the RISE interdisciplinary group.

Graduate Education

Currently there are four PhD programs associated with the faculty involved in this proposal: Chemistry, Applied Physics (pending), Electrical and Computer Engineering, and Environmental Sciences and Resources. The coursework for energy sciences and technology cited above will primarily be at the 400/500 level so as to be appropriate for both advanced undergrads and graduate students. Support for graduate students will be sought by submitting a proposal to the NSF Integrative Graduate Education and Research Traineeship (**IGERT**) Program.

Research Infrastructure

The PSU Center for Electron Microscopy and Nanofabrication (CEMN) is an outstanding research facility that has proven extremely useful for enhancing basic research in a wide variety of areas as well as initiating collaborations with academic and industry partners. CEMN allows visualization of materials at the ultimate spatial resolution. We would like to augment that facility by creating a **center for ultrafast phenomena**, in particular equipment for the

observation of events at the ultimate time resolution. Femtosecond laser spectroscopy is now available as turn-key instrumentation from **Ultrafast Systems** and others. This system follows processes that occur at the ultimate speed limit - in femtoseconds, nothing moves except light, and even light travels only 300 nm in a femtosecond. Thus this allows direct observation of incremental steps in electron movements after an initiating laser pulse. Understanding the detailed kinetics of charge movement leads to the ability to control and optimize the desired processes that create efficient energy capture and utilization. Ultimately, we would like to consider that this capability could be combined with our nanometer spatial resolution as well. This proposal requests funding to help coordinate the multiple funding sources that will be needed to establish a center for ultrafast phenomena down to femtosecond resolution. As with the curricular development, we will need to evaluate our current resources and decide on the most appropriate steps to build to the next level. Nanosecond lasers are already available in several labs as well as terahertz analysis equipment.

Outreach and Collaborations

As the research group develops its focus, we intend to survey the current frontiers and opportunities through a variety of means. We would start with a **summer workshop**, in September 2009 if funding is available that soon. The workshop would invite leading researchers in the area of sustainable energy science and technology to join with the PSU faculty and graduate students in exploring the current research opportunities and needs. The workshop should end with a clear agenda for the directions the PSU faculty can choose to pursue. During the academic year, an interdisciplinary energy **seminar series** will be established. We expect that the facilitated interactions among PSU faculty and external experts will lead to additional collaborations and bring even more faculty into successful external funding.

It will be important to maintain connections with a broad range of groups with similar interests. We will explore the establishment of an **advisory board**, drawing on the numerous local companies connected with solar energy and energy-related industries. We will collaborate with **RISE** to assure that sustainable energy research at PSU maintains a high profile and covers all of the diverse aspects of the field. Centered at the University of Oregon, a statewide initiative called **SuNRISE** is under development to coordinate researchers and industries with interests in solar energy. The Oregon Department of Energy has an established **Solar Energy Working Group**, of which Carl Wamser has been a continuing member. Many of the faculty in this group are members of **ONAMI** and **BEST**, connecting their work to the broader issues supported by those statewide initiatives.

Faculty Group Members

Primary Contact: Carl C. Wamser, Professor of Chemistry (wamserc@pdx.edu, x5-4261)

Chemistry

Carl Wamser - nanoscale organic materials for solar energy conversion, artificial photosynthesis
Shankar Rananavare - nanostructured semiconductors for optoelectronics applications
Rob Strongin - synthesis of novel broad-spectrum light-absorbing and light-emitting dyes
Andrea Goforth - fluorescent silicon nanoparticles, fluorescent/magnetic nanoparticles
Mingdi Yan - functional organic surfaces and interfaces
Tami Lasseter Clare - environmental analysis of corrosion and preservation of materials surfaces

Physics

Rolf Koenenkamp - controlled semiconductor nanostructures and interfaces for solar energy
Raj Solanki - thin film and nanowire semiconductors for solar energy and electroluminescence
Jun Jiao - biotemplated semiconductors for photovoltaic applications
John Freeouf - multilayer cells, InP photovoltaics, charge carrier lifetime measurements
Andres LaRosa - near-field analysis of energy transfer in nanostructures
Peter Moeck - characterization and optimization of silicon crystal grain boundaries
Sergei Rouvimov - role of crystal defects in electronic properties of silicon
Gary Goncher - nanowire silicon hybrid photovoltaic devices

Electrical and Computer Engineering

Jim Morris - electrically conductive adhesives, electronic conductivity in nanoparticle thin films
Lisa Zurk - modeling and analysis of electromagnetic and acoustic wave phenomena
Brano Pejcinovic - terahertz analysis of carrier transport in photovoltaic materials
Christof Teuscher - computational modeling of nanostructured networks for energy conversion

Materials and Mechanical Engineering

Jack McCarthy - top contact metallization systems for photovoltaics
Graig Spolek - energy conservation and utilization in buildings

Current Capabilities

Collectively and individually the faculty members cited in this proposal already have ongoing collaborations with a wide range of local, national, and international institutions with ongoing grant support from numerous agencies. On the PSU campus we have access to an impressive collection of equipment and expertise in the area of materials science. Foremost is the Center for Electron Microscopy and Nanofabrication, which provides several world-class instruments capable of imaging as well as manipulation and analysis at the nanoscale. The broad usage of this facility by local industry as well as researchers across campus indicates the potential of such facilities for enhancing collaborations. Other specialized labs include the Integrated Circuit Design and Testing Lab and the Northwest Electromagnetics and Acoustics Lab. Additional specialized capabilities are briefly summarized below; the intention is to collect a definitive listing on our website and use it to attract collaborations among ourselves and off-campus. Synthetic techniques: chemical vapor deposition, atomic layer deposition, spin coating, photolithography, and preparation of nanowires and conductive organic nanofibers. Analysis techniques: high-resolution photoemission electron microscopy, atomic force microscopy, small-angle x-ray scattering, electron precession diffraction, terahertz impedance analysis, open-access crystallography database and software, computer simulations of semiconductor and photovoltaic devices, and numerous more traditional types of spectroscopic, electronic, and luminescence analysis.

Budget and Justification

The year one budget is designed to allow the group to coordinate our activities and interact with one another and with outside experts.

PSU summer workshop on sustainable energy (Sept 2009 or summer 2010)	$30,000
Academic year multidisciplinary seminar series on sustainable energy	10,000
Travel to meetings for PSU faculty	5,000
Travel to PSU for outside consultants	5,000
Curricular development (summer salary for faculty)	10,000
Graduate student support (one year, for logistical support)	25,000
Web page development, other administrative support	10,000
Proposal writing support, new faculty mentoring	5,000
TOTAL REQUEST, Year 1	$100,000
Years 2 and 3 budget requests	approximately $75,000 each year

Timeline and Deliverables

current	establish a **web page** to coordinate the group's activities
Sept 2009	host a workshop at PSU including leading researchers in sustainable energy
fall 2009	establish an advisory board of local experts, mainly from industry
fall 2009	establish an ongoing interdisciplinary seminar series in sustainable energy
2009-2010	submit external grant proposals for various aspects of this work
2009-2010	coordinate curricular offerings and plan new coursework
summer 2010	pilot test new 400/500 level coursework in energy science and technology
2010-2012	years 2 and 3 will continue to expand the curricular, research, and outreach activities based on decisions and recommendations from workshops, our advisory board, and in support of new collaborations and new faculty hires

Sustainable Funding

By establishing a cohesive group centered on sustainable energy science and technology, opportunities for external funding will become more numerous and easier to pursue. The individual faculty members in this group have an excellent record of external funding. Newly uncovered common interests and collaborations will lead to additional funding opportunities from the traditional sources, e.g., NSF and DOE, as well as broader interdisciplinary proposals such as the NSF CCLI and IGERT programs cited earlier. The establishment of a center for ultrafast phenomena will require a cohesive effort involving multiple funding sources. The faculty in this group have a record of successful collaboration and funding, and we're looking forward to the opportunity to further broaden our scope in this very crucial area of research.