FESC
Florida Energy Systems Consortium

2009 FESC Annual Report

Research and Outreach Progress Reports

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Florida Atlantic University

Center for Ocean Energy Technology

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Description: Ocean energy is an emerging technology that uses the power of ocean currents, waves, tides, and salinity gradient to create renewable energy. Tapping ocean energy resources will reduce our reliance on fossil fuels. Research areas of focus include ocean current and thermal differential systems, cold, deep ocean water-based air-conditioning, underwater hydrogen generation and storage, and environmental impact and mitigation.

The Center for Ocean Energy Technology's program is structured to be the catalyst that will enable the ocean energy industry in Florida in providing solutions to the state's energy challenge. This project focuses on determining the potential of harnessing specifically the ocean current resource and ocean thermal energy conversion. The regulatory process at State and Federal levels for ocean energy infrastructure and operation in the offshore continental shelf is not clearly defined nor the roles and interdependencies of the individual agencies clearly articulated. In addition, knowledge to make these decisions is more on a macro rather than micro level necessary to assess individual devices. COET's mission is to bridge the gap between concept and commercial deployment of ocean energy technologies by providing at-sea testing facilities for both ocean current and thermal energy research and for technology development. Research cuts across environmental, ecological, resource and technology areas.

Budget: $8,750,000.00
Universities: UCF, FSU, ERAU, Oregon State University, University of New Hampshire, University of Hawaii, University of Edinburgh, Heriot-Watt University
External Collaborators: NREL, NaREC (UK), FPL, OOE, Vision Energy, Dehlsen Associates, Ecology & Environment, Lockheed Martin, OREC, ASME, ASCE, IEC US TC 114 TAG, ISO/TC 108/SC 5

Progress Summary

The Center for Ocean Energy Technology (COET) was founded with a $5M award received January 2007. During FY'08, because it became apparent that regulatory jurisdiction for the offshore continental shelf was in a formative stage for both Federal and State agencies, a program re-organization was completed to accommodate regulatory efforts and to ensure ocean energy research was pursued as a total system to include: environment, resource, ecology, and technology. With the additional funding in 2009 of $8.75M the Center has moved forward in strategic research, in pursuing key technology, in defining standards criteria, and is deeply engaged in regulatory process formation which will influence the development of ocean energy in Florida, while continuing to educate and engage the public.

Research and development for an ocean energy industry is being addressed with a system-level, phased approach. Joint research is ongoing at FAU, with FESC partners, and other industrial, government, and academic partners. Initial research in areas such as ocean resource analysis and modeling, prognostics and health monitoring systems, materials and anti-fouling, mooring and anchor systems, and environmental/benthic baseline assessment have been funded.

COET's technology and industry support efforts are underway in three distinct but inter-related tracks. First, the Center is actively engaged in sensor and instrument acquisition, deployment, and analysis to more fully characterize offshore energy resources, as well as the benthic and ecological environment. Second, in support of ongoing research and to further an operational and technical understanding of offshore energy systems and challenges, the Center has designed, partially fabricated, and will begin testing a small-scale hydrokinetic turbine system. Testing will be completed for components, sub-systems, and major systems of the turbine, eventually evolving to full system testing in a phased, risk-reduction process. Finally, the Center is working to begin early development of, and recognition of, a National Open-ocean Energy Laboratory for system-level test operation and data collection infrastructure. This effort is intended to support and promote a phased approach for early-stage testing to minimize risk and further scaled development for the growing industry, as well as to help establish standards criteria and practice for the future sector.

Notable accomplishments during the past year include completed milestones in resource assessment, research, regulatory process activity, partner relationships, infrastructure development, and outreach. Stand-alone instruments have been successfully deployed offshore in conjunction with shore-side systems to develop a baseline understanding of the kinetic and thermal energy resources in the Florida Straits. An interim draft application has been submitted and reviewed with the US Mineral Management Service for deployment of an ocean current research turbine, and the system has begun fabrication and testing onshore. More than twenty CDAs and five MOUs have been executed with national and international academic, government, and industrial partners to formalize collaboration with the Center. An in-lab 20kW dynamometer and test system is being finalized and installed, and through many conferences, presentations, and other events, the public continues to be engaged in the development of ocean energy.

2009 Annual Progress Report

1. Introduction

The Center for Ocean Energy Technology (COET) was founded with a $5M award received January 2007. During FY'08, unfamiliarity of regulatory processes for both Federal and State agencies for operation and research in the offshore continental shelf drove the Center to re-organize the program. A phased approach was adopted to accommodate regulatory efforts and to ensure ocean energy research was pursued as a total system to include: environment, resource, ecology, and technology. With the additional funding in 2009 of $8.75M COET has moved forward in strategic research, in pursuing key technology, in defining standards criteria, and is deeply engaged in regulatory process formation which will influence the development of ocean energy in Florida. COET is a key player in developing global ocean energy advocacy and public awareness.

Research and development for an ocean energy industry is being addressed with a system-level, phased approach. Joint research is ongoing at FAU, with FESC partners, and other industrial, government, and academic partners. Initial research in areas such as ocean resource analysis and modeling, prognostics and health monitoring systems, materials and anti-fouling, mooring and anchor systems, and environmental/benthic baseline assessment have been funded.

The Center's technology and industry support efforts are underway in three distinct but inter-related tracks. First, the Center is actively engaged in sensor and instrument acquisition, deployment, and analysis to more fully characterize not only offshore energy resources, but the benthic and ecological environment as well. Second, in support of ongoing research and to further an operational and technical understanding of offshore energy systems and challenges, the Center has designed, partially fabricated, and will begin testing a small-scale hydrokinetic turbine system. Testing will be completed for

components, sub-systems, and major systems of the turbine, eventually evolving to full system testing in a phased, risk-reduction process. Finally, the Center is working to begin early development of, and recognition of, a National Open-ocean Energy Laboratory for system-level test operation and data collection infrastructure. This effort is intended to support and promote a phased, scaled development for the growing industry, as well as to help establish standards criteria and practice for the future sector.

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2. Areas of Progress

2.1 New Funding

In 2009, COET received $1.19M through the U.S. Department of Energy of Congressionally Directed Program funding. In collaboration with a number of industry, university and laboratory partners, COET was successful in five DOE awards of 2009 funding amounting to $565,712. In addition, the Center received $25K through the Industry Affiliates program.

2.2 Sponsored Research

The Center currently funds research of FAU PIs and students, collaborative research with other universities, and incubates research relevant to tool development and modeling.

2.2.1 FAU Graduate Program Research

The Center has fully funded a variety of research through support of graduate student tuition and research assistantships. Research topics cover a broad spectrum of near and far-term questions which have broad and specific applications, such as the following:

Biofouling as a Function of Velocity: Dynamic Experiment. To select an appropriate antifouling coating, a test should be performed to gauge biofouling as a function of velocity. Current evaluations of biofouling in dynamic conditions either test at a single speed or in an uncontrolled boundary layer condition. The research proposes a model test system that can both test at a variety of speeds as well as keep the hydrodynamics simple and well understood. Test specimens can be examined to show threshold speeds above which specific species can not settle to promote biofouling.

Investigating the hydrodynamic flow about the Gulf Stream Turbine using a numerical algorithm based on the vortex lattice method (VLM). The thesis focus is on determining turbine performance and efficiency for a range of current speeds and variations; momentum deficit to the Gulf Stream caused by a turbine; and by comparison the accuracy of empirical turbine formulas.

Survey both the state of the art in Machine Condition Monitoring and the construction of fault trees for submerged ocean machinery. This entails derivation and use of a mathematical structure combining the features of ordered binary decision diagrams and zero-suppressed binary decision diagrams.

Design a Finite Element Analysis of an Ocean Current Turbine Blade. A composite 3 meter ocean current turbine blade has been designed and analyzed using Blade Element Theory (BET) and commercial Finite Element Modeling (FEM) code, ANSYS.

Modeling of composite marine turbine blades under fatigue loading. Finite element methods are being used to predict fatigue life using material stiffness and strength degradation models.

Methodology for Fault Detection and Diagnostic in an Ocean Turbine using Vibrations Analysis and Modeling and apply directly to the 20 KW turbine designed by the Center. Develop a methodology

combining numerical Finite Element Modeling and modern vibration techniques for condition monitoring and faults diagnosis of hydro-turbines.
Ontogenetic habitat shifts in marine turtles from the Gulf Stream to near-shore habitats.
A Fuzzy Logic Material Selection Methodology for Renewable Ocean Energy Applications. Develop material selection methodology for use in ocean energy projects.
Dissipation and eddy mixing associated with flow past an underwater turbine. A modeling and simulation effort involving computation of flow through a current turbine under various conditions and estimating the energy loss to the current stream due to turbine. The work is support of providing an "eddy viscosity" representation of the losses in a large scale computational model of the Gulf Stream circulation.
Numerical Performance Prediction for a First Generation Ocean Current Turbine (OCT). This effort is numerically estimating the performance of the Center's 20 kW OCT. The numerical simulation is being used to model the motions of the turbine, drag on the turbine, shaft power output from the turbine, forces on the rotor shaft, forces on the buoyancy compensation module mounting bracket, and forces in the cable over the expected operating conditions. These predictions are being made to investigate possible failure modes and determine the affect of design changes on the system's performance.
CFD Analysis of the Hydrodynamic Performance of Underwater Turbine in
Gulf Stream Using RANS and LES Methods. This research is focused on how the velocity and pressure fields in the immediate vicinity of a turbine's blades are dependent on blade velocity and the ambient flow and whether perturbations are sufficiently large to impact life forms in the water column, independently of blade strikes.
Ocean Thermal Energy Conversion (OTEC) Resource Characterization and Production Potential Estimation. Locate and determine the OTEC extractable power production potential in the Straits of Florida and what methods can be used to calculate that power. Power production potential variance with location and over time is also included.
Ocean Hydrokinetic Resource Characterization and Production Potential Estimation. What are the hydrokinetic and physical properties of the Florida Current in the Florida Straits and how do they vary cross-channel, along channel, with depth, and with time? What is the hydrokinetic power production potential in the Straits of Florida and what are methods that can be used to calculate that power? What is the power production potential variation with respect to location and time? What are the limiting factors in hydrokinetic power production and what is the maximum sustainable production that can be achieved in the Straits of Florida? How close together can hydrokinetic turbines be spaced?
20 kW Buoy and Mooring Design Optimization. This effort investigates the details of optimizing the support infrastructure for the OCT. It will assist with determining the effects of forcing environmental factors and response characteristics of the system during minor and major weather and environmental conditions to mitigate system risk.
Anchoring Study and Analysis to Support Ocean Energy Development in the Straights of Florida. Investigate the range of appropriate mooring technologies that can be utilized in the Straits of Florida and how they vary with location. Identify the deficiencies of current mooring systems in terms of providing the holding power and longevity need under normal conditions, as well as, during extreme 20, 50, and 100 year events, and enhance/optimize conventional mooring systems for the Straits of Florida.
Complete Thermal Design and Modeling for the Pressure Vessel of an Ocean Turbine – Using a Numerical Simulation and Optimization Approach, this work will provide methodologies that allow accurate estimation of the heat transfer rate inside the pressure vessel domain of an ocean turbine for the analysis, design and control of thermal systems using finite element analysis, genetic algorithms and artificial neural networks.

2.2.2 Subcontracted Research

The COET ADCP measurements, when combined with historical oceanographic datasets, will be invaluable to understanding the energy resource of the Florida Current as well as its variability. However, it is also important to understand the impact of large-scale energy extraction on the current itself, and for this it is necessary to turn to numerical simulation. To that end, COET and the Center for Ocean-

Atmospheric Prediction Systems at the Florida State University have teamed to use the HYCOM (hybrid coordinate ocean model—see www.hycom.org) as implemented at COAPS to simulate the effect of arrays of turbines in the current. Because the COAPS effort also includes real-time prediction of the variations of the Florida Current, using observed forcing functions from the weather and oceanic data assimilation, this partnership will, in the future, provide a forecasting capability for energy developers.

2.2.3 Other Research

Other research is focused on modeling and tool development, specifically for the 20 kW Ocean Current Turbine (OCT) which is being developed and tested as a research platform. This research involves developing a numerical simulation which includes an unsteady blade element momentum rotor mode to predict the rotor performance, including the power output and drag, in an unsteady environment. The numerical simulation will be used to predict the motion of the turbine when operating in waves, a current that decreases with depth, with variability in magnitude or direction with time, or when the MTB is moved by environmental forces. It will be expanded to model different horizontal axis turbines and will be validated with OCT test data.

2.3 Partners

To facilitate offshore energy research and development, partners from academia, government, industry, and other organizations have been engaged by the COET. Over 20 Confidential Disclosure Agreements, more than 5 Memoranda of Understanding, and other agreements have formalized these relationships. Hundreds of other partners have been engaged in common discussions through a variety of organized events. One notable partnership is a Cooperative Research and Development Agreement (CRADA) which is being finalized with the National Renewable Energy Laboratory (NREL). This affords both organizations the opportunity to access and enhance the resources already developed, and under development, to assist with future industrial testing, standards, and certification.

2.4 Regulatory and Licensing

Significant progress was achieved in advancing not only the permission that the COET requires for individual deployments and activities, but also helping shape and influence the national dialog regarding offshore ocean energy project development and regulation. The Center has successfully obtained an MMS Non-jurisdictional waiver and subsequent US Army Corps of Engineers permit through a Nation-wide License to deploy several bottom-mounted Acoustic Doppler Current Profiler (ADCP) buoys, an approved US Coast Guard Private Aids to Navigation Application (CG-2554) for its future 20 kW Ocean Current Turbine deployment, and nation-wide first Federal Communications Commission license to transmit Class A Automatic Identification System (AIS) information by a buoy which will enhance the safety and fidelity of the future deployment of the Center's 20 kW OCT deployment. In addition, local permission and permits were obtained to install two ocean surface radar stations on Florida's southeast coast, allowing the Center to monitor approximately 900 sq miles of sea surface current direction and magnitude. Agreements with both private and public entities were attained and final siting is ongoing.

Finally, a draft application has been submitted to the US Minerals Management Service under the interim offshore hydrokinetic projects rule for the Center's 20 kW Ocean Current Turbine. This application has been evolving from an executive summary to a full license application through a new process being established for such projects. The Center's application has been useful to agencies to help develop rule and requirements for future development applications, specifically for prototype and non-commercial scale testing projects. This effort has helped to accelerate access to offshore testing areas which will enable reduced-risk industrial development.

2.5 Resource Assessment

The Center has been actively engaged in collecting hydrokinetic and thermal resource data for the offshore energy available in the Florida Straits. Since February, three deployments of five acoustic current measurement devices have been measuring continuous ocean current data offshore of Ft. Lauderdale, FL. The instruments will be recovered, refurbished, and redeployed at the end of this year. The information about current profiles and behavior will assist further research regarding the

extractability and quality of the kinetic resource. The thermal profile of the Florida Straits has been regularly measured with offshore vessel deployed instruments. Weekly temperature and depth measurements have been taken off the coast of Ft. Lauderdale and up to 30 miles offshore in up to 2400 ft of depth to develop a thermal resource baseline. This is supplemented by monthly transects offshore of Miami, Lake Worth, and Stuart, which provides a larger picture of the resource along more of Florida's southeastern coast.

2.6 Experimental Platforms and Infrastructure

COET's 20 kW OCT provides a research platform to investigate first-stage offshore turbine technologies, effects, and interactions. Modeling and tool development will be enhanced through system validation. A moored presence in the Gulf Stream (a first) will afford collection of baseline environmental and benthic data to begin to characterize potential system effects and interactions. This information will be useful to technology developers and regulators alike.

The system's design was completed and fabrication, assembly, and testing of the system components, sub-systems, and systems are underway. Due to the new perspective of technology phasing based upon regulatory process, an opportunity arose to enhance the safety, technology, and value of the planned system. The deployment methodology was refined to accommodate an offshore testing range early-stage development in parallel with device research platform development. Federal funding is being leveraged to begin development and installation of offshore device testing infrastructure and practice while the 20 KW OCT is being finalized and deployed. The opportunity also allowed research areas such as Prognostics and Heath Monitoring system development to expand scope, accelerating broad-impact technology development. The offshore testing range early development is aimed at installing a National Open-ocean Energy Laboratory (NOEL), which will act as a national laboratory for the testing, certification, and development of offshore kinetic and thermal energy device technologies.

Florida State University

Biofuels Through Thermochemical Processes: Approach to Produce Bio-jet Fuel

PI: A. Krothapalli

Project Description:
The objective of the proposed research is to develop technologies to produce bio-jet and bio-diesel fuels from sustainable sources. Bio-oils and hydrogen will be produced from biomass generated synthetic gas. We will (1) produce liquid biofuels (bio-jet & bio-diesel) from renewable resources of cellulosic biomass and nonedible bio-oils; (2) demonstrate that the biofuels have comparable performance characteristics to conventional fossil fuels; (3) demonstrate that the new biofuels do not require major changes in current engine design & operation, (4) demonstrate that biofuels produced from cellulosic biomass and bio-oils can be economically competitive in current market with fossil fuels

Budget: $420,567

Progress Summary

A laboratory-scale fluidized bed steam gasifier has been designed and a fluidized bed test loop is under construction. This test loop will employ nitrogen (N2) and carbon dioxide (CO2) to simulate the gasification process and verify that the synthesis gas does not move with the fluidized bed. Also, a commercial 10 kW downdraft gasifier has recently been purchased for comparison testing with the fluidized bed gasifier, as well as laboratory class use. The necessary infrastructure for both of the gasifiers is being implemented at the Energy & Sustainability Center.

Task 1: Production of Hydrogen enriched synthetic gas: Biomass Steam Reformer
A test loop of the dual fluidized bed steam gasifier, a schematic illustration of which is given in Figure 2, was built and tested using nitrogen and carbon dioxide to verify that the synthesis gas will not move with the fluidized bed

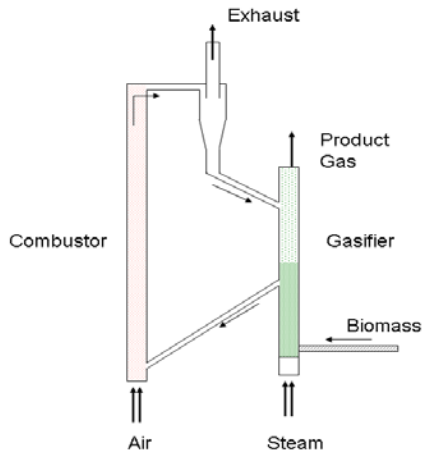

Figure 2. Schematic of the dual fluidized bed steam gasifier.

An electric steam superheater has been ordered for use with the dual fluidized bed. It is expected to arrive by mid-October.
Fabrication of the updraft gasifier portion of the dual fluidized bed is expected to begin by mid-October.
A commercial 10 kW downdraft gasifier was purchased for comparison testing with the dual fluidized bed. It is currently en route and it is scheduled to arrive by mid-October. The necessary infrastructure is currently being implemented at the Energy & Sustainability Center.

Task 2: Gas clean-up technology
Analytical equipment specification for product gas analysis was completed and
custom built Varian GC was purchased. Reactor furnace with special heat equalizing blocks was purchased from ATS and delivered. Wet test meter with pulse generator has been purchased from Ritter to measure product gas. Process plant control systems were evaluated and National Instruments hardware and software have been selected to control the biofuels micro unit.

Task 3: Hydroprocessing of Nonedible Bio-oils
This particular step is being carried out by our industrial partner Energia
Technologies inc, of Oakland, California. Energia Technologies is currently building high pressure and temperature bench scale unit capable of independently testing bio conversion unit. This work is being carried out under a Office of Naval Research STTR phase I program (FSU is a sub contractor to this effort)

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Florida State University

Planning Grant: Constructual Optimization of Solar Photo-Bioreactors for Algae Growth

PI: Juan Ordonez

Description: This planning grant money will be used for partial support of a graduate student. We will (1) design a small (lab scale) photo-bioreactor for algae growth and (2) select the type of algae for future experimentation. The main objectives are to place us in a more competitive position in future submissions in the area of biofuels. By the end of this one year effort we expect to have a complete design of a small-scale photo-bioreactor for algae growth and to obtain additional funds that will allow us to build the photo-bioreactor.

Budget: $15,000

Progress Summary

No progress reported.

Florida State University

Environmental Impacts of Energy Production Systems: Analysis, Evaluation, Training, and Outreach

Principal Investigator: Amy B. Chan-Hilton **Co-PIs:** Gang Chen, Wenrui Huang, Michael Watts, Ming Ye, Paul Lee

Description: The goal of this project is to develop tools and conduct research to objectively assess environmental and water resources needs and constraints of fuel cycle and energy production systems. The objectives of this project are to:
1. Analyze environmental and water resources demands and potential impacts, specific to Florida's unique geographical challenges, of fuel cycle systems.
2. Develop an objective environmental impact screening and evaluation tool for energy planning and policy making.
3. Provide outreach to industry, utilities, government for discussion and better-informed decisions on energy strategy, regulation, and permitting.
4. Provide training on "Energy and the Environment" to ensure environmental stewardship without sacrificing energy production.

Budget: $118,470

Progress Summary

Received our project budget number recently (on April 7, 2009).
Submitted a Pre-Application to the US DOE/USDA Biomass Research and Development Initiative (Funding Opportunity Number: DE-PS36-09GO99016) in March 2009.
Title: Comprehensive Systems Analysis of Biofuels: Environmental Impacts, Energy, Economics and Sustainability.
PI: Amy Chan-Hilton (CEE). Co-PIs: Gang Chen (CEE) Julie Harrington (CEFA), Wenrui Huang (CEE), R. Mark Isaac (Economics), Michael Watts (CEE), and Ming Ye (SCS).
Requested budget: $1,849,031 (4 years)

Will submit a full application (invited) to the Florida Department of Environmental Protection (FDEP) Hinkley Center for Hazardous and Solid Waste in May 2009.
Title: Usage of Microbial Fuel Cell Technology to Prevent Iron Release nearby Landfills in Northwest Florida
PI: Gang Chen (CEE). Co-PIs: Amy Chan Hilton (CEE), Kamal Tawfiq (CEE)

Progress made toward deliverables:
We are in the first phase of Task 1 of this project. We are conducting literature reviews on how a wide range of energy production technologies (e.g. biomass, nuclear, renewable, fossil fuel-based), and when possible energy distribution systems, affect our environmental resources and quality will be conducted. This includes impacts on the potential contamination of water, soil, and air, demands on water resources, ecosystem and human health, and emissions of greenhouse gases.

Florida State University

Planning Grant: Climate modeling and outreach activities

PI: Shawn R. Smith
Co-PIs: Steve Cocke, David Zierden, James O'Brien, Julie Harrington

Description: The objective of this proposal is to develop at least one external funding proposal that focuses on areas of climate modeling and/or climate outreach that support the activities of the Institute for Energy Systems, Economics, and Sustainability (IESES).

Budget: $15,000

Progress: Over the first six months of the planning grant, the co-investigators have been assessing presently available information regarding off-shore wind power generation potential around Florida and in the Eastern Gulf of Mexico. According to previous research conducted by the Lawrence Berkeley National Laboratory and Navigant Consulting at the request of Florida's Public Service Commission, offshore wind has "large technical potential" in Florida, and certain sections off the northeast and northwest panhandle are economically sustainable. About 40,000 Megawatts (MW) of offshore power were identified, enough to power ~2.6 million homes and about four times the current installed capacity of wind energy in the U.S. Coastal wind (within 300 m of the coast) was also recognized as a marginally economically viable wind resource, with a potential power of 186 MW (~120,000 homes). However, this study and similar research have largely been based on climate data from land-surface and upper air meteorological observations, and little information is known about offshore wind power and its dependence on mesoscale processes or the impact of coastal circulations, like sea and land breezes, on coastal wind power. Taking advantage of COAPS expertise in marine climatology and our access to a number of off-shore observing sites, we believe we are in a good position to assess the potential for wind power in the offshore and near-shore regions around Florida. In particular, tower N7 – with a suite of weather instrumentation deployed by FSU as part of the Northern Gulf of Mexico Institute- is uniquely sited, and can collect wind measurements at a height similar to most standard offshore turbines.

In Fall 2009, we initiated a pilot study that will examine the offshore climate data to compute the annual wind resource and its seasonal variability at a few select stations. We will compute the wind power density by summing the product of the air density and the cube of the hourly wind speed. The hourly wind speed is estimated at the turbine hub height so we will be using stability-dependent surface layer wind height relationships that were developed by Prof. Mark Bourassa for the FSU marine flux program at COAPS. Once that is completed the next step will be to evaluate regional scale models to see how well they capture the wind climate at the station locations. If the pilot study shows potential based on selected stations, a fullscale study will be proposed to an appropriate state or federal agency.

Scope of effort:
The evaluation of offshore and near-shore wind power potential falls under one of the potential topic areas outlined in our IESES statement of work:

Developing a high-resolution wind climatology for application to wind power generation Initial results for N7 indicate the potential to scale up to a full proposal. If possible, we will incorporate economic and environmental assessments, marine geospatial planning, and outreach components into the proposal. Determining the viability of offshore and near-shore wind power will target FESC and IESES goals to expand economic development in sustainable energy industry in Florida. The results will provide policy

makers with essential information to determine which offshore regions are suitable for wind energy production.

Progress and plans:

To date the co-investigators have conducted the background research on wind power potential and available offshore wind products with the assistance of Dr. Mark Powell from NOAA's Atlantic Oceanographic and Marine Laboratory (currently stationed at COAPS). Dr. Powell is an unfunded collaborator with a broad interest in sustainable energy development. We have initiated the pilot study by employing an undergraduate meteorology student to assess the wind power potential at tower N7 in the northern Gulf of Mexico. A preliminary assessment of the hourly winds from N7 shows that sufficient wind exists for near-shore power generation in Apalachee Bay. We must confirm the results and conduct the comparison to available wind climatologies from models. This analysis will be complete by December 2009. Submission of a full proposal to develop improved offshore wind climatology will be developed and submitted in late 2009 or early 2010, once a suitable RFP is identified.

Florida State University
Visiting Law Professor

PI: JB Ruhl and Jim Rossi, **Co-PIs**: Uma Outka

Description:
The visiting law professor will conduct research and prepare a series of reports suitable for distribution to the Legislature and to Florida local governments on four topics:
(1) Land use codes to identify provisions and practices that either facilitate or impede the location of renewable energy production facilities, etc.
(2) Florida state and local government comprehensive plans, other policy statements, and land use litigation to identify the primary policy trade-offs associated with the location of renewable energy production facilities
(3) Other states' government land use codes to identify "best practices" for facilitation of the location of renewable energy production facilities, with particular attention to how those best practices respond to the policy trade-offs
(4) Then draft model local legislation designed to most effectively allow Florida local governments to facilitate the location of renewable energy production facilities and other innovative or new energy infrastructure consistent with State policy taking into account economic, social, environmental, and geographic variables.

Budget: $214,603

Progress Summary

None Reported

Florida State University

Reliable and Resilient Electrical Energy Transmission and Delivery Systems

PI: Steinar Dale
Co-PIs: Mischa Steurer, Kamal Tawfiq, Rick Meeker, Horatio Rodrigo

Description: The project goal is to address the challenges of the reliable movement of electrical energy throughout the state as the power system is transformed to include far more renewable and alternative sources, increased use of distributed energy resources and microgrids, possible expansion of new very-large centralized baseload (nuclear), and incorporation of new power conversion, transmission, measurement, communication and control technologies. In addition, the system must continue to accommodate future demand due to population growth and expanded use of electrical power (including the possibility of more widespread electric transportation), continue to improve ability to survive and recover from extreme events, and deal with increasingly constrained siting options for generation, transmission, and distribution systems.

Budget: $431,982

Progress Summary

No progress reported.

Florida State University

Energy and Efficiency Video Public Service Announcements

PI: Andy Opel, **Co-PIs:** Phil Steinberg, Leslie France-Patterson, Laura Arpan, Ian Weir

Description: This interdisciplinary team will produce 6-8 short (30-second/one-minute) video public service announcements (PSAs) that address issues of energy and efficiency and one 12-15 minute informational documentary targeted to Florida legislators and the Governor's office. These videos will be tailored to reinforce existing IESES efforts.

Budget: $200,720

Progress Summary

Beginning in January 2009, our five member faculty team began meeting, with the addition of two quarter time doctoral graduate students funded by the grant; Jia Lu from Communication and Adam Keul from Geography. Laura Arpan and Jia Lu assembled an up to date literature review of research in the area of communication campaigns and environmental communication/persuasion. A summary of this work was presented to the group in late February 2009, with the goal of shaping the message strategy that would be emphasized in the PSAs.

Arpan and Lu then went on to develop a survey questionnaire to be administered to a random sample of Florida residents. This survey data will serve as baseline data as we begin message testing specific PSAs. Data from the survey was collected in May 2009 and analysis of that data is on-going. In addition, Arpan established partnerships with the Yale Project on Climate Change and the Center for Climate Change Communication at George Mason University. These partnerships include data sharing and survey question collaboration.

Based on the communication research aggregated by Arpan and Lu, Opel, Steinberg, France-Patterson, Weir, and Keul brainstormed PSA ideas resulting in over 20 potential PSA videos. This list was narrowed down to the top eight concepts through consultation with Arpan and Lu. Production plans were developed for each concept, including locations, costumes, cast, script, storyboards and props. Production plans included variations within each PSA that will allow for message testing in the fall of 2009.

In May 2009, four PSAs were shot. In June, rough cuts of 3 PSAs were assembled. In July and August, two more PSAs were shot, with post production scheduled for September.

Deliverables
Power point presentation summarizing recent research on influencing audience attitudes and behavior.
Three rough cuts of original PSAs.
Three PSAs in production or post-production.
Two PSA concepts in pre-production.
Energy efficiency attitudes data from 400 person survey of Florida residents.

Scholarship
Andy Opel attended the Full Frame Documentary Film Festival in Durham, NC, April 2-6, 2009 where he took part in the Full Frame Fellows Program that connects filmmakers with producers, funders and distributors.

Andy Opel presented rough cuts of two PSAs as well as some of our initial findings from the research literature at the Conference on Communication and the Environment, Portland, ME, June 27-30, 2009.

External Funding Initiatives

Opel, Arpan, and Steinberg have been in close contact with Scott Minos from the US Department of Energy over a proposed Center of Excellence in Energy Information and Communication. We have a revised draft of a proposal that we have developed with the assistance of Scott Minos and he recently circulated a white paper that will eventually serve as the basis for an RFP from the DOE. We also met with Chuck McClure and Chris Hinnant from the Information Institute in the College of Communication and Information and they have agreed to be active partners in pursuit of the CoE.

Adam Keul developed a list of potential funding sources, ranked by applicability. From the list, we submitted a grant application to the Mazda Foundation for $25,000 in June. We have not heard anything back on this application.

Florida State University

Planning Grant: Enhanced Thermal Performance and Microstructure Simulation of Nuclear Fuels

PI: Justin Schwartz

Description: The objective of this proposal is to perform preliminary investigations to determine the viability of improved oxide nuclear fuels through high thermal conductivity coatings such as "BeO." To meet Florida's sustainable energy demands, we will pursue the option of enhanced oxide nuclear fuel performance by considering the potential for improved thermal behavior through high thermal conductivity oxide coatings. This work will include a literature search of past investigations of the impact of enhanced thermal conductivity on nuclear fuel and reactor performance, the temperature and irradiation dependence of the thermal conductivity of BeO and other high thermal conductivity oxides, the chemical and thermal compatibility of BeO and nuclear fuels (UO2, PuO2, ThO2 and MOX), and initial studies into BeO coatings on HfO2 particles, where HfO2 serves as a benign surrogate for nuclear fuel oxides. We will conduct an evaluation of possible coating processes and measure their thermal behavior. We will use these findings to pursue external funding.

Budget: $15,000

Progress Summary

No progress reported.

Florida State University

Development of a Renewable Energy Research Web Portal

PI: Charles R. McClure, **Co-PIs**: Ian Douglas, Chris Hinnant

Description: This project will identify, organize, and make available via a web portal, research generated as part of the FESC effort as well as other selected related information resources and tools as identified by FESC participants. The primary tasks to be completed in this process include:
Conduct needs assessment of IESES and FESC energy researchers and related experts to determine (1) the most important content to be included in the web portal, and (2) preferences to be considered in the design of and applications for the web portal;
Identify and obtain relevant energy research information from IESES and FESC and other sources as appropriate;
Develop a web portal such that identifies, organizes, and accesses energy research information;
Field test and conduct usability, feasibility, and accessibility testing on web portal; The goal of this project is to provide IESES, FESC researchers, and others in the state of Florida with the research information they need to accomplish statewide energy goals and to help IESES meet the thirteen objectives it has undertaken by providing access to research information.

Budget: $194,542

Progress Summary

The project team designed the study to include five tasks: 1) gather background information pertaining to renewable energy research, 2) conduct needs assessment, 3) design and develop renewable energy web portal, 4) evaluate the renewable energy web portal, and 5) disseminate and publicize the renewable energy web portal. In the first six months of the project, the project team has completed the first task, and work on tasks 2 and 3 is ongoing. The project team will undertake evaluation, dissemination, and additional publicity in the next several months. Table 1 lists the tasks that have been completed to-date for each phase of the project.

Table 1. Summary of Completed Activities by Task

Tasks	Activities
Gather background (4/15/09 to 5/27/09)	Review and refine project tasking
Conduct literature review	
Create sampling frame	
Conduct needs assessment (5/28/09 to Ongoing)	Develop data collection instruments
	Survey deployment: recruitment letter mailed
	Follow up emails requesting survey completion
Expert interviews conducted	
Design and develop Web portal (4/15/09 to Ongoing)	Develop Beta versions of the portal and related applications
	Begin collecting data to populate the project database
	Begin collecting data to populate the event calendar
Begin collecting content resources	

2009 Annual Progress Report

During the first six months of the project, the study team conducted a number of activities to address the project tasks, including the following:

Task 1: Gather Background Information Pertaining to Renewable Energy Research
The project team completed a preliminary literature review. The review covers the following areas:
1. Cyberinfrastructure; and
2. Information seeking behavior of scientists, engineers and researchers.

The project team used information collected and analyzed during the literature review in development of the needs assessment activities and initial design phase of the web portal.

Task 2: Conduct Needs Assessment
The project team is in the process of conducting a systematic assessment of the specific information to be included in the web portal. The needs assessment includes the identification of key materials and research information concerning renewable energy from subject matter experts. The project team has completed the following activities:

1. *Identify IESES and FESC researchers and resources and catalog the type of research that they are conducting*: The sampling frame developed from this process included scientists, engineers, and social scientists from many disciplines who conduct research related to renewable energy;
2. *Pinpoint specific IESES and FESC researchers to target for follow-up interviews*: The project team is using data gathered from interviews to provide more detailed contextual information regarding how researchers use information in their research activities and their preferences regarding online information sources;
3. *Develop a survey instrument designed to assess how renewable energy researchers seek and use information and to determine preferences that will guide the building of the web portal*: The project team designed the survey instrument using information obtained from the literature review;
4. *Implement an online survey of the renewable energy researchers*: On May 28, 2009, the project team mailed 263 recruitment letters to IESES and FESC researchers and as of October 15, 2009, the project team has logged 105 respondents (40% response rate) with the survey still open and respondents continuing to participate;
5. *Conduct follow up expert interviews in order to determine other information resources, applications, and interactive services that these researchers perceive to be important for inclusion in the web portal*: The research team completed nine interviews with IESES and FESC researchers from universities such as Florida State University, the University of Florida, University of South Florida, and Florida Atlantic University and interviewing continues;
6. *Contact recruited researchers who have not taken the survey*: The project team has sent several rounds of email reminders and conducted follow-up phone calls; and
7. *Prepare a preliminary analysis of the needs assessment*: The research team is using this data to inform portal development efforts.

Work on task 2, the needs assessment, continues into the next six-month period. Data from the completed data collection efforts is currently being used to develop academic research articles pertaining to the development of online research portals and the information seeking and use behaviors of renewable energy researchers.

Task 3: Design and Develop Renewable Energy Web Portal

The development of the web portal is ongoing. Activities associated with this task that the project team has completed include the following:

1. Initiate design of the web portal based on findings from the needs assessment activities;
2. Build an initial development, or Beta version, web portal with representative content, links, and interactive applications that meet the developed criteria for inclusion in the web portal and include the following components:

a. A website that introduces the project goals and background; and
b. Four portal applications, including:

i. A searchable geo-coded Florida renewable energy project database that includes information on research projects and research centers, is linked to a map, and can be searched by keyword and browsed by category;
ii. A renewable energy events calendar containing information on renewable energy conferences, symposia, and seminars;
iii. A researchers database designed to connect renewable energy researchers; and
iv. An articles database that researchers will annotate;

The first two applications (the projects database and the events calendar) were included in the original design of the project. The latter two applications (the researchers' database and the articles database) were designed proactively in response to feedback from FESC and IESES researchers obtained during the needs assessment.

3. Collect content for the portal, including:

a. Information to populate the Florida renewable energy project database;
b. Information to populate the event calendar;
c. Resources derived from renewable energy researchers during the needs assessment research.

Work on task 3, portal design and development, continues into the next six-month period. Appendix A includes selected screen shots of the Beta version of the project website and web portal applications.

Detailed Next Steps

In the next phase of the project, the project team will complete the needs assessment and portal development, and begin the portal evaluation and dissemination tasks. Specific next steps for the project include:

1. Send a final reminder to recruited researchers who have not participated in the survey;
2. Complete a full analysis of the needs assessment and disseminate findings to the project team;
3. Evaluate and adjust the Beta versions of the web portal and all related components;
4. Conduct usability testing of the Beta version of the web portal and analyze the data collected during these tests;
5. Revise and expand the web portal as indicated by the usability analysis;
6. Complete task 4, evaluation of the renewable energy web portal activities, including:

a. Conduct focus groups and surveys of users to determine the extent to which the portal allows them to better manage and access renewable energy research;
b. Assess whether the web portal facilitates increased IESES and FESC researcher productivity;
c. Determine whether the web portal allows FESC to better leverage and share resources and funding;
d. Examine the extent to which the web portal provides researchers and policy makers valuable information to make decisions regarding the future uses and development of renewable and alternative energy in Florida; and
e. Assess the degree to which the project contributed to obtaining additional external funding; and

7. Begin task 5, dissemination and publicity of the renewable energy web portal, including:

a. Develop and implement a publicity plan to increase knowledge and awareness of the web portal.

b. Attended and made a research presentation at the 2009 FESC Summit at the University of South Florida in Tampa, FL (September 30, 2009).
c. Obtain external support to maintain and expand the web portal. The preliminary plan for obtaining support includes:
i. Write a letter of inquiry to pursue funding from the Alfred P. Sloan Foundation to expand the scope of the web portal;
ii. Develop a grant proposal to be sent to the National Science Foundation Office of Cyber infrastructure (OCI) with a proposal to expand the portal's focus from Florida to the entire United States;
iii. Develop a grant proposal to Department of Education focused on disseminating renewable energy information to the public.
d. Write final project report and project-related articles for publication.

The project team has completed task 1 in the first six-month period, is continuing work on tasks 2 and 3 and beginning work on tasks 4 and 5 in the next six-month period.

Summary

During the past six months (March 12, 2009 – September 15, 2009), the study team organized the project, collected and analyzed data, and began web portal development efforts. In the next six months of the project, the study team will focus on data analysis and portal development, with a goal of launching and publicizing the live web portal. The study team has made substantial progress and remains on schedule.

FESC
Florida Energy Systems Consortium

Florida State University

Promoting Energy and Land Use Through Land Use, Transportation and Green Infrastructure Polices

PI: Tim Chapin; **Co-PIs**: Ivonne Audirac, Jeff Brown, Chris Coutts, Jeffrey Lowe, Greg Mark, Melanie Simmons, Horner Thompson

Description: This project is aimed at continuing the momentum in Florida for developing broad-based solutions to these problems by helping to develop a knowledge base for informing state policy in the areas of energy, sustainability, and land use and transportation planning. Teams of researchers will generate "issue papers" in four areas of inquiry and report their findings via events that inform legislative leaders, state agency staff, and local government officials as to how energy sustainability objectives can be achieved through transportation, land use, and green infrastructure programs.

Budget: $177,460

Progress Summary

The project began in May 2009 and will continue through the end of the spring 2010 semester. During the summer 2009 term the research team worked to review the current state of knowledge in the issue areas and to develop a resource base to inform this work. A project Blackboard site was created and has been utilized as a common pool resource for the team. Under direction of the PIs, two graduate students were hired during the summer to obtain and review materials. In fall 2009 the project moved onto the next phase, including bringing on board two new graduate assistants, initiating a review of state and local energy and climate change policies and beginning to outline the report. We have also begun identifying potential outside funding sources for future work.

Linkage to IESES Priorities and Core Mission

The IESES mission statement reads that the "primary mission is to provide Florida and the country with up-to- date and pragmatic tools and analysis to assist in meeting challenges, and to forge new opportunities for an unprecedented energy and climate constrained era." This research project directly serves this mission in that the project report will inform public officials and elected officials about the breadth and form of the policy options available to them. In terms of the objectives and thrusts of the IESES initiative, this project specifically targets Objective 2 (Assisting Florida's Governing Bodies) and Thrusts #5 and #6 (Enhancing Energy Efficiency and Energy System Environmental and Economic Impacts). This research project contributes directly to the IESES objective to "assist Florida's governing bodies in the successful development and implementation of a comprehensive, long term, environmentally compatible, sustainable, and efficient energy strategic plan for the state".

Key Accomplishments to Date

Developed a Blackboard website for course materials
Houses relevant reports, articles, and chapters
Houses summaries of key literatures
Reviewed the substantial (and growing) literatures revolving around transportation, land use, and green infrastructure.

Chapin presented at the Transportation System Strategies to Reduce Greenhouse Gases (GHG) In Florida That Support Healthy Communities event in May 2009, hosted by the Florida Departments of Transportation and Health and 1000 Friends of Florida. The talk was entitled: Planning's Wicked

Problems: The Search for Solutions to our Transportation, Land Use,Environmental, and Community Health Challenges.

Chapin, Audirac, and Coutts presented a project overview to the State Agency Smart Growth Committee in October 2009. The members of this committee agreed to serve as members of Technical Advisory Committee for the project.

Begun to identify possible funding sources for continued research in the project area (NSF, state agencies, local governments)

Project Technical Advisory Committee Agency Membership
Florida Department of Community Affairs (agreed); Florida Department of Environmental Protection (agreed); Florida Department of Transportation (agreed); Florida Department of Health (agreed); Florida Department of Elder Affairs (agreed); Florida Governor's Energy Office (invitation to be made); 1000 Friends of Florida (invitation to be made); Association of Florida Community Developers (invitation to be made); Florida Home Builders Association (invitation to be made); Florida Regional Councils Association (invitation to be made)

Florida State University

Marketing Strategies to Incentives Entrepreneurship and Innovation in the Development of Sustainable Energy

PI: Joe Cronin

Description: The objective of this project is to investigate the role of market pull strategies in advancing sustainability goals. Specifically, the intent is to identify what "drives" consumers' attitudes and behaviors relative to sustainable products. This includes consumers' personal attitudes, opinions, and beliefs, their perceptions of their own and organizations' abilities to affect or change the environment in which they live, and their personal characteristics (e.g. demographics). In addition, in collaboration with the College of Communications, the strengths and weaknesses of the various modalities that can be used to deliver sustainability knowledge to consumers (e.g. advertisements, testimonials, expert word-of-mouth communications, public relations, publicity, etc) will be assessed. Specifically, the research will attempt to identify the optimal market pull modality; that is, the means by which to deliver to consumers the knowledge that drives the purchase of sustainable goods and services. The overall objective of the research is to provide much needed market pull information for organizations embarking on "green" marketing strategies; that is, firms in the process of developing or expanding their mix of environmentally friendly goods and services.

Budget: $191,555

Progress Summary

The specific intent is to provide deliverables, including published conference papers, journal articles, presentations, and other modes of educational knowledge transfer. To date, as is reported below, the research team has published conference papers, made conference presentations, and embarked on specific knowledge transfer activities. Specifically, four conference papers have been published, six presentations have been given, a website has been developed, a special session at 2010 AMA Winter Educator's Conference, Sustainability in Action: a professional and practitioner-oriented conference is planned for Spring 2010, and numerous journal articles are in preparation.
In addition to the tasks noted, the Research Team initiated contact through Dean Caryn Beck-Dudley of the College of Business relative to securing additional funds to support sustainability research. Contact was made with the City of Tallahassee Utilities Department and their support was received for both research projects and the Sustainability in Action conference. At the suggestion of the Dean, we are engaged in an effort to secure the support of private resources for sustainability research. Specifically, the Research Team is engaged in an ongoing effort to meet with and develop a relationship with Interface, a world leader in the manufacture of sustainable commercial carpeting. Interface has made major donations to several U.S. educational institutions to support sustainability business research and are actively seeking additional research partners.

Task 1: Documenting Sustainable Business Practices
Progress Update:
Center for Sustainability Initiatives website is approved per FSU College of Business standards and operational: csi.cob.fsu.edu
Green marketing literature is collected and will be loaded onto csi.cob.fsu.edu Fall 2009
Information collected on local and regional sustainability-oriented businesses

The Research Team plans to attend the University of Kentucky Sustainability Center Conference in December 2009

Task 2: Benchmarking Sustainability Practices
Progress Update:
Best Practices materials collected and currently stored electronically for placement on the Center for Sustainable Initiatives website
These Best Practices materials will be continuously updated to reflect the growing interest in sustainability

Task 3: Developing a Florida Sustainability Research Panel
Progress Update:
Sustainable Consumer Research Panel online participant collection website created and approved form letter developed and approved by the College of Business have received approval from FSU Foundation for use of Alumni mailing list to secure initial panel participants approval received to contact current College of Business iLab participants for participation in the Sustainable Consumer Research Panel. Research panel to be operational by end of Fall semester 2009

Task 4: Florida Sustainability Index
Progress Update:
Created Sustainability Index using established scales and will be implemented as part of the ongoing research related to the sustainability panel

Task 5: Development of One-Two Day Sustainability Seminar
Progress Update:
We are in the preliminary planning stages of creating the Sustainability in Action conference a professional and practitioner-oriented conference
The conference is tentatively planned for early Summer 2010

Task 6: Development of Sustainability Marketing Class
Progress Update:
After reaching out to faculty members at other institutions, we have proposed to teach this course in either the new MS in Marketing program or as an elective at the undergraduate-level

Task 7: Consumer perceptions of sustainable firms: a qualitative approach
Progress Update:
Against the Green: A Examination of Non-Green Consumers accepted for publication at 2010 AMA Winter Educators Conference, New Orleans, LA
Transumers: Motivations for Non-Ownership accepted for publication at 2009 ACR North American Conference, Pittsburgh, PA
Holistic Green Behavior: The Impact of Lifestyle on Sustainable Practices in progress with an expected completion date of December 2009

Task 8: Consumer motivations for sustainable purchasing
Progress Update:
Segmenting Non-Green Consumers: Discovering Consumer Motivations for Non-Green Purchasing with an expected completion date of October 31, 2009
Shades of Green: Profiling Florida's Green Consumption with an expected completion data of November 2009

Task 9: The impact of sustainability messages on perceived product quality
Progress Update:
The Role of Eco-Labeling on Consumer Behavior Intentions presented at 2009 Academy of Marketing Science World Marketing Congress in Oslo, Norway and 2009 FESC Summit in Tampa, FL
An Investigation of the Effects of Perceived Environmentally Responsive Organizations on Consumer Perceptions of Quality and Satisfaction with an expected completion date of December 2009

Task 10: Consumer motivations for sustainable purchasing
Progress Update:
The Affects of a Firm's Perceived Environmental Orientation and Familiarity on Consumer Perceptions. Specifically, this research investigates whether brand familiarity is detrimental to positioning green products if consumer perceptions of the brand are already established as being non-green. The expected completion date for this research is December 2009

Task 11: The impact of regret on sustainable purchase intentions
Progress Update:
Project on-hold until completion of other tasks

Task 12: Consumer motivations for sustainable purchasing
Progress Update:
A dissertation entitled, Three Essays on Sustainability, is currently being completed. Specifically, data for Essays 1 and 2 has been collected and IRB approval sought for further research

Task 13: Co-creation of eco-efficiencies: The role of shared values in sustainability initiatives
Progress Update:
Collaborative research project underway with an expected completion of December 2009. Specifically, the goal of this project is to collect data from a sustainable firm to develop an understanding of how firm objectives impact consumer perceptions.

Task 14: Customer as partners in corporate sustainability: How does voluntary performance of pro-social behaviors impact perceived service quality
Progress Update:
Research on-hold pending Research Panel completion

Task 15: The role of employees in promotion and adoption sustainable behaviors
Progress Update:
An Examination of Shared Values: How do Firms Influence Employee Attitudes toward Sustainability. Literature review in progress.

Task 16: The role of transparency on the adoption of sustainable practices
Progress Update:
Knowledge Matters: The Impact of Knowledge and Message Framing on Attitudes toward Sustainable Behavior. Research completed with a planned revision

Task 17: Online social networking: The influence of others on consumer adoption of sustainable practices
Progress Update:
Literature review and instrument completed. Waiting on final panel implementation to complete research.

Florida State University

Energy Sustainable Florida Communities

PI: Richard Fieock**, Co-PIs:** Ivonne Audirac, Keith Ihlanfeldt

Description: The objective of this proposal is to develop an energy sustainability index to measure local governments' adoption and capacity to implement energy policy innovations in response to the provisions of new energy legislation in Florida. This measure will be applied to investigating factors influencing local government energy policy decisions and be disseminated to research and governmental decision-makers. The following tasks are proposed to FSU for funding: archival data collection; survey of local governments; construction of a Florida Sustainable Communities web site; statistical analysis, hold a workshop on sustainable energy governance in local government; preparation of reports; papers journal manuscripts and grant proposals.

Budget: $125,424

Progress Summary

RESERACH ACIVITIES:
1) Local Government Institutions and Turnover. RAs Lee and Ha have been collecting longitudinal data from Florida League of Cities and FL Association of Counties, ICMA, and online municipal codes .
2) Compilation of Information of State Energy Policy Environment. PI Audirac and RA Spector have been working on a report on state energy policy relevant to local governments
3) Survey Instrument. The Project Team was met on a weekly basis for the past two months to design the first survey instrument that will be directed to city, county and school district planning officials.
4) Proposal Preparation. PI Feiock is preparing a proposal to the NSF Political Science Directorate August 15th target date. PI Audirac is preparing a proposal for the NSF Innovation and Organizational Sciences Program September 3rd target date.

OUTREARCH/INSTRUCTION ACTIVITIES:
1) Florida League of Cities and FLCIR. In June PI Feiock met with representatives of FLC and LCIR to brief them on our project and to coordinate activities.

2). Consultation with CGLFE. The Project Team met with Robert Lee, the Director of the of The Center for Florida Local Government Excellence. We discussed cooperative actions including a Webinar with on Local Government Sustainability and Energy Conservation and a workshop for local government managers on sustainability to be held in South Florida.
3) Mentoring. In addition to the funded RAs two fellowship supported doctoral students Yi (University Fellow) and Kassekert (DMC and NSF Dissertation Improvement Grant Awardee) have volunteered their time and are working closely with PI Feiock and the project and proposals and they are included as co-authors of forthcoming presentations at the American Political Science Association.

PUBLICATIONS/PRESENTATIONS
Mark Lubell, Richard Feiock and Edgar Ramierz. "Local Institutions and the Politics of Urban Growth," with Mark Lubell and Edgar Ramirez, American Journal of Political Science 53(3): 649-665, 2009.

Florida State University

Innovative Proton Conducting Membranes for Fuel Cell Applications & Protein Enhanced Proton Conduction Membranes for Advanced Fuel Cells

PI: Ongi Englander, **Co-PIs:** Anant Paravastu, Anter Al-Azab, Subramanian Ramakrishnian

Description: The objective of this proposal is to establish new research directions in the development of proton conducting materials for fuel cell applications. We will build novel high surface area silica particle based membranes as supports, and infuse in them newly discovered proton conducting protein nanomaterials as well as oxide-based nanocomposites. In order to test electrical transport mechanisms, we will build microfabricated electric testing structures, and subsequently integrate materials with fuel cell test setups.

Budget: $30,000

Progress Summary

Task 1: Fabrication of silica and latex-supported membranes and oxide- based nanocomposites
To help carry out this work, two students so far have been recruited – 1) Erin Holley: a graduate student (masters) has started school at FSU in the newly formed materials science and engineering department. Erin was an undergraduate at FSU in the department of chemical and biomedical engineering whom we have convinced to stay on and pursue graduate school due to her interest in the proposed research. 2) Mayra Gonzalez: A Junior in chemical and biomedical engineering has started working in our labs to help characterize the membranes and is working with Erin Holley. Recruiting these two students we feel is a key step forward in the project.
Experimental setup of equipment for gas and water permeability:
A considerable amount of time was spent by Erin in overcoming difficulties and in setting up the equipment for gas and water permeability measurements (Figure 1). Commercial membranes were then successfully characterized using the above equipment (Figure 2). Thus, we now have the capability to characterize membrane pore size and water permeability's in our capabilities and this will play an important role in characterizing the membranes.

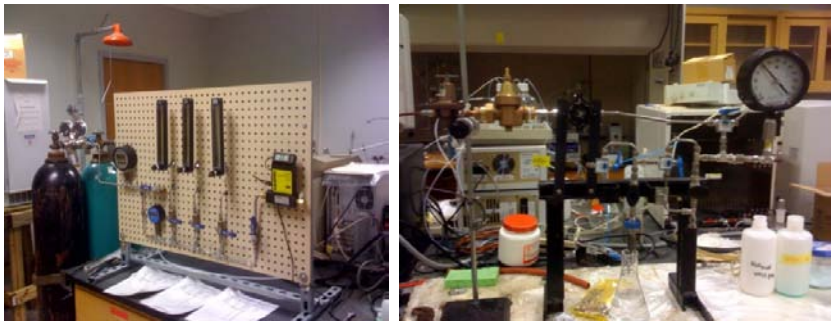


Figure 1: Experimental setup to measure pore size distribution and water permeability of membranes.

FLORIDA STATE UNIVERSITY

Planning Grant: Advancing Knowledge of Network Theory for Analysis and Design of Smart Power Grids

PI: Svetlana V. Poroseva **Co-PIs:** Yousuff Hussaini, Per Arne Rikvold

Description: With power grids evolving towards increasing size, complexity, and integration, it has become more difficult to describe and predict their behavior, even under normal operational conditions. With technological development, climate change, and activities in the political arena, adverse circumstances (natural disasters, intelligent adversary, software design errors, human errors, etc.) have become more probable and costly events. The Project seeks to provide industry and government with advanced analytical and computational tools necessary for the automated evaluation of the structural resilience and reliability of power grids. The potential applications of the Project's results go beyond power grids. Any infrastructure essential to our society and economy (e.g., computer, communication, transportation) can benefit from the Project's results.

Budget: $15,000

Progress Summary

1. Proposal "Advancing Knowledge of Network Theory for Analysis and Design of Power System Architectures Resilient to Massive Damage" was submitted to NSF with the budget of $598,191 (PI: S. V. Poroseva, Co-PIs: P. A. Rikvold, M. Y. Hussaini)

2. Literature review for future proposals has been conducted to identify the state-of-the-art in the areas of i) power system resilience, ii) integration of power and communication systems, and iii) network analysis in application to power systems

3. Contacts of Possible Collaborators

Dr. S. V. Poroseva discussed possibilities for future collaboration visiting Departments of Mathematics and Electrical and Computer Engineering, Purdue University, and participating in the following project-related meetings The 2009 ESRDC Team Meeting, Mississippi State University, May 26-28, 2009 The FREEDM Systems Center Conference, Raleigh, NC, May 18-19, 2009 The IEEE Electric Ship Technologies Symposium, Baltimore, MD, April 20-22,2009

The visit and meetings participation was supported from sources other than IESES.

4. Undergraduate and graduate student education and research

Dr. S. V. Poroseva has been advising R. Ford, undergraduate student from the Electrical & Computer Engineering Department, in Spring, Summer, and Fall 2009 on the integration of power and communication systems. The research of the student was supported by IESES.

Prof. P. A. Rikvold has been advising B. Israels, undergraduate student from the Department of Physics, in Summer and Fall 2009 on the network analysis in application to power systems. The research of the student was supported from sources other than IESES.

Prof. P. A. Rikvold and Dr. S. V. Poroseva were advising A. Williamson, undergraduate student from the Department of Physics, in Spring 2009 on the network analysis in application to power systems. The research of the student was supported from sources other than IESES.

A. Williamson participated at the first annual Physics Department Undergraduate Research Poster Session on April 2, 2009, and presented her poster "Topology of Power Grids" there.

Conference paper "Computational Analysis of the Network Survivability due to its Topology" by S. V. Poroseva, R. Ford, and M. Y. Hussaini was submitted to International Workshop on Reliable Networks Design and Modeling.

Planned Activities:

1. Proposal submission
2. Visit of granting organizations (December, 2009)
3. Advising two undergraduate students: R. Ford and B. Israels (Fall 2009)
4. Invited presentations at Graduate Student Seminars (Fall 2009)
5. Participation in three professional meetings (Fall 2009)

FLORIDA STATE UNIVERSITY

Establishment of the Center for Marine Bioenergy Research: Systems Approach to BioEnergy Research (SABER)

PI: Joel E. Kostka
Co-PIs: William Cooper, Ivonne Audirac, Amy Chan-Hilton,Ellen Granger

Description: This proposed SABER research center will blend fundamental and applied research to: 1. Develop sustainable, biologically-based fuel alternatives and renewable energy strategies.
2. Capture, recycle or clean up environmental pollution (greenhouse gases, excess nutrients) associated with energy production and use. Equally important to our research goals will be partnering with public and private institutions to immediately implement our research for the benefit of society. Biosolutions will be rapidly incorporated into the solid waste treatment and power plant industries. We will partner with the other IESES groups to promote awareness that the nearterm realization of clean, cost-effective energy alternatives will occur only through a multidisciplinary systems-based approach from research to planning and implementation. We will assure sustainability by assessing the environmental impacts and promoting the mitigation of those impacts of alternative energy technologies on the geosphere.
The centerpiece of the proposed project will be the development of sustainable practices for the production of transportation fuels from algal biomass feedstocks. Algal cultivation practices will also be incorporated into industrial processes such as CO2 capture and sequestration from coal-fired power plants and wastewater treatment.
The project will create a consortium of scientists from FESC, the Oak Ridge National Laboratory (ORNL), and the Midwest Research Institute of Palm Bay, Florida. State-of-the-art R&D facilities will drive consortium efforts: an off-grid, zero emissions algal cultivation facility at the FSU Coastal and Marine Laboratory (FSUCML), a biomass characterization facility in FSU's Chemistry department, a marine bioprospecting/ biomass conversion facility in FSU's Oceanography department, and a freshwater bioprospecting, algal cultivation and biomethanation facility at UF's Soil and Water Science department.
The proposed program is projected to create 30 undergraduate research fellowships, 15 graduate student assistantships, 8 Ph.D. level positions, 5 technician positions, 10 temporary construction jobs, and 3 highly skilled positions in the biotech work force. Undergraduate and graduate research fellowships will be offered in the natural sciences, engineering, and the social sciences at the host institutions.
Oak Ridge National Laboratory (ORNL) personnel will aid by training students through internships in next generation biotechnology and bioengineering skills, thereby enhancing the skilled workforce to build the energy industry in Florida.
The Midwest Research Institute (MRI) in Palm Bay, Florida, currently supports 6 positions in algae-related research. We expect to double their workforce in this area. MRI will provide optimization and application of harvest and extraction methods to the cultivation facilities and integrated process engineering.
The project will stimulate rural development in Franklin County, Florida, where the FSUCML is located. Architects and construction workers will be employed to build the state-of-the-art, algal cultivation facility. Permanent technicians and engineers will be employed to run the facility. Graduate students will be in residence at the FSUCML to complete their research. Federal, private, and international funds will be sought out to continue to support these positions.

Budget: $494,135

Progress Summary

This project began a little over 6 months ago. The primary metrics as articulated in the Memorandum of Agreement were the recruitment of graduate students, contacts with the legislature and federal funding agencies, contact with the legislature, contact with federal funding agencies, and publications in refereed journals. At 6 months, it is too early to have completed publications. However, all of the remaining metrics have been addressed and substantial progress has been made on each of them. Under the Milestones and Schedules section of the Memorandum of Agreement, the following 7 Deliverables were to commence within the first 6 months of the project: visit energy facilities, recruit speakers, recruit visiting scholars, build an algal cultivation facility, survey of algal biomass, recruit graduate students, and attend meetings.

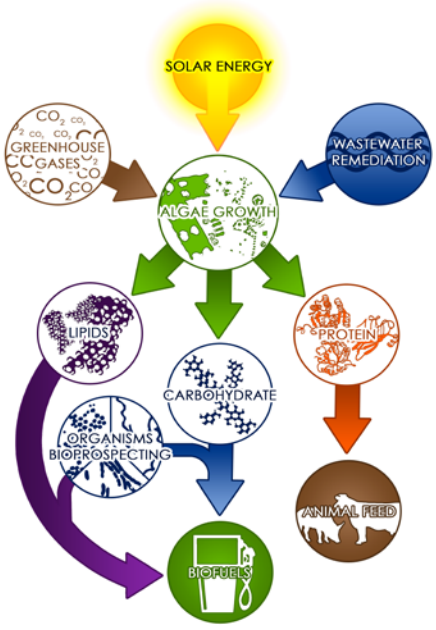


Figure 1. The centerpiece of the SABER project is the development of state-of-the art technology to tap marine or aquatic algae as a biomass source for fuel production.

A state-of-the-art, off-the-grid algal cultivation facility will allow us to produce algae with a minimal ecological footprint. Once cultivated, the algae yield lipids, carbohydrates, and protein, which can be processed into biofuels using microorganisms or used as biomass in animal feed. Wastewater from the process (and other sources) can then be reintroduced into the system during cultivation, making this a highly efficient, ecologically friendly alternative for producing fuel from the sun. A multidisciplinary team of faculty and students at FSU has been assembled to cover biofuels R&D across the entire value chain from biomass feedstock production to distribution and greenhouse gas life cycles. Areas of ongoing research include: algal strain selection and growth optimization, biomass analysis and conversion, and the use of green power in sustainable, carbon neutral algal cultivation. SABER is particularly focused on coupling algal cultivation to wastewater remediation.

In the first month, PI Kostka and coPI Wetz visited companies engaged in algal biofuels research throughout the state. Contact was made with the following four different biofuels companies: the Midwest

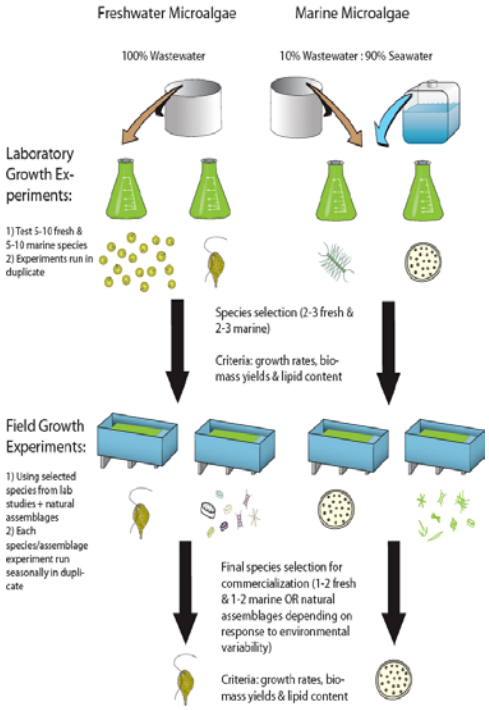
Research Institute (MRI) of Palm Bay, Petroalgae in Melbourne, Aurora Biofuels of Vero Beach, and Algenol of Bonita Springs. Most of the companies provided us with a tour of their facilities and we discussed potential research collaborations. Aurora Biofuels informed us that they already have a university partner from Florida Institute of Technology. Algenol was the only company that was not interested in further collaboration. Thus, we pursued further contacts with Petroalgae and MRI. Contact with MRI resulted in the submission of two research proposals and we remain in communication on further opportunities (please see Deliverables section). Petroalgae contacted us at the beginning of the summer about leasing land for the construction of algal cultivation facilities and they asked us if we would be interested in teaching a workshop to their personnel on algal cultivation. The partnership with Petroalage requires that we build an marine algal cultivation facility close to the ocean. Thus, we are currently in discussions with the Director of the FSU Coastal and Marine Laboratory, Dr. Felicia Coleman, to move forward on this partnership with Petroalgae.

Within the first two months of the project, two excellent Ph.D. students, Claire Smith and Kristina Welch were recruited to work on the project. Claire and Kristina were admitted to the Oceanography Department, and both of them began their work in August. Kristina's research is squarely focused on the growth of algae for biofuels applications. Claire will pursue research on the environmental impacts of biofuels production and is currently carrying out an experiment on carbon biosequestration for a proposal to be submitted to the U.S. Department of Energy is this area.

The algae-to-biofuels research community is growing and changing rapidly. Most investigators have been involved with this research area for less than 2 two years. To develop a unique bioenergy research portfolio for IESES at FSU, we are investigating a number of opportunities. The main focus is on optimizing the growth of marine and freshwater algae to be used as a biomass feedstock for the production of transportation fuels such as ethanol or biodiesel. Industry reports indicate that in order to develop this technology in a cost effective manner, the growth of algal biomass should be coupled to some other industrial process such as wastewater remediation or the mitigation of carbon dioxide emissions from the flue gas of coal-fired power plants. The growth of marine algae was discussed above. For the growth of freshwater algae, we have developed a number of partnerships and projects are farther along. These projects are focused on using the growth of algal biomass as an inexpensive alternative for the remediation of municipal and rural wastewater. Contact was initiated with Greenpointe, LLC, of Jacksonville, Florida in early August. Greenpointe has initiated a project on the cleanup of wastewater that enters the St. Johns River. We have offered to help them with the analysis of their waste stream and they will contact us when samples are available.

In September, discussions were initiated with the City of Tallahassee. The city's wastewater treatment plant is near capacity. To address future needs in capacity, the city requires alternative means to dispose of reclaimed water as well as methods to reduce operational costs. SABER has entered into a partnership with the city to optimize the growth of algal biomass for fuel from the city's nutrient-rich wastestream. See Figure 2 for details on the research plan. The city has offered the use of land at the plant to build a pilot scale algal cultivation facility. SABER will build the pilot scale facility and the city will offer some analytical services as a match. Design and construction are underway. In the meantime, Ph.D. student, Kristina Welch, will obtain wastewater samples and begin cultivation in October. During our meetings with the city, two other possibilities of collaboration were discussed. The city has an operating biorefinery for transforming vegetable grease into biodiesel through a transesterification process. We will explore the possibility of using this refinery to produce biodiesel from algal biomass. Secondly, we discussed the establishment of a recycling program on campus for oils from food waste to be used as a feedstock for the production of biofuels. Co-PI Michael Wetz is an accomplished algal physiologist and is leading the algal growth experiments. The growth of algae is a key component that drives the other components of our research plan. Wetz arrived as an assistant professor at FSU in December of 2008. SABER research on

algal growth has been hampered by delays in the renovation of the Wetz laboratory. The laboratory was recently finished and algal cultivation has commenced.



Professor Juergen Wiegel, Distinguished Professor of Microbiology at the University of Georgia was recruited by the PI Kostka to be a visiting scientist for IESES and he has accepted in principle, pending scheduling. Professor Wiegel will advise the project on the conversion of algal biomass to biofuels using microbial enzymes. He will assist with the development of research proposals, and he will also teach a short course in biomass conversion focused on hydrolysis and fermentation of biomass to ethanol.
Professor Wiegel pioneered the study of microorganisms that grow at temperatures above 55 degrees in the absence of oxygen. He has established one of the premier laboratories in the world for the isolation and characterization of such "thermophilic anaerobes." As a postdoc at UGA, Wiegel isolated Thermoaerobacter ethanolicus, which represents a novel thermophilic genus, species, and family and was the first wild-type organism patented in the United States for ethanol production. Recently, his laboratory extended the known limits of life when it isolated new genera of bacteria that thrive in alkaline hot springs and salt flats. Some of his novel isolates are a rich source of industrial-relevant enzymes. His laboratory developed a genetic system for thermophilic anaerobes, which is now used in industry. Wiegel's work has resulted in more than 190 original scientific publications, three patents, and $5.7 million in extramural funding. In 2007 he received the Bergey's Award, the highest honor in systematic bacteriology, for his contributions to the systematics of thermophilic and alkaliphilic microorganisms in extreme environments.
Professor Wiegel is scheduled to visit FSU during spring/ summer of 2010.

A total of 9 proposals and white papers have been submitted to federal agencies for funding. A number of biofuels meetings were attended by the PIs. A principal investigator meeting for the SABER program was convened by the PI in September. The goal of the meeting was to report on research progress and discuss further collaborations within IESES at FSU. This meeting was a resounding success, and the

presentations are available upon request. Numerous other meetings were attended by the PI with state and local officials that are not listed. Please see the list of Deliverables below for further details.

Deliverables

Proposals and white papers submitted under IESES-SABER for federal funding:

1.) Florida Renewable Energy Technologies Grant Program. Biogas Production from High-Rate Anaerobic Digestion (AD) of Sewage Sludge at Eglin Air Force Base, $2,433,000, J.E. Kostka (PI).

2.) U.S. Department of Agriculture, Biomass Research and Development Initiative, Renewable Transportation Fuel Production Utilizing Native Florida Algae, $4,300,000, J.E. Kostka (coPI).

3.) U.S. Department of Agriculture, Biomass Research and Development Initiative, Systems approach to the development of biofuels from photosynthetic algae, $2,500,000, J.E. Kostka (PI).

4.) Florida Energy Systems Consortium, ARRA Program, Research & Development of Bioenergy Alternatives from Algal Biomass, $15,000,000, J.E. Kostka (PI).

5.) U.S. Department of Energy, ERSP Program, A Single Cell Platform for Discovery of Novel, Active, and Transformative Subsurface Microorganisms with High Remediation Potential, 10/1/09 – 9/30/12, $479,627, J.E. Kostka (PI).

6.) U.S. Department of Energy, ERSP Program, Microbial Electrochemistry: The Role of Electrical Potential in Shaping the Composition and Activity of Metal-Reducing Microbial Populations within the uranium Contaminated Subsurface, 10/1/09 to 9/30/12, $253,234, J.E. Kostka (Co-PI).

7.) American Wastewater Research Program, Freshwater and marine microalgal growth on wastewater nutrients: an environmentally friendly and cost-effective approach for making biomass for biofuels production, M. Wetz (PI).

8.) U.S. Department of Agriculture, An integrative approach to remediate groundwater nitrate pollution within a watershed receiving recycled wastewater, 7/16/09-7/15/12, $100,000 to IESES, J.E. Kostka (co-PI).

9.) U.S. Department of Energy, Genomics GTL Program, Genome-enabled systems approach for the interrogation of carbon biosequestration in peatlands, 2/1/10-1/31/13, $1,500,000, J.E. Kostka (PI).

Meetings attended by the PIs.

Future of Biofuels, Snowbird, Utah, April.

Goldschmidt Conference, Davos Switzerland, June.

International Symposium on the Microbiology of Oil Field Systems, Aarhus, Denmark, June.

Florida Farms to Fuels, June.

Awards and Service Dr. Kostka was nominated and is currently running unopposed to become the next chairperson of the Division of Microbial Ecology in the American Society for Microbiology (ASM). ASM is among the largest life sciences organizations in the world.

Dr. Kostka has accepted an invitation to serve on the merit review panel for the U.S. Department of Energy, Office of Science's Early Career Scientist competition. The panel will occur in Washington, DC, in December, 2009.

FLORIDA STATE UNIVERSITY

Microgrids for a Sustainable Energy Future

PI: Chris S. Edrington
Co-PIs: Jim Zheng, Mischa Steurer, Dave Cartes

Description: A microgrid strategy can provide a solution for meeting Florida's sustainable energy needs; this effort focuses on the following:

Reduce the number of system-wide power outages by providing islanding capabilities allowing grids to separate from each other, providing for a more stable and reliable power delivery infrastructure.

Provide a framework in which non-traditional, low-carbon footprint, energy sources such as: wind, solar, and fuel cells can be easily integrated into the existing power system.

Provide for intelligent energy management and increased efficiency via high-penetration levels of power electronics and control strategies.

Provide for streamlined integration of both stationary and non-stationary energy storage devices as well as future energy conversion resources such as: ocean current and tidal.

Directly address greenhouse gas targets.

Budget: $719,333

Progress Summary

To meet Florida's renewable energy and greenhouse gas targets, there must be an aggressive sustainable energy plan. A microgrid strategy can provide a solution for meeting Florida's sustainable energy needs. Microgrids are an amalgam of: loads; distributed generation such as: photovoltaic, wind, fuel cells and other renewable energy sources; distributed energy storage devices which include: stationary (flywheels, ultracapacitors, and batteries) and non-stationary entities such as plug-in hybrid electric and electric vehicles. Possible benefits of microgrids are:

Reduce the number of system-wide power outages by providing islanding capabilities allowing grids to separate from each other, providing for a more stable and reliable power delivery infrastructure.

Provide a framework in which non-traditional, low-carbon footprint, energy sources such as: wind, solar, and fuel cells can be easily integrated into the existing power system.

Provide for intelligent energy management and increased efficiency via high-penetration levels of power electronics and control strategies.

Provide for streamlined integration of both stationary and non-stationary energy storage devices as well as future energy conversion resources such as: ocean current and tidal.

Directly address greenhouse gas targets.

To this end, the PI and co-PIs formed a research proposal that was submitted to IESES and subsequently, after peer review, approved for an award. Appendix A contains the original full statement of work. The PI and co-PIs have put together a team of undergraduate, graduate, post-doctoral associates, and visiting scientists to achieve the outcomes of the statement of work.

In Table II below is listed by PI the synergistic activities that have been associated with the opportunities that this research grant have provided. The table is intended to provide an indication of the activity and results that are currently being generated by this effort.

Table II
Investigator Activity

Chris S. Edrington
1. Traveled to Washington, DC for IEEE Applied Power Electronics Conference Planning Meeting.
2. Served as session chair for IEEE APEC, in Washington, DC.
3. Attended workshop in Little Rock, AR entitled: "Renewable Energy Systems for Building Professionals".
4. Attended IESES Productivity Summit in Tallahassee, FL.
5. Attended NSF – ERC Planning Meeting in Tampa, FL.
6. Co-PI on pre-proposal for ARPA-E proposal. (see item 1under Dave Cartes).
7. Co-PI on LOI for NSF – ERC. (see item 4 under Dave Cartes).
8. Co-PI on iLEV proposal. (see item 3 under Dave Cartes).
9. Site visit with Dave Cartes to Jacksonville Electric Associates.
10. Invited to become Associate Technical Editor for IEEE Power Electronics Society.
11. Invited to become an Editorial Board Member for the Journal of Electric Power Components and Systems.
12. Designated as Enterprise Thrust Leader for FSU in NSF – ERC proposal submitted by FESC through IESES.
13. Brought in Professor Gerald Hurley, IEEE Fellow from National University of Ireland, Galway, to give the seminar entitled: "Development of a Battery Charger for Emergency Power Supplies for Pitch Control Systems of Off-shore Wind Turbines".

Helen Li
1. Invited seminar at Zhejiang University, China.
2. Invited seminar at Hua Zhong University of Science and Technology.
3. Co-PI on LOI for NSF – ERC. (see item 4 under Dave Cartes).
4. Attended NSF – ERC Planning Meeting in Tampa, FL.
5. Designated as Enterprise Thrust Leader for FSU in NSF – ERC proposal submitted by FESC through IESES.
6. Created a new course for the fall semester: Renewable Energy Systems

Mischa Steurer
1. Attended IESES Productivity Summit. Juan Ordonez 1. Site visit to First Coast Wind LCC to explore collaboration opportunities.
2. Site visit to Black Lion to explore collaboration opportunities.
3. Site visit to UTEX at the University of Texas - Austin.

Jim Zheng
1. Invited seminar: "High Performance Fuel Cells using Buckypaper", Louisiana State University, Baton Rouge, LA, February 13, 2009.
2. Site visit for proposal of "An International Collaboration Group on Solar Cell Technologies Development", Sponsor: Chinese Academy of Sciences, Budget:

$877,193 (¥6,000,000 RMB), Project Dates: 4/09-4/14.

3. Co-PI on iLEV proposal

Dave Cartes

1. Traveled to Washington DC in March to discuss an ARPA-E opportunity with Siemens and Johns Hopkins University APL.
2. Traveled to Washington DC in March to discuss and ARPA-E opportunity ARRA 2009 Smart Grid proposal to DOE OE FOA by BGE, Johns Hopkins University, and IESES/FSU.
3. Submitted DOE proposal: ILEV (Institute for Low Energy Vehicles) with Tallahassee Economic Development Council. This ILEV will start a Professional Science Master's degree in electric vehicle and component entrepreneurship.
4. Submitted an NSF ERC Letter of Intent entitled Smart Grid – Smart Car that will integrate electric vehicle energy storage into the Smart Grid energy management scheme.
5. Site visit to Jacksonville Electric Associates.
6. Traveled to Tampa, FL for NSF – ERC Planning Meeting.

In Table III, below, is a list of journal, conference and other publications that are a direct result of the efforts of this research and are meant as a measure of the effectiveness of the investigators in fulfilling the research objectives that are in the statement of work. In total, 10 conferences, 4 journals, and 1 web article(s) has been submitted, accepted or are in process.

Table III
Article Type

R. Bhuvanesawri, C. S. Edrington, D. A. Cartes, and S. Srikrishna, "Online Economic Environmental Optimization of a Microgrid Using an Improved Fast Evolutionary Programming Technique", accepted to the North American Power Symposium, Starkville, MS, Nov. 2009.Conference

T. Bevis, B. Hacker, C. S. Edrington, and S. Azongha, "A Review of PHEV Grid Impacts", accepted to the North American Power Symposium, Starkville, MS, Nov. 2009.Conference

R. Bhuvaneswari, C.S. Edrington, D.A. Cartes, and S. Subramanian, "Economic Emission Generation Scheduling in a Microgrid Using an Improved Fast Evolutionary Programming Technique," submitted to the International Conference on Power Systems, 27-29 December 2009, IIT Kharagpur, India.Conference

Il-Yop Chung, Wenxin Liu, Siyu Leng and David Cartes, "Controller Optimization for Inverter-Interfaced Distributed Generators Considering Islanded Operation of a Microgrid," accepted to 2009 IEEE Energy Conversion Congress and Exposition to be held in San Jose, California, USA, September 20-24, 2009.Conference

Il-Yop Chung, Wenxin Liu, David A. Cartes, and Seung-Il Moon, "Control Parameter Optimization for Multiple Distributed Generators in a Microgrid Using Particle Swarm Optimization," submitted to European Transactions on Electrical Power. Journal

B. Hacker, S. Azongha, and C. S. Edrington, "PHEV Impacts on Microgrid Systems", submitted to the IEEE Electric Power and Energy Conference, Montreal, Canada, Oct. 2009. Conference

B. Hacker, C. S. Edrington, and F. Bogdan, "The Future of Power Distribution", submitted to Ecoterra, 2009. Web Article

W. Hang, J.C. Ordonez, J.V.C. Vargas, "Nondimensional Model for SOFC structure optimization", in preparation. Journal

L.S. Martins, J.C. Ordonez, J.V.C. Vargas, “Experimental Validation of a simplified PEMFC Simulation model”, Proceedings of ES2009, Energy Sustainability 2009, July 19-23, 2009, San Francisco, California USA. Conference

L.F. Zanette, E.C. Telles, R.L.S. Marinardes, J.V.C. Varags, A.B. Mariano, J.C. Ordonez, “Development and Analysis of a tri-generation System”, submitted to COBEM 2009. Conference

E.M. Sommer, J.V.C. Vargas, L.S. Sanches, J.C. Ordonez, Development and Experimental Validation of a Mathematical Model for Alkaline Membrane Fuel Cells (AMFC), submitted to COBEM 2009. Conference

R. Hovsapian, J.V.C. Vargas, J.C. Ordonez, F.G Dias, “Experimental validation of a solar powered absorption system”, in preparation. Conference

L. Liu, Z.C. Wu, H. Li, “A Single-stage Grid-interactive Inverter Integrating Micro-Energy Storage (μES) with Enhanced Reactive Power Compensation”, submitted to APEC 2010. Conference

P.L. Moss, G. Au, E.J. Plichta, and J.P. Zheng, “Investigation of solid electrolyte interfacial layer development during continuous cycling using ac impedance spectra and micro-structural analysis”, J. Power Sources, 189, 66 (2009). Journal

J.P. Zheng, “High energy density electrochemical capacitors without consumption of electrolyte”, J. Electrochem. Soc. 156, A500 (2009). Journal

PROPOSALS

Table IV shows a list of the proposals that are either submitted or are in the pre-proposal stage, based on the information provided to the PI by the co-PIs on this project. The purpose of the table is to give an indication of the effort by the PI and co-PIs to leverage the resources that this grant has provided to obtain further research funds to sustain the work. The participants are not a complete listing, but reflect only the involvement of the PIs from this project.

Table IV
Proposal Working Title Participants Agency Amount

Institute for Low Energy Vehicles (iLEV)
D. A. Cartes, C. S. Edrington, J. P. Zheng
National Energy Technology Laboratory
$7.3 M

NSF – ERC MAESTRO-SC (Mastering Energy Storage through Smart Control)
D. A. Cartes, C. S. Edrington, H. Li
National Science Foundation
$18.5 M

ARPA – Concept Paper (pre-proposal on development of smart controls for grids)
D. A. Cartes, C. S. Edrington
Department of Energy
$2.6 M

International Collaboration Group on Solar Cell Technologies Development
J.P. Zheng Chinese
Academy of Sciences
$877 K

3-D Nanofilm Asymmetric Ultracapacitor, a Phase I SBIR Project
J. P. Zheng
Department of Energy
$30 K

CONCLUSIONS

Due to budget cuts at the initial stage of the project, the original $1M that was awarded was cut to approximately $ 719K and additionally the 3rd year of the project was left unfunded. The original set of PIs included Dr. Farukh Alvi who at this initial stage decided to decline participation in the research effort since he could fund the same type of work under FCAAP. Due to this, the portion of the Statement of Work relating to Dr. Alvi's work will not be pursued and essentially does not impact the overall objectives of the project. It is envisioned that, due to importance of solar PV installations that are being proposed in the State of Florida, that a modification to the SOW is in order that will address control, stability, and integration of high levels of penetration of solar PV in existing and new grid topologies. A new student will begin working on this research area starting in the fall semester. Another modification to the SOW was proposed for the work that is responsible by Dr. Mischa Steurer. The original intent was to set up a Power Hardware in the Loop (PHIL) interface for experimental work. However, it is felt that a more important issue is to investigate where and how microgrids might be instantiated in the State of Florida. A student was placed on this research effort, but due to lack of interest and performance was not retained. In the fall semester a new student will start on this effort. It is felt that the burn rate is quite appropriate at the moment for this research award and that at the 6 month mark approximately 50% of the first year allotment has been spent. Of primary importance is the fact that: 1) all graduate students have been fully funded, 2) all support requests for summer support for faculty have been honored, 3) there has been a sufficient amount of travel to present research results and participate in workshops and proposal planning meetings, 4) support for undergraduate researchers has been available and utilized, and 5) stipends for visiting scholars has been made available. However, based on the current burn rate, it may be possible to pick up another visiting scholar, partially fund an additional post-doctoral researcher, and another graduate student starting this fall. This is primarily due to a vacancy created by Dr. Wenxin Liu who is leaving this fall to take an assistant professor position at New Mexico State University. In general the research team is making good progress toward the research goals that were set forth in the original SOW, as evidenced by the level of publications in national and international forums.

Additionally, the educational goals are being amply met and the funding is providing opportunities for undergraduate and graduate students to achieve an education in an area that is clearly of national importance. Moreover, the PIs have utilized the knowledge and opportunity provided for by the grant to write additional proposals that if funded will help support the initiatives of IESES and FSU.

FLORIDA STATE UNIVERSITY

Planning Grant: Hydrogen storage using carbon-based adsorbent materials

PI: Efstratios Manousakis

Description: We propose to theoretically investigate a variety of carbon based nano-porous materials, such as activated carbon or single-wall or multi-wall carbon nanotubes, which can be used to store and transport hydrogen. We find that by doping with metallic elements, the micro-surfaces of these carbon-based porous materials provide increased van der Waals forces to the adsorbed hydrogen molecules; this effect significantly enhances the volumetric energy density for hydrogen storage and we propose to carry out a full theoretical investigation to find the optimum conditions.

Budget: $15,000

Progress Summary

As a result of the realization that the originally proposed project has low funding priority we have recently turned our attention to a different idea which was not included in our original White Paper. The idea is to use a radically different class of materials to produce highly efficient solar cells. We have found that the photovoltaic effect, which as it is well known works with doped band insulators, works in addition, with a class of materials which are called Mott-Insulators. Namely, first, we can show that a p-n junction can be produced by making an interface between a p-doped and an n-doped Mott-insulator. Most importantly, we find that if we appropriately choose these materials to be narrow-band and narrow-gap Mott-insulators they give rise to a very high quantum efficiency. We find, theoretically, that a solar photon when it is absorbed by the type of device produces several electron/hole pairs and only very little amount of energy is dissipated by photon emission or other dissipative processes. We are in the process of using Molecular Beam Epitaxy to produce the first such device.

FLORIDA STATE UNIVERSITY

Multi-Generation Capable Solar Thermal Technologies

PI: A. Krothapalli**; Co-PI:** Brenton Greska
Students: John Dascomb (Ph.D.), Ifegwu Eziyi (Ph.D.), Jon Pandolfini (Ph.D.), Michael Gnos (M.S.)

Description: The objective of the proposed research is to develop and demonstrate small-scale solar thermal technologies that can be used separately, in conjunction with one another, or with existing waste heat producers, thus improving the overall system efficiency.

The development of an indoor solar simulator capable of providing and sustaining 1 kW/m2 over an area of 10 m2.

The development of a Rankine cycle-based solar concentrating system that is capable of producing at least 2 kW of electricity adaptation and integration of small-scale absorption-based refrigeration systems that can employ the waste heat from the aforementioned Rankine system.

Integration of existing membrane distillation technology for waste heat recovery from either, or both, of the above-mentioned technologies.

Demonstration of a multi-generation system that combines all of the above-mentioned technologies.

Budget: $544,226

Progress Summary

Task 1: Develop an indoor solar simulator
Testing of the solar simulator components has begun (Figure 1). The results from two of the test configurations are shown in Figure 2. It can be seen that there is uniform light distribution without the reflector but it is only 40% of the desired intensity. With the reflector the maximum intensity rises to 80% of the desired value but it is concentrated over an unacceptably small area. A number of configurations will be tested in an attempt to address these issues.

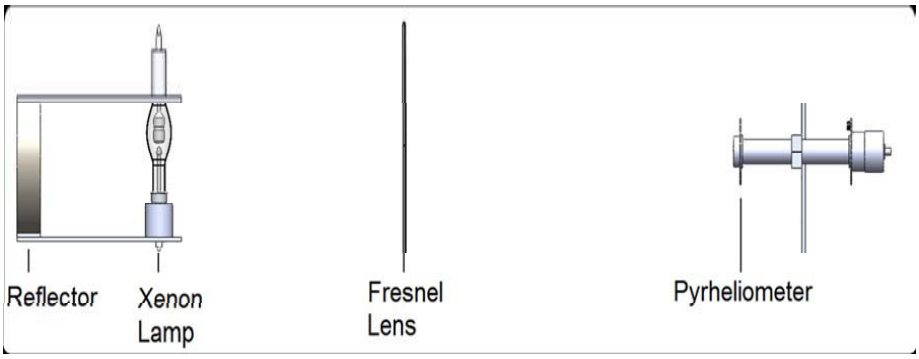


Figure 1. Experimental setup for solar simulator design development.

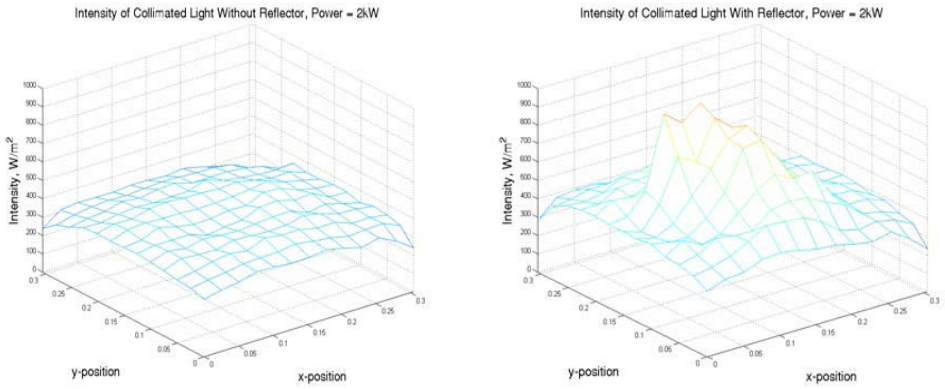


Figure 2. Measured intensity of the solar simulator light. Left – no reflector; Right spherical reflector.

A low-cost pyreheliometer is under development at ESC for use with the simulator and other outdoor activities requiring direct beam radiation (Figure 3). The low-cost unit has been tested in tandem with a commercially available unit and Figure 4 presents some of the results from the testing. Work on the tracking system for the low-cost unit is currently underway.

Figure 3. ESC-MG-1 Prototype

Design Specifications:
Circular field of view of about 5(similar to Eppley's NIP)
Needs to comply with the standards given by the World Meteorological Organization [2]
Reading of irradiance value in the range of volts rather than mvolts
Response time less than 140 seconds
Accuracy better than □3% compared to Eppley's NIP
Cost for pyrheliometer and tracking system ~$500

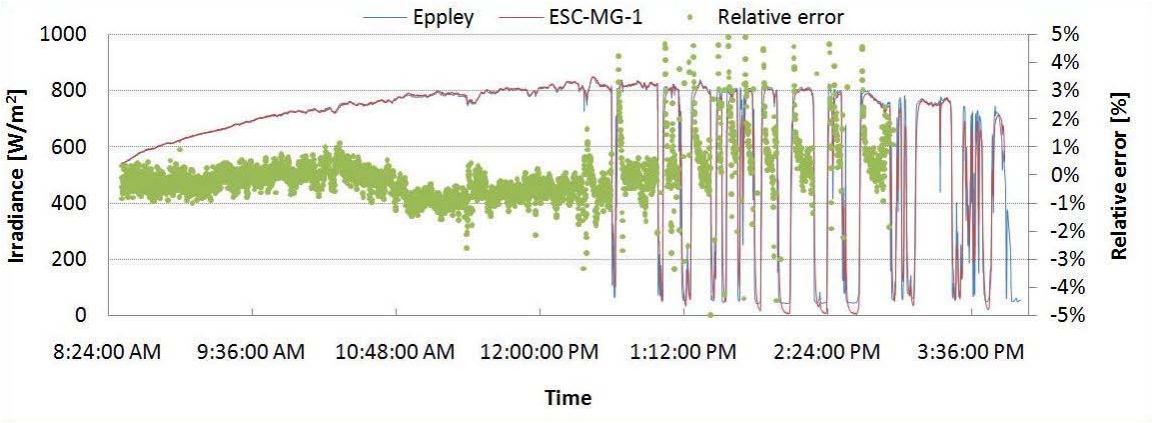


Figure 4. Comparison of the results obtained using the commercially available (Eppley) and low-cost (ESC-MG-1) pyrheliometer.
Students: John Pandolfini (Ph.D. Student) Michael Gnos (M.S. Student)

A first generation solar generator has been built to verify the basic design principles of solar steam generation using dish system. Figure 5 is the system system installation picture on the FSU at ESC. The results of this work is described in a recent M.S thesis (John Dascomb, August 2009)

Figure 5. ESC 14 m2 parabolic dish concentrator with a steam boiler - solar steam generator.

Arrangements have been made to have a 15-foot diameter commercial concentrating dish donated by Infinia Inc. to ESC for use in the development of a small-scale cavity type steam boiler.

Figure 6. Infinia 3 kW dish-Stirling system.(The dish is being donated to ESC for the steam generation project)
Student: John Dascomb (Ph.D. Student) and Justin Kramer (Engineer)

Task 5: Integration of existing membrane distillation technology for use with the waste heat from the Rankine cycle and the refrigeration system (unfunded). Because of the importance of efficiency improvement in solar thermal systems, ESC has been developing waste heat recovery methods with particular emphasis on a novel water purification system (Figure 7). This work is carried out in collaboration with the Royal Institute of Technology (KTH) in Sweden. A typical multi-generation solar power system is shown schematically in Figure 8. Such systems are being studied currently with a goal of building a demonstration system during the second year of the program.

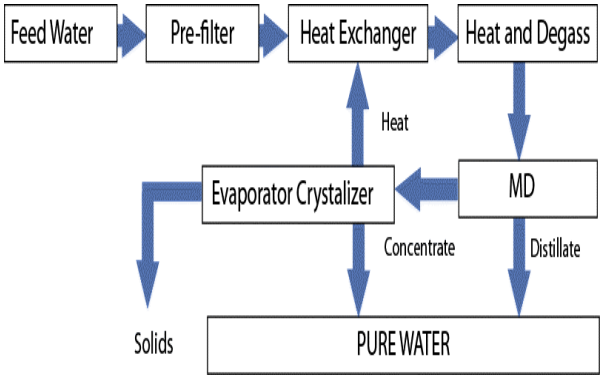


Figure 7. Membrane distillation process steps.

A multi-generation solar thermal system. MD: membrane distillation unit; ORC: Organic Rankine Cycle.

A membrane distillation (MD) unit for water purification has been purchased. This unit is capable of utilizing waste heat to operate and understanding of its operation will allow for an optimal solar thermal system design.

FLORIDA STATE UNIVERSITY

Planning Grant: Meteorological Factors Affecting Solar Energy Efficiency in the Tropics

PI: Paul Ruscher**, Co-PIs:** Yaw Owusu, Hans Chapman

Description: We wish to document the atmospheric factors that both limit and enhance solar energy utilization in this project, particularly those in the tropics. This will benefit Floridians as well as people in developing nations who wish to deploy solar technologies, to help them understand the benefits and limitations that they can expect to achieve.

Budget: $15,000

Progress Summary

No progress reported.

FLORIDA STATE UNIVERSITY

Political and Economic Institutions Regarding Siting of Energy Facilities: "Hold Out" and "NIMBY" problems, with concurrent developments in undergraduate education

PI: R. Mark Isaac; **Co-PIs:** Douglas Norton, Svetlana Pevnitskaya

Description: The "holdout" problem occurs when one economic agent attempts to construct a portfolio of economic assets (often land) from multiple sellers. When a public good has diffuse public benefits but costs concentrated on a few, a "NIMBY" problem (Not In My Back Yard) may exist.

Budget: $79,621

Progress Summary

1) The "Hold-Out" project (with graduate student Sean Collins). The experimental design is complete, the programming is complete, IRB approval has been obtained, and we are conducting the experiments. This research has been invited for presentation on one of the Presidential Sessions at the 2009 Meetings of the Southern Economics Association in November in San Antonio.

The "hold-out" concept in discussed repeatedly in the context of public policies regarding land acquisition and facilities siting, but a clear definition is elusive. To economists, the most likely definition is that a profitable amalgamation of land parcels by one buyer from competing sellers does not obtain because of the failure of the private bargaining process. However, sometimes the term seems to be used more for delay instead of failure in bargaining, or even the very different concept of creation of any bilateral bargaining situation of the buyer and the "last" or "holding-out" seller, which may be inconvenient to the buyer but is immaterial in terms of economic efficiency unless efficient trades actually fail.

Our goal in this first set of experiments was simple. If "hold-out" is an empirically worrisome economic phenomenon, we ought to be able to find it in subjects who make decisions in our laboratory. Therefore, our first task was to create a "best case" scenario to observe holdout, which could then serve as a test-bed in which to examine changes in institutions and/or information conditions to ameliorate hold-out. Several design issues were obvious in creating this best-case scenario. There was no possibility, not even a threat, of any eminent domain proceeding. The buyer would have to purchase all of the parcels in order to reap the synergistic gains from amalgamation. There would be no contingent contracting, so that the buyer would face the so-called "exposure problem" of having to pay for some of the parcels before knowing whether he/she could successfully obtain all of them. And, the buyer would be capital constrained, that is, unable to borrow against the eventual value of the amalgamated properties. All of this would unfold in the context of valuations which made the amalgamation profitable to the buyer relative to the separate values placed on the parcels by the sellers. If hold-out existed, it would mean the failure of bargaining to capture mutually beneficial gains from exchange. The design conditions above were good as far as they went, but we then had to choose certain information conditions whose effects on the "best case" objective were ambiguous. For example, should the terms of the contracts be common knowledge? On the one hand, that might stoke the fires of "me last" among the sellers; on the other hand, it might be a vehicle for the development of reasonable expectations among the sellers as to what to expect from the negotiations. What we realized was that there was an array of these information conditions that, while ambiguous as to their propensity to promote holding-out, were clearly different from what one might recognize as the archetypal approach to the facilities siting problem when approached by governments or by private parties. In the contemporary era, governments often operate in the context of "Government in the Sunshine" and "Freedom of Information" provisions that promote transparency and common knowledge.

On the other hand, private acquirers of large parcels often resort to just the opposite: institutions such as non-disclosure agreements and dummy corporations to keep as little information as possible from seeping into the negotiations. Therefore, even in our "best case" scenario, we began with two information conditions. One we call "government" in which sellers know how many units the buyer has purchased, all contract prices as they occur, and they can continue to communicate with one another throughout the negotiations. In the other, "private," information condition, sellers do not know how many of the parcels the buyer has purchased, they do not know the other contract prices, and there is an enforced non-disclosure condition.

We have obtained one unambiguous result even after only 4 pilot sessions (12 groups, each making four decisions) and the first "fine tuned" baseline session (2 groups, each making four decisions): we observe the hold-out problem in our design. In fact, in about half of the cases so far, the contracting fails. This means that we have successfully created a test-bed which we can use to investigate institutional and information conditions that might ameliorate hold-out. After completing four more groups in the baseline condition, the first institutional modification we will examine is contingent contracting. We had our first test of the contingent contracting program last week, and we anticipate conducting those experiments shortly after Fall semester classes begin.

2) The "NIMBY"project (with Co-PIs Doug Norton and Svetlana Pevnitskaya). The experimental design is substantially complete. The programming is well underway. Writing the experimental instructions has begun. Completing a draft of the instructions, completing the programming, and submitting the research for IRB approval are the tasks for Summer C, so that the actual experiments can begin quickly in the Fall Term. This research has been accepted for presentation at the 2009 Meetings of the Southern Economics Association in November in San Antonio.

Just to review for anyone who did not read our original proposal, the NIMBY issues deals with siting issues in which external effects are "good" for some members of "society" and bad for others. If the debate over the alternate energy bio-mass facility in Tallahassee had not happened, people might have thought we were making things up if we had hypothesized a scenario. Different citizens with credentials as "environmentalists" ended up viewing the plant as either a "good" (because of the development of an alternative energy infrastructure with an eye to global issues of sustainability and global warning) or a "bad" (because of the local environmental effects). Examination of public goods provision problems in such a heterogeneous preferences situation is, by itself, opens a new direction for research in economics.

3) The undergraduate course (The Economics of Sustainable Energy) with Doug Norton has been approved by Economics Chair Bruce Benson for inclusion on the Spring 2010 schedule, MW 3:35-5:15. The course will be capped and set for "instructor" permission so that we can work on getting Engineering students into the course. Doug and I have met with Amy Chan-Hilton and our two undergraduate engineering major advisors regarding content and issues of "requirements satisfaction" for engineering majors. We have begun outlining early lectures, particularly those on the topic: "What exactly does the word 'sustainability' mean?"

4) IESES funded travel. Doug Norton and I traveled (with the grant paying part of the funds) to Guatemala in April. In addition to presenting previous but related work on the Association of Private Enterprise Economists, the trip allowed us to visit the ampus of and interact with faculty from Universidad Francisco Marroquin. We attended sessions at APEE on related topics that were composed entirely of economists from outside of North America. Since that visit, faculty at Francisco Marroquin have reiterated the possibilities of working jointly with our experimental social science research group. And, we met with an engineering student in Guatemala who works in the development area and discussed how issues of sustainability are impacting a developing country such as Guatemala.

5) NSF DMUU grant. Last month, I submitted as PI a large (for the social sciences: tentatively $2,700,000+) NSF grant to the Decision Making Under Uncertainty Initiative. Several IESES-associated faculty (Chan-Hilton, Isaac, Norton, Pevnitskaya, and Ryvkin) are participating, as are several non-IESES faculty who nevertheless have research interests in this area. I have attached a copy of the "Project Description" to giveyou an idea of what a broad base of research we have going on in this area.

FLORIDA STATE UNIVERSITY

Reducing Residential Carbon Emission in Florida: Optional Scenarios Based on Energy Consumption, Transportation, and Land Use

PI: Tingting Zhao**, Co-PI:** Mark Horner

Description: The objective of this proposal is to explore energy and fuel sustainability as well as CO2 mitigation in Florida by investigating the household-level energy and transportation fuel consumption and by analyzing changes in land use.

Budget: **$60,844**

Progress Summary

No progress reported.

FLORIDA STATE UNIVERSITY

Investigating the Effect of Appliance Interface Design on Energy-use Behavior

PI: Paul Ward; **Co-PIs:** Ian Douglas, David Eccles

Description: Our goal in this study is primarily to examine the behavioral differences between efficient and inefficient energy consumers that are related to interface design. Specifically, we are interested in relationship between the informational feedback afforded by the device, an individual's understanding of how a device works, and their combined effect on energy use-behavior.

Budget: $247,720

Progress Summary

In the original statement of work, we proposed nine tasks to be completed over the two year funding period for this project. These included three types of task: (a) organization and information gathering exercises, (b) task analyses and home inventories, and (c) assessment, evaluation and design recommendations. We review progress on each task relative to these foci below and, for reference, indicate the original task list # from our statement of work in parentheses. The statement of work is provided as an appendix.

A) Organization and Information Gathering Exercises

Project personnel and recruitment (Tasks 1.1). Three graduate research assistants (GRA), 1 post-bacc and 1 undergraduate student have been recruited to assist on the project since it was activated (Project Activation Date: April 28th, 2009). These students receive a stipend from this project and tuition waiver in proportion to their FTE contribution. One directed independent study (DIS; PSY4920) undergraduate student and 2 volunteer graduate students also contribute to the project as indicated below. The status, department, FTE and start date of all students are indicated in Table 1.

Table 1. IESES personnel/recruitment history.

	May	June	July	Aug	Sep	Oct
Team member working on IESES project each month (incl. status and department) FTE and start date indicated in month of hire / change	Jason Torof (Post-bacc; Psychology) GRA FTE: 0.75 Start: 5/11	FTE: 1.00 Start: 6/1	Stephanie Robertson (PhD student; College of Education) GRA FTE: 0.50 Start: 7/1	Jackie Kott (Undergraduate; Psychology) DIS student Jarrett Evans (MS student; Psychology) GRA FTE: 0.18 Start: 8/10 Avner Dachoach (MS student; Psychology) GRA FTE: 0.18 Start: 8/10	Mike Marshall (Undergraduate; Computer Science) GRA FTE: 0.5 Start: 9/1 Edson Filho (PhD student; College of Education) Volunteer	Katerina Kudlackova (MS student; College. of Education) Volunteer

Contacts (Tasks 1.3, 3.1, & 3.2). We established contact with City of Tallahassee Utilities to determine local programs and initiatives that could potentially dovetail into our project. Several conversations with various departments, including the audit team, lead to a meeting of the principal investigators with Mr. Henry Swift, P. E., Project Manager for the Smart Metering Project. We discussed several issues at this meeting: (i) the new Smart Metering technology installed in 95% (to date) of Tallahassee homes, (ii) changes in time-of-day (as opposed to flat rate) billing, (iii) how the Smart Meter System will be implemented/rolled out, (iv) its impact on energy efficiency, and (v) behavioral and design implications of the system. Most importantly, we discussed several collaborative ideas for research that would allow us to examine the behavioral impact of this system of energy efficiency by incorporating it into our future research. Mr. Swift and his seniors are currently considering these proposals.

We established contact with approximately 12 other agencies and numerous researchers to familiarize ourselves with existing research centers on behavioral aspects of energy efficiency and to identify programs and initiatives on energy efficiency.

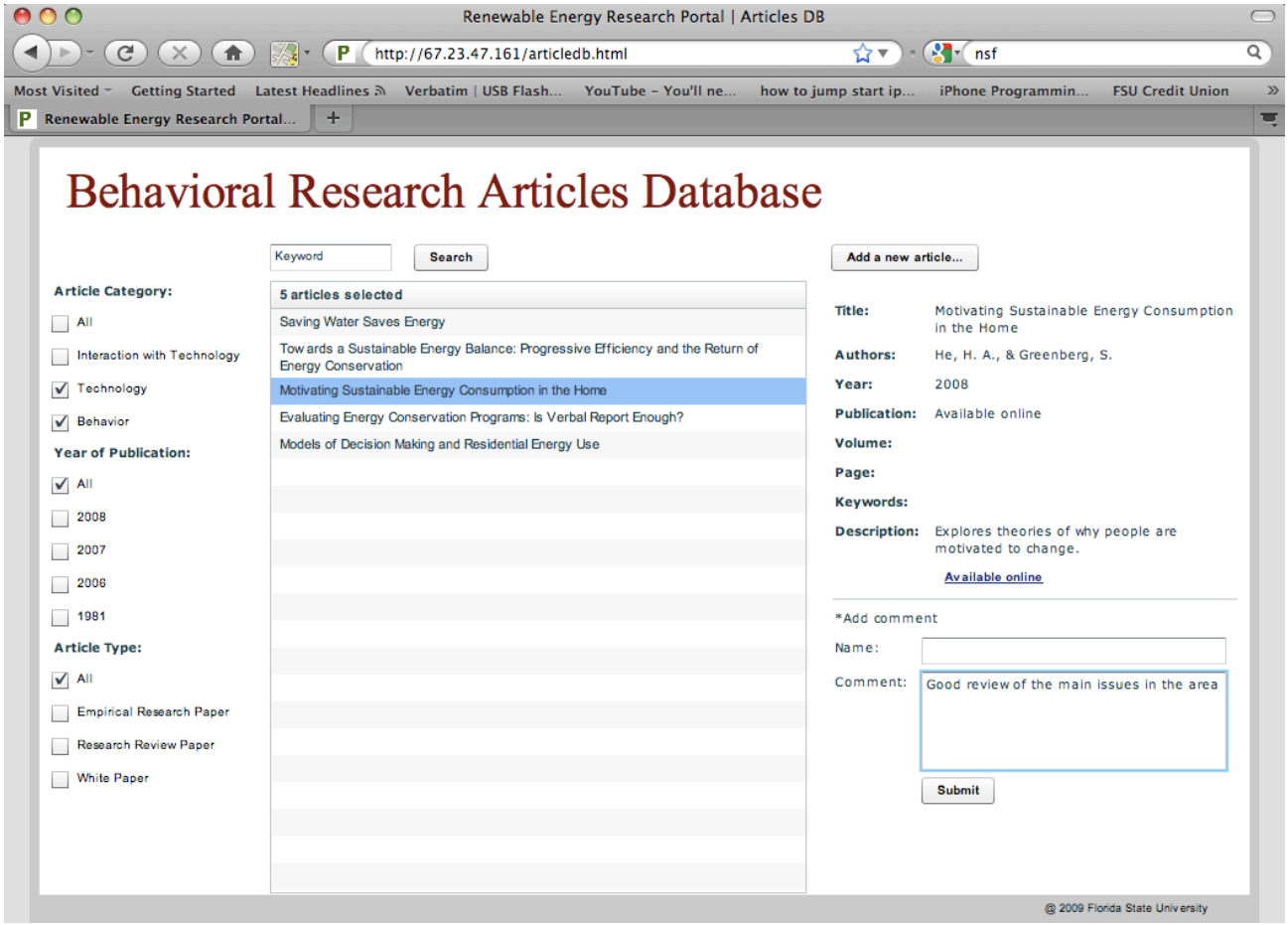


Figure 1. Web access to the database

Literature search (Tasks 2 & 3.2). From the four research areas outlined in our statement of work we identified two primary research themes that cut across these areas: *consumer feedback* and *technology design and human interaction*. Consumer feedback relates to the frequency, amount, and type of information given to consumers about their performance (i.e., consumption rate, efficiency, etc.), the method of conveying that information to the consumer (e.g. interface type/device design), and how this information is used to change behavior (e.g., become more energy efficient). Technology design and human interaction relates to the interface-design-related factors that softly constrain consumers to interact with devices in particular ways, often inefficiently. We also identified a secondary theme of research on *feeling of knowing*. This research relates to how an individual's knowledge about how to perform a given task (e.g. how to operate a device) influences the judgments they make when performing that task, and affects their ability to change their behavior (e.g., engage in more energy efficient behaviors).
To date we have identified over 290 articles using both lab-based and field-based approaches to address one of these research themes. We have also identified a number of State-level reports on behavioral aspects of energy efficiency. We have created a database in which to store titles of details of these articles and reports and have entered 88 of these into the database so far. In collaboration with one of the other IESES projects, we have made this information database available online (see Figure 1). This will enable the database to become a valuable resource for all researchers in this emerging field and will also allow for other researchers to add new papers in the future.
The literature search has informed the design of several laboratory-based experiments and a field-based survey related to this project (see section B: Task Analyses and Home Inventories). An example summary of how some of this research pertains to behavioral impacts on energy consumption is provided in the appendix. A similar database exists at the Precourt Energy Efficiency Center (PEEC) and contains the titles of over 800 articles that relate more generally to energy efficiency.

Energy efficiency programs and initiatives (Task 3.3). We have created a database of programs and initiatives (and the corresponding agencies) related to energy efficiency in U.S. and FL. This database will be made available via our online guide and any explicit recommendations made by these programs will be highlighted.

Device search (Tasks 3.3, 4.2 & 4.5). We have conducted an extensive search for information about energy consumption rates of household devices. The most promising information we have found to date includes an Energy Star database for 4 types of devices (dishwashers, washing machines, air conditioners, and fridge/freezers) that include energy consumption/efficiency information (including kWh, Energy Factor, Federal Standard, and % better than the average non-Energy Star appliances) for all Energy Star brands available in each category. These are available online and we will make these accessible via our online guide. We are currently attempting to obtain information on consumer device usage from www.consumerreports.org and from manufacturers of different devices. This information will serve to
Several add-on systems/devices have been identified that provide the consumer with additional information about their energy consumption, either in general or for each device. These devices could be used to increase the type and frequency of feedback as well as the accessibility to this information. A list of these devices will be made available in an online guide. The effectiveness of these types of devices in increasing energy efficiency will be assessed in the field study.

B) Task Analyses and Home Inventories

Identify and survey households (Task 5). We have filed an IRB application for this survey-based research project. This application has been approved pending minor changes. We developed an initial survey instrument to examine (i) the typical energy consuming technology owned by homeowners, (ii) their interactions with that technology, (iii) the types of behaviors related to and/or misconceptions about how devices work, the energy they consume, and how to increase efficiency, and (iv) the available sources of

feedback about their energy consumption and how these are used. This survey is currently under revision based on an in-house pilot. In addition to providing useful data about behavioral and technological factors that affect energy efficiency, the survey will allow us to screen participants for, and inform the design of, the field-based study.

Behavioral data collection and household inventories (Tasks 6 & 7). We have filed a second IRB application for a series of experiments examining behavioral issues identified in our literature search. This application is pending approval (review date: October 14, 2009). The proposed experiments will examine issues related to (i) design-related limitations that restrict access to information necessary for behavioral change, (ii) the role of feedback in changing behavior, and (iii) overconfidence in ability to bring about changes in behavior (e.g., that may have come about because of misconceptions/misunderstanding about how things work). These lab-based experiments will be conducted using PC-based simulations of energy consuming devices and/or related devices/tasks. In September, we hired a part-time computer programmer to create these task environments for use in the experiments, which are in various stages of development. In addition to the information garnered from the in-home survey, the proposed laboratory experiments will serve to inform the field-based experiment proposed in our statement of work.

C) Assessment, Evaluation and Design Recommendations.
The majority of evaluation, assessment and design recommendations will primarily result from the survey, laboratory- and field-based studies. However, the information-gathering exercises described above will also prove to be useful resources to the consumer, as well as commercial and research communities. As indicated above, we have created a database of articles and reports related to behavioral aspects of energy consumption. In collaboration with one of the other IESES projects, this has now been made accessible online. Likewise, we have created a database of programs and initiatives related to energy efficiency, which will be available online shortly. Our intention is to use the data we collect during our survey/experiments to produce online guidelines related to behavioral and design-related factors associated with increasing energy efficiency in the home

SUMMARY

Considerable progress has been made towards our research objectives. Our original milestones and schedules (see statement of work) were to have completed organization and a search of the literature by month 6, to begin identification of energy initiatives and to create the associated database.
To date, we have established the research team, conducted an extensive search of the literature (which is ongoing), created a database of articles relevant to energy efficiency that has already been made (partially) available online, identified energy efficiency programs and initiatives, established contact with the City of Tallahassee Utilities Smart Metering Project, created a pilot energy survey, submitted two IRB applications—one for a field-based survey study and another for series of laboratory experiments on human factors that will affect energy efficiency, gathered information on energy consumption characteristics of household devices, and identified several add-on devices capable of providing more direct feedback to consumers about their energy consumption.
Although our milestones and schedules indicated that this project would generate products, such as conference presentations, papers and grant applications, AFTER data had been collected in year 2, we have already begun to seek opportunities to obtain funding and data collection is ahead of schedule.

FLORIDA STATE UNIVERSITY

Planning Grant: Real-Time Power Quality Study For Sustainable Energy Systems

PI: Dr. U. Meyer-Baese, **Co-PIs:** Helen LI, Simon Foo, Anke Meyer-Baese, Juan Ordonez

Description: Power quality problems can lead to process disruption, unplanned downtime, shorter appliance lifetime, wasted resources, higher energy costs and value of work in progress destroyed. These problems are substantially larger in sustainable energy systems with multiple power generators. CEIDS estimates the loss due to low power quality at $119-188 B/year. The quality problems can be detected in advance by measurements and monitoring. By choosing good design practices and the right equipment such as active harmonic conditions most of the effects can be avoided. Typical indicator and consequences of power quality problems are computer lock-ups, equipment damage, blackouts, light flicker, nuisance tripping or overheated neutrals. To enable an universal real-time detection of power quality on the large and small scale, we will provide algorithmic as well as implementation working prototypes.

Budget: $15,000

Progress Summary

No progress reported.

FLORIDA STATE UNIVERSITY

Sustainably Integrated Advanced Building Subsystems (OGZEB)

PI: A. "Yulu" Krothapalli, **Co-PI:** Justin Kramer

Description: This project focuses on the development of building subsystems that minimize the use of natural resources and carbon-based energy in Florida while also using materials that are renewable and sustainable. A key component of this project is the Off-Grid Zero Emissions Building, which will allow for the testing of these subsystems.

Budget: $503,168

Progress Summary

Phase 1: Building Design

A team of engineers and architects were chosen to design the OGZEB. This team spent one year considering LEED certification, energy efficiency and construction optimization of the OGZEB. All design expenses were donated by the design team.

Phase 2: Building Construction

The construction of the building is complete with the issuance of the Certificate of Occupancy. The shell of the house has been designed and constructed to enable research into Sustainably Integrated Advanced Building Systems. The layout is designed to allow for new technology to be compared against a baseline technology for cost effective analysis and thorough analysis. The construction also allows for ongoing modifications allowing the newest technologies to be implemented.

Phase 3: Power Generation System Implementation

Solar panels have been installed, including inverters. Solar thermal panels are installed and a 300-gallon water tank is used to store thermal energy. These systems are oversized to allow for system integration and optimization allowing adequate research possibilities.

Phase 4: Power Storage System

Redesign of the hydrogen storage system is currently underway and will require a new water electrolysis device that is not included in the current funding. Hydrogen cylinders and a small battery array have been installed and a 5 kW fuel cell will be installed shortly.

Phase 5: Monitoring System Design and Installation

The monitoring system is being installed in two stages. The first stage is complete with the installation of an Indoor Air Quality system that measures temperature, humidity, carbon dioxide and volatile organic chemicals every 5 min. The second stage involves the installation of a power monitoring system that will track every kilowatt-hour and British thermal unit that is utilized by the OGZEB. A partnership with Johnson Controls has been established and we are currently working with them to identify all of the locations for acquiring measurements prior to system installation. The data collected by this system will be used to compare and test technologies and will be provided to the public via a web portal

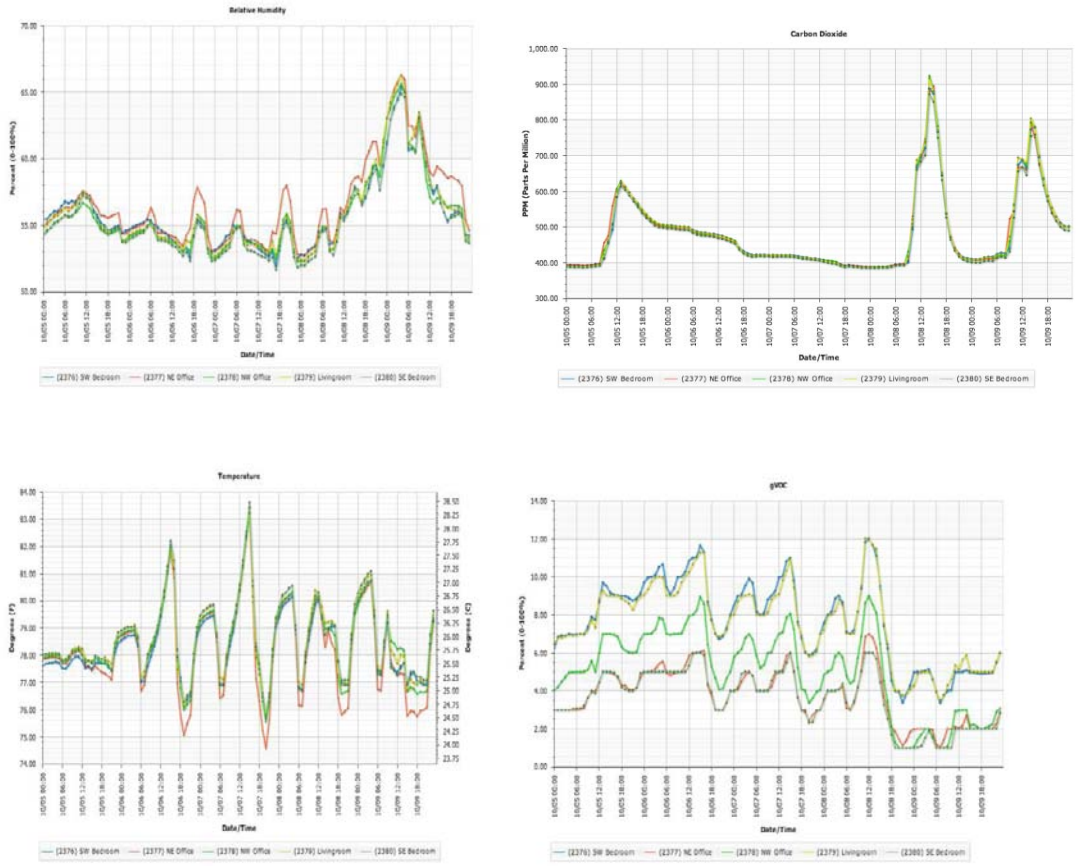


Figure 3: Plots of measured humidity, carbon dioxide, temperature and volatile organic compounds measured in the OGZEB from October 5-9, 2009

Phase 6: System Integration

The initial system integration task is the integration of the HVAC system and the solar thermal system. Students will design a system that will allow energy to move between the systems in a manner that increases the efficiency of each system.

FLORIDA STATE UNIVERSITY

Planning Grant: High Performance and Low Cost Fuel Cells for Future Vehicles

PI: Jim Zheng, Co-PIs: Richard Liang, Chuck Zhang, Ben Wang

Description: The objective of this project is to provide an innovative approach to revolution of current energy storage and conversion technology and greatly leverage FSU position in the strategic important area for sustainable energy. The following tasks are proposed to FSU for funding of the planning grant "High Performance and Low Cost Fuel Cells for Future Vehicles". The proposed tasks will be performed by Drs. Jim Zheng and Richard Liang at the Department of Electrical and Computer Engineering and Department of Industrial Engineering, respectively. First to demonstrate preliminary results in high performance of energy storage and conversion materials and devices in order to seek outside funding consistent with the vision of IESES. The deliverables will be conference proceedings and journal papers and proposal submissions for additional funding.

Budget: $15,000

Progress Summary

1. Students your have employed/funded on the grant and their current status. Michael Greenleaf, a Ph.D. student at ECE department. He is currently working on (1) development of equivalent circuit models for energy storage devices, and (2) investigation of Li-ion batteries safe due to over-charge conditions.

2. Researchers and post-doctoral people who are being funded on the grant. None

3. Travel to conferences, workshops, seminars etc. you have made from the grant and the purpose of these travels and how they help achieve the overall objectives of the research effort.

3.1 Invited seminar: High Performance Fuel Cells using Buckypaper, Louisiana State University, Baton Rouge, LA, February 13, 2009. Increase our research and develop future research projects.

3.2 Site visit for proposal of "An International Collaboration Group on Solar Cell Technologies Development", Sponsor: Chinese Academy of Sciences, Budget: $877,193 (￥6,000,000 RMB), Project Dates: 4/09-4/14. Developed an international collaboration on renewable energy researches and recruit international graduate students and postdoctors.

3.3 Invited paper on 2009 China-North America Workshop on Fuel Cell Science and Technology: Highly Efficient and Stable CNT Paper-Based Electrodes for PEMFCs, Shanghai, China, August 14, 2009.

4. Status of your research efforts, what has been accomplished to date, change of direction/focus, etc.

4.1 The Pt catalytic electrode was developed using carbon nanotube film (buckypaper) as a supporting medium through use of the electrodeposition method. Buckypapers are free-standing thin films consisting of single-walled carbon nanotubes (SWNT), carbon nanofibers (CNF) held together by van der Waals forces without any chemical binders. Mixed buckypapers may be developed by layered microstructures with a dense and high-conducting SWNT networks at the surface, as well as large porous structures of CNF networks as supports. This unique microstructure may improve Pt catalyst accessibility and the mass exchange properties. Pt particles were uniformly deposited in porous buckypaper and had an average particle size of about 6 nm. A promising electrochemical surface area of about 40 m2g-1 was obtained from these electrodes. A Pt utilization of as low as 0.28 gPtkW-1 was achieved for the cathode

electrode at 80 oC. Pt utilization efficiency may be further improved by optimization of the electrodeposition condition in order to reduce the Pt particle size. 4.2 Due to their unique microstructure, buckypaper-supported platinum (Pt) catalysts derived from carbon nanotube (CNT) and carbon nanofiber (CNF) have demonstrated a high Pt utilization in proton exchange fuel cells (PEMFCs). The durability of a buckypaper-supported Pt catalyst was investigated using an accelerated degradationtest (ADT) in a mimic cathode environment of PEMFC. Compared to commercial carbon black-supported Pt, Pt/buckypaper showed better catalyst durability after holding at 1.2 V for 400 hours; specifically, almost 80% of Pt electrochemical surface area was lost for Pt/carbon black, while only 43% loss for Pt/buckypaper. Transmission electron microscopy (TEM) and cyclic voltammetry (CV) were used to study the Pt degradation mechanism. It was concluded that Pt coarsening and Pt detachment from buckypaper support due to carbon corrosion make the major contribution to the Pt surface area loss under this condition. The Pt loss via detachment from supports after the ADT was calculated as 18% in Pt/buckypaper, while the Pt loss was 69% in Pt/C. It is supposedly due to the higher corrosion resistance of buckypaper because of its high graphitization degree which is indicated by a slower formation rate of surface oxides in buckypaper than in carbon black.

5. Papers, presentations, etc. that you have produced from the work.

5.1 Journal Papers P.L. Moss, G. Au, E.J. Plichta, and J.P. Zheng, “Investigation of solid electrolyte interfacial layer development during continuous cycling using ac impedance spectra and micro-structural analysis”, *J. Power Sources*, 189, 66 (2009).

J.P. Zheng, “High energy density electrochemical capacitors without consumption of electrolyte”, *J. Electrochem. Soc*. 156, A500 (2009).

W. Zhu, J.P. Zheng, R. Liang, B. Wang, C. Zhang, G. Au, and E. J. Plichta, “Durability Study of Carbon Nanotube/Nanofiber Buckypaper Catalyst Support for PEMFCs”, *J. Electrochem. Soc*. 156, B1099 (2009).

5.2 Grants

N. Da, F.Y. Huang, S.L. Wang, X.N. Li, J.P. Zheng (co-PI), and D. Wei, “An International Collaboration Group on Solar Cell Technologies Development”, Sponsor: Chinese Academy of Sciences, Budget: $877,193 (￥6,000,000 RMB), Project Dates: 4/09-4/14.

J.P. Zheng (sole PI), Title: 3-D Nanofilm Asymmetric Ultracapacitor, a phase I SBIR Project, Sponsor: Department of Energy, Budget: $30,000, Project Dates: 06/09 to12/09.

FLORIDA STATE UNIVERSITY

Experimental Investigation of Economic Incentives of Policies, Institutions, and R&D in Environmental Conservation

PI: Svetlana Pevnitskaya, **Co-PI:** Dmitry Ryvkin

Description:

The objective of this proposal is to identify key features determining investment behavior in renewable energy technologies and sensitivity of response to incentives and environment. The study will combine theoretical and experimental economics methods. We will provide analysis of efficiency of existing institutions and compare them to alternative mechanisms. In addition we will study some fundamental aspects of this dynamic decision-making problem.

The deliverables will include:

1. A theoretical model and experimental design of an economic environment with dynamic and uncertain negative externalities.

2. A computer program and instructions for conducting experiments

3. A set of experimental sessions exploring the investment and adoption behavior in the absence of institutions and regulation

4. A set of experimental sessions exploring the effect of several regulatory institutions on the investment and adoption behavior

5. Analysis of experimental results and conclusions about the role and efficiency of different institutional designs.

Budget: **$43,217**

Progress Summary

Our statement of work includes two major tasks. Task 1, scheduled to be completed by the end of the first year, serves as a foundation for the subsequent comparative study of institutions (Task 2) in year two. The goal of Task 1 is to design, implement, and test the baseline experimental environment of a global economy with climate change, within which the role of institutions will be assessed. At this point in time, six months into year one, we practically completed our research plan pertaining to Task 1, and even ran initial experiments within Task 2. The main questions we addressed in the first stage of the project are as follows.

1) Game theory and previous experimental research have shown that the behavior in dynamic games with a known *fixed end* differs from those where the *end is uncertain*. As uncertainty is critical to decision making under environmental change, we explored the role of uncertain end in our dynamic environment. We found the end-game effect of production and resulting pollution decisions that is different from the Nash equilibrium and Social Optimum predictions.

2) We studied the effect of heterogeneity in pollution, which is relevant to organizations with heterogeneous members, for example international treaties among countries with different levels of technological development. Heterogeneity was implemented via differences in pollution intensity of production.

3) We modeled the ability of firms to invest in clean technologies, resulting in endogenous rates of emissions.

4) We explored the role of values in economic decision making by framing the experiment in an environmental context. We find that subjects' decisions reflect some homegrown environmental values. The results provide a solid foundation for the direct test of the role of specific institutions in the investments in, and adoption of, sustainable technologies in a dynamic environment with climate change.

Report on Deliverables for Task 1 (scope of Task 1 is one year)

1. A theoretical model and experimental design of an economic environment with dynamic and uncertain negative externalities.

We developed three theoretical models for corresponding decision-making environments and applied two solution concepts to each of them (Nash equilibrium and Social Optimum). We also developed two more solution concepts, *sustainable threshold* and *target pollution level*, that we intend to use in the future. Based on the theoretical predictions we formulated decision-making hypotheses and designed several experimental treatments as described above.

2. A computer program and instructions for conducting experiments

We worked with Sean Collins, our graduate assistant on creating a computer program and completed software for 5 treatments. Instructions were developed for each of those treatments.

3. A set of experimental sessions exploring the effects of dynamics and uncertainty of

externalities on decision making we conducted 13 experimental sessions to collects data for 6 treatments. Subjects were recruited using the standard XS/FS laboratory protocol and each session lasted 2 hours. Subjects were paid with the check at the end of the experiments and their earnings included a flat show up fee plus earnings based on their decisions.

4. Analysis of experimental results and design of a baseline treatment for Task 2.

We conducted econometric analysis of our data and compared theoretical predictions with decisions of subjects in the experiments. We used these results to start designing treatments forTask 2. Actually in early July 2009 we conducted 2 first sessions to serve as initial baseline for Task 2.

We are happy to report that we are ahead of our proposed timetable and are close to completing all 4 deliverables planned for the first year. Such productive start will likely allow us to expand the scope and depth of the study and increase the "research per dollar" effectiveness of the IESES grant even further.

Report on Metrics (planned across the two years)

A) Theoretical predictions, experimental designs and research hypotheses

B) Computer programs and experimental instructions ready to conduct sessions

C) Completed experimental sessions

D) Experimental data analyzed

All four are completed for Task 1 as described above

E) Working papers written, circulated and presented

Svetlana Pevnitskaya presented our work at 1. “Economic Games and Mechanisms to Address Climate Change,” a workshop organized by the Mathematical Sciences Research Institute at UC Berkeley, May 5, 2009 (invited speaker)

2. International Meeting of Economic Science Association (ESA), Washington DC, June

26, 2009

3. IESES research seminar series (first talk in the series), FSU, July 1, 2009

At this time we are in the process of writing the first paper. Results of our study have been circulated in the Powerpoint presentation form and were part of IESES Newsletter.

F) Papers submitted to journals

We plan to submit the first paper by the end of the year.

G) Proposals for external funding submitted

We submitted a proposal for a NSF grant (both of us are co-PIs, Mark Isaac is a PI). The 5-year grant proposal includes 5 FSU faculty members as PI or co-PIs (and 9 faculty total), including one from the College of Engineering.

University of Central Florida

Enhanced and Expanded PV Systems Testing Capabilities at FSEC

PI: Stephen Barkaszi, Robert Reedy

Description: An important FSEC function is consumer protection from poorly designed and manufactured PV modules and systems. FSEC's test capabilities were established over 10 years ago and were adequate at the time to test and certify PV modules for certification. However, PV costs have fallen and competing electric utility rates have risen. In the last two years, these curves have crossed under some economic scenarios and incentive programs, and the demand for PV module testing and system certification has jumped. Thus, this task will provide for enhanced and expanded PV testing and certification capabilities. The task will also be done in close coordination with FSEC's work with the U.S. Department of Energy's PV program.

Budget: $196,018

Universities: UCF/FSEC

Progress Summary

The objective of this project is to provide for enhanced and expanded PV testing and certification capabilities at the Florida Solar Energy Center. Using funding from the Consortium, this project has been used to either purchase or leverage the purchase of photovoltaic test equipment that will be used to expand the research and commercial testing capabilities at FSEC.

A state of the art long-pulse simulator has been purchased and will increase the turn-around time for commercial testing and will allow more accurate testing of newer thin-film and multi-junction modules. The new solar simulator and the existing simulator will be housed in the enclosed inverter and module test facility. The simulator test area in the facility will be more than twice the size of the existing simulator lab.

Plans are in progress for expanding the outdoor test area for PV module, inverter, and system testing at the FSEC site. Additional module I-V multi-tracers have been specified and will triple the number of modules that can be tested concurrently. This allows commercial short-term testing of production modules to be conducted concurrently with the long-term testing of different modules for research without conflict or interruption.

Space has been allocated for expanding the fixed module exposure area to approximately double the available rack space. This planned expansion has already attracted contract research for small systems side-by-side testing at FSEC. An area is also planned for installation of a dual axis tracker to enhance the existing test capabilities.

2009 Annual Progress Report

Project Impact: The U.S. PV industry has been growing at a rate of 52% per year (increasing from 271 Megawatts in 2007 to 412 Megawatts in 2008). The 2009 increase is projected to still be large, but not as large as 2008. The states with major PV markets are California, New Jersey, New York, Arizona and Texas. The present U.S. PV industry is primarily comprised of seven companies with manufacturing facilities in Arizona (2), and one each in California, Michigan, Maryland, Massachusetts and New Mexico. (Florida has a better solar resource than any of these states except Arizona and has doubled the solar resource of the world's largest PV market – Germany).

Yet, in spite of the vast potential, photovoltaics currently provides only about one-millionth of the worlds total electricity supply. The huge gap between our present use of PV and its enormous undeveloped potential presents a grand challenge in energy research. As Edison suggested in 1931, sunlight is a compelling solution to our need for clean, abundant sources of energy. It is readily available, secure from geopolitical tension, and its use poses no threat to the environment or climate through pollution or emission of greenhouse gases.

Solar PV creates more jobs per MW of capacity than any other energy technology. Since PV has no fuel cost, instead of sending money out of state to buy fossil fuel for power plants, a PV solar initiative will create high-quality jobs and a more robust state economy. Estimates have shown that a 4 GW solar program would generate approximately 54,000 direct job-years in Florida in 12 years.

Project Description:

The demand for PV products is driven by three major forces: the recent "boom" in green energy awareness, the globalization of the solar industry with many previously uncertified overseas manufacturers and the rapid change in PV cell and module technologies. Thus, the need for providing enhancement and expansion of FSEC's PV testing and certification capabilities. The testing capacity will implement by the following plans:

Enclose and outfit a permanent PV Module and Inverter Test Area
Upgrade and expand test and analysis equipment and software that includes permanent outdoor test stations with I-V curve tracing equipment
Purchase a long-pulse simulator for indoor PV testing
Install and instrument a dual-axis tracking platform
Construct additional fixed rack space for outdoor testing

In addition to these specific equipment improvements, FSEC intends to enhance the general testing infrastructure to include improved instrumentation, documentation and test procedures.

Testing Instrumentation

The instrumentation used for PV testing has been adequate for the previously pace of testing, and the emphasis on research testing. However, for the high-throughput commercial testing now needed, it will be necessary to completely rebuild the wiring and instrumentation setup, with a focus on organization, quick connect/disconnect ability and flexible configurations.

Reporting and Certification

With more automated test data gathering and processing resulting from the upgraded laboratory instrumentation and computational capabilities, PV Test Reports will be more expeditiously completed. In addition, the format of the test reports is to be improved for more accuracy, rapid preparation and ease of use.

Certification Application Documents

Along with reporting and certification tasks, FSEC will also improve the format and content of the Application Forms submitted by the clients. These improvements are geared to both simplify the client's tasks in preparing the Application, aid the client in better defining their products and improving the facilitation of the preparation of the resulting test report.

The instituting of the advancements summarized above will require approximately six months for implementation of the procedural and general infrastructure (non-capital) improvements. It is the Center's goal to aid the PV industry by responding as quickly as possible to the new and growing markets with the essential constraints of reliable and credible high quality testing and certification.

Deliverables:

Expanded Testing Facilities for PV modules and systems, with proven capabilities:
Long-pulse solar simulator for new multi-junction cell designs
One dual-axis tracking platform for maximum exposure and aging testing
Stationary I-V curve tracers, with flexible connection systems
Doubling of fixed test rack space
Improve certification process and minimize time requirements

Industry Support:

This task will be strongly supported by the PV manufacturers. Many such companies have already contracted with FSEC for testing in our uniquely hot, humid and lightning-prone environment. Further, the US DOE is expected to continue support FSEC's PV test program with contract work for accelerated aging, high voltage and generalized testing.

UNIVERSITY OF CENTRAL FLORIDA

PV Manufacturing Data Base and Florida Applications

PI: David Block, Robert Reedy

Description: The overall goal of this project is to assist in the stimulation of the development of a photovoltaic (PV) manufacturing industry in Florida. The project objective is to conduct a review of the national and international PV manufacturing data for the purposes of establishing industry practices and an industry data base. The data base will then be available to assist Florida in establishing PV manufacturing firm(s).

Budget: $81,120

Universities: UCF/FSEC

Progress Summary

This project has established a data base for assisting in the establishment of PV manufacturing facilities in Florida. The following information has been determined:

Worldwide Statistics
In 2008, the worldwide PV industry produced 6,941 Mw and experienced its strongest growth – an increase of 87%.
Europe leads in world production with 1,909 Mw at 27.5%, closely followed by China with 1848 Mw at 26.6%.
The U.S. only accounts 412 Mw or 5.9%.
The U.S. installed 6.4% of world installations in 2008.
The U.S. has only one manufacturer in the top 15 world companies – First Solar is at number 2.

U.S. Statistics
The top seven U.S. manufacturers supply 96% of the U.S. total.
The two largest U.S. producers use thin film technologies and these producers account for 65% of the U.S.'s capacity – First Solar and United Solar.
For the seven U.S. manufacturers, 2 are located in Arizona, and one each in Maryland, Massachusetts, Michigan and New Mexico.
California leads in PV installations with 178.7 Mw or 62% of the U.S. total followed by New Jersey with 22.5 Mw or 8% of total.

Key Florida Results
Four 2009 PV installations for a total of 37 Mw has moved Florida to second in U.S. PV installations.
140 Mw of Florida PV installations are now in planning for the next 5 years – GRU, FMEA, OUC, and Lakeland.
Four PV manufacturers now have or have proposed Florida locations – Advanced Solar Photonics, Willard & Kelsey, Mustang Vacuum Systems, and Blue Sky Solar.

2009 Annual Progress Report

In order to set the background for PV manufacturing in Florida, a data base of PV in the world and then the U.S. was first established. Florida's opportunities and prospects are then evaluated.

World PV Manufacturing Statistics

The following Table 1 presents the world's PV manufacturing output (from Reference 1) for the years 2006, 2007 and 2008 (2008 is the latest available data).

Table 1 - World PV Output by Country/Region
All values are in megawatts (Mw)

Region/Country	2006	2007	2008	07 to 08 Growth	World Percent
U.S.	177.6	270.6	412.0	52.3%	5.9%
Japan	926.4	923.5	1,224.0	32.5%	17.6%
Europe	673.3	1,069.0	1,906.6	78.4%	27.5%
China	341.8	837.8	1,848.4	120.6%	26.6%
Taiwan	169.5	377.0	853.9	126.5%	12.3%
India	38.4	41.2	157.0	281.0%	2.3%
ROW	131.5	195.4	539.2	175.9%	7.8%
Total	2,458.5	3,714.5	6,941.1	86.9%	100.0%
% Thin Film	6.9%	11.6%	13.7%		

It is noted that for 2008 the worldwide PV industry experienced its strongest growth – an increase of 87% as shown above. From Table 1, Europe leads in world production with 27.5%, closely followed by China with 26.6%. The U.S. only accounts for 5.9% or 412 Mw.

The type of manufactured PV modules by material showed that thin film production grew at 121% from 2007 to 2008. The thin film increase was sparked by First Solar and United Solar. However, crystalline silicon also grew and still controls 86% of the world's market.

With world production established, let's next examine the individual companies that are the world's largest manufacturers. Presented in Table 2 are the top 15 companies in terms of yearly production (Reference 1).

Table 2 – Top 15 companies in PV production. All values are in megawatts.

Company, Location	2007	2008	07-08 Growth	Capacity 09
Q-Cells, Germany	389.2	570.4	46.6%	800
First Solar, U.S., Germany, ML	207.0	504.0	143.5%	10,970
Suntech Power, China	327.0	497.5	52.1%	1,000
Sharp, Japan	363.0	473.0	30.3%	855
Motech, Taiwan	176.0	384.0	118.2%	800
Kyocera, Japan	207.0	290.0	40.1%	495
Baoding Tiamwei Yingli, China	142.5	281.5	97.5%	600
JA Solar, China	113.2	277.0	144.7%	875
Sunpower, Philippines	99.5	236.9	138.1%	450
SolarWorld, Germany	95.0	160.0	68.4%	200
Trina Solar, China	37.0	210.0	467.6%	400
Sanyo, Japan	165.0	210.0	27.3%	500
Gintech, Taiwan	55.0	180.0	227.3%	560
Solarfun, China	88.0	172.8	96.4%	420
Canadian Solar, China	7.5	167.5	2,133.3%	420

Note that there is only one U.S. company, First Solar, and its production takes place in three regions – U.S. at 147 Mw, Germany at 196 Mw and Malaysia at 161 Mw for the total of 504 Mw. The large 2009 capacity for First Solar is because of its reporting that the Malaysian plant has a production capacity of 754 Mw.

It is also interesting to note that the total yearly production from the 15 companies are 2,471.9 Mw for 2007 and 4,614.6 Mw for 2008, or 33.5% of the world's total output for each of those years.

U.S. PV Manufacturing Statistics

Now let's examine the U.S. manufacturers in more detail. The following Table 3 presents the top seven U.S. manufacturers for 2006, 2007 and 2008 (Reference 1).

Table 3 - U.S. PV Manufacturers and Output for 2007 and 2008

Company	Location	Material	2006	2007	2008	07 to 08 Growth	Capacity 09
First Solar	AZ	Cadmium Telluride	60.0	120.0	147.0	22.5%	147.0
United Solar	MI	Amorphous Silicon	28.0	48.0	113.0	135.4%	238.0
Solarworld CA	CA	Silicon	35.0	35.0	61.0	74.3%	250.0
BP Solar	MD	Silicon	25.6	27.7	27.7	0.0%	44.0
Evergreen Solar	MA	Silicon Ribbon	13.0	16.4	26.5	61.6%	160.0
Schott Solar	NM	Silicon	13.0	9.0	11.0	22.2%	NR
Global Solar	AZ	CIGS	2.5	4.0	7.2	78.9%	60.0
Other	--	--	0.5	10.5	18.7	77.8%	251.5
Total	--	--	177.6	270.6	412.0	52.3%	1,150.5

These seven manufacturers supply 96% of the U.S. total. It is also interesting to note that the two largest U.S. producers both use thin film technologies. Thin film accounts for 65% of the U.S.'s capacity. Of the seven U.S. manufacturers, 2 are located in Arizona, and one each in Maryland, Massachusetts, Michigan and New Mexico. Florida had no manufacturers in 2008.

Installed Data

Of interest next is the world statistics for PV installations. Table 4 presents the world data for installations in 2008 and for total capacity installed (Reference 2 and 3). Note that the 2008 installed capacity is less than the production capacity for 2008. The reason for the difference is in the collected data – installed capacity is more difficult to obtain and installation follows production.

Table 4 – World PV Installed in 2008 and Total Installed Capacity – Values in Mw

Region/Country	Installed in 2008	%	Total Installed Capacity	%
Europe	4592	85.6%	9533	72.3%
Spain	2281		2973	
Germany	1500		5308	
France	105		175	
U.S.	342	6.4%	1200	9.1%
S. Korea	224	4.2%	352	2.7%
Japan	208	3.9%	2100	15.9%
Total	5366	100%	13185	100%

Next the PV installations in the U.S. by state for 2007 and 2008 are presented in Table 5 (Reference 4).

Table 5 – Top 10 States of PV Installations

2008 Rank by State	2007 (MW_{DC})	2008 (MW_{DC})	07-08 % Change	2008 Market Share	2007 Rank
1. California	91.8	178.7	95%	62%	1
2. New Jersey	20.4	22.5	10%	8%	2
3. Colorado	11.5	21.7	88%	7%	4
4. Nevada	15.9	14.9	-6%	5%	3
5. Hawaii	2.9	8.6	200%	3%	6
6. New York	3.8	7.0	85%	2%	5
7. Arizona	2.8	6.4	129%	2%	7
8. Connecticut	2.5	5.3	109%	2%	8
9. Oregon	1.1	4.8	330%	2%	11
10. North Carolina	0.4	4.0	899%	1%	16
All Other States	7.2	15.9	122%	5%	
Total	160.3	289.8	81%		

From the above, California leads with 178.7 Mw and 62% of the total followed by New Jersey with 22.5 Mw and 8% of the total; in the data for 2008, Florida does not have a ranking. It is noted that there is a difference in the installed data between references 3 and 4.

However, because three installations completed in 2009, Florida is now ranked second in installations. These three installations are:

Table 6 – Recent Florida Installations

Location	Size	Status
FPL DeSoto County	25 Mw	Installation complete
FPL at Space Coast	10 Mw	Complete in Dec.
FPL at NASA/KSC	1 Mw	Installation ongoing
Orange County Convention Center	1 Mw	Installation complete
Total in 2009	37 Mw	

Thus, in six months, Florida went from last to second in the U.S.

Other Florida Installations

In addition to the three recent Florida installations mentioned in Table 6, there are several large installations proposed or close to being bid. These are:

1. Gainesville Regional Utilities – GRU, the utility for the cities of Gainesville and Alachua County, has begun the process of offering an individual user profit-based feed-in tariff as a financial mechanism to support the area's growing solar electrical generation capacity. The feed-in tariff will require GRU to compensate local renewable energy producers at a rate of $0.32/kw-hour for power they generate over a 20-year contractual agreement period. GRU presently serves 80,000 residential and 10,000 nonresidential customers, and according to the utility, the rate increase for this program amounts to about a dollar a month for all its customers. To maintain this fee, GRU will limit the feed-in tariff to 4 megawatts per year.

2. Florida Municipal Power Agency – FMPA has announced a plan that it intends to install up to 100 Mw of PV over the next five years. These installations will be at member utilities and will be throughout the state.

As a part of the FMPA program, Lakeland City Electric has announced that it is in the early stages of developing a total of 24 megawatts of photovoltaic capacity throughout their service territory using commercial customers' rooftops and city properties including the rooftop of Staples and Kohl's department stores. This plan is for three years and parts are under construction.

3. Solar in Schools – The Governor's Energy Office through the federal stimulus program has proposed putting PV on 90 schools. This $10 million program could put 900 kw or about 1 Mw on Florida schools in the next few years.

4. Orlando Utilities Commission – OUC has issued a qualifications for bid to vendors for the installation of 10 Mw. The qualifications for bid is preliminary to the issuing of the RFP for the project.

Tampa Electric Company – TECO is planning to sign a power purchase agreement to install 25 Mw of PV on reclaimed phosphate land in Polk County.

Adding the above together gives about 145 Mw to be installed in the next five years.

Florida PV Manufacturing Information

In a similar fashion to the PV installations, announcements of PV manufacturers locating in Florida have dramatically increased in the past year and one half. The following presents the best available public information on proposed manufacturers.

1. Advanced Solar Photonics – Advanced Solar Photonics (ASP) announced that the company's monocrystalline solar panels are slated to come on the line in July of 2009. The company announced that clean rooms are in place, equipment is being installed and a pilot line will be up and running to allow for full certification. Starting at 5 Mw in July and ramping up to 100 Mw at the end of 2009, ASP will increase production capacity by 50 Mw every quarter thereafter to be at 500 Mw by 2011. Additionally, full thin film production is scheduled to ramp up to 40 Mw by late 2010. If true, the SolarFABT facility will be largest thin film and monocrystalline solar manufacturing plant in the U. S. ASP is located in Lake Mary, Florida and employs an international team of technology driven professionals. ASP's cutting-edge laser equipment for solar panel processing, solar cells, and commercial solar products for the solar industry is applicable to both the silicon and thin-film processes. ASP expects to hire approximately 200 people by the end of the summer of 2009 and another 1300 over the next two years. (Announced by ASP press release on May 11, 2009.)

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2. Willard & Kelsey Solar Group – Willard & Kelsey is an Ohio-based solar company that may bring a new PV plant to Orlando. According to the *Orlando Sentinel* (May 22, 2009) the company may bring up to 3,600 jobs to Orange County and could collect as much as $31 million in state and local incentives – one of the largest public payouts in years to lure a private company here.

The *Sentinel* information was obtained from a 31-page energy grant application that the Willard & Kelsey Solar Group used to win a recent $2.5 million Florida clean-energy grant. The application says the company is considering building a new Florida headquarters and 1 million square feet of solar-panel-production space. The records also show that the company is – for now, at least – focused on building near Orlando, though other Florida cities and the Toledo, Ohio, suburb where it recently opened another facility are also competing for the plant. Plant officials said that they are discussing this with many states. Everybody has a different incentive package, including Ohio, but they have not signed any deal with anybody. We are talking to Florida, but we are also talking with Michigan, Mississippi, and Ohio.

The project could cost $1.2 billion, and they have applied for $100 million in federal stimulus money to build the facility in Ohio. Its 262,000-square-foot plant along State Rt. 25 in the former Delafoil plant is a $14 million project.

The Orlando news story said Willard & Kelsey signed a preliminary deal with Orlando area developer Crockett Development Property to build a solar panel park on 238 acres near Orlando International Airport.

The start-up plant management has said it has orders for 300 megawatts worth of solar panels – about two million panels or what four lines produce in a year – and is negotiating to sell another 1,000 megawatts.

3. Mustang Vacuum Systems, LLC, Manatee County, FL – This company received $577,636 from the Florida Renewable Energy Grants Program in May 2009. It has stated that it will match the Florida grant with $18,430,680 in cost share. This project will allow Mustang Vacuum Systems to expand its thin-film solar photovoltaic cell production. To meet the project goal of reducing solar energy costs, the company has designed and built three types of machines to meet the particular needs and specifications of solar cell manufacturers.

With the Florida grant, the company will design and manufacture larger machines to meet customer demands as well as increase its production capacity by moving to a larger facility. The project will increase the availability and production of thin-film solar photovoltaic cells by improving and expanding plant operations.

4. Blue Sky Solar, Inc. – Blue Sky Solar has made preliminary comments concerning the location of a PV manufacturing plant in Orlando. It has a website at www.blueskysolar.com which states that Blue Sky Solar is a U.S. based manufacturer of large-sized solar modules. Each frameless glass module, 5.72 square meters in size and less than 10 millimeters thick, will produce more than 514 watts of electric power. The module's proprietary technology consists of fine layers of amorphous silicon/microcrystalline silicon (a-Si/µc-Si) which are deposited on a glass substrate. The technology uses techniques developed through 40 years of industry experience that combine proven silicon thin film technology with very large area manufacturing and industry time-tested equipment. The result is a versatile, aesthetically pleasing module with a lower cost per watt of energy produced and competitive with current electricity generation. The website also lists key personnel. Modules from China (which use the same Applied Materials manufacturing equipment and process) are in shipment to FSEC and NREL for performance and exposure testing.

Projections for 2009

Because of both the world's and the U.S.'s present economic conditions it is doubtful that 2009 can meet the growth experienced in 2008. A growth of 13% has been predicted by PVNews (Reference 1). The following is taken from PVNews:

"As detailed in last month's PVNews, we project a 13 percent increase in global installations in 2009, a sobering number compared to the explosive growth of years past, particularly 2008. While the long term prospects for the industry remain bright, it seems increasingly likely that the next two years will be a bumpy ride, with many sub-optimal and less differentiated performers being shaken out of the market, and only the fittest surviving."

There was also a very interesting article about PV manufacturing called "Solar Shakeout" in Reference 5. This article stated that of the present some 250 companies, there will probably only be a couple of dozen in five years.

Which companies will be the winners? The ones with deep pockets, cutting-edge technology, and a rigorous focus on cutting costs. They'll need to be big enough to build a brand name and demonstrate staying power. As close observers explain, customers want to know that the solar-energy companies they buy from today will be around to honor their warranties in the future.

Although opinions differ on who the winners will be, four names keep popping up: First Solar Inc. and SunPower Corp., both based in the US; Sharp Corp., headquartered in Japan; and SunTech Power Holdings in China.

In their own way, these firms have already distinguished themselves in the crowded field. If they do emerge as winners, their host countries can probably bank on building networks of solar-energy related suppliers around them, analysts say.

Another article that discusses the U.S. in 2009 is Reference 4. It has made the following statement:

"Over the long-term, the prospect for growth in solar installations is bright. Early indicators point to market growth in 2009, though likely at a slower rate than during the last several years. The market should return to high growth rates in 2010. The long-term extension of the federal Investment Tax Credit (ITC), new rules that allow utilities to take advantage of the ITC, and the establishment of a grant program alternative to the commercial ITC will all help solar installations. Since these policies were just recently enacted (in October 2008 and February 2009 respectively), the market will take some time to respond to these new policies. Companies have announced plans for many large solar electric projects, including solar thermal electric projects, utility-owned projects, and third-party owned projects. A few of these projects will be completed in 2009, but most will come on-line in 2010 and beyond."

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UNIVERSITY OF CENTRAL FLORIDA

Concentrating Solar Power Program

PI: Charles Cromer **Co PI:** Robert Reedy
Students: Pablo Izquierdo (Ph.D.)

Description: Solar concentrating systems use direct beam solar energy focused to produce high temperatures for power production. They hold promise for Florida given a sufficient direct beam resource and assuming the technology can meet production and cost goals. Existing measurements of direct beam solar energy are limited to a few Florida locations. The objective of this R&D project is to advance concentrating technologies by conducting an analytical study of the Florida solar resource in order to predict performance and the amortized cost of energy from this technology in the Florida environment. Later years may include experimental tests for validation of the predicted results.

Budget: $52,000
Universities: UCF/FSEC
External Collaborators: FPL

Progress Summary

The evaluation of solar concentration systems for performance and energy production requires as input, a prediction of the solar direct beam resource throughout the year for the anticipated installation location. These systems have been previously installed in the desert southwest where direct beam data has been accumulated over many years. A problem was identified – the lack of validated direct beam measurements for the State of Florida.

Literature Search Completed: Various methodologies to resolve the problem were investigated through literature search. Over 40 published papers were reviewed for information on the determination of the direct beam resource and the establishment and validation of predicting equations.

Method Selected: The Heliostat-2 method was selected as the most viable to provide validated direct beam historical data for Florida. This method (developed a few years ago by Ecole de Mines de Paris) basically consist of using two parameters, turbidity (atmospheric conditions), and elevation as input, to provide an estimation of the total, beam and diffuse radiation based on a "clear sky model". That is, the amount of direct beam and diffuse radiation that would reach the ground for a totally clear sky, given location, time of year, and time of day. Then satellite images (visible band – grey level on the pixel/point of the image), are used to calculate a prediction of the cloudy level for each pixel of the satellite image. This level is then used by equation to modify the "clear sky" data to produce a predicted value of the beam and diffuse solar radiation. These values are validated with on-the-ground measurements. Once these values are calculated and validated they can be used to produce a historical data set of solar radiation for any given lat – long location across Florida. The data is also used to produce a statistically based 95% confidence interval for the expected solar radiation for any site. This information is a necessary input for existing performance/output models to determine projected cost per kWh of solar concentrating power plants in the Florida environment.

Programming of Algorithms Underway: It was determined to program the equations for each stage in the calculation sequence into two separate calculation platforms: Matlab and Excel. Matlab was selected for its ability to handle and manipulate the very large number of matrices needed to make the calculations

for the entire data base. Excel was selected to provide a step by step visualization of each calculation, for a single pixel and time, as a check on the programming and matrix manipulations of Matlab. Turbidity calculations have been completed and published for Europe, but are not available for the US or Florida. Thus, this must be part of the calculation sequence for the model. Programming for the model on these two platforms has begun.

Proposals Written: One objective of the Consortium effort is to leverage the activity with funding from other sources and the model developed could be used in other locations. To this end, two proposals for outside funding were written and submitted in this past review period. The Commonwealth of Puerto Rico is also interested in the viability of concentrating solar power production. They have the same difficulty as Florida, the lack of validated historical data on the direct beam solar resource needed to evaluate this opportunity. The two proposals were: a. $208K Determination of the Solar Resource for Puerto Rico, to the Puerto Rico Energy Office for an island wide study, and b. $35K Determination of the Solar Resource at the Phillips Plant, to Puerto Rico Electric Power Authority (PREPA), to do a resource evaluation for a specific site. These proposals are still under review – not yet funded.

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The general objective of this R&D project is to advance concentrating technologies that can be deployed in Florida for the near term and to develop advanced technologies that make future solar trough concentrating power plants more competitive with conventional power plant sources.

The project will consist of two phases as follows:

Phase I: Conduct analytical study of Florida solar resource and predict the performance of a concentrated solar power plant.

Phase II: Perform experimental tests and evaluations of the analytical results from Phase I.

Project Impact:

Solar concentrating systems use mirrors to focus sunlight onto receiver pipes located at the focal point of the parabolic mirrors. The fluid is then stored and used to generate electricity from a conventional steam turbine. Given a sufficient input of direct beam solar energy, concentrating solar system plants are one of the lowest-cost centralized solar power options, with great potential to become directly competitive with conventional power sources. After many years of applications, solar concentrating technology has the ability to produce electricity for about $0.10/kWh in the desert southwest environment. The technology holds promise for Florida and could also produce low cost solar electricity in Florida assuming the direct beam resource is sufficient and the technology can meet production goals.

Solar concentrating technology has been successfully applied in the U.S. desert southwest. To use the same southwest desert technology in Florida may not be applicable because Florida's solar resource (amount of direct solar radiation) is significantly less than the desert southwest, and because of Florida's harsher environment conditions of high humidity and salt air.

Trough Concentrating System in Arizona.

In the first phase, this project will conduct a literature search, and develop a model to produce a historically based solar resource set of tables for locations across Florida. These tables will be validated by comparison with the direct solar radiation data collected at FSEC as part of the solar collection testing program. This data has been collected for longer than 10 years at FSEC's location and was also collected at FSEC's old location in Cape Canaveral. The first outcome of this effort will be validated values for the solar direct beam and diffuse resource available across Florida. This solar resource data will then be used to predict the power output performance of a solar trough system, given the potential location of installation.

Assuming that Phase I results are satisfactory, Phase II will perform an experimental test in order to evaluate the analytical predictions. In addition, this project will test complete prototype systems and each of the system components for their application, durability and reliability. Without a durable and reliable system, the solar concentration project has the potential of not providing the energy it was design to produce. The research plan is to install one solar concentrator pilot system and collect the operating and performance data.

Project Description:

The goal of this program is to analytically evaluate and then develop and test concentrating solar thermal power systems as they are applied to the solar radiation and the environment conditions of the state of Florida. The specific project goals are:

Phase I
Analytically evaluate the solar radiation resource for Florida.
Evaluate concentrator performance for potential Florida locations.

Phase II

Evaluate collector support pylons

Field test collector support bearings
Deploy, test and evaluate hydraulic drive mechanisms
Implement and check ball joint assemblies
Field test tracking controller (sun tracking)
Collect operating and performance data

In achieving these goals, the project is designed to increase the potential of U.S. solar collector technology, improve concentrating receivers and support development of advanced thermal storage technologies. The project will also improve computer simulation tools and testing capabilities and improve the technological knowledge base necessary to support the growth of a new solar concentrating industry in the southeast.

For Phase II, this project will be closely coordinated effort with FPL and will use FPL's solar concentrators that are to be used for the Florida solar power project. FPL support will be required. One of the technologies to be studied is the Ivanpah Solar Electric Generating System. The Ivanpah System is presently planed to be used on three solar thermal power plants near Ivanpah Dry Lake in California on land managed by the Bureau of Land Management. The proposed California project is to be constructed in three phases: two 100-megawatt (MW) phases (known as Ivanpah 1 and Ivanpah 2) and a 200-MW phase (Ivanpah 3). The three plants are collectively referred to as the Ivanpah Solar Electric Generating System and would be located in the Mojave Desert close to the California-Nevada border.

The intent of this project is obtain the initial groundwork technical data needed for implementing FPL's recently announced 300 mega-watt solar power plant for Florida. Performance and durability data will be taken in collaboration with FPL.

Industry Support:

After many years of applications, solar concentrator technology has the ability to produce electricity for about $0.10/kWh in the southwest desert. The technology holds high promise for Florida assuming it can meet production and cost goals. The technology also has large potential to generate electrical power and to produce the local jobs that support this form of power production. The electrical mega-watt power needs for Florida far exceeds the ability to build enough solar concentrator plants to meet the state's demand.

The prime supporter of this project is FPL. All of the other Florida and Southeast utilities will be interested in the project's outcome and the data produced.

Estimated Budget:

Annual budget for this task is $52,000 to be allocated for 0.5 FTE faculty member. Continuation of this task will depend upon securing of federal or industry support.

Phase I Effort:

Phase I has two tasks that must be completed sequentially:

Task 1. Determine the solar resource for any designated installation site in Florida.
Task 2. Calculate the expected amortized cost of energy that would be produced from that site given its location and the solar concentrator equipment anticipated to be installed at that site.

The effort of the past months has focused on the completion of Task 1: The determination of the solar resource for any designated installation site in Florida. These systems have been previously installed in the desert southwest where direct beam data has been accumulated over many years. A problem was identified – the lack of validated direct beam measurements for the State of Florida.

Literature Search Completed: Various methodologies to resolve the problem were investigated through literature search. Over 40 published papers were reviewed for information on the determination of the direct beam resource and the establishment and validation of predicting equations. The five most appropriate to the task – providing validated equations – were:

Kasten, F., and A. T. Young. 1989. Revised optical air mass tables and approximation formula. Applied Optics 28:4735–4738.

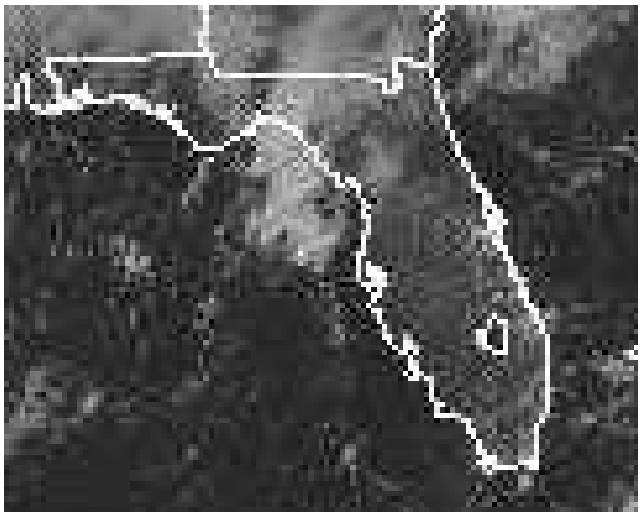
Young, A. T., and W. M. Irvine. 1967. Multicolor photoelectric photometry of the brighter planets. I. Program and procedure. Astronomical Journal 72:945–950.

Young, A. T. 1994. Air mass and refraction. Applied Optics. 33:1108–1110.

Hardie, R. H. 1962. In Astronomical Techniques. Hiltner, W. A., ed. Chicago: University of Chicago Press, 184–. LCCN 62009113

Rozenberg, G. V. 1966. Twilight: A Study in Atmospheric Optics. New York: Plenum Press, 160. Translated from the Russian by R. B. Rodman. LCCN 65011345

Method Selected: The Heliostat-2 method was selected as the most viable to provide validated direct beam historical data for Florida. This method (developed a few years ago by Ecole de Mines de Paris) basically consist of using two parameters, turbidity (atmospheric conditions), and elevation as input, to provide an estimation of the total, beam and diffuse radiation based on a "clear sky model". That is, the amount of direct beam and diffuse radiation that would reach the ground for a totally clear sky, given location, time of year, and time of day. The calculation protocol begins with a calculation for the "extra terrestrial insolation value." The air mass is then calculated given the altitude of the site and surface barometric pressure. The turbidity (absorption and scattering) of the air mass is then calculated based on ground temperature and humidity which is used to derive the "clear sky" data.



GOES – STATIONARY SATELLITE IMAGE OF FLORIDA (FROM NOAA)

Then satellite images (visible band – grey level on the pixel/point of the image), are used to calculate a prediction of the cloudy level for each pixel of the satellite image. This level is then used by equation to modify the "clear sky" data to produce a predicted value of the beam and diffuse solar radiation. These values are validated with on-the-ground measurements. Once these values are calculated and validated they can be used to produce a historical data set of solar radiation for any given lat – long location across Florida. The data is also used to produce a statistically based 95% confidence interval for the expected solar radiation for any site. This information is a necessary input for existing performance/output models to determine projected cost per kWh of solar concentrating power plants in the Florida environment.

Programming of Algorithms Underway: It was determined to program the equations for each stage in the calculation sequence into two separate calculation platforms: Matlab and Excel. Matlab was selected for its ability to handle and manipulate the very large number of matrices needed to make the calculations for the entire data base. Excel was selected to provide a step by step visualization of each calculation, for a single pixel and time, as a check on the programming and matrix manipulations of Matlab. Turbidity calculations have been completed and published for Europe, but are not available for the US or Florida. Thus, this must be part of the calculation sequence for the model. Programming for the model on these two platforms has begun.

Proposals Written: One objective of the Consortium effort is to leverage the activity with funding from other sources and the model that is in development under this effort could be used in other locations. To this end, two proposals for outside funding were written and submitted in this past review period. The Commonwealth of Puerto Rico is also interested in the viability of concentrating solar power production. They have the same difficulty as Florida, the lack of validated historical data on the direct beam solar resource needed to evaluate this opportunity. The two proposals were: a. $208,000 Determination of the Solar Resource for Puerto Rico, submitted to the Puerto Rico Energy Office for an island wide study, and b. $35,000 Determination of the Solar Resource at the Phillips Plant, submitted to the Puerto Rico Electric Power Authority (PREPA), to do a resource evaluation for a specific site. These proposals are still under review by the potential funding agencies – not yet funded.

FESC
Florida Energy Systems Consortium

UNIVERSITY OF CENTRAL FLORIDA

Development of High Throughput CIGS Manufacturing Process

PI: Neelkanth Dhere
Students: Sachin Kulkarni, Ph.D.; Vinay Hadagali, Ph.D.; Parag Vasekar, Ph.D.; Shirish Pethe, Ph.D.; Ashwani Kaul, Ph.D.; Eigo Takahashi, M.S.; Saisitaram Ramesh, Ph.D.; Bihag Joshi,Ph.D.

Description: A reduction in the cost of CIGS and other thin PV film modules is required for wide scale PV applications. The goal of this project is to attract a PV manufacturing company to Florida by developing a high-rate manufacturing process for $CuIn_xGa_{1-x}Se_2$ (CIGS) solar cells. The objective is to develop a high-rate deposition process for synthesis of CIGS absorbers and other layers by employing in-line and batch deposition techniques.

Budget: $141,620

Universities: UCF/FSEC

Progress Summary

In order to attract a PV manufacturing company, it is essential to develop a PV process that has high yield and low cost of production. Therefore, multi-faceted efforts are undertaken to improve and optimize each of the process involved in the preparation of $CuIn_xGa_{1-x}Se_2$ (CIGS) thin film solar cells.

Initial efforts were directed towards increasing the deposition rate for the metallic precursors that are deposited by DC magnetron sputtering. The deposition rate was increased to ~7 Å/sec. but the deposition rate was not increased further due to possibility of overheating of the sputtering targets. Next, experiments were carried out to determine if a single layered molybdenum film can be developed to replace the multi-layered molybdenum film that is currently being used. Various sputtering power and pressures were evaluated and the peel test was carried out on each sample. For samples that passed the peel test, the resistivity and average roughness were measured. From the initial experiments, it can be concluded that a single layered molybdenum film that exhibits good adhesion as well as high conductivity can be produced. Further experiments are being carried out to determine the exact process parameters of power and pressure needed to produce such a film.

The cost of production was evaluated and the results showed that cost can be reduced by reducing the total material utilization without adversely affecting the device performance. In case of a copper based chalcogenide solar cell, the theoretical limit for absorber layer thickness is 0.5 µm. However, in practice, the device performance has been shown to reduce drastically as the thickness reduces below 0.7 µm and the yield also goes down for such low thicknesses. Therefore, experiments were carried out to reduce the absorber layer thickness in the range of ~1 µm to ~1.5 µm. The first step in reducing the absorber thickness is to reduce the metallic precursor thickness. The metallic precursor thickness was determined based on the thickness for standard processes where the absorber thickness is ~2.5 µm. However, it is essential to optimize the process parameters such as annealing time and temperature. Therefore, experiments were carried out on $CuIn_xGa_{1-x}S_2$ (CIGS2), CIGS and $CuIn_xGa_{1-x}(Se,S)_2$ (CIGSeS) absorber layers. In case of CIGS2 absorber layers, cell efficiencies exceeding 10% were achieved for ~1.5 µm thick absorber layer.

Further experiments will be carried out to improve the efficiency of CIGS and CIGSeS solar cells. One experiment uses sodium. Sodium is known to have beneficial effect on CIGS absorber layer; however, excess sodium tends to degrade the device efficiency. Sodium from the sodalime glass substrate tends to out-diffuse; however, this out-diffusion is non-uniform as well as uncontrollable. When fabricating over large areas the uniformity of the electrical as well as material properties over the entire area is very important. Hence, it is essential to deposit a barrier layer to avoid the out-diffusion of sodium from the sodalime glass and to optimize the thickness of the barrier layer such that it minimizes the sodium out-diffusion and does not affect the adhesion of the thin films to the substrate.

Other experiments were carried out to study the effect of varying silicon nitride layer thickness on device performance as well as adhesion of the molybdenum films to the substrate. It was concluded from the experiment that 800 Å was the optimum thickness of the silicon nitride barrier layer. An important issue involved in taking a process from lab environment to pilot plant scale is the yield of the process. Hence, it is necessary that the processes deliver absorber films that exhibit good adhesion to molybdenum back contact and good hardness along with higher efficiencies.

Mechanical scribing that is used for making electrical interconnects in CIGSeS thin film solar cells can also be used to test the mechanical properties of the absorber film. Therefore, a mechanical scriber was designed and developed to make scribes with width of ~42 nm. From this design, clean and complete scribes were successfully carried out.

2009 Annual Progress Report

It is essential to optimize and accelerate all the PV production processes involved in preparation of PV devices in terms of the deposition rate as well as yield of each process in order to develop a high-rate manufacturing process for $CuIn_xGa_{1-x}Se$ (CIGS) solar cells. Moreover, it is important to consider the uniformity of each process in terms of performance when deposited over large areas. Therefore, simultaneous, systematic experiments are being carried out on various layers of the CIGS solar cell device. Efforts are being made to increase the deposition rate of the metallic precursors, to develop a single layered molybdenum back contact, to reduce the absorber thickness, to develop and optimize a silicon nitride barrier layer and to develop mechanical and laser scribing techniques. The following paragraphs discuss each of these experiments in detail.

Deposition Rates for Metallic Precursors:
The metallic precursors are deposited by DC magnetron sputtering from Cu-Ga alloy and In target. In the case of sputtering, the deposition rate changes with the changes in sputtering power and pressure. However, the deposition rate versus sputtering power and pressure follows a U shaped curve and therefore, it is essential to optimize the sputtering power and pressure in order to get the highest possible deposition rates for a given system. The sputtering power employed for the Cu-Ga target was varied while keeping the sputtering pressure constant at 1.5 mTorr. The sputtering power was varied from 200 W to 350 W and the thickness calibration was carried out using a Dektak Profilometer. It was observed that the deposition rate increased linearly with increase in the sputtering power. Figure 1 shows the variation of deposition rate with respect to the sputtering power. Table I shows the total thickness deposited for each sputtering power for the total deposition time of 800 seconds.

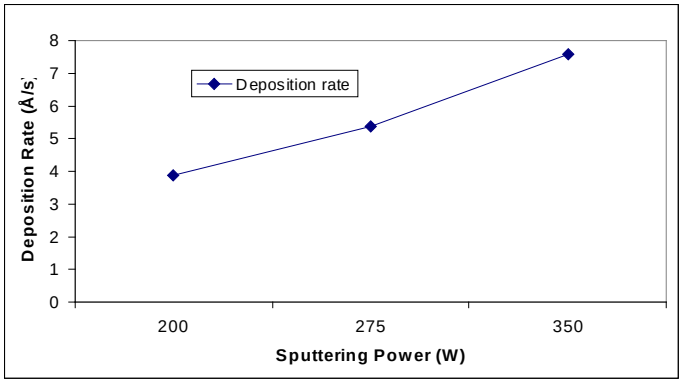


Figure 1: Effect of Sputtering power on deposition rate

Table I: Sputtering Power with corresponding thicknesses

Sputtering Power (W)	Total Time for Deposition (secs)	Average Thickness (Å)
200	800	3100
275	800	4300
350	800	6050

Single Layered Mo Back Contact:

Molybdenum back contact is deposited using DC magnetron sputtering. The properties of the thin film are dependant on the process parameters. Films deposited at high power and low pressure tend to be less resistive since the films are under compressive stress, however, such films exhibit poor adhesional strength. Films deposited at low power and high pressure tend to be under tensile stress and exhibit higher roughness and resistivity, while the film adhere very well to the sodalime glass substrate. Therefore, it has been a practice to deposit multi-layered Mo back contact to achieve the properties of good adhesion as well as low resistivity. As can be seen, the above mentioned process parameters and the corresponding film properties are at the two extreme end of the spectrum. Hence experiments are being carried out to optimize the sputtering power and pressure that will produce films that show acceptable properties of both the good adhesion and low resistivity. Efforts are being made to develop a single layered Mo film. Various combinations of sputtering power and pressure were experimented with. Tape test was done on each film to determine the adhesional strength of the films. Moreover, the sheet resistance and the average roughness for each film were measured using a four probe measurement setup and the Dektak Profilometer, respectively. The effect of sputtering power and pressure on the average roughness of the films and the resistivity of the films is shown in Figures 2 and 3, respectively. All the films considered in the figures have passed the tape test and, hence, can be concluded that the films exhibited good adhesion to the substrate.

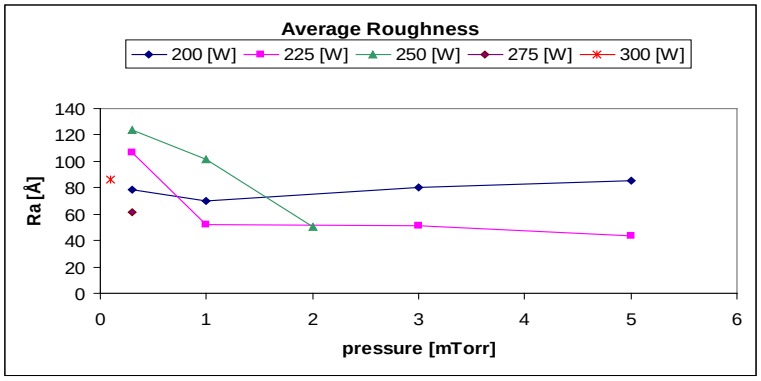


Figure 2: Effect of sputtering pressure and power on average roughness

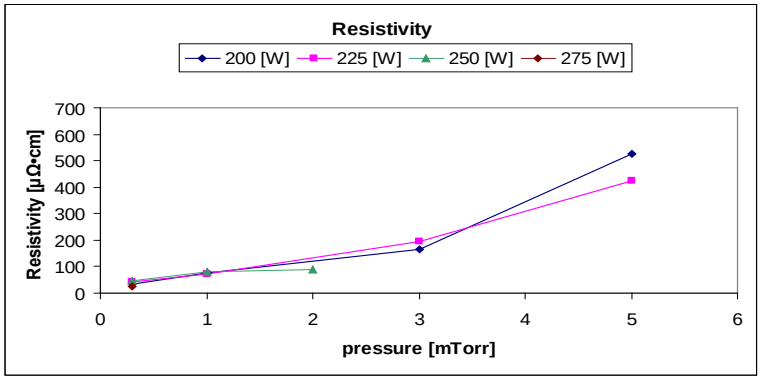


Figure 3: Effect of sputtering pressure and power on resistivity

Reduced Thickness of Absorber Layer:

The effective deposition time of the thin film solar cell and correspondingly cost of production can be reduced by either increasing the deposition rate of each layer or by reducing the thickness of each layer or both. In case of CIGS absorber layer, the theoretical limit for the thickness of the absorber layer is 0.5 µm. However, in practice the cell efficiencies are known to reduce significantly as the thickness of the absorber layer is reduced below 0.7 µm. Moreover, as the thickness is reduced the yield of the process may reduce, thus, affecting the total cost of production. In order to avoid reducing the yield of the process with decreasing absorber thickness, it is essential to understand the effect of various process parameters on the device performance and further optimize the process parameters accordingly. Therefore, experiments were carried out to reduce the thickness of the $CuIn_xGa_{1-x}S_2$ (CIGS2), CIGS and $CuIn_xGa_{1-x}(Se,S)_2$ (CIGSeS) absorber layers.

CIGS and CIGSeS Absorber Layer:

The thickness of CIGS and CIGSeS absorber layers prepared in a conventional furnace and by rapid thermal processing (RTP), respectively, was reduced to less that 1 µm. In case of the conventional furnace, experiments were carried out by varying the selenization time. It is essential to optimize the selenization time for reduced absorber layer in order to achieve larger grain size without adversely affecting the Mo back contact. Three different selenization times of 60, 40 and 30 minutes were tried. As expected the selenization time of 60 minutes increased the series resistance of the device due to the over selenization of the Mo back contact resulting in a thick $MoSe_2$ layer. It was observed that the device performance improved as the selenization time was reduced from 60 minutes to 30 minutes. Figure 4 shows the effect of selenization time on the photovoltaic parameters.

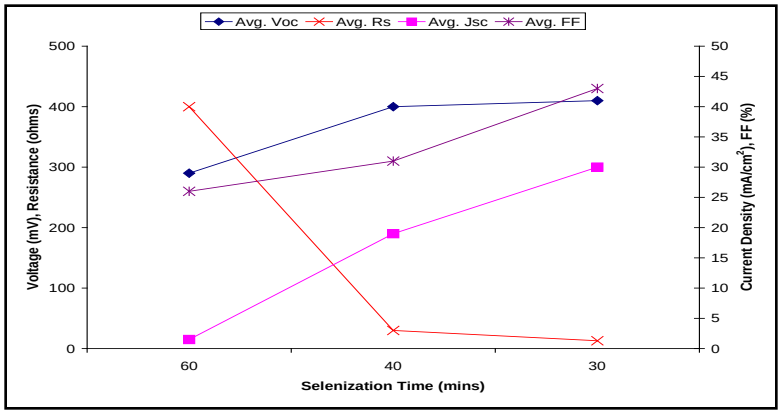


Figure 4: Effect of selenization time on photovoltaic parameters

In the two stage process for preparation of CIGS thin films, gallium tends to segregate to the back of the film resulting in higher bandgap near the back contact and lower bandgap near the heterojunction. This results in lower open circuit voltage due to the reduction in band bending. Therefore, sulfur is introduced so that the bandgap of the absorber layer increases near the heterojunction. However, in case of thin absorber films it is critical to control the extent of sulfur diffusion because of danger of reduction in the current produced by the device. In case of rapid thermal processing (RTP), experiments were carried out by varying the selenization and sulfurization times as well as by varying the amount of sulfur introduced during the sulfurization. The amount of sulfur was adjusted by varying the partial pressure of the sulfur source, H_2S. Table II shows the effect of partial pressure on the various photovoltaic parameters.

Table II: Effect of H_2S partial pressure on photovoltaic parameters

H_2S partial pressure (Torr)	Avg. V_{oc} (mV)	Avg. J_{sc} (mA/cm2)	Avg. R_{sh} (Ω)	Avg. R_s (Ω)	FF (%)
7.5	540	26	60	26	32
15	520	26	200	18	47

CIGS2 Absorber Layer:

Similar to the CIGSeS absorbers, the thickness of the CIGS2 absorbers was reduced in the range of 1.5-1.2 µm. The initial set of experiments resulted in solar cell efficiencies of 4-5%. Higher series resistance and lower shunt resistance were obtained for the completed cells resulting in poor fill factor. As the thickness of the absorber layer is reduced, it is critical to understand the effect of the process parameters on the device performance. Post-sulfurization annealing treatment can increase the grain size and improve the film morphology for thinner films. However, it can reduce the gallium gradient by homogenization of the constituent elements and, thus, partly offset the benefit of larger grains. Hence, it is essential to optimize the post sulfurization annealing. Therefore, experiments were carried out by varying the post sulfurization time and temperature profile. Figure 5 shows the effect of post sulfurization annealing on photovoltaic parameters. Further experiments were carried out to improve the device performance. With significant improvement in photovoltaic parameters efficiencies exceeding 10% were obtained as depicted in Figure 6 showing the device performance at each experimental stage.

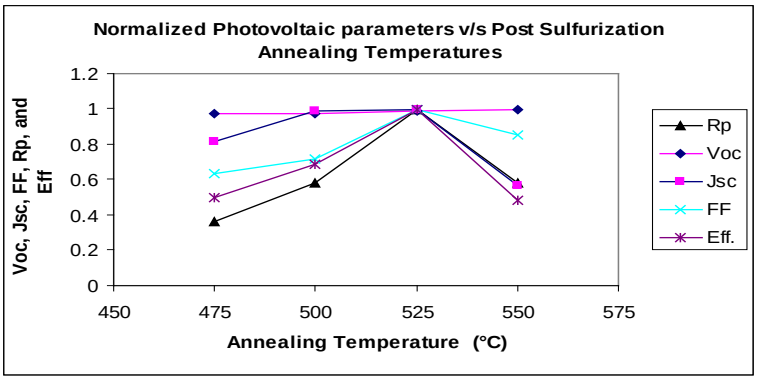


Figure 5: Effect of post sulfurization annealing on device performance

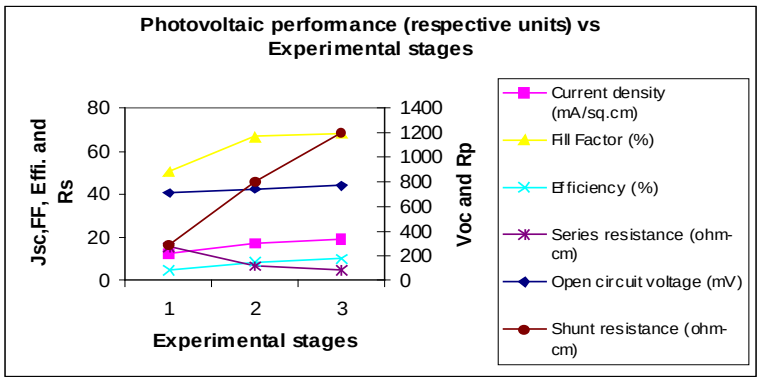


Figure 6: Improvement in device performance with each experimental stage

Silicon Nitride Barrier Layer:

Sodalime glass is the most commonly used substrate in fabrication of CIGS thin film solar cells. Small amount of sodium is known to have a favorable effect on device performance; however, an excess amount degrades device performance. The sodium out-diffusion from the sodalime glass is not well-controlled. An alkali barrier layer, such as Si_xN_y, is deposited before the molybdenum layer and then followed by a sodium precursor to obtain the advantages of sodium without losing process control. It is essential to optimize thickness of the barrier layer in terms of the ability to effectively avoid the diffusion of sodium from the sodalime glass into the absorber as well as in terms of the adhesion properties of the alkali barrier layer with the sodalime glass substrate. The alkali barrier silicon nitride layer was deposited using reactive RF sputtering from a silicon target. Various thicknesses of silicon nitride were deposited to determine the effect of alkali barrier silicon nitride layer on the device performance. Transmission electron microscopy (TEM) was used to study the silicon nitride and molybdenum layer (Figure 7). Moreover, electron emission loss spectroscopy (EELS) was carried out to detect the presence of the silicon nitride layer (Figure 8). Various sputtering powers were experimented with to deposit the silicon nitride layer with a respectable deposition rate and to carry out thickness calibration. Efforts are being made to increase the deposition rate of the silicon nitride alkali barrier layer. However, it is essential to first optimize the thickness of the silicon nitride barrier layer. Therefore, experiments were carried out with various thicknesses of silicon nitride layer. CIGSeS devices were prepared on samples with no silicon nitride layer, and with 400 Å, 800 Å, and 1200 Å silicon nitride layer. Peel test on the molybdenum films was carried out on each sample and it was observed that as the thickness of the silicon nitride layer was increased to 1200 Å, the molybdenum film failed the peel test. All other samples survived the peel test and hence devices were prepared on these samples. From the device performance of each sample (Figure 9) it was concluded that 800 Å thick silicon nitride layer is the optimum layer.

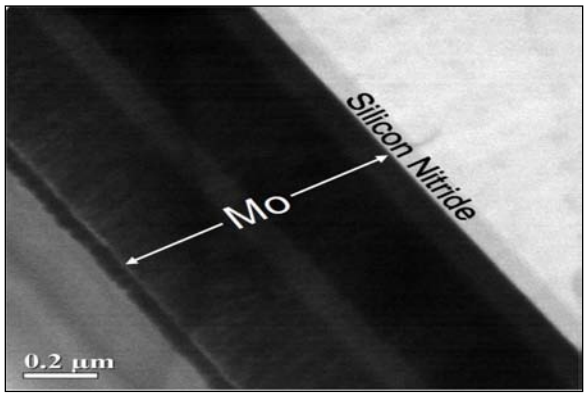


Figure 7: Bright field TEM image

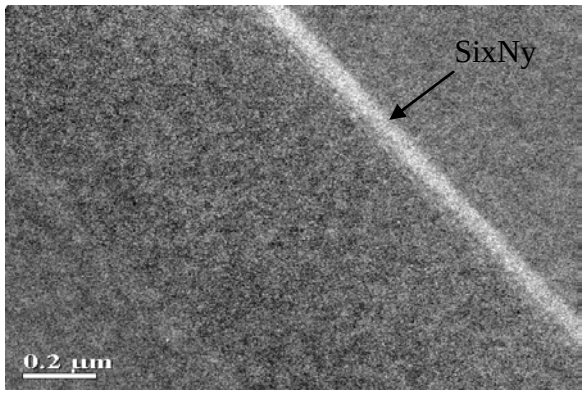


Figure 8: EELS mapping for nitrogen from Si_xN_y

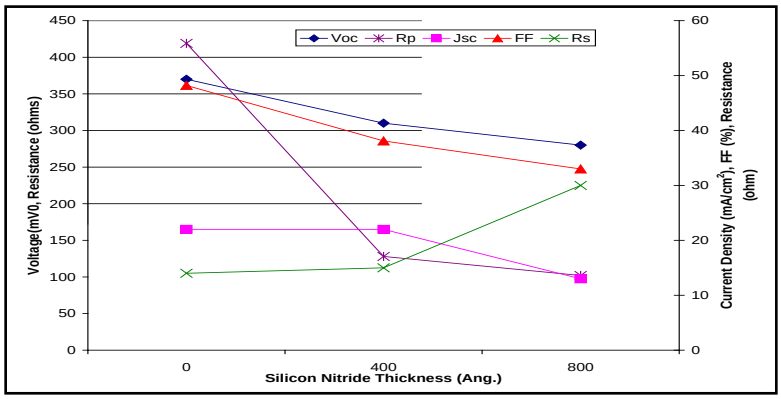


Figure 9: Variation of photovoltaic parameters with respect to silicon nitride thickness

Mechanical and Laser Scribing:

One of the important issues involved while taking a process from lab environment to pilot plant scale is the yield of the process. Hence, it is necessary that the process delivers absorber films that exhibit good adhesion to molybdenum back contact and good hardness along with higher efficiencies. Mechanical scribing that is used for making integral interconnects in CIGSeS thin film solar cells can also be used to test the mechanical properties of the absorber film. Optical and scanning electron microscopy can be used to study the effect of scribing on the absorber film and the morphology of the scribe lines. Therefore, a mechanical scriber was designed, developed and built to carry out scribing of the CIGSeS absorber layer. Several factors such as the hardness of the scribing tool, the pressure applied by the tool on the absorber film need to be considered while designing the mechanical scriber. The scribing tool needs to be harder than the CIGSeS absorber layer but not as hard as the molybdenum back contact. Moreover, it is essential to avoid application of excessive pressure that might lead to tearing of the film. Figure 10 shows the possible integration scheme for the CIGS thin film solar cell where the scribe P2 is made using the mechanical scriber. The pressure applied on the sample was optimized by adjustment of spring tension and clean scribes were made on the absorber layer as shown in figure 11. Optical micrograph of the scribe in figure reveals that the absorber film has not flaked or was not torn and exhibited good adhesion to the molybdenum back contact. An absorber layer with known poor adhesion was scribed to determine if the scriber can be used as a tool to determine the quality of the film. As can be seen from figure 12, the film flaked at the edge of the scribe and therefore it can be safely said that the scriber can be used as tool to determine the adhesional property of the absorber layer.

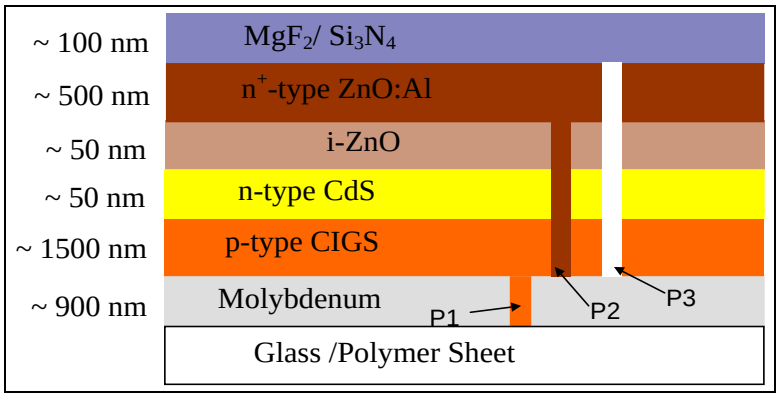


Figure 10: Monolithic Integration of CIGS thin film solar cell

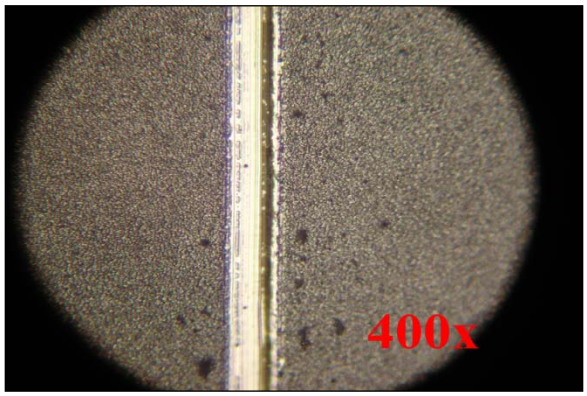


Figure 11: Optical image of complete clean scribe

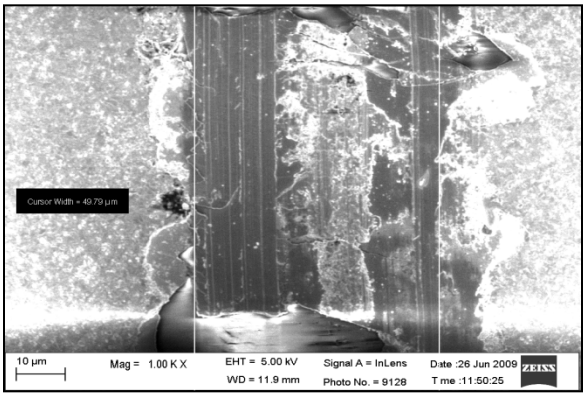


Figure 12: Scribe where absorber film flaked off

Human Resources:

Following three PhD students recently graduated from the Material Science Department with thesis based on CIGSeS and CIGS2 thin film solar cells; Sachin Kulkarni, Vinay Hadagali and Parag Vasekar. Shirish Pethe (PhD in Electrical Engineering), Ashwani Kaul (PhD in Material Science), and Eigo Takahashi (M.S. in Material Science) are nearing the end of their research and will graduate early next year. Saisitaram Ramesh and Bihag Joshi are the two new PhD students from the Electrical Engineering Department that have been hired recently and will continue to work on this project.

Publications:

Kaul, A., Vasekar, P., Pethe, S. A., Dhere, N. G., "Effect of post-sulfurization annealing and gallium grading on thinner CuIn1-xGaxS2 absorbers", SPIE Optics + Photonics, San Diego, CA, August 2009.

Pethe, S. A., Mendoza, M. J., Kaul, A., et al., "Mechanical scribing as a quality and reliability analysis tool for CIGSeS thin film solar cells," SPIE Optics + Photonics, San Diego, CA, August 2009.

Pethe, S. A., Hadagali, V., Dhere, N. G., "Development of silicon nitride barrier layer for CIGSeS thin film solar cells", SPIE Optics + Photonics, San Diego, CA, August 2009.

Vasekar, P., Kaul, A., Dhere, N.G., "Beneficial effects of sodium on CIGS2 thin film solar cells", 34th IEEE Photovoltaic Specialist Conference, Philadelphia, PA, June 2009.

UNIVERSITY OF CENTRAL FLORIDA

Research to Improve Photovoltaic (PV) Cell Efficiency by Hybrid Combination of PV and Thermoelectric Cell Elements

PI: Nicoleta Sorloaica-Hickman**,** Robert Reedy
Students: Kris Davis, Steven Nason

Description: Photovoltaic/thermoelectric (PV/TE) cell integration is a promising technology to improved performance and increase the cell life of PV cells. The TE element can be used to cool and heat the PV element, which increases the PV efficiency for applications in real-world conditions. Conversely, the TE materials can be optimized to convert heat dissipated by the PV element into useful electric energy, particularly in locations where the PV cell experiences large temperature gradients, i.e. use the thermoelectric module for cooling, heating and energy generation depending on the ambient weather conditions. Thus, the goal of this research effort is to research and develop nanoscale design of efficient thermoelectric material through a fundamental understanding of the materials properties and to design and build a photovoltaic thermoelectric (PV/TE) hybrid system.

Budget: $167,820

Universities: UCF/FSEC

Progress Summary

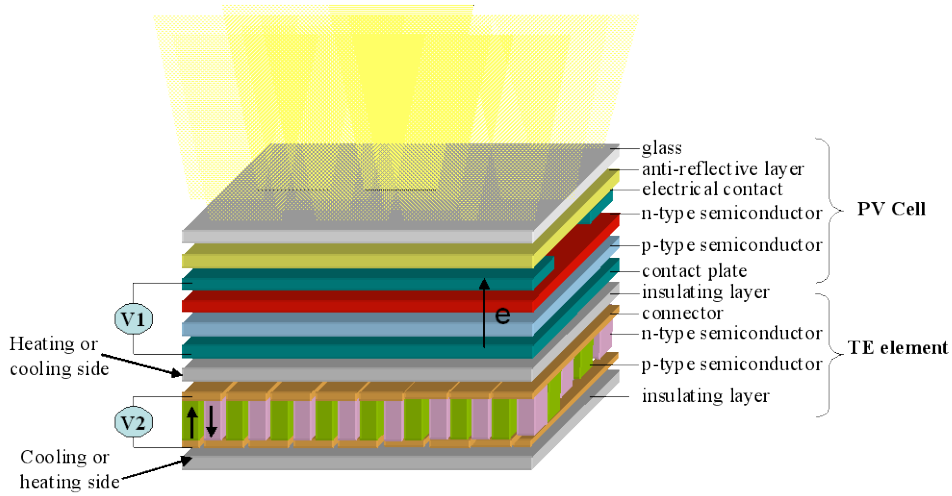
In the field of photovoltaic energy generation, thermoelectric materials have been underutilized. The use of such materials can increase the efficiency and longevity of the solar cells and facilitate their operation in varying weather conditions. There is also an increasing demand for new thermoelectric materials with high efficiency which can function in environments that are severe, but still have a very long life span. To solve this problem, research will be conducted on the modeling of electron and thermal transport in controlled size and shape nanocomposite thermoelectric TiNiSn based materials. This research will lead to the development of novel methods to synthesis, characterize and study thermoelectric properties via bulk synthesis.

Research for improved high-temperature thermoelectric materials was done on controlled size and shape of TiNiSn based Half-Heusler phase materials. The materials also combined substitution of Zr and Hf on some of the Ti sites, Pt on the Ni sites and doping of Sb into the Half-Heusler structure. By controlling the grain boundary size and shape, control of the thermoelectric figure of merit should be accomplished. This accomplishment involved an extensive theoretical study of the thermoelectric-related transport properties of a TiNiSn system and TiNiSn based systems.

Due to the research strategy adopted, these materials are expected to have low thermal conductivities, due to the mass fluctuation, the strain field effect and their complex structure. First principles methods based on quantum mechanics were used to calculate thermoelectric properties of size and shape controlled materials. These calculations included the real structural and chemical complexity of materials, which yielded quantitative predictions, both of the thermoelectric properties and their variation with chemical composition. Trends were identified and used to suggest other compositions to be analyzed by detailed calculations. Our theoretical result predicted compositions with improved thermoelectric performance.

This approach was unique in that it first created a theoretical framework for predicting the electrical and thermal properties of each new structural configuration and improved the figure of merit from 0.2 to

almost 0.9. From the beginning, the research strategy was to lower the lattice thermal conductivity by creating mass fluctuation and internal strain field effects and controlling the size of the micro-grains by annealing the system. Using this as a basis, improvements can be made in the efficiency of the thermoelectric materials and then used in a PV/TE hybrid system design.



Schematic of PV/thermoelectric hybrid system

2009 Annual Progress Report

Photovoltaic/thermoelectric (PV/TE) cell integration is a promising technology to improved performance and increase the cell life of PV cells. The goal of this research effort is to research and develop nanoscale design of efficient thermoelectric material through a fundamental understanding of the materials properties and to design and build a photovoltaic thermoelectric (PV/TE) hybrid system.

Preliminary investigations done at Clemson University, developed a novel approach to optimize the TiNiSn based Half-Heusler phase materials. This research combined the substitution of Zr and Hf on some of the Ti sites and doping of Sb into the Half-Heusler structure. It also involved an extensive experimental and theoretical study of the thermoelectric-related transport properties of a TiNiSn system and TiNiSn based systems. A theoretical framework for predicting the electrical and thermal properties was developed. Material optimized was reported on the electronic and thermal transport property measurements at low and high temperature (from 6K up to 1000K) and elastic properties. The plot shown in Fugure 1 show these results.

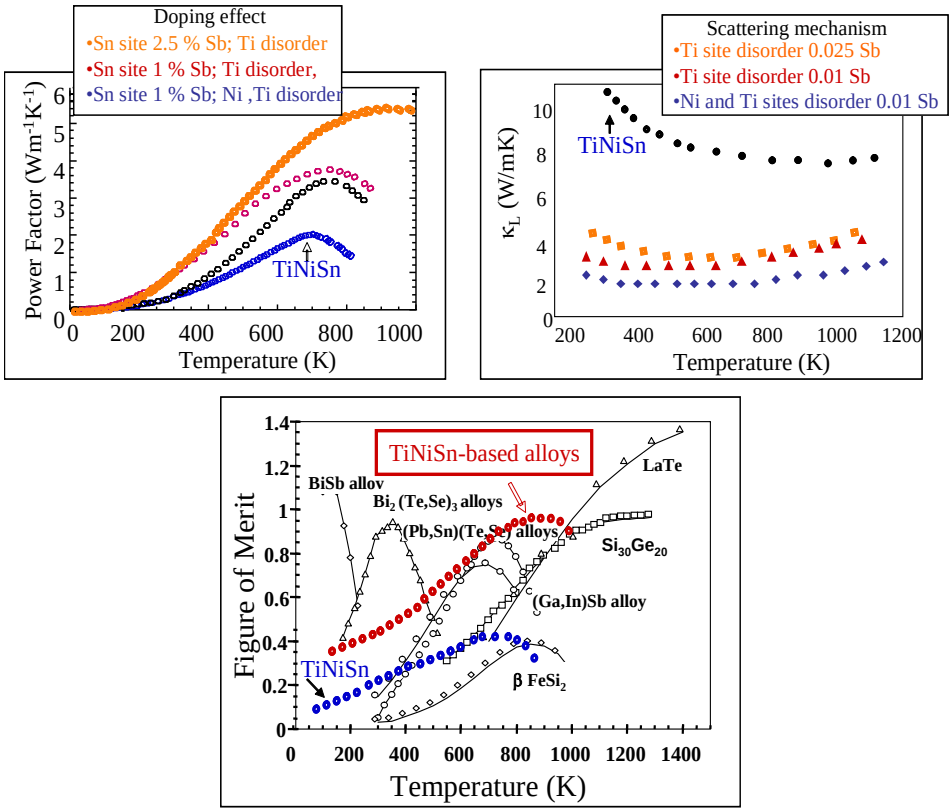


Figure 1 Mass fluctuation, internal strain field and micro-grain size effects on the electronic and thermal properties of the TiNiSn based materials (research performed by Dr. Sorloaica-Hickman at Clemson University)

In 2001, Sharp, et al published a paper on grain boundary scattering and the thermoelectric figure of merit. They showed that the lattice thermal conductivity of a thermoelectric material can be significantly reduced at ordinary temperatures by boundary scattering, but the beneficial effect on the figure of merit can sometimes be more than offset by boundary scattering of the charge carriers. They extend the previous theory to include both weak and strong boundary scattering and demonstrated that the relative magnitudes of the effects on the phonons and charge carriers can be estimated. They illustrated their predictions by applying them to Si-Ge alloys, Bi-Sb alloys, and Bi_2Te_3 alloys which were state of art thermoelectric materials. They also presented an alternative treatment for the case when the materials have large unit cells using a classical method for assessing the thermal conductivity due to the acoustic phonons. The new technique was applied to one of the half-Heusler alloys, $Zr_{0.5}Hf_{0.5}NiSn$ and the result indicated that the grain size and boundary scattering effects should be greater on the lattice conductivity than that on the electrical mobility. See Figure 2.

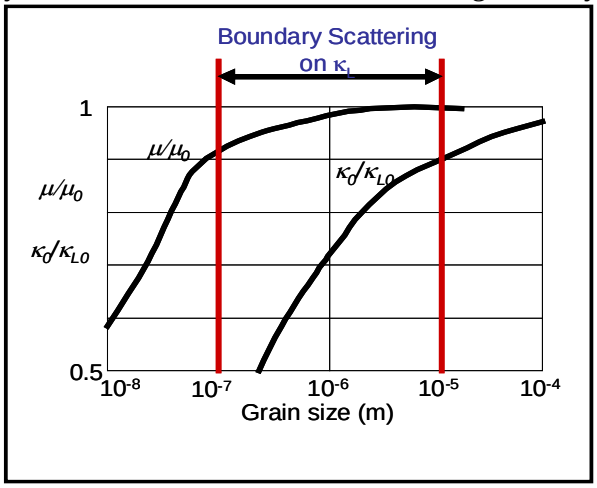


Fig. 2 Boundary scattering in $Zr_{0.5}Hf_{0.5}NiSn$

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UNIVERSITY OF CENTRAL FLORIDA

Research and Develop PV Device Science and Laboratories

PI: Nicoleta Sorloaica-Hickman**,** Robert Reedy
Students: Kris Davis (PhD)

Description: The objective of this project is to develop a world class PV cell laboratory for various cell and cell device research. The R&D to be conducted in the lab will focus on developing new and improved PV cells such as organic PV, nano-architectures, multiple excitation generation, plasmonics, and tandem/multijunction cells. This new PV lab called the Laboratory for Photovoltaic and Thermoelectric Materials and Devices (PVTMD) has been sited in a room originally used as a machine work facilities room in the Low Bay of the Florida Solar Energy Center (FSEC). The PVTMD lab is to be used as an interdepartmental laboratory and will concentrate on developing the fundamental science and engineering base required to improve PV and TE device performance and processing technologies. The end goal is to transfer these laboratory results to large-scale manufacturing and to exploring new frontiers in manufacturing research and scientific education.

Budget: $882,507

Universities: UCF/FSEC

Progress Summary

A laboratory for photovoltaic and thermoelectric materials and devices (PVTMD) has been sited in a room originally as a machine shop in the low bay of Florida Solar Energy Center (FSEC). The new lab is an interdepartmental laboratory at FSEC devoted to developing the fundamental science and engineering base required to improve PV and TE device performance and processing technologies and to effectively transfer these laboratory results to manufacturing and educational programs.

Multidisciplinary research teams perform programs at the leading edge of advances in electronic, thermal and optical PV materials (nanostructures, thin film and bulk). The interdisciplinary philosophy of research within the Laboratory for Photovoltaic and Thermoelectric Materials and Devices combines the disciplines of physics, materials science, chemistry and electrical engineering leading toward attracting research opportunities. The background of students and researchers within the lab reflect this breadth, and as a result, the laboratory is vertically integrated in its activities, straddling from basic to applied research.

Five major areas of core competency underpin activities at FSEC in the Laboratory for Photovoltaic and Thermoelectric Materials and Devices:

1. Materials discovery, design, synthesis and processing
2. Analytical instrumentation/device design/fabrication
3. Integration of modeling, fundamental science, engineering and economic expertise for energy issues
4. Condensed matter theory (including photonic band gap and other novel materials)

5. Materials characterization,

We believe that these five core competencies will enable FSEC to perform a significant role in Florida's PV research laboratory systems, and to pursue its vision for scientific excellence and pre-eminence in the area of fundamental materials research for PV and TE applications. The new lab will provide the development of analytical techniques and instrumentation. This PVTMD laboratory will be state of the art and will position Florida's universities for active roles in PV research and development.

2009 Annual Progress Report

The vision of this PV device research program is to combine and coordinate the research efforts of the participating universities and industries to insure that PV technologies will overcome the cost, manufacturing and efficiency barriers to make PV electricity competitive with conventional electricity. The primary challenge facing the industry is to dramatically reduce the cost/watt of delivered solar electricity by approximately a factor of 2 to 3, to increase the manufacturing volume by a factor of 10 and to improve the cell efficiencies by a factor of 2 to 3. PV research in meeting these challenges will be directed at the development of new materials that efficiently absorb sunlight, new techniques that harness the full spectrum of solar light radiation, and new approaches based on nanostructure architectures that can revolutionize PV cell efficiencies.

The Laboratory for Photovoltaic and Thermoelectric Materials and Devices (PVTMD) is an interdepartmental laboratory at Florida Solar Energy Center devoted to developing the fundamental science and engineering base required to improve PV and TE device performance and processing technologies and to effectively transfer these laboratory results to large-scale manufacturing exploring new frontiers in manufacturing research and education.
The description of this new PVTMD laboratory follows.

Solar Energy Basic Research Facility at FSEC

Basic energy sciences are the major research area conducted in the PVTMD lab at FSEC. Currently 700 sq ft area of the approx 2000 sq ft in room 111 in FSEC's Lo-Bay laboratory is being used as the PVTMD Lab. The laboratory will be used to develop semiconductor material for research on high-efficiency crystalline solar cells, to fabricate prototype solar cells, to analyze the semiconductor material used to make solar cells and to measure and characterize solar cell and module performance. The PVTMD lab has recently been renovated to allow the FSEC research group the opportunity to conduct PV and TE material and devices fabrication characterization and testing. It has two 14'x14' modular clean room, "Econo-Tents" received as a donation from Kennedy Space Center and the UCF NanoTechnology Center. These Econo-Tents Control the environment in a 14'X28" giving space to fabricate and analyze new PV materials and Solar Cells. Equipment that have been installed into the lab area are Customized Newport Quantum Efficiency Measurement System on an existing optical table, Dimatix Materials Printer (DMP), a Class 3A Solar Simulator, a Spectrophotometer, a Refractometer and various other equipment for testing and experiments. In addition, the lab contains a Plasma Depositions System received as a donation from the UCF Nano Science Center.
Renovations to laboratory spaces are planned to be completed next year. Planned upgrades include further reorganization of laboratory and office spaces to accommodate new students, staff and faculty. Also the roof of the building has a platform to mount PV panels that can then

be used evaluate the performance of integrated PV systems. A plan view of the lab and it's instruments is presented in Figure 1.

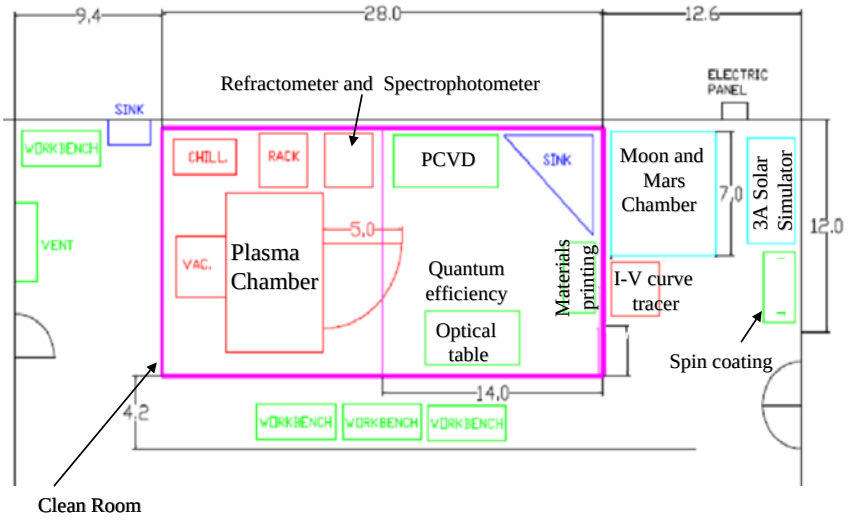

Figure 1 - Lab Schematic.

State of art equipment

Equipment in the PVTMD lab is described in the following sections.

1. Inject materials printing systems

The need to reduce the cost of extracting PV electricity in order to achieve cost parity with nonrenewable energy sources is driving search for increased module efficiency and for savings at all points of the photovoltaic (PV) supply chain. Inkjet materials deposition has multiple unique benefits that can be leveraged for efficiency gains, as well as environmentally responsible cost reduction at the basic material and cell processing nodes of the supply chain. As a digital manufacturing process with properties of both printing and coating processes, inkjet has been applied to the patterned deposition of conductive fluids for contact formation on silicon cells, but inkjet also has the capability to manufacture entire thin film cells. (see Figure 2)

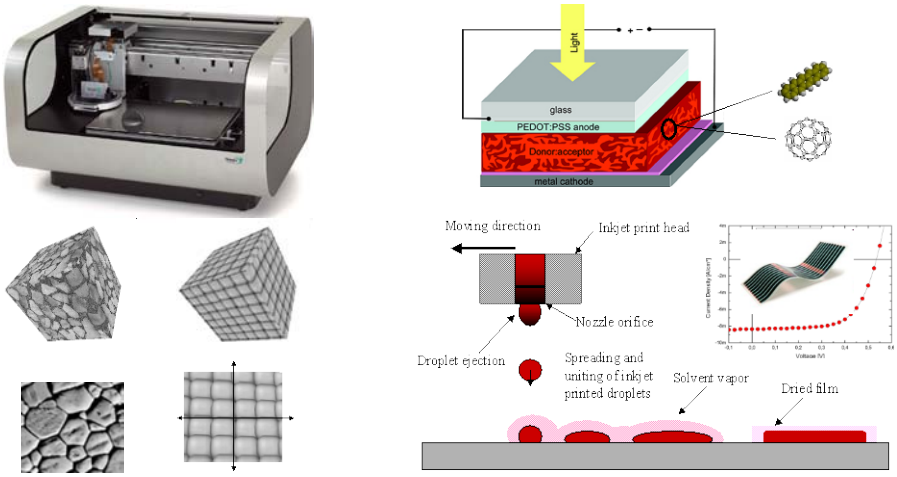

Figure 2 Inject Procass

2. Plasma chemical vapor deposition system to fabricate nanorods and controlled size and shape nanostructures

Plasma Enhanced Chemical Vapor Deposition (PECVD) is a process used to deposit thin films from a gas state (vapor) to a solid state on a substrate.(see Figure 3) There are some chemical reactions involved in the process which occur after creation of plasma of the reacting gases. The plasma is generally created by RF (AC) frequency or DC discharge between two electrodes, the space between which is filled with the reacting gases. To grow aligned nanotubes, plasma-enhanced chemical vapor deposition (PECVD)may be used. The resulting nanotubes could be 200nm diameter and 10um long.

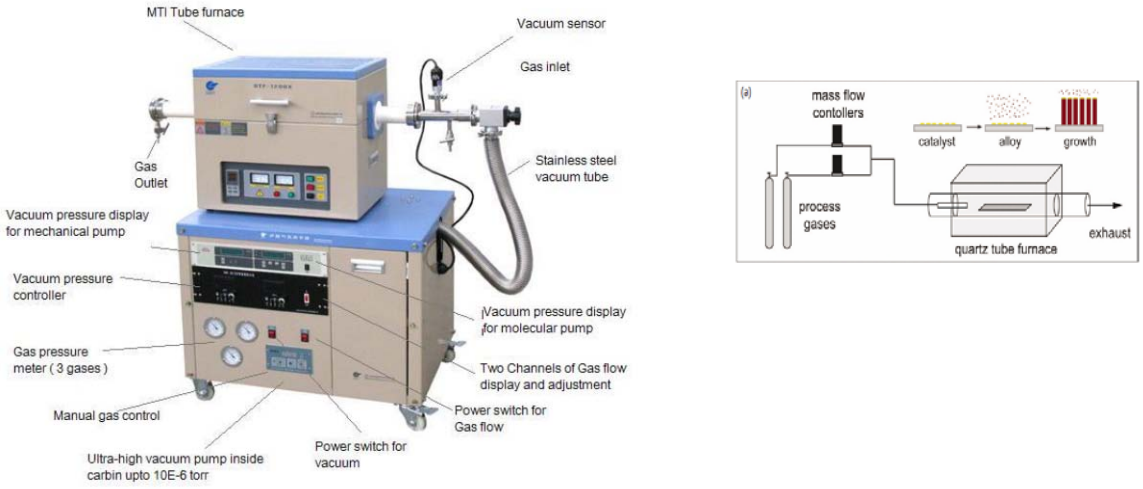

Figure 3 - PECVD system.

3. Spin coating systems for fabricate organic-inorganic hybrid solar cells

Spin coating is a procedure frequently used to fabricate thin film organic solar cells. The process is done by placing an excess amount of a solution on the substrate, and then rotating at high speed in order to spread the fluid by centrifugal force. A machine used for spin coating is called a spin coater, or simply spinner.(See Figure 4) Rotation is continued while the fluid spins off the edges of the substrate, until the desired thickness of the film is achieved. The applied solvent is usually volatile, and simultaneously evaporates. The thickness of the film also depends on the concentration of the solution and the solvent. Spin coating is widely used in microfabrication, where it can be used to create thin films with thicknesses below 10 nm.

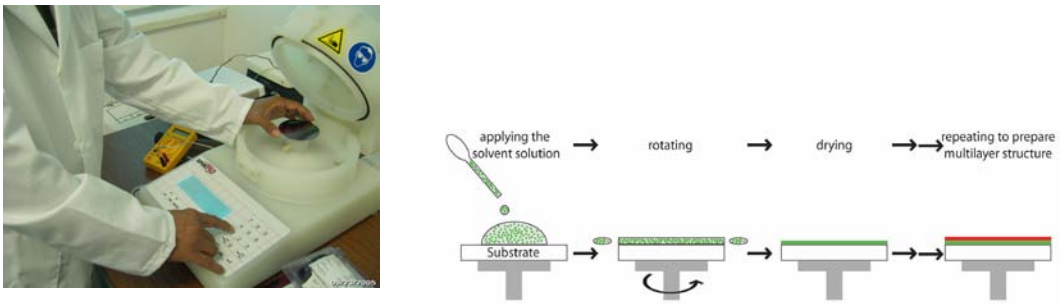

Figure 4 - Spin Coating System.

4. Customized External and Internal Quantum Efficiency System and 3A Solar Simulator for characterization of novel developed solar cells

Quantum efficiency of a solar cell is an important measure as it gives information on the current that a given cell will produce when illuminated by a particular wavelength. If the quantum efficiency is integrated (summed) over the whole solar electromagnetic spectrum, one can evaluate the current that a cell will produce when exposed to the solar spectrum. The ratio between this current and the highest possible current (if the QE was 100% over the whole spectrum) gives the electrical efficiency of the solar cell. With solar cells, one often measures the external quantum efficiency (EQE, sometimes also simply referred to as QE), which is the current obtained outside the device per incoming photon. See Figure 5.

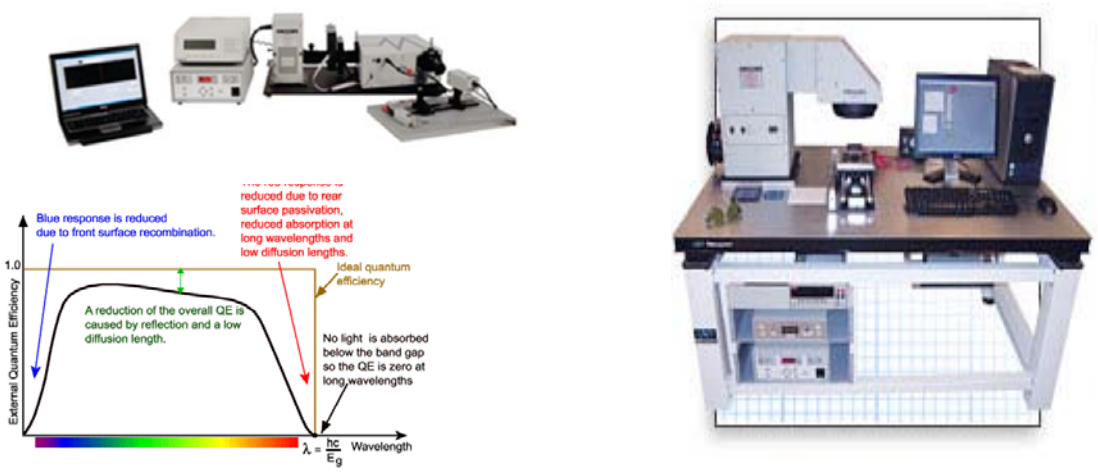

Figure 5 - Quantum Efficiency Measurements.

5. Other Optical characterization and I-V testing systems

In addition, equipment to measure UV/VIS/NIR spectroscopy, refractometer and IV and CV characterization has been purchased. See Figure 6.

Figure 6 - Other Characterization and Testing Equipment.

UV/VIS/NIR Spectroscopy a critical tool in the design of PV cells

Refractometer for the thickness and index of refraction measurements of films on textured solar cells

IV and CV Characterizations of Solar/Photovoltaic Cells Using the B1500A

UNIVERSITY OF CENTRAL FLORIDA

PV Energy Conversion and System Integration

PI: N. Kutkut
Co-PI's: J. Shen, I. Batarseh, Z. Qu, X. Wu, W. Mikhael, L. Chow
Students: Kejiu Zhang (PhD), Souhaib Harb (PhD),
Karthik Padmanabhan (PhD), Xiang Fang (PhD), Ala Alsaeed (PhD)

Description: The objective of this project is to develop a system-driven Plug'N'Gen solar power system demonstrating architecture of decentralized, low-cost, mass-produced, PV panel-mounted micro-inverters. This system will be able to compete with today's centralized multi-kW PV inverters that require cost prohibitive professional installation. The project tasks are: 1) novel inverter topology and control concepts; 2) advanced digital control algorithms; 3) SmartTie interface with the utility grid; and 4) low cost and ultra-compact PV inverter in package.

Budget: $1,267,000

Universities: UCF

Progress Summary

To date, analysis and simulation have been conducted on four tasks of the project. Progress on these tasks is detailed below:

Advanced Digital Control Algorithms
A full mathematical model of the PV panel mounted inverter was developed and verified with experimental testing. The model was used to develop an optimal pulse skipping control technique that can boost the micro inverter efficiency operating at low insolation levels.

SmartTie Interface with the Utility Grid
Inverter control schemes are being developed to allow the PV panel inverter to operate in the voltage mode for micro grid operation as well as in VAR mode to support ancillary services.

Ultra Compact PV Inverter Packaging
A low profile planar transformer has been fully analyzed, optimized and designed using ANSOFT computer simulation. Electrical core and winding design have also been finalized. For the mechanical design, the heat sink size and profile has been analyzed and optimized. Using FLOWTHER, detailed modeling of the heat sink design parameters have been analyzed and optimized to yield a lighter and efficient design.

The next phase will focus on building prototypes and carrying out experimental work to verify the expected results.

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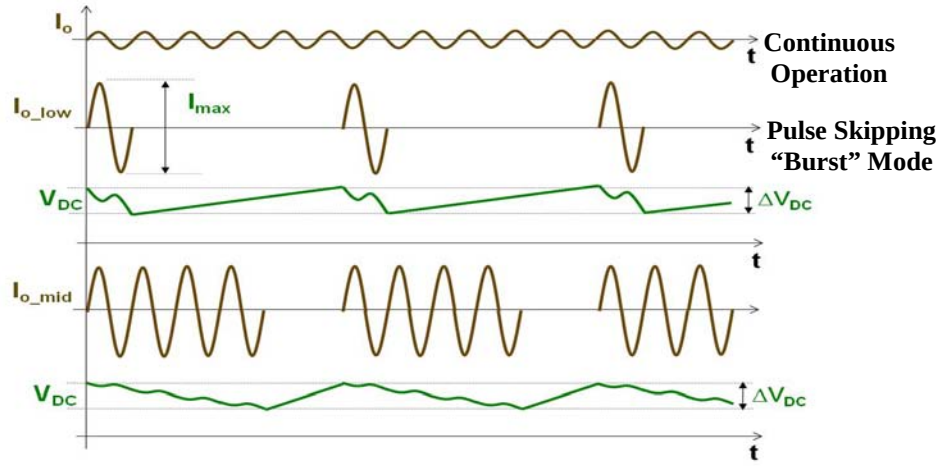
Below is a summary of the progress and results to date for each of the project tasks.

1. Advanced Digital Control Algorithms

When PV inverters operate at low insolation levels (low input power), the inverter efficiency drops dramatically as shown in the figure below. This drop in the inverters' weighted efficiency (CEC efficiency) limits the maximum power that can be harnessed at low insolation levels.

To optimize the performance and efficiency of the PV panel mounted inverters, advanced digital control algorithms are being explored. In particular, the research focus is placed on boosting the inverter efficiency at low insulation conditions. To achieve this focus, pulse skipping techniques are being explored.

Pulse skipping, or burst mode operation, is a technique that refers to an intermittent power delivery from the inverter to the utility grid. This technique is usually performed at low power levels (low insolation levels). The figure below shows operation under pulse skipping control.



Pulse Skipping "Burst" Mode Operation

As shown in the figure, during lower power operation intervals (low insolation levels), instead of continuously operating the inverter at low current levels, the PV energy can be stored in the intermediate DC bus capacitor which can be then injected into the utility grid at higher current levels. This allows the inverter to operate at its maximum efficiency point.

The pulse skipping mode of operation will reduce energy losses which occur due to continuous operation at low insolation levels. By employing pulse skipping mode, it is anticipated that the high power conversion efficiencies at medium and high power levels can be extended down to very low power levels.

Although pulse skipping techniques have been presented in the past, there was little work done on optimizing the performance of the inverter with pulse skipping operation. As such, this research task has focused on:

Pulse skipping control strategy development

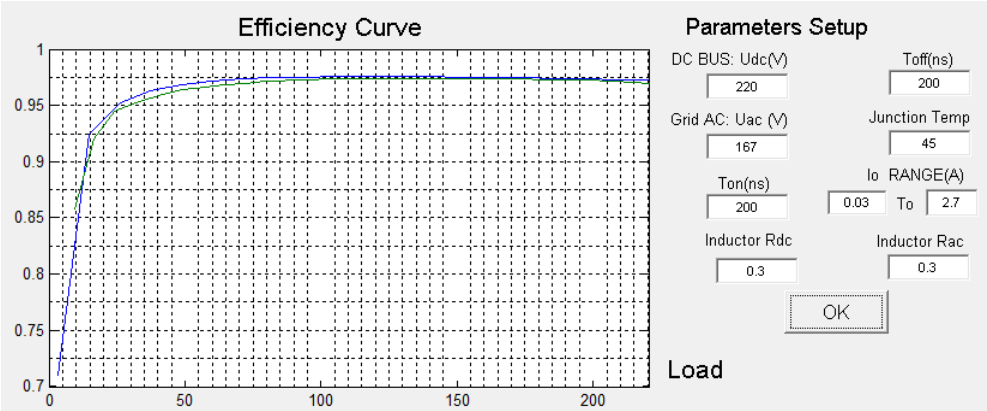
The pulse skipping control strategy is based on detecting the conditions below which pulse skipping mode of operating is enabled at which point the inverter ceases continuous mode operation and enters the pulse skipping mode.

Mathematical loss model

A fully detailed mathematical model of the inverter has been developed to estimate the power loss of the full-bridge inverter (see below). The model is based on the datasheets of the power devices and the specifications of passive components used in the power stage. The model includes power losses of the

gate drivers, switching losses, conduction losses of power devices as well as inductor copper and core losses.

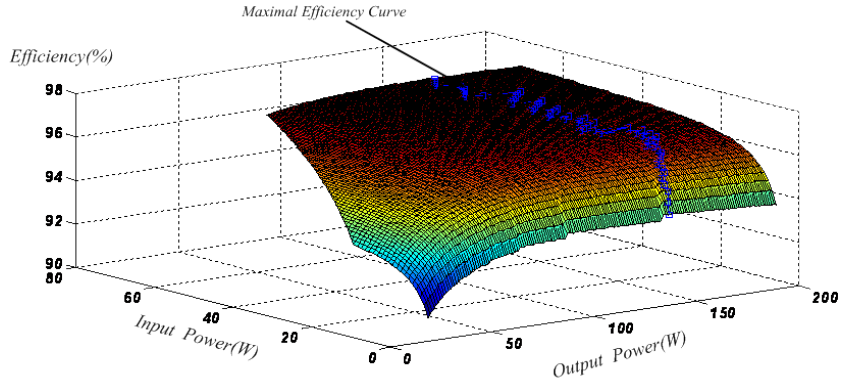
Model verification
The model was verified by carrying out all loss calculations and taking actual measurements of the actual micro inverter unit. The figure below shows perfect matching between measurements and calculations.



Model vs. Experimental Efficiency Verification

Optimization for pulse skipping
Next, the optimization of the pulse skipping mode of operation was carried out by varying the (1) power level to start pulse skipping; (2) power level of pulse, and (3) the DC voltage ripple. The developed mathematical model was used to evaluate the inverter efficiency for all scenarios. An maximal efficiency curve was then calculated as shown below.

For the 200W panel integrated inverter, the optimum power level to start pulse skipping was 70W, the optimum pulse power was 150W, and the optimum DC voltage ripple was insignificant.



Optimal Parameters for Maximal Efficiency Pulse Skipping Operation

Experimental verification
Experimental testing will be carried out in the next phase to verify findings.

SmartTie Interface with the Utility Grid
One of the main aspects of PV panel integrated inverters is their ability to generate reactive power (VARS), which can help meet the VAR demand by the distributed loads as well as potentially reduce the

need for capacitor banks for reactive power compensation. However, the reactive power capability is mainly available when the PV panel is energized, i.e. when the sun is out. On cloudy days or throughout the night, no PV power is available, which will de-energize the inverter and eliminate its ability to generate any reactive power.

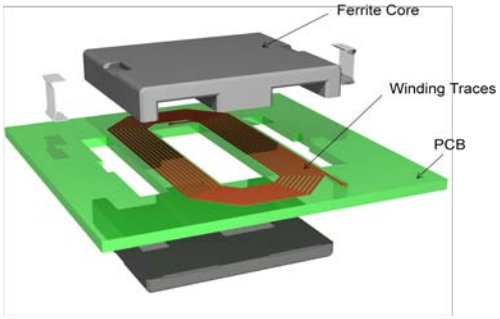
One approach to overcome the absence of PV power is to extract power from the AC line to energize the inverter power and control circuitry. As such, this research is focused on ways to utilize the existing hardware to extract control power as well as energize the DC bus to inject VARs into the AC grid even in the absence of PV power. To date, a simulation model is being developed where detailed simulations of the operation during night time will first be done and then tested.

Ultra Compact PV Inverter Packaging

The development of an integrated and low cost PV inverter packaging involves utilizing compact and integrated magnetic components, a DC-DC stage integration using a custom multi-chip module (MCM) and thermal design and optimization.

Magnetics Integration:

Low profile planar magnetic structures are being explored to replace the bulky and less efficient conventional pot or PQ transformer design. Low profile planar magnetics offer many advantages including high power density and high efficiency, low profile and weight, excellent electromagnetic and thermal characteristics, low leakage inductance, and excellent integration with PCB circuitry.



Low Profile Planar Magnetics

Finite element analysis techniques (ANSOFT) are being utilized to optimize the design, minimize the winding and core losses in order to optimize the efficiency of the planar transformers. The design optimization steps include: core loss minimization, winding loss minimization, and PCB winding design and layout.

Core Loss Minimization

A number of core shapes, sizes, and materials where analyzed using ANSOFT. The 3C95 and 3C91 core materials exhibited the lowest core losses as shown in the figure below and as such will be selected for the final implementation.

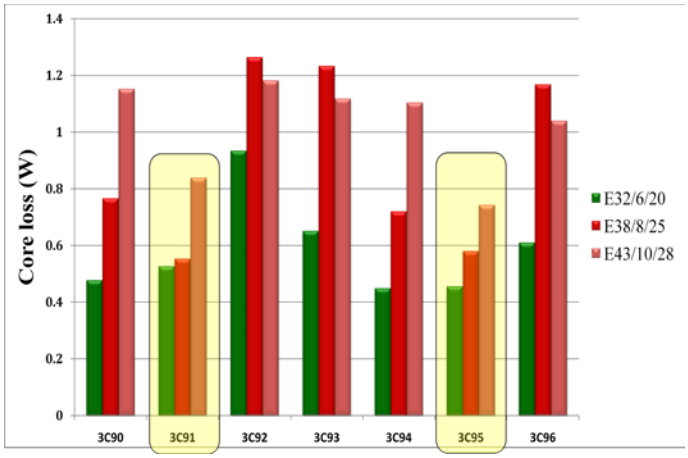
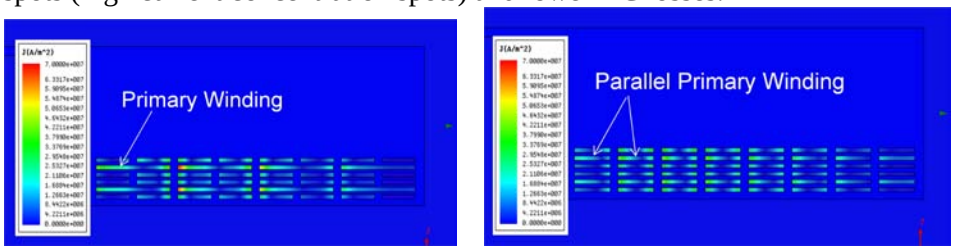


Fig. 5: Core Loss Optimization

Winding Loss Minimization

Various winding designs and structures were analyzed and considered. It has been found that interleaving impacts winding losses and loss distribution within windings. In addition, the winding losses can be further reduced by splitting the primary windings into two parallel windings as that tends to reduces hot spots (high current concentration spots) and lower AC losses.

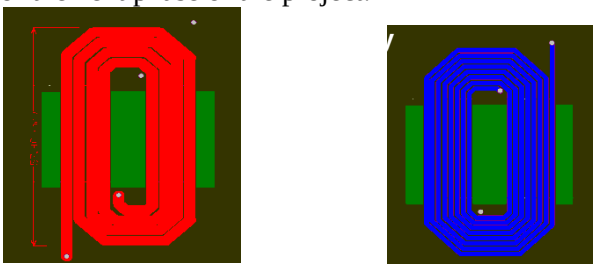


Winding Loss Optimization

More specifically, an integrated planar transformer for the flyback DC-DC converter stage was designed. The choice of magnetic core material, core shape, winding design and interleaving, and air gap design are being explored to yield the best design in terms of compactness and highest efficiency. Initial design iterations have yielded planar transformers with total power loss of less than 1 W, a 50% improvement using conventional transformer design techniques.

Winding Design

A PCB based winding design has been proposed. The planar transformer will be built and tested as part of the next phase of the project.



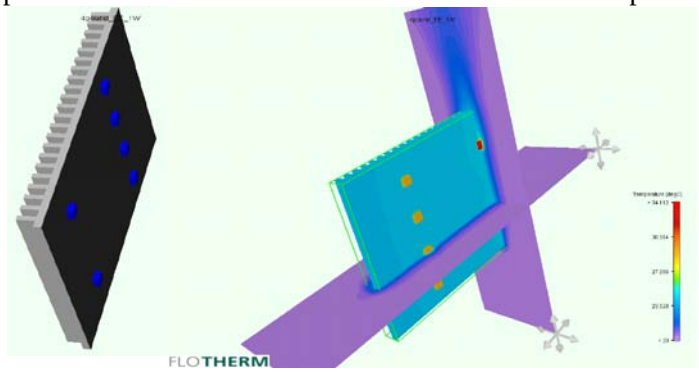
Winding Design

Thermal Design and Optimization:

In order to optimize the thermal performance of the panel mounted inverters, a thermal model utilizing FLOTHERM was developed. The model first attempts at characterizing the thermal performance of the

present inverter design. Next, the design will be optimized by improving the heat transfer from the power dissipating components as well as improving the heat sink design.

In the FLOWTHERM model (shown below), heat dissipating power devices, such as MOSFETs and diodes, are mounted on the power PCB, which is coupled to an aluminum heat sink through thermal vias as well as a 0.3-mm thick high thermal conductivity Thermal Interface Insulation Pad (HTIP). The HTIP provides electrical isolation as well as a heat transfer path.



Aluminum heat sink simulation result

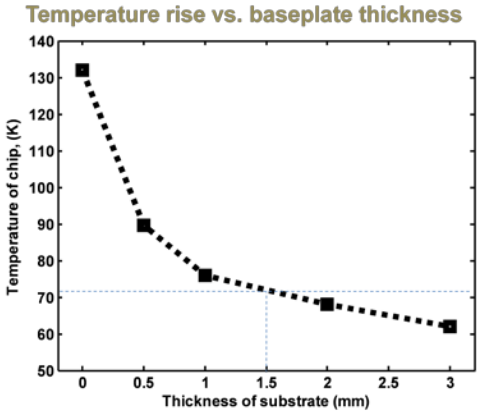
The thermal modeling is intended to optimize the heat sink parameters: heat sink base plate thickness, fin height, thickness and spacing, and PCB via optimization (thermal resistance of PCB).

Heat Sink Base Plate Thickness Optimization

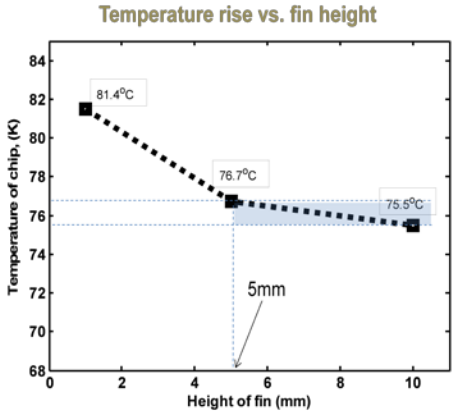
The heat sink base plate thickness was varied and the resultant maximum temperature rise of the power MOSFETs was computed. The calculations show that the optimal heat sink base plate thickness is approximately 1.5 mm. Thicknesses larger than 1.5mm will yield diminishing improvements.

Fin Height Optimization

Next, the heat sink fin height was varied and the resultant maximum temperature rise of the power MOSFETs was computed. The calculations show that the optimal heat sink fin height needs to be approximately 5 mm. Fin heights larger than 5mm will yield diminishing improvements.



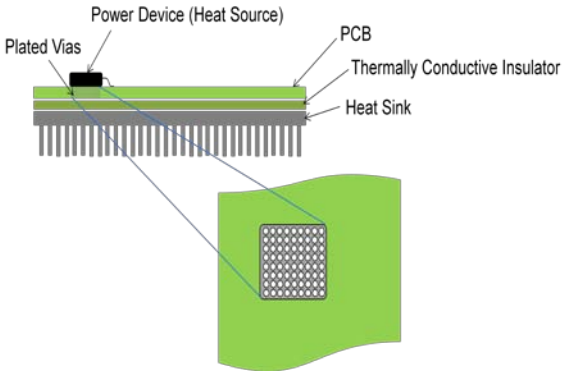
Heat Sink Base Plate Thickness

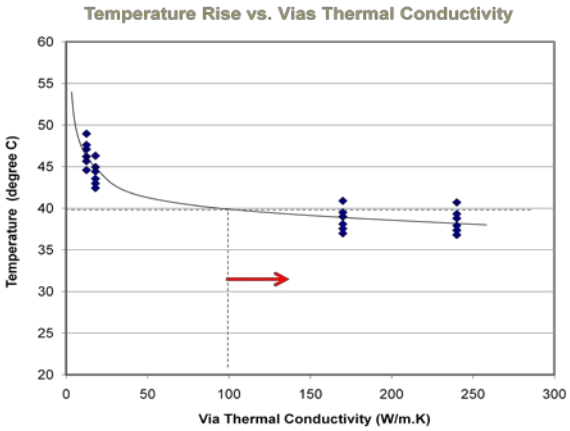


Heat Sink Fin Height

PCB Thermal Via Optimization

The PCB thermal via conductivity was investigated next. The number of vias and size of vias was varied and the resultant maximum temperature rise was computed. The calculations show that an optimal thermal via conductivity of 100 W/mK is required. This necessitate minimum mitalization of 25% of the thermal pad area.





The next phase of this task will involve building an optimized heat sink based on the calculations above to verify the findings.

UNIVERSITY OF CENTRAL FLORIDA

Buoy Array for Ocean Wave Power Generation

PI: P.I. Z. Qu **Co-PI**: K. Lin
Students: Shiyuan Jin (Ph.D), Steven Helkin (M.S.), Carlos Velez (B.S.)

Description: The objective of this project is to analyze, design, and demonstrate a wave power generation system with novel multi-functional energy converting devices. The tasks include component design and modeling, system integration, system testing and evaluation. The proposed system consists of an array of buoys floating on the ocean and tethered to the floor. Each of them has one or multiple devices inside that can convert the kinetic energy of the motion of the waves into electrical energy. The electricity generated is then transmitted through the cable that goes along or inside the tether to the ocean floor, expending to an energy processing/storage station on the ocean shore.

Budget: $150,000

Universities: UCF

Progress Summary

Nature offers a tremendous source of renewable energy in the kinematic motion of ocean waves.
This project involves the development and optimization of a wave energy converter model that is innovative in design. For this project, a prototype has been built using machine components. The prototype was mounted onto a special motion platform that can oscillate vertically to simulate wave motion, which drives a shaft to produce electricity using a permanent magnetic generator.

The project began with a literature review and a Matlab/Simulink simulation. Next, two prototypes were developed and tested. The first prototype simulated wave moving up and down with an amplitude of 15-cm, and could generate between 35 to 40 watts electricity. The experiences gained in testing of this prototype helped design and build the second prototype (Figure 2). The second prototype used two sprockets and a longer chain giving more mechanical advantages. In addition, a more efficient generator that requires less torque reduces frictional losses imposed on the shaft. Test results have shown that the power output increases from 37.3 to 206 watts. See prototype figures in next section.

In order to make the generator run more continuously and, thus, generate more power for a given wave input, a load control mechanism was designed to dynamically control the electric load. This requirement is needed when there is no pulling force of the wave at the down-stroke and the load is not applied so that the flywheel runs continuously. Tests of the second prototype were done for a number of different configurations.

In addition to the prototype tests, the buoyancy force of the waves on a small buoy has been studied. For these experiments, the output of the force is recorded by a computer based data acquisition system and the results will help verify the computation fluid dynamics model to be used in the future.

Currently, the work is focused on the next prototype design, as well as the power conditioning circuit design. To build a system that can operate reliably in the harsh ocean environment, the current prototype will be changed and reinforced. The chain is replaced by a reliable belts, a new gear train will be used to convert excess rotational velocity into a greater driving torque for a new, powerful GL-PMG-3500

generator. The new design will replace different buoy designs under consideration. See Figure 3 in the next section.

A microcontroller will be used to replace the LabView computer in future real environment to automatically control electric load and a power control strategy is being designed for stabilizing the variable frequency, variable voltage output and for satisfying the grid requirements of constant voltage, frequency, and power.

2009 Annual Progress Report

The objective is to analyze, design, and demonstrate a wave power generation system with novel multi-functional energy converting devices. The tasks include component design and modeling, system integration, system testing and evaluation. The proposed system consists of an array of buoys floating on the ocean and tethered to the floor. Each of them has one or multiple devices inside that can convert the kinetic energy of the motion of the waves into electrical energy. The electricity generated is then transmitted through the cable that goes along or inside the tether to the ocean floor, expending to an energy processing/storage station on the ocean shore.

The project began with a literature review and a Matlab/Simulink simulation. Next, two prototypes were developed and tested. The first prototype (Figure 1) shows that a simulated wave moving up and down with an amplitude of 15-cm, can generate between 35 to 40 watts electricity. The experiences gained in testing of this prototype helped design and build the second prototype (Figure 2). The second prototype uses two sprockets and a longer chain giving more mechanical advantages. In addition, a more efficient generator that requires less torque reduces frictional losses imposed on the shaft. Test results have shown that the power output increases from 37.34 to 206 watts.

In order to make the generator run more continuously and, thus, generate more power for a given wave input, a load control mechanism was designed to dynamically control the electric load. This requirement is needed when there is no pulling force of the wave at the down-stroke and the load is not applied so that the flywheel runs continuously. Tests of the second prototype were done for a number of different configurations.

In addition to the prototype tests, the buoyancy force of the waves on a small buoy has been studied. For these experiments, the output of the force is recorded by a computer based data acquisition system and the results will help verify the computation fluid dynamics model to be used in the future.

Currently, the work is focused on the next prototype design shown in Figure 3, as well as the power conditioning circuit design. To build a system that can operate reliably in the harsh ocean environment, the current prototype will be changed and reinforced. The chain is replaced by a reliable belts, a new gear train will be used to convert excess rotational velocity into a greater driving torque for a new, powerful GL-PMG-3500 generator. The new design will replace different buoy designs under consideration.

A microcontroller will be used to replace the LabView computer in future real environment to automatically control electric load and a power control strategy is being designed for stabilizing the variable frequency, variable voltage output and for satisfying the grid requirements of constant voltage, frequency, and power.

Figure 1 First generation of prototype

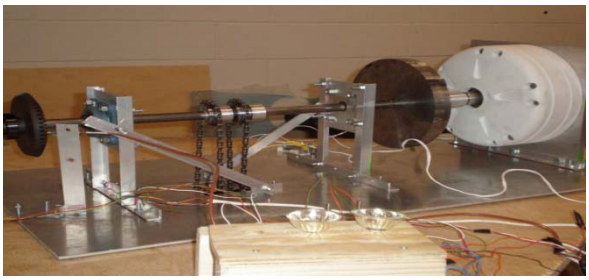


Figure 2 Second generation of prototype

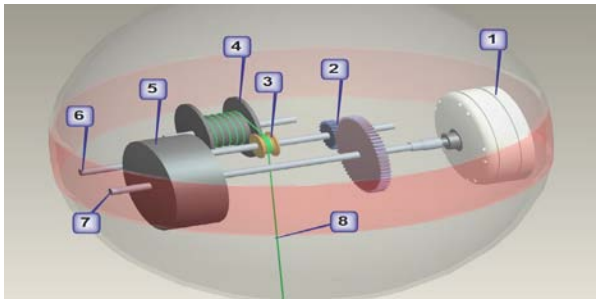


Figure 3 Conceptual design of next generation

The result for this phase of the effort is presented in the following table which gives the timelines, task and description results or actions.

Timeline	Main Task	Description
10/15/2008-11/30/2008	Literature review Matlab/Simulink modeling and simulation	A literature review was performed to demonstrate the novelty of the project. Matlab/Simulink was used to solve hydrodynamic and mechanical differential equations and simulate the wave input and electric power output.
12/01/2009-3/31/2009	First prototype design	Mechanical AutoCAD design and implementation of the prototype were done. Initial tests show that a simulated wave moving up and down with amplitude of 15-cm, can generate between 35 to 40 watts of electricity (see Figure 1).
	Motion platform setup and LabView data acquisition	A 6-DoF motion table was set up to simulate the wave motion. A LabView machine was used to collect measurement data for analysis.
	Hydrodynamic test	The buoyancy force of the waves on a small buoy was studied. The wave motion pushes the buoy up and down and motion force readings from the force transducer were shown to vary accordingly. The output of the force is recorded in a computer based data acquisition system. The results will help verify the computation fluid dynamics model in the future.

Timeline	Main Task	Description
4/1/2009-7/31/2009	Second prototype design	A second prototype was designed with two sprockets and a longer chain in order to utilize more mechanical advantage (see Figure 2). A more efficient generator that requires less torque and reduced frictional losses imposed on the shaft. Power measurements increased from 37.34 to 206 watts.
	Electric load control; RPM, potentiometer, strain gauge sensor data measurement	A number of sensor data were measured – voltage output, shaft rpm, chain tension force, platform motion instantaneous height, etc. These data are useful for electric load control and buoy design.
8/1/2009-9/14/2009	Different configuration tests and system optimization	Second prototype was tested in different configurations: two sprockets running in opposite/same direction, different number of flywheels, and load control window size. Results were used to remodel the system and maximize the power output based on the model for a given wave size. The power output was shown to be directly proportional to the angular velocity of the shaft in the system.
9/15/2009-present	Microcontroller and circuit conditioning design	The existing LabView control machine is planned to be replaced by a PIC microcontroller in order to achieve a real environment and to dynamically control the electric load. Furthermore, a power control strategy is required for stabilizing the variable frequency, variable voltage output and for satisfying the grid requirements of constant voltage, frequency, and power.
	Next generation prototype and buoy design	To build a system that can operate reliably in the harsh ocean environment, the current prototype will be changed, and reinforced, and redesigned (see Figure 3). Planned procedures are: The chain should be replaced by a reliable belt. The input and output shafts are coupled together through the use of a gear train which can convert excess rotational velocity into a greater driving torque for new generator GL-PMG-3500. Different buoy designs are under discussion.

UNIVERSITY OF CENTRAL FLORIDA

Solar Water Heating Systems Facility

PI: James Roland, David Block

Description: The objective of the task was to design with air conditioning (A/C), develop construction drawings, obtain permits and then hire a construction firm to add the walls, windows, doors and A/C to an existing FSEC roof facility. The enclosing of this existing space was done for the purpose of increasing laboratory space and to allow for conducting tests on solar water heating systems and PV inverters. The action was taken following a study which determined this project was the most cost effective means of adding valuable laboratory space.

Budget: $600,609

Universities: UCF/FSEC

Progress Summary

Due to the resurgence of the solar industry, FSEC has received a significant increase in demand for solar systems testing and certification. This occurrence has resulted in requiring the Center to correspondingly amplify its capabilities to respond to the increased demand. Thus, the objective of this task was to add walls, windows, doors and A/C to an existing FSEC roof only facility for the purpose of increasing conditioned laboratory space and to allow for conducting tests on solar water heating systems and PV inverters.

In 2005, FSEC constructed a slab and roof only facility on the west side of its Cocoa site. Due to the increase in testing and certification requirements, the need for conditioned laboratory space has become a critical requirement. Following a study, the most cost-effective program that could be done to add laboratory space was to design an enclosure for an existing roof facility located at FSEC. This facility is called the Applications Testing Facility (Bldg. #1940).

Results to Date

The enclosing of the FSEC roof facility began in September 2008. Since that time, the following has been completed or is scheduled:

A design build firm* was hired on April 1, 2009.
Construction drawings were completed July 2009.
State Fire Marshal approval was requested and received on September 15, 2009.
A meeting was held to discuss cost and timing with the design build firm on September 8, 2009.
Following the meeting, a purchase order for construction was issued on September 19, 2009.
The estimated completion date of the new facility is April 30, 2010
*PPI Construction Management of Orlando, FL.

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Background

The Florida Solar Energy Center (FSEC) is one of the nation's leading testing and certification organizations for solar products and equipment. The center's expertise is based on nearly 30 years experience conducting accredited solar energy testing and certification programs. FSEC believes that independent, third-party testing and certification has extensive value in the marketplace, especially for products that are not widely "proven" with consumers such as solar water heating systems and solar electrical (photovoltaic) systems. Independent, third-party certification provides not only protection for consumers, but also much needed consumer confidence. Even more important, third-party certification provides protection to reputable manufacturers, ensuring that lower quality products, often from foreign markets, do not compete head-to-head with Florida and U.S. products unless they meet the same standards.

In addition, to be eligible for the 2005 EPAct federal tax credits for solar thermal systems, the consumer must purchase a solar thermal system certified by the Solar Rating and Certification Corporation (SRCC) or FSEC. Since this federal tax credit has been extended through 2016, solar thermal testing and certification will continue to be required. While SRCC or FSEC may accept test results from other testing laboratories for certification, today, FSEC is the only accredited solar thermal testing laboratory in the U.S.

Due to the resurgence of the solar industry, FSEC has received a significant increase in demand for solar collector and solar system testing and certification. This occurrence has resulted in requiring the Center to correspondingly amplify its capabilities to respond to the increased demand.

Thus, the objective of the task is to add walls, windows, doors and A/C to an existing FSEC roof only facility for the purpose of increasing conditioned laboratory space and to allow for conducting tests on solar water heating systems and PV inverters.

Existing Facility

In 2005, FSEC constructed a slab and roof only facility on the west side of its Cocoa site. The purpose of this facility was to allow for PV module and inverter testing. Due to the increase in testing and certification requirements, the need for conditioned laboratory space has become a critical requirement. Thus, the most cost-effective program that could be done to add laboratory space was to design an enclosure for an existing roof facility located at FSEC. This facility is called the Applications Testing Facility (Bldg. #1940). The following three photographs (Figures 1, 2 and 3) show this existing facility before any renovation has begun.

Figure 1: Ground level front view

Figure 2: Roof view showing PV panels being tested.

Figure 3: Inside view of Applications Testing Facility.

Results to Date

The enclosing of the FSEC roof facility began in September 2008. Since that time, the following has been completed or is scheduled:

A study was completed on the needs for using the existing Applications Testing Facility
A design build firm* was hired on April 1, 2009.
Construction drawings were completed July 2009.
State Fire Marshal approval was requested and received on September 15, 2009.
A meeting was held to discuss cost and timing with the design build firm on September 8, 2009.
Following the meeting, a purchase order for construction was issued on September 19, 2009.
The estimated completion date of the new facility is January 31, 2010
*PPI Construction Management of Orlando, FL.
Although not a part of this program the following section describes the FSEC solar thermal system approval process and PV inverter testing.

Solar Thermal Systems and Certification

FSEC is responsible for approving all solar water and pool heating systems that are sold or manufactured in Florida. The FSEC standards program has been designed to meet the intent of the legislation while also helping the Florida solar industry to develop quality products, aiding building departments in product approval, and instilling confidence in the consumer who chooses to use solar energy in their residence or business.

The solar water heating systems that are certified by FSEC are done in accordance with the Florida System Standards Program for Solar Thermal Systems. These systems have been found to meet the minimum standards established by FSEC. The certification also provides FSEC-developed system ratings. Ratings have been developed by FSEC to provide the solar industry and consumers a reasonable method of comparing solar water heating systems. The ratings provided are intended for comparing solar systems and will not accurately predict the performance of a system installed at a specific site. System ratings are

an estimate only and are not a guarantee. They are based on specific collector or system test results, typical operating conditions, and typical Florida climatic conditions. When multiple options are specified for a particular component, the ratings are based on the components that result in the lowest rating. The actual solar contribution can vary and is dependent on the weather, the user, and proper system installation and maintenance.

FSEC provides three annual ratings for certified solar systems. These are:

Energy Factor
Energy Output
Solar Fraction

Ratings are based on the estimated annual performance of the system as modeled using the TRNSYS system simulation program and typical meteorological year weather data (TMY2). The ratings are based on TMY2 weather data for the three regions defined by the Florida Building Code. These are North (Jacksonville), Central (Tampa), and South (Miami).

Power Conditioning Equipment

The critical component in the power conditioning package of a PV system is the PV inverter which transforms DC electrical current from the PV array to AC electrical current for the power application. A complete PV system documentation package is a fundamental requirement for system approvals. At a minimum, this documentation must include system specifications, parts lists, electrical schematics, mechanical drawings, and instructions for the installation, operation and maintenance of the system.

In conducting FSEC's PV system certification program, the requirement for inverter testing has become a need. Thus, capabilities to test PV inverters have been established and this capability is located at the Applications Testing Facility.

Industry Support:

This task will be strongly supported by the solar thermal manufacturers, who must have certification (FSEC within Florida, and FSEC-contracted SRCC nationwide) to effectively sell their products and qualify those products for various state and federal incentives and rebates. The Solar Rating and Certification Corporation (SRCC) currently contracts with FSEC for $500,000 of annual work in test and certification. Further, FSEC expects the US Department of Energy to fund test work at an annual rate of $200,000 during through 2011. However, this support is directed to labor and other operating expenses, and will not provide for the capital expansion and enhancements proposed under this task.

UNIVERSITY OF CENTRAL FLORIDA

PV Power Generation Using Plug-in Hybrid Vehicles as Energy Storage

PI: J. Shen **Co-PI's:** I. Batarseh, N. Kutkut
Students: Michael Islas, John Elmes

Description: The objective of this project is to develop and demonstrate the architecture of an alternative PV power generation system that uses plug-in hybrid vehicle as the energy storage and transfer element. The total system cost target is $3.50/watt. The project tasks include developing efficient, reliable and inexpensive maximum power tracking DC/DC battery chargers and 3-phase converters. The developed system will be demonstrated on the UCF campus by contracting to construct a 10kW solar carport charging station. A plug-in hybrid vehicle with a 25kWh battery bank (battery-only driving range of 50-100 miles) and onboard bidirectional AC charging system will be operated at the station.

Budget: $380,816

Universities: UCF

External Collaborators: City of Tavares, FL

Progress Summary

This project will develop and demonstrate an alternative PV power generation architecture that uses plug-in hybrid vehicle as the energy storage and transfer medium. The total system cost target is $3.50 watt. Included in the development of this project are efficient, reliable, and inexpensive maximum power tracking DC/DC battery chargers and 3-phase converters.

The developed technology will result in a 10kW demonstration solar carport charging station to be built on UCF campus. A plug-in hybrid vehicle with a 25kWh battery bank (battery-only driving range of 50-100 miles) and onboard bidirectional AC charging system will be demonstrated at the charging station.

The progress to date included the completion of all physical and electrical designs, finalizing contracting arrangements and obtaining all permits related to the solar carport design. Construction is planned to start in November 2009 depending upon procuring of the construction materials. The system architecture design and specifications are completed and work is being done on hardware prototyping of the conversion electronics.

The technology is also planned to be implemented at the parking lot of Wooten Park in the City of Tavares. A schematic of the solar charging structure is shown in the Annual Progress Report.

2009 Annual Progress Report

This project will develop and demonstrate an alternative PV power generation architecture that uses plug-in hybrid vehicle as the energy storage and transfer medium. The total system cost target is $3.50 watt. Included in the development of this project are efficient, reliable, and inexpensive maximum power tracking DC/DC battery chargers and 3-phase converters.

The developed technology will result in a 10kW demonstration solar carport charging station to be built on UCF campus. A plug-in hybrid vehicle with a 25kWh battery bank (battery-only driving range of 50-100 miles) and onboard bidirectional AC charging system will be demonstrated at the charging station.

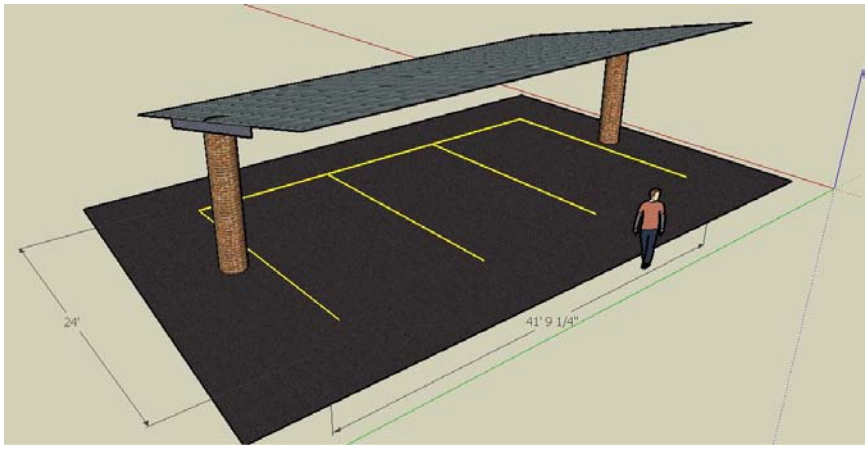
The technology is also planned to be implemented at the parking lot of Wooten Park in the City of Tavares.

Progress:

The progress to date of the project is examined by review of the activities and programs on three elements – design and construction of the solar charging station, development of the power electronics, and dissemination of the technology to Tavares. The details follows:

1. Design and Construction of the Solar Charging Station (see model of concept below)

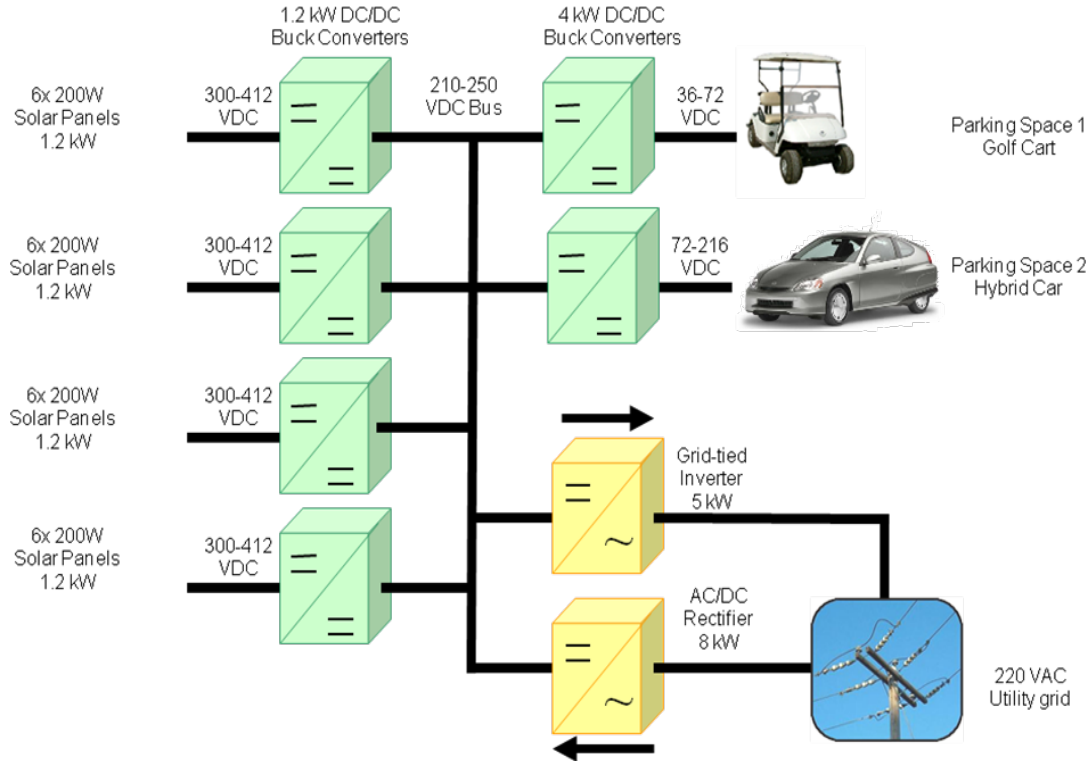
Initial design concept completed
Contractor bidding and selection completed. Wharton-Smith Construction Group will be in charge of the project construction with a maximum budget of $300,645.
Construction site and permit finalized
Electrical design completed
Construction permit application completed
Construction to start in November 2009



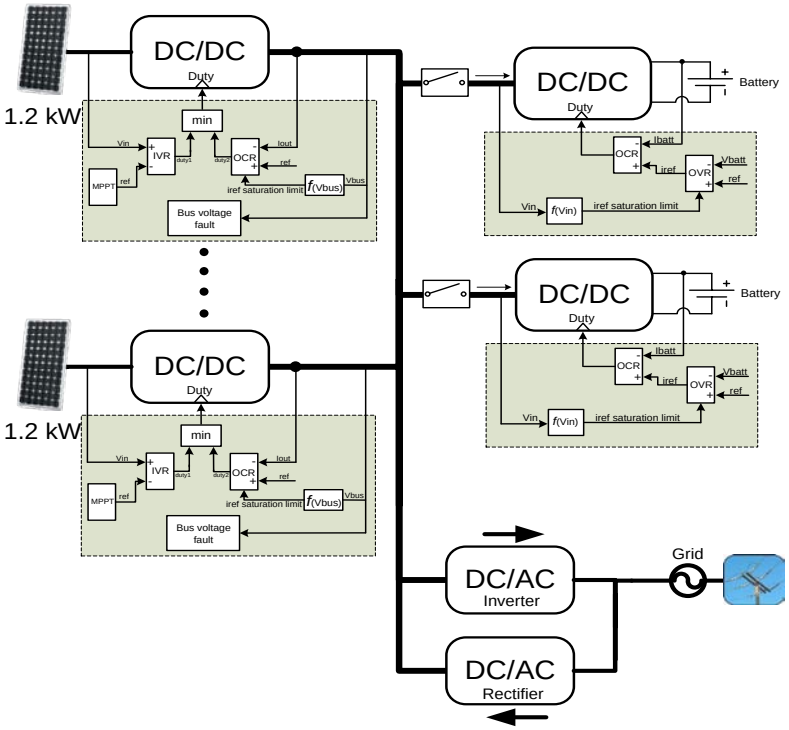
2. Development of the Power Electronics

Design concept completed
Design specifications completed
System modeling and simulation being conducted
Hardware prototyping being conducted
Building of system begun in August 2009

The system was designed to be modular in order to be easily expanded to the desired number of parking spaces. A single module will provide charging for two parking spaces. The module consists of 4 groups of panels. Each group has a set of 6 panels in series rated at 200W each. This yields a maximum power of 1.2 kW per group. Each group is connected to a 1.2 kW DC/DC MPPT converter which actively maximizes the power to the electrical bus. A buck converter is the topology of choice for the 4 DC/DC MPPT converters as well as two DC/DC converters for the battery charger. The following figure illustrates the set-up for each PV module system.



The control structure for each module is illustrated in the following figure.



3. Dissemination of Technology

The technology will be disseminated by partnering with City of Tavares, Florida. Tavares plans to implement the project's outcome in its Wooton Park. See below for a Wooton Park overview. The Wooton Park project is planned to serve as a regional multi-modal transportation hub that will be an "economic engine" serving as catalyst for revitalization of downtown Tavares into a regional destination and waterfront event venue. The City of Tavares promotes green transportation and supports installation of solar charging stations in the Wooton Park for both plug-in hybrid vehicles and electric neighborhood vehicles. The UCF team will provide the project's results and technical support for the city's projects. Several meetings have been held between the parties.

City of Tavares Wooton Park where UCF's solar charging station concept will be implemented in the parking lot.

UNIVERSITY OF CENTRAL FLORIDA

Chemical and Mechanical Degradation of Fuel Cells

PI: Darlene Slattery
Co-PI's: Len Bonville, Xinyu Huang, Marianne Rodgers
Students: B. Pearman, W. Yoon, W. Rigdon (all Ph.D. students)

Description: The objectives of the program are to gain insight into fuel cell membrane degradation mechanisms including both chemical and mechanical degradations. Topics to be researched include a detailed investigation into factors that accelerate degradation, namely OCV and high temperature operation. The chemical and mechanical durability of fuel cell membranes will be evaluated to include varying cell temperature and cell load under static testing conditions. The membrane degradation mechanism will be used to suggest membrane degradation mitigation strategies and the conductivity of more efficient tests to carry out membrane durability studies.

Budget: $324,000

Universities: UCF/FSEC

Progress Summary

The objective of the program is to gain insight into membrane degradation mechanisms for the polymer electrolyte membranes used in fuel cells. To this end, a detailed investigation into factors that accelerate degradation, namely open circuit voltage (OCV) and high temperature at low relative humidity operation is being carried out. The chemical and mechanical durability of fuel cell membranes is being determined and the data will be analyzed as a function of testing conditions. Both cell temperature and cell relative humisity are being varied under static testing conditions, while all other testing conditions are being held constant.

A major accomplishment for the year was the verification of the high-throughput MEA Durability Test System (MEADs) that was recently added to the FSEC fuel cell lab, under separate funding (see Figure 1). This equipment, the very first machine of its kind, was designed and fabricated by Scribner Associates to FSEC specifications . The MEADs allows simultaneous, independent operation of eight fuel cells at or near open circuit voltage (OCV), a fuel cell operation condition frequently used in accelerated test protocols. This unique instrument is being used to conduct chemical degradation tests on various commercial, as well as FSEC MEAs on a multiple sample basis. These MEAs are then subjected to mechanical durability testing.

An additional accomplishment was the design and construction of test equipment for determination of pinholes in membranes. In this apparatus, a membrane is placed within a specially constructed cell and a low boiling solvent is added. An inert gas is then used to lightly pressurize one side of the cell, while the other side is observed for any bubble formation. These bubbles indicate the presence of pinholes in the membrane. A number of membranes were tested for pinholes and the location of the pinholes was documented. A surprising result from the pinhole testing is that the majority of pinholes appear to be located along the gas inlet stream. The cause for this is unknown.

Eight fuel cells were prepared for testing on the MEADs. Three of the cells had previously been through a 5-day performance test, two were freshly assembled from commercially available IonPower catalyst coated membranes (CCMs) and the final three were freshly assembled from CCMs prepared in-house.

After preliminary humidification and verification steps, the membrane electrode assemblies (MEAs) prepared from these CCMs underwent a 76 hour durability test. Following the durability test, the MEAs were subjected to pinhole tests, as well as mechanical tests to determine the effect of open circuit voltage on the strength of the membrane.

2009 Annual Progress Report

This program focuses on the verification of chemical and mechanical degradation of fuel cell membranes, as well as the interaction between these two types of degradation. To be successful in automotive application, membranes must survive 10 years in a vehicle and 5,500 hours of operation including transient operation with start-stop and freeze-thaw cycles. Recent work has shown that the catalyst plays an important role in the overall membrane degradation mechanism. The same membrane, with different catalyst in the electrode has shown an improvement of over 100x in lifetime. Similarly, using the same membrane electrode assemblies (MEAs) under different operating conditions have shown that the degradation rate can differ by more than an order of magnitude. This suggests that membrane durability needs to be evaluated in the overall MEA under fuel cell operating condition. Since time is a major constraint under actual operating conditions, new membrane materials can be evaluated by operating under conditions that accelerate the membrane decay rate.

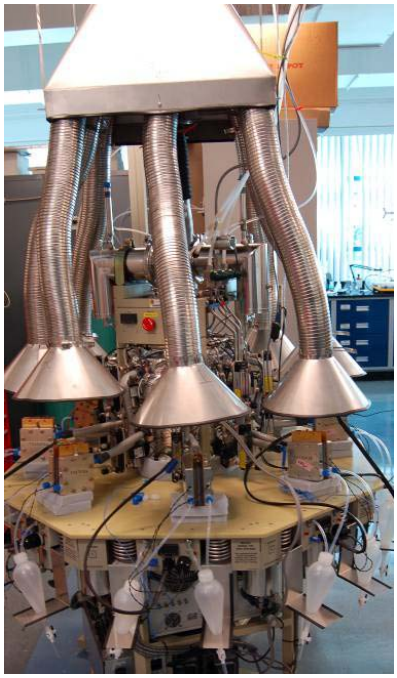


FIGURE 2. MEADS SYSTEM FOR ACCELERATED DURABILITY TESTING

A major task for this program has been the calibration of the system purchased (under unrelated funding) for performing accelerated degradation testing. This system, called the Membrane Electrode Assembly Durability Test System or MEADS, was purchased from Scribner Associates and was designed, in collaboration with FSEC, especially for such tests. The system allows for the simultaneous, independent operation of eight cells at or near open circuit voltage (OCV) and is capable of running load cycling at various relative humidities. The MEADS, shown in Figure 1, has a number of advantages including all test samples can be operated at exactly the same condition temperature, RH, current, and operating time can be varied allows direct comparison of the MEA degradation based upon voltage Provides condensate for Fluoride Emission Rate (FER) testing FER is direct measurement of ionomer degradation

The MEADs calibration verified that the data obtained is accurate, repeatable and reproducible when any number of stations is in operation. The system is designed to function with one to eight cells and any of these may be removed or replaced without interrupting the test.

As a part of the program, a failure modes and effects analysis (FMEA) was performed on the MEADs to ensure its safe operation. As a result of the FMEA, hardware and operational modifications were made.

After the MEADs was calibrated and the FMEA completed, the first eight cells were installed on the system for the first durability test. These fuel cells underwent concurrent 76 hour open circuit voltage (OCV) testing. Monitoring the OCV during testing allows direct observation of the degradation of the cell. The shape of the OCV curve during testing gives insight into the degradation mechanism and the total voltage loss can be correlated to the extent of membrane degradation. The voltage drop that was

observed indicates membrane thinning or loss of electrochemically active surface area of the electrode. The data from these cells can be seen in Figure 2.

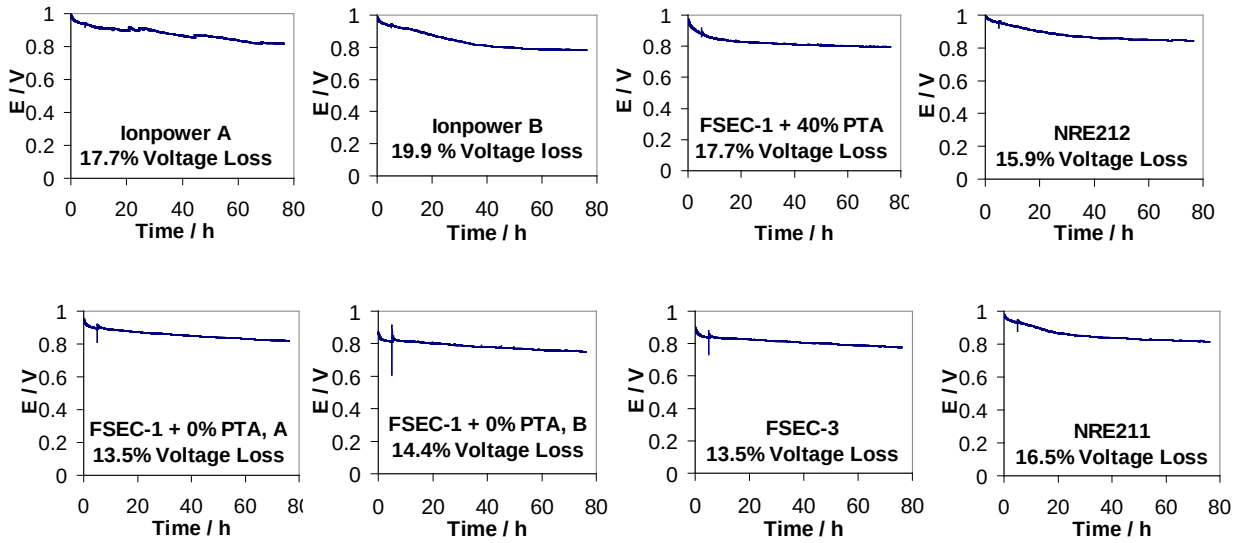


Figure 3. OCV Data obtained from the first eight cells tested on the MEADS

Detailed examination of OCV curves such as those in Figure 2 and correlation of the curves with other degradation measures will give additional insight into the degradation mechanisms that are occurring in these cells and the relationship between chemical and mechanical degradation.

Sudden fuel cell failure is associated with the massive gas crossover through holes and tears formed in the membrane. Evidence suggests that membrane degradation results in both uniform and localized manifestations. The localized manifestations results in pinholes which are a major cause of cell failure. Knowledge of the pinhole location can aid in the determination of degradation mechanisms. Therefore, a modified fuel cell that has a transparent plate on the cathode side of the MEA, was assembled for testing the MEAs after the durability run. The MEA is mounted in this cell and a liquid that wets the MEA is injected into the cathode flow field. The gas then is allowed to flow to the cell, through the anode flow field using a controlled pressure. If there are any holes present in the MEA, the gas flows through them, and is visualized as bubbles on the cathode side. These bubbles can be seen and are photographed and noted. A schematic of the device is shown in Figure 3 and an example of the pictures that are obtained during testing is shown in Figure 4. While the pinholes are too small to be found by visual inspection, their size can be inferred by the time necessary for the bubbles to appear. Larger holes allow the gas to quickly form bubbles, while smaller holes require additional time before the bubbles appear.

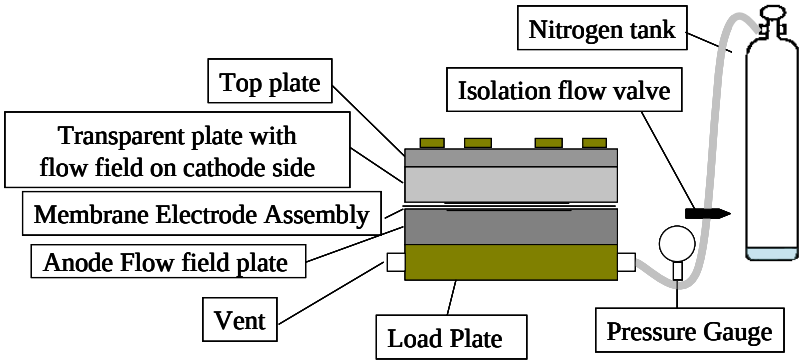


FIGURE 4. DEVICE FOR DETERMINING PRESENCE OF PINHOLES IN MEA

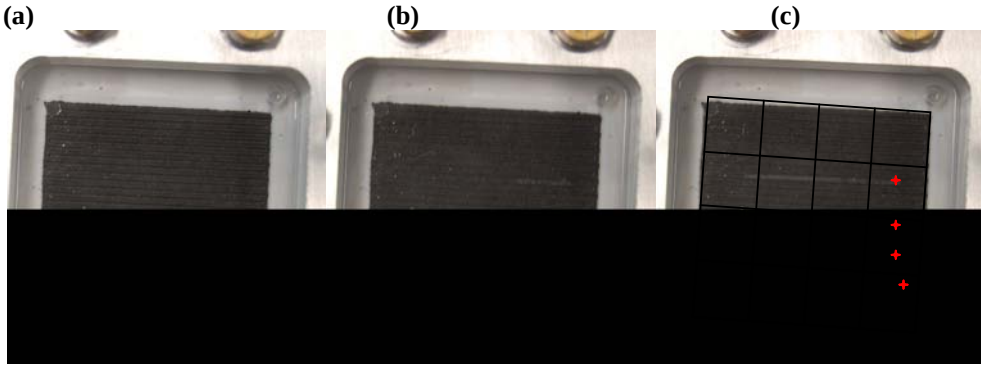


FIGURE 5 PINHOLE TESTING FOR CELL CONTAINING IONPOWER A BEFORE (A) AND DURING (B, C) PRESSURE BEING APPLIED. RED CROSSES DENOTE PLACES WHERE PINHOLES WERE FOUND AT 30 CM WATER PRESSURE.

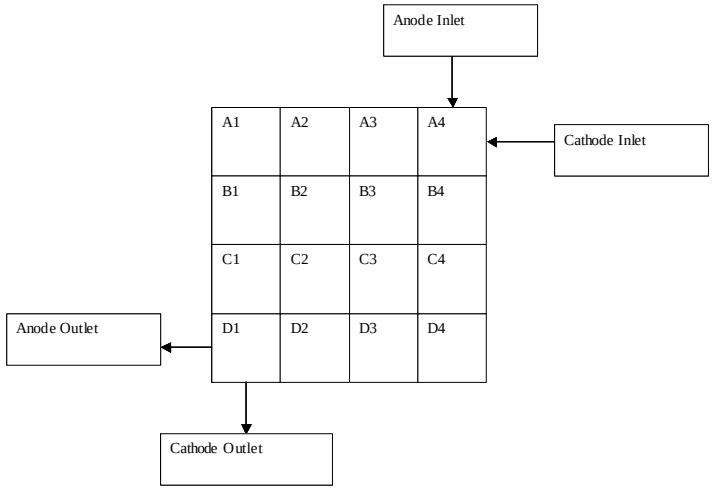


FIGURE 6. SCHEMATIC OF CELL WITH A FOUR BY FOUR GRID, NOTING ANODE AND CATHODE INLET AND OUTLET LOCATIONS.

To study the degradation mechanism associated with pinhole formation, the pictures of the MEAs were divided into four by four grids and the areas where the pinholes occurred were noted as shown in Figure 4c. Figure 5 shows a schematic of the cell with the grid in place, pointing out the locations along which the anode and cathode inlet and outlet flows flow.

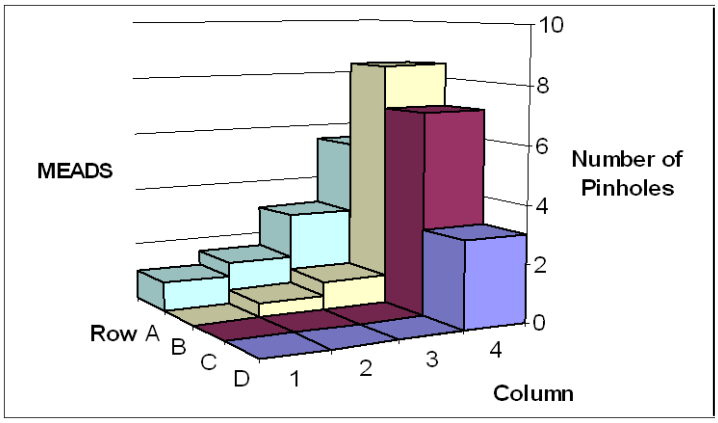


FIGURE 7 THE NUMBER OF PINHOLES AT EACH LOCATION WHEN COMBINING ALL THE DATA FROM ALL EIGHT CELLS THAT WERE TESTED 76 HOURS UNDER OCV ON THE MEADS

When the pinhole data for the cells tested on the MEADS was summarized according to pinhole location on the grid, it was observed that the majority of the pinholes occurred along the anode and cathode inlets, as seen in Figure 6. To determine the cause of the non-random distribution of pinholes, additional tests will be carried out. For example, tests will be stopped at different points to determine when the pinholes begin to appear.

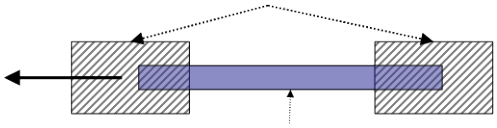


FIGURE 8. SCHEMATIC OF THE MECHANICAL ANALYZER

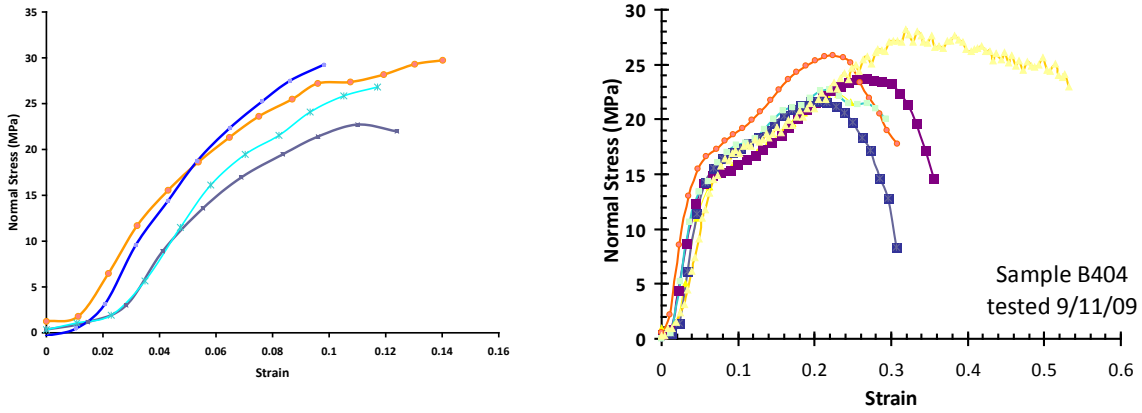


FIGURE 9. STRESS-STRAIN CURVES FOR FSEC-1 MEA, WITH (RIGHT) AND WITHOUT (LEFT) PTA ADDITIVE

In addition to testing for pinholes, the MEAs that have been subjected to durability runs are tested for mechanical strength. An in-house built mechanical test system was used to for this purpose. A schematic of the device that is used is shown in Figure 7. A piece of the MEA is cut and fastened between two clamps and a piston pulls the clamps apart at a fixed rate. Stress/strain data is recorded and plotted. The amount that the sample can stretch before it breaks is then measured. The higher the amount of stretching before breakage occurs, the better the membrane. A lower percentage of stretch before break means the membrane has hardened and become more brittle, more pinholes, etc. Typically, before OCV testing, MEAs can stretch between 100 – 200%. As can be seen in Figure 8, after the OCV testing significant degradation has occurred and stretching has decreased to 10 – 15% for the membrane without the phosphotungstic acid (PTA) additive to 30 – 35% for the membrane with the PTA additive.

To summarize Year 1 of this project, the objectives of the program are to gain insight into membrane degradation mechanisms, and to this end, a detailed investigation into factors that accelerate degradation, namely OCV and high temperature operation, are being carried out at various relative humidities. The Membrane Electrode Assembly Durability System has been calibrated and the test data was found to be accurate, repeatable and reproducible. An FMEA was performed to ensure safe operation of the system. Following this, a set of eight cells were assembled and the MEAs underwent a concurrent 76 hours open circuit voltage (OCV) test. A pinhole detection test apparatus was constructed and used to visualize holes that occur in a membrane during testing. And, finally, the MEAs from the OCV test were subjected to mechanical testing.

During Year 2 of the project, additional cells will be run in order to acquire enough data for meaningful analysis to estimate the characteristics associated with the chemical and the mechanical degradation mechanisms. Samples are examined by scanning electron microscopy before and after the OCV test to better understand the changes that occur. Comparison of electrochemical properties of the cells such as the electrochemically active surface area, cell polarization, and hydrogen crossover before and after the OCV test also provide information on the degradation mechanism. Additionally, the effluent from the cells will be analyzed to determine the fluoride emission rate from the membranes, another indicator of degradation.

Acknowledgements

The PIs would like to acknowledge Dr. Paul Brooker, Postdoctoral Associate, for MEA preparation and Christina Scigliuto, graduate student, for mechanical analysis. Additionally, the PIs would like to thank the Florida Energy Systems Consortium for financial support.

UNIVERSITY OF CENTRAL FLORIDA

Energy Efficient Building Technologies and Zero Energy Homes

PI: Robin Vieira
Co-PIs: Philip Fairey, Jeffery Sonne

Description: The project consists of two elements: 1) the construction of two flexible research homes to conduct research on advanced building energy efficiency technologies under controlled conditions and 2) a staged, field retrofit study in a small number of unoccupied homes to measure and document the effectiveness of a series of current technology retrofit measures.

Budget: $1,224,000

Universities: UCF/FSEC

Progress Summary

In order to maximize impact and field research value, the FESC team has joined with FSEC's Building America team, local governments and non-profits to perform retrofits to housing stock.

The local government partners are:

Sarasota (City & County)
Brevard County
Orange County
Alachua County

The non-profit partners are:

Habitat for Humanity (HFH) International
Neighborhood Stabiliaztion Program 2 (NSP2) Proposal - 4 Florida sites
HFH Partners Participating in NSP1
HFH Broward County (FL)
HFH of Lakeland FL
Sarasota HFH

FSEC staff met with or teleconferenced with teams from each of these entities. They each are working on projects to retrofit existing homes. Through our partnering with them each is targeting some of their homes to reach high energy efficiency levels. As part of this program the following assistance will be provided for each partner:

Run simulations to estimate savings from a number of options

Work with teams to assure construction/installations are done correctly

Meter some sites to see how energy use matched predicted

Make suggestions for future home retrofits.

Two identical new test structures (rendering on right) are being built at FSEC's Cocoa campus to help determine the best retrofit and new home practices. The structures will serve as a control and experiment for evaluating energy saving measures. The buildings are designed to allow ready change-out of wall and window systems, as well as equipment and appliances. The initial conf iguration will replicate the envelope efficiency of a typical 1960s residence, with appliance and HVAC efficiency typical for a home from that era on the market today. The homes will be monitored consistent with a lab home monitoring plan being developed by the National Renewable Energy Laboratory and Building America teams. An architect was hired and construction drawings are being developed.

2009 Annual Progress Report

The project consists of two elements: 1) the construction of two flexible research homes at FSEC to conduct research on advanced building energy efficiency technologies under controlled conditions; and 2) a staged, field retrofit study in a small number of unoccupied homes to measure and document the effectiveness of a series of retrofit measures that can be deployed using current technology.

Background

Forty percent of the primary energy consumed in the U.S. is in the building sector.[1] Buildings consume more than 80% of Florida's electrical energy.

Significant opportunities exist to cost-effectively increase residential energy efficiency, especially in new Florida homes. The American Council for an Energy Efficient Economy (ACEEE) recently completed a report on Florida's energy use showing a significant potential to cost-effectively construct homes that are at least 30% more efficient than Florida's 2007 Energy Code and 15% more efficient than Florida's 2009 Energy Code.[2] The Energy Code has brought energy efficiency to the new home market as depicted in Figure 1.

[1] USDOE Databook.
[2] Elliot, N., et.al, 2007. "Potential for Energy Efficiency and Renewable Energy to Meet Florida's Growing Energy Demands." ACEEE Report E072, American Council for an Energy Efficient Economy, Washington, DC.

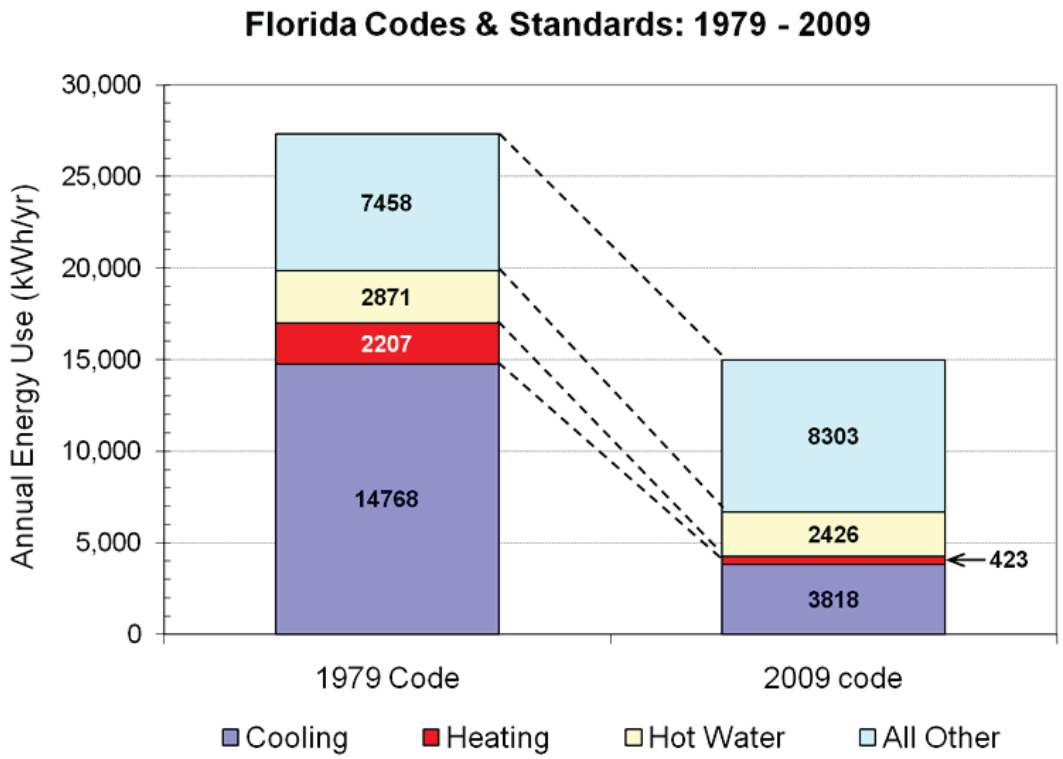


Figure 1. Energy and equipment codes have greatly reduced the heating, cooling and hot water energy use of new homes. Note that the "other" energy use categories not covered by code has increased. Figure from Fairey, Philip, *Effectiveness of Florida's Energy Efficiency Code, 1979 – 2009*, FSEC 1806-09, June, 2009.

New commercial buildings (term used to describe all non-residential buildings) have also benefited from improved energy codes. However, most commercial buildings have significant energy use from equipment, and some have high density of people. These are the key cooling loads along with fresh air requirements. Thus advances in envelope and HVAC equipment cannot achieve similar levels of savings as in the residential sector.

The 2008 Florida legislature has called for a dramatic increase in the efficiency of new homes – 50% more efficient by 2019 than Florida's 2007 Energy Code. This significant building efficiency increase will be difficult to cost-effectively achieve using only current building technologies. Thus, additional building energy research and development will be needed to bring new building technologies to the point that these efficiency increases can be cost effectively achieved. In addition, if substantial green house gas (GHG) and building energy reductions are to be realized, the vast majority of these savings must come from Florida's existing building stock, which overwhelmingly outnumbers annual new building construction units by more than 50 to 1. Recent studies on existing buildings indicate that the cost-effective retrofit potential in this sector likely exceeds 30% of current building energy use.[3]

Research and development advances in building and energy efficiency technologies provide substantial value to Florida, not only for GHG and energy use reduction but also for economic activity and job creation. Florida has about 8 million existing homes. The cost effective retrofit of just half of these homes would reduce Florida's total annual electrical energy use by approximately 7.5% or about 18,000 GWh

[3] Ibid.

per year, save Florida consumers about $2.2 billion per year in energy costs and obviate about 6,000 MW of power plant capacity, which in turn would reduce Florida's CO_2 emissions by about 11.3 million metric tons per year. Additionally, these retrofits would preserve approximately $60 billion annually in homeowner purchasing power while promoting strong in-state economic activity through 450,000 direct and indirect construction and energy technology jobs.

Project Description:

Research Homes: The objective is to design, construct, and instrument and monitor two highly-reconfigurable, geometrically-identical, residential-scale, side-by-side building energy research facilities at FSEC. This facility is envisioned as a long-term test facility that, because it is reconfigurable, can be used for many years to study and optimize residential energy performance related to both individual building efficiency measures and the interactions that occur between building energy systems and their environment. One of the principal uses of the facility will be to collect detailed data on specific heat and moisture transport phenomena that are critical to understand building science in hot-humid climates. High quality research data can then be used to develop state-of-the-art building energy technologies and to verify and improve building energy simulation software tools used for Florida's building energy codes and rating systems. Another objective will be to conduct research spanning a range of efficiency technology – from average existing Florida houses to Zero Energy Homes (ZEH) that employ highly efficient envelope and equipment.

Some of the testing enabled by the test buildings includes various innovative component and system combinations such as the following:
Quantify the effects of flooring options (e.g. carpet vs. tile) on the efficiency of ground coupled (slab) construction and investigating crawl-space foundation energy and moisture issues
Determine the extent of the energy and interior moisture impacts of newly identified air conditioner sizing issues
Maximize roofing system performance such as vented vs. sealed attics and assess their effect on attic ductwork performance
Evaluation of window performance under realistic conditions, including exposed slab floors
Assessment of various window shading options (overhangs, awnings etc), frame types, frame colors and glazing types
Evaluation of duct insulation, leakage and location impacts
Evaluate structures cooled by innovative cooling and distribution systems
Measure overall impacts of various internal load control methodologies.

Progress: An architect was selected and initial design made. The homes will be built on the FSEC Cocoa site and will have all of the roof structure supported by interior columns, thus allowing the flexibility of changing out wall and window systems. Each home will be 48' by 32' with an attached garage of 20' x 20'8". The garage is important as it allows for testing of water heaters and air handlers in an environment that they often experience. The homes will each face South as will the longer sides, but glass area is equally divided on four sides initially for testing purposes. As indicated, change outs of windows and entire walls can be accomplished. Initially the flexible labs will be constructed with uninsulated block walls typical of construction in much of Florida prior to the 1980s.

Future Plans: The buildings will be bid out and constructed. A null test will assure that the buildings operate the same. The first experiment will consist of retrofitting the experimental home to levels of the current energy code and better whie maintaining the control at the existing home level .

Staged, Field Retrofits: The original objective of this element was to conduct detailed field retrofit experiments with two unoccupied, foreclosed or unsold homes in central Florida that are leased by the project for two years and improved incrementally over the period.

However, FSEC has been working with some Florida Counties that have received block grant money for rehabilitating homes through the Neighborhood Stabilization Program 2 (NSP2) from the Department of Housing and Urban Development.. These counties are seeking to improve these targeted homes with energy efficiency as well as other measures and with our help the retrofits will be to a much higher level of energy efficiency than would have otherwise occurred Thus, the plan has changed so that it is possible to partner with the counties and effect many more homes. FSECs Building America team, funded by the US DOE, is also contributing.

Progress: The project team has reviewed past research funded by DOE and utilities. In order to maximize impact and field research, this FESC project team has joined with FSEC's Building America team, local governments and non-profits to perform retrofits to housing stock. The local government partners are:
Sarasota (City & County)
Brevard County
Orange County
Alachua County

The non-profit partners are:
Habitat for Humanity International
3 Site "Weatherization" Pilot – Dallas, Chicago, and Philadelphia
NSP2 Proposal - 4 Florida sites
HFH Partners Participating in NSP1
HFH Broward County (FL)
HFH of Lakeland FL
Sarasota HFH.

FSEC has obtained commitments each of the counties to take some of their homes to the Builders Challenge level of efficiency. The Builders Challenge program by DOE is 30% better than current national building codes and about 20% more energy efficient than Florida's 2009 Energy Code. This is a large improvement for older existing homes.

As part of this program the following assistance will be provided by FSEC staff:
Run simulations to estimate savings from a number of options
Work with teams to assure construction/installation is done correctly.
Meter some sites to see how energy use matched predicted
Make suggestions for future home retrofits.

Table 1. Builders Challenge Improvement Package for a 1960s home.

Builders Challenge Improvement Package		
Parameter	**Description**	**Efficiency**
Roof	Choose Light Color Shingle	Absorptance= 0.75
Ceiling Insulation	Add insulation to Reach	R – 30
Windows	New Energy Star Windows	U 0.40, SHGC 0.35
Floors	Replace Vinyl with Tile	Improved heat transfer
Heating System	New Heat Pump	HSPF 8.2
Cooling System		14 SEER
Ducts/Return	New Duct System	QN = 0.03
Water Heater	New Electric Tank + ICS Solar DWH	
Lighting	75% CFL	--
Appliances	New ENERGY STAR Refrigerator & Dishwasher	
Infiltration	Seal Exterior Envelope	ACH50 = 6
Ventilation	Passive Runtime Ventilation System	30cfm

Some of the assistance has begun. A sample home was put through a Builders Challenge level efficiency improvement analysis and a set of improvements developed as shown in Table 1.

The incremental cost of such a retrofit for a home would be about $10,000. That is above about $15,000 that might already be spent obtaining new minimum efficiency HVAC equipment, a new roof and new paint. The improvement are projected to deliver $1029 in annual energy savings as calculated using Florida's EnergyGauge code and rating software with a Home Energy Rating index of 69. Amortizing the cost in a 30-year mortgage results in an annual positive cash flow of $180 for the homeowner.

Future Plans: The data collection process will vary depending on the details of each retrofit. At a minimum utility bills will be collected after the retrofit. Many times the homes may have been vacated and there may not be any comparable before retrofit evaluation period. Often, HVAC equipment is missing or non-functional when the home is purchased by the housing agency.

If homes are obtained by the counties or non-profits that lend themselves to more robust evaluation, these homes will be instrumented, controlled and monitored to provide for simulated occupancy and to obtain detailed performance data under realistic operating conditions. A full complement of both indoor and outdoor environmental driving condition data will be collected.

Before the project begins, if necessary, the homes will be brought up to livable conditions by repairing plumbing, interior finishes etc. to the minimum standards required for a sale. At the conclusion of the retrofit phase, each home will be placed in "saleable" market condition and advertised and marketed for its improved energy efficiency. The project team will seek to collaborate with real estate and mortgatge professionals who are interested in differentiating homes based on their energy efficiency.

Industry Support: The Florida Solar Energy Center currently conducts a major project funded by the U.S. DOE called the Building America Industrialized Housing Partnership (www.baihp.org) The BAIHP funds are annually appropriated by DOE based on a proposal from FSEC. DOE and FESC are partnering on the two energy efficiency tasks.

UNIVERSITY OF CENTRAL FLORIDA

Enhanced and Expanded Solar Thermal Test Capabilities

PI: Joseph Walters**,** Robert Reedy

Description: The Florida Solar Energy Center (FSEC) believes that independent, third-party testing and certification has extensive value in the marketplace, especially for products that are not widely "proven" with consumers such as solar water heating systems and solar electrical (photovoltaic) systems. In addition, due to the resurgence of the solar industry, FSEC has received a significant increase in demand for solar collector and solar system testing and certification. This occurrence has resulted in requiring the Center to correspondingly amplify its capabilities to respond to the increased demand This project has the objective of increasing FSEC's solar thermal testing and certification activities by the following actions: test and analysis equipment and software upgrades and expansion, integration of the solar collector and system laboratories, enhancing documentation and reporting methods and streamlining and devising more comprehensive client test and certification application documents.

Budget: $654,295

Universities: UCF/FSEC

Progress Summary

The enhanced and expanded solar thermal test capabilities are well under way and significant progress has been achieved. The following is summary of the key aspects of the project.

Objective: Improve the capabilities of the thermal test facility through improved equipment, procedures and increasing the number of test platforms.
Measurable Results:

Year	Test Rate	Report Rate
2008 (before project)	4 collectors/year	4 reports/year
2009 (post project start)	17 collectors*/year	19 reports*/year

* These rates include the interim test and report category which allows collectors to get to market prior to performance testing while still protecting the consumer from poor quality product.

Key Elements: Ten (10) major projects were identified to attain the goal. Following is a brief project summary with an indicator of % complete.

Interim Test and Report for Certification – 100%

Provide a process that allows collectors to get to market quickly while maintaining consumer protection for quality.

Mobile Tracking Platform (MTP) Unit 2 Wind System – 100 %

Provide wind source for collector testing to meet wind requirement on demand.

MTP Unit 1 Wind System – 100%

Provide wind source for collector testing to meet wind requirement on demand.

MTP Unit 1 Conversion to Dual Flow – 100 %

Provide this test platform the capability to process the predominant collector type like the other platforms.

LabVIEW® based Collector Testing – 90%

Provide updated data logging automation for improved reliability and data transfer.

Sensor Improvement – 80 %

Research and implement new sensors and applications of sensors for more reliable and precise data measurement.

MTP Unit 4 – capacity increase – 60%

Bring into production a new test platform that has all the improvements to date with respect to sensors, automation, and wind systems.

Information Control System – 15 %

Provide an information control system that allows customer and user access to determine material status and report on material testing with the ultimate goal of automatically generating the test reports.

MTP Unit 3 – capacity increase – 0 %

Bring into production a new test platform that has all the improvements to date with respect to sensors, automation, and wind systems.

Fixed Stand Configuration - 0%

Provide a permanent or semi-permanent test platform to improve throughput by reducing the set up and take down time associated with mobile platforms.

2009 Annual Progress Report

Project Impact:

The Florida Solar Energy Center (FSEC) believes that independent, third-party testing and certification has extensive value in the marketplace, especially for products that are not widely "proven" with consumers such as solar water heating systems and solar electrical (photovoltaic) systems. Independent, third-party certification provides not only protection for consumers, but also much needed consumer confidence. Even more important, third-party certification provides protection to reputable manufacturers, ensuring that lower quality products, often from foreign markets, do not compete head-to-head with Florida and U.S. products unless they meet the same standards.

In addition, to be eligible for the 2005 EPAct federal tax credits for solar thermal systems, the consumer must purchase a solar thermal system certified by the Solar Rating and Certification Corporation (SRCC) or FSEC. Since this federal tax credit has been extended through 2016, solar thermal testing and certification will continue to be required. While SRCC or FSEC may accept test results from other testing laboratories for certification, today, FSEC is the only accredited solar thermal testing laboratory in the U.S.

Solar thermal systems for residential domestic water heating are subject to much variability in quality and performance. An important function of FSEC is consumer protection from poorly designed and manufactured thermal collectors and systems. For many years, the solar water heating industry has experienced very slow and steady growth. FSEC's test capabilities were quite adequate to test and certify the 3-5 new collectors introduced each year. However, in the last two years, the demand for testing has jumped dramatically, and is now projected at 30-50 new collectors annually, at least for the next 5 years. This increase is driven both by the recent "boom" in green energy awareness and the globalization of the

solar industry, resulting in many requests from overseas manufacturers wanting to enter the US market. This project will allow FSEC to meet the new demand for testing and certification of solar thermal collectors and systems.

Project Description:

This project has the objective of increasing FSEC's solar thermal testing and certification activities by the following actions:

Test and Analysis Equipment and Software Upgrades and Expansion
Integration of the Solar Collector and System Laboratories
Enhancing Documentation and Reporting Methods
Streamlining and Devising More Comprehensive Client Test and Certification Application Documents

Testing Instrumentation

Over the years, the instrumentation used in testing solar thermal collectors at FSEC has aged to the extent that an unacceptable level of failures occur that causes negative impacts on the time period required to complete a given test. For example, problems with sensors, connectors, computers, data cabling and the like often corrupt the test data and require not only trouble-shooting, but further losses of testing time because testing must be repeated until quality data is obtained over the full test protocol. Thus, FSEC will implement a modern instrumentation and testing system using advanced but proven hardware and software. Specifically, powerful Central Field Point (CFP) data loggers, processors and controllers are to be applied in these instrumentation upgrades.

One CFP has already procured which will be used as the baseline for new instrumentation program and will be applied to the test laboratory's fourth Mobile Tracking Platform. When the application learning curve has been achieved with MTP-4, the remaining test stands, including the ambient instrumentation facility and instrument calibration functions will follow suit. Due to the highly developed features embodied in this contemporary instrumentation and test equipment, not only will the testing time be significantly reduced, but the test data can be processed faster and reporting will be improved.

Reporting and Certification

Partly due to more automated test data gathering and processing resulting from the upgraded laboratory instrumentation and computational capabilities, the Test Reports will be more expeditiously completed. In addition, the format of the test reports is to be improved for more rapid preparation and ease of use.

Certification Application Documents

In hand with reporting and certification tasks, FSEC is also improving the format and content of the Application Forms submitted by the clients. These improvements are geared to both simplify the client's tasks in preparing the Application, aid the client in better defining their products and improving the facilitation of the Department's preparation of the test report.

The Test and Certification program is instituting the advancements summarized above and anticipates it will require on the order of six months to implement the majority of (non-capital) improvements. After implementation and the current backlog is completed, it is expected that the period between the Center receiving a fully and correctly prepared Application and the performance of the testing, reporting and certification will be reduced to an acceptable duration. It is the Center's goal to do all it can to aid the

solar industry in responding as quickly as possible to the new and growing markets within the essential constraints of reliable and credible high quality testing.

Key Results
Ten (10) major projects were identified to attain the project's goals. The following is a project summary of key elements with an indicator of % complete.
Interim Test and Report for Certification – 100%
Provide a process that allows collectors to get to market quickly while maintaining consumer protection for quality.
Mobile Tracking Platform (MTP) Unit 2 Wind System – 100 %
Provide wind source for collector testing to meet wind requirement on demand.
MTP Unit 1 Wind System – 100%
Provide wind source for collector testing to meet wind requirement on demand.
MTP Unit 1 Conversion to Dual Flow – 100 %
Provide this test platform the capability to process the predominant collector type like the other platforms.
LabVIEW® based Collector Testing – 90%
Provide updated data logging automation for improved reliability and data transfer.
Sensor Improvement – 80 %
Research and implement new sensors and applications of sensors for more reliable and precise data measurement.
MTP Unit 4 – capacity increase – 60%
Bring into production a new test platform that has all the improvements to date with respect to sensors, automation, and wind systems.
Information Control System – 15 %
Provide an information control system that allows customer and user access to determine material status and report on material testing with the ultimate goal of automatically generating the test reports.
MTP Unit 3 – capacity increase – 0 %
Bring into production a new test platform that has all the improvements to date with respect to sensors, automation, and wind systems.
Fixed Stand Configuration - 0%
Provide a permanent or semi-permanent test platform to improve throughput by reducing the set up and take down time associated with mobile platforms.

Measurable Results:

Year	Test Rate	Report Rate
2008 (before project)	4 collectors/year	4 reports/year
2009 (post project start)	17 collectors*/year	19 reports*/year

* These rates include the interim test and report category which allows collectors to get to market prior to performance testing while still protecting the consumer from poor quality product.

Deliverables:

Expanded solar thermal testing facilities for domestic hot water collectors and systems, with proven capabilities:

Pursue with all deliberate speed another collector certification mechanism that ensures collector durability and quality, but allows time-limited provisional collector performance ratings such that new collectors and systems can enter the marketplace within three months of application.

Increase FSEC's collector testing capacity to handle the surge in demand for solar thermal hot water systems. Capacity will move from the current 10 collectors per year to 40 collectors per year.
Develop performance rating system based on simulation

Industry Support:

This task will be strongly supported by the solar thermal manufacturers, who must have certification (FSEC within Florida, and FSEC-contracted SRCC nationwide) to effectively sell their products and qualify those products for various state and federal incentives and rebates. The Solar Rating and Certification Corporation (SRCC) currently contracts with FSEC for $500,000 of annual work in test and certification. Further, FSEC expects the US Department of Energy to fund test work at an annual rate of $200,000 during through 2011. However, this support is directed to labor and other operating expenses, and will not provide for the capital expansion and enhancements proposed under this task.

UNIVERSITY OF CENTRAL FLORIDA

Integrated Florida Bio-Energy Production with Carbon Capture and Sequestration

PI: Ali T. Raissi
Co-PIs: Nazim Muradov, Amit Gujar, Gary Bokerman
Students: Nathaniel Garceau (BS-Ch.E.), James Pardue (BS-M.E.)

Description: The aim of this project is to produce liquid hydrocarbon fuels derived from Florida grown biomass utilizing a two-step process. In the first step, biomass or biomass-derived pyrolysis oils are gasified with oxygen and steam to synthesis gas (syngas) comprised of mostly hydrogen, carbon monoxide and carbon dioxide gas. For this step, an electrical power source is used for electrolysis of water to oxygen (for use in the biomass gasifier) and hydrogen gas needed to supplement H_2 content of the syngas. Use of oxygen for gasification of biomass improves the overall energy conversion efficiency of the process by eliminating the need for an air separation unit. In the second step, hydrogen enriched syngas from step 1 is fed into a Fischer Tropsch (FT) synthesis unit and converted to liquid hydrocarbon fuels, *e.g.*, diesel fuel. The process can be used with any lignocellulosic material including crop residues, forest waste, yard clippings, and energy crops. The technology also provides a means for sequestering carbon in the form of a high-value soil enhancing bio-char (terra preta) by simple modification of the gasification step 1.

Budget: $648,000

Universities: UCF/FSEC

Progress Summary

In the results to date, the aim of this project is to produce liquid hydrocarbon fuels derived from Florida grown biomass utilizing a two-step process. In the first step, biomass is gasified with oxygen (instead of air) to synthetic gas (syngas) comprised of mostly hydrogen, carbon monoxide and a carbon rich residue (char). In the second step of the process, hydrogen enriched synthetic gas from step 1 is fed into a Fischer Tropsch (FT) synthesis unit to generate liquid hydrocarbon fuel, *e.g.*, diesel. The process is applicable to any lignocellulosic material such as crop residues, grasses, yard clippings, landfill gas, municipal solid waste (MSW), *etc*. An imbert-style downdraft oxygen gasifier has been designed and is in the process of being fabricated. The gasifer has been designed to run on southern yellow pine pellets from Green Circle Bio Energy Inc., produced in their Cottondale, FL plant. The gasifier would produce enough gas so as to produce 1 liter of gasoline or diesel fuel over the Fischer-Tropsch reactor in 8 hours.

Various catalysts preparations have been tested for their activity towards producing liquid hydrocarbon fuels from synthesis gas mixtures. These catalysts include Fe, Co and Mo based bulk and supported catalysts. The potassium promoted iron catalyst was found to give the highest liquid yield amongst all the catalysts tested. One of the problems with the use of iron catalyst is that it yields olefin rich hydrocarbons. The resulting hydrocarbon product is prone to undesirable oxidation and polymerization - requiring post-treatment to convert it to saturated hydrocarbons via catalytic hydrogenation. Tests have been performed with a dual-bed catalytic system with a hydrogenating or a cracking catalyst in the downstream bed. In addition to the above tests, the effect of CO_2 on the catalyst performance has been studied. The results of the project to date can be summarized in a point-wise fashion as follows:

1. The use of cracking catalyst H^+/ZSM-5 in combination with Fe catalyst results in an increase in the yield of gasoline fraction in the liquid product and a decrease in the olefin to paraffin ratio.
2. A highly paraffinic liquid product is obtained when a dual-bed catalytic system including Fe and Ni-Mo/alumina hydrogenation catalyst is employed in the F-T synthesis.
3. Presence of Ni-Mo catalyst did not significantly alter the product slate for the liquid fraction, but practically eliminated olefins from the raw product.
4. Presence of CO_2 in the feed gas adversely affects syngas conversion and space time yield of liquid products.
5. Upon further development, the process described here can provide a more facile and direct route to production of high quality liquid hydrocarbons from biomass-derived syngas.

2009 Annual Progress Report

The aim of this project is to produce liquid hydrocarbon fuels derived from Florida grown biomass utilizing a two-step process. In the first step, biomass is gasified with oxygen (instead of air) to synthetic gas (syngas) comprised of mostly hydrogen, carbon monoxide and a carbon rich residue (bio-char). In the first step, a water electrolysis system is used to provide oxygen for the biomass gasifier and hydrogen needed to elevate H_2 concentration in the syngas. Use of oxygen for gasification of biomass significantly improves the overall energy conversion efficiency of the process eliminating the need for an air separation unit. In the second step of the process, hydrogen enriched synthetic gas from step 1 is fed into a Fischer Tropsch (FT) synthesis unit to generate a liquid hydrocarbon fuel, *e.g.*, diesel. The process is applicable to any lignocellulosic biomass such as crop residues, grasses, yard clippings, landfill gas, municipal solid waste (MSW), *etc*. FSEC has developed a robust FT synthesis catalyst capable of converting syngas to liquid hydrocarbon fuels. The technology also provides a means for not only converting biomass feedstocks to valuable liquid hydrocarbon fuels but also sequester carbon in the form of a high-value soil enhancing bio-char (*terra preta).*

Project Impact:

Florida imports all of its transportation fuels. The economy of Florida depends heavily on tourism and agriculture – both of which energy intensive (more appropriately, liquid fuel intensive) end-use sectors. Transportation accounts for 35% of all energy consumption in Florida, which makes it the largest energy-consuming sector of the state economy. In 2005, just the motor gasoline consumption per capita in Florida exceeded 491 gallons. According to the data compiled by the U.S. Department of Energy (DOE) Energy Information Administration (EIA), in 2006, Florida spent close to $30B on the petroleum-based fuels – money that could have remained in the state creating jobs and improving Florida's economy.

Production of liquid hydrocarbons from biomass is more desirable than generating oxygenated fuels such as ethanol, butanol and biodiesel made by fermentation or esterification of biomass-derived feedstocks. For example, the lower heating value (LHV) of ethanol (an oxygenated fuel) is 21,282 MJ/m^3, which is considerably lower than that of gasoline: 32,343 MJ/m^3. The higher energy content of fuel translates to longer driving range of a vehicle for a given quantity of fuel stored onboard. Furthermore, the chemical composition and physical characteristics of synthetic hydrocarbons is essentially similar to that of petroleum-derived fuels (although less polluting), which simplifies their introduction into the existing engines and fuel distribution infrastructure.

Biomass can be converted to liquid fuels by gasification followed by FT synthesis. FT synthesis for indirect biomass-to-liquid fuels production offers many advantages. For example, hydrocarbon synthesis

is generally non-selective process (that is governed by so-called Schulz-Flory distribution). But, FT process has the ability to produce a range of gaseous and liquid hydrocarbons easily upgraded via conventional refinery operations (*e.g.*, distillation, hydrocracking). The design of the reactor also affects the products slate. Fluidized bed reactors maximize gasoline yields, while fixed-bed reactors produce mostly diesel range hydrocarbons.

Traditional processes for thermochemical conversion of biomass to synthetic liquid fuels by air gasification have several drawbacks as follows. Air gasification produces syngas that is highly diluted with nitrogen, which requires a difficult and expensive nitrogen removal downstream before it can be converted to FT hydrocarbons. On the other hand, if an oxygen gasifier is used, it will require an expensive air separation unit upstream of the gasifier. In both of these cases, the H_2/CO ratio in the syngas is less than 1, making it unsuitable for FT synthesis – requiring a typical H_2/CO ratio of 2.

The approach proposed here for mitigating the technical issues described above is to employ a water electrolysis unit to generate oxygen and supplemental hydrogen. Oxygen is fed into the gasifier and hydrogen is added to the producer gas and fed to the FT reactor. **Figure 1** depicts a simple schematic of the proposed plant. First, an electrolyzer splits water to produce hydrogen and oxygen. Electricity to operate the electrolyzer can be derived from a solar PV array or carbon fuel cell that utilizes the char generated by gasification of biomass. Oxygen (alone or in combination with steam) is feed into the biomass gasifier producing syngas according to:

$$CH_{1.4}O_{0.6} + 0.3O_2 \rightarrow 0.6H_2 + 0.9CO + 0.1H_2O + 0.1CO_2$$

Where, $CH_{1.4}O_{0.6}$ represents the empirical formula for biomass.

In the equation above, the H_2/CO molar ratio for the syngas is 0.67. Depending on the biomass feedstock and operational parameters in the gasifier, a high-surface area carbonaceous byproduct (char) is also produced (thus, increasing H_2/CO ratio). The char byproduct combined with activated carbon (AC) will then be used to capture N-, P-, and S-containing impurities in the raw gas exiting gasifier. The final char/AC product is enriched with the mineral compounds (N-, K-, P-based) and is then available for use as either an effective soil amending bio-char or feedstock into the carbon fuel cell.

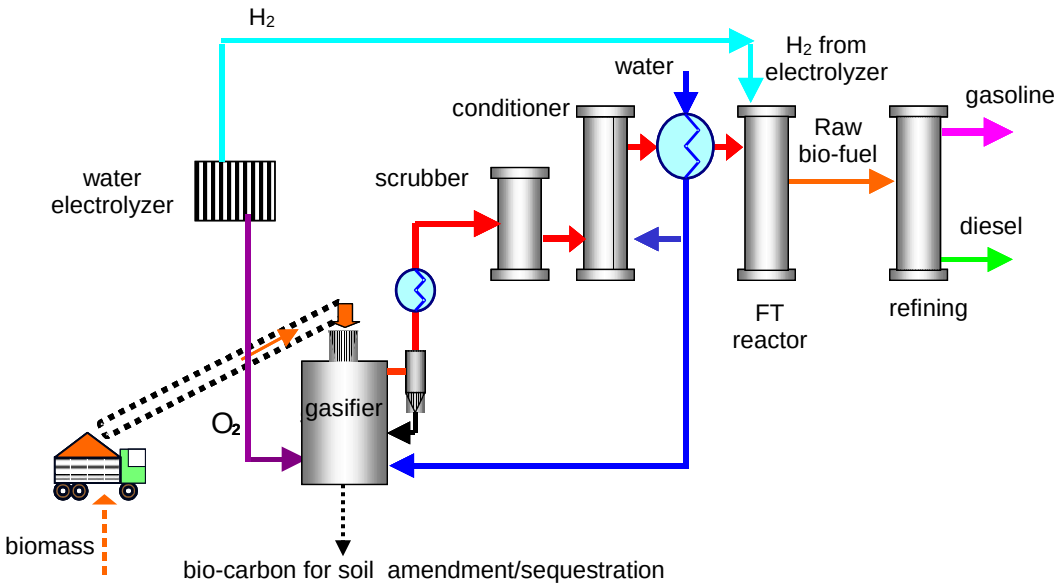


Figure 1. Simplified diagram depicting liquid hydrocarbon fuel production via integrated processing of biomass feedstock.

In the next step, the syngas is supplemented with H_2 produced by the electrolyzer to elevate and adjust the H_2/CO ratio to 2 (required for the FT synthesis). The syngas then enters into a FT reactor where catalytic hydrocarbon synthesis reaction takes place according to:

$2H_2 + CO \rightarrow (-CH_2-) + H_2O$

The FT synthesis reactor produces a mixture of liquid hydrocarbons (typically, C_5-C_{35}). To make the hydrocarbon mix suitable as a transportation fuel, the raw liquid product has to be processed further (*e.g.*, via distillation or hydrocracking) to gasoline (C_5-C_{11}) and/or diesel (C_{12}-C_{18}) fractions.

The FT catalyst development is still an area of intense research. FT-synthesized hydrocarbons have many advantages over oil-derived hydrocarbons as they do not contain sulfur, nitrogen or heavy metals, and also have low aromatic content, which results in the production of high-quality liquid fuels.

Gasifer Design effort:

An imbert-style downdraft oxygen gasifier has been designed and is in the process of being fabricated. The gasifier has been designed to operate using southern yellow pine pellets from Green Circle Bio Energy Inc., produced in their Cottondale, FL plant. The gasifier is batch-fed and is designed to run for 8 hours on a single charge. This would be enough synthesis gas so as to produce 1 liter of hydrocarbon fuel (gasoline or diesel) in 8 hours. Figure 2 shows the internal cross section of the designed gasifier.

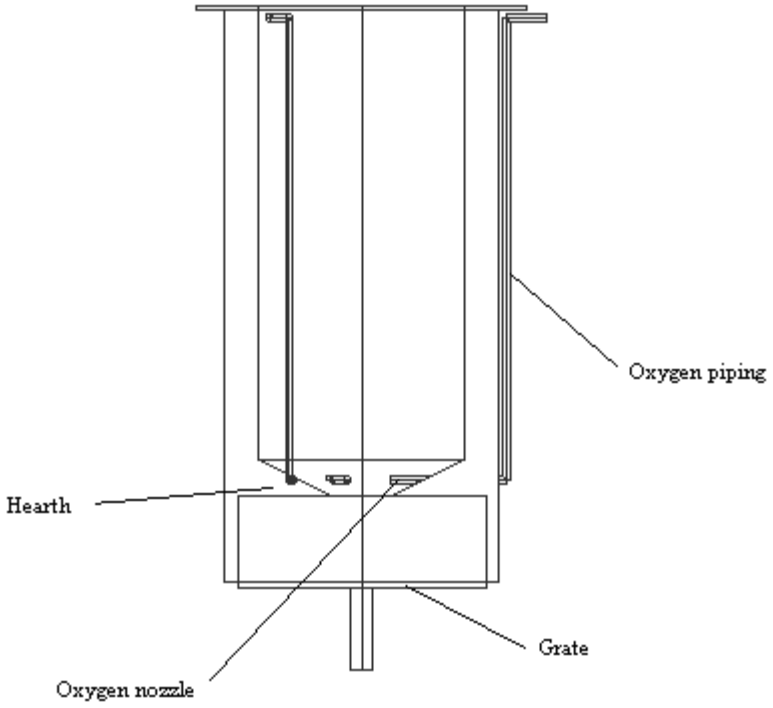


Figure 2: Gasifier Internal Cross Section.

The downstream gas conditioning unit is also in the process of being designed. This unit would consist of cyclone separator and tar cracking unit in order to produce clean synthesis gas suitable for the Fischer-Tropsch reaction.

Fischer-Tropsch catalyst selection effort:
During this reporting period, we have tested a number of Fischer-Tropsch catalysts for their activity towards conversion of synthesis gas to hydrocarbons. These tests were conducted over varying temperatures, pressures, space velocities and syngas compositions with an aim of increasing the liquid hydrocarbon yield and improving the quality of the gasoline/diesel fuel. The catalysts tested included Fe, Co and Mo based bulk as well as supported catalysts.

Experimental details:

Catalyst preparation- The two main types of catalysts prepared were supported transition metal catalysts and bulk metal catalysts synthesized using precipitation technique. The catalyst preparation procedure for the supported transition metal catalyst is exemplified here by the 20wt%Co on silica catalyst. The 20 wt% Co/silica was prepared by incipient wetness impregnation method. 4.94g of Cobalt nitrate hexahydrate was dissolved in appropriate amount of deionized water to make 6cc of the solution. This solution was added in a drop-wise manner to 4g of silica gel powder (Alfa Aesar) while mixing it continuously with a glass rod. The wet powder was then dried in a muffle furnace at 120°C for 2 hours and calcined at 500°C for 4 hours. The resulting powder was pelletized and crushed to 40-60 mesh size particles. These particles were calcined at 500°C for 2 hours before packing them in the reactor. Similar procedure was followed for preparing supported Fe and Mo catalysts.

The bulk metal catalysts preparation procedure is illustrated here by the synthesis procedure for the precipitated iron catalyst. The preparation of the precipitated iron catalyst consisted of preparing a 0.1M iron nitrate solution by dissolving 40.4g of iron nitrate nonahydrate (Aldrich) in deionized water to make a 1000ml solution. 40cc of ammonium hydroxide (28% NH_3 in water, Fisher) was dissolved in DI water in order to make 250cc of the basic ammonium hydroxide solution. This is twice the molar equivalent of the amount required to precipitate out the iron hydroxide. This was added in a drop wise fashion to the iron nitrate solution. The precipitation of $Fe(OH)_2$ was observed as the ammonium hydroxide solution was added. At the end of the process the final pH of the solution was about 8 (measured by pH paper). The iron hydroxide was filtered in a buchner funnel and washed with 2000ml of DI water. The precipitate was then dried overnight and calcined at 500°C for 3 hours. The iron oxide chunks obtained were milled in a SpexCertiprep 8000M mill for 1 minute to reduce the particles size. These particles were then sieved so as to separate the 40-60 mesh particles.

Apart from the above catalysts a commercially obtained K-promoted Fe catalyst was also tested along with commercial Co-Mo/alulmina and Ni-Mo/alumina for FT product upgrading.

Catalyst Testing: In a typical experiment, a FT catalyst was packed in a 1/2 inch stainless steel tube (int. dia.=10mm). The heat input to the reactor was provided by a heating tape, and the temperature of the reactor was controlled by an external thermocouple placed near the wall of the reactor. The catalyst bed was pretreated at 400ºC by passing 300cc/min of H_2 for 12 hours and at 500ºC for 2 hours. Appropriate syngas mixture (typically 33% CO and 67% H_2) entered the reactor at pre-determined temperature and pressure conditions. The hydrocarbon and aqueous phases were separated and analyzed using the GC (Shimadzu 14b) and the GC-MS (Agilent 6890 with JEOL GC MateII MS). Two online GCs (SRI Instruments) measured the concentrations of uncondensed gases. The GCs were calibrated everyday with standard gases. Some of the synthesized catalysts were tested in the new BTRS-jr flow reactor system. The reactor is a 0.312" ID stainless steel reactor with a heated length of 12". The system consists of mixer-vaporizer assembly which gives it the ability to mix 4 different gases at the same time. The system has the ability to test catalysts up to pressures of 2500 psig.
The conversion of reactant was calculated as:

$$Conversion\,of\ CO = \frac{F^0 \times C^0_{CO} - F \times C_{CO}}{F^0 \times C^0_{CO}}$$

and the selectivity towards formation of product (exemplified by CO_2 here) was calculated as:

$$Selectivity\,of\ CO_2 = \frac{F \times C_{CO_2} \times n}{F^0 \times C^0_{CO} - F \times C_{CO}}$$

Where,
F^0 and F are the inlet and exit flow rates respectively,
C^0 and C are the inlet and exit concentration of the species respectively,
n is the number of C atoms in the species.

Results and Discussion:

The results for the iron-based catalyst are reported here since they have been found to give the highest liquid hydrocarbon yield amongst all the catalysts tested. It is noted that iron based catalysts are currently being used by Sasol for their coal to liquids plant in South Africa. The advantages of Fe-based catalysts are that they are inexpensive, durable and can be used over a wide range of H_2:CO ratios. However, one of the problems with the use of Fe catalyst is that it yields olefin rich hydrocarbons. The resulting hydrocarbon product is prone to undesirable oxidation and polymerization - requiring post-treatment to

convert it to saturated hydrocarbons via catalytic hydrogenation. One of the objectives of this work is to develop a catalytic system for the single-step conversion of syngas to saturated hydrocarbons (paraffins). To accomplish this objective, we have investigated syngas conversion over a dual catalyst bed comprised of Fe catalyst paired with hydrogenation catalyst. This allows the in-situ conversion of olefinic fraction produced by the Fe catalyst to paraffinic ones that are more desirable as transportation fuel. The performance of the iron catalyst coupled with a cracking catalyst in the dual-bed configuration has also been investigated.

The Fe catalyst required pre-activation: first with hydrogen and then with syngas resulting in the formation of catalytically active iron species (*e.g.*, in carbidic form) during the activation stage. Figure 3 shows the effect of syngas (33% CO and 67% H_2 by volume) flow rate on the Fe catalyst performance at reactor temperature of 333ºC and 200 psig pressure (only gaseous products are shown).

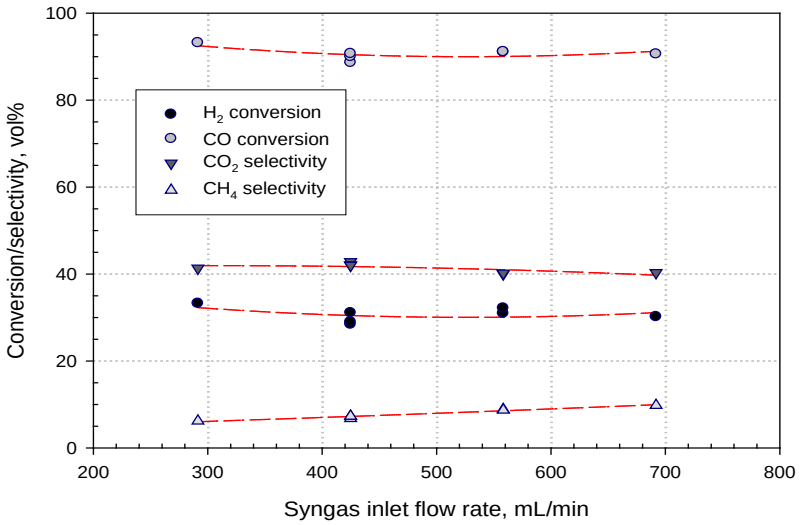


Figure 3: Conversions and selectivities for the reactants and products vs. syngas flow rate (T= 333°C P= 200 psig).

It can be seen that the CO and H_2 conversions don't change markedly at higher space velocities - implying a highly active catalyst. The selectivity toward methane seems to slightly increase with increased space velocity.

Table 1 shows the distribution of liquid hydrocarbons produced by Fe-catalyzed F-T reaction at the conditions specified in Figure 1 along with olefin to paraffin molar ratio. The data of Table 1 also includes that obtained for the dual-bed catalytic system comprised of Fe and H^+/ZSM-5 catalysts. It is apparent that addition of H-ZSM-5 increases the yield of gasoline range hydrocarbons and decreases the yield of wax formation as well as the olefin/paraffin ratio.

Table 1. Comparison of organic phase product composition for the Fe and Fe+H^+/ZSM-5 catalysts.

Product	Fe-catalyst	Fe-catalyst+H-ZSM-5
Gasoline range (C_5-C_{10})	55.79	71.08
Kerosene/jet fuel range(C_{11}-C_{12})	15.46	14.40
Diesel range (C_{13}-C_{16})	15.30	11.74
Lube oil and wax range(C_{17}-C_{26})	13.46	2.78
Olefin to paraffin molar ratio (for C_8)	5.72	1.86

Table 2 shows the comparative results for the conversion of the reactants and selectivity of the gaseous products obtained for Fe and Fe+ H^+/ZSM-5 catalysts operating at 340°C, 200 psi pressure at the syngas input flow rate of 290 mL/min.

Table 2. Conversion and selectivity comparisons for Fe and Fe+ H^+/ZSM-5.

Catalyst	H_2 conversion (%)	CO conversion (%)	CO_2 selectivity (%)	CH_4 selectivity (%)
Fe	30.71	87.00	46.77	6.14
Fe+H-ZSM-5	27.06	89.16	47.96	11.75

The $CO+H_2$ conversion and CO_2 selectivity are essentially equal in both cases, whereas the methane selectivity has increased when H^+/ZSM-5 present. These results can be attributed to the cracking activity of ZSM-5 catalyst that allows lower yields of higher hydrocarbons (*e.g.*, wax) and higher yields of gaseous hydrocarbons (*e.g.*, methane).

In addition, a dual-bed catalytic system consisting of Fe and Ni-Mo/alumina catalysts has been tested. The objective was to hydrogenate unsaturated hydrocarbons (olefins) produced by Fe catalyst in situ and in the presence of Ni-Mo/alumina catalyst. Figure 4 depicts the effect of reaction temperature on the conversion of the reactants and product selectivities for the Fe + Ni-Mo/alumina dual catalyst.

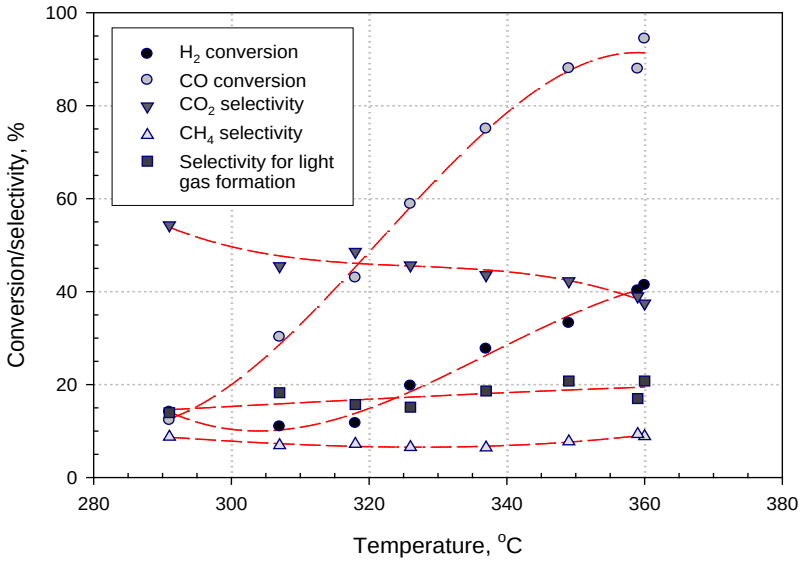


Figure 4. Effect of temperature on the syngas conversion and product selectivities using Fe+Ni-Mo/alumina catalyst (X and S denote species conversion and selectivity, respectively).

The Figure 4 implies that increasing the reaction temperature has a positive effect on the CO conversion - reaching 94.35% at 360°C. The selectivity toward CO_2 seems to decrease with increased temperature, whereas the selectivity toward light gases (LG: C_1-C_4) seems to increase at higher temperatures.

The effect of total pressure on the reactant conversion and products selectivities is shown in Figure 5.

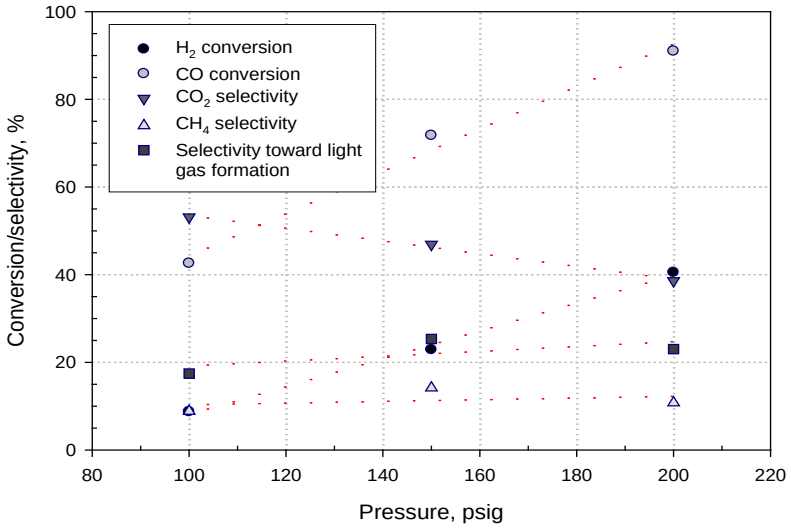


Figure 5. Effect of pressure on the conversion of CO and H_2, and product selectivities. T= 359°C, catalyst: Fe+Ni-Mo/alumina.

Running the reaction at higher pressures has a positive effect on the conversion of the reacting species. The selectivity toward CO_2 formation decreases as the pressure increases and the selectivity toward formation of the light gases remains almost the same over the range of pressures examined.
A comparison of the composition of liquid products obtained for Fe and Fe+Ni-Mo/alumina catalysts is shown in Table 3. It is evident that in the presence of Ni-Mo/alumina catalyst, olefinic hydrocarbons are completely hydrogenated to paraffinic compounds. At the same time, Fe+Ni-Mo/alumina catalyst does not significantly affect the yield of gasoline, jet and diesel fractions.

Table 3. Comparison of liquid product slate obtained from F-T synthesis of CO/H_2 in the presence of Fe and Fe+Ni-Mo/alumina catalysts.

Product	Fe	Fe+Ni-Mo/Alumina
Gasoline range (C_5-C_{10}), %	55.8	55.4
Kerosene/jet fuel range(C_{11}-C_{12}), %	15.5	17.1
Diesel range (C_{13}-C_{16}), %	15.3	16.8
Lube oil and wax range (C_{17}-C_{26}), %	13.5	10.7
Olefin to paraffin molar ratio (for C_8)	5.7	0.0

Figure 6 depicts a picture of the liquid hydrocarbon product obtained from the F-T synthesis using Fe + Ni-Mo/alumina combined catalyst.

It is known that syngas generated in a biomass gasifier may contain appreciable amounts of CO_2. So it is of interest to determine the effect of CO_2 on the yields of products during F-T synthesis. Table 4 shows the effect of CO_2 at two different $CO:CO_2$ molar ratios using Fe+Ni-Mo/alumina as a F-T catalyst.

Figure 6. Liquid hydrocarbon product obtained by the F-T synthesis in the presence of combined Fe+Ni/Mo/alumina catalyst.

It can be seen that CO_2 conversion is negative in both cases. In other words, there is a net generation of CO_2 as a result of water gas shift reaction. However, at higher CO_2:CO ratios, the selectivity for CO_2 formation decreases allowing a better utilization of CO for the formation of hydrocarbons.

Table 4. Effect of feed CO_2 concentration on the F-T reaction parameters.

Reaction conditions	$CO:CO_2$= 1.0	$CO:CO_2$= 0.5
Temperature, °C	370	370
Pressure, psig	200	200
WHSV, mL/gcat./hr	18000	18000
CO conversion, %	82.33	73.66
CO_2 conversion, %	-17.06	-2.65
$CO+CO_2$ conversion, %	32.54	23.13
CO_2 selectivity, %	20.76	7.07
CH_4 selectivity, %	11.86	7.87
STY, g of liq. HC/gcat./hr	0.3887	0.3608

Industry Support:

FSEC has an on-going relationship with the PetroAlgae LLC of Melbourne, Florida. The company provided funding that helped initiate a BTL program based on microalgae and duckweed as the starting biomass feedstock for the processes under development at FSEC.