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Solar Thermal Power for Bulk Power and Distributed Generation

PI: David W. Hahn **Co-PIs:** James Klausner, Renwei Mei and Helena Weaver
Students: Richard Stehle (PhD); Michael Bobek (PhD); Kyle Allen (PhD); Justin Dodson (PhD), Like Li (PhD)

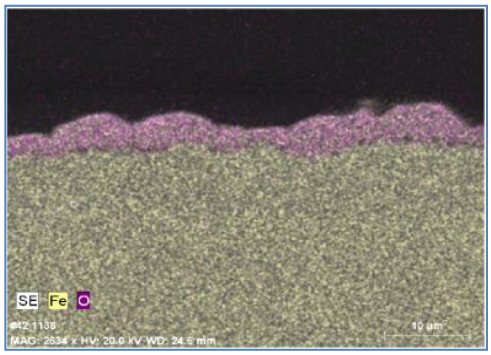
Description: While there are many different approaches to hydrogen generation, the most attractive means is to split water molecules using solar energy. The current approach is to develop highly reactive metal oxide materials to produce intermediary reactions that result in the splitting of water to produce hydrogen at moderate temperatures (<1000 K). It is envisioned that the metal oxide reactors will ultimately be mounted within a solar concentrating reactor, and irradiated via heliostats. This Task is structured toward the overall goals of solar-driven, thermochemical hydrogen production, with associated efforts toward the enabling surface science, catalysis, particle science, material synthesis, nano-structures, multiscale-multiphase physics modeling, and process simulation that will enable the realization of solar hydrogen-based fuels to power the transportation economy. Successful efforts as targeted in this project are a critical step toward increased renewable-resource based fuels and energy, reduction of GHG emissions, and establishment of a new power industry in Florida.

Budget: $446,400
Universities: University of Florida

Progress Summary

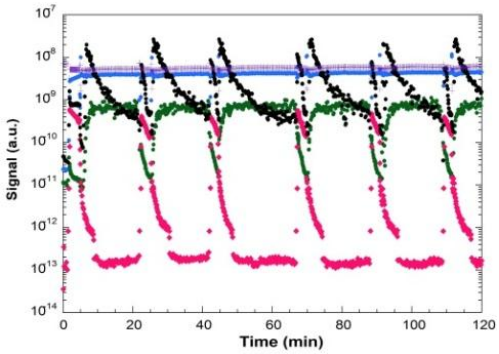
Research continues to focus on highly reactive metal oxide materials to produce intermediary reactions that result in the splitting of water to produce hydrogen at moderate temperatures (<1000 K). This year we have quantified the fundamental reaction kinetics using our laboratory reactor, and extensively studied the oxidation-reduction cycles that are necessary for practical reactors with high efficiency. In parallel, activities have progressed toward reactor scale-up and modeling using a fluidized bed design, and efforts have advanced to identify novel new nano-particulate catalysts. For example, a nano-particle zirconia (n-ZrO_2) support was identified as a promising catalyst for two-step water-splitting reaction that does not readily agglomerate, thus the surface area of this catalyst is larger and the potential for H_2 production remains high. Successful efforts, as targeted in this project, are a critical step toward increased renewable-resource based fuels and energy, reduction of greenhouse gas emissions, and establishment of a new power industry in Florida.

A temperature range of 600 to 750 K was investigated as the temperature for the water-splitting process because of the thermodynamic favorability of the reaction in this range. Under excess reactant conditions, it is concluded that resulting oxide thickness presents only a negligible barrier to diffusion of the water reactants when compared to the kinetic rates, allowing accurate calculation of the effective hydrogen production kinetic rate coefficient, as well as the Arrhenius pre-exponential factor and the overall activation energy (49 kJ/mol). Of significant importance in any practical reactor, which remains an important practical goal, is the exact nature of the oxide layers formed during water splitting. Extensive Raman spectroscopy and energy dispersive spectroscopy (EDS) were used to verify the presence of magnetite (Fe_3O_4) as the primary oxide. Furthermore, depth profiling was



Magnetite oxide layer formed during water splitting at a reactor temperature of 650 K.

performed to examine the local O/Fe atomic ratio through the matrix. A slight gradient was observed, with diminished oxidation moving away from the outer surface, suggesting minor diffusion effects as the reaction progresses. Finally, knowledge of the oxide states and kinetic growth rates enables calculation of an effective linear growth rate, which ranged from about 6 to 45 nm/min over reaction temperatures from 600 to 750 K, respectively.



Reactor output showing real-time H_2 production and reactor oxide regeneration over 6 cycles.

A final area of critical importance for practical hydrogen production is the ability to cycle between oxidation (hydrogen production) and reduction (reactor regeneration). Preliminary experiments were performed to cycle between these two reactor conditions. As shown in the adjacent plot, repeatable cycling between these two processes was achieved, which shows premise for operating a scaled-up production system. Future efforts will focus on several remaining critical questions, including efficient and repeatable reactor cycling, kinetics and mechanics of surface oxides under oxidation/reduction, and fluidization for efficient scale-up of hydrogen production.

Presentations:

1) FESC Summit in Orlando, Florida (September 28, 2010). Oral presentation by Richard Stehle. Co-authors: D.W. Hahn and M. Bobek. Fundamental oxidation reaction kinetics for the steam-iron process in a solar thermal reactor.

Papers:

L. Li, R. Mei, J.F. Klausner, D.W. Hahn, Heat transfer between colliding surfaces and particles, ASME/JSME 8th Thermal Engineering Joint Conference, ATJEC2010, March 13-17, 2011.

R.C. Stehle, M.M. Bobek, R. Hooper, D.W. Hahn, Oxidation Reaction Kinetics for the Steam-Iron Process in Support of a Solar Thermal Reactor, to be submitted in May 2011 to *International Journal of Hydrogen Energy*.

Grants Awarded

Title: Novel magnetically fluidized bed reactor development for the looping process: Coal to hydrogen production R&D.
Agency: US DOE
Investigators: J. Klausner (PI), D.W. Hahn (co-PI), R. Mei (co-PI), and J. Petrasch (co-PI).
Period of performance: 9/30/2009 to 9/30/2011.
Funding: $1.25M

Proposals

Title: Sunlight to Fuel: A global sustainable energy future.
Agency: NSF Science and Technology Center
Investigators: J. Klausner (PI). Co-PIs: D.W. Hahn, R. Mei, J. Petrasch, N. Sullivan, H. Cheng, K. Schanze, J. Weaver, H. Weaver, P. Dickrell at UF. Additional partnering institutions: Univ. of Minnesota, Cal Tech, ETH-Zurich, Johns-Hopkins, University of Illinois, and University of Colorado.
Period of performance: 5 years
Funding: TBD
Status: Passed internal UF review and currently preparing pre-proposal for NSF.

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Joint Optimization of Urban Energy-Water Systems in Florida

PI: James P. Heaney

Student: Miguel Morales and John McCary (PhD students)

Description: Urban water infrastructure systems for providing water supply, collecting and treating wastewater, collecting and managing stormwater, and reusing wastewater and stormwater require major energy inputs. End users of the water require even more energy to heat this water for showers and baths, clothes washing, cooking and other uses. Increasingly, cities will rely on alternative water supplies such as desalination that require much more energy per gallon of water produced. Conservation is the ideal way to save energy and water by managing the demand for these precious commodities. Major strides have been made in reducing indoor water use from about 75 gallons per person per day to as low as 40 gallons per person per day. However, these gains are being offset by concurrent increases in outdoor water use for irrigation that range from 30 to 300 gallons per person per day depending on irrigation practices and the size of the landscape. From a water use perspective, perhaps the greatest challenge will be the expected growing competition for water if certain energy options are implemented in order to reduce our current dependence on foreign oil. Several recent national studies warn of this impending energy-water crisis. This project will build on our extensive experience in evaluating urban water conservation options to include the implications for energy use and to develop integrated energy-water management systems that are compatible.

Budget: $72,000
Universities: UF

Progress Summary

Efforts during the past six months have focused on the following areas associated with the water-energy nexus:

1. Estimating the energy expenditures for pumping drinking water through water distribution systems and the associated costs. Water distribution system models are used to estimate energy usage.
2. Further literature review on the water-energy nexus for urban systems.
3. Developing estimates of life cycle energy costs associated with water conservation best management practices.
4. Incorporation of these results into our water conservation model called EZ Guide and into an associated time series process simulation model for evaluating the impact of historical water use patterns on observed demand.

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Unifying Home Asset and Operations Ratings: Adaptive Management via Open Data and Participation

PI: Mark Hostetler
Co-PI/Student: Hal S. Kowles (Ph.D.)

Description: Recent environmental, social, and economic challenges are fostering a wave of interest in maximizing energy efficiency and conservation (EE+C) in existing U.S. homes. Long standing programs, ratings, and metrics are being reapplied into new stimulus initiatives such as the *Recovery through Retrofit*[1] program. Simultaneously, electric and gas utilities are expanding their demand side management (DSM) programs from weatherization and conventional technology replacement incentives to include conservation behavior campaigns with "recommendation algorithms" designed to assist in homeowner energy retrofit decision making. Furthermore, loan programs are emerging to address the financial barriers that commonly limit initiation of the necessary retrofits.

Collectively, these approaches most often project future home energy performance based on engineering models of the physical characteristics of homes (i.e., "asset ratings"). Yet to date, the marketplace is inadequately integrating historical household energy consumption patterns (i.e., "operational ratings") into the decision tree to optimize retrofit program efficacy and consumer benefits. Moving toward the unification of asset and operational ratings is crucial for successful program management, proper monitoring/measurement/verification (MMV), loan risk assessment, and for the persistence of reduced home energy use over time. However, unification will not be easy. This research project combines qualitative and quantitative research methods in social science and building science using Florida case studies to evaluate the opportunities and constraints of asset and operational rating unification and the steps necessary to get there. Relationships between our project and the collaborative, transparent, and participatory nature of "open government" initiatives are also being explored.

Budget: $24,000
University: UF
External Collaborators: Nick Taylor (Ph.D. Student, UF School of Natural Resources & Environment), Jennison Kipp (Assistant In, UF Program for Resource Efficient Communities)

Progress Summary

Key qualitative survey questions on asset and operational ratings and their interactions were developed for a series of focus group sessions conducted in February and March, 2011. These sessions explored household utility service information needs and the usability of a home energy and water reporting website (http://gainesville-green.com/) for customers within the Gainesville Regional Utilities service territory (University of Florida IRB-02 #2011-U-0003). Though these sessions were funded under a separate grant project, the integration of asset and operational rating issues into the research design was made possible by this FESC project.

The combination of individual user testing and semi-structured group interviews was developed as a first phase investigation into how diverse users with unique needs perceive of the website, its features, and its functions. Approximately 1,500 minutes of individual usability testing audio feedback for 37 separate individuals and 440 minutes of focus group audio feedback for 7 separate stakeholder groups was collected. These stakeholder groups consisted of the following 6 group types: (1) homebuilders; (2)

[1] See, http://www.whitehouse.gov/assets/documents/Recovery_Through_Retrofit_Final_Report.pdf

homeowners; (3) Realtors®; (4) local government staff/officials; (5) home energy raters; and (6) bankers/loan originators.

Preliminary findings from these qualitative data provided a foundation for the in-depth inclusion of asset and operational rating considerations into a significantly larger grant proposal as detailed in the "Funds Leveraged" section. Transcriptions are still in progress and long term qualitative data analysis will inform future directions for both the original grant under which the research took place, as well as this FESC grant. Additional collaborations are in the nascent stages of development.

New collaborations		
Partner	**Title or short description of the collaboration**	**Funding**
Charlotte Software Systems	UF/PREC is in discussion with this potential collaborator on a variety of potential benefits from utilizing non-linear computational optimization for evaluating various energy efficiency and climate action strategies in the residential sector including the inputs, interactions, and outputs of asset and operational rating systems.	Opportunities under consideration
Gainesville-Alachua County Association of Realtors® (GACAR)	Very preliminary discussion has begun on potential future collaboration on integrating residential asset and operational rating information into Multiple Listing Service (MLS) data and/or various local "green" real estate efforts.	N/A
Alachua County Department of Growth Management	Very preliminary discussion has begun on potential future collaboration on integrating residential asset and operational rating information into property appraiser data, building code enforcement data, and/or various local "green" building efforts.	N/A

Proposals						
Title	**Agency**	**Reference Number**	**Investigators Collaborators**	**Funding requested**	**Duration**	**Date submitted**
EnergyIT: Home Energy Use Software for Education, Comparison, and Evaluation	DOE Office of Science	DE-FOA-0000508	PI: Pierce Jones Co-PI: Hal Knowles Collaborators: Jennison Kipp & Nick Taylor	$243,008 (UF Subcontract portion on a $992,020 overall proposal)	2 years (Anticipated from July 2011 – June 2013)	April 4, 2011
Gainesville Regional Utilities: On-Bill Energy Efficiency Financing Program Proposal	Gainesville Regional Utilities (Municipally Owned Utility)	N/A (Unsolicited proposal)	PI: Pierce Jones	Gainesville Regional Utilities: On-Bill Energy Efficiency Financing Program Proposal	Gainesville Regional Utilities (Municipally Owned Utility)	N/A (Unsolicited proposal)

EnergyIT: Home Energy Use Software for Education, Comparison, and Evaluation

Hal Knowles, Co-PI and the primary supported person on this FESC project was a major University of Florida Program for Resource Efficient Communities (UF/PREC) contributor to the development of this

new proposal. UF/PREC proposed to provide the following services in continued collaborative support of the Energy Tracking Software Platform:

1. Continued development, testing, and refinement of protocols and algorithms for accurately comparing energy/water performance of homes/buildings;
2. Data analysis, trend evaluation, and measurement/verification of operational energy/water performance, building asset mix, efficiency measures implemented, and their interaction effects;
3. Support for the development of an energy/water efficiency and conservation measure "recommendation engine" tailored according to building operational performance and asset mix;
4. Support for the development, deployment, and analysis of survey instrument(s) and new/improved feature sets (e.g., visualization tools, associated narrative, goal-based competitions, community-based social marketing strategies, and crowdsourced data entry pathways such as home energy auditor forms and user-specified behavioral and asset conditions).

Gainesville Regional Utilities: On-Bill Energy Efficiency Financing Program Proposal

Hal Knowles, Co-PI and the primary supported person on this FESC project was a major University of Florida Program for Resource Efficient Communities (UF/PREC) contributor to the development of this new proposal. UF/PREC proposed to provide the following five major services as a subcontractor for this energy efficiency financing program: (1) energy pre-screening; (2) consumer education; (3) contractor training; (4) quality control; and (5) measurement and verification.

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Outreach Activities for the Florida Energy Systems Consortium

PIs: Pierce Jones, Kathleen C. Ruppert, Hal S. Knowles III, Nicholas Taylor, Barbra Larson, Craig Miller

Description: Developing educational outreach programs and materials designed to deliver practical, applicable information and knowledge on energy-related topics to the general public as well as targeted to specific audiences such as builders, planners, engineers, architects, small businesses, local governments, and utilities through the Cooperative Extension Service and others. By focusing educational programming on climate and efficient use of energy and water, the program aims to provide the knowledge needed by building and energy professionals, local governments, and the general public, to significantly reduce greenhouse gas emissions in Florida.

Budget: $497,671
Universities: UF
External collaborators: Tampa Bay Water, UF/IFAS County Extension Offices, American Water Works Association, River Network, Alliance for Water Efficiency, Florida Section of the American Water Works Association, American Council for an Energy Efficient Economy (ACEEE), St. Johns River Water Management District, Southwest Regional Planning Council, Florida State University, University of South Florida, University of Central Florida, Florida A&M University, Florida Atlantic University, Gainesville Regional Utilities, Clay Electric, Florida Progress Energy, Canin Associates, Inc., Orlando Utilities Commission, City of Tallahassee, etc.

Progress Summary

Assistantships funded directly for students working on research projects contributing to promotion of resource efficient design, construction and management of master planned communities: Sarah Dwyer-MS-Use of utility meter data for evaluating residential energy efficiency program performance; Flavio Hazan – PhD- Developing land planning GIS tools to account for resource consumption and greenhouse gas emissions; Hal Knowles-PhD-Developing internet-based social marketing tools to support quantifiable reductions in household energy consumption.

Energy/Climate Awareness Fact Sheets: Completed eight fact sheets for the FESC website with five more currently in various stages of development. Additional topics have been determined. Updated the publication *Energy Efficiency Retrofit and Renewable Energy Programs Using Property Assessed Financing: Florida Guide for Local Governments* to address developments in the PACE financing markets. The new version of the book was published in October 2010 with the title *Options for Clean Energy Financing Programs: Scalable Solutions for Florida's Local Governments*.

Energy Extension Service:

- Co-authors and/or co-reviewers for new Sustainable Floridians program the mission of which is to train and inspire a core of volunteers to deliver information to residents on the significance of sustainability; the value of lifestyle choices and its impact on the environment; and the challenge to share the responsibility for protecting Earth's limited resources. The course was piloted in Leon and Marion County to date with additional county participation planned. Module topics include: The Case for Change, Principles of Sustainability, Energy, Water, Transportation and Land Use, and Leadership and Community.
- Reviewed and promoted SAVE (Steps in Achieving Viable Energy) materials, designed for youth ages 11 to 13 that explore the different forms, sources and uses of energy, and the effects of our

energy use. The curriculum materials include a teacher guide, club leader guide, and youth guide and are available online at http://florida4h.org/projects/SAVE.shtml.

- Energy Efficient Home Series three-hour course for homeowners planned to be presented three times over the next few months.
- Worked with speakers on development of a Low Impact Development (LID) - Water Resource Protection Strategies in the Built Environment web-based training for county extension agents that provides detailed information on implementation of low impact development practices for residential community development. Participants have received access to approximately 8 hours of web-based presentations and video tours to complete at their own pace (currently in progress), and the training will end with a 2-hour live web session in early May.
- Prepared for an in-service training emphasizing energy consumption and energy production in residential settings.
- Participated in the Extension Climate Variability and Change Focus Team and developed a survey for county extension offices to solicit input from local governments on their needs with respect to energy and climate issues in local planning (results not yet available).
- Published refereed publications: Jones, P., N. Taylor, M. J. Kipp, and H. Knowles. (2010). *Quantifying Household Energy Performance Using Annual Community Baselines*. International Journal of Energy Sector Management. 4(4): 593-613 and Jones, Pierce, Ujjval K. Vyas, Nicholas Taylor, and M. Jennison Ki*pp.* (2010). *Residential Energy Efficiency: A Model Methodology for Determining Performance Outcomes*. Real Estate Issues 35(2):41-47.
- Gave four presentations at the national level and eight presentations at the state/regional/local level to groups including the Federal Reserve Bank of Atlanta, American Society of Farm Managers and Rural Appraisers, Sarasota Board of County Commissioners, Northeast Sustainable Energy Association: Florida Local Environmental Resource Agencies, and the Southwest Florida Regional Planning Council.

Demand Side Management: Retrofit Analysis - DSM Analysis contracted with Utilities Commission of New Smyrna Beach; Analyzed program impact of weatherization for low income families by local non-profit Community Weatherization Coalition; Working with UF Shimberg Center and Alachua County Housing Authority to analyze impact of water heater retrofits in subsidized housing; FL DCA WAP analysis-working with utilities and municipalities across the state to gather data. Residential Green Building Programs: Residential green building program analysis and consultation for Austin Energy under contract; Working with JEA to analyze residential green building program; Working with Alachua County to develop a residential green building designation. Working with Tampa Bay Water on Energy and Carbon Costs of Water Supply: A Tampa Bay Water Case Study - This research and outreach project investigates the energy, monetary, and carbon (i.e., greenhouse gas) costs associated with water supply from Tampa Bay Water's system by evaluating facilities-level data from Tampa Bay Water, merging those data with power plant emissions data from U.S. EPA's eGRID and measuring costs associated with groundwater, surface water, and desalinated supply.

Continuing Education: Offered Greenhouse Gas Reduction and Energy Conservation I: Comprehensive Planning Under Florida's HB 697 (6 hours) – This workshop explores the implications of HB 697 as a comprehensive planning matter and examines lessons learned from other states and current best practices for the evolving approaches to compliance with the new energy- and greenhouse gas (GHG) emissions-related Comprehensive Plan requirements. Offered to Planners, Professional Engineers, Construction Industry Licensing Board, Landscape Architects, and Architects in Ft Myers. Offered three (Alachua, Pinellas and St. Lucie counties) Conserving and Restoring Biodiversity in Urban and Rural Environments CEU classes in which participants learn about tools, methodologies and strategies to conserve and restore urban environments and promote biodiversity and water conservation; how to evaluate the positive or

negative impacts of a proposed policy or development design on biodiversity and water conservation; and, how to retrofit older neighborhoods. Offered to Landscape Architects, Architects, Professional Engineers and Planners. Green & Profit and Energy Efficient Building Construction in Florida CEU courses planned for summer 2011. Developing online CEU classes for building professionals.

Demonstration House: Continued participation with Pinellas County Extension on structuring their $475,000 earmarked grant to build an energy-efficient demonstration facility.

Workforce Development: Continued working on the USDOE (Weatherization Assistance Program Training Center) grant including Development of the Certification Training and comprehensive review of same. Corresponding training-the-trainer materials were also reviewed. Test questions were developed and prerequisites are being established with Workforce Florida and various Technical/Vocational Training Centers for student recruitment. Pilot date to test materials was set.

Alternatively Fueled Vehicles: Working with Progress Energy to evaluate performance of PHEV using converted Toyota Prius equipped with GPS tracking system and software to monitor performance. A FESC publication on AFVs is planned.

Collaboration on New Initiatives: One copyright is being processed by UF's Office of Technology Licensing. It is titled "Quantifying Household Energy Performance Using Annual Community Baselines Annual Community Baselines" (2011).

Job Creation: Through additional grants to supplement FESC funding, 5.77 FTE jobs for 6-months were retained.

FESC Web Site (www.FloridaEnergy.ufl.edu) continues to be an important communication tool for our program. It is updated regularly to remain current and to better serve our users. FESC distributes electronic newsletters by email and available on the FESC web site. Based on a Google Analytics report, the FESC web site was viewed by 8404 Google visitors during the period Nov 1, 2010 to May 1, 2011. The viewers visited 23,864 pages. Viewers were from a total of 109 countries, including those in North and South America, Europe, Asia, Australia, and Africa.

New collaborations		
Partner name	Title or short description of the collaboration	Funding, if applicable
Harvard University	Energy Data Services	2,600
Sarasota County EECBG	Contractor and Homeowner Workshops	7,500
Utilities Commission of New Smyrna Beach	Green Energy Project	2,000
Alachua County	LID Manual	10,000
ACF Environmental Inc.	Assessment of Floating Wetland Treatment System	36,663
Pinellas County EECBG	Contractor and Homeowner Workshops	10,000
Manatee County EECBG	Contractor and Homeowner Workshops	10,000
Gainesville Regional Utilities	Soil Moisture Sensor Water Conservation Program	(in negotiation) 90,100
Accelerated Data Works	USDOE (Phase I Small Business Innovation Research)	19,843
Gainesville Regional Utilities	On Bill Energy Efficiency Financing Program	(in negotiation) 15,000

Proposals						
Title	**Agency and Grant Program**	**Reference Number**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame**	**Date submitted**
University of Florida Integrative Science for Sustainable Resources (ISSR)	National Institute of Standards & Technology (NIST) Construction Grant Program (NCGP)	2011-NIST-NCGP-01 CFDA #: 11.618	PI: J W. Jones Collaborators / Scientific Team: W Graham, P Jones, J Oliverio & J Sullivan	$7,228,352 (Federal requested portion on total estimated project cost of $9,459,340	5 years (Anticipated from 11/01/2011 to 10/31/2016)	April 4, 2011
Integrating Smart Growth Principles into Florida's Local Government Planning Process	EPA - Technical Assistance to Build More Sustainable Communities	CFDA #: 66.611	P Jones & B Larson	$826,457	5 years	March 31, 2011
Integrating Energy/Water Management and Climate Change Mitigation into Growth Management Policy	Department of Housing and Urban Development - Transformation Initiative: Sustainable Communities Research Grant Program (Preliminary Application)	CFDA #: 14.523	P Jones & H Knowles	$ 380,265	2 years	March 4, 2011
Energy Efficient Housing Research Partnership	Department of Energy -Building America Program		PREC is a proposed subcontractor in a University of Nebraska submittal UF/PREC PIs: P Jones & J Kipp	$107,209	6 months	March 4, 2011
Low Impact Development Manual	Duval County Low Impact Development Manual	RFP# P-03-11	PREC is a proposed subcontractor in a proposal submitted by MACTEC PREC PIs: P Jones, J Kipp & L Jarrett	$100,000	2 years	January 19, 2011

Grants Awarded					
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Period of Performance**	**Funding awarded**
Energy Initiative	Osceola County	N/A	(in negotiation)	2010-2012	$273,000
Weatherization Training Centers	USDOE	DE-EE0004203	P.I.: Pierce Jones & Craig Miller Collaborators: University of Central Florida, Conceptual Arts, Inc., Santa Fe College	2010-2012	$979,421
Weatherization Assistance Program Evaluation	FL-DCA	10WX-8K-12-00-22-508	P.I.: Pierce Jones	2010-2012	$398,437

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Clean Drinking Water using Advanced Solar Energy Technologies

PI: James Klausner

Students: Fadi Alnaimat/ Ph.D

Description: Water and energy scarcity poses a future threat to human activity and societal development around the world. The state of Florida is vulnerable to fresh water shortages. Florida ground water is contaminated in many locations from leaky underground tanks, agricultural pesticides, and other chemicals. Although it is possible to desalinate sea water, conventional systems are energy intensive. Solar energy utilization for desalination systems is being investigated to provide adequate fresh water for the state's needs. Solar diffusion driven desalination (DDD) system has been developed for both bulk water desalination and small community needs/disaster response. Solar DDD may be a competitive method for small scale seawater desalination.

Budget: $252,000
Universities: UF

Progress Summary

This work concerns the development of a cost effective, low power consumption, and low maintenance desalination process that is powered by solar energy. The solar diffusion driven desalination (DDD) process is most suitable for decentralized applications. While theoretical models have been developed to analyze the evaporation and condensation processes of the solar DDD under transient operating conditions (Alnaimat et al., 2011), experimental investigations have been conducted to validate the theoretical models. In this reporting period, the overall distillation performance of the solar DDD has been investigated under different design and operating conditions. The best operating modes have been proposed to improve the water production and reduce the specific energy consumption.

The solar DDD performance is primarily dependent on the solar heat input, saline and fresh water tank sizes, and evaporator and condenser inlet water temperatures and flow rates. A parametric study is conducted to examine the influence of these parameters under transient operating conditions. In the study, it is found that water production can be improved significantly by increasing the evaporator inlet water temperature. It is also found that increasing the evaporator inlet water temperature reduces the specific energy consumption. The evaporator water temperature is dependent on the solar heat input, saline water and air flow rates, initial saline water tank size and temperature, and the condenser inlet water temperature.

While the saline water storage tank enables the solar DDD system to operate in a re-circulating mode, the initial volume and temperature of the saline water tank impact the system performance. The study shows that small saline water tanks result in a small time delay for the system, which increases the evaporator inlet water temperature and water production rate. At the same time, small saline water tanks store lower thermal energy than larger saline water tanks, thus the fresh water production rate deteriorates more quickly when the solar flux is diminished or not active.

The study shows that decreasing the condenser inlet water temperature reduces the system water production efficiency. This is due to the fact that reducing the condenser inlet water temperature results in reducing the condenser exit air temperature. Since the air is re-circulated back to the evaporator, the evaporator air and water temperature reduction inhibits vapor production. The specific energy consumption can be minimized by running the system with a delayed operating time. This indicates that the system can be run without a cooling requirement. It is found that the solar DDD is best operated with the delayed operating time method. The electrical energy consumption can be reduced to 1.65 kWh/m^3,

which is small compared to other small scale desalination processes. The system fresh water production rate is approximately 7.5 L per solar collector surface area per day. An economic cost analysis on a small scale solar DDD unit has been carried out, and it is revealed that the fresh water production cost of the solar DDD is on the order of $\$7/m^3$.

While fresh water production rate and specific energy consumption are essential to evaluate the performance of desalination processes, other factors such as simplicity, ease of operation, and low maintenance requirement are also important practical factors especially for decentralized desalination applications. It is believed that the solar DDD process, with its low power consumption and low maintenance requirement is a competitive desalination technology that is well suited for small scale and decentralized applications. Commercialization of the solar DDD process is being perused.

Alnaimat, F., Klausner, J.F., Mei, R., "Transient Analysis of Direct Contact Evaporation and Condensation Within Packed Beds," Int. J. Heat Mass Transfer, in press, 2011.

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Economic Impacts of Renewable Energy and Energy Efficiency Policies

PI: Theodore Kury

Description: PURC is engaging in three new research projects that will provide important information for policy makers in Florida. The projects are:
Economic and Job Impacts of State Renewable Energy and Energy Efficiency Policies
This project will provide empirical estimates of state renewable energy and energy efficiency policies on economic development and jobs. Proponents of state and federal policies promoting renewable energy and energy efficiency policies often assert that the policies will have positive impacts on jobs, specifically the so called green jobs.
Electric Grid Impacts of State Renewable Energy and Energy Efficiency Policies
This project will provide an estimate of the impacts of renewable energy policies on the electric grid. It will fill a gap in the literature for Florida, which as to date focused on the impacts on electricity generation.
Effects of Energy Commodity Profit Margins on Effectiveness of Energy Efficiency Programs
This project will test an assumption that is built into many state energy policies and that is held by many policy makers at the national level, namely that utilities would improve consumer energy efficiency practices if utility prices were decoupled from utility profits.

Budget: $150,000.00
Universities: UF
External Collaborators: NA

Progress Summary

We have completed the data gathering on employment data and the evolution of state renewable energy policies across the United States. This includes granular data for myriad employment and demographic characteristics from a variety of sources including the Census Bureau and the Bureau of Labor Statistics. Model specification is important in the project, as the time series characteristics of data can produce spurious correlation, confusing the results. Therefore, we have tested many model specifications in order to ensure that we are deriving information from the data, rather than simply getting lost in the noise. This requires considerable data analysis and statistical testing. We have currently finished the model specification and are conducting the preliminary analyses. We anticipate preliminary results within 2 months.

Proposals					
Title	**Agency**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame**	**Date submitted**
Cost Benefit Analysis of Wind Gebneration Projects	Department of Energy	CEFA, FSU	$300,000	2 Years	3/11/11

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Combined Cooling, Heat, Power, and Biofuel from Biomass and Solid Waste

PI: William Lear
Students: Minki Kim (PhD); Elango Balu (PhD); Sada Gopan Sekar (MS)

Description: The goal of this project is to provide the underlying research and demonstration of a novel technology which would enable the economic utilization of dispersed biomass and solid waste resources to produce electric power, cooling, heat, and transportation fuels. This integrated gasification and power generation system combines University of Florida advances in high-temperature gasification, hydrogen generation and separation, and advanced gas turbine systems. Their integration is expected to result in significant improvements in the cost, emissions, feedstock flexibility, and water requirements, all in a relatively compact, modular plant system. This in turn will enable much greater utilization of renewable energy supplies, helping the development of a sustainable energy supply infrastructure.

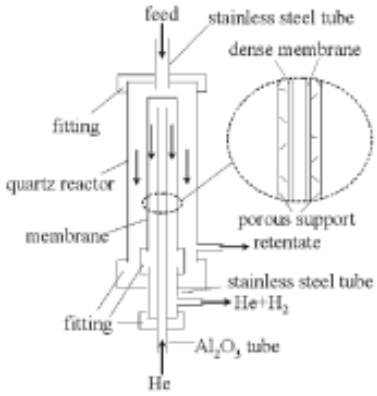
Budget: $576,000
Universities: UF
External Collaborators: Siemens Power Generation, Florida Turbine Technologies, Energy Concepts Co., Nu-Power Technologies LLC, PlanetGreenSolutions Inc., LPP Combustion, LLC.

Progress Summary

I. Flameless Combustion Experiments and Modeling

In order to enable syngas characterization, we have focused on the installation of a well-characterized commercial gas turbine engine, with completion expected by the end April 2011. A complete test plan has been developed for test rig shakedown and operation on simulated syngas, in preparation for coupling to the steam gasification syngas described below. The rig is based on a Capstone C60™ system, designed for multiple fuel sources, including methane, syngas, and a LPP Combustion artificial fuel skid. As a parallel activity, integrated system modeling, PoWER(turbine), absorption refrigeration, and HiTS (gasifier), is continuing.

Fig. 1. Micro-turbine test system photograph



II. Enhancing H_2 Yield Using SCZE Membranes

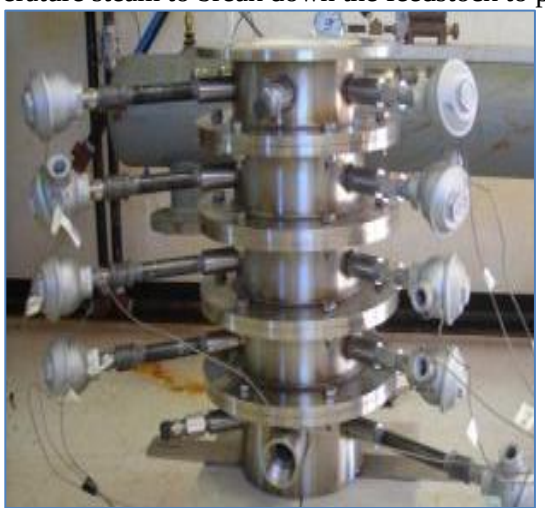
The membrane converts CO into CO_2 and provides additional H_2. It also separates H_2 out from syngas.

$H_2O + CO \rightarrow H_2 + CO_2 \qquad \Delta H_o = -40.6$ kJ/mol

Fig. 2. Membrane experimental system.

III. High-Temperature Steam Gasification

The biomass high-temperature steam gasification involves a thermal-chemical process that employs super-critical high-temperature steam to break down the feedstock to pure hydrogen-rich gaseous bio-fuels.



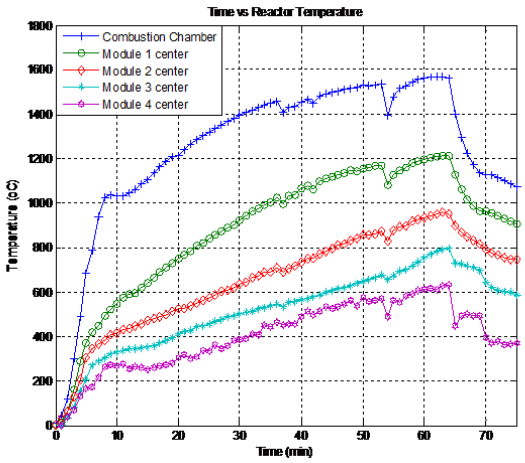
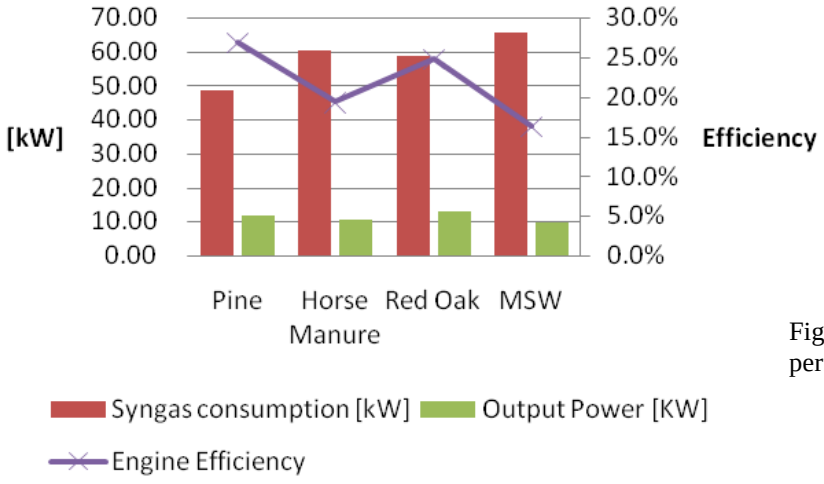


Fig. 3. Experimental System and system temperature profile.



IV. The Biomass Gasification to Power System

Trailer-scale downdraft gasification unit coupled with an IC engine-generator set has been demonstrated to produce power using four different feedstocks. Results are shown below.

Fig. 4. Gasification-power system performance

UNIVERSITY OF FLORIDA

Non-Contact Energy Delivery for PV System and Wireless Charging Applications

PI: Jenshan Lin
Students: Jamie Garnica (Ph.D.), Yan Yan (PhD), Gabriel Reyes (MS)

Description: Innovative non-contact energy delivery method will be used in photovoltaic energy generation system to accelerate the system deployment. Instead of delivering electric power using cables penetrating through building structures, magnetic field coupling allows power to be transferred wirelessly through building walls and roofs. In the meantime, the DC electric energy from photovoltaic cells is converted to AC energy. This enables the photovoltaic system to be quickly set up or relocated, and the collected solar energy from outdoor system can be conveniently delivered to indoor appliances. Techniques to achieve high efficiency at high power delivery through different building structures will be studied for this plug-and-play architecture.

In addition, the technique and the system can also be used for non-contact charging of electric vehicles. The transmitter/charger can be placed as a mat on garage floor or parking space. The receiver inside vehicle will pick up the energy delivery through magnetic coupling. This eliminates the need of connecting charging wires to vehicles and exposed metal contacts, which is a safer method of charging electric vehicles.

Budget: $252,000
University: UF

Progress Summary

Simulations and measurements were performed with various amplifier topologies, shown in figure 1, in order to explore the advantages and disadvantages of each topology. Previous work was done with the Class E amplifier topology. Advantages of this topology include theoretical 100% efficiency, simple driving requirements and the use of a single active device. The major disadvantages of this topology, for the application of wireless power, are the tuning requirements. For a system with a fixed transmission distance, a single tuning is sufficient and has few disadvantages. For a variable transmission distance, the tuning circuit must be made to change in order to compensate for the variable load. Failure to adjust the tuning will lead to a decrease in efficiency, and if the amplifier falls out of zero voltage switching (ZVS) the active device can be destroyed. An additional constraint comes from the high drain voltage of the Class E topology. This limits the maximum power the system can transmit for a given V_{ds} breakdown voltage.

Class D amplifiers and variations, including the full bridge class D, are investigated as alternatives. The tuning circuit in this configuration is less sensitive to variations in

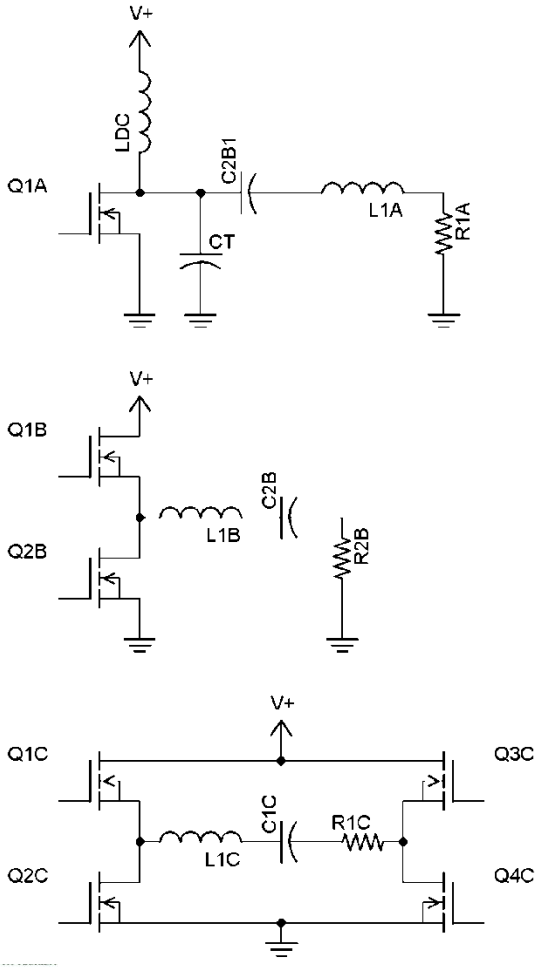


Figure 1. From top to bottom, Class E, Class D and Full-Bridge Class D amplifier topologies.

distance, as there is no requirement for ZVS, so as long as the tuning circuit is optimized for the correct frequency. Since the system is already operated at a series resonance determined by the self-inductance of the coils and a tuning capacitor, this can be used as the tuning circuit of the Class D amplifier. For Class D type amplifiers, there will be a minimum load Q below which efficiency drops sharply. Because of the way the load impedance is reflected to the transmit side, the Q requirement becomes an issue at short distances.

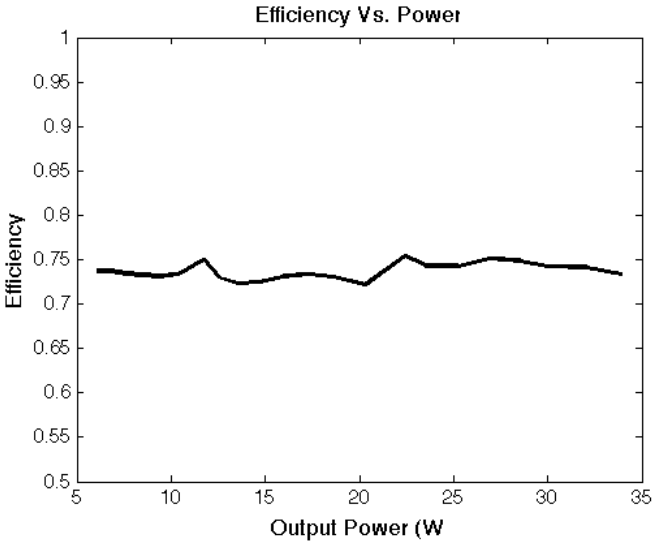


Figure 2. Measured efficiency for varying output power.

A full-bridge class D amplifier is constructed to drive the system. The full-bridge configuration is chosen because the total power capability is four times that of the half-bridge configuration for devices with the same ratings, or similar power from lower rated devices that may have other advantages, such as lower on resistance, lower C_{gs}, or lower C_{ds}. As before, the operating frequency is chosen to be near 500kHz. Tests performed at 508.5kHz with a full bridge class D amplifier showed efficiencies of 76% for transmitted power levels of up to 40W, up from a previous maximum power of 5.6W. The efficiency is fairly constant regardless of power level, and should remain so until the power dissipated in the windings of the coils reaches levels sufficient to increase the temperature of the wire. Figure 2 shows the efficiencies at different transmitted power levels.

Testing at various distances was performed to verify the circuit model. Better than 50% efficiency is measured for a range of 50cm to 130cm, and a peak efficiency of 85.3% is measured at a distance of 76cm. The efficiency drops rapidly at short distances due to the lower Q_L seen by the amplifier.

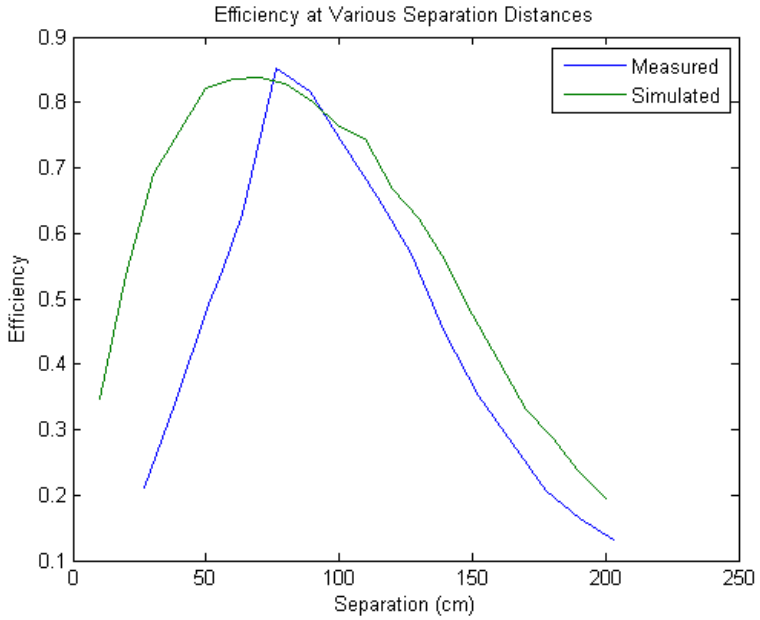


Figure 3. Comparison of measured and simulated efficiencies for a range of 0m to 2m.

UNIVERSITY OF FLORIDA

Database infrastructure for integrative carbon science research

PI: Sabine Grunwald **Co-PI:** Tim Martin
Students: C.W. Ross (M.S.); X. Xiong (Ph.D.)
Technical staff: Brandon Hoover, David DePatie
Post-Docs: Gustavo M. Vasques; Biao Zhong.

Description: Rising CO_2 concentrations in the atmosphere and effects on global climate change have been well documented, and future impacts are uncertain but potentially devastating. Florida's natural and agro-forest ecosystems have much potential to sequester carbon in biomass and soils due to unique climatic and landscape conditions. However, research gaps exist to accurately assess carbon pools and fluxes at coarse scales, ranging from county to the region and larger. The overarching objective of this project is to address these obstacles by creating a terrestrial carbon information system (called "TerraC") for the carbon science community, focused on ecosystems in Florida. The information system will be administered through the UF Carbon Resources Science Center (http://carboncenter.ifas.ufl.edu), a multi-disciplinary Center dedicated to research in support of enhanced agricultural and natural resource carbon management.

Budget: $199,440
Universities: UF
External Collaborators: **N**atural Resources Conservation Service-U.S. Department of Agriculture.

Progress Summary

Over the past year, we have enhanced the Terrestrial Carbon Information System (TerraC) by incorporating data and meta data standards from a variety of sources. These enhancements provide several benefits: (i) users new to the system will be familiar with the data standards since they are widely used in the community; (ii) data compatibility and exchange will be enhanced; (iii) meta data tracking (e.g. laboratory methods to measure carbon content, stocks or fluxes) is enhanced; (iv) carbon data from different projects will be more readily comparable because units are standardized; and (v) the TerraC search engine, essential for carbon synthesis projects, will return consistent results due to the standardization.

The following standards have been coded into TerraC:

1. Soil carbon data:
    a. Soil Survey Laboratory Methods Manual developed by Natural Resources Conservation Service (NRCS) - United States Department of Agriculture (USDA) (http://soils.usda.gov/technical/lmm/)
    b. Soil Data Mart – Soil Survey Geographic Data developed by NRCS-USDA
2. Atmospheric carbon data:
    a. aAmeriFlux

We are currently adding additional national standards for vegetation/biota and water. This requires to program in TerraC the variable names, variable descriptions, units, and methods used to measure variables. National standards also accommodate ancillary environmental variables which provide complimentary information related to carbon. For example, NRCS-USDA defines various soil carbon forms (e.g. total soil carbon, soil organic carbon, soil inorganic carbon) measured in form of concentration units and stocks. In addition, it also defines other environmental variables related to soil carbon, such as nutrients (e.g. soil phosphorus and soil nitrogen), soil taxonomic data (e.g. Soil Series or Soil Great Group), and soil hydrologic variables (e.g. hydric soil type). In TerraC users have the option to input not only the core soil carbon data, but also ancillary environmental data, which are extremely important for synthesis analysis and large-scale carbon modeling across ecosystems.

We are in the process of finalizing a TerraC tool which allows the creation of variables which are not defined by any national standard. Researchers may have measured in their projects physical (e.g. size partitioned carbon) or chemical (e.g. labile and recalcitrant forms, or mineralizable) carbon fractions in soils which characterize ecosystem processes. These laboratory methods are specialized and only documented in the peer-reviewed literature, but not any national or federal agency standard. TerraC will allow users to create new variables on-the-fly which are added to the core data fields of TerraC (SQL database) and TerraC meta data pool. This work is in progress and will be completed over the next 6 months.

UNIVERSITY OF FLORIDA

Optimization, robustness, and equilibrium modeling for the Florida Smart Grid

PI: Panos Pardalos

Description: The purpose of this research is to develop models and algorithms for optimal design and functioning of the nation's next generation power transmission and distribution system that will incorporate the new realities of the grid. Our goal is to create innovative real time capabilities for 1) optimal functioning of renewable energy sources (location, charging, discharging of batteries, etc.), 2) detecting and preventing instabilities and outages, and 3) operating models including generalized Nash equilibrium.

Budget: $30,000
University: UF

Progress Summary

We propose a game theoretic approach for electricity market participants with storage devices by formulating a Nash equilibrium problem and proposing extensions for generalized Nash equilibrium. While the theory of the generalized Nash equilibrium is well developed, its computation is a challenge. The difficulty stems from the fact that the Nash equilibrium is a fixed point of an appropriate mapping, and its calculation goes beyond the optimization theory. In the simplest case, our model presents a Nash equilibrium problem with quadratic cost functions. It is attacked with several methods recently developed. With electricity prices changing continuously over day storage devices can be used to reduce electricity consumption during peak-hours as well as reducing electricity prices, carbon emissions and peak transmission loads. However, if everyone shifts their demand toward a period when electricity is cheaper, that will have an inevitable effect on electricity price and will not lead to significant reduction of a peak demand but rather shift it for another period of the day. The goal is to develop "smart batteries" – a plan for charging and discharging batteries in such a way that every participant will enjoy the maximal possible gain.

Activities

Organized conference:
Systems and Optimization Aspects of Smart Grid Challenges
April 28-30, 2011 Gainesville, Florida, USA

Presented talk: "**Game Theoretic Approach for Micro-storage Management in the Smart Grid",** by Pando Georgiev, Alexey Sorokin, Marco Carvalho and Panos Pardalos.

Working towards publishing the results of this talk in a journal paper.
Ongoing work focuses on data mining in energy for detecting and preventing power grid instabilities and outages.

UNIVERSITY OF FLORIDA

Energy Intensive Crop Development

PIs: Gary Peter, Matias Kirst, Don Rockwood
Students: Juan Acosta (Ph.D.), Alejandro Riveros-Walker (Ph.D.), Jianxing Zhang (Ph.D.), Patricio Munoz (Ph.D.)

Description: To build a commercially viable, industrial scale system to produce transportation fuels and electricity from biomass requires both efficient conversion technologies and environmentally sustainable, cost effective supplies of biomass. In the US, Florida ranks first in its annual growth of plant biomass, because of its large cultivable land area and its subtropical climate, even though substantial land areas that can be planted are not currently in agricultural or forest production. The development of high yielding production systems for dedicated energy crops is considered essential for a sustainable, biomass to energy industry to be established, because the long-term availability of sufficient amounts of reasonably priced biomass is one of the most important factors in the site selection for new biofuel and bioenergy facilities. Dedicated energy crops are ones that 1) have high yields with minimum energy inputs in terms of agronomic practices, water and nutrient applications, 2) can be harvested, transported and processed efficiently into fuel or power, and 3) can be grown sustainably for generations without adverse environmental affects, or significantly impacting the food supply. We will evaluate likely energy crop species, *Eucalyptus* and southern pine to provide important yield and best management practices for growing these species for bioenergy conversion. We will also provide important chemical composition information that will impact the conversion efficiency of this biomass to ethanol, and identify and characterize important genes that regulate wood chemical composition

Budget: $432,000
Universities: University of Florida

Progress Report

Research Objectives for Current Reporting Period: 1) To develop rapid methods for determining wood and grass (in collaboration with the team from Agronomy) cell wall chemical composition, and 2) To establish field plantings of Eucalyptus for testing agronomic practices acquiring yield information.

Progress Made Toward Objectives During Reporting Period:
Objective 1: Calibration models were previously built for predicting the lignin, cellulose and hemicellulose chemical composition of grass, loblolly pine and poplar wood biomass samples. We have now made progress developing a calibration model for predicting lignin, cellulose and hemicellulose content of Eucalyptus. Wood samples from 36 Eucalyptus trees were collected, ground and NIR spectra obtained. We are now determining the lignin, cellulose and hemicelluloses contents by traditional wet chemical methods and will use multivariate methods to develop calibration models for predicting lignocellulosic components. We also measured wood specific gravity and stiffness. Mean wood stiffness ranged from 26 to 11 km^2/s^2. Mean wood specific gravity varied from 0.3 to 0.5. As expected, specific gravity and stiffness were not correlated. Interestingly, the high stiffness indicates that Eucalyptus wood is suitable for solidwood products such as flooring, and the high density indicates its utility as a wood source for pulp and paper as well as bioenergy.

In wood, oleoresin has the highest heating value, similar to that of petroleum. Currently, Arizona Chemicals of Jacksonville, FL sells SYLVABLEND Pitch Fuel, which is composed principally of α-pinene and β-pinene. Using mid-infrared spectroscopy (FTIR), calibration models were built for

predicting α-pinene, β-pinene, and abietic acid content in pine oleoresin. These calibration models were validated with strong statistical support and used for studying the genetic architecture of pine oleoresin composition. Loblolly pine oleoresin was collected from ~4000 trees growing on three sites in a clonally replicated genetic test. Genetic control of α-pinene, β-pinene, and abietic acid were all high with 0.54-0.61 across site clonal repeatabilities and high type B correlations indicating very low genetic x environment interaction. Low genetic by environmental interactions and high levels of genetic control demonstrate that breeding for pine oleoresin composition is straightforward.

Objective 2: In 2009, field plantings were established in central Florida with half-sib seedlings and the four locally adapted UF-IFAS *Eucalyptus grandis* cultivars and in north Florida with half-sib seedlings and clones of *Eucalyptus amplifolia* cultivar. The north Florida planting is about 16 acres and was put in by Buckeye Cellulose. The central Florida planting was about 3 acres and was put in by Mosaic Corp. This planting tested the genetic material at 3 initial tree spacings 3 x 3 ft, 3 x 4.5 ft, and 3 x 6 ft. In addition, it contained a Nelder design to identify the most productive tree spacing. First year height and diameter data were collected in the winter. Next year second year growth and biomass data will be collected. These data will be used for growth and yield estimates.

UNIVERSITY OF FLORIDA

Solar Fuels from Thermochemical Cycles at Low Pressures

PI: Jörg Petrasch

Students: Midori Takagi, Ben Erickson

Description: The project focuses on the production of solar fuels from solar thermochemical cycles employing metal/metal oxide redox pairs. These thermochemical cycles consist of a high temperature endothermic solar driven reduction step and a low temperature, slightly exothermic water or CO_2 splitting step. The high temperature step typically proceeds at temperatures above 2000 K. Hence, it poses a range of material and design challenges. According to Le Chatelier's principle, the temperature for the solar dissociation reaction decreases as the pressure inside the reactor is reduced. The central hypothesis of the project is that operating the high temperature step of metal/metal oxide solar thermochemical cycles at reduced pressures will lead to significantly relaxed temperature requirements, while the work necessary to produce the pressure difference will not significantly reduce the overall efficiency of the process.
The main goal of the project is to demonstrate the feasibility of carrying out high temperature thermal reduction of metal oxides in rarefied conditions using high intensity solar radiation from UF's solar simulator.

Budget: $100,000.00
Universities: UF
External Collaborators: Wojciech Lipinski, University of Minnesota

Progress Summary

Since October 2010, we have made significant progress in *two areas*. Firstly, the construction and commissioning *UF's high flux solar simulator* has been successfully completed. UF's solar simulator is a 56 kWe high flux solar simulator providing peak flux levels in excess of 5000 kW. It provides a unique platform for concentrating solar thermal research. Secondly the design of the solar thermogravimeter is nearing completion. The solar thermogravimeter (STG) consists of a high precision analytical balance with a sample holder that can be heated using high flux radiation emanating from the solar simulator. The STG can be evacuated to test chemical reactions under rarified conditions.

UF Solar simulator

UF's high flux solar simulator (Fig. 1a) is a 56 kWe experimental facility capable of delivering highly concentrated radiation at flux levels in excess of 5000 kW/m^2 (see Fig. 1b), equivalent to blackbody stagnation temperatures of approximately 3000 K.

Figure 1a. UF's High Flux Solar Simulator.

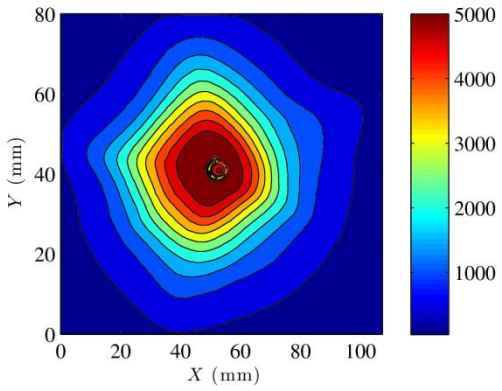


Figure 1b Measured flux distribution in the focal plane in kW/m^2.

The simulator provides the highly controllable radiation source necessary for fundamental investigations of solar thermochemical reactions, for testing and improving solar reactor prototypes. It will furthermore serve as an experimental platform for the development of control systems capable of dealing with rapid fluctuations in solar energy supply.

Solar thermogravimeter

The design of a solar thermogravimeter is ongoing. Figure 2a shows the conceptual layout. Figure 2b shows an exploded view of the current design revision. Construction of the STC is scheduled for summer 2011.

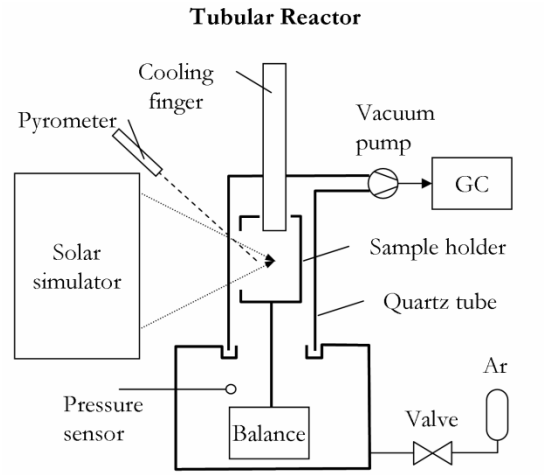


Figure 2a Solar thermogravimeter concept

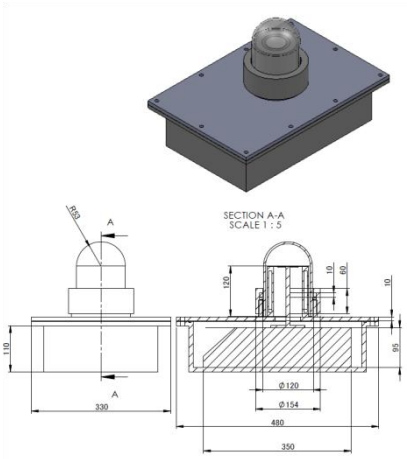


Figure 2b Solar thermogravimeter design.

UNIVERSITY OF FLORIDA

Development of Biofuel Production Processes from Synthetic and Biomass Wastes

PI: Pratap Pullammanappallil
Students Diane Chaulic, PhD, Microbiology and Cell Science; Zhuoli Tian, PhD, Agricultural and Biological Engineering; Gayathri Ram Mohan, MS, Agricultural and Biological Engineering, Nicholas Locastro, BS, Microbiology and Cell Science

Description: With the ever-increasing price of petroleum and its finite supply, it is of high priority to develop domestic sources of transportation fuel, as well as other chemicals. Ethanol is an attractive alternate fuel that is being produced from corn starch. It is necessary to target other feedstocks for biofuel production and develop processes that have a minimal environmental impact. There is considerable ongoing research on developing processes and catalysts for conversion of biomass to biofuels like ethanol (called cellulosic ethanol process). But this project addresses other feedstocks with the following objectives: 1) development of biocatalysts for the conversion of waste biodegradable poly lactic acid based plastics to ethanol and 2) development of processes that processes for the production of additional fuels like biogas, bio-oil and biochar from the waste and byproducts of a cellulosic ethanol plant for the clean up and reuse of these waste streams

Budget: $192,000
Universities: UF
External Collaborators: UCF

Progress Summary

Process development for biogasification and clean up of cellulosic ethanol stillage

- Demonstrated that struvite (a slow release fertilizer containing ammonia and phosphate) can be recovered from the anaerobically digested stillage.
- A process was developed to recover struvite along with other organic carbonaceous residue remaining in the digested stillage.
- Showed that this process can be applied with or without prior anaerobic digestion of stillage.
- Estimated that sufficient phosphorous is contained in the recovered sludge to grow the biofuel crop. The application of this sludge to grow the bioenergy crop offsets the need for addition of phosphate fertilizer.
- Demonstrated that nanoceria enhances anaerobic digestion of biomass.

Process development for preparation of enzymes to saccharify pectin rich biomass feedstocks.

- Developed a process that can be implemented in the biorefinery to prepare biocatalysts for saccharification of pectin-rich biomass and a method for saccharifcation of such biomass. This process has applications for pretreating citrus pulp, sugar beet pulp, apple pomace, fruit and vegetable wastes etc prior to production of liquid fuels.

Biocatalyst development for conversion of waste PLA based plastics to ethanol

- An *E.coli* mutant was constructed that is incapable of utilizing lactic acid.
- Into this mutant a Lactate dehydrogenase (LDH) gene was inserted. Currently experiments are underway to verify the expression of this gene.

UNIVERSITY OF FLORIDA

Engineering Biocatalysts for Hemicelluloses Hydrolysis and Fermentation

PI: James F. Preston

Project Description:

Goals and Objectives:
Our goal is to develop biocatalysts for the cost-effective production of fuel alcohols and chemical feedstocks from underutilized sources of renewable biomass and evolving energy crops. To reach this goal protocols for efficient saccharification of hemicellulose fractions from these resources will be developed.
Objectives are to:

1. Develop improved enzyme-mediated saccharification protocols of hemicelluloses with existing bacterial biocatalysts for production of biofuels and chemical feedstocks.
2. Develop Gram positive biocatalysts for direct conversion of hemicelluloses to biobased products.
3. Develop systems with bacterial biocatalysts for efficient bioconversion of the hemicellulose fractions of perennial energy crops (poplar, eucalyptus, switchgrass, energy cane) to targeted products.

Budget: $192,000
Universities: UF
External Collaborators: Collaborations are in various units within the University of Florida: L.O. Ingram and K.T. Shanmugam, Microbiology and Cell Science; F. Altpeter, Agronomy; G. Peter, Forest Resources and Conservation

Progress Summary

1. *Development of a bacterial biocatalyst for the complete conversion of hemicellulose hydrolysates to biobased ptoducts.*

Genes encoding endoxylanases and alpha-glucuronidases have been identified in Gram negative *Xanthomonas* spp. These have been cloned for expression in Gram negative ethanologenic biocatalysts with type 2 secretion systems, including *Klebsiella oxytoca*. Formation of these enzymes in K. oxytoca may provide a biocatalyst for direct conversion of glucuronoxylans, the predominant polysaccharide in the hemicelluloses fractions from hardwoods and agricultural residues, to biofuels and chemicals. This will extend applications of the patent UF #12617, "Biocatalyst for complete conversion of hemicellulose to biobased products" and potential interests for licensing.

2. *Develop improved enzyme-mediated saccharification protocols of hemicelluloses with existing bacterial biocatalysts for production of biofuels and chemical feedstocks*

Endoxylanases, alpha-glucuronidases and arabinofuranosidases, encoded by genes from mesophilic *Paenibacillus* sp. JDR-2 and the extreme thermophile *Thermotoga maritima*, have been produced as recombinant enzymes for the efficient conversion of the xylans of hemicelluloses to ethanol using the biocatalysts *Klebsiella oxytoca* P2 and *Enterobacter asburiae* E1. In collaboration with Fredy Altpeter in Plant Cell and Molecular Biology, genes encoding endoxylanases from *Thermotoga maritima* have been cloned and expressed in tobacco and

sugarcane to produce quantities of enzymes to use as amendments during pretreatment for saccharification and fermentation. These studies have now been published:

Kim, J.Y., K. Musa, W. Fouad, G. Nong, J.F. Preston and F. Altpeter. 2010. Production of hyperthermostable GH10 xylanase Xyl10B from *Thermotoga maritima* in transplastomic plants enables complete hydrolysis of methylglucuronoxylan to fermentable sugars for biofuel production. Plant Mol. Biol. On-Line ahead of print. 2010.

3. **Develop Gram positive biocatalysts for direct conversion of hemicelluloses to biobased products**

Genes encoding intracellular xylanase and alpha-glucuronidase from *Paenibacillus* JDR2 have been engineered to include secretion sequences for *Bacillus* spp. Transformation of *Bacillus subtilis* with these modified genes has provided new strains that efficiently ferment glucuronoxylan to ethanol, lactate and butanediol. Further downstream engineering of these strains for homoethanol and homolactate fermentation will provide biocatalysts more efficient and cost-effective conversion of woody biomass to fuels and chemicals. This will extend applications of the patent UF# 12619, " Xylan-Utilization Regulon for Efficient Bioprocessing of Hemicellulose and Uses Thereof", and potential interests for licensing.

Funds leveraged/new partnerships created

Targeting plant cell wall degrading enzymes to mitigate pathogenesis of *Xanthomonas axonopodis* pv. *citri*
USDA Citrus Canker Funds
J.F. Preston as PI, J. Jones Co-PI 06/01/10-08/30/11 $84,000 Total and Direct
My on-going collaboration with Professor Jeffrey B. Jones, Dept. Plant Pathology, University of Florida, has been concerned with defining proteins, including enzymes, that contribute to virulence of plant-pathogenic bacteria. Genomic sequence comparisons of different *Xanthomonas* spp. have identified gene clusters that express xylanolytic enzymes. These can be used to engineer Gram negative bacterial biocatalysts, e.g. *Escherichia coli*, *Klebsella oxytoca*, and *Enterobacter asburiae* strains to efficiently convert hemicelluloses to targeted products. We are now engineering strains *Klebsiella oxytoca* to secrete enzymes that will allow direct conversion of woody biomass (forest biomass, agricultural residues and energy crops) to fuels and chemicals.

Next-Generation Sweet Sorghums: Sustainable Production of Feedstocks for Fuels, Chemicals and Value-Added Products
USDA
W. Vermerris (PI) et al. (8 Co-PI's) 4 yr $4,800,000 J.F. Preston (20% commitment) $800,000
Previous collaborations with faculty in the Genetics Institute, including Professor Wilfred Vermeris, have led to the production and chacterization of xylanolytic enzymes in plants, with the goal of production of plant biomass for pretreatment and conversion to fuels and chemicals. This newly awarded grant and support from FESC are complementary with respect to the development of bacteria biocatalysts for direct conversion of cellulosic biomass to fuels and chemicals. Funds ($50,000) from our FESC budget, as well as salaries provided by the University of Florida, provided matching funds for this award.

UNIVERSITY OF FLORIDA

Thermophilic Biocatalysts for the Conversion of Cellulosic Substrates to Fuels and Chemicals

PI: K.T. Shanmugam
Students: Yue Su (Ph. D.) and Brelan Moritz (Ph. D.)

Description: Biomass is an attractive source of sugars for a state like Florida that produces very limited amount of corn for fermentation to produce ethanol as transportation fuel or other products such as lactic acid that can be converted to bioplastics. Florida currently generates about 8.7 million tons of dry cellulosic biomass per year (US-DOE) that can be converted to about 0.7 billion gallons of ethanol. With specific energy crops and short rotation trees cultivated for energy production using the abundant sunshine and water resources, the ethanol produced from biomass can be significantly increased to meet the demand for transportation fuel in the State of Florida. Before biomass-based fuels and chemicals become an economic reality, several key steps in the depolymerization of biomass to constituent sugars need to be addressed. One is depolymerization of cellulose to glucose by fungal cellulases before fermentation to ethanol by microbes. The current estimated cost of fungal cellulases is $0.32 per gallon ethanol produced and this cost is targeted for reduction to $0.10 or less by year 2012 (DOE). We have demonstrated that by increasing the temperature of Simultaneous Saccharification and Fermentation (SSF) of cellulose from 30-35 ºC to 50-55 ºC, the amount (and associated cost) of cellulases can be reduced by the required 3-fold with the current commercial enzyme preparations. A microbial biocatalyst that produces ethanol or other chemicals as the main fermentation product and can also function at this higher temperature and pH 5.0 in conjunction with the fungal cellulases in the SSF process is a critical component of this process. We have identified a thermophilic facultative anaerobe, *Bacillus coagulans*, with versatile metabolic capability as the microbial platform for the SSF of biomass to products and engineering this L(+)-lactic acid producing bacterium to produce ethanol. *The primary objective of this proposed study is to construct a B. coagulans derivative that produces ethanol as primary product of fermentation and to enhance the ethanol productivity of the engineered derivative.*

Budget: $192,000.00
Universities: UF

Progress Summary

Optically pure lactic acid is an attractive chemical for production of bio-based, renewable, polylactide-derived plastics and this is currently produced by microbial fermentation of sugars at temperatures below 40°C. Fermentations at 50-55 °C is expected to enhance the use of non-food carbohydrates for production of optically pure lactic acid while also reducing potential contamination that could lower the optical purity. Biodegradable plastics of varying thermal and physical properties can be produced by judicious mixing of D(-)- and L(+)- lactic acid derived polylactides. This requires optically pure lactic acid and only microbial fermentation is known to produce such a product. We have engineered a thermotolerant bacterium, *Bacillus coagulans* that grows optimally at 50-55 °C and produces (L+)-lactic acid as the primary fermentation product to produce D(-)-lactic acid by deleting the genes in the competing pathways: *ldh* (L-lactate dehydrogenase) and *alsS* (acetolactate synthase). Neither a single (*ldh*) (strain QZ4) or a double (*ldh, alsS*) (strain QZ5) mutant produced D(-)-lactic acid although a native *ldhA* encoding D-LDH is present in the chromosome. Upon metabolic evolution of strain QZ5 for anaerobic growth at pH 5.0 and D(-)-lactate production, a derivative, strain QZ19, was selected. Strain QZ19

produced about 90 g/L of optically pure D(-)-lactic acid in less than 48 hours in batch fermentations at 50°C. The wild type *B. coagulans* and the mutant strain QZ19 can each provide the necessary optical isomer of lactic acid at high titer and yield from biomass-derived non-food carbohydrates at 50-55 °C for production of polylactides and bio-based plastics.

The double mutant is currently being evolved for ethanol production from lignocellulosic biomass derived sugars at 50-55°C.

A provisional patent application with the US Patent Office was filed on the development of the thermotolerant bacterium that produces D(-)-lactic acid.

Proposals						
Title	**Agency**	**Ref. #**	**Investigators/ collaborators**	**Funding requested**	**Duration**	**Date submitted**
Next-generation sweet sorghums: sustainable production of feedstocks for fuels, chemicals and value-added products	DOE-USDA (BRDI)	2010-05340	K. T. Shanmugam (Co-PI) W. Vermerris (PI)	$5,430,439	4 years	October 2010