FESC Florida Energy Systems Consortium

University of Florida

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

PI: Jenshan Lin
Students: Jaime Garnica/PhD, Raul Chinga/PhD,
Xiaogang Yu/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
Universities: UF

Progress Summary

Power can be transmitted wirelessly using various methods. For moderate distances (up to a few meters), near field coupling through either the electric or magnetic fields is used to achieve high efficiency. Recent publications in scientific and engineering journals and demonstrations in Consumer Electronics Show have generated strong interests. Many companies are now investing resources into research and product development of wireless power systems and creating jobs in this field. In consumer electronics, companies are developing technologies to charge cellular phones and other portable electronic devices wirelessly. In automobile industry, companies are developing technologies to charge electric vehicles through wireless power. High efficiency of wireless power transmission is the key in developing this type of wireless charging technologies. For charging cellular phones, currently there are already products available on the market and engineers are working hard to improve their performances. Considering the vast amount of portable electronic devices in the world and the growing number of electric vehicles, the market of wireless power has a great potential.

This project performed at the Radio Frequency Circuits and Systems Research Group in the University of Florida is focusing on developing wireless power transmission systems for various applications and new technologies to improve their efficiency. Several wireless power systems have been demonstrated and the results have been published.

During the past year, our research results have attracted attentions from many companies in industry. Some companies are interested in licensing the technologies, and some companies have sent their engineers to University of Florida as visiting researchers to establish collaborations. So far, our lab has hosted visiting researchers from NEC (Japan), Research Institute of Industrial Science & Technology (Korea), and Industrial Technologies Research Institute (Taiwan). These companies also sponsor research projects in the lab and plan to hire students from the lab as interns. With new technologies being developed that may lead to potential new intellectual properties, new companies and new jobs in this field is highly possible.

Funds leveraged/new partnerships created:

- New collaboration with NEC (Japan) established.
- New collaboration with Research Institute of Industrial Science & Technology (Korea) established.
- New collaboration with Industrial Technologies Research Institute (Taiwan) established.

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Midrange Wireless Power System

Midrange power transmission over moderate distances is investigated for use in transmitting power from a source outside of a building to the interior (i.e. a solar panel) without modifying the structure. Such a system would also be useful in situations where power delivery via physical wires would be impractical or dangerous, or where a lack of physical connection would provide an advantage that offsets the decrease in efficiency (for example, wireless charging at bus stations for electric busses). To this end, a system capable of power transfer over distances of about one meter is investigated and built.

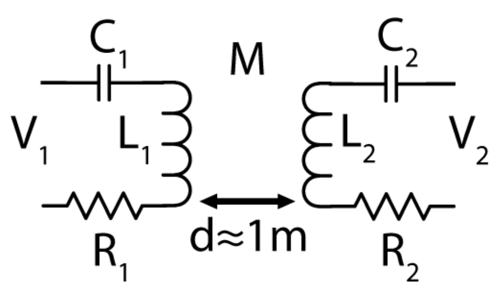

Figure 1: Series resonant arrangement of coils, including coupling, parasitic resistance and tuning capacitor.

In previous works, a system capable of wireless charging over short distances was developed. A magnetic field is generated in the near-field and a receiving coil is placed physically close to the source in order to achieve high efficiency transfer. This idea is extended to moderate distances (about one meter) by increasing the size of transmit and receive coils to increase the mutual inductance and choosing the appropriate conductor to minimize resistive losses. A series resonant circuit (Figure 1) is used to obtain high-efficiency power transfer. In this configuration the efficiency can be written as:

$$\eta = \frac{\omega^2 M^2 R_L}{(R_2 + R_L)^2 R_1 + (R_2 + R_L)\omega^2 M^2}$$

It can be seen that there are two methods to increase efficiency. First, the mutual inductance can be increased. In the two systems to be presented, the mutual inductance is increased by making the characteristic size of the coupling coils similar to the distance desired (one meter flat square spiral and one meter diameter helix) and using multi-turn coils. Second, the efficiency can be increased by reducing the parasitic resistance (R_1 and R_2) of the coils themselves (as well as the series resistance of any other components). To minimize these values, litz wire as well as ¼" copper pipe are used in the construction of the coils.

Two coils made of litz wire on wooden forms comprise the first system (Figure 2). Fixed film capacitors are used for series tuning. A full-bridge amplifier using IRF530 MOSFETs and a HIP4081A driver is used to power the system at 500 kHz. The maximum power transferred using this system is 38.3W with 76% efficiency. The transmitted power is limited primarily by the high voltage that develops as a result of the series resonant circuit. The high voltage will cause arcing between turns of the litz wire and breakdown of the capacitor used to tune the circuit. These faults can damage the driving amplifier.

Figure 2: The first wireless power system achieving 38.3W with 76% efficiency. The coils are made of litz wire: 6 turns, 1 m each side, 1725 strand, 48 AWG.

Several methods are used to combat the above issues and increase the transmitted power further. The most obvious issue is the breakdown of the capacitor. The capacitors used initially have a very low ESR (less than 0.1 ohm) at the operating frequency, but are only rated for 600 V. Higher rating capacitors of similar values are available, however the losses in the capacitors approach the magnitude of the losses caused by the resistance of the coils.

The second system utilizes ¼" copper pipe (Figure 3) to form two 1 m diameter helical coils on PVC coil forms. A higher voltage rated capacitor is formed from several film capacitors in parallel with a 10 kV vacuum variable capacitor for fine tuning. With this system a maximum power of 114 W was delivered to a 25 ohm load with 65% efficiency at one meter separation. Virtually all of the dissipated power is lost to the resistances of the coils, not in the amplifier, thus the amplifier should be able to supply up to 450 W without further modification, which should allow for received power to approach 300 W.

Figure 3: The second wireless power system achieving 114 W and 65% efficiency. The coils are made of ¼" copper tubing on PVC form: 9 turns, 1 m diameter.

High Efficiency Power Amplifier

The power amplifier in transmitter is the most important active component in the system. Several different designs of power amplifier have been studied in this research. These include Class-E, Class-D, and full-bridge Class-D. It was found out that the full-bridge Class-D amplifier is the best for midrange wireless power system. The efficiency remains constant when power level is changed. It is less sensitive to variation in distance when compared to Class-E. The full-bridge Class-D also requires half of the supply voltage of Class-D. Figure 4 shows a picture of the full-bridge Class-D amplifier. A detailed study and results were described in the previous report.

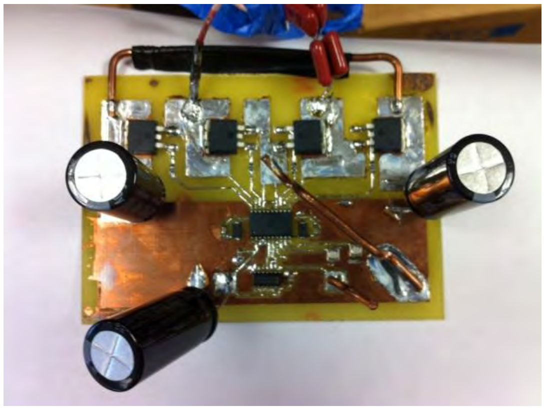

Figure 4: Full-bridge Class-D amplifier.

For some wireless power applications requiring smaller size with less power, operating at higher frequency is more suitable. For wireless charging of portable devices at a fixed short distance, Class-E is a good topology because its power output at a fixed supply voltage is higher than that of Class-D. High efficiency Class-E power amplifiers at 13.56 MHz are developed. 13.56 MHz is a popular Radio Frequency Identification (RFID) frequency band. The improvement of power amplifier efficiency will benefit the widely used RFID systems at this frequency and potentially can be applied to many other wireless communication devices and systems.

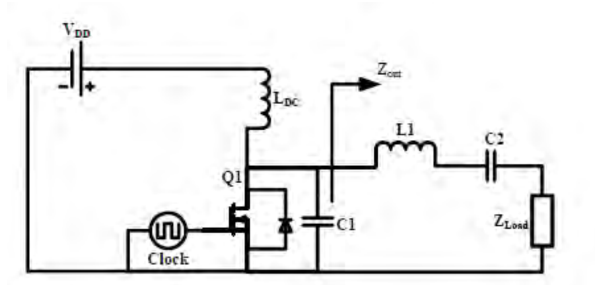

Figure 5: Class-E power amplifier

The schematic of Class-E amplifier is shown in Figure 5. Operating at 13.56 MHz brought up a few challenges:

1. The internal shunt capacitance across the drain and source of the transistor is not negligible. In most cases, this parasitic is larger than the value determined for C1, not allowing an optimal implementation.
2. Ideally, we want a high Q on the load to only allow a single tone to pass through the filter. However, there is a tradeoff between the Q and the size of the inductor L2. If L2 is too large, the parasitic resistance is very large (~5-10 ohms), which will cause power loss across it. Therefore, a low Q is preferable (but not less than 1.8) to maximize efficiency. In the case of wireless power transmission system, the quality of the output signal does not have to be a perfect sine wave since the objective is to transmit energy.

Shunt Capacitance and GaN transistor:
The parasitic shunt capacitance across the drain and the source of the transistor is significantly larger in power MOSFETs at 13.56 MHz than at lower frequencies. Various MOSFET's were tested, in simulation and on the test bench, but failed to work due to either long rise and falling times (fully switch from ON to OFF was not possible at 13.56 MHz) and/or the internal shunt capacitance was too large. Given these constraints, a different transistor technology GaN was considered. This type of transistor is significantly smaller, more efficient, and capable for handling large current and drain voltages, which means high power delivery is possible. Most importantly, it works well at 13.56 MHz, having fast fall and rise times as well as small Cgs.

Circuit Implementation:
The shunt capacitance was removed since the internal shunt capacitance of the GaN transistor was large enough to satisfy the design criteria. The Q of the load was set to 5 to allow a small inductor on the load network, minimizing the parasitic and power loss across the inductor L2. The values of circuit components are shown in Table 1 (refer to Figure 6).

M1	EPC1010	C1	690pF
Gate Driver	IXDI502	C2	0.1uF
Oscillator	K50-HC	C3	0.1uF
L1	50uH	C4	0.1uF
L2	0.3uH	C5	22uF
Rload	13ohm	C6	0.1uF
		C7	22uF

Table 1: Component values

A complete Class-E transmitter consisting of an oscillator, a gate driver, and a Class-E amplifier was set up (Figure 6 & Figure 7). The gate voltage was varied from 4V to 6V with the purpose of finding an optimal point at which the highest efficiency is achieved. Unlike a power MOSFET, the GaN transistor is very delicate, causing it to break when the maximum gate voltage is exceeded.

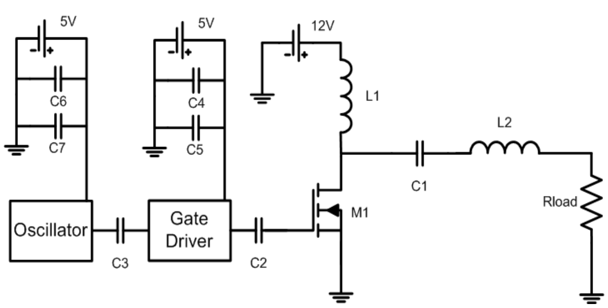

Figure 6: Complete Class-E transmitter with load

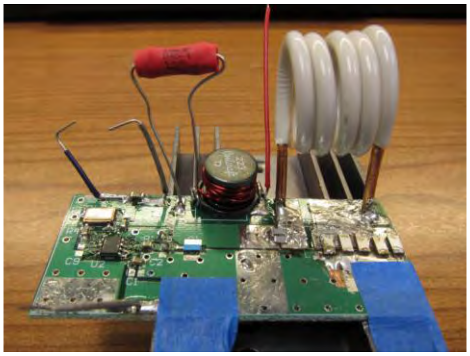

Figure 7: Picture of Class E amplifier

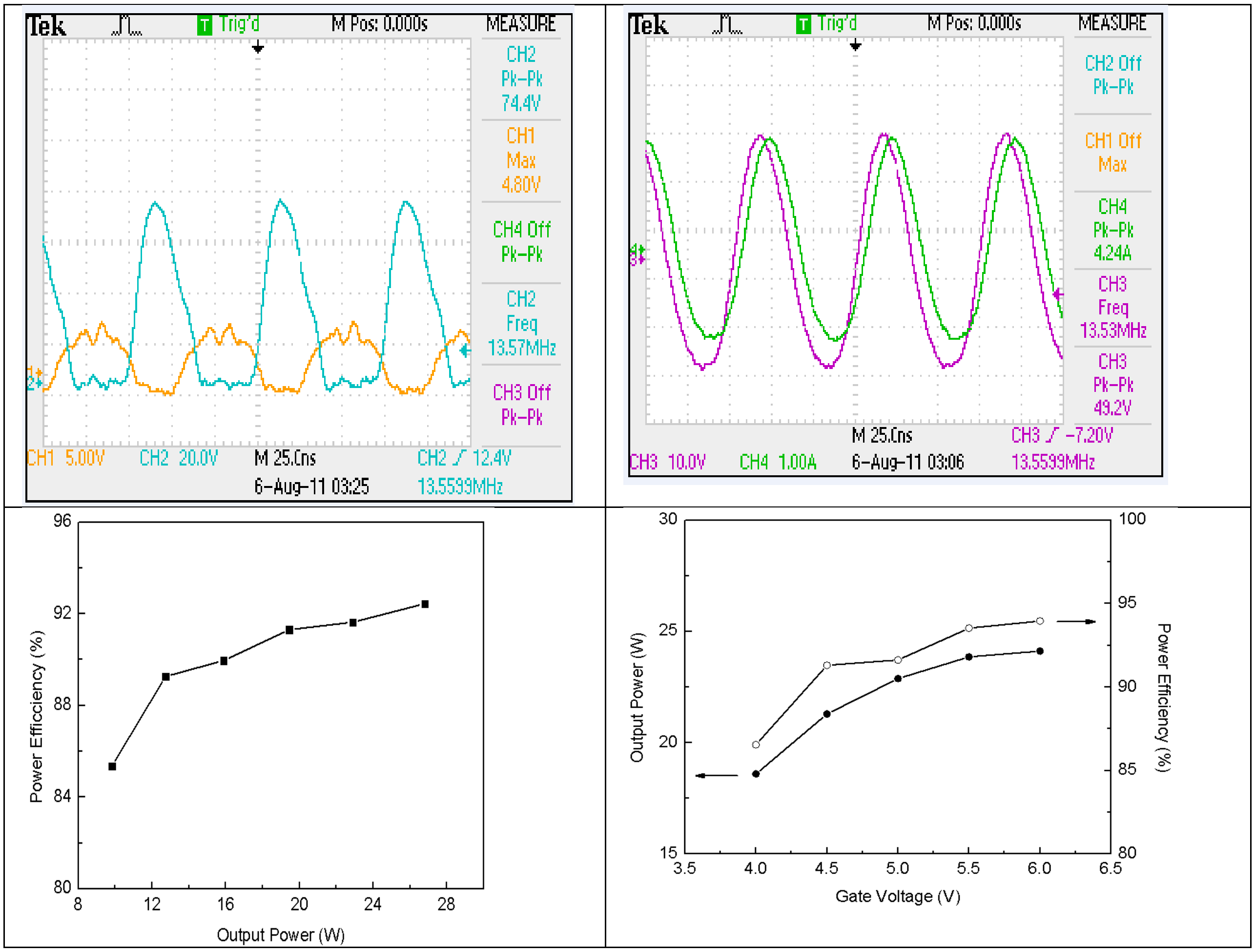

Figure 8: Measurement results of Class-E power amplifier

Figure 8 shows the measurement results obtained. In the top left, the drain waveform shows a proper ZVS is attained, which is critical for a high efficient Class-E amplifier. On the right, the output voltage and

current waveforms are slightly out of phase. This is due to parasitics of the resistor and the probing of the system (voltage probe has a capacitance of 15pF). As shown, a 94% drain efficiency is achieved with an output of 27W (overall efficiency including driving circuit drops to 92%). Theoretically, a Class-E can yield 100% efficiency. However, the parasitics of components as well as the switching losses of the transistors reduce the efficiency.

In summary, the implementation of a Class-E amplifier used as an inverter for wireless power transmission systems has been successfully achieved. Using a GaN transistor, it was possible to deal with the internal shunt capacitance problem as well as the slow rising and falling times of a power MOSFET. In addition, compared to the power MOSFET, the GaN transistor is much smaller in size for the same power capability.

University of Florida

Optimization of Algae Species for Biofuels Production Using Genetic Alteration

PI: Edward Phlips
Student: Bailey Trump, PhD degree

Description: The central challenges to viable algal biofuel production are the solar energy conversion efficiency for algae growth, sustainable yields of usable products and operational constraints on production systems. While theoretical solar conversion efficiencies for algae and plants are between 5 and 6% of total insolation, most algal systems operate at average annual efficiencies well below this range. Therefore large areas are needed to produce significant amounts of biofuels from algae, and production systems must be able to sustainably produce biomass convertible to biofuels within reasonable logistical and economic constraints. Logistical constraints include minimal use of valuable freshwater and arable land resources. Economic constraints may demand the use of low tech open pond systems, rather than more costly and maintenance intensive closed bioreactor designs. Sustainability of production will depend on the ability to maintain relatively pure mass cultures of algae capable of producing high levels of desirable products (e.g. hydrocarbons or convertible lipids). These considerations point toward the need to focus on the development of systems which use ocean water and algal species adaptable to extreme conditions that minimize competition from "weed" species, such as high salinity, temperature, pH, low nitrogen availability or UV light exposure.

The focus of this study is genetic alteration of selected species of algae to optimize their performance in biomass production systems aimed at biofuels. Two approaches to genetic alteration will be explored, mutagenesis and transformation. The research program began with the use of chemical mutagens to generate altered strains of algae currently available in the culture collection of the PI (E. J. Phlips). Mutated algae are going through a selection process to identify strains with favorable characteristics. The selection criteria include growth rate, tolerance to environmental extremes (e.g. salinity, temperature, pH, UV exposure), and lipid content. The initial target species for mutagenesis research will include: 1) *Botyrococcus braunii*, a green alga (Chlorophyta) known for its high levels of hydrocarbons, but low growth rates and low adaptability to high salinities and temperatures, 2) *Synechococcus sp.* a fast growing cyanobacteria high biomass production potential, and adaptability extreme environmental conditions, such as high salinity and temperature.

Budget: $15,000
Universities: UF
Collaborators: Drs. Mathius Kirst in the University of Florida's Genetic Institute and Charles Guy in the Department of Environmental Horticulture at the University of Florida.

Progress Summary

The funds provided by FESC are being used to fund the dissertation research of Bailey Trump, a PhD student. The focus of her dissertation research is the **Optimization of Algae Species for Biofuels Production Using Genetic Alteration.** Her dissertation research program began in August of 2011. During the initial stages of her program she has begun the development of the methodologies for mutating and screening the target species of algae, in cooperation with Drs. Mathius Kirst in the University of Florida's Genetic Institute and Charles Guy in the Department of Environmental Horticulture at the University of Florida.

One of the two initial target species *Synechococcus* sp. was immediately available from the culture collection of the PI. The other species, *Botryococcus braunii* Strain B, was obtained through a cooperative agreement with the University of California at Berkeley (Dr. Irvin Mettler, Associate Director).

New Partnerships: A new research partnership was formed with Drs. Pratap Pullammanappallil of the Department of Agricultural and Biological Engineering (U. of Florida), Spyros Svoronos of the College of Engineering (U. Florida) and Ben Koopman of the College Engineering (U. of Florida) for the submission of a proposal to NSF's Emerging Frontiers in Research and Innovation 2012 (EFRI-2012) program. The proposal is titled Development of a Photosynthetic Biorefinery Employing a Novel Hypersaline, Nitrogen-fixing, Polysaccharide Secreting *Synechococcus s*p. of Cyanobacterium, and will be submitted in November 2011.

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Optimization, Robustness and Equilibrium Modeling for the Florida Smart Grid

PI: Panos Pardalos
Students: Alexey Sorokin / PhD

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: $30000
Universities: UF

Progress Summary

The project develops a game theoretic approach for electricity market participants with storage devices. 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 a model for "smart batteries" – a plan for charging and discharging batteries in such a way that every participant will enjoy the maximal possible gain. The model developed in the project formulates a Nash equilibrium problem and propose extensions for generalized Nash equilibrium. In the simplest case, our model presents a Nash equilibrium problem with quadratic cost functions. It is attacked with several methods recently developed.

Funds leveraged/new partnerships created:
Steffen Rebennack, PhD,
Assistant Professor
Colorado School of Mines
Division of Economics and Business
816 15th Street
Golden,CO, 80501, USA

Neng Fan, PhD
Sandia National Laboratories

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We consider a problem of micro-storage management where household communities have common batteries installed and can buy electricity from the grid for home use, for charging the battery, or can use battery for the house when the current electricity price is high.

The objective is to develop a model such that every agent minimizes the cost for electricity and battery running cost. The model describes a Nash equilibrium problem and proposes 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.

Assumptions:

- There are several communities present and together they can affect electricity price by changing electricity demand.
- Every community shares a common battery.

The first assumption leads to Nash equilibrium problem, i.e. the solution of each agent problem depends on the rest agents. The second assumption leads to a generalized Nash equilibrium problem, which is much more difficult. Both models are new and difficult to solve. The fact that several communities work on Nash equilibrium problem (without knowing each to other) shows the importance and applicability of this model where non-cooperative equilibrium is sought.

0.1. **Agents.** There is a set of agents (customers) A who want to minimize their electricity cost. The agents form communities i, which are presented in a set I. An agent has a load profile l_t^{ia}, which shows the demand for electricity at any time moment $t \in T$ not considering the battery charging/discharging. The sum of load profiles among the agents of all communities will define the total electricity demand at time moment $t \in T$: $d_t = \sum_i \sum_a l_t^{ia}$. Every agent has an access to a common battery within a community i with the following parameters:

- total capacity e^i,
- efficiency α^i,
- running cost c^i,

For minimizing the cost, an agent a can change their storage profile b_t^{ia}, $\forall t \in T$: $-b_-^i + \sum_{A/a} b_{t-}^i \leq b_t^{ia} \leq b_+^i - \sum_{A/a} b_{t+}^i$, where b_-^i is a discharging capacity of the battery and b_+^i is charging capacity of the battery. Clearly, the charging profile for an agent a at time moment t is a difference between the amount charged and discharged : $b_t^{ia} = b_t^{ia+} - b_t^{ia-}$. Summing up over all the agents we get the net storage profile: $b_t = \sum_i \sum_a b_t^{ia}$.

0.2. **Market.** Total amount of electricity bought from the market at time moment t is $q_t = d_t + b_t$. The market price of the electricity is defined by supply curve of that market, which is assumed to be a nondecreasing: $p_t = s_t(q_t)$ and each agent will pay $p_t \cdot (l_t^{ia} + b_t^{ia})$. Total cost of electricity for all the agents will be $p_t \cdot q_t$.

I	Set of communities
A_i	Set of agents within community i
T	Set of time periods
l_t^{ia}	load profile – demand not considering battery use
$d_t = \sum_i \sum_a l_t^{ia}$	Total electricity demand at t
e^i	battery total capacity
α^i	battery efficiency, if q is charged then $\alpha^i q$ is discharged
c^i	battery running cost
b_t^{ia}	storage profile – amount of electricity charged/discharged at time moment t by an agent a in a community i
b_-^i	Discharging capacity of a battery i
b_+^i	Charging capacity of a battery i
b_t^{ia+}	Amount of electricity charged at time period t
b_t^{ia-}	Amount of electricity discharged at time moment t
q_t^{i-}	Amount of electricity that can be discharged in battery i at time moment t
q_t^{i+}	Amount of electricity that can be charged to battery i at time moment t
p_t	Price of electricity at time moment t

The Model:

Every agent minimizes the cost for electricity and battery running cost:

$$cost^{ia}(b^{ia}) = \sum_t \left(p_t \cdot (l_t^{ia} + b_t^{ia}) + c^i \cdot b_t^{ia+}\right) \tag{1}$$

s.t.

storage profile:

$$b_t^{ia} = b_t^{ia+} - b_t^{ia-}, \ \forall i \in I, \ a \in A, \ t \in T, \tag{2}$$

total daily charging can not exceed battery capacity:

$$\sum_a \sum_t b_t^{ia+} \leq e^i, \ \forall i \in I, \tag{3}$$

battery efficiency constraints:

$$\sum_a \sum_t b_t^{ia-} = \sum_a \sum_t \alpha^i b_t^{ia+}, \ \forall i \in I, \tag{4}$$

charging profile feasibility constraints:

$$\sum_a b_t^{ia+} \leq q_t^{i+}, \ \forall i \in I, \ t \in T, \tag{5}$$

$$\sum_a b_t^{ia-} \leq q_t^{i-}, \ \forall i \in I, , t \in T, \tag{6}$$

$$q_t^{i-} = \alpha^i \left(q_0^{i+} + \sum_a \sum_{k=1}^{t-1} (b_k^{ia+} - b_k^{ia-}/\alpha^i) \right), \ \forall i \in I, t \in T, \tag{7}$$

$$q_t^{i+} = e^i - \left(q_0^{i+} + \sum_a \sum_{k=1}^{t-1} (b_k^{ia+} - b_k^{ia-}/\alpha^i) \right), \ \forall i \in I, t \in T, \tag{8}$$

electricity reselling is not allowed:

$$l_t^{ia} \geq b_t^{ia}, \ \forall i \in I, \ a \in A, \ t \in T. \tag{9}$$

Activities:

Organized conference (Organizer Panos Pardalos)
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.

Accepted talk at the INFORMS conference, November 16
"Nash Equilibrium Model for Micro-storage Management in the Smart Grid"
by Alexey Sorokin, Pando Georgiev, Marco Carvalho and Panos Pardalos.

Working towards to publish the results in this talk in a journal paper.

Ongoing work on data mining in energy for detecting and preventing instabilities and outages of the power grid.

Edited books:

Handbook of Networks in Power Systems I co-editors: Alexey Sorokin, Steffen Rebennack, Panos Pardalos, Niko Iliadis, Mario Pereira, Springer, (2011).

Handbook of Networks in Power Systems II co-editors: Alexey Sorokin, Steffen Rebennack, Panos Pardalos, Niko Iliadis, Mario Pereira, Springer, (2011).

University of Florida

Outreach Activities for the Florida Energy Systems Consortium

Co-PIs/Outreach Team Members: Pierce Jones, Kathleen C. Ruppert, Hal S. Knowles III, Nicholas Taylor, Barbra Larson, Craig Miller
Students: Sarah Dwyer (MS), Flavio Hazan (Ph.D.), Hal Knowles (Ph.D.), Nicholas Taylor (Ph.D.)

Description: UF's Program for Resource Efficient Communities (PREC) develops 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

Energy/Climate Awareness Fact Sheets: Completed twelve fact sheets for the FESC website with four more currently in various stages of development. Additional topics have been determined. Updated the publication to address developments in the PACE financing markets with new version published in October 2010 titled *Options for Clean Energy Financing Programs: Scalable Solutions for Florida's Local Governments*.

Energy Extension Service: Co-authored and/or co-reviewed content 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 twice in Leon, Marion, and Pinellas counties to date. Reviewed and promoted *S.A.V.E. (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 are available online at http://florida4h.org/projects/SAVE.shtml. The Pasco County School System is contemplating adopting the curriculum for 5th graders for all schools in their district. Presented a Low Impact Development (LID): Water Resource Protection Strategies in the Built Environment web-based training for county extension agents. Prepared and delivered two 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. As senior or co-author published or they have been accepted the following refereed publications: "Stakeholder Analysis of a Collaborative Watershed Management Process: a Florida Case Study," September 2011, *Journal of the American Water Resources Association*; "Implementing Low-Impact Development in Florida: Practitioners' Perspective," *Florida Watershed Journal;* "Evaluating the Energy Performance of HERS-Rated Homes Using Annual Community Baselines." Conference proceedings of

Strengthening the Green Foundation: Research & Policy Directions for Development & Finance. Produced a "Low Impact Development (LID) Design Manual for Alachua County, Florida." Gave 31 presentations at the national, state, regional, and local level.

Demand Side Management: In addition to other activities, with the assistance of a ~$450,000 grant, working with all of Florida's utilities and weatherization retrofit providers to evaluate the performance of weatherized homes pre- and post-retrofit.

Continuing Education: Offered and taught: Greenhouse Gas Reduction and Energy Conservation I: Comprehensive Planning Under Florida's HB 697; Energy Efficient Building Construction in Florida; Remodel Green & Profit; Residential Green Advantage®; and via webinar, Community Planning: Challenges and Opportunities for Local Government in Florida CEU classes.

Workforce Development: Collaborated with the Employ Banner Center for Construction and the Florida Solar Energy Center, using a grant from the U.S. Department of Energy, to develop curriculum and establish statewide access to weatherization training.

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: Copyright applied for and received for "Quantifying Household Energy Performance Using Annual Community Baselines Annual Community Baselines" (2011).

Funds leveraged/new partnerships created

#	Faculty	University	Source/Agency	Project Title	Start Date	End Date	Amount
	P Jones	UF-PREC	Florida Energy Office (from DOE)	Energy Efficient and Renewable Energy Retrofits for Multi-Family Housing	6/29/11	4/30/12	$499,114
	P Jones	UF-PREC	DOE Building America Program (UF is partnering with UNL, as a subcontractor)	Energy Efficient Housing Research Partnerships – Field Data Supporting Retrofit Analytical Research	8/8/11	12/31/11	$85,767
	P Jones	UF-PREC	DOE/FECC/ Osceola County	Osceola Energy Initiative	5/10/11	9/30/12	$373,000
	P Jones, H. Knowles	UF-PREC	DOE SBIR/ Accelerated Data Works	Energy Tracking Software Platform	10/15/10	3/18/11	$19,843

#	Faculty	University	Description of Collaboration	Name of Institution
	P Jones	UF-PREC	Collaborations on energy efficiency research and training	University of Nebraska
	C. Miller	UF-PREC	Collaboration on development of statewide training network for weatherization contractors	Banner Center for Construction, Santa Fe College

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Energy/Climate Awareness Fact Sheets (FS) and Publications

Worked with faculty from Florida Atlantic University, Florida International University, Florida State University, University of Central Florida, University of Florida, the University of South Florida, and employees with Orlando Utilities Commission, Energy Services of Tallahassee, and the St. Johns River Water Management District as authors and/or reviewers of twelve factsheets for homeowners that are now available on the FESC website. Titles include: GHG Case Study: Reducing Landscape Inputs; Batteries for Home Electronics; GHG Case Study: Green Building Ordinance (Gainesville, FL); GHG Case Study: Preserving Natural Areas for Carbon Sequestration (Restoration, FL); GHG Case Study: Reducing VMT (Vehicle Miles Traveled) via Clustered Development (Restoration, FL); GHG Case Study: Reducing Road Infrastructure via Clustered Development (Restoration, FL); GHG Case Study: Reducing the Area and Inputs of Managed Landscapes (Restoration, FL); GHG Case Study: Utility Home Energy Efficiency Rebate Programs (Gainesville Regional Utilities); Green Jobs: What, Why, How, When & Where; Batteries for Automobiles; Tips for Becoming a Water-Wise Floridian; and Programmable Thermostats. Revised one book (new title): *Options for Clean Energy Financing Programs: Scalable Solutions for Florida's Local Governments*.

Energy Extension Service (EES)

Thirty-one professional presentations were conducted during the year at the national, state and local levels.

UF/PREC continued to be involved with the Climate Variability and Change Focus Team, specifically with the Local Government Working Action Group, providing participating Extension Agents with information on FESC-related activities. Also participating on the Sustainable Housing and Home Environment Focus Team along with actively working with the new UF Housing Specialist, who recently assisted us in updating two energy-related factsheets intended for homeowners.

The book *Energy Efficient Building Construction in Florida* continues to be sold to contractors studying for the Construction Industry Licensing Board's certification exam. Over 4,600 books have been sold in the past two years. With the change in the exam to meet the state's updated building code scheduled to go into effect with the April 2012 exam, the book is currently under revision.

PREC partnered on a services agreement with Alachua County Environmental Protection Department to develop a draft *Low Impact Development Design Manual* for use in the county's land development review process. The target audience for the draft manual is developers and design engineers, and the county intends to expand content to include a guidance manual for builders and homeowners. A workshop to engage local stakeholders, the Florida Department of Environmental Protection, St. Johns River Water Management District, and Suwannee River Water Management District was held on June 23, 2011. The final draft manual (Produced a manual: *Low Impact Development (LID) Design Manual for Alachua County, Florida*) and feedback report were provided to Alachua County on September 30, 2011.

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. Data from water years 2006-2009 have been analyzed, and since February 2010, results have been presented at 20 events. Through outreach activities, results have been shared with over 300 professionals, many of whom deal directly with natural resource (water, energy and land use) management issues in Florida and nationally.

Also a result of this FESC-funded project, Jennison was invited to participate as a representative of the University of Florida in a national workshop to develop a joint Blueprint for Energy and Water Efficiency. This workshop was sponsored by the Turner Foundation and convened by the Alliance for Water Efficiency and American Council for an Energy Efficient Economy in December 2010. The results of this workshop were published May 2011 in a report titled "Addressing the Energy-Water Nexus: A Blueprint for Action and Policy Agenda", accessible at http://www.aceee.org/white-paper/addressing-the-energy-water-nexus.

Organized and delivered two Emerging Energy Issues and Topics In-Service Trainings. The first, conducted in May of 2011, emphasized energy consumption and energy production in residential settings. The second, held in September 2011, emphasized social and technological issues related to energy efficiency based on current research. Combined, these trainings reached County Extension faculty in 18 Florida counties and included both classroom and hands-on instruction that can be utilized back in their home counties.

Worked with Florida 4-H on the *S.A.V.E.: Steps in Achieving Viable Energy* youth education outreach program and materials intended for middle-school aged youth. Florida 4-H previewed the curriculum at the FESC 2010 Summit in Orlando. The curriculum is designed for students in middle school and high school and also for 11-13 year-olds in afterschool programs or clubs. The program focuses on 4 areas of energy awareness: forms, sources, users and impacts. The afterschool and club program consists of 30 activities and can be used over a 3 year period. A website is also a part of the project to support the materials (http://florida4h.org/projects/SAVE.shtml). The Pasco County School System is contemplating adopting the curriculum for 5th graders as the materials closely align with the new Florida Next Generation Education Standards.

Co-developed the *Sustainable Floridians* pilot course with Kathryn Ziewitz and Wes MacLeon, UF Department of Family, Youth, and Community Sciences and Extension faculty in Leon, Manatee, Marion, Osceola, Pinellas, Sarasota, and Wakulla counties.

The course consists of the following elements:

Information to provide a foundation in understanding key sustainability issues, with a geographic concentration on Florida. This information will be shared through **multi-media informational presentations** delivered by course leaders and **readings and other supplemental materials** that provide informative and stimulating material.

- **Group discussions** in which participants talk about the readings and share experiences in implementing sustainability actions.

- **Activities** designed to help the participants take practical steps toward greater personal sustainability, including reducing energy and water consumption, and personal miles of travel. Participants will receive a data log to record and track their monthly usage of energy and water and the number of miles driven. During this course and after, they will be contacted at several intervals to collect data.

The course was piloted in Leon (twice), Marion (twice), and Pinellas (twice) counties to date with additional county participation planned in Osceola and Sarasota counties.

The Energy Efficient Home Series – (3 hours) – equips homeowners with the knowledge of building energy and water uses and efficiency strategies that can be applied to their homes. A series of factsheets (18) addressing topical residential energy efficiency issues as well as a complete homeowner handbook (~100 pages) is provided. Osceola County Extension offers a 3-hour *Saving Money on Your Electric Bill* class where participants learn no cost, low cost and some cost actions to save money every month on their electric bill at home. The also learn about the Osceola Energy Initiative (OEI) www.osceola.org/go/energy and other incentives to lower costs of energy saving options.

Continued collaboration with eXtension's Home Energy Community of Practice following Barbra Larson's assisting with developing/editing materials for the website at Montana State University's Weatherization Training Center in July. This group brings together Cooperative Extension, research, and other professionals to develop, enhance, and maintain a national online presence on energy, sustainability, and housing. As a follow-up she will be attending the Housing Education and Research Association's Annual Conference in Baton Rouge, LA, in October of 2011.

Demand Side Management

Jacksonville Electric Authority (JEA): UF/PREC is providing Measurement and Verification services for JEA's Energy Efficiency Evaluation program, which includes analyzing billed consumption data, creating annual community baselines, developing case studies on retrofit packages achieving a 15% energy savings, and providing average savings estimates for groups of homes with different levels of energy audits performed.

New Smyrna Beach DSM Analysis: An analysis of New Smyrna Beach's utility demand side management program was completed. This quantitative analysis of utility DSM programs is being standardized and will be marketed as a service to be offered to utilities throughout the state.

Florida Department of Community Affairs, ARRA-WAP Household Energy Consumption Evaluation: FESC funds are also being leveraged through this ARRA project that continues this year with a focus on collecting data from utility companies throughout the state and evaluation of Weatherization Assistance Program retrofitted homes. An allocation formula was redeveloped for the state's use in future distribution of the DOE WAP funding. Data for populating the state's updated allocation formula has been identified and collected, i.e., heating and cooling days, climate regions, kilowatt cost, low-income population, etc. The formula has been populated and tested. The most recent data to quantify low income populations in each county have been identified and collected from the US Census Bureau. Annual heating and cooling degree day data for weather stations throughout Florida have been identified and collected from the National Climatic Data Center (NCDC). Each weather station has been linked to its county, providing a comprehensive view of heating and cooling demand across the state. Electric cost information has been collected for each utility district from the Florida Public Service Commission. This information has been tagged to each county to provide an estimate of electric service rates and energy expenditures for each county. Written guidelines have also been developed to allow for annual update by the state office. An evaluation of the effectiveness of ARRA WAP regarding client energy savings overall and by measures installed utilizing consumption data obtained through recipients' utility bills is currently being conducted. The evaluation covers the project period and utilizes utility bills for the twelve months pre- and post- weatherization work per weatherized dwelling. It is estimated that approximately 6,500 dwellings will be weatherized during this project period and that a minimum of 90% of these completed dwellings should be evaluated (contingent upon utility cooperation).

Florida Weatherization Training Center: Funds continue to be leveraged through DOE funding to establish the Florida Weatherization Training Center as a statewide network of contractor training for weatherization installations. The goal of this project is to advance measurable improvements in residential energy efficiency in Florida and other hot-humid regions, resulting in utility bill reductions for low-income households. An additional major goal is to improve adoption of best occupational safety and health practices on weatherization retrofit jobsites. To move toward these goals, the main focus is the development and statewide delivery of consistent, high-quality training to contractors and others directly involved in remodeling homes under the WAP. This includes: 1.) Development of a standardized training curriculum based on DOE WAP materials, but customized to address Florida's hot-humid conditions both in terms of building science issues and occupational safety and health practices on residential retrofit jobsites that can effectively prepare a weatherization workforce for Florida (and the region); 2.) Development of collaborative relationships among relevant educational/training institutions and local weatherization providers in Florida to leverage resources, work more efficiently, and strengthen existing WAP activities; 3.) Establishment of a statewide delivery network for training Florida's WAP contractors and green remodeling jobs market participants; 4.) Establishment of specified certification programs, continuing education credits for training courses, and associated record-keeping systems; and 5.) Formation of a self-funding business model to sustain Florida Weatherization Training Center activities beyond DOE funding.

Energy Efficient and Renewable Energy Retrofits for Multi-family Housing: UF/PREC has leveraged additional energy funds with a new grant from the Florida Energy Office funded by DOE. Partnering with Orlando Utilities Commission, the team will establish a rebate program designed to promote the installation of energy efficient and renewable energy improvements in multi-family housing units. The project targets the Orlando and Saint Cloud areas, and in addition to establishing a rebate program, it will provide a data collection process that will be used to educate and promote the expansion of the rebate program to other service areas. An additional partnership with Accelerated Data Works will provide an online platform for potential renters to see energy costs of apartments in comparison to the community baseline. Apartments represent an energy efficiency market that entails unique barriers, but one that has the potential to produce significant energy savings. This project will document the benefits of a multi-family energy efficiency retrofit program to pave the way for the adoption of similar programs in communities throughout the state. The performance data provided by this project and the resulting program analysis will help to define the parameters of how energy efficient and renewable energy improvements can be successfully implemented in the multi-family housing sector. There are currently no models in Florida for such programs that utilities and local governments can adopt, and this project will fill that gap. The project is in its early stages and the project team has so far been preparing and reviewing the retrofit application and program procedures.

Osceola Energy Initiative: In another example of obtaining leveraged funds, UF/PREC is designing an Energy Efficiency Finance Program (EEFP) for Osceola County. The program is aimed at utility customers at residential, commercial, industrial and institutional locations within Osceola County to reduce their annual energy consumption by implementing upgrades with the greatest return on investment as identified by energy audits and performance evaluations. The intention is to offset the cost of the energy efficiency upgrades in the EEFP by savings on energy bills resulting from reductions in energy consumption. Project activities include training county staff as well as participating homeowners and the contractors who will be doing the retrofit work. The project team is coordinating with the Technical Education Center of Osceola (TECO) on their curriculum to facilitate the ability of graduates of the TECO program to obtain apprenticeships with contractors performing retrofits under the EEFP. The project also includes development of a county-wide web-based mapping tool, which is being developed in partnership with Accelerated Data Works. The tool will utilize a customized user-friendly interface based on an energy tracking platform to give County residents access to a comparative and in-depth look at their energy use. The web-based tool will also provide information to prospective and active program participants, contractors, auditors and other stakeholders about the progress and results of the energy efficiency retrofits through the integration of program performance metrics.

GRU Soil Moisture Sensor (SMS) Pilot Program: Recognizing the energy savings embodied in outdoor water conservation successes, UF/PREC is partnering with Gainesville Regional Utilities to develop a pilot demand side management program based on retrofitting residential landscape irrigation systems with SMS controls. Development of the DSM program involves: establishing community water use baselines, identifying customers who over-irrigate (relative to baselines), providing SMS controller training for irrigation contractors, providing homeowner landscape maintenance training, and creating an incentive based retrofit program for homeowners. UF/PREC has trained homeowners participating in the program and developed educational materials that explain proper use of the installed equipment. Once all installations are completed, water use data of participants will be analyzed in comparison to the overall community water use baseline.

Continuing Education

UF/PREC has completed set up of an online registration and course administration system to be able to provide energy training more efficiently. A webinar on changes to state growth management laws delivered on August 31 was attended by 84 planners and local government staff and served as the first in a series of webinars for planners that will discuss ways to incorporate energy and water efficiency and conservation into local government planning.

The following additional energy-related continuing education classes were offered during the reporting period:

Energy Efficient Building Construction in Florida – (8 hours) Reviews 8 key elements of energy efficient construction and identifies related benefits (economic, IEQ, comfort, durability…). Topics include: Building as a System; Air Leakage-Materials and Techniques; Insulation-Materials and

Techniques; Windows and Doors; Design for Cooling and Heating (HVAC) System Efficiency; Duct Systems for Florida's Hot, Humid Climate; Domestic Water Heating; Appliances and Lighting; and Siting and Passive Design Features.

Greenhouse Gas Reduction and Energy Conservation: Development Impacts Under HB 697 – (6 hours) Explores the implications of HB 697 as a comprehensive planning matter and examines issues and best practices from other states with GHG regulations.

Remodel Green & Profit - (6 hours) Establishes cost-effective measures for determining energy efficient retrofits and techniques for utilizing solar thermal and solar PV systems. Building "weatherization" techniques are addressed as a measure for energy and water retrofitting.

Demonstration House (DH)

The energy-efficient demonstration house in Pinellas County is scheduled to be built on the campus of St. Pete College.

Workforce Development (WD)

Offered the following:
Residential Green Advantage® – (8 hours) Provides an overview of key building features that effect building performance. An overview of appropriate provisions found in the *Florida Building Code* is included. The course addresses the Building as a System and examines building failures due to outdoor and indoor environments through both building design and building construction techniques. An overview of green building certification programs is included, but not limited to, USGBC - LEED for Homes, NAHBA Green Building Standards, DOE/EPA Energy Star and FGBC - Green Homes Standard.

Description of training curricula and the method of delivery for the following courses currently under development:
General WAP Procedure and Building Science Fundamentals; Green Remodeling Certification; and Remodeling Health and Safety Certification
The *General WAP Procedure and Building Science Fundamentals* training will reinforce the DOE Standardized weatherization training curricula: Introduction to Weatherization, Communication Skills, Building Science, and Mobile Home and Multi-Family Basics. A review of the State of Florida Weatherization Assistance Program Procedures and Guidelines will be included. Selected FSEC and UF/PREC building science training materials that address hot-humid building practice will be introduced.

The *Green Remodeling Certification* will be built around the DOE Standardized weatherization training curricula: Blower Door Basics, Pressure and Thermal Boundaries, Materials, Tools & Equipment and Typical Weatherization Measures. The training will review the Florida Weatherization Handbook: Materials, Installation and Workmanship Standards and the Southeastern Field Guide. Energy and Water efficiency will be reinforced using existing UF/PREC and FSEC training materials. The training will combine classroom lecture, hands-on exercises, demonstrations and case studies. The Green Remodeling Certification will be achieved by completing the General WAP Procedure and Building Science Fundamentals training and successfully completing (passing) a Green Remodeling core competency exam.

Remodeling Health and Safety Certification will be built around the Combustion and Worker Safety DOE Standardized curricula topical areas. The certification will reinforce EPA Lead Safe work practices and relevant OSHA Safety Guidelines. The interaction of the building systems and Indoor Environmental

Quality will also be included utilizing existing NIOSH, EPA and UF/PREC teaching materials. The training will combine classroom lecture and hands-on demonstrations, inspections and case studies. Remodeling Health and Safety Certification will be achieved by completing the General WAP Procedure and Building Science Fundamentals training and successfully completing (passing) a Remodeling Health and Safety core competency exam.

Each module will be developed using a combination of UF/PREC, the Banner Center for Construction and FSEC content specialists and each module will include a PowerPoint presentation; participant guide and facilitator training guide at a minimum. Information will be provided in the participant guide to directly supplement materials presented in the PowerPoint presentation. In addition, links to more detailed information will be provided. All programs will include a core competency exam that participants must pass to receive a certificate.

UF/PREC is also partnering with the University of Nebraska (Lincoln) to develop a training curriculum for electrical contractors. The Advanced Building Analyst Training Program for Electrical Contractors will focus on commercial building efficiencies from retrofitting lighting and plug loads. Once developed, the training will be delivered in a 3-day format and will consist of approximately 20 contact hours, which may, in whole or in part, be credited toward continuing education units (CEUs) required for licensure in Nebraska and Florida. UF/PREC is currently developing the curriculum materials, including an Instructor's Manual of presentation materials (e.g. PowerPoint slides) and a comprehensive student workbook/resource guide for each module. Modules will include a list of objectives, skills, requirements (e.g. instructional spaces, equipment, PPE, etc.) and a table of contents. Each module will consist of 'hands-on' demonstrations, exercises and/or activities, delivered through a series of case studies.

Alternatively Fueled Vehicles (AFV)

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

Copyright received on "Annual Community Baselines: A Protocol for Using Metered Consumption Data to Measure and Verify Performance of Residential Energy Efficiency Programs."

Florida Energy Systems Consortium

University of Florida

Secure Energy Systems

PI: Pramod P. Khargonekar
Student: Tejaswini Akunuri (graduated)

Description: The goal of this project is to investigate the concept of secure energy systems and formulate a concrete vision of a broad-based, comprehensive research program. An additional project goal is to develop architecture for modeling, analysis, and design of secure energy systems. An energy system consists of a collection of interconnected subsystems representing energy generation devices, energy consumption devices, transmission, distribution, and storage devices, and communications and computing devices. Such systems are dynamic and its operation is influenced by external perturbations. Definition of the system and it environment depends on the problem of interest. This project is motivated by strong interest among key decision makers in understanding and assuring security of energy systems in the face of various natural and man-made threats. Increasing penetration of renewable energy sources and capabilities offered by smart grid have the potential to enhance or degrade security of energy systems. Thus, these new developments present additional motivation for understanding of secure energy systems. Whereas there is an intuitive understanding of security and assurance, much work remains to be done in formulating precise definitions that cover problems of interest and devising an overall architecture that may facilitate a system level analysis and design of such secure energy systems. Taking into account rapid changes in the energy issues in a wide variety of private and public sectors, this project is a proactive effort to develop a vision and architecture for analysis and design of secure energy systems. It is expected that the results of this project will lead to future development and integration of specific analysis and design algorithms and software that will assist system designers in assessing and ensuring an appropriate level of system security.

The term security can take on different meanings depending upon the context. There are risks associated with intentional disruption of the system (sabotage) and operational risks of the system (whether from physical failure of the plant, human error, or market-based instability). Both can pose short- and long-term national security risks for the electric energy system which consists of the basic elements: generation, transmission, distribution, the load (users); and the control system. These elements are the choke points and can cause great harm by causing outages and moderate-term disabling of important elements in the energy system. We present the security issue by considering the various elements of the energy system one-by-one. At the generation end, we consider the security of the power plant. The attacks on the power plant are mainly physical i.e. the attack on the pipelines which carry the gas or oil (input to the turbine), attacks on the manual valves (which can be opened/closed physically), physical security of a nuclear power plant is in itself a topic which has been extensively researched. Thus we start with the generation system and move onto the transmission system (transmission towers and lines), the distribution system (local transmission lines and substations), and finally the control system which connects all these elements. Network security at the plant level (the connection of the control system and SCADA to the physical components) has also been considered.

Budget: $220K
Universities: UF

Progress Summary

We have focused much of our efforts in two related directions: electric grid and a graphical user interface that can help visualize potential security analysis tools. In electric grid, we have worked on the new issues that arise in the smart grid from the cyber-security perspective. These issues are already central to the future of the electric grid. We have also investigated integration of intermittent renewable energy into the electric grid. This is one of the major goals for the smart grid. A major goal is to understand how renewable electric power can be integrated into the electric grid while maintaining the FERC reliability requirements. With distributed renewable generation and smart grid enabling components, the electric grid becomes much more open to cyber-attacks. Here we are investigating attacks on the SCADA based state estimation by cyber-attacks on the measurement system. We are working on optimal deployment of the new synchrophasors (which will be integrated using the new NASPInet framework) for thwarting attacks on the SCADA system. A paper based on this work will be presented at the 2011 IEEE SmartGridCom. This work is being done in collaboration with colleagues at the University of California at Berkeley and Idaho National Labs. We have also written several papers on secure and reliable integration of renewable electricity production into the grid operations.

We next describe the outline of a graphical user interface which will form the external interface for the analysis system. This will serve as a framework for a tool which will be able to analyze the security situation of the energy system. The graphical user interface will consist of the various threats faced by the energy systems and the analysis of the situation in case of an attack. In the work conducted so far, we have found that there is no document or analysis present which takes a complete look at the energy system as a whole. We are hoping to develop a comprehensive view and research agenda for analysis and design of secure energy systems.

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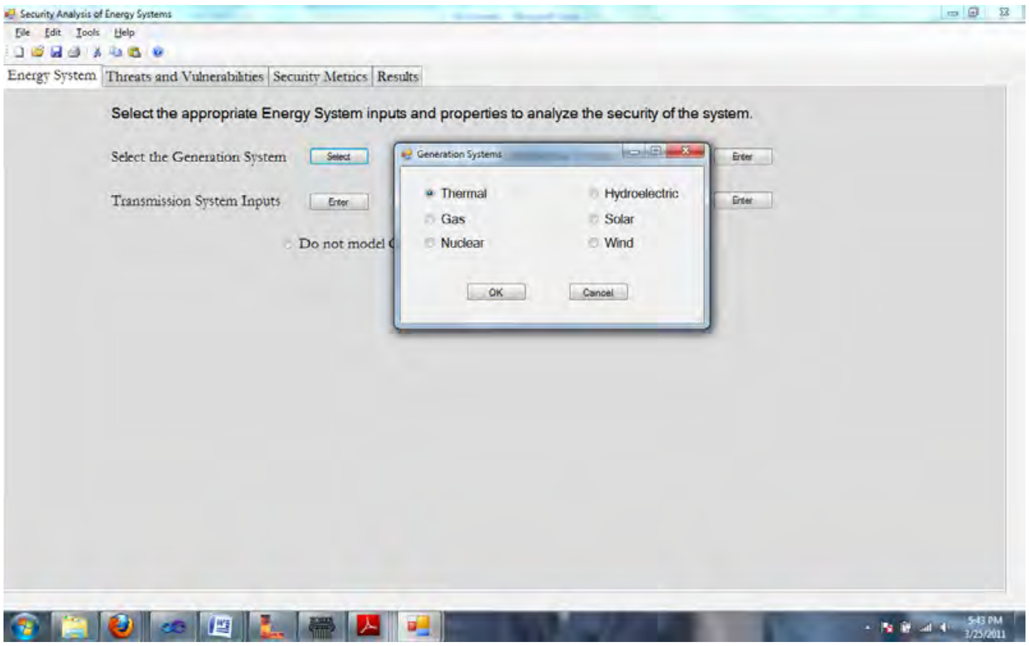
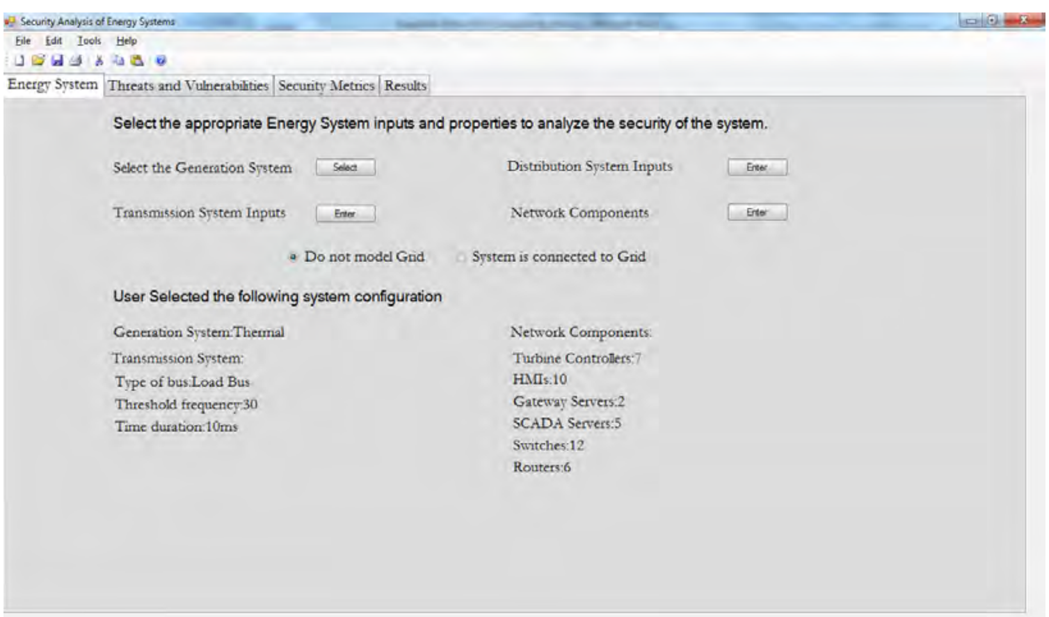
The initial framework for the Security Analysis GUI has been created. The salient features of the GUI include the user's inputs specifying the kind of generation system, transmission and generation system and the network architecture i.e., specifying the control system applications and network switches. The GUI has been created used C# language in Visual Studio 2010 tool. The concept of this framework has been based on the following elements:

- Degree of loss and damage due to the impact of the hazard.
- Degree of exposure to the hazard i.e., the likelihood of being exposed to the hazards of as certain degree and the susceptibility of an element at risk to suffer loss and damages.
- Degree of capacity of resilience i.e., the ability of a system to anticipate, cope with/absorb, resist and recover from the impact of a hazard or disaster. For example, the vulnerability of the electric power system might be assessed in terms of the frequency of major blackouts and the associated severity. A number of approaches can be undertaken for the vulnerability assessment depending on the type of system, the objective of the analysis and the available information.

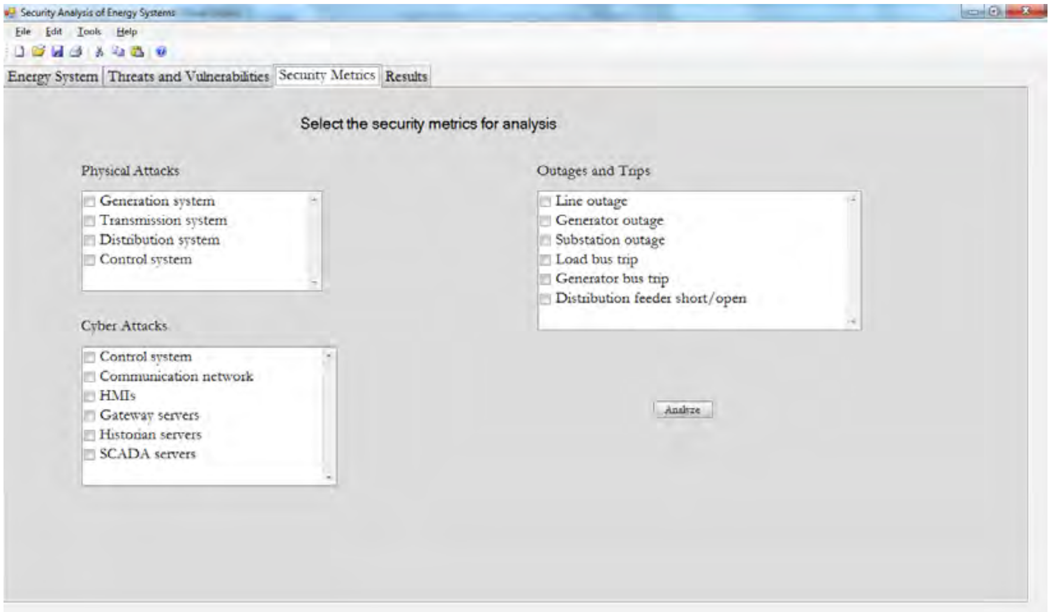
The GUI developed has the functionalities for analyzing the energy system as a complete system, including the generation, transmission, distribution and the control system; the snapshots of the GUI are as follows:

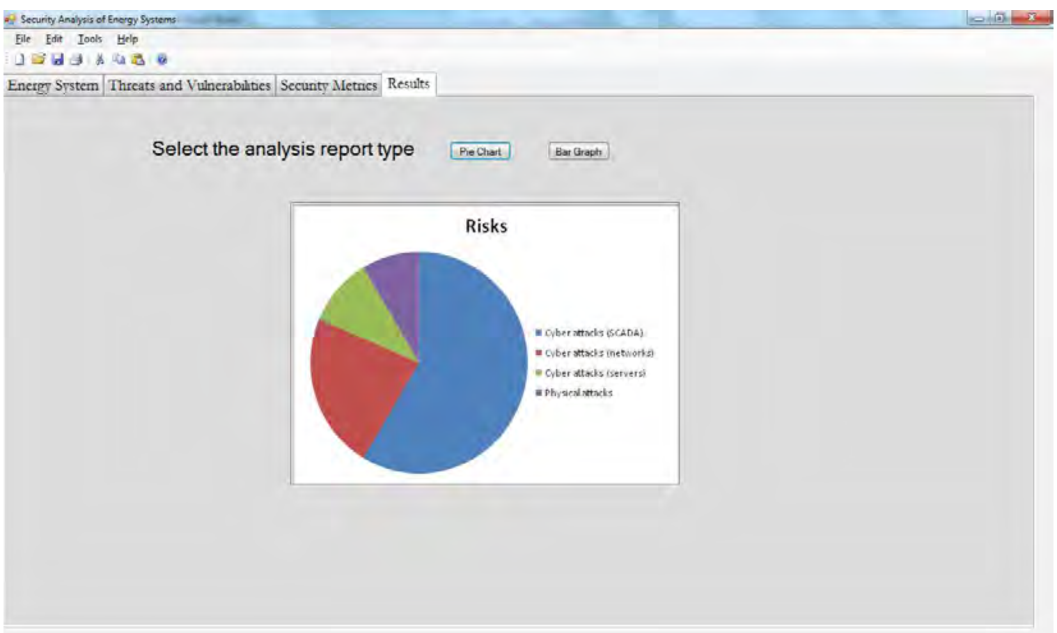


By clicking the Select button, the user can select the type of generation system. This would give the user the ability to analyze the selected energy system. The database at the back-end would contain the elements which are contained in the generation system. Similarly, the user can select the transmission, distribution and control system elements. The inputs are reflected back for the user to review and make changes if needed.



The threats and security metrics for the analysis are then selected and the analysis yields results which can be viewed as a pie chart or a bar graph.





Publications:

E. Bitar, R. Rajagopal, P. P. Khargonekar, K. R. Poolla, and P. Varaiya, “Bringing Wind Energy to Market,” submitted for publication to IEEE Transactions on Power Systems.

E. Bitar, A. Giani, R. Rajagopal, D. Varagnolo, P. P. Khargonekar, K. Poolla, P. P. Varaiya, “Optimal Contracts for Wind Power Producers in Electricity Markets,” Proc. 50th IEEE Conference on Decision and Control, pp. 1919-1926, December 2010.

E. Bitar, R. Rajagopal, P. P. Khargonekar, and K. Poolla, “Optimal Bidding Strategies for Wind Power Producers: the Role of Reserve Margins and Energy Storage,” Proc. American Control Conference, pp. , June 2011.

A. Giani, E. Bitar, M. Garcia, M. McQueen, P. P. Khargonekar, and K. Poolla, “Smart Grid Data Integrity Attacks: Characterizations and Countermeasures,” Proc. IEEE Smart Grid Comm, pp. 2011.

E. Bitar, P. P. Khargonekar, and K. Poolla, “Systems and Control Opportunities in the Integration of Renewable Energy into the Smart Grid,” to appear in the Proc. International Federation of Automatic Control, 2011.

D. Bakken, A. Bose, K. M. Chandy, P. P. Khargonekar, A. Kuh, S. Low, A. von Meier, K. Poolla, P. P. Varaiya, and F. Wu, “GRIP – Grids with Intelligent Periphery: Control Architectures for Grid2050,” Proc. IEEE Smart Grid Comm, pp. 2011

E. Baeyens, E. Bitar, P. P. Khargonekar, K. Poolla, “Wind Energy Aggregation: A Coalitional Game Approach,” Proc. IEEE Conference on Decision and Control, pp. , 2011.

E. Bitar, K. Poolla, P. P. Khargonekar, R. Rajagopal, P. Varaiya, and F. Wu, “Selling Random Wind,” Proc. 2012 Hawaii International Conference on Systems Science.

Funds leveraged/new partnerships created:

Proposals						
Title	Agency		Multi-institution proposal with several universities	Funding Requested (UF portion)		
DIEGO: Distributed Intelligence in Electricity Grid Operations	NSF		I was the UF PI	$300K	Not funded	
GRIP: Grid with Intelligent Periphery	DOE		I was UF-PI	$300K	Not funded	

Grants Awarded					
Title	Agency	Reference Number	PI, Co-investigators and collaborators	Funding received	Project time frame
Collaborative Research: Integrating Random Energy Into the Smart Grid	NSF		Khargonekar Poolla, Varaiya (Berkeley)	$273K	3 years

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 has been completed and ready for construction. 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.

Funds leveraged/new partnerships created

Proposals						
Title	Agency	Reference Number	PI, Co-investigators and collaborators	Funding requested ($)	Project time frame (1 year, 2 years, etc.)	Date submitted
Solar Thermochemical Fuel Production via a Novel Low Pressure, Magnetically Stabilized Bed, Non-Volatile Iron Oxide Looping Process	DOE	DE-FOA-0000471	James Klausner, Jörg Petrasch, David Hahn, Renwei Mei	3,132,639	3 years	18 July 2011

Grants Awarded					
Title	Agency	Reference Number	PI, Co-investigators and collaborators	Period of Performance	Funding awarded ($)
Solar Thermochemical Fuel Production via a Novel Low Pressure, Magnetically Stabilized Bed, Non-Volatile Iron Oxide Looping Process	DOE	DE-FOA-0000471	James Klausner, Jörg Petrasch, David Hahn, Renwei Mei	negotiations ongoing	negotiations ongoing (2’975’920 according to award notice

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This report summarizes the activities related to the investigation of solar thermochemical processes at low pressures carried out in my group during the reporting period (December 2011 through October 2011). The main focus has been the completion of a high flux solar simulator and the design of a low pressure solar thermogravimeter as well as a low pressure dual cavity solar reactor prototype. FESC funding has been successfully leveraged to obtain a 3 million dollar DOE ARPA-E award. Concepts originally devised and demonstrated within this FESC grant will be further persued within the ARPA-E project. I have accepted a position in Europe and will leave UF in December 2011, I have therefore tried to minimize utilization of FESC funds.

Solar simulator

A solar simulator system has been constructed and tested. It provides highly concentrated radiation (5000 kW/m^2) to investigate high temperature solar thermal processes for the production of solar fuels. In particular metal/metal-oxide cycles at low pressures are of interest. The solar simulator provides highly controlled boundary conditions to the experiment.

Figure 1a UF’s High Flux Solar Simulator.

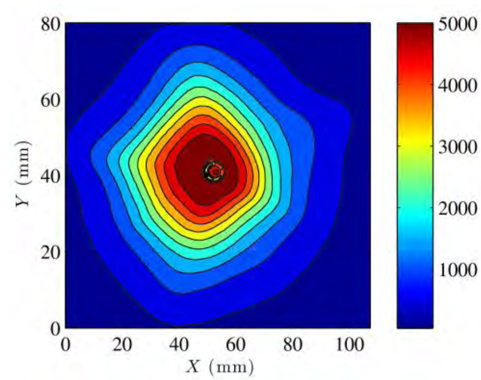

Figure 1b Measured flux distribution in the focal plane in kW/m^2.

Figure 6: The partially assembled solar simulator at UF.

Design and Specifications

The simulator consists of seven, 6 kW Xe-arc lamps, which closely approximate the spectral distribution of the sun. Each lamp is close coupled to an ellipsoidal mirror. All lamp/mirror assemblies focus the light onto a common focal point. The measured peak flux is 5000 kW/m^2. Higher fluxes are possible however have not been demonstrated yet since the flux target's coating quickly degrades at fluxes in excess of 5000 kW/m^2.

Construction

Construction of the simulator has been completed. The simulator comprises:

- An extruded, adjustable aluminum frame,
- Seven, 6 kW lamps close-coupled to elliptical mirrors to focus the radiation,
- Air cooling system to keep the lamp and mirror assembly cool,
- A power rack containing power supply equipment,
- A safety wall with a retractable door (controlled from a separate room),
- A fully controllable and customizable x-y table to mount and position experiments,
- Adequate DAQ systems as required (flux measurement, thermocouples, pressure sensors, etc.)
- Comprehensive, redundant safety systems.

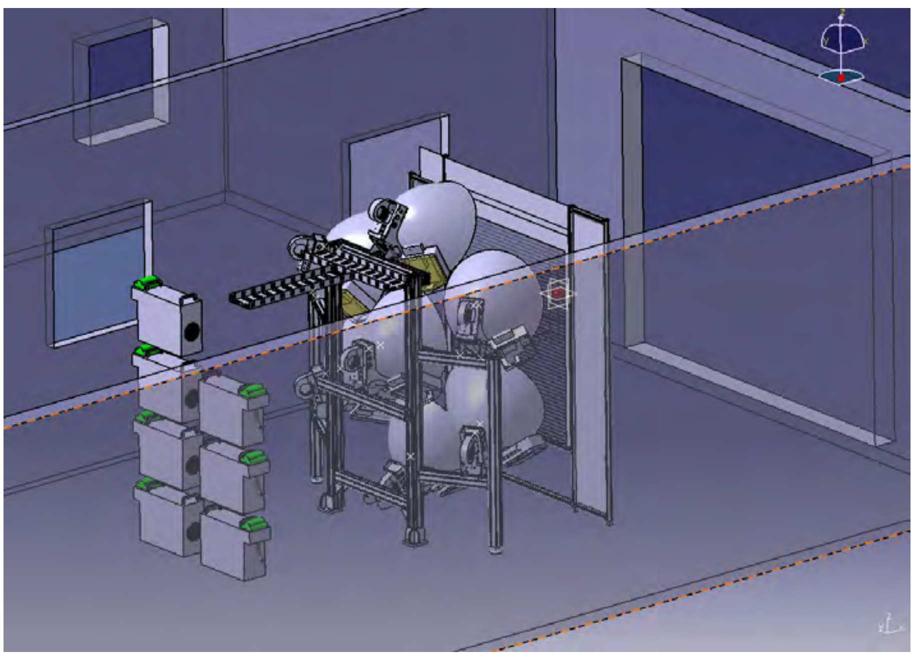

Figure 7 Three dimensional model (rear view) of the solar simulator.

Flux measurement system and Monte Carlo Simulation

In order to characterize the spatial and directional intensity distribution of concentrated radiation in the simulator's target plane, a combination of camera-based flux mapping (figure 3) and Monte Carlo ray tracing simulations is carried out. An in-house Monte Carlo ray-tracing program [1], [2] has been employed for simulating radiative transfer in the UF solar simulator. Monte Carlo calculations will be validated using flux measurements.

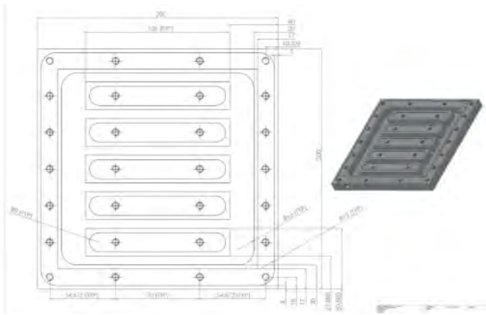

Figure 8 Drawing of Al flux target.

Solar thermogravimeter

The design of a solar thermogravimeter has been completed. Figure 2a shows the conceptual layout. Figure 2 shows an exploded view of the final design. Currently, different manufacturing options are being evaluated and quotes are obtained from manufactures of vacuum equipment.

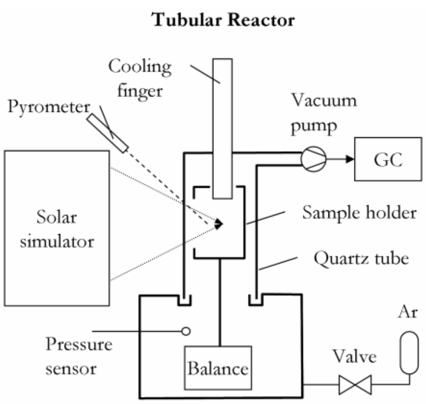

Figure 4a Schematic of low pressure experimental setup.

Figure 4b Solar thermogravimeter design, exploded view.

Low pressure solar reactor

A low pressure dual cavity receiver-reactor has been designed and built (Fig. 3). It consists of two concentric Alumina tubes held together by grooved faceplates. The assembly is currently being tested.

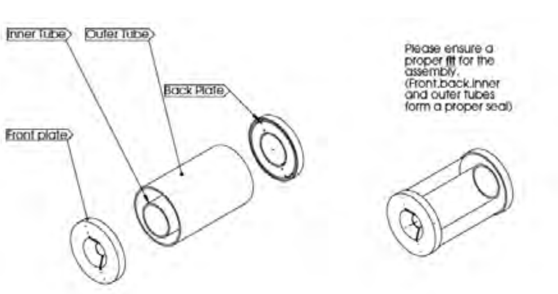

Figure 5a Dual cavity reactor design

Figure 5b Dual cavity reactor prototype

Journal Papers:

[1] A. Singh, F. Al-Raqom, J. Klausner, and J. Petrasch "Hydrogen Production via the Iron/Iron Oxide Looping Cycle", International Journal of Hydrogen Energy, in preparation.

Conference Proceedings:

[1] J. Petrasch, "A free and open source Monte Carlo ray tracing program for concentrating solar energy research," presented at the ASME 4th International Conference for Energy Sustainability, Phoenix, AZ, 2010.

[2] A. Singh, F. Al-Raqom, J. Klausner, and J. Petrasch "Hydrogen Production via the Iron/Iron Oxide Looping Cycle", Proceedings of ASME 2011 5th International Conference on Energy Sustainability & 9th Fuel Cell Science, Engineering and Technology Conference ESFuelCell2011, August 7-10, 2011, Washington, DC, USA

Presentations:

[1] B. Erickson, J. Petrasch"High Flux Solar Simulator for the Investigation of Solar Thermochemical Cycles at Low Pressures", Poster presentation at the Florida Energy Systems Consortium, Summit, Orlando, FL, 2010.

[2] B. Erickson, J. Petrasch "Inverse identification of intensities from multiple flux maps", Poster presentation at the Florida Energy Systems Consortium, Summit, Gainesville, FL, 2011.

References:

[1] J. Petrasch, "A free and open source Monte Carlo ray tracing program for concentrating solar energy research," presented at the ASME 4th International Conference for Energy Sustainability, Phoenix, AZ, 2010.

[2] J. Petrasch and P. Coray, "A free and open source Monte Carlo ray tracing program for surface exchange," *Journal of Solar Energy Engineering*. In preparation

[3] S. Abanades, P. Charvin, G. Flamant, and P. Neveu, "Screening of water-splitting thermochemical cycles potentially attractive for hydrogen production by concentrated solar energy," *Energy*, vol. 31, no. 14, pp. 2805-2822, Nov. 2006.

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[5] C. Perkins and A. W. Weimer, "Likely near-term solar-thermal water splitting technologies," *International Journal of Hydrogen Energy*, vol. 29, no. 15, pp. 1587-1599, Dec. 2004.

[6] A. Steinfeld, P. Kuhn, A. Reller, R. Palumbo, J. Murray, and Y. Tamaura, "Solar-processed metals as clean energy carrier and water-splitters," *International Journal of Hydrogen Energy*, vol. 23, no. 9, pp. 767-774, Sep. 1998.

[7] A. Roine, *HSC Chemistry*. Outotec.

[8] A. Steinfeld and R. Palumbo, "Solar thermochemical process technology," in *Encyclopedia of physical science & technology*, vol. 15, 2001, pp. 237-256.

[9] S. Abanades, P. Charvin, F. Lemont, and G. Flamant, "Novel two-step SnO_2/SnO water-splitting cycle for solar thermochemical production of hydrogen," *International Journal of Hydrogen Energy*, vol. 33, no. 21, pp. 6021–6030, 2008.

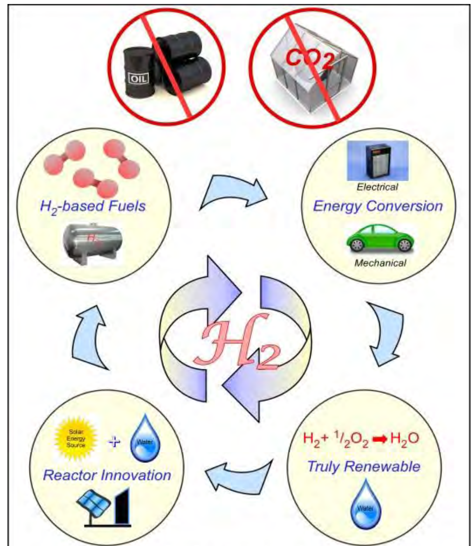
FESC
Florida Energy Systems Consortium

University of Florida

Solar Thermal Power for Bulk Power and Distributed Generation

PI: David W. Hahn **Co-PIs:** James Klausner, Renwei Mei, 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 greenhouse gas emissions, and establishment of a new power industry in Florida.



Carbon-neutral solar-driven hydrogen production

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Budget: $446,000
Universities: UF

Progress Summary

As previously reported the effort has focused on the experimental activity of two thermal reactors for fundamental studies of the reactor processes and surface chemistry for hydrogen production. The first reactor has a monolithic configuration in order to obtain fundamental reaction kinetics for the oxidation and reduction of the metal ferrite. The second reactor design is configured around the concept of a fluidized bed to achieve high efficiency with actual reactors. As of the current date, initial work into the basic mechanisms that represent the oxidation of iron into the iron oxide magnetite (Fe_3O_4) has been completed and investigation into regenerative cycles has commenced.

From the experimental data for iron oxidation in the temperature range of 600K – 850K, the activation energy associated with this hydrogen producing step correlates to the dissociation energy of water molecules on a chemisorption surface. This activation energy is representative of the kinetically limited regime for the oxidation reaction which follows the initial transient induction period. This result is used for initial consideration into the length of reaction for the oxidation step and to help characterize the corresponding regenerating reduction step.

At present, the regenerative cycle approach has been optimized based on experimental data from iron oxidation along with experimental approaches into the cycling process. The length of the oxidation step is intended to last the extent of the transient reaction period but concluded before steady state hydrogen production is reached. Reduction takes place to regenerate the vacancies lost during oxidation. The length of this step aims to correlate to the amount of oxygen adsorbed during hydrogen production.

Additional efforts have focused on understanding of surface reaction processes and the relationships between surface properties and functionality, specifically the comparisons of the properties at the end of the oxidation and reduction steps; and clarifying mechanistic details of the surface reactions.

At present, the fluidized bed rector is complete and has undergone testing and has now been used for extensive experimental investigations under actual hydrogen production conditions. The reactor was constructed about a high-temperature tube furnace to provide uniform process heat. A reduced iron-oxide power was used for assessment of the reactor performance, including assessment of magnetically-assisted fluidization. On-line mass spectrometry was used to quantify hydrogen production over a range of conditions.

Furthermore, preliminary thermo-gravimetric analysis data associated with particle sintering indicated that iron oxide supported on nanoparticle zirconium oxide (n-ZrO_2) and nanoparticle yttria-stabilized zirconium oxide (n-ZrO_2(Y_2O_3) with 8% Y_2O_3) are promising combinations in the two-step water splitting reaction. After being heated to 1500°C both catalysts remained as powders rather than sintering into solid blocks. These catalysts were therefore characterized further to determine the effect of high temperatures on the catalysts.

Finally, computational activities are focused on the fluidized bed, in which critical transport phenomena are being addressed with regard to scaling to larger processes or to solar-driven processes.

Funds leveraged/new partnerships created:

Received 2011 ARPA-E award for $2.975M. James Klausner is PI, D.W. Hahn, R. Mei, and J. Petrasch are co-PIs. Title: Thermal Fuel: Solar Thermochemical Fuel Production via a Novel Low Pressure, Magnetically Stabilized, Non-volatile Iron Oxide Looping Process

2011 Annual Report

Our project efforts to date have focused on direct hydrogen splitting from water in support of our overall mission to conceive, design, and develop advanced reactor technologies that utilize concentrated solar energy and highly reactive materials to produce low cost hydrogen. These activities directly align with the National Academy of Engineering Grand Challenge and published DOE strategic goals.

High temperature thermochemical production of hydrogen that uses concentrated solar radiation for process heat has been suggested as a candidate technology for renewable hydrogen. This process entails a two-step approach where endothermic dissociation of a metal oxide is driven in a solar furnace. The liberated metal (or reduced metal oxide) is mixed with water vapor, and the resulting exothermic reaction liberates hydrogen molecules and re-oxidizes the metal. The metal oxide decomposition requires very high temperatures, on the order of 1500 C. The advantage of the two-step process is that the high-temperature separation of H_2 and O_2 is avoided and no explosive H_2 and O_2 mixtures are formed, since the H_2 and O_2 are formed in different steps. Current technological hurdles to achieving successful hydrogen production are the high operating temperatures needed to achieve reasonable reaction kinetics, cyclic stability of the reactive material, non-uniform transient heating, and recuperation of thermal energy lost through high temperature operation. In order to overcome these technological hurdles, our FESC team has specifically initiated a plan to revolutionize thermochemical reactor design through the development of magnetically fluidized bed reactors. There are many technological advantages to operating such a reactor including, very high reaction surface area to yield rapid kinetics at more moderate operating temperatures (<1000 K), more spatially uniform temperature distribution during transient heating, and substantial control over the fluidization characteristics of the bed using magnetic fields. For the reactor temperature operating regime, the most likely phase transition during the iron oxidation process is a conversion of iron powder to magnetite. Both have excellent magnetic properties and are easily fluidized using electromagnets. Activities for the past year have focused extensively on experimental characterization of key process kinetics and on reactor design, with supporting modeling efforts and fundamental catalysis studies.

Fundamental Kinetics Study

During this reporting period, the thermal reactor that was built and reported on in the previous report was used extensively to finalize our investigation into the reaction kinetics for the oxidation of iron to magnetite. The results from the study have been published in the International Journal of Hydrogen Energy and are illustrated in the figures below. Figure 1 is a schematic of our reactor and can help further visualize the oxidation process. A change that needs to be noted in relation to the reactor conditions that were reported that year corresponds to temperature measurements.

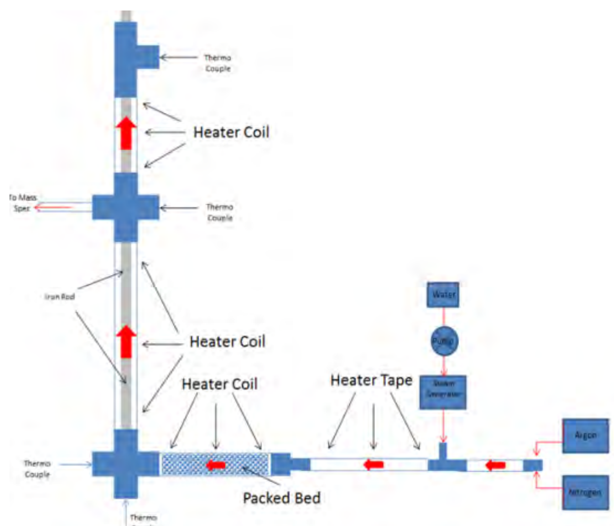


Figure 9: Reactor Schematic

Previously it was mentioned that our reactor operated at four distinct temperatures of 600, 650, 700 and 750k, but these temperatures were in correctly measured and have been reiterated for temperatures of 690, 740, 790 and 840k. The system continued to operate under constant flows of inert nitrogen (100cc/min) and argon (200cc/min) along with an input of vaporized water (~12.5cc/min) for approximately 3 hours. The results of the oxidation experiments can be seen in figure 2 as a relation of hydrogen production rate vs. Temperature and in figure 3 as an effective arrhenius form. What's important to note from figure 2 is not only the increase in production rate as temperature increases but also the effect time has on the production. There are 3 distinct limiting regimes that correlate to production rate and more importantly to oxide production. The first regime occurs in very short intervals (<5 min) and is not identified in figure 2 but can be expressed in the numerical data. This initial oxidation period is very transient and spontaneous in relation to the other regimes and occurs due to lattice vacancies that exist on the surface of the iron. As the surface becomes oxidized, the reaction becomes kinetically limited and the production rate reaches steady state which corresponds to hour 1 in figure 2. As the oxide layer becomes more developed diffusion through the layer to the surface of the iron becomes the limiting affect and the production rate begins to drop which is represented as hour 2 and hour 3. The ideal conditions for the oxidation process exist as a purely kinetic-limited reaction that is attributed to water adsorption. Figure 3 represents the production rate data during 1 hour of oxidation in an effective arrhenius form.

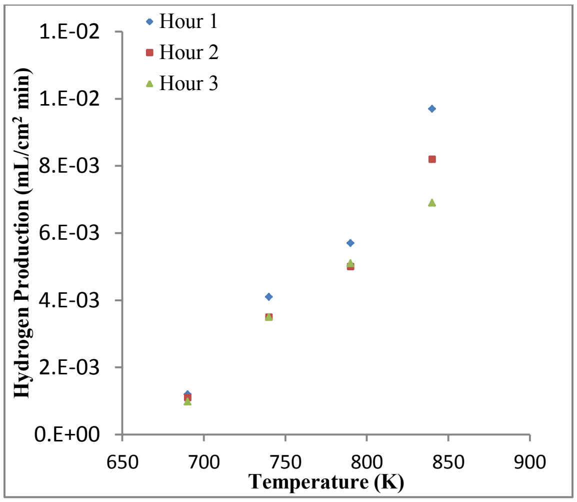


Figure 2: Production Rate vs. Temperature

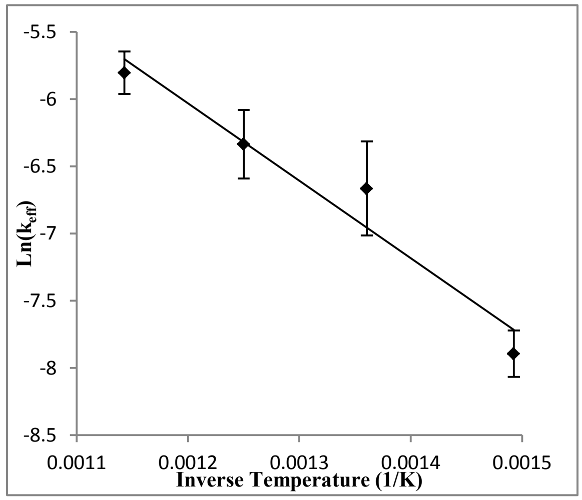


Figure 10: Arrhenius

The activation energy of 50kJ/mol obtained as a result of the linear fit of the Arrhenius equation shows a strong correlation to the dissociation energy of water via chemisorption onto magnetite. This result suggests that the water dissociation step for the oxidation mechanism is the rate limiting step in the kinetic-limited regime. The next step into the investigation of fundamental reaction kinetics focuses on the reduction step and more importantly the coupling of reduction and oxidation reactions into regenerative cycles. Iron oxide samples were formed by oxidizing iron under the conditions stated previously for approximately 45 minutes at 790K. Reduction of the iron oxide was done under the same reactor conditions without the flow of water and by replacing nitrogen with carbon monoxide (100cc/min). Cycling between reduction and oxidation was achieved by first exchanging the supply of nitrogen (MWN2=28) under oxidation with helium to prevent confusion during data acquisition with carbon monoxide (MWCO=28) under reduction conditions. The length of an oxidation step was estimated to correspond to production rates that precede the kinetically-limited regime so as to maximize cycling efficiency. Figure 4 shows multiple oxidation steps that lasted 20 minutes following 1 minute of reduction. The 45 minute oxidation period that preceded the cycling process also is represented in the figure to signify where oxidation should be stopped and reduction commence.

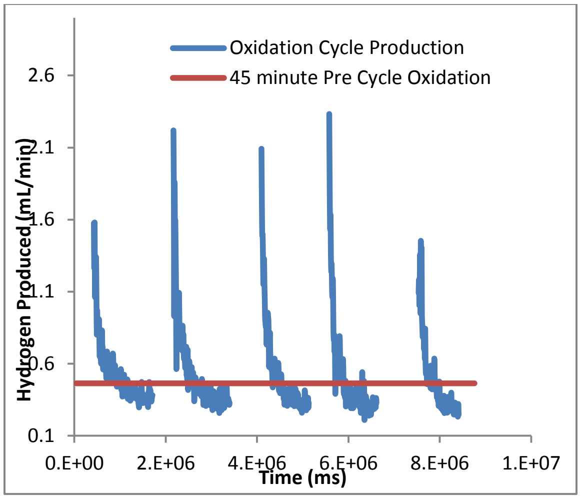
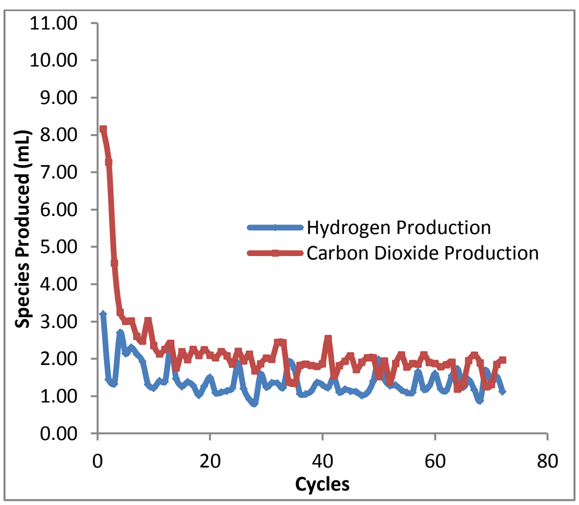
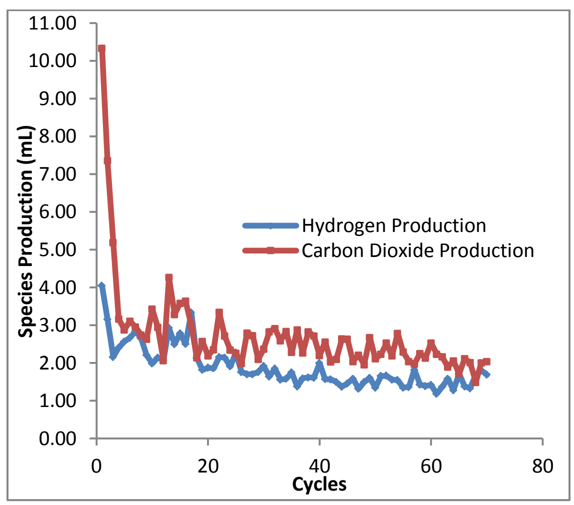


Figure 4: Preliminary Cycling Results

Initial optimization for the cycling process has been estimated for 7 ½ minute cycles for a 75 cycle experiment. Oxidation lasts for about 4 minutes and reduction for 1 minute. Figures 5 and 6 express promising results as future experiments are conducted and further optimization of the cycling process is obtained. Both figures show the amounts of hydrogen produced and carbon dioxide produced for each cycle. Every mole of hydrogen that is formed as a result of oxidation can correlate to a mole of carbon dioxide obtained as a result of reduction. The optimal cycling condition would allow for all lattice vacancies filled during oxidation to be regenerated during reduction. The results in Figures 5 and 6 show carbon dioxide formation at a slightly elevated rate in relation to the amount of hydrogen produced. This may be due to resolution issues within the mass analyzer.





Figures 5 and 6: Species Production For The Oxidation and Reduction Steps.

Another consideration taken into account for cycle optimization is for the reduction and oxidation steps to occur as surface reactions on the oxide layer. This would mean that as water molecules are adsorbed, they do not diffuse through the oxide layer or dissociate under the surface of the oxide. Figure 7 and 8 represent oxygen to iron ratios at different points within the oxide layer. As the oxide layer grows, the ratio of oxygen on the surface should be slightly higher than that at the iron/iron-oxide interface. Figure 7 represents the oxygen ratios after an oxidation and Figure 8 is for post reduction. As you can see under both cases the ratios at the material interface and mid-point of the oxide layer are similar. At the surface however, the reduction shows a lower oxygen ratio. This signifies surface reactions and limited diffusion.

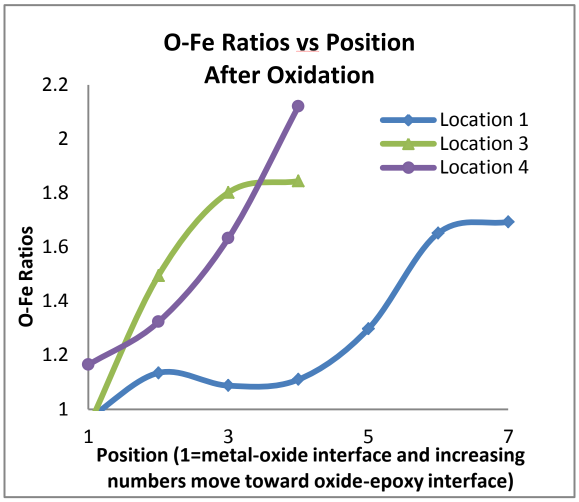


Figure 7: Oxide Ratios after Oxidation.

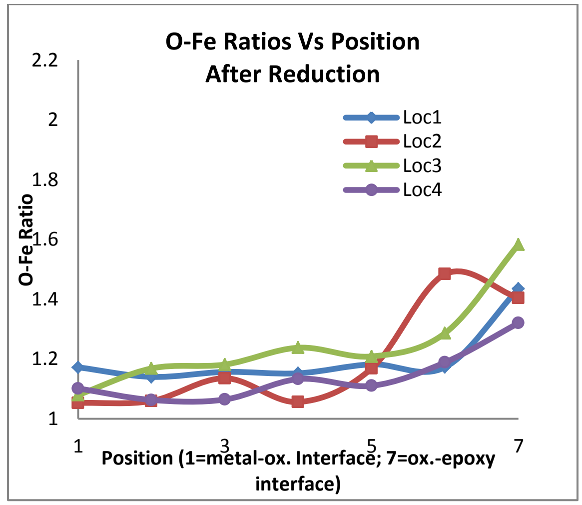


Figure 8: Oxide Ratios sfter Reduction.

As further investigation into the reaction kinetics for the cycling process continues further optimization of the process will be done and repeatable experimental tests will be conducted in order to obtain the fundamental kinetic parameters of the reaction mechanisms. This would include testing different cycling conditions and reconfiguring our mass analyzer. Future work may include identifying and testing alternative reduction techniques.

Fundamental Catalysis Work

X-ray diffraction data was obtained from the two catalysts; 20wt% Fe on n-ZrO_2 and 20wt% Fe on n-$ZrO_2(Y_2O_3)$, after heat treatment at 1500°C for two hours. The XRD patterns obtained from the FeO_x/n-ZrO_2 is presented in Figure 9.

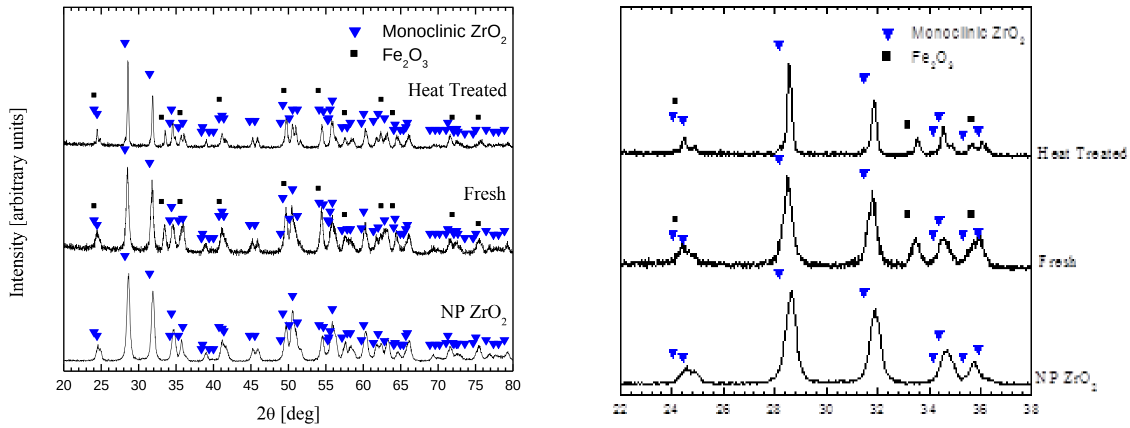


Figure 9: XRD Spectra For 20wt% Iron Deposited On Nanoparticle Zirconium Oxide; (A) Full Range From 2Ө= 20° To 80° And (B) Narrow 2 Ө Range Between 22° And 38° To Reveal Fe2O3 Peaks.

The monoclinic crystal phase of n-ZrO2 is present in all XRD patterns and an increase in ZrO2 particle size is evident in the sharper peaks from the heat treated catalyst. However, the increase in particle size is not as significant as would be expected after a heat treatment at 1500°C. Both the fresh and heat-treated catalysts reveal iron (III) on the surface (Fe2O3). While this suggests that the major iron oxide on both catalysts is Fe2O3, it does not rule out the presence of other oxides or iron metal as they may be below the detection limit of XRD. Particles on the order of 1-2 nm and below are difficult to detect with XRD. The particle sizes for the Fe2O3 on the catalysts were calculated using the peak widths and the Scherrer equation. According to these calculations, the iron oxide particle size increased from 46 nm to 74 nm during the heat treatment. Since a much larger increase in particle size is expected after a heat treatment at 1500°C, this indicates that the n-ZrO2 limits iron oxide particle growth. The XRD patterns obtained from the 20wt% Fe on n-ZrO2 (Y2O3) catalysts before and after heat treatment are presented in Figure 10. The XRD patterns obtained from these catalysts are very different from those obtained from the FeOx/n-ZrO2 catalysts, mainly due to the fact that the ZrO2 is monoclinic in the n-ZrO2-supported catalysts and cubic in the n-ZrO2 (Y2O3)-supported catalysts. The cubic phase has fewer XRD peaks than the monoclinic phase. However, there are other differences between the n-ZrO2- and the n-ZrO2 (Y2O3)-supported catalysts. Compared to the n-ZrO2-supported catalyst, it appears that the ZrO2 particles are significantly larger after heat treatment on the n-ZrO2 (Y2O3)-supported catalyst. Also, the original Fe2O3 peaks are difficult to detect on the heat treated FeOx/n-ZrO2 (Y2O3) catalyst. Instead there is an indication of Fe3O4, i.e. reduction of Fe2O3. It has been noted in literature that iron oxide is incorporated in the lattice of yttria-stabilized zirconia when heated to very high temperatures. This can explain why it is difficult to detect the iron oxide in the XRD patterns obtained from the heat treated FeOx/n-ZrO2 (Y2O3) catalyst. Incorporation of FeOx into the lattice frame work of Y2O3-doped ZrO2 is interesting, if it can minimize sintering of the iron oxide particles.

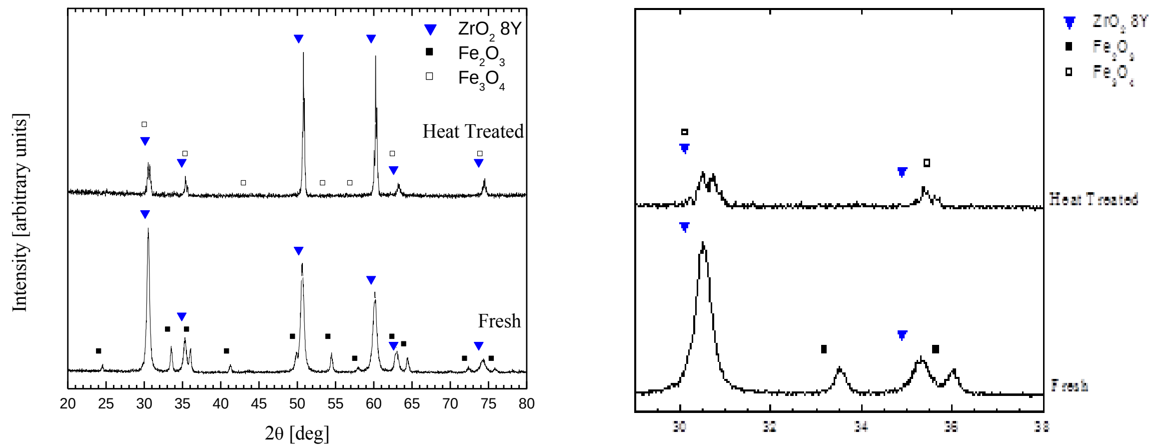


Figure 10: XRD Spectra Obtained From 20wt% Iron Deposited On Yttria-Stabilized Zirconium Oxide; (A) Full Range From 2ϴ= 20° To 80° And (B) Narrow 2ϴ Range Between 28° And 38°.

The design of a reactor system for testing of the catalysts in the two-step water splitting reaction has been completed (Figure 3). The reactor system requires a high temperature furnace to allow reactions at 1500C. This furnace has been ordered and received. We are in the process of building the rest of the system and are looking into purchasing a mass spectrometer (MS) for continuous monitoring of reaction products.

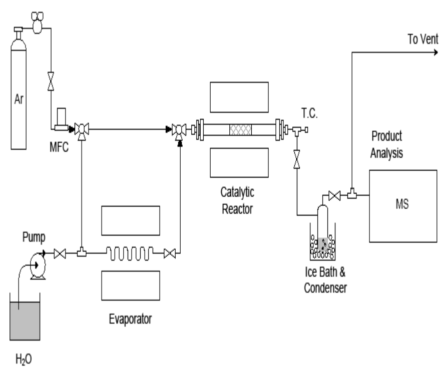


Figure 11: Reactor System Diagram for Both The Oxygen Removal Step And Hydrolysis Step For Two-Step Water-Splitting.

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University of Florida

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

PI: K. T. Shanmugam
Students: Brelan Moritz (Ph. D.); Deepika Awasthi (Ph. D.)

Description: The primary objective of this study is to engineer a thermophilic bacterium *Bacillus coagulans* that grows optimally at 50-55 °C and pH 5.0, the optimum conditions for the activity of commercial fungal cellulases, for cost-effective depolymerization of cellulose to glucose for simultaneous fermentation to ethanol or other commodity chemicals as the sole fermentation product.

Budget: $192,000.00
Universities: UF

Executive Summary

Although various transportation fuels can be produced from lignocellulosic biomass by either a biochemical process using enzymes or microbial biocatalysts or by a thermochemical process, cost-effective production of chemicals, such as optically pure lactic acid, depends on microbial fermentation of sugars. In this study, we focused on developing thermotolerant and acid-tolerant microbial biocatalysts that produce either of the two optical isomers of lactic acid as a fermentation product at high titer and yield in addition to ethanol. Lactic acid is used as an additive in foods, pharmaceuticals and cosmetics as well as an industrial chemical. Optically pure lactic acid (LA) is increasingly used as a renewable, bio-based starting material for plastics to replace petroleum-based plastics. However, current production of lactic acid depends on food-based carbohydrates and in the near future these chemicals need to be derived from non-food carbohydrates, such as cellulose and hemicellulose from lignocellulosic biomass. Use of lignocellulosic biomass as a feedstock requires pretreatment of biomass by both chemicals and cellulases to release the sugars before fermentation to ethanol or lactic acid. The cost of fungal cellulases in this process has been reported to account for about 25% of the overall production cost of ethanol. The use of non-food feedstocks by current commercial microbial biocatalysts is further limited by inefficient pathways for pentose utilization. A fermentation process at 50-55 °C and pH 5.0 by a microbial biocatalyst that can ferment all the sugars in biomass is expected to lower the overall process cost of conversion of biomass to ethanol and/or lactic acid.

B. coagulans strain 36D1 is a thermotolerant bacterium that can grow and efficiently ferment pentoses and all other sugar constituents of lignocellulosic biomass at 50°C and pH 5.0, conditions that also support optimum simultaneous enzymatic saccharification and fermentation (SSF) of cellulose using commercial fungal enzymes. Using this bacterial biocatalyst, high levels (150-180 g/L) of L-lactic acid was produced from xylose and glucose by trapping the lactic acid as calcium salt. In a fed-batch SSF of crystalline cellulose, $CaCO_3$ addition also improved lactic acid production by *B. coagulans* with a yield of near 80% based on a final titer of about 80 g L^{-1}. These results demonstrate that *B. coagulans* can effectively ferment non-food carbohydrates from lignocellulose to L(+)-lactic acid at sufficient concentrations for commercial application.

As a first step towards developing *B. coagulans* as an ethanologenic microbial biocatalyst, activity of the primary fermentation enzyme L-lactate dehydrogenase was removed by mutation (strain Suy27). Strain Suy27 produced ethanol as the main fermentation product from glucose during growth at pH 7.0 (0.33 g ethanol per g glucose fermented). Pyruvate dehydrogenase and alcohol dehydrogenase (ADH) acting in series contributed to about 55% of the ethanol produced by this mutant while pyruvate formate-lyase and ADH were responsible for the remainder. Strain Suy27-13, a derivative of the *ldh* mutant strain Suy27, that produced PDH activity during anaerobic growth at pH 5.0, grew at this pH and also produced ethanol as the fermentation product (0.39 g per g glucose). These results show that construction of an ethanologenic *B. coagulans* requires optimal expression of PDH activity in addition to the removal of the LDH activity to support growth and ethanol production.

Lactic acid based plastics are renewable and biodegradable. L-lactic acid is currently commercially produced from sugars and the plastics produced from L-lactic acid have limited application due to its thermochemical characterisitcs. Appropriate mixture of polylactides containing D- and L- lactic acid derived lactides is expected to expand the applications of these bio-based plastics by improving the thermochemical properties of the mixed polymer. In addition, to move away from food carbohydrates (corn starch, sucrose, etc.), microbial biocatalysts that can cost-effectively ferment all the sugars in lignocellulose to optically pure lactic acid are needed. As stated above, we have demonstrated that *B. coagulans* can produce L-lactic acid at high titer and yield with lower cellulase enzyme loading under appropriate process condition. We have metabolically engineered *B. coagulans* strain P4-102B to produce D(-)-lactic acid. The engineered microbial biocatalyst produced over 80 g/L of D(-)-lactic acid from glucose in about 48 hours. The optical purity of D(-)-LA was close to 100%. Similar titer of D-LA was obtained from fermentation of xylose, a major constituent of hemicellulose. Highest volumetric productivity in SSF of cellulose to D-LA was achieved with about 7.5 FPU of commercial cellulases per g of cellulose. This amount of cellulases is only about 30% of that required for SSF of cellulose to LA by other lactic acid bacteria (*Lactobacillus lactis*).

This study supported by FESC led to the production of a set of thermotolerant microbial biocatalysts that can be used to ferment all the sugars in lignocellulosic biomass to either ethanol as a transportation fuel or to lactic acid for production of renewable and biodegradable plastics. Further development and industrial adaptation of these microbial biocatalysts could lead to sustainable production of these chemicals from Florida-grown biomass as petroleum replacements.

This project has been completed.

University of Florida

UFTR Digital Control System Upgrade for Education and Training of Engineers and Operators

PI: Gabriel Ghita
Faculty Participants: DuWayne Schubring, Kelly Jordan
Students: S. Brown (BS), G. Fekete (BS), A. Holcomb (BS), D. Lago (BS), M. Marzano (MS), J. Musgrave (MS), J. Lewis (MS), G. Bickford (MS)
Staff participants: Matthew Berglund, Brian Shea

Description: The goal of this project is to contribute to a major initiative on design, licensing and construction of a fully digital control system for the University of Florida Training Reactor (UFTR). This makes the UFTR the first operating nuclear power plant in the United States that uses a fully digital control system. This facility will provide for the training and education of the necessary workforce in the area of digital control and instrumentation for nuclear reactors. With this effort, a new focus/certificate on digital control and instrumentation will be developed at the Nuclear and Radiological Engineering (NRE) Department. Further, the UFTR facility will offer training courses for community colleges (Central Florida, Indian River, and Jacksonville) in the State of Florida, personnel from nuclear utilities and government agencies including the Nuclear Regulatory Commission (NRC). The project has already received significant funding from industry and government in form of grants, contracts, equipment/systems, and engineers' time.

Budget: $308,000
Universities: UF
External Collaborators: Several engineers from AREVA NP Inc & Siemens Corporation

Progress Summary

In order to make the UFTR capable of offering training to engineers and operators, it is necessary to receive approval from NRC on reactor relicensing application and on the Licensing Amendment Request (LAR) for the digital control upgrade. Then install and test the new digital system. Thus far, we have been working on:

i) Licensing applications (submitted to NRC)
   a. UFTR Relicensing Application
   b. LAR for digital protection system
ii) Basic Design Documentation (submitted/to be submitted to AREVA)
iii) Application Software Development

i) a. UFTR Relicensing Application

In August, 2011 a NRC team performed an Audit. The first part of the audit, August 1-3, was dedicated to UFTR license renewal. The discussion comprised the current version of the proposed UFTR technical specifications and the draft request for additional information in order to complete the review for the UFTR relicensing.

A new set of RAI is expected from the NRC.

i) b. LAR for the digital protection system

August 3 -5, 2011, the NRC has been conducted an audit of the UFTR application for a license amendment to install a Digital Control System Upgrade.
The intent of the audit was to gain understanding of the project progress and current facility status. In addition, it was identified information required to be docketed in order to support the basis of the licensing decision. The regulatory audit will allow the NRC staff to more efficiently gain insights on the UFTRs software development programs and processes.

An Audit Summery is expected from NRC with recommendation of the approach for completion of the LAR Application.

A paper entitled Implementation of Digital Upgrades to the UFTR Protection and Control Systems was submitted and accepted for presentation at the American Nuclear Society Meeting in Washington DC, in November.

ii) Basic Design Documentation (submitted/to be submitted to AREVA)

We have prepared the documents in support of TXS protection system manufacturing in Germany, as part of the Basic Design Documentation and submitted to AREVA for review.

iii) Application Software Development

We have been working on the *FunBase* and *SPACE* software tools. The former tool was used in support of document preparation, particularly the Software Requirements Specifications, and latter tool is used to prepare network diagrams, and eventually the necessary *object* file for operating the TXS system.
Here, currently we are training ourselves and trying to determine the limitations and capabilities of the two tools.

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- i) Licensing applications (submitted to NRC)
  - a. UFTR Relicensing Application
  - b. LAR for digital protection system
- ii) Basic Design Documentation (submitted/to be submitted to AREVA)
- iii) Application Software Development

i) a. UFTR Relicensing Application

The work was completed in 2010. In August, 2011 a NRC team performed an Audit to the UFTR and has dedicated time for reviewing the license renewal. The discussion comprised the current version of the proposed UFTR technical specifications and the draft request for additional information in order to complete the review for the UFTR relicensing.

A new set of RAI is expected from the NRC.

i) b. LAR for the digital protection system

We are following the following licensing approach for which we have submitted a modified Final Safety Analysis Report (FSAR) based on NUREG 1537 "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," and referenced various documents related to licensing of a digital protection system. Figure 1 below depicts this process:

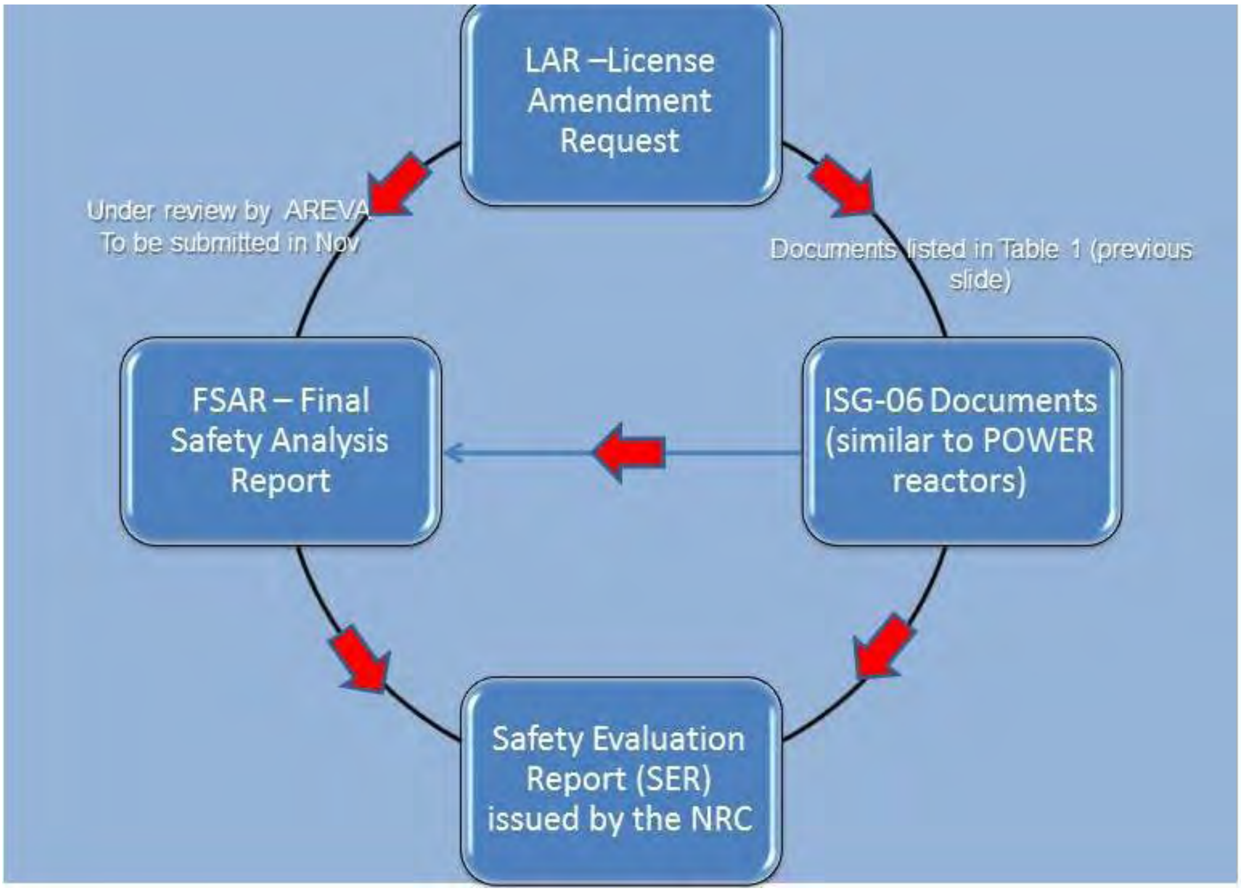

Fig. 1: New licensing process for the UFTR Digital Control upgrade

Up to now, we have prepared the modified FSAR and completed 20 documents from which 17 documents have been submitted to the NRC (Table I).

Table I - List of Documents for the UFTR LAR on Digital Upgrade

#	Document ID	Document Title	Status/Due Date
1	UFTR-QAP	UFTR QA Program	Done
2	UFTR-QAP-01-P	Conduct of Quality Assurance	Done
3	UFTR-QA1-QAPP	Quality Assurance Project Plan (QAPP)	Done
4	UFTR-QA1-01	Software Quality Assurance Plan (SQAP)	Submitted
5	UFTR-QA1-02	Software Configuration Management Plan (SCMP)	Submitted
6	UFTR-QA1-03	Software Verification and Validation Plan (SVVP)	Submitted
7	UFTR-QA1-05	Software Safety Plan (SSP)	Submitted
8	UFTR-QA1-06.1	Software Test Plan – SIVAT Plant	Submitted
9	UFTR-QA1-06.2	Factory Acceptance Test (FAT) Plan	Submitted
10	UFTR-QA1-07	Software Installation Plan	Work in progress
11	UFTR-QA1-08	Software Integration Plan	*
12	UFTR-QA1-09	Software Operations and Maintenance Plan	Submitted
13	UFTR-QA1-10	Software Training Plan	Submitted
14	UFTR-QA1-11	Software Reviews and Audit	Submitted
15	UFTR-QA1-12	System Description	Submitted
16	UFTR-QA1-14	Safety System Design Basis	Submitted
17	UFTR-QA1-100	Functional Requirements Specification (FRS)	Submitted
18	UFTR-QA1-101.1	List of I/O (with the FRS)	Submitted
19	UFTR-QA1-102.1	Software Requirements Specifications (SRS)	AREVA review
20	UFTR-QA1-102.3	ID Coding	Submitted
21	UFTR-QA1-103	Diversity and Defense-in-Depth (D3) Analysis	Submitted
22	UFTR-QA1-105	Teleperm XS Cyber Security	Submitted
23	UFTR-QA1-109	Software Library and Control	Submitted
24	UFTR-QA1-110	Software Generation and Download	Work in progress
25	UFTR-QA1-111	Interface Specification	Work in progress
26	UFTR-QA1-112	HW Requirement Spec (HRS)**	**
27	UFTR-QA1-113	System Architecture.	AREVA review
28	UFTR-QA1-114	QDS Software Requirement Specification (QDS SRS)	Work in progress
29	UFTR-QA1-115	HW Design Solution (HDS)	Work in progress
30	UFTR-QA1-116	Component Arrangement Specification	Work in progress
31	UFTR-QA1-117	Hardware Parameters Listing	Work in progress
32	UFTR-QA1-118	Periodic Test Concept and Operation and Maintenance	Work in progress

*Postponed to the later phase
** Not needed

August 3 -5, 2011, the NRC conducted an audit of the UFTR application for a license amendment to install the Digital Control System Upgrade. The intent of the audit was to gain understanding of the project progress and current facility status. In addition, it was identified information required to be docketed in order to support the basis of the licensing decision.

An Audit Summery is expected from NRC with recommendation of the approach for completion of the LAR Application.

A paper entitled "Implementation of Digital Upgrades to the UFTR Protection and Control Systems" was submitted and accepted for presentation at the ANS Meeting in Washington DC, November 2011.

In November 2010 also, a paper was presented to the ANS Winter Meeting and Nuclear Technology Expo, in Las Vegas, NV: "Digital Upgrade of the UFTR Protection and Control Systems."

ii) Basic Design Documentation (submitted/to be submitted to AREVA)

We have prepared the documents in support of TXS protection system manufacturing in Germany, as part of the Basic Design Documentation and submitted to AREVA for review.

iii) Application Software Development

We have been working on the *FunBase* and *SPACE* software tools. The former tool was used in support of document preparation, particularly the Software Requirements Specifications, and latter tool is used to prepare network diagrams, and eventually the necessary *object* file for operating the TXS system.
Here, currently we are training ourselves and trying to determine the limitations and capabilities of the two tools.

FESC
Florida Energy Systems Consortium

University of Florida

Unifying Home Asset & Operational Ratings: Adaptive Management via Open Data & Participation

PI: Mark Hostetler **Co-PI:** Hal S. Knowles, III
Student: Hal S. Knowles, III (Ph.D. Student, UF School of Natural Resources & Environment)

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 over two years ($12,000 from 01/01/2011 to 12/31/2011 and $12,000 from 01/01/2012 to 12/31/2012)
Universities: 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

Through literature reviews, direct research, industry outreach, networking, and a variety of related channels, this FESC project has helped to inform and been leveraged into multiple proposals and fostered a diversity of potential collaborations and next steps.

Specifically, 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

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

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) 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.

Funds Leveraged/New Partnerships Created:

New collaborations		
Partner name	Title or short description of the collaboration	Funding, if applicable
DwellGreen, Inc.	UF/PREC is in discussion with this potential collaborator on a variety of opportunities for market segmentation, outreach, consumer behavior change campaigns, and measurement and verification of performance results for energy efficiency strategies in the residential sector including the inputs, interactions, and outputs of asset and operational rating systems.	Opportunities under consideration
Simonton & McKinney	Same as above.	Same as above
University of Florida Shimberg Center for Housing Studies	Same as above	Same as above
Well Home (a business of Masco Home Services, Inc.)	Same as above. (*Contact arose as a result of networking at the US DOE Building America National Technical Conference in Denver in August 2011 and via subsequent follow up*)	Same as above
Great Reward, LLC	Same as above. (*Contact arose as a result of networking at the US DOE Building America National Technical Conference in Denver in August 2011 and via subsequent follow up*)	Same as above
The Shelton Group, Inc.	Same as above. (*Contact arose as a result of networking at the US DOE Building America National Technical Conference in Denver in August 2011 and via subsequent follow up*)	Same as above

Partner name	Title or short description of the collaboration	Funding, if applicable
Navigant Consulting, Inc.	Same as above. (*Contact arose as a result of networking at the US DOE Building America National Technical Conference in Denver in August 2011 and via subsequent follow up*)	Same as above
Various local and community banks in Florida	UF/PREC has approached multiple financial institutions for potential collaboration on energy efficient financing programs for building retrofits in the residential and light commercial sectors.	N/A
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

Proposal #1						
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame (1 year, 2 years, etc.)**	**Date submitted**
Gainesville Regional Utilities: On-Bill Energy Efficiency Financing Program Proposal	Gainesville Regional Utilities (Municipally Owned Utility)	N/A (Unsolicited proposal)	PI: Pierce Jones Collaborators: Hal Knowles, Craig Miller, Kathleen Ruppert, Nick Taylor,	$15,000 (UF Subcontract portion on a $80,000 to $135,00 overall proposal)	1 year (Option for annual renewal)	March 25, 2011

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.

Proposal #2						
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame (1 year, 2 years, etc.)**	**Date submitted**
EnergyIT: Home Energy Use Software for Education, Comparison, and Evaluation	U.S. Department of Energy Office of Science	DE-FOA-0000508 CFDA #: 81.049 (FY 2011 SBIR/STTR Phase II Grant Applications)	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

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 crowd sourced data entry pathways such as home energy auditor forms and user-specified behavioral and asset conditions)

FESC Florida Energy Systems Consortium

Proposal #3						
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame (1 year, 2 years, etc.)**	**Date submitted**
University of Florida Integrative Science for Sustainable Resources (ISSR)	National Institute of Standards and Technology (NIST) Construction Grant Program (NCGP)	2011-NIST-NCGP-01 CFDA #: 11.618	PI: James W. Jones Collaborators / Scientific Team: Wendy D. Graham, Pierce Jones, James C. Oliverio, James 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

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 (under the supervision of Collaborator/Scientific Team Member, Dr. Pierce Jones) to the development of this new proposal under the direction of Principal Investigator, Dr. James W. Jones, Director of the Florida Climate Institute. This proposal pursued funding through the National Institute of Standards and Technology (NIST) Construction Grant Program (NCGP) to finance and build an innovative 25,000 gross square foot joint facility housing the Florida Climate Institute, the Water Institute, and the Program for Resource Efficient Communities. Many of the considerations under evaluation and insights being gained on this FESC project were used to inform the development of some features and services envisioned for this space. The following excerpt from the Executive Summary references some of these synergies:

We propose to construct a unique facility to provide an innovative and effective platform to empower solutions for complex environmental issues increasingly facing our nation. The Integrative Science for Sustainable Resources (ISSR) research building will empower the transdisciplinary research necessary to inform complex decisions, policies, and adaptive actions related to climate change and the sustainable management of our country's water, energy, and land resources. Designed to catalyze research that crosses disciplinary and scientific boundaries while integrating knowledge and theory within science and society, the proposed ISSR facility will house three unique and effective collaborative spaces: the Indicator Incubator, the Decision Visualization and Evaluation Theater (D-VET), and the Application Development Laboratory (AppLab).

Strategically, the research conducted in the ISSR facility will mesh historical data with present conditions in ways that will rapidly enable the conceptualization and evaluation of potential alternative futures. Spatially, the ISSR will centralize computational power for large-scale integrated modeling, a state-of-the-art immersive decision theater, and collaborative multi-touch interfaces that allow for simultaneous onsite and remote access to scientifically-accurate models and simulations. Cognitively, the ISSR facility will allow researchers to link observations of natural and human resources with decision and planning support tools using 3D visualization to provide intuitive views into the consequences of resource management choices across variable scales of time and virtual space.

Physically, the facility will be located in the heart of the University of Florida (UF) campus, easily accessible by faculty and students from all of UF's sixteen colleges. Organizationally, our facility will bring together four major interdisciplinary research programs: 1) the Florida Climate Institute; 2) the UF Water Institute; 3) the Program for Efficient Resource Communities; and 4) the Digital Worlds Institute. This intellectual infrastructure will coalesce in a shared physical venue with highly advanced technologies to allow scientists and external organizations to engage in integrated systems research related to climate, hydrology, engineering, land use, development, the built environment, policy, health, and economics. The ISSR's physical location will serve as a high profile destination for researchers from across the state and region, providing a unique opportunity for national and international leadership in research for solutions to the most pressing climate, water, energy, and land use problems faced by society now and in the future. This type of transdisciplinary research, not possible in the absence of such a facility, will lead to greater innovations in research ideas and designs. Also, the infrastructure will facilitate distance interactions with those who otherwise might not have access to integrated resources of this scale.

University of Florida

Water-Use Efficiency and Feedstock Composition of Candidate Bioenergy Grasses in Florida

PI: Lynn E. Sollenberger **Co-PIs:** John Erickson, Joao Vendramini, Robert Gilbert
Students: Jeff Fedenko (M.S.; completed Aug. 2011); Pedro Korndorfer (M.S.; completed December 2010); Xi Liang (Ph.D.; current), Chae-In Na (Ph.D.; current),
Arkorn Soikiew (M.S.; current), Kenneth Woodard (postdoctoral research associate)

Description: Florida ranks first in the USA in annual growth of plant biomass because of a large cultivatable land area, high rainfall, and long growing season. The development of high yielding production systems for energy crops that can be grown in Florida is considered essential for establishment of a sustainable biomass to energy industry. This is the case because long-term availability of sufficient amounts of reasonably priced biomass will be an important determinant of if and where new biofuel and bioenergy facilities will be built. Because of its size and large number of climatic zones, there may be large regional differences in what energy crops can be used at various locations in Florida and how they will perform. In this project, we are conducting applied research at locations throughout Florida with sweet sorghum, sugarcane, energycane, giant reed, miscanthus, erianthus, and elephantgrass to provide important agronomic practice, yield, water use, and chemical composition information for Florida growers, bioenergy producers, and policy makers. This information will support decision making regarding which crops are adapted to specific environments, which are best suited to particular management practices (e.g., irrigation or none), and which have the desired chemical composition for the intended bioenergy use.

Investigators include Dr. Lynn Sollenberger and Dr. John Erickson (agronomists at University of Florida), Dr. Joao Vendramini (agronomist at the Range Cattle Research and Education Center; Ona, FL), and Dr. Robert Gilbert (agronomist at the Everglades Research and Education Center; Belle Glade, FL). The five graduate students mentioned above all started their graduate programs in 2009 or 2010. External collaborators include Speedling, Inc., which provided planting material of miscanthus, and Nutri-Turf, Inc. which provided land for testing perennial grasses.

Budget: $191,981
Universities: UF
External Collaborators: Speedling, Inc.; Nutri-Turf, Inc.

Progress Summary

Miscanthus, giant reed, erianthus, sugarcane, elephantgrass, and energycane are being compared in regional trials throughout Florida. All plots were fully established by early summer 2009. Biomass yield of the grasses was quantified at the end of the growing seasons in December 2009 and 2010 and will be measured in 2011. Yields of elephantgrass, energycane, erianthus, and sugarcane were not different in 2009, but all were greater than giant reed and miscanthus in that year. In 2010, yields were greater for elephantgrass, energycane, and sugarcane at Citra, but erianthus performed better and elephantgrass worse at Ona. Dryer weather at Ona resulted in reduced yields in 2010 vs. 2009. The study will be continued in 2011. Nitrogen and phosphorus removal in plant biomass was greatest for elephantgrass and least for miscanthus. Maximum ethanol production was estimated based on carbohydrate content. This ranged from approximately 330-375 liters/metric ton of giant reed, elephantgrass, energycane and erianthus dry biomass, but was 435 liters/ton for sugarcane bagasse. Data show that elephantgrass, energycane, erianthus, and sugarcane outyield giant reed and miscanthus in biomass and potential ethanol per hectare. Analysis of feedstock composition shows that fiber concentration in dry biomass is similar for all perennial grasses except sugarcane which has much less fiber.

Three varieties of sweet sorghum, Dale (early maturity), Topper 76-6 (medium-late maturity) and M81-E (late maturity) were grown in 2009 and 2010 at the three sites used for the perennial grass trial. Plots were established on three planting dates (PD) in spring (PD1 - 1st week of April, PD2 - 2nd week of May, and PD3 - middle of June) from seed. Each plot was fertilized with a total of 130 kg N/hectare for the plant crop, with part applied at planting and the remainder at three to four weeks after seedling emergence. An additional 65 kg N/hectare was applied to the ratoon crop. The Belle Glade location had the greatest potential ethanol yields from sweet sorghum due to a longer growing season which enabled the ratoon crop to be much more productive. There was no difference between Citra and Ona. Estimated ethanol yield was greatest for the earliest planting date due to greater contribution from the ratoon crop. Topper 76-6 had the highest estimated ethanol yields of the three cultivars because the ratoon crop contribution was greater than for M-81E (Table 7). Our results indicated that sweet sorghum production in Florida can be competitive with corn ethanol yields in the Midwest, but understanding cultivar, environment, and management interactions will be critical to optimizing sugar yields from sweet sorghum in Florida.

Characterization of water use in field plots occurred in sweet sorghum, elephantgrass, energycane, and giant reed during summer of 2009 and 2010 and in the greenhouse in 2010 and 2011. Measures of plant transpiration allow for direct measurement of crop water use under real-world field conditions. These data were then combined with stem density measurements, leaf area index measurements, and/or stem basal diameter measurements to calculate water use by each species. These daily measurements were integrated with climate data (measured at the site) to calculate seasonal water use by each crop. In addition, seasonal crop water use data were coupled with yield and composition data (e.g., biomass, lignocellulose and/or simple sugars) to estimate ethanol produced per unit of water used by the crop. Results from 2009 and 2010 indicate that energycane and elephantgrass produce more biomass per unit of water than does giant reed.

Funds Leveraged/New Partnerships Created:

The Biomass Research & Development Initiative (BRDI), a program funded jointly by the USDA and the U.S. DOE has awarded $5.4 million to the University of Florida for the project "Next-Generation Sweet Sorghums: Sustainable Production of Feedstocks for Fuels, Chemicals and Value-Added Products" led by Associate Professor of Agronomy Dr. Wilfred Vermerris and Assistant Professor Dr. John Erickson, a collaborator on this FESC project. The new project will focus on the development of sweet sorghums adapted to Florida that can be used for the production of fuels and bio-based chemicals from both the sorghum juice and the crushed stems. The aim is to produce and process sweet sorghums sustainably, while generating employment opportunities in rural communities.

Through the current grant, relationships have been developed with Versipia Biofuels, Lykes Brothers, and BP Biofuels. There are several promising areas of collaboration being explored in support of a $400 million biomass conversion facility being constructed in Highlands County, in particular the choice of which feedstocks to plant on the thousands of acres required to support this facility. Building this facility will provide 400-600 construction jobs followed by an estimated 200 permanent jobs.

Collaboration has been developed with Speedling, Inc. which is expanding its bioenergy energy plant propagation business. Dr. Sollenberger is serving as a member of Speedling's Scientific Advisory Board and is interacting with the company regarding propagation models that may be well suited for elephantgrass and energycane.

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Perennial Grass Evaluation

Miscanthus, giant reed, erianthus, sugarcane, elephantgrass, and energycane were compared in regional trials throughout Florida. Biomass yield was quantified in December 2009 and 2010. Yields of elephantgrass, energycane, erianthus, and sugarcane were not different in 2009, but all were greater than giant reed and miscanthus (Table 1). In 2010, yields were greater for elephantgrass, energycane, and sugarcane at Citra, but erianthus performed better and elephantgrass worse at Ona. Dryer weather at Ona resulted in reduced yields in 2010 vs. 2009. The study has been continued in 2011.

Table 1. Dry biomass (ton/hectare per year) yield of six perennial grasses at Citra and Ona locations in Florida.

	Citra			Ona		
Grass	2009	2010	Average	2009	2010	Average
Elephantgrass	35.5	38.9	37.2	31.2	19.8	25.5
Energycane	38.4	40.9	39.7	33.2	27.8	15.5
Erianthus	36.0	31.2	33.6	30.8	28.1	29.5
Giant reed	13.4	29.1	21.3	14.9	16.2	15.6
Miscanthus	10.9	13.8	12.4	9.4	8.0	8.7
Sugarcane	34.8	38.9	36.9	32.9	25.0	29.0

Tissue N and P concentration and removal were determined in 2009 using dry biomass harvested for each species. Tissue N concentration and removal were greater for elephantgrass than most other species (Table 2). Giant reed had comparable tissue N concentration to elephantgrass, but soil N removal by giant reed was much less due to its lower yield. Tissue P concentration was greater for elephantgrass than any other perennial grass in the trial, and this resulted in elephantgrass having greater P removal than any other grass (Table 3).

Table 2. Tissue N concentration, N removal, and apparent N uptake efficiency for six perennial grasses averaged over three locations in Florida during the 2009 growing season.

Perennial Grass Species	Total N Removal (kg/ha)	Tissue N Concentration (%)	Apparent N Uptake Efficiency (%)
Elephantgrass	230 a†	0.71 ab†	82
Energycane	197 ab	0.57 bc	70
Erianthus	161 bc	0.50 c	58
Sugarcane	160 bc	0.49 c	57
Arundo	131 c	0.75 a	47
Miscanthus	48 d	0.46 c	17

†Means within a column not followed by the same lower case letter are different.

Table 3. Tissue P concentration, P removal, and apparent P uptake efficiency for six perennial grasses averaged over three locations in Florida during the 2009 growing season.

Perennial Grass Species	Total P Removal (kg ha^{-1})	Tissue P Concentration (%)	Apparent P Uptake Efficiency (%)
Elephantgrass	50.0 a†	0.149 a	162%
Energycane	32.6 b	0.094 b	106%
Erianthus	34.4 b	0.105 b	112%
Sugarcane	28.9 b	0.090 b	94%
Arundo	15.2 c	0.081 b	49%
Miscanthus	10.4 c	0.099 b	34%

†Means within a column not followed by the same lower case letter are different.

The harvested tissue of the perennial grasses was subjected to fiber analyses in 2009 and 2010. Except for sugarcane, NDF concentration of the perennials was similar in 2009 (Table 4), but in 2010 miscanthus had greatest NDF. Fiber concentration of sugarcane was more than 20 percentage units lower than the other perennials. Lignin concentrations in NDF was also greatest in miscanthus in 2010. At present, it is not certain what magnitude of difference in plant fiber composition has a significant effect on conversion, but differences among these perennials grasses appear to be relatively small.

Table 4. Tissue neutral (NDF) and acid detergent fiber (ADF) concentration and hemicellulose concentration for six perennial grasses during the 2009 and 2010 (next page) growing seasons.

Perennial Grass Species	**%NDF (cellulose, hemi-cellulose and lignin)**	**%ADF (cellulose and lignin)**	**% Hemicellulose**
Elephantgrass	76.7 b†	50.3 a	26.5 b
Energycane	72.6 c	46.8 bc	25.8 c
Erianthus	77.9 ab	49.3 ab	28.6 ab
Sugarcane	51.2 d	30.6 d	21.3 d
Arundo	74.1 c	45.8 c	28.3 c
Miscanthus	79.5 a	48.4 abc	31.1 a

†Means within a column not followed by the same lower case letter are different.

2010	**% NDF**	**% ADF**	**% Lignin**
Miscanthus	81.1 a†	57.8 a	11.9 a
Erianthus	77.1 b	54.3 ab	11.2 a
Elephantgrass	75.6 b	55.9 ab	11.5 a
Arundo	71.8 c	48.0c	9.6 b
Energycane	70.1 c	49.5 c	9.2 b
Sugarcane	50.4 d	32.5 d	5.9 c

†Means within a column not followed by the same lower case letter are different.

Sweet Sorghum Evaluation

Three varieties of sweet sorghum, Dale (early maturity), Topper 76-6 (medium-late maturity) and M81-E (late maturity) were grown in 2009 and 2010 at the three sites used for the perennial grass trial. Sorghum plots were 5-m wide by 6 m in length and included six rows per plot with a 0.76-m row spacing. Plots were established on three planting dates (PD) in spring (PD1 - 1st week of April, PD2 - 2nd week of May, and PD3 - middle of June) from seed. Each plot was fertilized with a total of 130 kg N/hectare for the plant crop, with part applied at planting and the remainder at three to four weeks after seedling emergence. An additional 65 kg N/hectare was applied to the ratoon crop. Plots were irrigated at sign of visual stress (i.e., leaf rolling) by overhead spray irrigation.

A 4-m section of one of the inner two rows in each plot was harvested when at least 50% of the plants were determined to be at soft dough stage (i.e., can easily pinch individual grains between your thumb and fore-finger without 'milk' squirting out of the grain). The total 4-m section was immediately weighed in the field and two subsamples were then collected for brix analysis and determination of plant part biomass. Samples for plant part biomass were placed in an oven and dried at 60°C until constant weight was achieved, and this weight was recorded to estimate dry matter percentage and dry matter yields.

Table 5. The effect of site on plant crop, ratoon crop and total crop fresh biomass yield (FW), brix values, and estimated ethanol yield. Data for plant crop and ratoon crop fresh biomass yield are means across 2 yr, three varieties, three planting dates and four replications (n = 72). All other data are means across 2 yr, three varieties, two planting dates and four replications (n = 48).

	Plant Crop			Ratoon Crop		Total Crop	
Site	FW	Brix	Ethanol	FW	Ethanol	FW	Ethanol
	Mg ha^{-1}	mg g^{-1}	L ha^{-1}	Mg ha^{-1}	L ha^{-1}	Mg ha^{-1}	L ha^{-1}
CIT	70ab†	156b	3670ab	17b	1060b	96b	4981b
ONA	62b	160a	3223b	16b	890b	87b	4306b
BG	78a	129c	3939a	35a	2389a	129a	6637a

† Values within a column not followed by the same letter are different ($P < 0.05$)

The Belle Glade location had the greatest potential ethanol yields from sweet sorghum due to a longer growing season which enabled the ratoon crop to be much more productive (Table 5). There was no difference between Citra and Ona. Estimated ethanol yield was greatest for the earliest planting date due to greater contribution from the ratoon crop (Table 6). Topper 76-6 had the highest estimated ethanol yields of the three cultivars because the ratoon crop contribution was greater than for M-81E (Table 7).

Table 6. The effect of planting date on plant crop, ratoon crop and total crop fresh biomass yield (FW), brix values, and estimated ethanol yield. Data are means across 2 yr, three varieties, three sites and four replications (*n* = 72).

Plant	Plant Crop		Ratoon Crop			Total Crop	
Date	FW	Ethanol	FW	Brix	Ethanol	FW	Ethanol
	Mg ha^{-1}	L ha^{-1}	Mg ha^{-1}	mg g^{-1}	L ha^{-1}	Mg ha^{-1}	L ha^{-1}
PD1	74a†	3770a	38a	143a	1940a	112a	5715a
PD2	76a	3954a	20b	134b	952b	96b	4901b
PD3	60b	3109b	10c	--	--	--	--

† Values within a column not followed by the same letter are different ($P < 0.05$).

Table 7. The effect of variety on plant crop, ratoon crop and total crop fresh biomass yield (FW), brix values, and estimated ethanol yield. Data for plant crop and ratoon crop fresh biomass yield are means across 2 yr, three varieties, three planting dates and four replications (*n* = 72). All other data are means across 2 yr, three varieties, two planting dates and four replications (*n* = 48).

	Plant Crop			Ratoon Crop			Total Crop	
Variety	FW	Brix	Ethanol	FW	Brix	Ethanol	FW	Ethanol
	Mg ha^{-1}	mg g^{-1}	L ha^{-1}	Mg ha^{-1}	mg g^{-1}	L ha^{-1}	Mg ha^{-1}	L ha^{-1}
Dale	60c†	155a	3338b	25a	155a	1623a	94c	5166b
Top 76-6	69b	157a	3757a	22b	153a	1591a	103b	5642a
M-81E	81a	134b	3737a	21b	107b	1125b	115a	5116b

† Values within a column not followed by the same letter are different ($P < 0.05$).

Our results indicated that sweet sorghum production in Florida can be competitive with corn ethanol yields in the Midwest, but understanding cultivar, environment, and management interactions will be critical to optimizing sugar yields from sweet sorghum in Florida.

2011 Refereed Publications:

1. Castillo, M.S., L.E. Sollenberger, J.M.B. Vendramini, K.R. Woodard, G.A. O'Connor, M.L. Silveira, and J.B. Sartain. 2011. Incorporation of municipal biosolids affects organic N mineralization and elephantgrass biomass production. Agron. J. 103:899-905.
2. Erickson, J.E., Z.R. Helsel, K.R. Woodard, J.M.B. Vendramini, Y. Wang, L.E. Sollenberger, and R.A. Gilbert. 2011. Planting date affects biomass and brix of sweet sorghum grown for biofuel across Florida. Agron. J. 103:1827-1833.

3. Erickson, J.E., K.R. Woodard, and L.E. Sollenberger. 2011. Enhancing sweet sorghum production for biofuel in the southeastern US through nitrogen fertilization and top removal. Bioenergy Res. doi:10.1007/s12155-011-9129-3.

2011 Abstracts:

1. Castillo, M.S., L.E. Sollenberger, J.M.B. Vendramini, K.R. Woodard, Y.C. Newman, and G.A. O'Connor. 2011. Management of municipal biosolids as an alternative nutrient source for biomass production. p. 25-26. *In* 3rd Annual Florida Energy Systems Consortium Summit. Gainesville, FL. 27-28 Sept. 2011.
2. Erickson, J.E., L.E. Sollenberger, K.R. Woodard, J.M.B. Vendramini, R.A. Gilbert, and Z.R. Helsel,. 2011. Biomass yield and mineral composition of six potential perennial grass bioenergy crops for the Southeast. *In* ASA/CSSA/SSSA, San Antonio, TX.
3. Fedenko, J.R., J.E. Erickson, L.E. Sollenberger, L.O. Ingram, Z.R. Helsel, K.R. Woodard, J.M.B. Vendramini, and R.A. Gilbert. 2011. Biomass composition and theoretical ethanol potential of six tall grass species grown in Florida. p. 7. *In* 3rd Annual Florida Energy Systems Consortium Summit. Gainesville, FL. 27-28 Sept. 2011
4. Fedenko, J.R., J.E. Erickson, L.E. Sollenberger, K.R. Woodard, R.A. Gilbert, J.M.B. Vendramini, and Z.R. Helsel. 2011. Lignin and fermentable sugars of perennial biofuel crops. *In* ASA/CSSA/SSSA, San Antonio, TX.
5. Na, C., L.E. Sollenberger, J.E. Erickson, and K.R. Woodard. 2011. Seasonal changes in physiological and morphological characteristics of perennial bioenergy grasses in Florida. p. 27. *In* 3rd Annual Florida Energy Systems Consortium Summit. Gainesville, FL. 27-28 Sept. 2011.
6. Na, C., L.E. Sollenberger, J.E. Erickson, K.R. Woodard, M. S. Castillo, M.L.A. Silveira, and J.M.B. Vendramini. 2011. Harvest frequency and timing affect perennial bioenergy grass yield and composition. *In* ASA/CSSA/SSSA, San Antonio, TX.
7. Na, C., L. E. Sollenberger, J.E. Erickson, K.R. Woodard, N.C. Krueger, J.M.B. Vendramini, and M.L.A. Silveira. 2011. Seasonal changes in growth and morphological characteristics of bioenergy grasses in the USA Gulf Coast Region. *In* ASA/CSSA/SSSA, San Antonio, TX.
8. Sollenberger, L.E., K.R. Woodard, J.M.B. Vendramini, C.D. Chase, Y. Lopez, M. Gallo, J. Seib, K.A. Langeland, and H. Gerardo-Cuervo. 2011. Characterization of invasive potential of naturalized populations and cultivated types of elephantgrass, a bioenergy species for Florida. p. 14. *In* 3rd Annual Florida Energy Systems Consortium Summit. Gainesville, FL. 27-28 Sept. 2011.