FESC
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

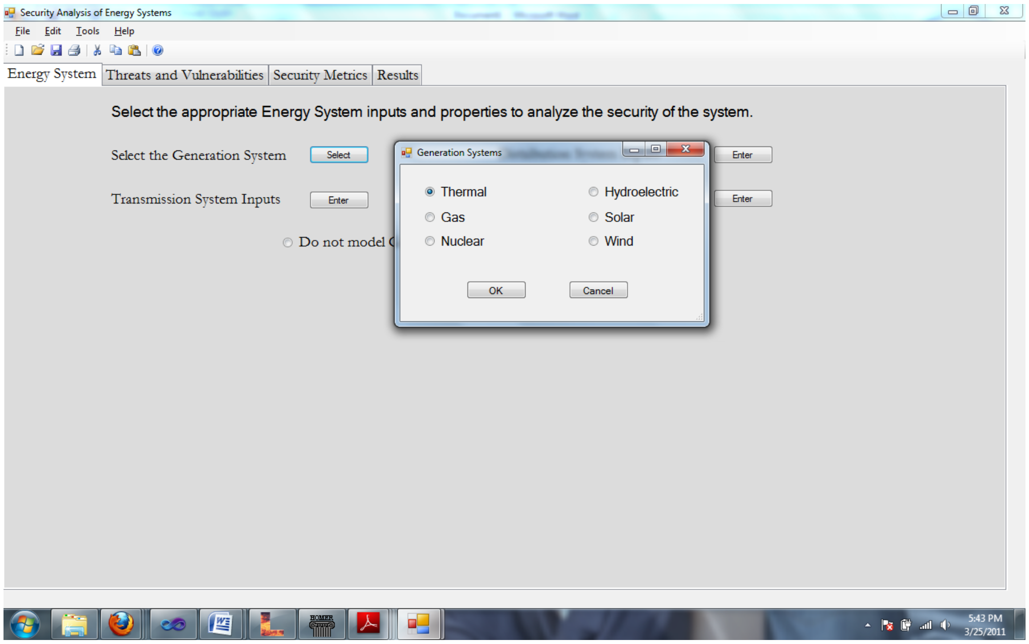
We have focused much of our efforts in two related directions: electric grid and a graphical user interface that can help visualize potential security analysis tools. In electric grid, we have worked on the new issues that arise in the smart grid from the cyber-security perspective. These issues are 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.

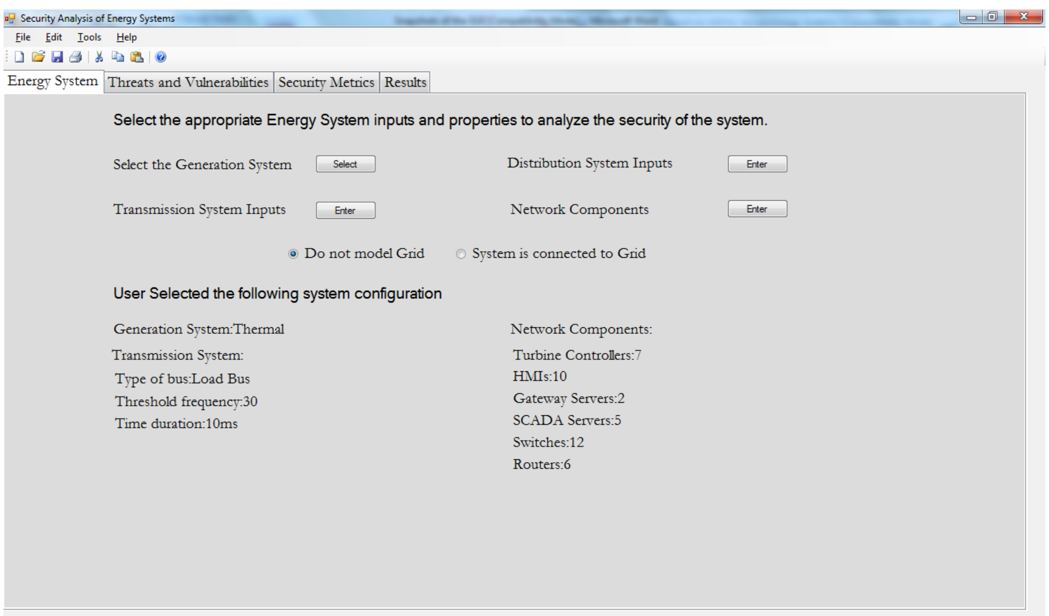
The initial framework for the Security Analysis GUI has been created. The salient features of the GUI include the user's inputs specifying the kind of generation system, transmission and generation system and the network architecture i.e., specifying the control system applications and network switches. 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.

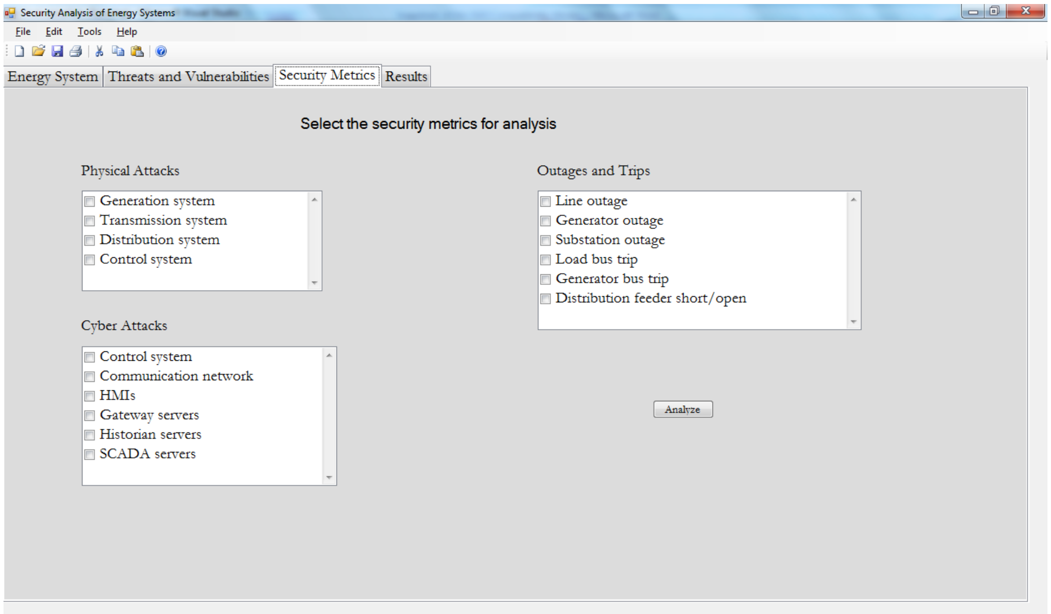
The GUI developed has the functionalities for analyzing the energy system as a complete system, including the generation, transmission, distribution and the control system; the snapshots of the GUI are as follows:

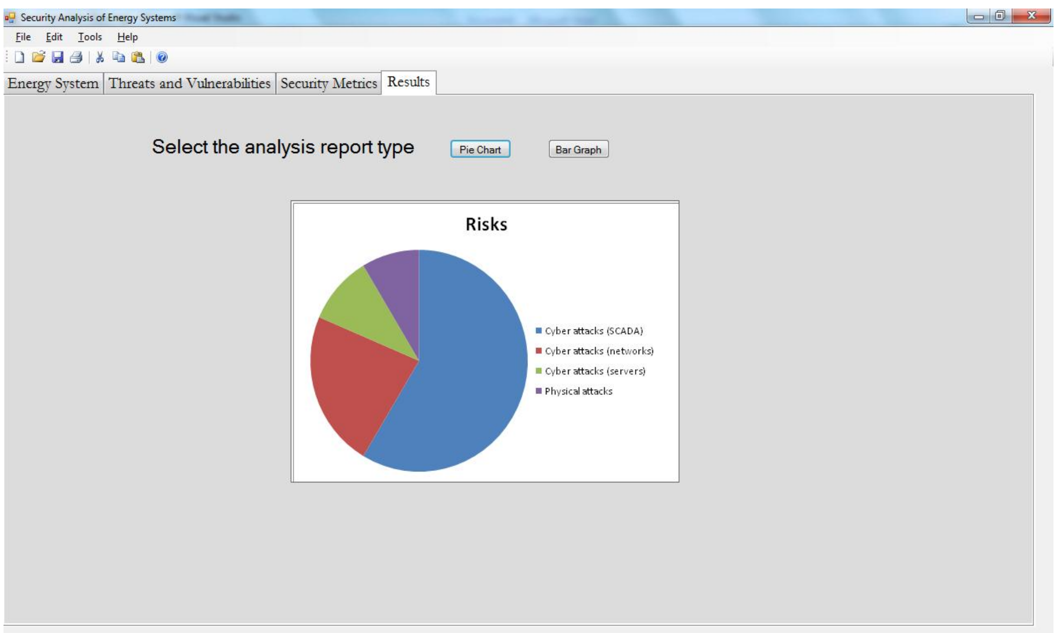


By clicking the Select button, the user can select the type of generation system. This would give the user the ability to analyze the selected energy system. The database at the back-end would contain the elements which are contained in the generation system. Similarly, the user can select the transmission, 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.

E. Bayenes, E. Bitar, P. P. Khargonekar, and K. R. Poolla, "Coalitional Aggregation of Wind Power," submitted for publication to IEEE Transactions on Power Systems.

A. Giani, E. Bitar, M. Garcia, M. McQueen, P. P. Khargonekar, and K. Poolla, "Smart Grid Data Integrity Attacks," submitted for publication to the IEEE Transactions on Smart Grid.

E. Bitar, E. Baeyens, P. P. Khargonekar, K. Poolla, and P. Varaiya, "Optimal Sharing of Quantity Risk for a Coalition of Wind Power Producers Facing Nodal Prices," Proc. 2012 American Control Conference.

A. Subramanian, E. Bitar, P. P. Khargonekar, and K. Poolla, "Market Induced Curtailment of Wind Power," Proc. 2012 IEEE PES General Meeting, 22 - 26 July 2012, San Diego, CA, USA.

Y. Guo, M. Pan, Y. Fang, and P. P. Khargonekar, "Coordinated Energy Scheduling for Residential Households in the Smart Grid," Proc. 2012 IEEE SmartGridComm, pp. , November 2012.

X. Geng and P. P. Khargonekar, "Electric Vehicles as Flexible Loads: Algorithms to Optimize Aggregate Behavior," Proc. 2012 IEEE SmartGridComm, pp. , November 2012.

Funds leveraged/new partnerships created:

Proposals						
Title DIEGO: Distributed Intelligence	Agency NSF		Multi-institution proposal with several universities	Funding Requested (UF portion)	Not funded	

in Electricity Grid Operations GRIP: Grid with Intelligent Periphery	DOE		I was the UF PI I was UF-PI	$300K $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
CPS: Synergy: Collaborative Research: Coordinated Resource Management of Cyber-Physical-Social Power Systems	NSF		Khargonekar Bitar (Cornell) Callaway, Poolla, Varaiya (Berkeley)	$280K	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

Executive Summary

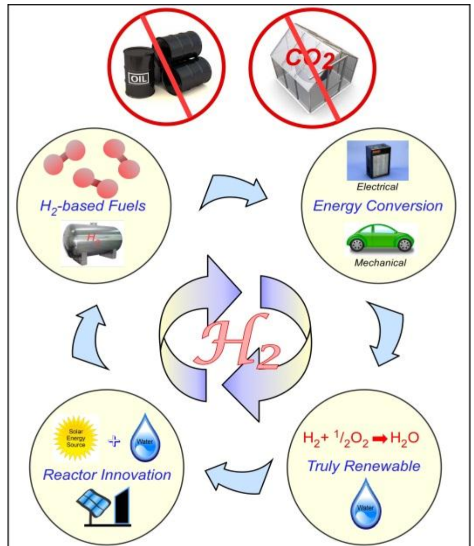
This project has been acquired by David Hahn, and as such, the report has been included in the "***Solar Thermal Power for Bulk Power and Distributed Generation"*** final report.

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. Thrusts include study of the fundamental reaction kinetics, catalysis work, and development of a solar-simulator reactor for scale-up testing under radiative heating.



Carbon-neutral solar-driven hydrogen production

Budget: $446,000
Universities: UF

Executive Summary

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, taking advantage of Florida's sunlight. This process entails a two-step approach where endothermic dissociation of a metal oxide is driven in a solar furnace. 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. 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.

Importantly, the FESC funds have provided very significant leveraging to date, playing a key role in the establishment of a significant high-temperature solar program at UF, with follow-on grants in excess of $4M from the Department of Energy. Current efforts are also underway to provide spin-off commercial ventures.

Fundamental Studies of Reactive Materials

With hydrocarbon fuel prices on the rise, the last decade has seen a renewed emphasis in research of the steam-iron and CO_2-iron process as a method of pure syngas production. This process requires a large surface area of available iron, often in the form of small particles, in order for large quantities of syngas to be produced. However, as high temperatures are involved with the process, sintering of the iron is commonplace, which dramatically decreases the chemically active surface area of the iron after only a few oxidation and reduction cycles.

To cope with this problem, several novel ideas, including the sintering of a fluidized mixture of metal-doped ferrite and buffer particles, has been tried. Rather than combating the natural tendency of the iron particles to agglomerate at high temperatures, sintering is exploited to form a stable, porous structure with buffer (silica, zirconia, etc) particles as segregators to the ferrite particles. Another newly developed idea that has shown promise – which is explained in detail later – includes activated carbon oxidation structure (ACOS) synthesis.

The repeatability of the ACOS formed by cobalt ferrite loaded by different mass percentages (5, 10, 20, 30 and 50%) in an 8 mol% yttria stabilized zirconia matrix (F-YSZ) during oxidation and reduction cycles is examined here using thermogravimetric analysis (TGA). The crystal structure of these different samples is determined via x-ray diffraction (XRD). Microstructural differences are analyzed via scanning electron microscopy (SEM). The synthesis procedure for the ACOS is described in detail. Experimental results demonstrate that the ACOS has good reactivity and can resist particle sintering during the oxidation and reduction steps in the looping process.

Investigation using Mixed Metal Ferrites

Here, a solar-driven, low-pressure thermochemical cycle has been proposed. Common operating temperatures in this type of process can exceed 1400°C. However, wüstite (FeO), the form of iron oxide that would be present after reduction of magnetite (Fe3O4), has a melting temperature of 1377°C. Thus, to push the reactive material melting temperature higher, metal-doped ferrites have been synthesized. As an initial selection, nickel, copper, manganese, zinc and cobalt have been chosen as the metal-dopants. This is based on characteristics of these materials reported in the open literature. For consistency, a 30 percent metal-dopant to 70 percent iron oxide ratio was selected.

From this work, it has been determined that a 10% Co-ferrite in 8YSZ structure better suits CO_2 splitting than the other compounds tested. While the extent of reduction of the sample doesn't exceed that of a 20% or 30% Co-ferrite in 8YSZ sample, the kinetics and the thermal stability of the 10% sample is superior. This has been validated via TGA and SEM analyses. In a separate TGA experiment, the 5% Co-ferrite in 8YSZ sample (used because of the low percentage of reactive material) was taken to 1500 °C and reduced with 120 sccm of Ar for one hour, followed by 1250 °C CO_2-oxidation with 120 sccm for one hour. By converting the mass gain of the 5% Co-ferrite in 8YSZ sample to the stoichiometric equivalent amount of carbon monoxide produced, a peak rate of 0.12 cc/min-g of total material (2.4 g of active ferrite material) of CO produced is obtained. This is four times greater than reported last quarter

(0.03 cc/min-g total material) from the 30% Co-ferrite in 8YSZ sample. A similar test on the 10% Co-ferrite in 8YSZ sample is currently underway and will be reported in the future.

Fundamental Modeling Studies

In order to create a more accurate heat transfer model, the thermal properties including thermal conductivity and interstitial heat transfer coefficient of the magnetically stabilized structure have to be determined. The transient hot wire method is well established as the most accurate, reliable, and robust technique for evaluating the thermal conductivity of fluids and solids. In solids, it has replaced steady state methods primarily because of the difficulty in determining whether steady state conditions have been established. With fluids, it is extremely difficult to prevent natural convection and its consequences on the heat flux. While the application of this method to gases is straightforward, its corresponding application to electrically conducting liquids and solids needs further attention. The iron particles in our structure are electrically conductive. Therefore, we use a thin electrical insulation coating layer to cover the nichrome wire instead of using a bare metallic wire, a technique developed by Nagasaka and Nagashima. It essentially relies on a simple analytical formula derived from the solution of the transient heat conduction from a line heat source embedded in the target medium. This simple and elegant analytical formulation was derived for uniform and homogeneous fluids or solids.

When an external magnetic field of 65 G is applied perpendicular to a hot wire axis, the geometry of iron particles are constrained, such that the thermal conductivity decreased 21% compared to the one without any magnetic field. One reason could be the increase in porosity of the structure upon applying the external magnetic field. This needs further investigation. Continued work will explore the following:

- Investigation of effect of different orientation/flux magnetic field on thermal conductivity of the packed bed reactor.
- Investigation on effect of higher temperature on thermal conductivity of our structure.
- Investigation on effect of higher temperature on thermal conductivity of the sintered pours structure.
- Computing the convective heat transfer coefficient by a similar method and investigation of the influence due to magnetic field presence.

Fundamental Kinetics Studies

The efforts described in detail in our previous reports have continued in order to finalize and conclude the investigation into surface reaction rates and mechanisms for the oxidation process for both hydrogen and syngas production. The recent was on reactor preparation for low pressure application and beginning the investigation into oxygen release rates during thermal reduction.

We have implemented a dual reactor design that allows for one furnace to operate under atmospheric conditions during syngas production and oxygen regeneration. The second furnace operates under atmospheric pressure during the syngas production oxidation step as well but experiences a low pressure environment during the thermal reduction step. Figure 1 is a schematic of the low pressure reactor implemented during both oxidation and reduction steps. During oxidation, liquid water along with inert argon and helium flow through a steam generation system and enters the main reactor furnace where the reactive material is supported. The species are analyzed by the mass spectrometer post reactor and are released to the atmosphere. During reduction, the exhaust gases are passed through a rotary vane pump with an ultimate pressure $2x10^{-3}$ mbar. Upstream of the main reactor furnace, the stream generation system is manually turned off and an inlet of inert argon and helium are supplied that pass through a critical orifice than ranges in diameter from .0004-in. and .0016-in. The critical orifice holds the upstream under atmospheric conditions, while downstream the pump lowers the main reactor pressure. A pressure relief valve is placed between the pump and the mass spectrometer to control the reactor pressure and a second release valve is placed between the critical orifice and the inert gases flow controllers to allow for different flow rates through the critical orifice.

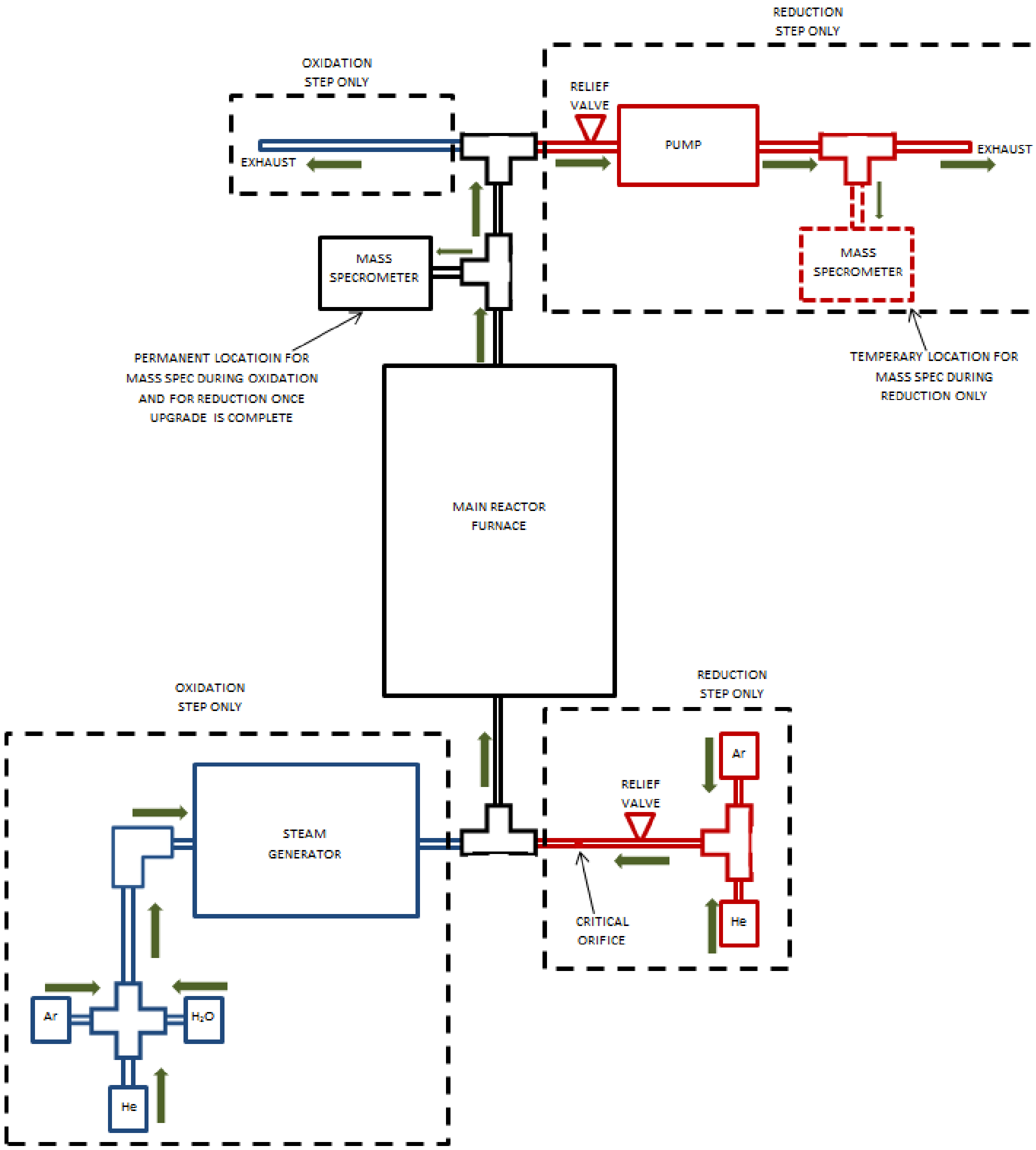


FIGURE 1: Schematic of the Low Pressure Thermal Reactor

Pure iron monoliths are supported within a ½-in. alumina tube inside the reactor furnace during the oxidation step which occurs at 800ºC for 30 minutes in order to control the rate of oxide layer growth so as to limit spallation effects. Once the oxidation step concludes, the steam generator is disconnected and flow through the critical orifice begins. The flow downstream of the orifice has been measured to be 23mL/min for an orifice size of .0004in under an upstream argon flow of 60mL/min and a helium flow of 20mL/min. The flow through the upstream relief valve is 39mL/min, resulting in an upstream back pressure of 43.7 psi. The downstream flow rate of inert gas is best utilized at the lowest possible flow rates in order for appropriate oxygen release measurements. However, the sample speed of the mass spectrometer inlet is on the order of 20mL/min. The 23mL/min flow rate downstream of the orifice is an acceptable minimum at this time and increasing that rate would jeopardize the signal strength of the oxygen production. When the pump is turned on, the downstream relief valve is fully closed to allow for the lowest chamber pressure possible, which levels off after a few minutes around 2mbar based on the current chamber flow conditions. This pressure can be increased by opening the relief valve at controlled steps but at this time the lowest possible chamber pressure is preferred. Studies will continue making use of these unique facilities.

The reaction rate data presented in earlier reports suggested that the amount of hydrogen produced during water splitting is far more dominant when compared to the CO produced from oxidizing iron by CO_2. This result was expected based on thermodynamic favorability of hyrdogen production at temperatures lower than 1000ºC while CO production favors temperatures that exceed 1000ºC. Table 1 shows that hydrogen production was between 6-11 mL/min based on the concentration of the water at 1000ºC, while CO production in Table 2 was between 0.46-1.12mL/min for the same reactor conditions

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Table 1: Hydrogen Produced during Oxidation processes involving 1) steam and 2) a combination of steam and CO_2.

	1) Hydrogen From Steam Oxidation			**2) Hydrogen From Steam and CO_2 Oxidation**		
Steam Flow	**12.5 mL/min**	**25 mL/min**	**50 mL/min**	**12.5 mL/min**	**25 mL/min**	**50 mL/min**
700˚C	0.70	0.90	1.11	-	-	-
800 ˚C	0.76	1.14	1.69	-	-	-
900 ˚C	3.23	4.52	7.27	1.74	3.17	5.97
1000 ˚C	6.77	8.62	11.04	5.06	6.22	8.75
1100 ˚C	-	-	-	15.52	28.68	52.42

Table 2: CO Produced during Oxidation processes involving 1) CO_2 and 2) a combination of steam and CO_2.

	1) CO From CO_2 Oxidation			**2) CO From Syngas Production**		
CO_2 Flow	**12.5 mL/min**	**25 mL/min**	**50 mL/min**	**12.5 mL/min**	**25 mL/min**	**50 mL/min**
700 ˚C	0.27	0.43	0.57	-	-	-
800 ˚C	0.31	0.50	0.68	-	-	-
900 ˚C	0.49	0.68	1.06	0.37	3.76	1.93
1000 ˚C	0.46	0.72	1.12	0.34	0.63	1.22
1100 ˚C	1.04	1.68	2.84	1.88	3.82	5.85

This understanding can be visualized below in Figure 2 where two sets of SEM images are shown that display the produced oxide layer that formed following oxidation steps at 1000 ºC. The left image represents the oxide layer resulting from hydrogen production with the right corresponding to the oxide layer from CO production. The oxide layer in the left image can be seen as the illuminated section with a thickness on the order of 10 microns. In the left image, the slightly more shaded region is the oxide layer which is on the order of 1-2 mircons. Oxide formation was ten times more rapid for hydrogen production based on SEM approximation which is consistent with the quantitative data for species production. This relationship between oxidation processes is expected but the more important question is: how will the reactions take place simulaneously and compete with one another?

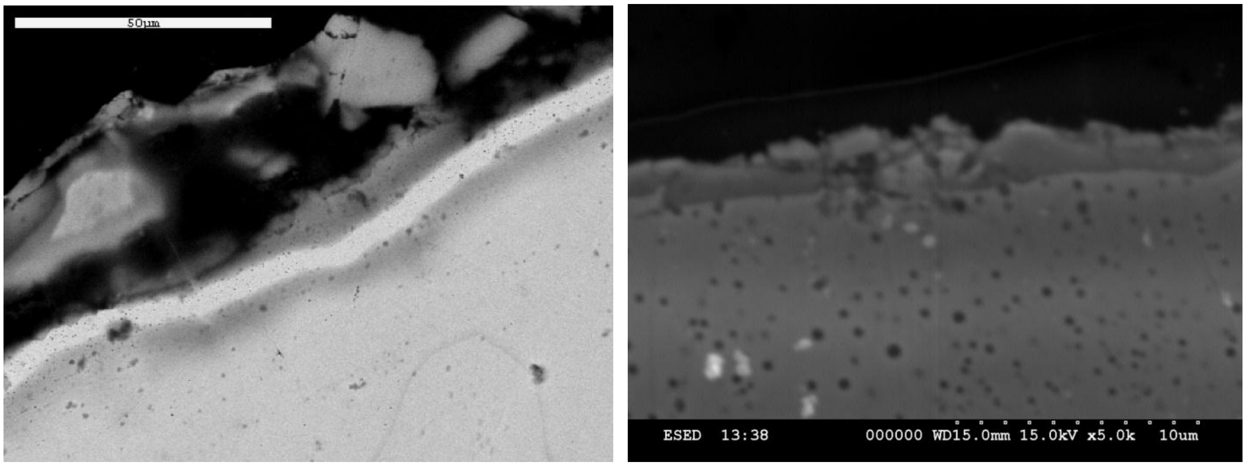

Figure 2: SEM images of produced oxide layers following oxidation processes.

Because of the dominance of the hydrogen production step during syngas production, structural analysis into cyclic hydrogen production is of great interest. A previous study was done where cyclic hydrogen production using CO as a reducing agent was investigated. Pure iron was oxidized based on the previously discussed methods to obtain a stable oxide layer. The iron was then reduced and oxidized in 7 minute cycles in an effort to slightly reduce the outer most surface of the oxide layer and then replenish the oxygen with a short oxidation step. Redox cycles were accomplished that lasted for 25-50 cycles. SEM/EDS analysis was conducted on the resultant samples to provide insight into material stability and oxide states. The EDS data allowed for measurements into oxide ratios throughout the oxide layers that remained after the redox experiments. The experiments ended in reduction or oxidation in alternating fashion to show the differences between each step. A successful water-splitting process using a reactive metal redox cycle must operate efficiently over many (e.g. thousands) of redox cycles. We note in this study and in our previous work that iron oxide, namely Fe_3O_4, is subject to spallation due to structural incompatibilities between the bulk and oxide states, and appears most stable at layer thickness on the order of 5 to 10 microns. Given the equilibrium thermodynamics of the various iron oxide states, combined with the physical morphology and stability of the oxide layers, the ability for total (i.e. complete) stoichiometric reduction will be difficult to achieve in any practical reactor with high surface-to-volume ratios (e.g. fine grain powders) and rapid cycling times. Considerable attention has been given to reactor design for iron-based redox systems, although the role of resulting oxide film structures, as related to oxidation and reduction kinetics, has been somewhat overlooked.

Our efforts in the coming year will be to conclude and finalize the investigation into reaction rate mechanisms for both syngas production and oxygen release reaction steps. The structural analysis will continue on oxidized species and will commence for thermal reduced species in hopes to obtain the surface structure model for the complete redox reaction.

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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. The final report can be found here.

University of Florida

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

(Project was initiated by Dr. Aliriza Haghighat and Dr. Gabriel Shita. Dr. Haghighat left the University of Florida. The project was transferred to Dr. Kelly Jordan. FESC provided an additional $45K as equipment support towards the completion of the project. The new project title is **“Equipment Support for the University of Florida Training Reactor Digital**”)

PI: Kelly Jordan

Original Project 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 +$45,000 new
Universities: UF
External Collaborators: Several engineers from AREVA NP Inc & Siemens Corporation

Progress Summary

The UFTR is implementing the first ever fully digital control and safety system at a nuclear reactor in the United States. This is the key piece in a full renovation of the facility, which has been in operation since 1959. This upgrade will replace the analog system with a digital control system from Siemens Energy. This facility will provide for the training and education of the necessary workforce in the area of digital control and instrumentation for nuclear reactors. The upgrade ensures that the UFTR is on a footing to continue its research and education missions over the next decades.

As nuclear power plants age, analog safety technologies become harder to maintain. Adoption of digital technologies in the nuclear sector has significantly lagged that of other technological industries. Utilities have been slow to implement these systems due to regulatory licensing uncertainty and a lack of internal expertise with new systems. As the previous generation of the nuclear workforce retires, the pool of available expertise in analog technology declines. The experience at Japan’s Fukushima Power Station shows us the need to continually modernize and augment reactor safety and operational systems.

The University of Florida has undertaken an ambitious project to replace its 50-year old protection and control system with a new, modern digital system. This project was conceived in 2008 and initiated in late 2011. All progress on design and implementation has taken place in the latest reporting period.

Once modified, the facility will provide training and education for the future workforce in the area of digital control and instrumentation for nuclear reactors. This effort ushers in a new focus on digital control and instrumentation, and augments the existing Nuclear Engineering Program at UF. Further, the UFTR facility will offer training courses for other educational institutions in the State, as well as training for personnel from nuclear utilities and government agencies, including the Nuclear Regulatory Commission.

The UFTR is upgrading its current analog control and protection systems, last refurbished in 1970, to encompass two independent digital systems, a protection system and a control system, both implemented using the T-3000 hardware from Siemens. This will be a first of its kind fully digital safety-and-control system that will become an operational testing and training platform for these technologies, helping shepherd future commercial nuclear power plants. Adoption and licensing in a training facility paves the way for acceptance in larger power reactors. The wider adoption of this technology further requires a trained base of operators and experts who are familiar with this new technology. The UFTR will be the most advanced training platform in an operating reactor environment. University of Florida students will have an unparalleled exposure to these technologies and an opportunity to graduate ready to help industry pursue and implement the next generation of digital facilities.

This project will contribute to safe operation of existing and future nuclear reactors by providing the means for training and education in the nuclear workforce needed to help the industrial transition to digital technologies. Because of the renewed interest in building new nuclear plants, and plans for life extension of existing plants, the utility industry has become interested in the use of digital safety and control systems. As a result, the Nuclear Regulatory Commission (NRC) has placed renewed effort on establishing new and updated regulation.

Funds leveraged/new partnerships created: We have obtained $167,000 in new federal funding for equipment at the UFTR relating to the upgrade from the Department of Energy. We have also progressed in discussions with Siemens Energy to provide a donation of controls equipment.

Annual Progress Report:

System Design Details: Originally, UF was partnered with AREVA to supply both a reactor protection system and a reactor control system. The control system was to be supplied by subcontract by Siemens. After the dissolution of this agreement, UF approached Siemens about continuing with their portion of the partnership, and assumption of the AREVA deliverables. This was accepted in principle by Siemens management. Therefore the system design concept is based exclusively on Siemens equipment.

There are two important design decisions that are reflected in this concept, namely a choice of independent Control and Shutdown subsystems, and an implementation of an additional analog shutdown system using relay logic. These features reduce the engineering scope of the project by completely eliminating the legacy UFTR control system, and provide us with more control within the regulatory licensing process.

Combined vs. Separated Control and Shutdown systems: Implementing a combined system reduces hardware requirements, as only one application server is required. It is a simpler conceptual design, however, by combining the systems, all inputs, hardware, and software must be treated as a safety system. This implies that we must engineer the entire system to a System Integrity Level 3 (SIL 3, defined in IEEE 1012), imposing substantial engineering overhead on the implementation. Equally important is the preference expressed by the NRC in public meetings for a two, independent system solution. By making the systems independent, we may reduce the scope of software verification and validation (V&V) processes to the shutdown system alone.

Since we have chosen to implement separate shutdown and control systems, network isolation is needed to obtain full regulatory benefit. The entirety of the control system will functions as an analog input into safety system, which will provide complete digital isolation.
This system provides a regulatory hedge against adverse developments in the licensing process due to NRC discomfort with digital systems. It provides a simple, mechanical, fully analog shutdown capability to backstop the digital system. With this system, we retain the option to proceed with an install of the digital system via the 10CFR50.59 process. All safety trip functions would be covered by the analog relay system, rendering the digital system non-safety relevant. Retention of the 10CFR50.59 option is the mechanism for the UFTR to guarantee scheduling.

The reactor will not be recommissioned before install of digital control system. Once the legacy system is removed, we will have reached a point of no return – only with a successful digital upgrade will the reactor be restored. During the duration of the project, the reactor will not be available for operation.

Licensing strategy for the DCP: In November 2011, with the advice of the UFTR Advisory board, and due to feedback from the August 2011 NRC audit, it was decided to change licensing strategy away from power reactor space to research reactor space. This means that the UFTR will no longer pursue industrial-level certifications for the equipment. The equipment will be identical, however the level of QA testing and, for example, seismic qualification will be reduced. This is both a cost-saving measure and will streamline the licensing process with the NRC.

The NRC, up to now, has not had a formal process for licensing digital upgrades in research reactors. New draft regulation – an update to NUREG 1537 – is being written, which will formalize the process for approving these upgrades. The switch to a research reactor licensing strategy combined with better definition of requirements from the regulatory agency will enhance our ability to make these upgrades with confidence that they will be accepted by the NRC.

20-year NRC Relicensing of the UFTR: NRC relicensing, a prerequisite for evaluation of the Digital Controls license amendment, was expected in December 2011. The relicensing has not yet occurred, and is now expected for the mid 2013. Outstanding issues relate to a reworking of the technical specifications for the reactor, a change in the way security procedures are regulated, and analysis of effluent monitoring methodology.

In May 2012, the UFTR was awarded a $180k infrastructure grant for gaseous effluent monitoring equipment from DOE. This money will resolve the licensing issue.

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

1. Annual Progress: Summary from October 1, 2011 through September 30, 2012
   As reported in the 2010/2011 annual progress report, extensive qualitative data were procured via a series of focus groups conducted in February and March, 2011. These data are being transcribed, analyzed, and integrated into a more cohesive research plan and prospective grant proposals. During the 2011/2012 project year, a complementary quantitative data approach has been delineated through literature reviews, research proposal formulation, and preliminary data analysis.

   Collectively, the qualitative and quantitative approaches related to asset and operational ratings for residential buildings have been combined into a dissertation that proposes to investigate the following questions: (1) are homes complex adaptive systems (CAS) as evidenced by nonlinear, scale invariant patterns of energy consumption over time; (2) do nonlinear energy consumption patterns correlate to

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

weather variability; and (3) do individuals and groups differentially perceive of the privacy considerations and usability of conventional home energy consumption feedback displayed in a novel online tool. Research outcomes will suggest alternative methods to evaluate home energy consumption patterns and will inform new narratives to engage utility customers in verbal, written, and graphical forms.

2. Funds Leveraged/New Partnerships Created (This Period)

New collaborations		
Partner name	Title or short description of the collaboration	Funding, if applicable
Building Media, 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
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

Proposal #1						
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame (1 year, 2 years, etc.)**	**Date submitted**
Coming to Cultural Consensus: Residential Utility Bill Transparency, Personal Privacy, and Social Norms	Knight Foundation: Informed & Engaged Communities	News Challenge 2: Data[2]	PI: Hal Knowles Collaborators: Chris McCarty Nick Taylor, Ryan Davis	$160,000	18 months	June 20, 2012

Hal Knowles, Co-PI and the primary supported person on this FESC project was the main University of Florida Program for Resource Efficient Communities (UF/PREC) contributor to the development of this new proposal. UF/PREC proposed the following:

1. What do you propose to do? [20 words]
Study the cultural implications of complete transparency of monthly residential energy consumption data as comparative benchmarks to generate peer pressure.

2. How will your project make data more useful? [50 words]
Technological innovation in geographic information systems, the World Wide Web, computer-assisted data visualization, and utility advanced metering infrastructure are converging within a

[2] http://newschallenge.tumblr.com/

rapidly evolving residential energy efficiency feedback industry. Our project fosters a more democratic dialogue on data sharing and social norm experimentation while finding common ground for privacy protection.

3. How is your project different from what already exists? [30 words]
The primary companies within this industry (e.g., http://opower.com/) currently control comparative feedback via "black box" algorithms. Our tool makes disaggregated usage history visible at the address-scale enabling adaptive, user-defined comparisons.

4. Why will it work? [100 words]
Cultural consensus analysis, a cognitive anthropology method, tests for consistent domains of knowledge within cultures around topics by evaluating degrees of agreement on sets of questions. Our project would apply this method to our existing online tool to improve consistency and consensus on the following questions: (1) what underlying rules govern culturally acceptable social norms on household energy consumption; (2) how can and/or should utility billing data be used to promote energy efficiency via these norms; and (3) who should have access to what data and why?

5. Who is working on it? [100 words]
Acceleration.net and the University of Florida Program for Resource Efficient Communities (UF/PREC) collaborated via a public-private partnership to build the first (and believed to be only) monthly, individual meter disaggregated, open access, online, residential energy consumption mapping and benchmarking platform. This market transformation tool lets "everybody see everybody." Ryan Davis (Acceleration.net, Director of Programming), Nick Taylor, and Hal Knowles (both UF/PREC PhD Students and Faculty), are working with multiple Florida utilities on energy efficiency and conservation benchmarking and consumer visualization with varying degrees of data access as we navigate questions of privacy, social norms, and culture change.

6. What part of the project have you already built? [100 words]
The most transparent online tool (http://gainesville-green.com/) is already built and allows access to monthly electricity, natural gas, and water billing data for all residential addresses in a single North Central Florida utility. A more filtered online tool (http://oei.compareandconserve.com/) is currently in an "alpha" stage of development and allows more constrained access to electricity billing data for two Central Florida utilities. Collectively, these tools offer an existing path to both conduct our proposed research, as well as, to apply our findings through user interface refinements including, but not limited to, data sharing rule determination, social norm self-organization, and comparison network delineation.

7. How would you use News Challenge funds? [50 words]
With these funds, Dr. Chris McCarty (UF, Director of the Bureau of Business and Economic Research), Ryan Davis, Hal Knowles, and Nick Taylor would: (1) develop add-ons to the online tools; (2) conduct cultural consensus analysis via these add-ons; and (3) democratically share findings of social norm form and function.

8. How would you sustain the project after the funding expires? [50 words]
These online tools would be sustained through a TBD mix of utility conservation program budgets, advertising revenue, premium content fees, and/or other funding sources. Additionally, our project findings would be openly shared and expected to alter the future course of technologies and industries leveraging data on household lifestyles.

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, Lonnie Ingram
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.

Executive Summary

Project-related work began in Summer 2009. Miscanthus, giant reed, erianthus, sugarcane, elephantgrass, and energycane were compared in regional trials throughout Florida. Locations included North (Citra), South Central (Ona) and South (Belle Glade). Biomass yield of the grasses was quantified at the end of the growing seasons in December 2009, 2010, and 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 and 2011, 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 2011 and 2010 vs. 2009. 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/dry metric ton of giant reed, elephantgrass, energycane and erianthus, 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.

Project funds were leveraged to acquire additional grant support. 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.

The USDA-AFRI Sustainable Bioenergy Research-Land Use Change program has awarded $499,842 to the University of Florida for the project "Direct Effects of Converting Conventional Agroecosystems to Bioenergy Cropping Systems on Carbon, Water, and Nutrient Cycling in the Southeastern U.S.A." The project is led by FESC collaborators Dr. J.E. Erickson and Dr. L.E. Sollenberger along with co-PDs, Dr. M.L.A. Silveira and Dr. L. Ingram.

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.

This Project has been completed, the final report can be found here.