FESC
Florida Energy Systems Consortium

University of Florida

Energy Intensive Crop Development

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Students: Alejandro Riveros-Walker, (Ph.D.), Jianxing Zhang, (Ph.D.), Patricio Munoz (Ph.D.)

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

Budget: $240,000
Universities: UF
External Collaborators: N/A

Progress Summary

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

Progress Made toward Objectives During Reporting Period: Objective 1: Genetic analysis of wood chemical composition is limited by the cost and throughput of direct analytical methods. Indirect methods such as Fourier transform near infrared (FT-NIR) offer an alternative for rapid, low cost method. In FT-NIR, calibration models and their predictions are typically developed and validated from small sample sets. These models are subsequently used to estimate wood chemical composition from larger sets of new samples. However, no direct comparison of direct and indirect estimates of wood chemical composition and the genetic parameter estimates have been reported for the same population. Here we compared for a single poplar family genetic parameter estimates obtained for wood chemical composition with data from pyrolysis molecular beam mass spectrometry (pyMBMS) and FT-NIR. Over 1500 young greenhouse grown wood samples were analyzed for chemical composition with pyMBMS. Randomly selected sample sets of 150, 250, 500 and 750 were used to build a Fourier transform near infrared (FT-NIR) calibration and validate a model based on partial least squares for lignin, G-lignin, S-lignin, S/G ratio and sugars (C5 and C6). The coefficient of determination (R^2) for the calibrations increased slightly, up to 500 samples. For 500 samples, the coefficient of determination (R^2) for the calibrations ranged from 0.56 to 0.87, and the prediction model R^2 ranged from 0.37 to 0.81. Stronger calibration and prediction statistics were obtained with lignin compared with carbohydrates, with the best prediction being R^2 = 0.81 for total

lignin. For carbohydrates, the strongest prediction statistics (R^2 = 0.70) were obtained for the m/z 144 ion which comes from cellulose. Comparison of genetic parameters showed that all heritabilities were lower for FT-NIR predictions but genetic correlations were similar for two-thirds of the traits, and 10 more quantitative trait loci (QTL) were mapped with pyMBMS. This analysis shows that larger sample sizes make better FT-NIR predictions for the chemical composition of unknown samples.

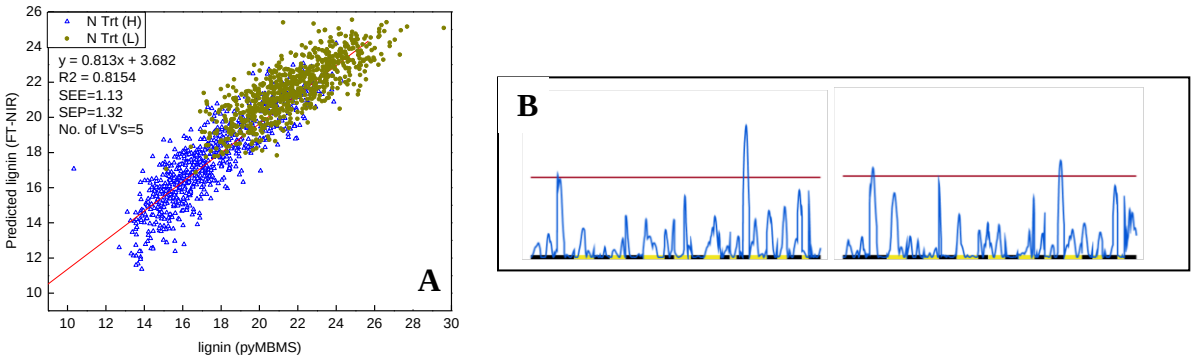

Figure 1: A) Comparison of total lignin content of 1500 poplar wood samples using FT-NIR spectra and py-MBMS. B) Comparison of QTL for lignin from py-MBMS (left) and FT-NIR (right).

Objective 2: In 2009, field plantings were established in central Florida with half-sib seedlings and the four locally adapted UF-IFAS *Eucalyptus grandis* cultivars and in north Florida with half-sib seedlings and clones of *Eucalyptus amplifolia* cultivar. The north Florida planting is about 16 acres and was put in by Buckeye Cellulose. The central Florida planting was about 3 acres and was put in by Mosaic Corp. Height and diameter measurements and biomass samples were taken this fall and will provide the data for growth and yield estimates.

Funds leveraged/new partnerships created:
A new $6.3 million project funded by ARPA-E, "Commercial Production of Terpene Biofuels in Pine" was obtained. This project includes new partnerships with the University of California Berkeley and DOE's Joint BioEnergy Institute, as well as with National Renewable Energy Lab and ArborGen, LLC.

A new alliance is being created to establish a collaborative breeding program for Eucalyptus in Florida and the southeastern US. This program leverages past breeding efforts and growth studies done with FESC. We have obtained substantial interest from the following companies in joining the alliance: ArborGen, Buckeye Cellulose, Foley Timber and Land, Florida Crystals, DeForsa, Evans Property, International Forest Company, International Paper, International Wood Fuels, Lykes Ranch, MeadWestvaco, Rayonier, Rotation Renewables, Rucks Nursery and Weyerhaeuser. We expect this alliance to begin in the summer of 2012. The breeding effort will focus on developing fast growing, disease resistant and cold hardy Eucalyptus hybrids for central and north Florida.

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Biomass to Energy:
Dedicated energy crops are ones that 1) have high yields with minimum energy inputs in terms of agronomic practices, water and nutrient applications, 2) can be harvested, transported and processed efficiently into fuel or power, and 3) can be grown sustainably for generations without adverse environmental affects, or significantly impacting the food supply.

For woody crops a broad number of conversion routes to bioenergy are possible and include, wood pellets, co-firing of chips and coal, and biomass combustion for heat, steam and power production, and production of biofuels, such as ethanol or longer chain hydrocarbons, via a number of different conversion technologies. In Florida, wood pellets are produced commercially from southern pine wood, and the city of Gainesville is building a biomass/wood power plant. There is substantial interest in producing biofuels from wood because of it is readily available and can be supplied steadily to a conversion facility. Three main aspects are needed for commercial production of bioenergy: 1) adequate supply of biomass with reasonable cost to site a facility; 2) efficient and cost effective conversion technology that can scale, and 3) markets for use of the bioenergy.

We are evaluating likely energy crop species, *Eucalyptus* and southern pine to provide important yield and best management practices for growing these species for bioenergy conversion. We will also provide important chemical composition information that will impact the conversion efficiency of this biomass to ethanol, and identify and characterize important genes that regulate wood chemical composition.

Objective 1

To conduct fundamental research to identify genes controlling biomass chemical composition and productivity that can be used ultimately to tailor crops for improved conversion efficiencies to biofuels and electricity.

Deliverables:

(1) Validate the candidate genes and pathways implicated in the regulation of biomass productivity and wood chemical composition useful for improvement of *Populus* and pine for biofuel and bioenergy conversion.

- We discovered a gene, cpg13, which regulates partitioning of carbon between lignin and carbohydrates and affects growth rate. We have created up and down regulated versions of this gene in transgenic poplars and are evaluating the effects on lignin to carbohydrate ratio, growth and metabolite levels.

(2) Application of discovered genetic markers to improve pine breeding populations, targeting higher biomass productivity and superior properties for conversion to biofuels.

- Genomic selection is increasingly considered vital to accelerate genetic improvement. However, it is unknown how accurate genomic selection prediction models remain when used across environments and ages. This knowledge is critical for breeders to apply this strategy in genetic improvement.

- We evaluated the utility of genomic selection in a *Pinus taeda* L. population of ~800 individuals clonally replicated and grown on four sites, and genotyped for 4,825 SNP markers. Prediction models were estimated for diameter and height at multiple ages using genomic random regression BLUP.

- Accuracies of prediction models ranged from 0.65–0.75 for diameter, and 0.63–0.74 for height. The selection efficiency per unit time was estimated as 53–112% higher using genomic selection compared to phenotypic selection, assuming a reduction of 50% in the breeding cycle. Accuracies remained high across environments as long as they were used within the same breeding zone. However, models generated at early ages did not perform well to predict phenotypes at age 6.

- These results demonstrate the feasibility and remarkable gain that can be achieved by incorporating genomic selection in breeding programs, as long as models are used at the relevant selection age and within the breeding zone in which they were estimated.

(3) Training of graduate students on the use of the most advanced genomics tools and approaches for analysis of complex traits.

- We are training 3 students in genomics and quantitative genetic analyses of complex traits.

Objective 2

To conduct applied research with Eucalyptus, to provide important agronomic practice, yield, and chemical composition information for Florida growers, producers and policy makers.

Deliverables:

(1). Regionally tested *Eucalyptus* species and cultivar yields and initial best management practices for biomass accumulation in south, central and north Florida.

- In 2009, field plantings were established in central Florida with half-sib seedlings and the four locally adapted UF-IFAS *Eucalyptus grandis* cultivars and in north Florida with half-sib seedlings and clones of *Eucalyptus amplifolia* cultivar. The north Florida planting is about 16 acres and was put in by Buckeye Cellulose. The central Florida planting was about 3 acres and was put in by Mosaic Corp. Height and diameter measurements and biomass samples were taken this fall and will provide the data for growth and yield estimates.

(2). Chemical composition of candidate biomass species and impact of genetic and silvicultural treatments.

- Genetic improvement of forest trees, such as Eucalyptus, *Populus*, and Pine species has increased growth, and improved form and disease resistance, leading to significant gains in field productivity. However, forest tree breeders have not directly selected for wood chemical composition, despite the substantial economic interest and knowledge about genes involved in synthesis of cellulose, hemicelluloses and lignin. With new interest in biomass chemical composition from the developing biofuels industry, there is a need for robust low cost and rapid methods to use in breeding. These methods need to support both traditional breeding practices and recent advances that utilize genetic markers such as genomic selection.

- A variety of methods for measuring the chemical composition of lignocellulosic biomass have been applied to understand genetic control and environmental effects. Although classic wet chemical methods have been widely used, their application for genetic analyses is limited by their high cost and low throughput. Composition data from classical chemical methods were used to calculate genetic parameters for wood chemical composition in loblolly pine and eucalyptus, and map quantitative trait loci (QTL) in loblolly pine. Pyrolysis mass spectrometry methods are more rapid and have been used to characterize lignocellulosic components in herbaceous and woody biomass. In particular, pyrolysis molecular beam mass spectrometry (pyMBMS) has been used to analyze large genetic trials to understand the genetic architecture, map QTL and identify genes that affect cellulose, hemicelluloses and lignin content in pine and poplar. Near infrared (NIR) spectroscopy is an indirect method that has been used for qualitative and quantitative chemical analyses in many fields and industrial applications, including, agricultural products, food, and forestry.

- The goals of this research are to calibrate a FT-NIR model based on the chemical components determined from pyMBMS, test the calibration model's performance with a separate prediction set, and utilize the FT-NIR predictions to estimate the genetic parameters and detect QTLs. Compare the genetic parameters from FT-NIR with those obtained with pyMBMS.

- Here we compared for a single poplar family genetic parameter estimates obtained for wood chemical composition with data from pyrolysis molecular beam mass spectrometry (pyMBMS) and FT-NIR. Over 1500 young greenhouse grown wood samples were analyzed for chemical composition with pyMBMS[2]. We randomly selected 500 samples to build a Fourier transform near infrared (FT-NIR) calibration and validate a model based on partial least square for lignin, G-lignin, S-lignin, S/G ratio and sugars (C5 and C6). A FT-NIR spectrometer, equipped with an X-Y stage auto-sampler was used to improve the scanning efficiency. The sample set was randomly divided into calibration (500) and prediction (1005) sets. The coefficient of determination (R^2) for the calibrations ranged from 0.56 to 0.87, and the prediction model R^2 ranged from 0.37 to 0.81. Stronger calibration and prediction statistics were obtained with lignin compared with carbohydrates. For lignin the best prediction (R^2 = 0.81) was obtained. For carbohydrates, the strongest prediction statistics (R^2 = 0.70) were obtained for the m/z 144 ion which comes from cellulose.

  Genetic analysis of pyMBMS data and FT-NIR predictions was compared to evaluate the utility of the indirect FT-NIR method relative to the direct pyMBMS method for parameter estimates. QTL analysis was used to compare the results between pyMBMS and FT-NIR

(3). Training of graduate students in production physiology, chemical composition, and management of Eucalyptus short rotation woody crops in Florida.

- We have trained one student in chemical composition analysis

Publications:

Resende, M.F.R., Jr., Munoz, P., Acosta, J.J., Peter, G.F., Davis, J.M., Grattapaglia, D., Resende, M.D.V., Kirst, M. 2011. Accelerating the domestication of trees using genomic selection: accuracy of prediction models across ages and environments. *New Phytologist* In press

Zhang, J., Novaes, E., Kirst, M., Peter, G.F. Comparison of pyrolysis mass spectrometry and near infrared spectroscopy for genetic analysis of lignocelluloses composition in Populus Biomass Bioenergy submitted

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University of Florida

Engineering Biocatalysts for Hemicelluloses Hydrolysis and Fermentation

PI: J.F. Preston
Students: Neha Sawnhey (Ph. D.)

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

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

Budget: $192,000.00
Universities: UF
External Collaborators: NA

Progress Summary

Develop improved enzyme-mediated saccharification protocols of hemicelluloses with existing bacterial biocatalysts for production of biofuels and chemical feedstocks.
A combination of endoxylanases from Gram positive bacteria have been expressed as recombinant enzymes for the efficient depolymerization of glucuronoxylans, the predominant hemicellulose components of hardwood biomass. As secreted enzymes these have been shown to release oligosaccharides for efficient assimilation and complete intracellularconversion to fermentable xylose. Along with an intracellular alpha-glucuronidase these have been identified for engineering bacterial biocatalysts for the efficient conversion of lignocellulosics to bioethanol.

A thermophilic xylanase has been produced as a recombinant protein in tobacco and sugarcane for production of quantities for saccharification of lignicellulosics on an industrial scale.

Develop systems with bacterial biocatalysts for efficient bioconversion of the hemicellulose fractions of perennial energy crops (poplar, eucalyptus, sugarcane, sweet sorghum) to targeted products.
The genome sequence of *Paenibacillus* sp. JDR2 has been completed, and has identified additional genes with which to engineer l bacteria biocatalysts with genes encoding arabinases as well as xylanases. These will be useful for the saccharification of glucuronoarabinoxylans from grasses.

A strain of *Bacillus subtilis* has been engineered with genes from *Paenibacillus* JDR2 for the efficient conversion of glucuronoxylans from poplar and glucuronoarabinoxylans from sugarcane to targeted fermentation products. This genetically pliable species shows particular promise for the development of a biocatalyst for the consolidated bioprocessing of lignocelliulosic biomass from agricultural residues and energy crops to biofuels and chemicals.

Funds leveraged/new partnerships created: A grant entitled "Next-Generation Sweet Sorghums - Sustainable Production of Feedstocks for Fuels, Chemicals and Value-Added Products" has been awarded to the University of Florida for four years starting 05/11/2011. Wilfred Vermerris from the Department of Agronomy is the PI, with seven Co-PI's including myself. This will provide a total of $509,915 direct cost for my efforts to pursue topics related to the development of enzymes for saccharification and bacterial biocatalysts for direct conversion of lignocellulosics from sweet sorghum to fuels and chemicals.

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Different forms of lignocellulosic biomass represent major renewable resources derived from solar energy via photosynthesis. Several of these are abundant in the southeastern United States and amenable to development as major sources of fuels and chemicals. Energy crops, poplar and energy cane, and agricultural residues, sugarcane bagasse and sorghum, are candidates for bioconversion to targeted products. The hemicellulose fraction, representing 20 to 30% of these resources, may be efficiently converted, via secreted xylanolytic enzymes, to sugars for intracellular metabolism and conversion to biofuels and chemicals by fermentative bacterial biocatalysts. We have identified and characterized xylan-utilization systems from bacteria at the gene and enzyme level, and applied the appropriate enzymes for efficient conversion of xylans to fermentable pentoses, xylose and arabinose. This has led to the identification of bacteria for the secretion of xylanolytic enzymes, assimilation of the products of extracellular depolymerization of xylans, followed by efficient intracellular metabolism. Xylanolytic bacteria, e.g. *Paenibacillus* spp., are candidates for downstream engineering to produce lactate or ethanol. Other bacteria capable of fermentation, e.g. *Bacillus subtilis*, have been engineered for secretion of xylanolytic enzymes for optimal conversion of hemicelluloses to lactate and ethanol. These developments may provide new biocatalysts for consolidated bioprocessing of hemicelluloses for cost-effective conversion of lignocellulosic resources to alternative fuels and chemicals.

Publications:

Kim, J.Y., K. Musa, W. Fouad, G. Nong, **J.F. Preston** and F. Altpeter. 2011. Production of hyperthermostable GH10 xylanase Xyl10B from *Thermotoga maritima* in transplastomic plants enables complete hydrolysis of methylglucuronoxylan to fermentable sugars for biofuel production. Plant Mol. Biol. In press.

Potnis, N., K. Krasileva, V. Chow, N. F. Almeida, P. B. Patil, R. P. Ryan, M. Sharlach, F. Behlau, J. M. Dow, M.T. Momol, F. F. White, **J. F. Preston**, B. A. Vinatzer, R. Koebnik, J. C. Setubal, D. J. Norman, B. J. Staskawicz, J. B. Jones. 2011. Comparative genomics reveals diversity among xanthomonads infecting tomato and pepper. BMC Genomics 2011, 12:146 http://www.biomedcentral.com/1471-2164/12/146

St John, F. J., J. C. Hurlbert, J. D. Rice, **J. F. Preston** and E. Pozharski. 2011. Ligand Bound Structures of a Glycosyl Hydrolase Family 30 Glucuronoxylan Xylanohydrolase. J. Molec. Biol. 407:92-109.

Patent application filed:

U.S. Provisional Application SN 60/982,623. UF# 12619. Xylan-Utilization Regulon for Efficient Bioprocessing of Hemicellulose and Uses Thereof. Preston, J.F., V. Chow, G. Nong, J.D. Rice, and F.J. St. John. Filed 10/22/2008

U.S. Provisional Application SN 61/115, 722 UF #12617 "Biocatalyst for complete conversion of hemicellulose to biobased products". Preston, J.F., C. Bi, and J.D. Rice. Filed 11/18/2008

FESC
Florida Energy Systems Consortium

University of Florida

Florida Advanced Technological Education Center (FLATE)

PI: Marilyn Barger

Description: FLATE (Florida Advanced Technological Education Center) will partner with FESC to develop the state wide strategy for developing the technician based workforce that will be needed to support new/improved energy technologies as developed within FESC research partners. Strategic elements include the development of statewide curriculum frameworks for technical A.S./A.A.S. degree programs supporting existing and new energy business sectors. FLATE will be responsible for the crafting and drafting of such frameworks as well as the direct actions involve in the FLDOE the industry-validated student competencies of the frameworks process. FLATE will also develop as required new courses for each new program of study. Additionally FLATE will help state and community colleges implement the new frameworks in their institutions. To support the new curriculum, FLATE will work closely with the FESC Public Outreach and Industry Partnership programs to provide professional development opportunities for teachers and faculty to upgrade and update their knowledge base.

Budget: $300,000.
Universities: FLATE/Hillsborough Community College

External Collaborators: Brevard Community College; Tallahassee Community College; Daytona State College; Central Florida Community College; Polk State College; Florida State College at Jacksonville; Valencia Community College; School District Hillsborough County; Florida Department of Education – Division of Adult and Career Education; West Side Technical School; WFI Banner Center for Energy; Advanced Technology for Energy and Environment Center (ATEEC); University of West Florida, Dept of Construction Technology; WFI Banner Center for Construction; WFI Banner Center for Clean Energy; USF College of Engineering; Madison Area Technical College ATE project for Alternative Energy certifications; Milwaukee Area Technical College Energy Conservation and Advanced Manufacturing Center (ECAM); Florida Energy Workforce Consortium (FEWC); TECO; Progress Energy; ISTEC (Ibero Science and Technology Education Consortium), Center for Energy workforce Consortium (CEWD); UF Industrial Assessment Center, CREATE NSF Center for Alternative Energy; EST2 NSF ATE Grant project; DOE's Office of Energy Efficiency & Renewable Energy; Gulf Coast State College; Palm Beach State College; University of South Florida's College of Engineering.

Progress Summary

The development of the process for the Florida State College System to respond to FESC's long term strategy to bring energy related technologies out of the Florida University System is well underway. Activities this year included identifying the current status of credit and non-credit energy related courses within the State College System. In addition, online curriculum related to Alternative Energy Systems has been developed. FLATE has the college contacts and process in place to respond to any FESC and/or regional economic development authority request to provide assistance to a designated State College because of a technician workforce development need as identified or triggered by a new or expanding energy related company's operations in the State.

Funds leveraged/new partnerships created: FLATE has leveraged its NSF and FESC resources to help Brevard Community College to apply for and be awarded a very competitive NSF grant, $ 500,000, implement two energy related specialization within the A.S. Engineering Technology Degree. In addition, FLATE was able to secure a $ 100,000 award from NSF to develop a faculty/student interchange that will allow Florida to benefit from the well advanced energy related technology educations practices at technology colleges in Spain.

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Since October 1, 2010 FLATE achieved several milestones. It completed the online curriculum of an introductory (overview) course in Alternative Energy Systems. Eighteen modules in the form of presentation slides are now available to the state colleges (and others) online at www.flate.pbwiki.com at the energy link. The modules have been reviewed by subject matter experts before posting for level and content. The detailed list includes energy storage, biofuels and bioenergy, wind energy, solar energy, geothermal, energy policy and regulations, etc.

In December 2010, FLATE surveyed the 28 state and community colleges to determine their offerings in three categories: (1) non credit courses and training programs; (2) academic programs; and (3) individual courses that had as a major component any type of energy science, technology or applications. 50% of the State and community colleges responded to all 3 parts of the survey. This survey information and links were used to update information about energy program offerings in the state on the FESC website. The data revealed that all of the 14 colleges that responded offered some energy curriculum and that offerings varied across the state depending on local industry needs. Several are offering non-credit curriculum developed by the Banner Center for Clean Energy. This survey will be revised and administered again in early 2012.

FLATE and its partners made several presentations during the past 12 months. Project Manager, Jorge Monreal, presented a poster entitled “Building the Technician Workforce for Florida’s Energy Future” at the Green Energy Summit in Milwaukee, WI, where he also gathered information about community college programs focused on industrial energy efficiency. Dr. Marilyn Barger gave a 30 minute presentation “Developing an Alternative Energy Credit Certificate for Florida” at the IREC 2011 Clean Energy Workforce Education Conference in Saratoga Springs, NY (March 2011).

Additionally, FLATE presented a poster at the annual FESC Summit, September 27-28, 2011 at the University of Florida, Gainesville. Finally, FLATE regularly updates / presents information about energy curriculum and training issues at the statewide Florida Engineering Technology Forum that meets twice per year at various colleges across the state. Many of these schools are looking to add “energy” curriculum and/or programs and are requesting guidance on what industry is asking for across the state and what and how other colleges are implementing credit programs. The goal of these activities is to keep colleges working together and sharing curriculum rather than develop independent programs not properly aligned to statewide frameworks. The ET Forum group and FLATE also undertook efforts to work with the state common course numbering system to identify a prefix for energy technology courses. The new prefix will be effective in the 2012 academic year and will be called ETP (Engineering Technology – Power).

On Monday Sept 26, 2011 FLATE and FESC sponsored an energy workshop for high school and college educators at the Center for Innovation and Economic Development at Santa Fe College in Gainesville, FL. Over 45 participants heard presentations from the new Department of Economic Opportunity (DEO) about newly released Green Job Report; heard updates from the Florida Department of Education (FLDOE) state supervisor of the Energy Cluster; learned about the new high school energy programs

from the Florida Energy workforce Consortium (FEWC); and shared new information from FLATE and the Banner Centers for Energy, Clean Energy and Construction as well as the colleges. A hands-on workshop in the afternoon demonstrating hand held tools for defining energy losses in buildings completed the day. 13 of the educator attendees took advantage of the support offered by FLATE to attend the Florida Energy System Consortium (FESC) Third Annual Summit at the University of Florida on the following 2 days (September 27028, 2011). Reviews of the event are still being tabulated, but the very positive verbal responses from the participants made it clear that there was a need and desire to have future events for this industry sector. Additionally, the participants were addressed by special guest, Henry Kelly, Acting Assistant Secretary & Principal Deputy Assistant Secretary, Office of Energy Efficiency & Renewable Energy who gave an overview of the newest resource for education and training: Department of Energy's National Training and Education Resource (NTER). All materials from the Workshop are now posted on the FLATE FESC page (www.fl-ate.org/projects/fesc).

Activities for the 2010-2011 year are listed below.

- Participated as Advisory Council Member for the Banner Center for Energy's Focus Group meeting to assess future educational needs from industry within the Indian River State College area. (Orlando, FL)
- Attended presentation from the Sustainability Education & Economic Development (SEED) on application of Nanotechnology to Solar Cells. (Brandon, FL)
- Reviewed proposed course curriculum and frameworks in the Florida Energy Workforce Consortium (FEWC) quarterly meeting. (Orlando, FL)
- Jointly with Brevard CC, Tallahassee CC, FSCJ and University of Florida's Industrial Assessment Center discussed possibilities of establishing new educational programs at the three colleges that would prepare a new workforce in commercial building and residential energy efficiency. (Gainesville, FL)
- Focus group participant for the Second Annual Gathering of Tampa Bay Sustainability Educators for idea generation and implementation plans to improve sustainability efforts in the Tampa Bay area. (Tampa, FL)
- Initiated discussions with Hillsborough CC on partnership arrangements with other Florida colleges for participation in an exchange course with Denmark for Sustainability Studies where see towns that utilize distributed power generation facilities such as CHP plant with trash as fuel source. Obtained partnership with SCF in Sarasota. (Tampa, FL)
- Completed and distributed a survey to all State/Community colleges throughout Florida to assess the state's current educational offerings in alternative/sustainable energy.
- Worked with HCC's Sustainability Council towards its goal of reducing greenhouse gas (GHG) emissions on a yearly basis. Energy audits are to be conducted by TRANE across all campus locations as well as implementation of GHG emission mitigation projects.
- Began planning phase on a professional development summer energy workshop for middle school/high school teachers.
- Discussed with a local development company, HCC leadership, and District's House Representative, Rachel Burgin, future development of a CHP site in the Valrico, FL area and the possibility of using a portion of the site as a training facility for hands-on alternative energy education.
- Presented a poster entitled "Building the Technician Workforce for Florida's Energy Future" at the Green Energy Summit in Milwaukee, WI.
- Presented "Developing an Alternative Energy Credit Certificate for Florida" at the IREC 2011 Clean Energy Workforce Education Conference in Saratoga Springs, NY.
- Compiled data from 14 State/Community colleges that replied to the survey of alternative/renewable energy courses offered in Florida. Following up with non-respondents.

- Completed upload onto FLATE's Wiki of course curriculum EST1830 Introduction to Alternative and Renewable Energy made up of 16 individual instructional "modules". Course content is made freely available to self-learners, students and educators. Material is available here: http://flate.pbworks.com/w/page/35326400/EST1830-Introduction-to-Alternative-Energy-Course-Content
- Attended FSEC Teacher Energy workshop to network with K-12 teachers and FSEC.
- Offered summer program for middle school students on energy for underrepresented students in conjunction with the EST2 grant partners (BCC, TCC and FSCJ). A total of 50 students participated across the state in 3 4-day events.
- Began collaborations with UF's Industrial Assessment Center (IAC) for refining the college curriculum. Dr. Tim Middlekoop has become an active participant in the work to write competencies required and possibly offering "field experience" on his various site visits, or helping to define what these could look like in an educational environment.
- Developed several flyers and brochures for FLATE - FESC
- Developed a model to crosswalk the Department of Labor's occupation codes with the military occupation codes to help returning veterans find jobs in related energy fields. A prototype aligning DOL's Electronics Engineering Technician has be cross walked with several MOS codes. Final review is being conducted. Next steps will be defined when this prototype is completed in Dec 2011.

University of Florida

Integrated PV/Storage and PV/Storage/Lighting Systems

PI: Franky So **Co-PIs:** Jiangeng Xue, Shirley Meng
Students: Ming-Che Yang/ PhD candidate;
Chris R. Fell/PhD candidate**;** Fred Steffy/MS candidate;
William Hammond (PhD candidate); Edward Wrzesniewski (PhD candidate)

Description: The goal is to increase the efficiency and reduce the cost of solar power through the integration of PV, Li-battery, and LED lighting technologies. Since all components are in the form of thin films, the PV/battery/LED system can be integrated as a single module. Since half of the materials cost of each device is the substrate, integrated module will also reduce materials costs and processing steps. Importantly, their integration further eliminates the need for inverters since they are all low-voltage devices. Such an integrated device can be used to store energy during the day and power the LED panel for lighting in the evening. In addition, we will explore the possibility of fabricating a semi-transparent module. The success of this Task will lead to a novel solar-power lighting panel that can be used as a sky light during the day and a lighting panel during the night without using grid-power. We not only will develop the technologies, but also integrate devices and perform technology-economic evaluation, including life-cycle costs.

Budget: $576,000
Universities: UF
External Collaborators: University of California San Diego, Oak Ridge National Lab

Project Summary

In the area of lighting and photovoltaics, we focused on light management and hybrid light emitting and PV devices. We have made use of "defective" grating structures to extract thin film guided modes in OLEDs. Because of the lack of long range ordering, we were able to achieve lambertian-like emitters with a 2X enhancement in light output. We have also developed novel optical structures for enhancing the efficiency of organic and hybrid organic-inorganic photovoltaic cells by allowing the active materials to more efficiently absorb the incident light. Two different optical structures were created and applied to the PV cells using a soft lithographic process, which could be easily implemented in large-scale high throughput manufacturing systems. Such enhancement mechanism could also be universally applied to any active materials or device platforms. For hybrid solar cells, we have significantly improved the efficiency of hybrid polymer-colloidal nanocrystal solar cells by engineering the chemical and electronic structures at the polymer-nanocrystal interface. This yields a maximum power conversion efficiency of 5%, the highest for solid-state hybrid solar cells. Finally, we also developed fully solution processed, multilayer quantum-dot based light-emitting devices that show high efficiency and full visible spectrum color tunability.

Lithium-ion batteries are efficient, light-weight and rechargeable power sources for consumer electronics such as laptop computers, digital cameras, MP3 players and cellular phones. However, for the use as energy storage component in this proposed work, the energy density, power density safety and cycling performance still can't achieve the requirements. In this research, three different strategies were selected to improve the rate capability, cycling performance and investigate the solid electrolyte interface. First, the first principles computation was used to selected suitable doping metal and proved by real experiment. Second, the TiO_2 nanostructure was synthesized and the electrochemical properties were examined. Finally, the thin film batteries were fabricated by pulsed laser deposition (PLD) and the solid electrolyte

interface were investigated by XPS. In addition, the layered lithium excess layered oxide compounds $Li[Ni_xLi_{1/3-2x/3}Mn_{2/3-x/3}]O_2$ ($0 < x < 1/2$) are of great interests as a new generation of positive electrode materials for lithium-ion batteries because of higher energy densities and lower costs. However, the rate capabilities of these materials are not adequate for future applications. Preliminary studies have proposed mechanisms to explain this material's anomalous capacity; however the mechanism still remains unclear. In order to break the rate capability barrier, a complete understanding of the lithium diffusion mechanism needs to be understood. We uses a series of characterization techniques to identify the rate limiting step that impedes lithium diffusion and propose new strategy to further improve the electrochemical properties of this new family of electrode materials.

Funds leveraged/new partnerships created:

- Northeastern center for chemical energy storage (NECCES) – a DOE energy frontier research center. Partnership with University of California San Diego (UCSD) and State University of New York (SUNY) at Stony Brook

Grants awarded

Title	Agency	Reference Number	PI, Co-investigators and collaborators	Period of Performance	Funding awarded
Materials and Devices compatible with high volume roll-to-roll manufacturing of polymer solar cells	Office of Naval Reseach		Franky So, John Reynolds and Frederik Krebs	Jan, 2011-Dec, 2013	$750,000
High efficiency OLEDs for lighting	DOE		Franky So, Nelson Tansu	Jun. 2009-May 2012	$780,000

Proposals submitted

Proposals (Xue)						
Title	Agency	Reference Number	PI, Co-investigators and collaborators	Funding requested	Project time frame (1 year, 2 years, etc.)	Date submitted
A Modular Supramolecular Approach to Organic Photovoltaic Materials	Research Corporation for Science Advancement		Co-PI	$250,000	3 years	01/18/11
SOLAR Collaborative: Solar Energy Harvesting Using Photon-Driven Molecular Nanomotor Assembly	NSF		Co-PI	$1,284,072	3 years	01/28/11
Development of Scalable Bottom-Up Nanomanufacturing Platforms	NSF		Co-PI	$2,000,000	4 years	01/10/11
Solution-processed, Earth-abundant Semiconductors for High Efficiency Solar Cells	DOE		PI	$1,500,000	3 years	06/28/11

Light management in organic solar cells and organic light emitting diodes

1. Light extraction using defective grating structure

In collaboration with Dr. Nelson Tansu at Lehigh University, OLEDs were fabricated on grating substrates. These grating substrates were fabricated by coating 1 μm diameter and 0.5 μm SiO_2 microlens array on glass substrates. Fig. 1 shows the AFM images of these microlens arrays along with their power spectral densities obtained from FFTs shown in the insets. The FFTs show that the lack of long range ordering in the arrays. As a result, the light emission profiles of the resulting OLEDs are very similar to a lambertian emitter.

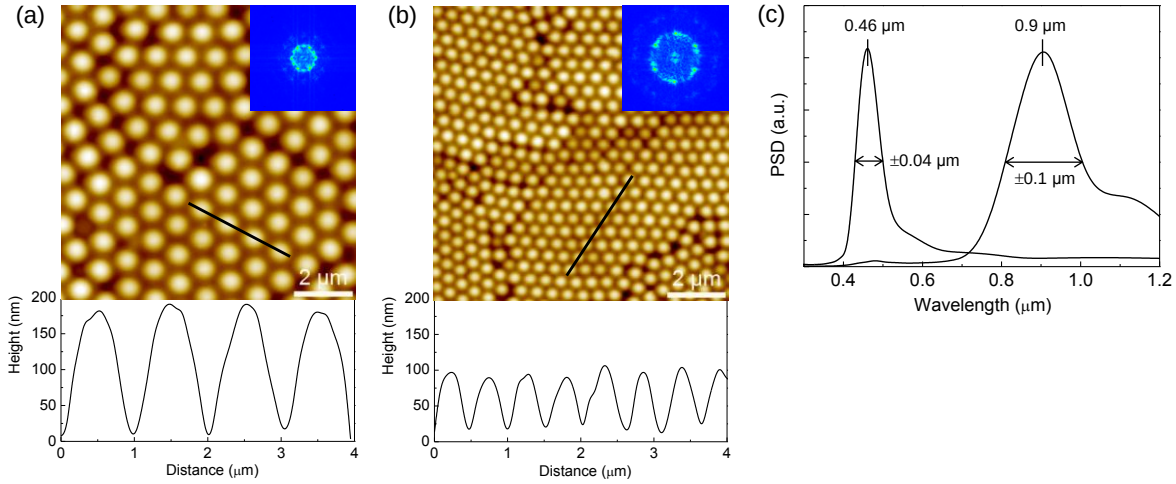

Figure 1: AFM Images Of A 1.0 Mm (A) and 0.5 Mm (B) Substrates. The Power Spectral Densities of the Corresponding Grating Substrates are Shown in (C).

Fig. 2 shows the current efficiency and the power efficiency of OLEDs fabricated on μm grating substrates along with the results of a controlled device. Enhancements of 70% and 100% were achieved for the current and power efficiencies due to the 0.5 μm grating. The larger enhancement of the 0.5 μm grating device compared to the 1.0 μm grating device is associated with the larger grating vector of the 0.5 μm grating.

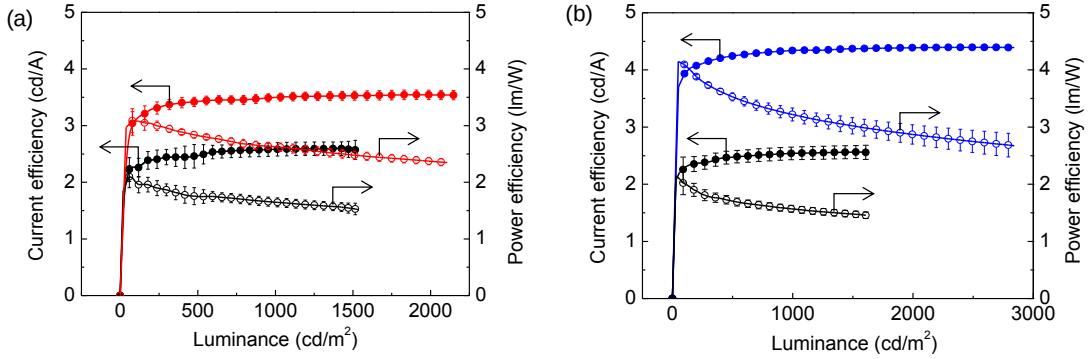

Figure 2: Current and Power Efficiency of Oleds Fabricated on 1 Mm (A) and 0.5 Mm (B) Substrates. The Data for the Control Device are Shown in Black.

2. Optical structures for enhancing light absorption in organic solar cells

We have developed novel optical structures for enhancing the efficiency of organic and hybrid organic-inorganic photovoltaic cells by allowing the active materials to more efficiently absorb the incident light. Two different optical structures were created and applied to the PV cells using a soft lithographic process, which could be easily implemented in large-scale high throughput manufacturing systems. Such enhancement mechanism could also be universally applied to any active materials or device platforms. In one structure, a pyramidal rear reflector structure was molded on a semi-transparent organic solar cell, as shown in Fig. 3(a). The total internal reflection at the device/air interface when the incident light attempts to escape the device leads to significantly increased optical path length in the device. As shown in Fig. 3(c), compared with the normal device with a planar rear reflector, this pyramidal structure could yield a 15-70% increase in the solar cell efficiency, depending on the active layer thickness and the alignment of the device with respect to the pyramid.

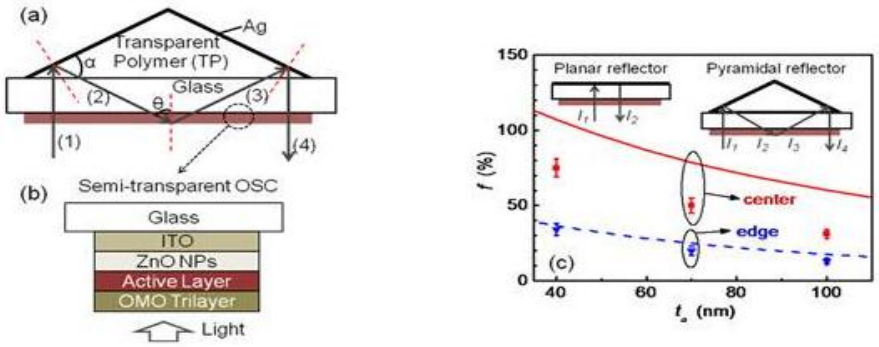

Fig. 3. Schematic illustrations of (a) a pyramidal rear reflector structure and (b) a semi-transparent organic solar cell. (c) shows the efficiency enhancement factor as compared to a device with planar rear reflector.

In the second optical structure, we have applied a molded microlens array (shown in Fig. 2a) to the organic solar cell light incident surface. Figure 4b shows the current density-voltage characteristics of a bilayer SubPc/C_{60} cell under 1 sun AM1.5G solar illumination, which shows a 20% enhancement in efficiency with the microlens array. Figure 2c shows that by varying the C_{60} layer thickness, a maximum enhancement of 60% could be achieved.

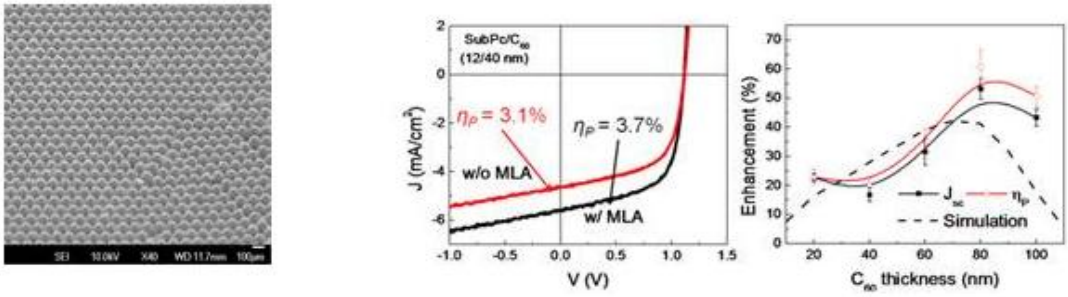

Fig. 4. (a) SEM image of a microlens array (MLA); (b) current density-voltage characteristics of a subPc/C_{60} bilayer organic solar cell with or without the microlens array; (c) enhancement factor in J_{SC} or efficiency as a function of the C_{60} layer thickness.

Hybrid polymer-nanocrystal solar cells

We have also greatly improved the efficiency of hybrid polymer-nanocrystal solar cells by applying proper chemical treatment to passivate the surface of the nanocrystals. The passivation leads greatly reduced defect densities on the CdSe nanorods, which otherwise would lead to recombination of photogenerated excitons and/or charge carriers. As shown in Fig. 5, using this treatment process, for hybrid solar cells based on CdSe nanorods and a low-gap polymer PCPDTBT, we obtain a more than 40% increase in the power conversion efficiency, leading to a maximum of ~5.0%, the highest so far achieved for this type of solar cells.

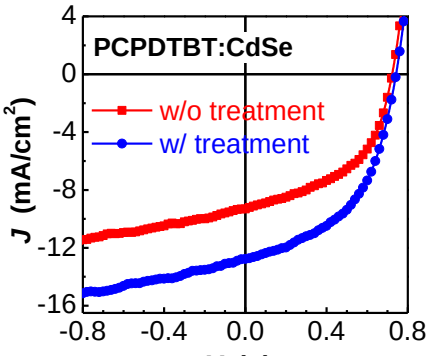

Fig. 5:. The I-V characteristics for PCPDTBT:CdSe nanorod hybrid solar cells with or without the chemical treatment.

Solution processed, quantum-dot based, multilayer light-emitting devices

We successfully fabricated multilayer quantum-dot based light-emitting devices using solution process. The device structure is shown in Fig. 6a where an organic layer poly-TPD acts as hole transport layer, a CdSe-ZnS core-shell quantum-dot layer acts as the light emitting layer, and a ZnO nanoparticle layer serves as the electron transport layer. By tuning the size and composition of the CdSe-ZnS quantum dots, we can achieve tuning of color emission from blue to orange-red (see Fig. 6b). The efficiency of these devices are several times higher than previously reported devices, with a maximum luminous efficiency of ~8 lm/W for the green device and a maximum luminance of over 10,000 cd/m^2.

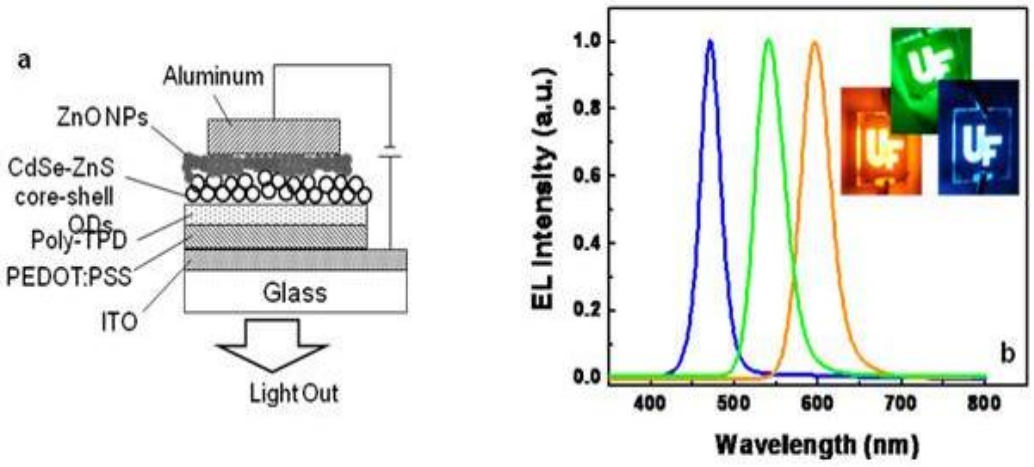

Fig. 6 (a) shows the device structure of the quantum LED and (b) shows the spectra of the RGB devices.

Lithium Ion Batteries

In order to improve the rate capability of $LiNi_{0.5}Mn_{1.5}O_4$.The Li diffusion activation barriers of $LiM_{1/2}Mn_{3/2}O_4$ (M= Ti, V, Cr, Fe, Co, Ni and Cu) are calculated by first principles computation. The results suggest that doping with Co or Cu can potentially lower Li diffusion barrier compared with Ni doping. $LiNi_xCu_yMn_{2-x-y}O_4$ were synthesized by sol-gel method. Although the capacity of the doped spinel materials decreases with the increasing doped Cu amount, $LiCu_{0.25}Ni_{0.25}Mn_{1.5}O_4$ spinel oxide exhibits higher capacity than undoped $LiNi_{05}Mn_{1.5}O_4$ spinel at high rates (more than 2C). Among the three samples, D_{Li} of $LiCu_{0.25}Ni_{0.25}Mn_{1.5}O_4$ is one order of magnitude higher than that of $LiNi_{0.5}Mn_{1.5}O_4$ and $LiNi_{0.45}Mn_{1.55}O_4$ as shown in Figure1. Moreover, a new explanation of the voltage profile for $LiNi_xCu_yMn_{2-x-y}O_4$ is proposed, supported by the results from first principles computation, and confirmed by electrochemical property measurement and *in situ* XAS experiment. We have shown that Cu cannot be further oxidized to Cu^{4+} and the plateau at 4.95V originates from extra electrons provided by oxygen ions.

Titanium dioxide flake nanostructures were fabricated by a simple spreading method. The pentane and titanium n-butoxide were used as the precursors and continuously added into the solution on the surface of flowing water. Their crystal structure, surface area, pore size and electrochemical properties are compared for flakes and nanoparticles. The electrochemical and structure properties of the nanoflakes are significantly influenced by subsequent heat treatment process. The calcined titanium dioxide flakes exhibits larger reversible discharge capacity, better rate capability and excellent cycling stability compared to Anatase titanium dioxide nanoparticles, due to their small grain size (8nm), larger surface area (7 times greater than particles) and porous structure (7nm). The smaller grain size of the flakes suggests the new $LiTiO_2$ forming during the lithiation process that improves the discharge capacity. The larger surface area of the flakes contribute to the larger electrode/electrolyte contact area, the short path lengths for both Li-ion and electron transport and lower specific current density of the active materials that lead to the better rate capability. The cycling performance of calcined flakes was benefited by its porous structure. At the same time, the nanosized grain (8nm) also excluded the extra strain formed during the lithiated process, which improves the cycling performance.

All-solid-state thin film batteries are most ideal sample for probing the intrinsic properties by Transmission electron microscopy (TEM) ,Scanning Probe Microscopy(SPM), X-ray Photoelectron Spectroscopy(XPS) and potentiostatic intermittent titration technique (PITT).A Lambda Physik KrF Excimer laser with wavelength 248 nm was used for the thin film deposition. All-Solid-State thin film battery TiO_2/LVSO/$LiNi_{0.5}Mn_{1.5}O_4$/stainless steel was fabricated successfully. It is very difficult to investigate the surface film of the cathode electrode with composite form, especially when the fluorine peak of PVDF and carbon peak of carbon black are presented and overlap with real surface film. The solid electrolyte interface of $LiNi_{0.5}Mn_{1.5}O_4$ thin film without adding carbon black and PVDF was investigated by XPS. The result confirms that the $LiNi_{0.5}Mn_{1.5}O_4$ electrode material is a promising high voltage (5V) cathode material.

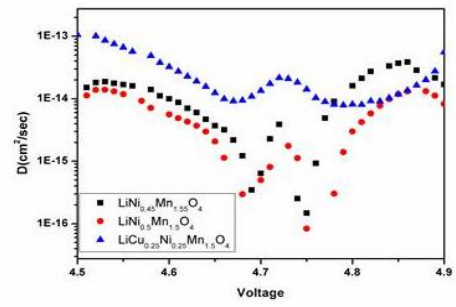

Fig. 7. Diffusion Coefficients of $LiNi_{0.45}Mn_{1.55}O_4$,$LiNi_{0.5}Mn_{1.5}O_4$ and $LiNi_{0.25}Cu_{0.25}Mn_{1.5}O_4$ (published in Chemistry of Materials, 2011, *23* (11) 2832)

For new cathode materials family - Li excess oxides, our research is designed to explore the effects of synthesis on the electrochemical properties of the material. We identified that the synthesis technique can alter the electrochemical performance of the material. Specifically we found that the surface characteristics as well as particle shape and distribution dramatically affect the electrochemical properties including cycling stability, rate capability and the lithium diffusion coefficient. This work is published in the Journal of the Electrochemical Society (2010). Once the complexity of interface in this material system was initially understood, the research progressed to identify the structural interface changes following electrochemical cycling. The characterization techniques linked the analysis of the electrolyte, the surface and the bulk of the cathode to gain a complete understanding of the delithiation mechanism. This research was performed through collaborations with the SHaRE program at Oak Ridge National Laboratory using their atomic-resolution TEM microscope and with Argonne National Laboratory with their synchrotron X-ray diffraction at the Advanced Photon Source (APS). The surface analysis led to the discovery of a new surface phase that is only 1 to 5 nm thick, which supports our previous research as well as led to the first detailed characterization of such a surface phase. This research provided a detailed cation rearrangement process and consequent phase transformation that can contribute to the variation of electrochemical properties following the charging/discharging cycle. More importantly such knowledge is pivotal to the optimization of these high voltage cathode materials. This work was published in Energy and Environmental Science, Figure 8 clear depicts the existence of a surface second phase after electrochemical cycling.

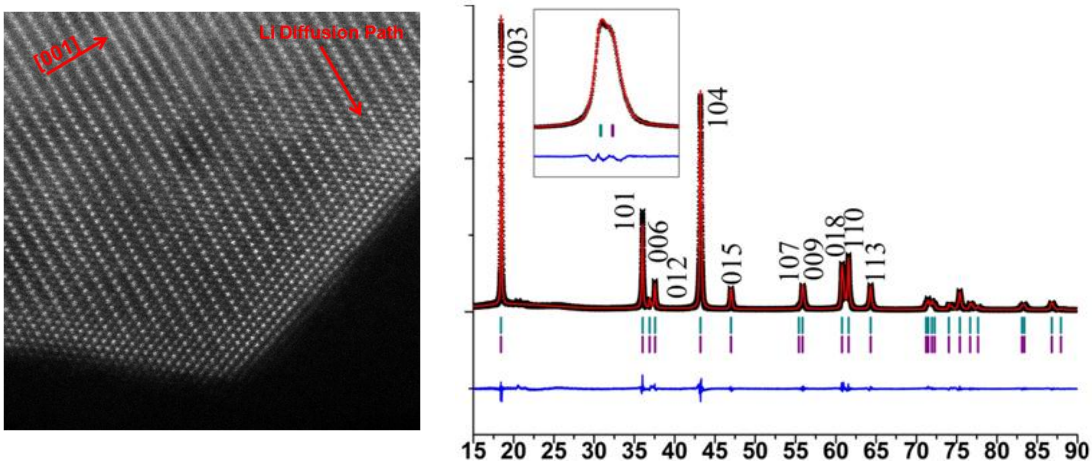

Fig. 8: Left: Atomic resolution STEM image of the material after electrochemical cycling. The diffusion path of Li is blocked by the presence of the heavy transition metal ions. Right: Synchrotron XRD refinement confirms the observation. This work is published in Energy and Environmental Sciences, 4, 2223-2233, 2011.

The analysis of structural changes before, during and following electrochemical property testing has led to a more thorough understanding of the Lithium transport mechanisms in the Li-excess series of materials. The findings from this research not only help to understand and eventually improve the Li-excess series of materials, but also can be expanded to other material systems to understand complex intricacies such as surface coatings, Li diffusion and oxygen loss mechanism, as well as phase transformation induced by ion migration. **The FESC student Chris Fell has been selected to receive the prestigious Electrochemical Society Battery Division Student Award.**

FESC
Florida Energy Systems Consortium

University of Florida

Joint Optimization of Urban Energy-Water Systems in Florida

PI: James P. Heaney
Students: John McCary (PhD) and Miguel Morales (PhD)

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

Budget: $72,000
Universities: UF
External Collaborators: Florida Department of Environmental Protection, South Florida, Southwest Florida and St. Johns River Water Management Districts, Gainesville Regional Utilities, Hillsborough County Water Utility Department, Sanford Water Utility, Water Research Foundation, Austin, Texas, Intelligent Software Development

Progress Summary

Water use analysis is typically done using utility-wide data since it is too difficult to organize and evaluate customer level attribute and monthly water billing data. A major breakthrough in the research of the Conserve Florida Water Clearinghouse has been the acquisition and use of customer level attributes including land use information, and utility level monthly water use data for every utility in the State of Florida. Thus, annually updated attribute and GIS data are available for nine million parcels in Florida and can be downloaded from the Florida Department of Revenue (FDOR) web site (ftp://sdrftp03.dor.state.fl.us/). Each of Florida's 67 counties has a property tax assessor's (CPTA) database that contains information that is included in the FDOR database and other attributes that are of interest in that county. The information in the county databases varies from county to county but the county data can be linked to the state database with a Unique Parcel Number. This information is of high quality since it is the basis for estimating property taxes. The key land use information for a parcel is its impervious and pervious areas. This information can be extracted directly from the FDOR/CPTA databases. The type of land use is available for about 65 land uses based on an FDOR land use code. Population information can be obtained from US Census data at the Census Block level of aggregation. Water utility service areas may not be contiguous with the political boundaries of the cities. Fortunately, the three largest of the five water management districts have developed GIS coverage that enables one to

assign parcels to the appropriate utility. These data sources can be combined to estimate the long-term trends in attributes of interest.

All utilities in Florida are required to submit Monthly Operating Reports (MORs) to the Florida Department of Environmental Protection (FDEP) that include information on daily water supplied by each treatment plant, water quality data, and information on the population served and the number of connections. Twelve years of monthly water use data are available for each utility from the FDEP web site (http://www.dep.state.fl.us/water/drinkingwater/download.htm) for every water treatment plant in Florida. This information can be used to evaluate historical trends and to project future growth patterns.

This information is compiled into software called EZ Guide that is used to find the optimal water conservation plan. Energy costs associated with end uses, e.g., showers, is included in EZ Guide. The next stage in the analysis is to include embedded energy that is expended in treating and transporting the water from its source to the customer. This procedure will be added to the existing EZ Guide. This valuable additional information allows for a much more accurate bottom up assessment of the interdependencies between water and energy.

The other initiative is to evaluate how to minimize energy costs associated with urban water supply. The methodology will build on our earlier research on water distribution systems (Lippai et al. 1999) and include a case study of the Hillsborough County water system. A state of the art hydraulic simulation model will be used that calculates the spatial and temporal variability in flows, pressures, and water quality.

Funds leveraged/new partnerships created: The inclusion of energy evaluations in the EZ Guide model will help minimize the damage to our base funding for the Conserve Florida Water Clearinghouse. We incurred a 60% reduction in base funding in June 2011, primarily due to the major budget cuts suffered by the water management districts. Fortunately, we were successful in obtaining new funding from St. Johns River Water Management District and the city of Sanford to develop new methods for water loss management. At present, Sanford has unaccounted for water in the range of 20-25% resulting in excess energy demand and reduced revenue. The goals of energy conservation and water loss control are synergistic. We also competed successfully for a national study of commercial, industrial, and institutional water use sponsored by the Water Research Foundation of the American Water Works Association. We are collaborating with Hazen and Sawyer, Inc., a recognized leader in this field. We are also collaborating with Austin, Texas, a leader in water conservation, in adapting our Florida methods for other utilities. Finally, we are working with a firm in Adelaide, Australia on a possible joint software development project to develop and apply agent based modeling to water demand management.

2011 Annual Report

Impact

Florida seeks to be a leader in developing innovative energy systems that will reduce our dependence on foreign oil and generate energy related jobs. The Florida Energy Systems Consortium will develop numerous innovations to address our needs for more energy. Concurrently, we face unprecedented challenges to meet our growing needs for more water. Florida is blessed with a relative abundance of high quality water, especially ground water. These water sources have been a major component of the economic engine that has nurtured Florida's development over the past century. However, beginning in 2013, Florida water users will not be allowed to tap traditional low cost, high quality, water supply sources to meet their new needs because their supply has dwindled to low levels. Thus, we are running out of low cost energy and water at about the same time. Worse yet, many of the newer energy and water

sources require more intensive use of these two resources, e.g., desalination of sea water is much more energy intensive than pumping from a nearby groundwater source; biofuel production requires far greater amounts of water to grow the crops and support the conversion process. National studies warn of the impending energy-water conflict (Cohen et al. 2004, Electric Power Research Institute 2003, National Research Council 2008, Navigant Consulting 2006, Sandia 2007, Webber 2008). Facing such dire circumstances, attention is shifting to developing more efficient systems and reducing our demands, where possible, through conservation. This project addresses how to evaluate energy-water linkages and find better ways to manage the demands for energy and water as a cost-effective way to reduce our future needs. It is essential for Florida to understand these water-energy trade-offs so that it can avoid myopic solutions that address one problem to the detriment of the other.

This three year study beginning July 1, 2009 seeks to integrate energy evaluations into our ongoing Conserve Florida Water Clearinghouse (CFWC) project that is addressing water use efficiency and conservation. CFWC already has a network of state agencies, water management districts, water utilities and professional water organizations. Some of these water utilities also provide energy services, e.g., Jacksonville Electric Authority, Gainesville Regional Utilities. These utilities will be targeted for more in-depth evaluations of energy and water use since they already have in-house expertise in both areas. The results of this study will be disseminated in the form of software tools and technical support to allow users to do accurate integrated evaluations of water and energy systems.

Description

Statement of the Purpose and Objectives of the Program:
Water and energy are fundamental necessities of modern civilization (Webber 2008). At the beginning of this project in July 2009, the economic recession was beginning to cause a reduction in water demand. Thus, the initial thrust of the research shifted from primary concern about inadequate water and energy to ways to stimulate the economy and reduce the costs of energy and water to free up resources for expenditures in other areas. Energy is a vital input to water infrastructure systems and vice versa and major tradeoffs exist. The overall purpose of this program is to develop new ways to integrate the evaluations of energy and water systems that recognize the tradeoffs that exist in satisfying needs in both areas with emphasis on better utilization of the these resources through improved efficiency and conservation. The importance of addressing the energy-water nexus issue was reaffirmed recently by a joint statement from the Alliance for Water Efficiency and the American Council for an Energy-Efficient Economy (2011)

Background and Significance:
The energy-water nexus for Florida is shown in Table 1. Water for power generation is a large user of fresh surface water and the dominant use of saline surface water. Agriculture is the largest user of fresh water and this use could grow significantly to support biofuel initiatives. All public water supply and most other water uses require that the water be delivered under pressure. Public water supplies consume about 4% of the nation's electricity (Sandia 2007). Per capita energy demands for supporting water supplies in Florida are expected to increase since cities are being required to meet future increases in water demand from more energy intensive alternative sources such as desalination and reuse.

[Compiled by the U.S. Geological Survey, Tallahassee; all values in million gallons per day]

Florida 2000	Freshwater			Saline Water		
	Ground	Surface	Total	Ground	Surface	Total
Public Supply	2,199.36	237.43	2,436.79	0.00	0.00	0.00
Domestic self-supplied	198.68	0.00	198.68	0.00	0.00	0.00
Commercial-industrial self-supplied	430.70	132.60	563.30	0.00	1.18	1.18
Agricultural self-supplied	1,989.95	1,933.06	3,923.01	0.00	0.00	0.00
Recreational irrigation	230.45	181.28	411.73	0.00	0.00	0.00
Power generation	29.53	628.73	658.26	3.82	11,950.82	11,954.64
TOTALS	**5,078.67**	**3,113.10**	**8,191.77**	**3.82**	**11,952.00**	**11,955.82**

Table 1. Total water withdrawals in Florida by category in the year 2000 (Marella 2004).

All electric vehicles are estimated to withdraw ten times as much water and consume up to three times as much water per mile as gasoline powered vehicles (Webber 2008). Biofuels have an even bigger impact on water supplies due to increases in irrigation water demand, and crop processing for conversion to biofuels can consume 20 or more times as much water for every mile traveled than the production of gasoline (Webber 2008). Low cost irrigation water is no longer available in most parts of the United States.

Examples of the interrelationships between energy and water are shown in Figure 1. Energy use for supporting public water supply activities can be divided into two major components: 1) the energy needed to deliver the water to the end user; and 2) the additional energy use by the end user for water heating, clothes washing and drying. Energy use at the end use level is the greater of the two components in California accounting for 14% of California's electricity consumption and 31% of its natural gas consumption, mostly in the residential sector (Electric Power Research Institute 2003).

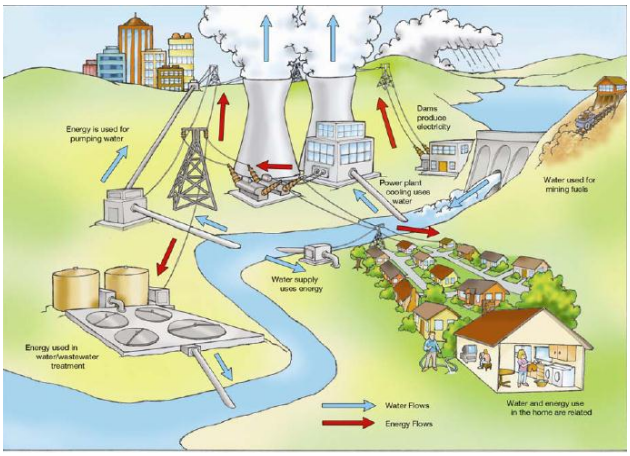

Figure 1: Examples of interrelationships between water and energy (Sandia 2007).

Project plans and activities:
The four project activities are described below. The key deliverable will be a public domain energy and water evaluation model that reflects Florida conditions and that can be used to do integrated evaluations of energy and water programs. Two manuscripts will be submitted for publication in archival journals. These manuscripts will provide detailed descriptions of the methods used and the key results.

Literature review

The literature review is focusing on assembling the results of previous energy-water studies that have been done at the national level and in other states, most notably California. The literature review includes a focus on developing energy and water use coefficients for various key activities. Available models for analyzing water-energy systems will be included in the review. The output of the literature review will be a recommended modeling approach for Florida.

Tampa Bay Water has developed and implemented a method to estimate energy use for water supply and greenhouse gas (GHG) emission rates associated with water production. Tampa Bay Water provides wholesale water for six utilities: Hillsborough County, Pasco County, Pinellas County, New Port Richey, St. Petersburg, and Tampa. The initial annual report on energy use and GHG emissions was presented in 2007 (Tampa Bay Water 2008). The most recent information for 2010 on the methodology and the results for the six utilities is presented in Tampa Bay Water (2011). The Tampa Bay Water method uses national databases for its model.

Energy-water efficiency simulation/optimization model

We have developed an urban water conservation evaluation model for Florida called EZ Guide as part of ongoing research. During the past year, three papers were accepted for publication in a national journal (Friedman et al. 2011, Morales et al. 2011) and a Florida water journal (Heaney et al. 2011) that describe the EZ Guide methodology. More complete information is available at web site for the Conserve Florida Water Clearinghouse (www.conservefloridawater.org). The current version of EZ Guide is available online and the data are uploaded automatically once the water utility boundaries are specified. The current funding does not provide support to include energy considerations in an in-depth manner. The funding from this project will allow us to add this critical element.

Energy Management in Water Systems

Urban water systems are required to deliver adequate quantities of water to customers continuously. The quality of this water must be suitable for drinking. This water must be delivered at suitable pressures. Sophisticated hydraulic simulation models are available to evaluate the flow rates, water quality, and pressures throughout the network. A current goal is real-time control of energy expenditures to meet these demands. We have partnered with Hillsborough County Water Utility Department to evaluate energy management options for their system. The primary work will be done by Mr. John McCary who is an engineer with Hillsborough County and a part-time PhD student at the U. of Florida.

Existing collaborations:

This project is made feasible by the research efforts during the past four years by the Conserve Florida Water Clearinghouse (CFWC) that is directed by Professor Heaney, the P.I. on this project. Details about CFWC can be found at our web site (www.conservefloridawater.org). The support from this project will allow us to expand our activities to incorporate the critical energy-water nexus that needs to be an integral part of evaluations of both water and energy options. Due to severe state budget cuts to Florida water agencies, our funding for 2011-13 has been reduced to $162,000 per year. Fortunately, other funding from the city of Sanford and the St. Johns River Water Management District, and the Water Research Foundation of the American Water Works Association will allow our research activities to continue.

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University of Florida

Low Cost Solar Driven Desalination

PI: James Klausner
Students: Fadi Alnaimat/Ph.D. Mechanical Engineering

Description: Water and energy scarcity poses a future threat to human activity and societal development around the world. The state of Florida is vulnerable to fresh water shortages. Florida ground water is contaminated in many locations from leaky underground tanks, agricultural pesticides, and other chemicals. Although it is possible to desalinate sea water, conventional systems are energy intensive. Solar energy utilization for desalination systems is being investigated to provide adequate fresh water for the state's needs. Solar diffusion driven desalination (DDD) system has been developed for both bulk water desalination and small community needs/disaster response. The research objective is to examine the best operating condition for the solar diffusion driven desalination (DDD) process using a computer models developed for the transient evaporation and condensation processes. The outcome of the study is the development of cost effective, low power consumption, and low maintenance desalination process that is powered by solar energy. Several operating modes for the solar DDD process have been investigated, and the best operating mode is used to design a small scale distillation unit. In addition, one of the main operational difficulties encountered in thermal distillation processes is the cooling requirement. Cooling is needed to reduce the condensing water temperature in the condenser to increase water production. In this study, the external cooling requirement has been tackled with a unique operating mode.

Budget: $252,000
Universities: UF

Progress Summary

There is significant interest to further explore solar diffusion driven desalination as a potentially low cost and low maintenance alternative to PV-RO systems. In this reporting period, the overall distillation performance of the solar DDD has been investigated under different design and operating conditions. The heat and mass transfer models developed by Alnaimat et al. [1] is used in the analysis. In this study, several operating modes for the solar DDD process have been investigated, and the best operating mode is used to design a small scale distillation unit. In addition, the solar heat input is recycled in a unique transient mode so that it does not require an external source of cooling water. A detailed analytical investigation suggests that this process can potentially produce 100 liters per day distilled water with an average specific electric energy consumption as low as 3.6 kW-hr/m^3 using a total of eight 2 m^2 solar collectors [1]. Water production and energy consumption have been investigated under various design and operating conditions. A unique operating mode has been explored to improve the water production and reduce the specific energy consumption. The study has shown that operation in the delayed mode significantly reduces the specific electric energy consumption compared with operation in the conventional mode. It is believed that the solar DDD process, with its low power consumption and low maintenance requirement is a competitive desalination technology that is well suited for small scale decentralized water production.

[1] F. Alnaimat, J.F. Klausner, R. Mei, Transient Analysis of Direct Contact Evaporation and Condensation Within Packed Beds, *Int. J. Heat Mass Transfer*, 54 (2011), pp. 3381–3393.

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

The process flow diagram is revised to enable a unique operation mode as shown in Fig. 1. Only one saline water tank (Tank 1) is used during operation. Fig. 2 shows the variable solar power input to the system over a twelve hour period, the saline water temperature response into the evaporator, and the corresponding fresh water temperature response into the condenser. The solar thermal input to the system is based on eight solar collectors; each has an aperture area of 2 m^2 and efficiency of 0.85. The total solar thermal input into the system over twelve hours of operation is 98.6 kW-hr. As the solar heat flux decreases, the system still has capacity for desalination due to the stored heat in the system. Further desalination is accomplished by recirculating the fresh water through the heat exchanger. At the same time, ambient saline water (25 °C) is pumped through the heat exchanger and fills the empty saline water tank (Tank 2). Heat is transferred from the fresh water to the saline water which fills the idle tank. During this process, the condenser cools down, and additional fresh water is produced. As shown in Fig. 2, after 8.5 hours saline fill water is directed through the heat exchanger to the idle tank. The feed saline water temperature to the evaporator (from Tank 1) drops as the system is cooled down by the fill water flowing to the idle tank. Operating the solar DDD facility in this manner is denoted as the *standard mode* of operation. Fig. 3 shows the total fresh water production and production rate for the 12 hour period with solar heating operating in the standard mode. It is evident that the fresh water production rate increases as the system increases in temperature. Also, there is a very high initial fresh water production rate when the fill period begins, and the production rate tails off during the three and a half hour fill period.

Fig. 4 shows the electric specific energy consumption during the distillation process operating in the standard mode. Initially the fresh water production rate is low, and thus the specific energy consumption is high. For approximately an 11 hour period after the first hour of operation the specific energy consumption is below 5 kW-hr/m^3 of fresh water, which demonstrates reasonably good performance. From approximately hours 10-12 the specific energy consumption increases because the production rate decreases with decreasing solar flux. At hour 8.5 when the fill process begins, the specific energy consumption is very low because the fresh water production rate is high, and then the specific energy consumption increases as the fresh water production rate decreases. The average specific energy consumption is 5.2 kW-hr/m^3 over the twelve hour desalination cycle. The average specific energy consumption compares well with RO systems, especially sea water PV-RO systems in which the specific energy consumption is typically 10-20 kW-hr/m^3.

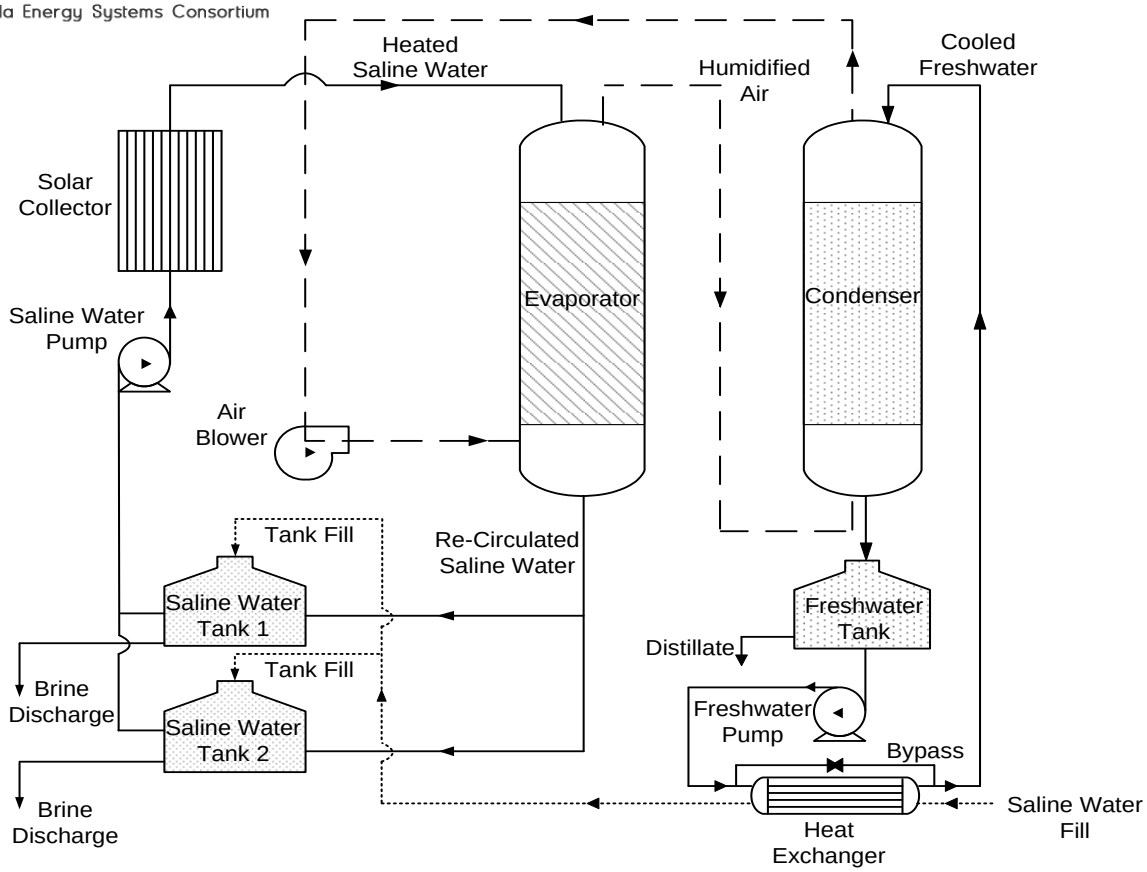

Figure 1: Process flow diagram

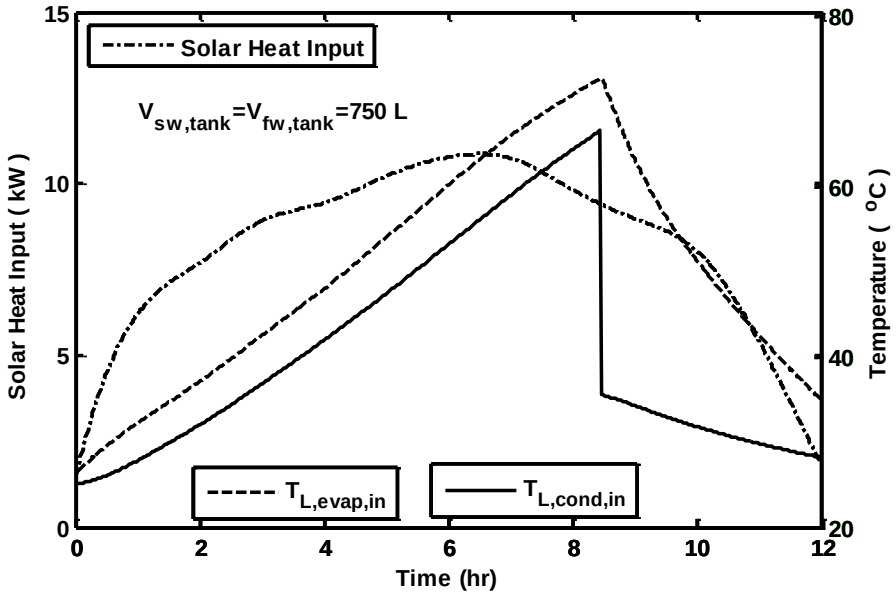

Figure 2: Solar thermal input, evaporator water inlet temperature, and condenser water inlet temperature; standard mode

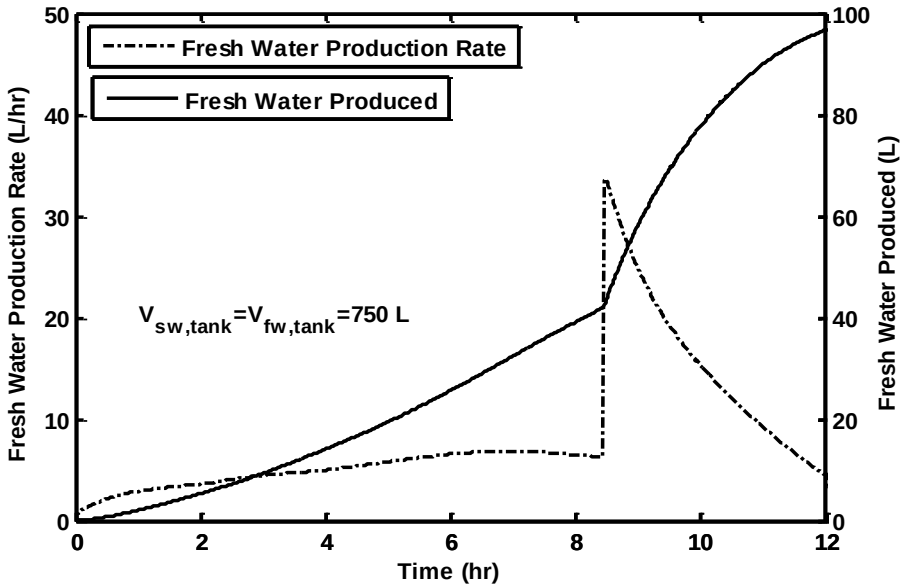

Figure 3: Total fresh water production and production rate; standard mode

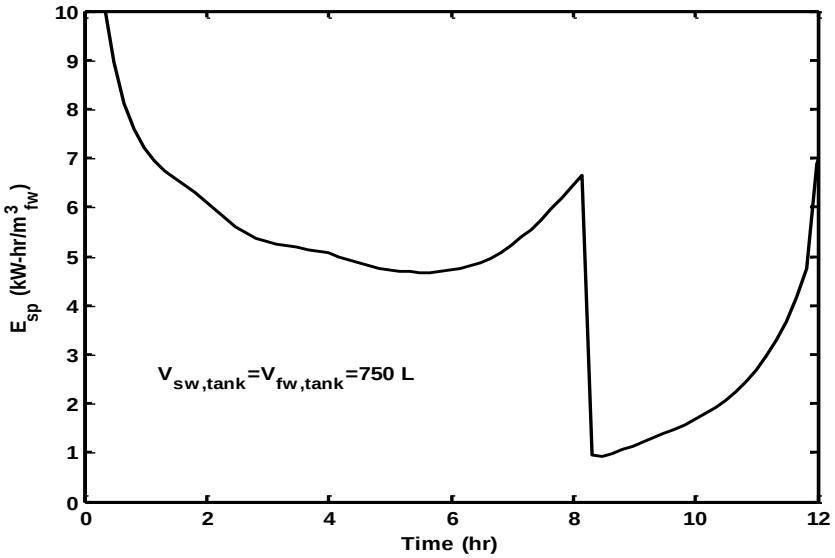

Figure 4: Electric specific energy consumption; standard mode

Examination of Figs. 2 and 3 reveal that the highest fresh water production rate coincides with the highest temperature in the saline water tank. In order to minimize the electric specific energy consumption, the distillation process should only be operational when the temperature of the saline water tank is sufficiently high to yield reasonable fresh water production rates. In order to improve on the specific electric energy consumption to drive the desalination process, it is not necessary to run the system when the solar flux is low and the specific energy consumption is high. Therefore, during the first three hours of operation, the saline water is only circulated through the solar collectors so that it heats up before the distillation cycle begins. The distillation cycle is initiated after three hours of heating the saline water with

the solar collectors. At approximately hour 8.5, the heat exchanger is switched into service and the tank refill process is initiated. The idle saline water tank is refilled in 3.5 hours, and the entire system is shut down at hour 12. Operation of the solar DDD facility in this manner is referred to as the *delayed mode* of operation. For operation in this delayed mode, the transient solar heat input, the saline water temperature into the evaporator, and fresh water temperature into the condenser are displayed in Fig. 5. The fresh water production and production rate are shown in Fig. 6, and Fig. 7 shows the corresponding specific electric energy consumption. It is observed that the total daily fresh water production is 100 liters per day (6.3 $l/m^2_{collector}$-day), as is the case for standard operation. However, the specific energy consumption is typically below 5 kW-hr/m^3, and the average specific energy consumption for the entire distillation cycle is 3.6 kW-hr/m^3, which is approximately a 30% reduction compared with the standard mode of operation.

Clearly, the delayed operating mode provides enhanced performance since the specific energy consumption is reduced. Approximately 8 solar collectors with 2 m^2 collector areas will be required to achieve 100 liter per day water production. For more or less production, the size of the system scales approximately linearly. This aforementioned system performance assumes that the system temperature drops back to the ambient temperature (25 °C) at the completion of each distillation cycle. When it is assumed that there is suitable insulation (especially around the saline water tank) to hold the system temperature at a temperature above ambient for the start each distillation cycle, the system performance will be enhanced.

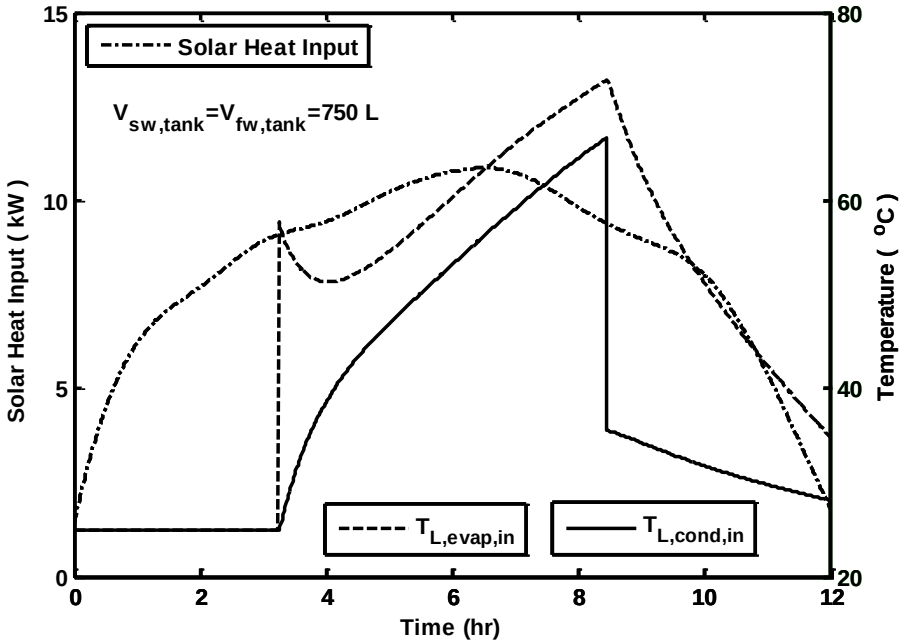

Figure 5: Solar heat input, saline water temperature into evaporator, and fresh water temperature into condenser; delayed mode

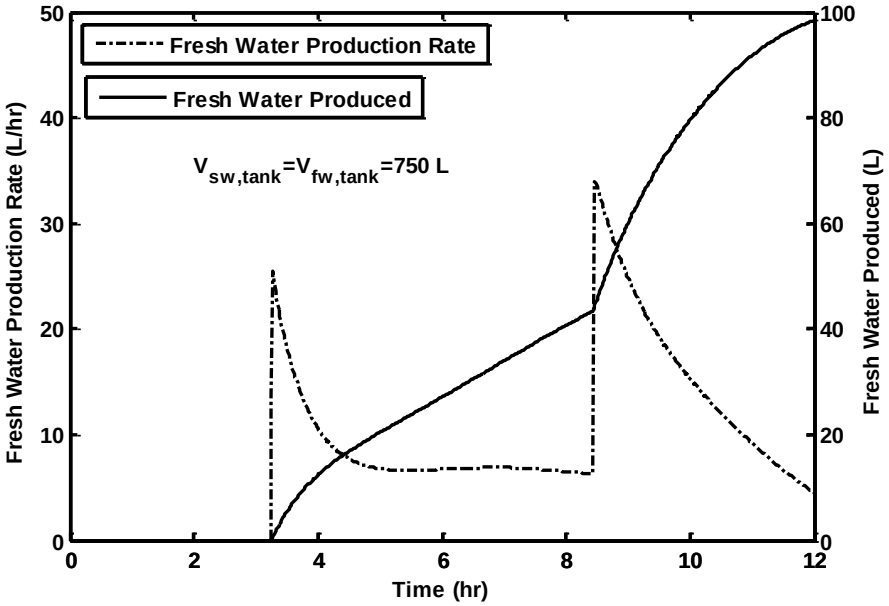

Figure 6: Total fresh water production and production rate; delayed mode

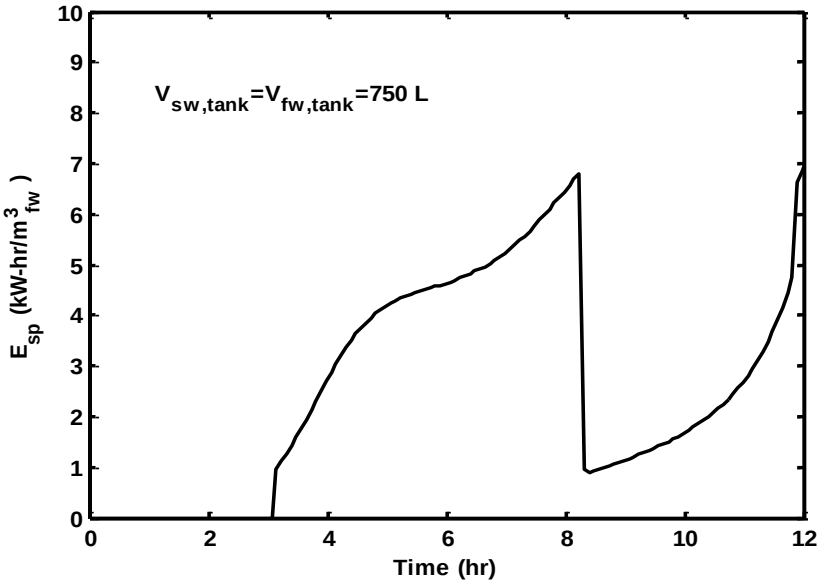

Figure 7: Specific electrical energy consumption; delayed mode

While fresh water production rate and specific energy consumption are essential to evaluate the performance of desalination processes, other factors such as simplicity, ease of operation, and low maintenance requirement are also important practical factors especially for decentralized water production. Clearly, this study has shown that operation in the delayed mode significantly reduces the specific electric energy consumption compared with operation in the conventional mode. It is believed that the solar DDD process, with its low power consumption and low maintenance requirement is a competitive desalination technology that is well suited for small scale decentralized water production.