Title: Phase II Bioenergy Production from MSW by High Solids Anaerobic Digestion

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ABSTRACT

High solids anaerobic digestion (HS-AD) is widely used in Europe and is gaining popularity in the US to produce biogas from the organic fraction of municipal solid waste (OFMSW), such as yard and food waste. HS-AD advantages include faster waste degradation and higher biogas quality than conventional or bioreactor landfills, lower water use and leachate production than liquid AD and production of a nutrient rich compost fertilizer product. Phase I of this project focused on: 1) improving methane (CH_4) yields from lignocellulosic waste by bioaugmentation with microbial communities from pulp and paper sludge, 2) evaluating the most appropriate technologies for implementing HS-AD of MSW in Florida and 3) identifying potential sites, collaborators and funding sources for a HS-AD demonstration project in Florida. In Phase II we propose to investigate co-digestion of yard and food waste and wastewater biosolids at varying temperatures (35, 45, 55 °C) in bench- and pilot-scale digesters. Experimental results will be integrated with life cycle cost analysis and environmental impact assessment studies to determine the most appropriate combination of waste sources and operating conditions for HS-AD to ensure environmental and economic sustainability.

INTRODUCTION & OBJECTIVES

Energy recovery from municipal solid waste (MSW) is commonly practiced in the US by collecting and utilizing landfill gas for heat, vehicle fuel or conversion to electricity using internal combustion engines or turbines. The most common strategy in the US for enhancing landfill gas production is through recirculation of leachate through the entire waste stream. Many landfills in Europe; however, separate the organic fraction of MSW (OFMSW) for energy recovery through anaerobic digestion (AD). This promotes faster OFMSW degradation, a higher biogas quality based on methane (CH_4) composition, lower fugitive greenhouse gas (GHG) emissions and production of a nutrient rich compost (also called digestate) that can be used as a fertilizer. Depending on the total solids (TS) concentration of the substrate, anaerobic digestion can be applied under wet ($\leq$ 10% TS), semi-dry (11-19% TS) or high solids ($\geq$20%TS) conditions. Advantages of High Solids AD (HS-AD; also known as solid-state AD [SS-AD] or dry fermentation) include lower parasitic energy losses, reduced water use and leachate production and recovery of nutrients as a compost product.

The overall goal of this project is to improve the environmental and economic sustainability of HS-AD of OFMSW in Florida. Specific objectives for Phase II (Fig. 1) are to:

1. Investigate the performance of HS-AD of OFMSW with varying substrate ratios (yard, food, biosolids) and temperatures (35, 45, 55 °C).
2. Apply life cycle analysis (LCA) to guide the selection of waste sources and operating conditions for HS-AD and
3. Compare HS-AD with other waste management options (e.g., landfilling, waste to energy (WtE), composting) to ensure economic and environmental sustainability.

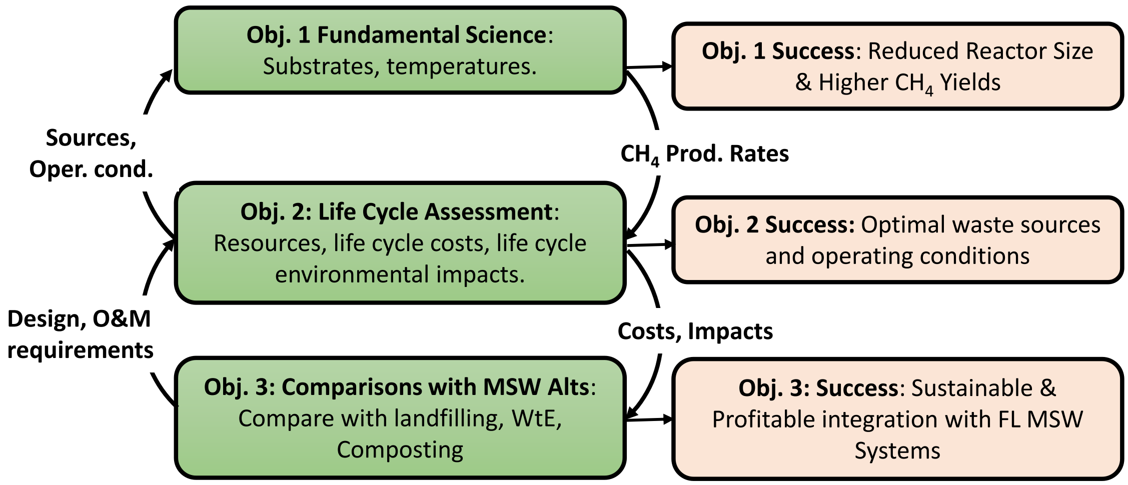

Fig. 1: Overall research approach and measures of success.

Through these objectives we will address the following 2016-2017 Hinkley research agenda items:

(2) Research is needed to develop and/or recommend viable uses for or management strategies other than landfill disposal of dewatered biosolids.

(4) Anaerobic digestion of solid waste and green waste is well established in Europe and has been gaining popularity in the US for recovering energy from food and yard waste and for producing a compost product. What are the barriers to implement this technology in Florida?

(8) Exploratory research is needed to focus on the energy and water footprints of the management of "food waste." Life cycle and water footprint analyses could be used under various scenarios of generation and disposal to evaluate energy and water costs associated with strategies for managing and recycling food waste.

(12) Research is needed for economic comparison of (a) landfilling versus (b) single stream recycling versus (c) waste to energy.

LITERATURE REVIEW

HS-AD is defined as any fermentation process performed on a non-soluble material that acts both as physical support and source of nutrients in absence of free flowing liquid. Feedstocks for these systems are stackable porous mixtures, including food waste, yard debris and crop residues, which can be moved using screw augers, high-power pumps, conveyer belts or front-end loaders. Both batch and continuous reactors have been used for HS-AD and they can be operated under either mesophilic or thermophilic conditions. In batch systems, such BIOFerm and SmartFerm systems, the waste is initially loaded into anaerobic cells using front-end loaders. Biomass is mixed with leachate and digestate to establish the appropriate solids concentration and microbial community. Leachate is recirculated as a form of mixing and to minimize the potential for volatile fatty acid (VFA) accumulation within the digester. Continuous reactors, such as Dranco, Kompogas, and Valorga, are currently in-use on an industrial scale in Europe. The Dranco process is a vertical plug flow system where fresh feed is mixed with digested waste and pumped to the top of the reactor. The Kompogas system involves horizontal plug flow reactors with slowly rotating impellers to homogenize and degas the system. In the Valorga system, horizontal plug flow occurs in a circular pattern and mixing occurs through the biogas recirculation from the bottom of the reactor (Lissens et al., 2001).

Food and yard waste make up approximately 25% of the overall MSW waste stream in the US. Co-digestion of food and yard waste has been shown to be advantageous because food waste provides an abundance of nitrogen (N) and yard waste serves as an adequate carbon (C) source. The appropriate balance of C/N is essential for efficient digestion; C/N ratios in the range of 20/1and 30/1 are considered good, with ~25/1 being optimal (Li et al., 2011; Kothari et al., 2014). Incorporation of biosolids as a co-substrate with food and yard waste in HS-AD has the potential to improve substrate characteristics and increase bioenergy production. In addition, biosolids management is increasingly expensive for Florida wastewater facilities due to relatively limited L-AD capacity for biosolids, stringent recent regulations on land application of biosolids and the high cost of biosolids disposal in landfills (Forbes, 2011). Co-digestion of biosolids and food waste is common in L-AD systems and is currently being done at the Reedy Creek Improvement District's Harvest Energy Facility (Sorensen, 2014). However, there is limited information on the incorporation of biosolids into HS-AD systems.

Although HS-AD has many advantages and has been promoted in Europe to recover energy from the OFMSW, the assessment of the environmental sustainability of HS-AD technologies is generally lacking. Various LCA studies have been conducted to evaluate and compare commonly used waste management strategies, such as landfilling, incineration, recycling of paper and plastics, wet AD and composting (Bernstad and la Cour Jansen, 2012). The systems evaluated in each study were different, but in general recycling of material and recovery of energy has been shown to result in lower environmental impacts and overall costs. Several LCA studies have specifically focused on quantifying the environmental sustainability of AD for MSW management (Haight, 2005; Edelmann et al., 2005; Kim and Kim, 2010; CIWMB, 2009; Zaman, 2009; Morris et al., 2011; Levis and Barlaz, 2011; Bernstad and la Cour Jansen, 2012). AD has been shown to provide environmental advantages over incineration WtE, landfill with landfill gas to energy (LFGTE), bioreactor landfill with LFGTE, and advanced thermal treatment (ATT) (gasification and pyrolysis) by more efficiently recovering energy from OFMSW with lower emissions. Based on the waste management hierarchy identified in previous studies (Edelman et al. 2005) and previous LCA studies on AD, HS-AD might be considered as a preferred waste management method because it can efficiently recover energy and nutrients. However, no life cycle environmental and cost analysis studies specifically on HS-AD technologies have been found in the literature. These studies are needed to compare the environmental and economic performance of HS-AD with other strategies, and to guide technology improvement.

PHASE I ACCOMPLISHMENTS

Phase I of this project was funded by the Hinkley Center's 2014-2015 solicitation and began on August 18, 2014 and was completed March 1, 2016. A draft report was submitted to the TAG on February 1, 2016, and their comments were incorporated into the project final report (Ergas et al., 2016). The overall goals of Phase I were to evaluate the potential for HS-AD in Florida and to improve the rate of CH_4 production during HS-AD of the OFMSW. Specific objectives were to: 1) evaluate the most appropriate technologies for implementing HS-AD of OFMSW in Florida, 2) carry out fundamental research at bench- and pilot-scale to improve the biodegradability of lignocellulosic waste through co-digestion with P&P, and 3) identify potential sites, collaborators and funding sources for a large scale HS-AD demonstration project in Florida The following is a summary of the major findings (see our final report and http://mbr.eng.usf.edu/yardwaste/ for additional information).

State of the art of HS-AD

A review of the published and grey literature and interviews with MSW and HS-AD industry professionals was carried out. In addition, six HS-AD facilities were visited in California and the Netherlands by RA Hinds and PI Ergas. OFMSW AD is well-established in Europe; as of 2014 there were 244 full-scale AD facilities processing ~8 million tons per year (TPY) of OFMSW (De Baere and Mattheeuws, 2012). Approximately 89% of this capacity were "stand-alone" systems treating only OFMSW, 62% were HS-AD, and 70% installed since 2009 was HS-AD. In the US, eight full-scale HS-AD facilities are currently in operation, with a total capacity of 189,600 TPY. Another 19 HS-AD projects were identified that are in the planning, permitting, or construction phases. In general, there has been a preference in the US for simple technologies, such as batch-type thermophilic digesters, over more complex systems. These systems are capable of processing a range of OFMSW sources and the digestate is considered compost based on the USEPA's *Process to Further Reduce Pathogens* (PFRP) program. These systems are currently also the most suitable for HS-AD in Florida. Other more advanced HS-AD technologies, such as continuous and multi-stage systems, may offer future advantages depending on industry and legislative developments.

Key factors affecting the economics of HS-AD include the quality, quantity, and proximity of available feedstocks, markets for compost, energy, and renewable energy credits (RECs), and the development of public-private partnerships. Source-separation of OFMSW was found to be a critical factor affecting the economics of HS-AD, as it improves energy recovery and enables the production of quality marketable compost. The banning of organics in landfills has been shown to rapidly accelerate HS-AD implementation. HS-AD has also been implemented at landfill sites for preprocessing comingled MSW prior to disposal. This practice improves energy recovery, saves landfill space, reduces GHG emissions, and reduces leachate generation at landfill sites.

Increase the Biodegradability and Methane Yield of Lignocellulosic Waste

Side-by-side bench-scale HS-AD experiments were carried out with yard waste inoculated with P&P and domestic wastewater anaerobic digester sludge (WW-AD). Average CH_4 yield with the bioaugmentation strategy reached 100.2 ± 2.4 L CH_4/kg VS, a 72.7% enhancement compared with WW-AD sludge (58.1 ± 1.2 L CH_4/kg VS) over 106 days of batch digestion under mesophilic conditions (Fig. 2). Trends in the evolution of leachate VFA concentrations suggested that hydrolysis was accelerated in the bioaugmented digesters, causing methanogenesis to become rate-limiting. Additional experiments were carried out to determine if the enhancement could be sustained through recirculating digestate from the initial digesters, resulting in a 68.5% enhancement of CH_4 yield (Fig. 3). The observed improvements were comparable to thermal and chemical pretreatment methods; however, P&P bioaugmentation could be a lower cost and less resource intensive alternative to pretreatment and improve the overall sustainability of HS-AD processes.

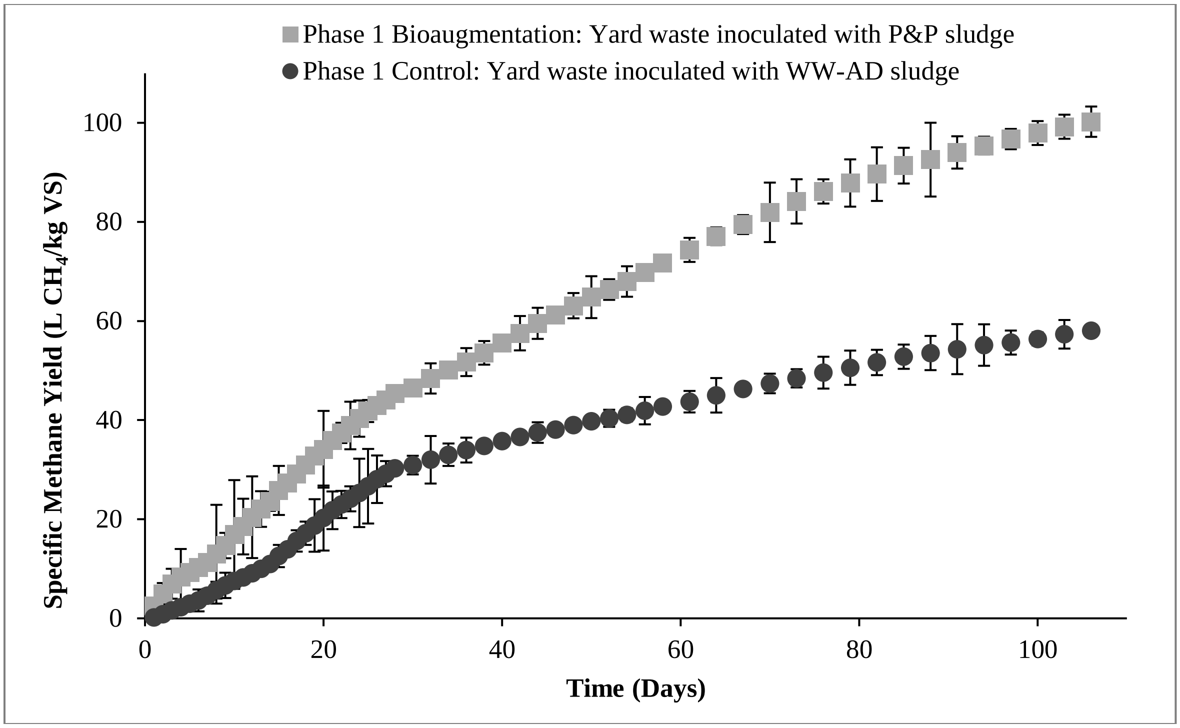

Fig. 2: Specific CH_4 yields observed in Phase 1 of batch HS-AD over 106 days; error bars represent standard deviations of samples run in triplicate.

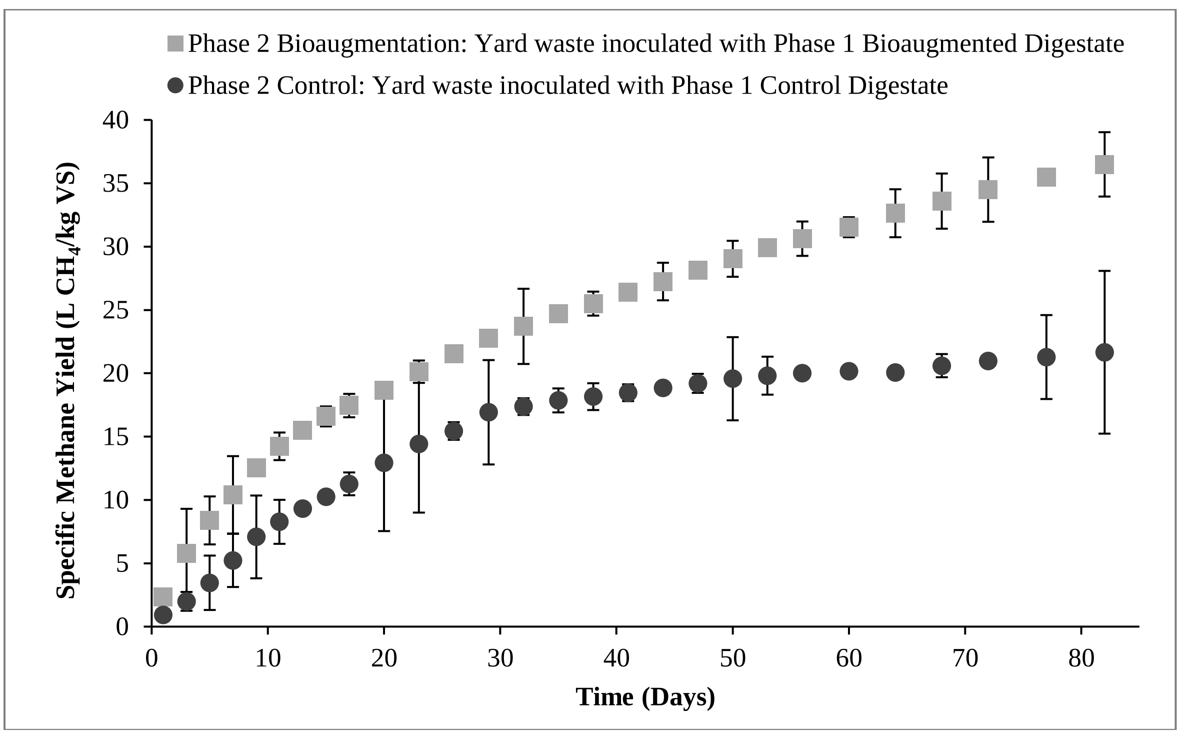

Fig. 3: Specific CH_4 yields observed in Phase 2 of batch HS-AD over 82 days; error bars represent standard deviations of samples run in triplicate.

Preliminary experiments were also carried out to investigate co-digestion strategies for improving the efficiency of HS-AD. Yard waste was co-digested with food waste and biosolids. Addition of food waste and biosolids led to increases in specific CH_4 yields, but reduced system stability due to high VFA production. Oyster shells were identified as a waste product that could be used as an alkalinity source (Sengupta et al., 2007) and were shown to enhance the stability of HS-AD during digestion food waste. A pilot-scale HS-AD reactor was constructed and preliminary experiments were carried out exploring the effects of scale on HS-AD.

Potential for HS-AD in Florida

A detailed review of MSW management trends in Florida was carried out, with a focus on recent trends in OFMSW generation, management and legislation. This information was used to identify locations where HS-AD would be most promising based on existing MSW infrastructure and potential for bioenergy production, GHG emissions reductions and nutrient recovery. Based on this research, it was found that there is a need for organics recycling infrastructure in Florida. The statewide recycling rate could be increased by as much as 13% through HS-AD of OFMSW. Based on 2014 food waste and yard waste generation, approximately 500 MW (4,000 GWh/year) of energy could be recovered from OFMSW via HS-AD, equating to approximately 175 MW (1,500 GWh/year) of electricity (~ 0.6% of Florida's electricity demand) and 325 MW of usable heat energy if the CH_4 were to be used in combined heat and power (CHP) units, or equating to nearly 80 million diesel gallon equivalents (DGEs) of compressed natural gas (CNG; ~ 11.5% of Florida's CNG vehicle fuel demand) if the CH_4 were converted to CNG. Additionally, more than 7,000 tons of nitrogen and 3,500 tons of phosphorous could be recovered annually and at least 660,000 metric tons of GHGs (as CO_2 equivalents) could be offset.

Miami-Dade, Broward, Palm Beach, Hillsborough, Orange, Pinellas, Duval, Lee, and Alachua Counties were identified as the most feasible counties for HS-AD implementation based on their high demand for OFMSW recycling and existing MSW infrastructure. Initial demonstration projects should be located at the University of Florida, University of South Florida or existing landfill composting sites. The low cost of energy and landfilling in Florida, lack of legislation incentivizing OFMSW recycling, and lack of markets for compost and RECs were identified as barriers to HS-AD implementation in Florida. Recommended policies to promote the transition to HS-AD include banning recyclables from landfills (including organics), source-separation mandates, pay-as-you-throw and extended producer responsibility policies.

PHASE II SCIENTIFIC APPROACH

As stated previously, the specific objectives of Phase II are to carry out additional bench- and pilot-scale studies to investigate the effect of varying yard waste, food waste and biosolids ratios, and temperatures on HS-AD performance; use LCA to guide waste source selection and operating conditions; and to compare the environmental and economic sustainability of HS-AD, landfilling, WtE and composting.

Task 1: Bench-Scale Studies

Bench-scale studies (Table 1) will be carried out to investigate CH_4 yields, VS destruction and biogas and digestate quality with varying substrate ratios (yard waste, food waste, biosolids) and temperatures (35, 45, 55 °C). Protocols have recently been developed in our laboratory to ensure reproducibility and homogeneity of substrate mixtures. For example, food waste will consist of typical ratios of fruit, vegetables, bread, egg and meat products. Yard waste will consist of oak leaves, pine needles, grass clippings and eucalyptus chips. Dewatered biosolids will be collected from Hillsborough County's Falkenberg Advanced Water Reclamation Facility. WW-AD sludge obtained from a local wastewater treatment facility (Clearwater FL) will be used as an inoculum. Bench-scale studies will be conducted using well-established lab protocols (Owens and Chynoweth, 1993; Angelidaki et al., 2009). Each digestion set will consist of six digesters (feedstock [initial], four intermediates and digestate [final]). Digesters will be set up in 250-mL glass bottles, sealed with crimp caps with septa, and placed in thermostatically controlled incubators. TS content will be set at 20% and the substrate to inoculum (S/I) ratio will be set at 1/1 on a VS basis based on prior studies (Rapport et al., 2008; Li et al., 2011; Brown and Li, 2013; Chen et al., 2014). Three blank digesters (with only inocula) will be prepared for each set to correct for CH_4 yields from the inocula.

Biogas production and quality will be measured daily for the first 30 days and 2-4 times weekly thereafter (as biogas generation rates decrease). Biogas volume will be measured volumetrically (Jerger et al., 1982; Owens and Chynoweth, 1993). Biogas CH_4 content will be determined by dissolving the CO_2 portion of biogas samples into a NaOH barrier solution (ASTM D1827-92, 2002). Biogas hydrogen sulfide (H_2S) concentration will be measured using RAE colorimetric gas detection tubes. Chemical analyses will be performed on liquid samples from the initial, final and intermediate digesters. Samples will be diluted with deionized (DI) water at a 1/2 ratio, mixed vigorously, and centrifuged to obtain a representative liquid fraction (EPA Method 9045D; EPA, 2004). *Standard Methods* (APHA, 2012) will be used to measure pH (4500-H+B) and alkalinity (2320B), VFA (10240), soluble chemical oxygen demand (sCOD; 5200B), total ammonia nitrogen (TAN; 10031), total nitrogen (TN; 10072), and total phosphorous (TP; 8190) concentrations. The total mass (wet weight) of digester contents will be measured at the beginning and end of each experiment. TS and VS will be measured using *Standard Methods* (2540). Ash from sample volatilization will be diluted and preserved for elemental analysis (Na, K, Ca, Mg, Fe, Cu, Cr, Ni, Zn, Pb, Co, Mo, Se, and Mn) by induced coupled plasma mass spectrometry (ICP-MS) at USF's Center for Geochemical Analysis.

Table 1. Experimental design of bench and pilot-scale experiments.

<table>
<tr><th>Stage</th><th>Scale</th><th>Substrate</th><th>Temp. °C</th><th>Effect of:</th></tr>
<tr><td rowspan="3">I</td><td rowspan="3">Bench</td><td>YW, FW</td><td rowspan="3">35</td><td rowspan="3">BS and OS</td></tr>
<tr><td>YW, FW, BS</td></tr>
<tr><td>YW, FW, BS, OS</td></tr>
<tr><td>II</td><td>Bench</td><td>YW, FW, BS*</td><td>35, 45, 55</td><td>Temperature</td></tr>
<tr><td>III</td><td>Bench</td><td>YW/FW/BS*</td><td rowspan="3">Based on Phase II</td><td>Substrate ratios</td></tr>
<tr><td>IV</td><td>Pilot</td><td>YW, FW, BS*</td><td>Scale</td></tr>
<tr><td>V</td><td>Pilot</td><td>Based on LCA</td><td>Data for LCA</td></tr>
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YW = yard waste, FW = food waste, BS = biosolids, OS = oyster shells
*oyster shell addition based on Stage I results.

Task 2: Life Cycle Assessment

Potential feedstocks for HS-AD include municipal (yard waste, biosolids), industrial (e.g. food manufacturers), institutional (e.g. schools, hospitals), commercial (e.g. supermarkets, restaurants) and residential wastes. Differences between these waste resources include composition, centralization of locations and required collection methods. For example, industrial wastes can be considered point sources (centralized) and collection and transportation inputs involved are relatively low compared with residential wastes (decentralized). On the other hand, energy production in HS-AD is dependent on the substrate mix and operating conditions (e.g. temperature, CH_4 enhancement strategies). LCA can be used to investigate tradeoffs between energy consumption in collection, transport and processing and production in HS-AD. A screening level LCA will initially be conducted considering collection, transportation and processing using Hillsborough County as a case study. Potential industrial, institutional and commercial waste sources will be mapped using GIS to estimate transportation distances. Energy consumption associated with residential waste collection and transport will be obtained from Hillsborough County's MSW Management System. Potential CH_4 production from different waste sources and conditions will be obtained from the literature and bench- and pilot-scale experiments (Table 1). The system boundary will be cradle-to-gate (waste collection, transportation, processing) and the functional unit will be 1 L CH_4 produced. The impact categories will include cumulative energy demand, GHG emissions, acidification and eutrophication. Results from the screening level LCA will guide the selection of waste sources and operating conditions for the second round pilot scale experiments (Stage VI in Table 1).

Task 3: Pilot-Scale HS-AD System

A pilot-scale HS-AD system (Fig. 4) was constructed in-house during Phase I. The unit is equipped with a 40-L tank for AD, a Wet-Tip gas meter for monitoring biogas production and a tank and pump system, which allows leachate recirculation to provide homogenization and mixing. A temperature control system is used to maintain controlled temperature conditions. The reactor will initially be filled with yard waste, food waste and biosolids and inoculated with WW-AD (Stage IV Table 2) for comparison with bench scale studies (Task 1) and to provide baseline data for LCA studies (Task 2). Once the first round of tests is completed, the pilot reactor will be operated based on the results suggested by the LCA. The duration of the pilot-scale experiments will depend on bench-scale results, but the anticipated time-frame is between 60 and 90 days.

Fig. 4. Pilot-scale HS-AD system.

Task 4: Life Cycle Cost Analysis

A LCCA will be conducted using the present value method to compare different waste management strategies including HS-AD, landfilling, WTE, and composting. Since different strategies will have different beneficial products, for example, energy and compost from HS-AD, energy from WTE facilities, and compost from composting facilities, the comparison will be based on the dry weight of waste processed. Locations of existing landfills, WTE, and composting facilities will be mapped using GIS to estimate collection and transportation costs. The LCCA will include infrastructure, operation, maintenance, collection and transportation costs and revenue from beneficial products. HS-AD infrastructure costs will be obtained from literature and existing HS-AD installations in other states (see Phase I final report). For other management strategies, cost information will be obtained from Hillsborough County's MSW Management System.

PROJECT TIMELINE AND MILESTONES

Table 2. Timeline for Project Completion of Phase II (proposed start date 1/1/2017):

No.	Task/Activity Description	Start Month	Complete Month	Deliverables/ Outputs	
1	Bench-Scale Studies	1	8	Data for LCA	Quarterly Reports 1 & 2
2	Screening Level LCA	1	8	Journal Publication	
3	Pilot Studies	4	11	Data for LCCA	Quarterly Reports 3 & 4
4	LCCA	6	11	Journal Publication	
5	Draft & Final Report	10	12	Draft & Final Report	
6	Education and Outreach	1	12	Publications & Presentations to K-12, USF Students, Professionals & Community Members	

PRACTICAL SPECIFIC BENEFITS FOR END USERS

HS-AD has a number of benefits for Florida MSW managers due to the high availability of OFMSW, warm climate and high energy demands in urban areas (see results from Phase I on pp. 7 or this proposal for specific benefits). Benefits of HS-AD include: 1) diversion of organic waste from landfills, 2) higher bioenergy production rates than conventional landfills or landfill bioreactors, 3) reduced fugitive GHG emissions, 4) lower leachate production and improved leachate quality and 5) production of a compost product that can be sold or used by municipal agencies or community members.

PROJECT DELIVERABLES AND DISSEMINATION PLAN

Project deliverables will include, quarterly progress reports, a draft and final technical report, a project website, TAG meeting slides and videos and photos and tracking information for faculty, staff and students working on the project. In addition, results from this project will be disseminated to a variety of stakeholders including FDEP, USEPA and county regulators, county solid waste directors and their staff, private waste management companies and other associated industries, university and K-12 students, engineers, operators, scientists and community members. This will be done through: TAG meetings, presentations at regional and national conferences, manuscripts submitted to professional and peer reviewed journals, incorporation of research into courses taught by the PIs, USF student theses and dissertations and outreach activities to K-12 students and the wider community. The co-PIs are faculty advisors to USF student chapters of the Florida Water Environment Association (FWEA) and the American Water Works Association (AWWA). Students in these service organizations regularly participate in outreach activities, such as USF's Engineering Expo (http://expo.eng.usf.edu/) and FWEA's Florida Water Festival (http://www.fwea.org/water_festival.php). Displays and activities at these events will provide a opportunity to educate K-12 students, teachers and families about biological waste-to-energy technologies. The proposed research will also be integrated into two courses taught by the co-PIs (Biological Principles in Environmental Engineering and Green Engineering).

Our past performance attests to our commitment to research dissemination. Phase I research has been disseminated through reports to the Hinkley Center (5 quarterly and 1 final), 1 MS thesis (Hinds, 2015), 3 newsletter articles, 10 poster presentations and one platform conference presentation (GWMS; 1st prize for best student presentation). Outreach activities have included displays and presentations at USF's Engineering Expo and Learning Gate Community School (an environmentally focused charter school in Tampa). A book chapter entitled, Microbial Biomethane Production from MSW Using HS-AD, has been accepted for publication in the book, *Microbial Fuels: Technologies and Applications* (CRC press-Taylor & Francis). A second manuscript has been submitted to the journal *Environmental Engineering Science* for a special issue on Innovative Global Solutions for Bioenergy Production.

BUDGET & JUSTIFICATION

The budget for the project is shown in Table 3. Salaries are requested for two graduate research assistants and one undergraduate research assistant who will carry out the day-to-day work on the project. Benefits include fringe benefits, health insurance and graduate student tuition. Materials and supplies are requested for glassware, chemicals, laboratory gases, and other miscellaneous supplies needed to carry out bench and pilot-scale studies. Travel funds are requested to collect materials and samples, attend meetings and disseminate results. The USF College of Engineering is providing matching for PI effort in the revised budget.

Table 3: Project budget.

Budget Category	Hinkley Center	USF
PI summer salary		3,639
Graduate research assistants	34,020	
Undergraduate research assistants	4,000	
Benefits	3,693	997
Domestic travel	2,461	
Materials & supplies	3,000	
Tuition	11,826	
Total Project	**$59,000**	**$4,636**

PLAN FOR SEEKING FUNDING FROM OTHER SOURCES

During Phase I of this research we were very successful with leveraging additional funds for Hinkley Center research and we plan to continue this strategy during Phase II. Additional funds for Phase I included the following:

1) MS student, Greg Hinds, was partially supported by scholarships from the National Science Foundation (NSF) and the USF Foundation Stessel Fund,
2) Undergraduate RA, Ariane Rosario, was partially supported (40%) by the College of Engineering research Experience for Undergraduates (REU) program,
3) Undergraduate RA, Lensey Casimir, was fully supported by a NSF REU site program,
4) Plant City High School science teacher, Matthew Dawley, was fully supported through an NSF Research Experience for Teachers (RET) site program,
5) A team of eight graduate and undergraduate engineering students carried out a feasibility study for a 5,000 tpy HS-AD facility at USF as a Green Engineering class project,
6) A visiting doctoral student from Prague University of Chemistry & Technology, Natalia Anferova, was funded by the EU as part of a Marie Curie International Research Staff Exchange Scheme Biological Waste to Energy Technologies (BioWET) grant,
7) PhD student, Phillip Dixon, was partially supported as a teaching assistant (TA) to carry out research on the effect of biosolids addition on biogas production during HS-AD.

We are also currently seeking funding from the Department of Energy (DoE) for collaborative research with Hinkley researchers, Drs. John Kuhn and Babu Joseph, related to biogas production from OFMSW using HS-AD combined with conversion of biogas to liquid fuels. Other future research directions include: 1) availability and biodegradability of other waste biomass resources (e.g. crop and forest residues), 2) application of HS-AD in developing countries (e.g. for CH_4 production from fecal sludge), 3) development of integrated LCA-economic assessment tools to assist in HS-AD decision making, 4) transportation related research (with Dr. Yu Zhang from our Transportation Engineering group). Funding sources include DoE, NSF, USEPA, USDA and USAID.

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degradation of corn stover. *Process Biochem*. 40, 2371–2377.
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Zhao, J., Zheng, Y., Li, Y. 2014. Fungal pretreatment of yard trimmings for enhancement of methane yield from solid-state anaerobic digestion. *Bioresour Technol*. 156, 176–81.

TAG MEMBERS PHASE II

The following individuals are knowledgeable about areas of the subject research and have committed to serve as advisors and peer reviewers to the researchers to ensure project success. These persons will form a project "Technical Awareness Group" (TAG) and will attend at least two (2) TAG Meetings and to read and comment on the Project's Draft Final Report.

Name	Affiliation/Title	Email
Chris Bolyard	Area Biosolids Manager Organic Growth Group, Waste Management, Inc.	cbolyard@wm.com
Stephanie Bolyard	Program Manager of Research and Scholarships, Environmental Research & Education Foundation	sbolyard@erefdn.org
Bruce Clark	Project Director, SCS Engineers	bclark@scsengineers.com
El Kromhout	Professional Geologist, FDEP, Permitting & Compliance Assistance Program	Elizabeth.Kromhout@dep.state.fl.us
Karen Moore	Environmental Administrator FDEP, Waste Reduction & Recycling Program	Karen.S.Moore@dep.state.fl.us
Melissa Madden	Environmental Consultant – Solid Waste, FDEP, Southwest District	Melissa.Madden@dep.state.fl.us
Wendy Mussoline	Postdoctoral Researcher, University of Florida	wmussoli@ufl.edu
Juan R. Oquendo	Senior Water Resources Principal, Gresham, Smith & Partners	juan_oquendo@gspnet.com
Debra R. Reinhardt	Asst. VP for Research & Commercialization, University of Central Florida	debra.reinhart@ucf.edu
Larry Ruiz	Landfill Operations Manager, Hillsborough County	ruizle@hillsboroughcounty.org
Beth Schinella	Operations & Maintenance Division, Hillsborough Co. Public Utilities Department	SchinellaB@HillsboroughCounty.org
Luke Mulford	Senior Professional Engineer Hillsborough Co., Public Utilities Dept.	MulfordL@HillsboroughCounty.ORG
Adrie Veeken	Research & Business Developer Attero, The Netherlands	adrie.veeken@attero.nl
Ramin Yazdani	Senior Civil Engineer, Division of Integrated Waste Management Yolo County, CA	ramin.yazdani@yolocounty.org
Wester Henderson	Hinkley Center	wester.henderson@essie.ufl.edu
John Schert	Hinkley Center	jschert@ufl.edu

GRADUATE STUDENTS PREVIOUSLY FUNDED BY HINKLEY CENTER FUNDING

The following is a list of graduate students who were funded or partially funded (e.g. through provision of research supplies) during Phase I of this project, and includes their job title, current employer and contact information:

Name	Degree at USF	Current Title	Current Employer	Contact Information
Gregory Hinds	MSEV 2015	Staff Engineer	Wildscape Engineering, Inc. S. Lake Tahoe, CA	ghinds@mail.usf.edu 530-401-0000
George Dick	MSEV 2015	Water Resources EI	Gresham, Smith & Partners, Tampa, FL	George_dick@gspnet.com 813-769-8961
Natalia Anferova*	Visiting PhD student	Doctoral candidate	Prague University of Chemistry & Technology	natasha.anf@gmail.com
Phillip Dixon*	PhD (in progress)	Research Assistant	University of South Florida	phillipdixon@mail.usf.edu 508-728-6125

*received funding for research supplies from Hinkley Center.

SARINA J. ERGAS, PhD, PE, BCEE

Professor & Graduate Program Director
Phone: (813) 974-1119, Fax: (813) 974-2957
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Dept. Civil & Environmental Engineering
University of South Florida
4202 E Fowler Avenue, ENB 118
Tampa, FL 33620

Professional Registration

Professional Engineer, Commonwealth of Massachusetts, Civil Engineering, 1995-present
Board Certified Environ. Engineer, Specialization: Water Supply/Wastewater Engineering, 2012-present

Education

Humboldt State Univ., Arcata, CA	Environmental Engineering	B.S.	1988
University of California, Davis, CA	Civil Engineering,	M.S.	1990
University of California, Davis, CA	Civil & Environmental Engineering	Ph.D.	1993

Academic Appointments

2011-present	Professor	Civil & Environ. Engineering., Univ. South Florida
2009-2011	Assoc. Professor	Civil & Environ. Engineering., Univ. South Florida
2009-2010	Professor	Civil & Environ. Engineering, Univ. Massachusetts, Amherst
2000-2009	Assoc. Professor	Civil & Environ. Engineering, Univ. Massachusetts, Amherst
1994-2000	Asst. Professor	Civil & Environ. Engineering, Univ. Massachusetts, Amherst
2007-2008	Fulbright Fellow	Civil, Environ. & Ag. Engr., Technion Israel Inst. Technol.

Selected Publications

Wang, M., Lee, E., Dilbeck, M.P., Liebelt, M., Zhang, Q., Ergas, S.J. (2016) Thermal Pretreatment of Microalgae for Biomethane Production: Experimental Studies, Kinetics and Energy Analysis, *J. Chemical Technology & Biotechnology*, in press.

Aponte-Morales, V., Tong, S., Ergas, S.J. (2016) Nitrogen removal from anaerobically digested swine waste centrate using a chabazite - sequencing batch reactor (chabazite-SBR), *Environmental Engineering Science*, in press.

Kinyua, M.N., Trimmer, J., Izurieta, R. Cunningham, J., Ergas, S.J. (2016) Viability and Fate of *Cryptosporidium parvum* and *Giardia lamblia* in Tubular Anaerobic Digesters, *Science of the Total Environment*, 554–555 (2016): 167–177.

Kinyua, M.N., Zhang, J., Camacho-Céspedes, F., Tejada-Martinez, A., Ergas, S.J. (2016) Physical and Biological Process Modeling of Tubular Anaerobic Digesters Treating Swine Waste in Rural Costa Rica, *Biochemical Engineering J.* 107(2016):35-44.

Kinyua, M.N., Rowse, L., Ergas, S.J. (2016) Review of Small-Scale Tubular Anaerobic Digesters Treating Livestock Waste in the Developing World, *Renewable Sus. Energy Rev.*, 58: 896–910.

Wang, M., Yang, H., Ergas, S.J. van der Steen, P (2015) A novel shortcut nitrogen removal process using an algal-bacterial consortium in a photo-sequencing batch reactor (PSBR), *Water Research*, 87:38-48.

Manser, N., Mihelcic, M., Ergas, S.J. (2015) Semi-continuous mesophilic anaerobic digester performance under variations in solids retention time and feeding frequency, *Bioresource Technol.*, 190: 359-366.

Manser, N., Wald, I., Ergas, S.J., Izurieta, R., Mihelcic, J. (2015) Assessing the Fate of *Ascaris suum* Ova during Mesophilic Anaerobic Digestion, *Environmental Science & Technology*, 49(5): 3128-3135.

Krayzelova, L., Lynn, T.J., Banihani, Q., Bartacek, J., Jenicek, P., Ergas, S.J. (2014) A Tire-Sulfur Hybrid Adsorption Denitrification (T-SHAD) Process for Decentralized Wastewater Treatment, *Water Research*, 61:191-199.

Kinyua, M.N., Cunningham, J., Ergas, S.J. (2014) Effect of Solids Retention Time on the Bioavailability of Organic Carbon in Anaerobically Digested Swine Waste, *Bioresource Technol.*, 162(2014);14-20.

Qiong (Jane) Zhang, Ph.D.
Civil & Environmental Engineering Department, University of South Florida,
4202 East Fowler Avenue ENB118, Tampa FL 33620
Phone: (813) 974-6448 Fax: (813) 974-2957 Email: qiongzhang@usf.edu

a) Professional Preparation:

The North-West Institute of Architecture Engineering, China	Water Supply and Sanitation Engineering	B.S. & 1992
TsingHua University, China	Environmental Engineering	M.S. & 1995
Michigan Technological University	Environmental Engineering	Ph.D. & 2001

b) Appointments:

8/09 – present	Assistant Professor, Dept. of Civil & Env. Engineering, USF
11/05 – 7/09	Senior Research Engineer, Dept. of Civil & Env. Engineering, MTU
10/05 – 7/09	Adjunct Ass. Prof., Dept. of Civil & Env. Engineering, MTU
1/02 – 10/05	Postdoctoral Researcher, Dept. of Civil & Env. Engineering, MTU
10/01 – 1/02	Lecturer, Dept. of Chemical Engineering, MTU
10/95 – 8/97	Assistant Professor, Dept. of Env. Science, Hangzhou University

c) Publications:

- Cornejo, P.K., M.V. Santana, Q. Zhang, D.R. Hokanson, J.R. Mihelcic, “Carbon footprint of water reuse and desalination: a review of greenhouse gas emissions and estimation tools,” *J. of Water Reuse and Desalination*, 4: 238-252, 2014.
- Maul, G.A., Y. Kim, A. Amini, Q. Zhang, T. H. Boyer, “Efficiency and life cycle environmental impacts of ion-exchange regeneration using sodium, potassium, chloride, and bicarbonate salts,” *Chemical Engineering Journal*, 254: 198-209, 2014.
- Santana, M., Q. Zhang, J.R. Mihelcic, “Influence of Water Quality on the Embodied Energy of Drinking Water Treatment,” *Environmental Science & Technology*, 48: 3084-3091, 2014.
- Cornejo, P. K., Q. Zhang, J. R. Mihelcic, “Quantifying benefits of resource recovery from sanitation provision in a developing world setting,” *J. of Environmental Management*, 131: 7-15, 2013.
- Tong, L., X. Liu, X. Liu, Z. Yuan, Q. Zhang, “Life cycle assessment of water reuse systems in an industrial park,” *J. of Environmental Management*, 129: 471-478, 2013.
- Mo, W., Q. Zhang, “Can Municipal Wastewater Treatment Systems be Carbon Neutral?” *J. of Environmental Management*, 112: 360-367, 2012.
- Pawelzik, P. F., Q. Zhang, “A Life Cycle Study of Cellulosic Ethanol with Technological Advances over Time,” *Biomass and Bioenergy*, 40: 162-173, 2012.
- Owens, E. L., Q. Zhang, J.R. Mihelcic, “Material flow analysis applied to household solid waste and marine litter on a small island developing state,” *J. of Environmental Engineering*, 137(10): 937-944, 2011.
- Clarke-Sather, A. R., M. J. Hutchinsa, Q. Zhang, J. K. Gershenson, “Development of social, environmental, and economic indicators for a small/medium enterprise,” Special Issue on "Sustainability, Accounting and Reporting" in the *International Journal of Accounting and Information Management - IJAIM*, 19(3): 247-266, 2011.
- Mo, W., F. Nasiri, M. J. Eckelman, Q. Zhang, J. B. Zimmerman, “Measuring the Embodied Energy in Drinking Water Supply Systems: A Case Study in The Great Lakes Region,” *Environmental Science and Technology*, 44(24): 9516-9521, 2010.
- Wright, H., Q. Zhang, J.R. Mihelcic, “Integrating Economic Input-Output Life Cycle Assessment with Risk Assessment for a Screening-Level Analysis,” *International Journal of Life Cycle Assessment*, 13(5): 412-420, 2008.

CURRENT AND PENDING SUPPORT

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may delay consideration of this proposal.

Investigator: Sarina J. Ergas	Other agencies to which this proposal has been/will be submitted.

Support: ☐ Current ☐ Pending ☒ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Flexible Process for Thermochemical Conversion of Biogas to Fuels and Chemicals
Source of Support: US Dept. Energy MEGA-BIO: Bioproducts to Enable Biofuels (John Kuhn PI)
Total Award Amount: $1,789,894 Total Award Period Covered: 1/1/2017-12/31/19
Location of Project: University of South Florida
Person-Months Per Year Committed to the 1.5 Cal: Acad: Sumr: 1.5

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Phase II Bioenergy Production from MSW by High Solids Anaerobic Digestion (this proposal)
Source of Support: Hinkley Center for Solid and Hazardous Waste Management
Total Award Amount: $81,563 Total Award Period Covered: 9/1/16-8/31/17
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.15 Cal: Acad: Sumr: 0.15

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
INFEWS/T3: Integrated Marine Aquaculture Systems for Sustainable Seafood Production in the Gulf of Mexico Region (S. Ergas PI)
Source of Support: National Science Foundation
Total Award Amount: $3,000,000 Total Award Period Covered: 1/1/2017-12/31/2020
Location of Project: University of South Florida, Mote Marine Labs, Auburn University, Texas A&M University
Person-Months Per Year Committed to the 1.0 Cal: Acad: Sumr: 1.0

Support: ☐Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Off Flavor Compound Removal in Recirculating Aquaculture Systems: Hybrid Adsorption Biological Treatment and Aquaponics Systems
Source of Support: US-Israel Binational Agricultural Research and Development (BARD) fund
Total Award Amount: $330,000 Total Award Period Covered: 1/16-12/18
Location of Project: University of South Florida, Mote Aquaculture Research, Hebrew University Rehovot
Person-Months Per Year Committed to the Project. .5 (as PI) Cal: Acad: .5 Sumr:

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Hybrid Adsorption Biological Treatment Systems (HABiTS) for Decentralized Wastewater Treatment
Source of Support: NASA
Total Award Amount: $5,000 Total Award Period Covered: 9/15-8/16
Location of Project: University of South Florida, Tampa
Person-Months Per Year Committed to the Project. 0 (as PI) Cal: Acad: Sumr:

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Implementing, Optimizing and Evaluating a hybrid-design recirculation aquaculture systems (HyDRAS) for Off-Flavor Compounds Removal
Source of Support: FL Aquaculture Review Council

Total Award Amount: $201,120 Total Award Period Covered: 6/15-6/16
Location of Project: University of South Florida, Tampa and Mote Aquaculture Research Park, Sarasota
Person-Months Per Year Committed to the Project. 1.5/.6 (as co-PI) Cal: Acad: .6 Sumr: 1.5

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Process Control Parameter Studies on Wastewater Treatment Systems at Falkenburg Advanced Wastewater Treatment Plant
Source of Support: Hillsborough County
Total Award Amount: $53,723 Total Award Period Covered: 12/13-5/16
Location of Project: University of South Florida
Person-Months Per Year Committed to the Project. 0 (as PI) Cal: Acad: Sumr:

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: High Ammonia Strength Wastewater Treatment Using an Algal-Bacterial Shortcut N Process
Source of Support: NSF
Total Award Amount: $330,000 Total Award Period Covered: 8/15-7/18
Location of Project: University of South Florida
Person-Months Per Year Committed to the Project. 0.25 (as PI) Cal: Acad: Sumr: 0.25

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Sustainable Production of Marine Fish, Vegetables and Wetland Restoration Plants in a Marine Aquaponics System
Source of Support: Florida Sea Grant
Total Award Amount: $66,246 Total Award Period Covered: 2/14-1/17
Location of Project: USF and Mote Aquaculture Research Park
Person-Months Per Year Committed to the Project. .34 (as co-PI) Cal: Acad: .34 Sumr:

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Reinventing Aging Infrastructure for Nutrient Management (RAIN*Mgmt*)
Source of Support: EPA
Total Award Amount: $2,500,000 Total Award Period Covered: 11/13-10-17
Location of Project: USF, East Tampa, Gainesville FL, Baltimore MD, Washington DC
Person-Months Per Year Committed to the Project. 1 (as co-PI) Cal: Acad: Sumr: 1

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: PIRE: Context Sensitive Implementation of Synergistic Water-Energy Systems
Source of Support: NSF
Total Award Amount: $3,912,276 Total Award Period Covered: 1/13-12/16
Location of Project: USF, UVI, Mexico, Belize, UK, the Netherlands, Czech Republic
Person-Months Per Year Committed to the Project. 1 (as Faculty Participant) Cal: Acad: Sumr: 1

Support: ☒Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: REU Site, Tampa Interdisciplinary Education and Research (TIER)
Source of Support: NSF
Total Award Amount: $418,611 Total Award Period Covered: 6/1/2013-6/31/2016
Location of Project: University of South Florida
Person-Months Per Year Committed to the Project. 0.2 (as co-PI) Cal: Acad: Sumr: .2

Current and Pending Form

This form must be completed for the Principal Investigator and for each Co-Principal Investigator. Failure to provide this information may result in disqualification of your proposal.

Investigator: Qiong (Jane) Zhang	Other agencies to which this proposal has been/will be

Support: ☐ Current ☐ Pending ☒ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Flexible Process for Thermochemical Conversion of Biogas to Fuels and Chemicals
Source of Support: US Dept. Energy MEGA-BIO: Bioproducts to Enable Biofuels (John Kuhn PI)
Total Award Amount: $1,789,894 Total Award Period Covered: 1/1/2017-12/31/19
Location of Project: University of South Florida
Person-Months Per Year Committed to the 1.5 Cal: Acad: Sumr: 1.5

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Phase II Bioenergy Production from MSW by High Solids Anaerobic Digestion (this proposal)
Source of Support: Hinkley Center for Solid and Hazardous Waste Management
Total Award Amount: $81,563 Total Award Period Covered: 9/1/16-8/31/17
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.15 Cal: Acad: Sumr: 0.15

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
INFEWS/T3: Integrated Marine Aquaculture Systems for Sustainable Seafood Production in the Gulf of Mexico Region (S. Ergas PI)
Source of Support: National Science Foundation
Total Award Amount: $3,000,000 Total Award Period Covered: 1/1/2017-12/31/2020
Location of Project: University of South Florida, Mote Marine Labs, Auburn University, Texas A&M University
Person-Months Per Year Committed to the 0.5 Cal: Acad: Sumr: 0.5

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Small, safe, sustainable (S3) public water systems through innovative ion exchange
Source of Support: EPA flow through University of Florida
Total Award Amount: $154,597 Total Award Period Covered: 8/16/2012 - 8/15/2016
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.75 Cal: Acad: Sumr: 0.75

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
PIRE: Context Sensitive Implementation of Synergistic Water-Energy Systems
Source of Support: National Science Foundation
Total Award Amount: $3,900,643 Total Award Period Covered: 1/1/2013 – 12/31/2017
Location of Project: University of South Florida, along with various international partners
Person-Months Per Year Committed to the 0.5 Cal: Acad: Sumr: 0.5

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt)
Source of Support: Environmental Protection Agency
Total Award Amount: $2,220,648 Total Award Period Covered: 9/1/2013 – 8/31/2017
Location of Project: University of South Florida and various partners
Person-Months Per Year Committed to the 0.75 Cal: Acad: Sumr: 0.75

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Water Innovation Network for Sustainable Small Systems: WINSSS
Source of Support: EPA flow through University of Massachusetts Amherst
Total Award Amount: $133,772 Total Award Period Covered: 8/1/2014-7/31/2017
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.75 Cal: Acad: Sumr: 0.75

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
CAREER: Envisioning Integrated Wastewater Management through the Lens of Reverse Logistics
Source of Support: National Science Foundation
Total Award Amount: $501,886 Total Award Period Covered: 1/1/2015-12/31/2019
Location of Project: University of South Florida
Person-Months Per Year Committed to the 1.0 Cal: Acad: 1.0 Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
A Novel Algal-Bacterial Shortcut Nitrogen Removal Process for Wastewater Treatment
Source of Support: National Science Foundation
Total Award Amount: $329,999 Total Award Period Covered: 8/1/2015 - 7/31/2018
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.25 Cal: Acad: Sumr: 0.25

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
CNH-L: Whither are the thresholds in a Florida Urban Water System: Replaying history in a future world
Source of Support: National Science Foundation flow through Florida State University
Total Award Amount: $398,600 Total Award Period Covered: 6/1/2016 - 5/31/2020
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.75 Cal: Acad: Sumr: 0.75

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
A lattice-Boltzmann framework simulating reactive incompressible turbulent flows with application to water disinfection
Source of Support: National Science Foundation
Total Award Amount: $334,984 Total Award Period Covered: 9/1/2016 - 8/31/2019
Location of Project: University of South Florida
Person-Months Per Year Committed to the 0.5 Cal: Acad: Sumr: 0.5

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Collaborative Research: NRT INFEWS: 21st Century Interdisciplinary Synergies for Food Energy Water Systems

Source of Support: National Science Foundation
Total Award Amount: $2,500,000 Total Award Period Covered: 9/1/2016-8/31/2021
Location of Project: University of South Florida, along with various partners
Person-Months Per Year Committed to the 0.5 Cal: Acad: 0.0 Sumr: 0.5

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
CRISP Type 2: Integrative Decision Making Framework to Enhance Resiliancy of Critically Dependent Infrastructures
Source of Support: National Science Foundation
Total Award Amount: $1,999,421 Total Award Period Covered: 9/1/2016-8/31/2020
Location of Project: University of South Florida
Person-Months Per Year Committed to the 1.5 Cal: Acad: Sumr: 1.5