

PROJECT DESCRIPTION

IRES: US-South Africa collaboration on sustainable sanitation and energy and resource recovery from wastewater

1. Introduction

The purpose of the proposed research is to bring five US students, recruited from groups including those under-represented in the sciences, to the University of KwaZulu-Natal (UKZN) in Durban, South Africa every boreal summer to conduct research on a wide range of environmental engineering topics related to resource and energy recovery from wastewater, new perspectives on wastewater treatment, and sustainable sanitation in under-served communities. This research experience is intended to give upper-level undergraduate students the opportunity to envision themselves as researchers and equip them with the research skills they need to transition into graduate school. The proposed research is further expected to strengthen the research and mentoring skills of graduate student participants. Also, environmental science and engineering undergraduate and graduate students will be working on novel research at the nexus of water, energy, and food with the Pollution Research Group at UKZN while also obtaining an enriching international experience on topics that are highly relevant for environmental scientists and engineers.

The United Nations projects that human populations will rise to almost 10 billion by the year 2050, and much of this growth is expected to continue along the world's coastlines. Indeed,

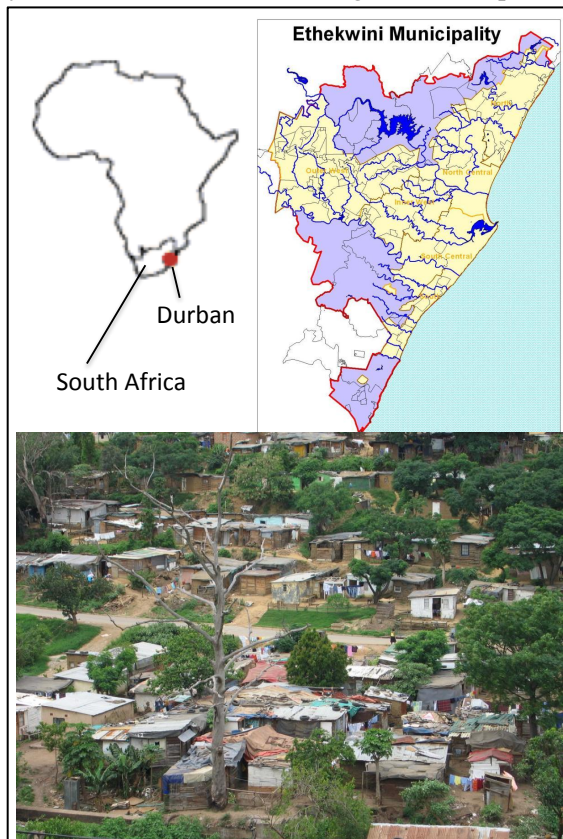


Figure 1. Maps of the eThekweni Municipality, encompassing Durban's old metro (yellow) and new metro (light blue) areas, and Durban in South Africa (inset). Photo shows high density of homes in informal settlements and lack of sanitation.

municipalities in coastal areas are home to the “poorest billion in the world” and struggle to provide adequate sanitation for residents. Consequently, access to clean water becomes an insurmountable challenge (through contamination) if sanitation needs are not met. Against this backdrop, new solutions are needed to improve basic sanitation for under-served populations.

Durban, South Africa is a stark example of what happens when infrastructure is unable to keep pace with population growth. In the eThekweni coastal metropolitan area that encompasses Durban, over one million people live in informal settlements (in the new metro area) largely without access to proper sanitation (Fig. 1). Each year that number grows by 10%. Dealing with both the realities of the situation and the need to innovate in the arena of wastewater treatment, the Pollution Research Group at UKZN has been conducting research on decentralized wastewater treatment (DEWATS) and resource recovery from wastewater for the past decade. Professor Chris Buckley has led the team in recent projects that answer a call from the Bill and Melinda Gates Foundation to “reinvent the toilet.” A project funded through the Gates Foundation Reinvent the Toilet Challenge seeks to modify existing urine diversion dry toilets to recover energy and nutrients from the waste streams and reuse

potable water from urine and flush water. Other projects that IRES students will be able to participate in include application of urine to agricultural plots, assessing the performance of anaerobic baffled reactors (ABRs) and other DEWATS, biosolids co-composting, and energy generation potential of oils, fats, and grease from wastewater.

The unifying theme of this IRES proposal is Sustainable Sanitation at the nexus of water, energy, and food. Throughout this international research experience, IRES students will need to consider how the innovations in technology are balanced with financial capacity, the environment and societal needs of Durban communities. After all, economic growth, social progress and environmental stewardship are the triple bottom line of sustainability. Applying environmental science and engineering knowledge and developing research and communication skills through the IRES experience will broaden student understanding of sustainability and will accomplish the learning objectives of this proposal, which are shown in Table 1.

Table 1. Learning objectives of the Sustainable Sanitation IRES project.

1.	To apply basic environmental science knowledge and engineering skills toward developing technological innovations
2.	To learn research skills and strengthen them during the period of the IRES program
3.	To demonstrate the capacity for self-directed learning and original investigation
4.	To identify and incorporate the elements of sustainable development into their research projects
5.	To strengthen skills for communicating scientific and engineering concepts to the public and to K-12 students.

Overarching theme and hypothesis

An overarching hypothesis for the broad research of this IRES proposal is that *decentralized sanitation with energy and resource recovery leads to sustainable solutions for waste management in informal and peri-urban settlements in Durban*. In the case of wastewater, DEWATS systems with primarily anaerobic (without oxygen) degradation offer many advantages compared to the conventional practice of primarily aerobic wastewater treatment, including lower capital and operating costs, simpler technology and lower requirements for highly skilled personnel (Singh et al., 2009). The potential to harness energy and reclaim resources in developing settings can empower and provide further economic incentive for communities to deal with their sanitation issues. In developed countries DEWATS are also used. The US Environmental Protection Agency reports that decentralized and on-site systems, such as septic tanks and small community cluster systems, are used by one in four US households to treat wastewater, albeit without energy or resource recovery. In the USA most of the large centralized treatment plants have already been built and the new generation of engineers will be designing satellite systems that treat much lower wastewater volumes than before (Crites and Tchobanoglous, 1998). Moreover, given that conventional wastewater treatment is resource- and energy-intensive, the idea of coupling wastewater treatment with more sustainable resource and energy recovery solutions has become increasingly valued in developed regions as well (Smith et al., 2012). A hypothetical anaerobic treatment system that captures methane for energy as a renewable source of energy from the conventional wastewater treatment processes was described by McCarty et al. (2011) and includes a secondary anaerobic membrane bioreactor to maintain high solids retention time for efficient biodegradation of organic matter. While producing a similar quality effluent to aerobic treatment, such anaerobic membrane bioreactors are also well suited to generating useful energy and producing substantially less residual waste products (Smith et al., 2012). The ABR coupled to membrane filtration will be an important component of several proposed research projects Newlands Mashu DEWATS facility (described in greater detail below) and will address key questions at the forefront of ABR technological development that

have been raised in recent reviews in environmental science and engineering.

Another important area of concentration of the Pollution Research Group is the reuse of resources from human waste. Human excreta contain millions of tons of fertilizer equivalents, 20 to 30 percent of what the global fertilizer industry produces annually, which to a large extent end up in water bodies via wastewater and surface runoff. According to Professor Buckley, “Such misuse of plant nutrients from human excreta is currently a neglected aspect of health in relation to sanitation.” In the Pollution Research Group laboratories at UKZN and at the Newlands site, a number of projects analyzing nutrient and resource recovery are underway.

This proposed US-South Africa collaboration will bring together students from two contrasting parts of the US, from the densely populated urban corridor of Southern California and from sparsely populated Kansas, to study decentralized wastewater systems and new approaches to energy and resource recovery in Durban where these systems are being intensively studied. A key component of this international research experience is the human element. Students participating in this Sustainable Sanitation IRES will have an opportunity to participate in research that is grounded in the eThekweni communities and observe and analyze sanitation systems that are both successful and unsuccessful. Students will learn about the triple bottom line of sustainability and better understand why community involvement, economics, and technology influence the outcome of water and sanitation development projects.

2. Nature of Student Activities

Students involved in the Sustainable Sanitation IRES will be immersed in an experience that will broaden their education by exposing them to an international view of engineering solutions coupled to societal needs where resources are limited. In addition, the experience will allow them to develop valuable technical skills, learn about sustainability solutions to wastewater challenges, improve their interpersonal skills, and develop a community with the faculty and student participants in the program. Table 2 summarizes the activities that will help the students achieve technical competence, develop their professional skills, and form a community with each other and the faculty mentors.

Table 2. IRES activities and their relevance to program objectives

Development of technical expertise	Professional development	Community development
<ul style="list-style-type: none"> • Pre-departure online assignments (technology summary, literature review) • Research basics workshop • Research project in Durban • Research presentations • Contribution to research or educational paper 	<ul style="list-style-type: none"> • Pre-departure seminars on graduate student experiences • Posting on program’s Facebook page[*] • Use of twitter as an online journal of the research experience[*] 	<ul style="list-style-type: none"> • Pinterest page[*] • Field trip • Video competition[*] • Outreach to US K-12 students after the IRES experience

^{*} Internet access is available at US institutions and at most South African institutions (UKZN) and accommodation (D’urban Elephant Bed & Breakfast).

Development of Technical Expertise

One main objective of the proposed IRES project is to develop technical expertise on the topic of innovative solutions in wastewater treatment and resource and energy recovery from wastewater. The intent is that the international experience at UKZN in Durban will provide students with access to novel technologies that are appropriate and sustainable for developing communities. One major advantage of partnering with UKZN faculty is the wide range of projects that are ongoing at the Newlands Mashu DEWATS facility (Figs. 2a, 2b, and 2d), in the Pollution

Research Group laboratories (Fig. 2c), and at the Frasers Community Ablution Blocks (CAB) ABRs. At these sites, while the processes and streams to be studied are sophisticated, the subsequent solutions need to be engineered to be managed by unskilled workers operating in an environment of minimal supervision. Below are the descriptions of new and ongoing projects and the new research directions that each project will take with the involvement of US NSF IRES-supported students:

- 1) *Anaerobic baffled reactor performance.* At the Newlands Mashu DEWATS facility, the anaerobic baffled reactor treatment system has received wastewater from 83 homes since 2010. The Frasers site contains four CABs servicing 75 households each. Foxon et al. (2004) determined that the ABR systems had a high retention time of solids in the reactor, which resulted in high treatment rates but still insufficient removal of organic waste and pathogens for river discharge or crop irrigation. Several unit operations are in place, including a biogas settler, ABR compartments, anaerobic filter (AF) compartments. Visiting students will work on the evaluation of the performance of individual unit operations by measuring the flow and composition of wastewater in the inflow and outflow of each unit as well as the residues to improve the system.
- 2) *ABR membrane post-treatment.* Anaerobic reactors coupled with membrane filter technology are known to produce much higher quality effluent, but Smith et al. (2012) highlight the need to conduct membrane fouling research to enable operation at varying fluxes and under the constraints of low energy requirements. At the Newlands DEWATS facility, anaerobically treated wastewater will be passed through an immersed fabric membrane as a post-treatment step. The objective is to allow a biofilm to form on the membrane surface, which will result in effluent (permeate) that has a low permeate flux (1 to 10 l/m²h) but will be sustained over long periods (months). The permeate is envisaged to be used for the irrigation of leafy exotic vegetables just prior to harvest. Student research will focus on analyzing membrane fouling, flow distribution, pressure drop, active biomass, and biodegradable COD in the inflow and outflow.
- 3) *Degradation rate and biogas potential of ABR fats, oils, and grease.* At the Newlands DEWATS facility the presence of large quantities of fats and oils in the influent wastewater is a major problem. These constituents block the pipelines, causing a reduction of the effective cross-sectional area and uneven flow distribution. The magnitude of the problem needs to be determined and the rate of anaerobic degradation needs to be quantified. Students will also assess the potential biogas production rate to determine if biogas production could become a feasible option for emerging entrepreneurs to start commercial fats, oils and grease collection services and install dedicated biogas facilities.
- 4) *Biosolids characterization.* All wastewater treatment works produce residues (biosolids). At the Newlands DEWATS facility the characterization of the biosolids produced (and inert material within the compartments) needs to be quantified so that strategies for their management can be developed. Possible processes will include microbiological stabilization, land application prior to or after co-composting. Students will determine the best management practices according to the solids properties.
- 5) *Biosolids co-composting.* McCarty et al. (2011) state that “reuse for irrigation is perhaps one of the best ways to capture the full resource potential of wastewaters.” Although vegetation samples irrigated with ABR effluent showed very low fecal bacteria coliforms (*E. Coli* as an indicator; Jackson et al., 2012), *Ascaris*, a helminth, is the pathogen of concern in the Durban environment. The eggs of this organism are resistant to usual types of disinfection. Students will evaluate the potential of co-composting of biosolids with green plant material in a controlled environment at a sufficiently high temperature and duration for pathogen and *Ascaris* deactivation.

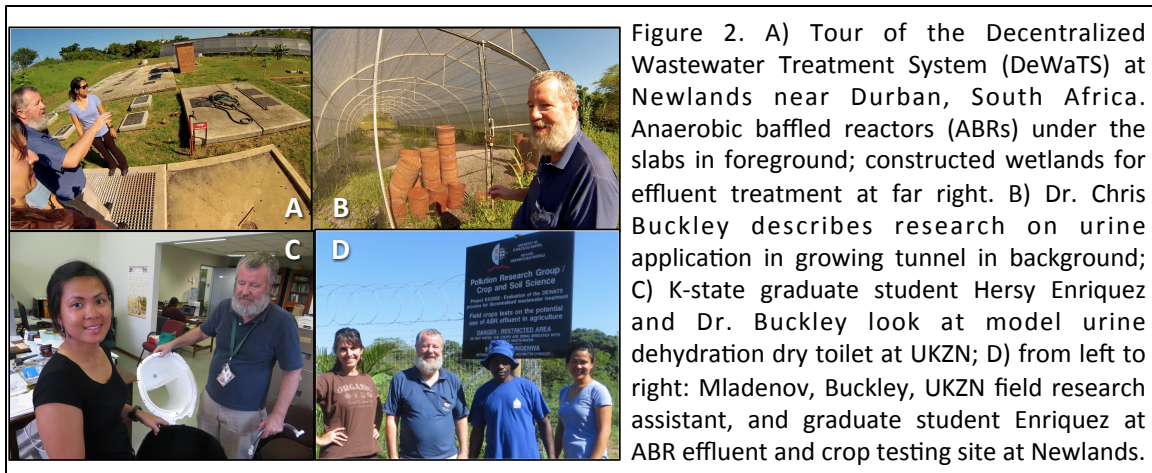


Figure 2. A) Tour of the Decentralized Wastewater Treatment System (DeWaTS) at Newlands near Durban, South Africa. Anaerobic baffled reactors (ABRs) under the slabs in foreground; constructed wetlands for effluent treatment at far right. B) Dr. Chris Buckley describes research on urine application in growing tunnel in background; C) K-state graduate student Hersy Enriquez and Dr. Buckley look at model urine dehydration dry toilet at UKZN; D) from left to right: Mladenov, Buckley, UKZN field research assistant, and graduate student Enriquez at ABR effluent and crop testing site at Newlands.

- 6) *Hydraulic modeling of effluent treatment process.* The efficient treatment of the effluent in the anaerobic baffled reactor is dependent on appropriate flow distribution through the system. The parallel configuration, which has been installed, is susceptible to uneven flow distribution with the concomitant carryover of biomass from one of the trains during storm events. The degree of dimensional accuracy in the construction of the system needs to be evaluated by undertaking a dynamic hydraulic modeling study of the system. Students who are interested in modeling will have the opportunity to contribute to a hydraulic model of flow through the anaerobic baffled reactor system (3 streets in parallel), which will include derivation, calibration and verification of the model.
- 7) *Biodigester performance.* A biodigester will be built at the Newlands DEWATS facility at the end of this year (2013). In a review of energy production from domestic wastewater, McCarty et al. (2011) described the needs for research on cost and energy-efficient methods for methane capture and control of unwanted sulfate reduction to sulfide, which competes with methane production and produces a toxic and corrosive gas (H_2S). Students will evaluate the performance of the system at Newlands with respect to efficient methane capture, rates of sulfate reduction and hydrogen sulfide generation, and stabilization of fats, oils and grease and other biosolids. The IRES student will have the option of using methods for enumeration of sulfate reducing bacteria (Mladenov et al., in revision) and, if a graduate student is interested in this project, s/he will be able to continue this research in the Department of Civil Engineering at K-state.
- 8) *Resource recovery from urine diversion dry toilets.* McCarty et al. (2011) discuss innovations in nutrient removal from wastewater, including chemical precipitation of P and conversion into struvite, which can be used as fertilizer, removal of N with newer annamox processes (instead of traditional nitrification/denitrification), and removal of both N and P via source-separation of urine (separating urine from the other components of wastewater). In a project funded by the Gates Foundation, the Pollution Research Group is modifying urine diversion dry toilets to recover energy from the solid waste and reuse potable water from urine and flush water (Fig. 3). Building on prior successes in testing separation, purification and recovery of the nutrient components in urine in the laboratory (Starzak et al., 2006; Grau et al., 2012), the way forward in this research project is up-scaling those processes to over 90,000 units in the eThekweni municipality. The IRES student will be able to contribute to various aspects of this research. Currently utilized urine-diversion toilets will be modified and developed to include three streams of waste (urine, faeces and wash water). The solid waste and bulk objects (e.g. toilet paper and diapers) will be processed to ultimately produce ash for fertilizer, flue gases and steam for water recovery, and energy for heating the drier and combustor, which are

integral to the process. The urine and flush water will be filtered and transferred to a water-recovery unit where a high-quality water stream will be removed and sent to a general water-storage tank. The remaining concentrated urine stream will then be processed in order to separate the urea and other salts.

- 9) *Improved nutrient recovery from urine diversion.* In a joint project of UKZN and Eawag, a struvite reactor was designed that had a > 91% phosphorus removal rate from urine (Grau et al., 2012). IRES students have the option to be involved with lab work taking on new directions on this research. The way forward in this research is to recover additional nutrients (N and K) using biological stabilization of the urine, evapoconcentration of the solution, and processing the concentrate into a powder form for fertilizer application.

Professional Development

During their stay, students will have the opportunity to interact with Pollution Research Group scientists and engineers. Professor Buckley and his team also work with scientists from EAWAG in Switzerland, BORDA in Germany, and representatives of the Bill and Melinda Gates Foundation and local and regional NGOs. Potential interactions with such individuals during the international research experience may give students an opportunity for networking. To further enhance the development of the IRES participants into outstanding scholars, all IRES participants will be required to present their results to an audience of Pollution Research Group scientists and students and other students in the IRES cohort in the final week of the international experience.

Also, upon return to the US, IRES students will have guidance from their US-based mentors, PIs Mladenov and Palomo, in the preparation of a final report to be provided to the Pollution Research Group. To disseminate their research results more broadly, IRES students will also be required to present their research at a local conference, as part of a meeting of a professional society, or at a regional or national conference in the academic year following their REU experience. To help make this possible, the K-State MEP office will contribute funds for conference travel (see support letter from L. Bitsie-Baldwin). Additionally, Cal Poly Pomona students will present the results from the research experience in the California Water Environment Association (CWEA) student club fall meeting, which will serve to prime the recruitment process for the second and third year of the project. Students who are interested in contributing to manuscript writing will also be encouraged to do so.

The Kansas venues for student presentations are:

- **K-State REU poster presentation** in early August. The forum is held on the K-State campus and showcases the student work from all of the summer REU programs on campus.
- **Future of Water in Kansas Conference** in October. The conference is held in Manhattan, KS every year and is open to student research.
- **2013 American Society for Engineering Education (ASEE) Midwest Section Annual Conference** in September. The conference is held in Salina, KS. Every year they have a call for student posters to showcase outreach, design, and research projects.
- **K-State Research Forum** in April. This conference showcases the work of all K-State students with competition at the graduate and undergraduate levels.

The Southern California venues for undergraduate students are:

- **The annual Southern California Conference for Undergraduate Research (SCCUR)** in October/November. Usually the Cal Poly Pomona campus pays for registration and on some occasions traveling expenses if the conference is out of town.
- **Cal Poly Pomona's annual CPP undergraduate research competitions** in early February. If students win the Cal Poly Pomona campus competition they represent the Cal Poly Pomona in the CSU system wide competition. Student teams representing Cal Poly Pomona are coached by faculty before going to the competition.

- **Stories of Successful Learning**, Cal Poly Pomona venue that takes place in spring quarter (April). Students are requested to prepare and submit an abstract for poster presentation.

This IRES program seeks to train undergraduates who are not only skilled in their technical area, but who can effectively present their research to both technical and non-technical audiences. We seek to enhance students' communication skills by engaging them in outreach activities to the general public and K-12 students. This type of approach has been demonstrated to dramatically enhance students' communication skills. The very process of explaining difficult concepts helps students develop a deeper understanding of the scientific content. In order to better equip future scientists and engineers to communicate to the public about their work, we have added activities to intentionally develop these skills.

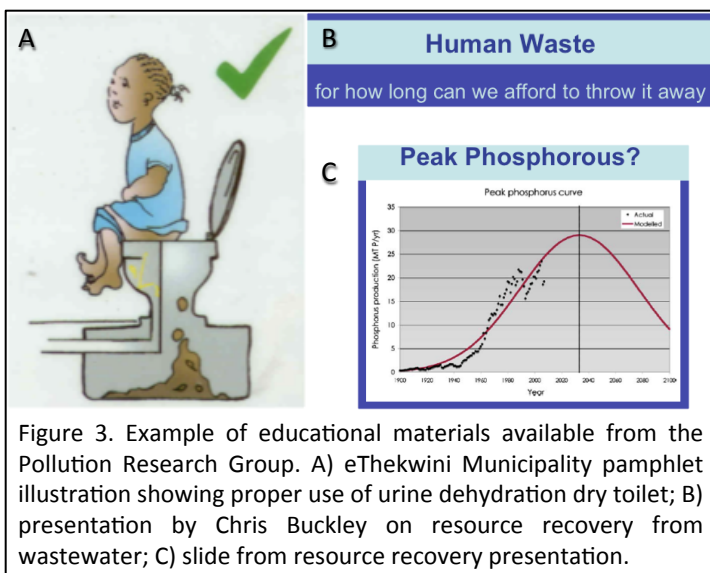
One activity is a video competition in which students will create a three-minute video describing the setting, their research problem and hypotheses, and results and conclusions in creative ways for a K-12 student audience. The videos will be available to use for outreach to local elementary – high school outreach projects. The videos will also be used as an educational tool for subsequent IRES cohorts. The video will be modeled on the three minute IGERT video competition (<http://posterhall.org/igert2013>) and can be as sophisticated (video clips merged with slide show and music) or simple (IRES student describing their research on video) as the participant desires. Students will be able to work on this project during their international stay.

Another activity that will be possible (but not a requirement) is blogging by IRES participants about their international activities on Twitter. In addition to wider distribution of the activities and scientific knowledge, this technology can engage other students and friends in the experience. Journaling, asking peers for advice, and disseminating results are examples of how IRES participants can use Twitter to communicate to the public.

At K-State, IRES participants who are further interested in outreach will have the opportunity to present their research to K-6 students at the Boys and Girls Club of Manhattan after school program (see support letter from C. Jones of the Boys and Girls Club).

Community Development

An important part of the IRES experience is for the students to feel a sense of community with their cohort and with the US based PIs and international faculty mentors. This collegial atmosphere is key towards creating a positive environment for student growth. It will also help in our efforts to promote research as an attractive career path for the students.



We expect that, even though it will be conducted online, the pre-departure orientation course will offer a number of opportunities for teamwork within the cohort. Sharing of Pinterest pages (described later) with each other and with the cohort, deciding on a Twitter hashtag for their experience, and working together on the online activities will all contribute to the sense of community.

Another way to promote community within the cohort is to make efforts for group travel. When possible, tickets will be purchased so that students and US

PI are on the same flights. Even if departing from different cities in the US, it is often possible to have travelers meet at a connecting airport (e.g. Washington D.C. or London or Frankfurt), which also makes international travel less daunting. All students will also be required to stay in the same accommodation, and some will share rooms. Students will also travel together to field sites and back and forth from their Bed & Breakfast, which will promote both sociability and safety.

To further promote a sense of community, a variety of activities will be planned in Durban in the first week. Professor Buckley and his team will meet with PI Mladenov (in years 1 and 3) and Palomo (in year 2) and their students for dinner together on the first night. The US-based PIs and IRES cohort will then visit one of Durban's many attractions (e.g., Botanical Gardens, KwaMuhle Museum, the Indian District, Inanda Heritage Trail) during the first weekend (prior to departure of US-based PIs).

3. Work plan

The Research Environment.

Prof. Chris Buckley and the Pollution Research Group have been working on water and sanitation research in developing communities since 2002, covering such topics as basic characteristics (organic, microbial, and hydraulic loads) of community sanitation systems (Arjun et al., 2006; Crous et al., 2012), microbiological (Lalbahadur et al., 2005; Jackson et al., 2012; Maraj et al., 2012) and process-level studies of the anaerobic baffled reactor (Dama et al., 2002; Foxon et al., 2007) and membrane coupled anaerobic baffled reactor (Pillay et al., 2008) for on-site sanitation in low income areas, upscaling dry sanitation technologies (Bhagwan et al., 2008), pit latrine characterization (Couderc et al., 2008; Foxon et al., 2009), nutrient recovery from urine (Grau et al., 2008), and methane generation from anaerobic digestion (Bond et al., 2012). Professor Buckley has also led research on the use of life cycle assessment as a valuable tool for increasing the efficiency of existing water supply and demand processes (Buckley et al., 2011). The Pollution Research Group has a FTP site that contains a database of the papers listed above as well as presentations and community outreach materials (Fig. 3). The Pollution Research Group has been leading the discourse on these topics by hosting the first two Faecal Sludge Management conferences in Durban.

One of the most desirable aspects of the proposed IRES project is the availability of diverse projects, including some that take place only on the UKZN campus and others that are conducted at two pilot test sites (Newlands and Frasers) receiving wastewater from eThekweni communities. The Pollution Research Group has been funded by the eThekweni Municipality, the National Research Foundation of South Africa, the Water Research Commission, the Water Institute of Southern Africa, the Eawag – Swiss Federal Institute of Aquatic Sciences and Technology, the Bremen Overseas Research and Development Association (BORDA), and the Bill and Melinda Gates Foundation. Most recently, the Pollution Research group was the recipient of a grant from the Gates Foundation “Reinvent the Toilet Challenge”. This grant is funding a UKZN project that seeks to harness the energy obtained from combusting organic material in human excreta to drive the separation of pure water from the waste. The UKZN project has attracted international attention because it takes a needs-based approach to develop and undertake specific methods and uses chemical process engineering fundamentals to account for process streams characteristics. IRES students will be able to participate in various components of this project.

The Durban location and amenities available to students (internet access at the foreign site, printing and copying facilities, access to nearby and affordable accommodation) also make the UKZN location well suited to supporting IRES students. Another convenience for IRES participants is that English is the official language. The ability to conduct the research in a common language makes for smoother facilitation of the research experience and collaborations.

The site is also suitable for the IRES research because this project will facilitate new

collaboration between Buckley, Mladenov, and Palomo. At K-State, PI Mladenov teaches courses in Sustainable Water and Sanitation Systems (CE690) and Wastewater Engineering (CE766) and conducts research on the US Army Net Zero Initiative at Ft. Riley, KS to create an installation that reduces, reuses, and recovers waste streams with zero waste going to landfill. This research is well-aligned with the energy and resource recovery foci of Prof. Buckley and the Pollution Research Group. Dr. Palomo teaches courses on Water Engineering (CE 431) and Wastewater Engineering (CE 432) and conducts undergraduate research on topics related to community education and sustainable solutions that use natural treatment or attenuation processes for quality control of pollutants. Collaborating with the Pollution Research Group is aligned with and will promote the new net-zero research being conducted by Mladenov and the ongoing pollutant control research of Palomo.

Student Recruitment

The recruitment of students for this IRES experience is a critical element of this project. In recruiting students we are looking to build a diverse team of: students that are motivated to advance engineering and science while also serving the community, students that want to enrich their education by broadening their research skills, and students that are considering graduate school.

Most of the recruitment of students for the proposed IRES project will be done via a unique collaboration between K-State and Cal Poly Pomona, a primarily undergraduate teaching and Hispanic Serving Institution. Professor Mónica Palomo in the Department of Civil Engineering at Cal Poly Pomona has five years of experience training undergraduates while conducting applied research projects. Dr. Palomo had interacted with PI Mladenov since spring 2012 in an effort to spread the word about K-State graduate research opportunities to Cal Poly Pomona undergraduate students. Thus far, recruiting efforts of Dr. Palomo have enabled three Cal Poly Pomona graduates (Enriquez, Oldani, and Paredes, all from under-represented groups in engineering) to carry on graduate research in PI Mladenov's research group. In the proposed project, each cohort of participants is expected to consist of four upper-level (junior and senior standing) undergraduate students and one graduate student. Undergraduate student applicants will be formally recruited from the large student body at California State Polytechnic University Pomona (Cal Poly Pomona). With nearly 1200 civil engineering students, Cal Poly's Civil Engineering program is one of the largest program's in the nation. About 95 percent of Cal Poly civil engineering students are from the surrounding metropolitan area (Los Angeles, Orange County, San Bernardino, and Riverside Counties) and ~30% are from Latino, Black, and American Indian minority groups. The College of Engineering Cal Poly Pomona Maximizing Engineering Potential (Cal Poly MEP) program (the largest MEP program in California), which has the aim of increasing the enrollment number and retention of diverse of student populations is a platform that will also assist with distribution of the request for applications. Dr. Palomo is the faculty advisor for the Cal Poly's Society of Hispanic Professional Engineers (SHPE) and works closely with the Cal Poly MEP program.

The motivation for including one graduate student is that this student will serve as a mentor for the undergraduate students. We expect that interactions between undergraduates and the graduate student will give the undergraduates additional insight into graduate research that the PI and foreign mentor are not able to give. The first graduate student to participate in Cohort 1 will be Perla Ramos, who will be starting on a project directed by PI Mladenov on Net Zero Energy Use for Wastewater Treatment at Ft. Riley Army Base. As a Latina Civil Engineer, Perla will be a strong role model for the undergraduate students, especially females and minority engineering students. Graduate students will be further recruited by advertising through the American Society of Environmental Engineering and Science Professors (AEESP) website and via MEP programs at K-State and Cal Poly Pomona.

Student selection

A website will be hosted by the Department of Civil Engineering that will contain eligibility information and an online application. The eligibility information will inform the applicants that they will need to be US citizens or permanent residents and available to reside in South Africa between mid-June and early August. The online application form will request general information (name, country of citizenship, residency status, dates when applicant is able to start the program), contact information, education information, optional demographic information (for project evaluation purposes), past experiences, awards, and honors, and a multiple choice question asking students to rank projects (short titles of projects described in Section 2 will be included) according to their research interests. The application will express that under-represented minorities and women are encouraged to apply. The application will further state that:

- Applicants must be available to be in residence in S. Africa between mid-June and early August each year.
- Applications should be sent in PDF format by e-mail to mladenov@ksu.edu.
- A valid passport, vaccination record and general medical exam will be required for the selected students before the trip to South Africa.

Applications for the IRES program will also request the following:

- **A one- to two-page statement of purpose** indicating the reason for the applicant's interest in the program, the applicant's plans following completion of the undergraduate degree, and information about any prior international experience(s) and ability to work in a team environment.
- **A one- to two-page resume.** The applicant will be asked to clearly indicate their cumulative undergraduate grade-point average, major field of study, current academic department, and current academic level (e.g., junior, senior).
- A copy of the **unofficial transcript**.
- **Two letters of recommendation.** Recommenders should ideally be able to comment on academic performance, ability to work in a team environment, ability and interest in future graduate studies in STEM disciplines, and the applicant's interest in community-based research in a foreign country. Letter writers will be asked to e-mail their recommendation letters directly to Dr. Mladenov at mladenov@ksu.edu.

The request for applications will go out in the fall. Applications will be due on January 5th, and decisions will be finalized by February 25th to give students adequate time to make preparations for the research experience. Preference will be given to juniors and seniors in environmental engineering or a related discipline (civil engineering, chemical engineering, biological engineering, agricultural engineering), students with previous research in environmental engineering, and/or students with substantial coursework in environmental engineering.

Logistics

We recognize that most students are to some extent connected to social media, such as Twitter, Facebook, and Google Chat. To make the IRES experience as accessible as possible to undergraduate students, we will exploit internet and social media technology to disseminate instructional materials, conduct cohort-building activities, and communicate across vast distances. The first step will be building a Facebook page for the IRES Sustainable Sanitation experience that includes all faculty and student participant "friends". Via Facebook, we will disseminate instructional materials, such as links to videos, webpages, literature review documents, news articles, and more.

In preparation for the IRES, all students will be required to participate in a five hours per

day intensive week-long orientation course that will be overseen by PI Mladenov. The course will be held at least two weeks before the date of international travel (in the last week of May of each year) so that students have time to prepare for the travel based on the knowledge they gain from the orientation course. The course will be offered through the K-State Division of Continuing Education (DCE) as credit/no-credit option course. This option will be offered to suit both those students interested in obtaining credit hours as well as those who do not want to spend money on additional credits. In no case will students be required to spend their own funds for the orientation course. The course will be conducted as a distance education course, which will ensure student participation from both K-State and Cal Poly Pomona. As mentioned previously, the main thrust is to attract students from K-State and Cal Poly Pomona, but superior students from other institutions may also be included. To accommodate students from multiple locations, Zoom is a high-definition video and audio conferencing tool that is available to all K-State students, faculty, and staff, and their guests will be used. IRES participants will be invited to meetings hosted by PI Mladenov and will have access to all features as a guest. The advantages of Zoom over other conferencing tools, such as Skype, are: simultaneous participation of multiple users (up to 25), screen sharing (e.g. video of the instructor and his/her presentation), improved picture clarity and higher definition, and potential to record video for later viewing. Because Zoom can be initiated from anywhere on campus, it is also advantageous should there be any need to move the class to different locations. As a backup, the orientation course will be hosted live in the 13-person video-conferencing facility at Dole Hall at K-State and through the Media Vision facilities at Cal Poly Pomona.

In the weeks leading up to the orientation, each student and faculty participant will be asked to: 1) submit a list of questions about the IRES program, 2) collect images of people, places, and things that they identify with and that are important to them using Pinterest.com, and 3) take a mandatory (free) online laboratory safety training course (offered by K-State to any DCE student). Additionally, undergraduates will submit a list of questions about pursuing a graduate degree. Pinterest pages will be posted on Facebook by each participant. IRES faculty will go through the list of questions and compile a “Frequently Asked Questions” and answers list to share with students on Day 1. On each day of the course there will be an online pre-class assignment on material to be covered the following day. The pre-departure orientation course will take place over five days during five hour blocks (with breaks for lunch) on each day as follows:

DAY 1: INTRODUCTION. As an ice-breaker, student and faculty participants will divide into groups of two and three, share their Pinterest pages, and introduce their new friend to the larger group. Mladenov will introduce the program and cover goals, expectations, learning objectives, and research background. K-State Study Abroad Office Faculty Services Coordinator, Rebecca Murrow, will provide a brief presentation on health and safety, emergency contacts, international health insurance (see support letter). Mladenov and Palomo will provide answers to the Frequently Asked Questions. The cohort will come up with a group name that best describes their various backgrounds and interests and a similarly-developed Twitter hashtag.

Online assignment: Select one aspect of Durban culture, music, art, or politics, upload one photo or link to a webpage, videos or songs to the Facebook page, and write a paragraph on this topic to share with members of the cohort. Learn and share one new word in Zulu.

DAY 2: SOUTH AFRICA. Students will each share one aspect of Durban culture, music, arts, and politics with the other members of their cohort. K-State MEP director, Laverne Bitsie-Baldwin will lead an activity on cultural sensitivity and interacting in diverse groups. Dr. Mladenov who lived in southern Africa for one year and has conducted research-related travel in South Africa, Botswana, Namibia, Zambia, and Zimbabwe numerous times since 1998 will give a seminar on travel (navigating airports) and culture, life, politics, and environmental issues in South Africa. Issues such as HIV-AIDS in South Africa will also be covered. Graduate student

Hersy Enriquez will provide a short presentation entitled “Packing your bags for Africa,” which will include suggestions on preparation for the foreign travel from the student perspective.

Online assignment: Reading from ASCE’s website on sustainability (<http://www.asce.org/sustainability/>). Define key terms in sustainability (e.g., life cycle assessment, triple bottom line, etc.) and upload links to the Facebook page.

DAY 3: SUSTAINABILITY. Students will discuss sustainable development and definitions of sustainability. Director of Sustainability at K-State, Dr. Ben Champion, will speak about sustainability in terms of waste and water resources (see B. Champion support letter). Mladenov will cover progress on the Millenium Development Goals related to water and sanitation. Jodi Gentry of the University of Kansas and past Engineers Without Borders – Sun Professional Chapter president will give a seminar on “International development projects: successes, failures, and pitfalls.”

Online assignment: Each of the five participants will conduct a brief literature review (< 1 page with links uploaded to Facebook) on each of five topics: 1) types of DEWATS (aerobic, anaerobic, constructed wetland, latrines), 2) anaerobic wastewater treatment (baffled reactors, membranes, etc.), 3) water recovery, 4) phosphorus recovery, 5) energy generation.

DAY 4: RESEARCH BASICS. A panel of graduate students from K-State will answer questions about graduate school and research and give their perspectives about the graduate career path. IRES participants will participate in an intensive overview of the various aspects of sustainable sanitation and resource recovery from wastewater. This will include sharing of the findings of the literature review amongst the cohort. Dr. Monica Palomo will teach students about “Best Practices in Research.” She will lead students in a group activity in which they conduct an in-class experiment and take notes in the field notebooks provided to them.

Online assignment: Using the database of Pollution Research Group materials (powerpoint presentations, pamphlets, etc) on the ftp site, write one paragraph about a technology used in the eThekweni municipality to improve water and sanitation. Upload one image that is representative of the technology you have chosen.

DAY 5: RESEARCH DISSEMINATION. Day 5 will start off with a morning (to account for the time zones) Zoom videoconference call to the Pollution Research Group in Durban. Participants will have a virtual meet and greet with Professor Chris Buckley and his staff. In the next seminar, IRES participants will learn about the key elements of effective dissemination of results. Palomo and Mladenov will present on the key aspects of effective poster and Powerpoint presentations. Participants will receive a blank powerpoint and poster template and will be asked to create a poster using the problem statement, hypotheses, methods, and results generated in the experiments of Day 4. This template will be available also for the students’ final presentations in Durban and their outreach activities back in the US.

Other information that will be relayed immediately after selection to all participants are instructions on how to apply for a passport, visa requirements for U.S. citizens (essentially that U.S. passport holders visiting the Republic of South Africa for ninety (90) days or less for tourism/business purposes do not need visas), and information that health insurance through the K-State Study Abroad Office will be available to all participants as well as any US-based faculty involved with the project (see R. Murrow support letter).

On their first full day in Durban, the US entourage will meet Buckley at the D’urban Elephant B&B and conduct introductions as an “opening activity”. The US group will be transported by minibus to UKZN. In subsequent days they will walk to campus from the B&B or be transported by minibus. At UKZN, participants will meet administrative personnel who will assist them during their stay in Durban and will be given a tour of the UKZN Pollution Research Group labs. After a lunch break, students will be transported to the Newlands DEWATS site by minibus and an overview of the various field research projects will be given by Buckley and his

staff. The “closing activity” for the IRES experience will occur early in the final week of the international visit. It will be a mini-symposium in which IRES students give 15 minute oral presentations about their preliminary findings to the cohort and Pollution Research Group faculty.

Leveraging Resources.

The K-State Study Abroad Office will offer resources to assist IRES participants and will provide a presentation on student health insurance, travel abroad, and related topics during the pre-departure orientation course (see R. Murrow support letter). Through the Division of Continuing Education, any IRES student interested in African culture and politics can take POLSC 626 African Politics. For students at K-State, the African Student Union holds “African Night”, a music and cultural event that is open to all students. The annual International Education Week held every November hosted by the Office of International Programs provides opportunities for students to learn about culture, language, and viewpoints of the global student population. Luncheons, art exhibitions, and movies are examples of international activities available to K-State students. K-State also has an International Buddies program that pairs local K-State students with international students, and this program is available to the returning IRES students as a way to further enrich their international experience.

The Multicultural Engineering Program at K-State will contribute funds for student conference travel (see L. Bitsie Baldwin support letter). Dr. Palomo will work with Cal Poly Pomona students to identify campus opportunities to obtain travel funds to cover dissemination expenses.

In South Africa, the resources of UKZN include well-established outdoor laboratories at Newlands Mashu and Frasers sites, ongoing research into which IRES students can be smoothly incorporated, well-funded projects with supplies and equipment needed to conduct research. The proposed project budget has requested modest funding in the case that additional supplies are needed for IRES student researchers.

4. Project Evaluation and Reporting

Implementing a meaningful project evaluation plan will be an essential part of this IRES project. The plan will be designed to evaluate the progress and impact of the project and provide feedback to the leadership team (Mladenov, Palomo and Buckley). The Office of Educational Innovation and Evaluation (OEIE; www.K-State.edu/oeie/) at K-State will serve as the independent evaluator for the project and will work in collaboration with PI Mladenov to assess project outcomes. OEIE has conducted a broad range of program evaluations for state and federally funded projects. Evaluators within the organization have extensive expertise in program evaluation design, curriculum development, faculty training, instrument development, and assessment of educational programs as well as international projects.

The evaluation plan will be designed to understand student experiences and strengthen project implementation over the course of the project period. The plan focuses on assessing student progress and understanding the success of the project to 1) equip upper-level undergraduates with the research tools they need to transition into graduate school, and 2) provide both undergraduate and graduate student participants with a broadening international experience. The overarching goal of the evaluation is to provide sound evidence on the impact of the project initiatives by understanding what works, under what circumstances, and why. This information will allow the project to identify, describe, and validate effective practices. The evaluation plan includes qualitative and quantitative strategies to assess the IRES project in terms of student research experiences and the professional development of student participants. OEIE will design and conduct participant interviews to assess participant perspectives regarding the elements of the program (e.g. orientation, research experience, mentoring, logistics) and the impact of the experience for the student in terms of learning outcomes, global understanding, professional

development, professional networks, and future career/academic goals (see supporting letter from J. Middendorf of OEIE). The impact stories and evaluation report will provide the PI with material to support the PIs strategies to disseminate results of the research within the scientific community and publicize the IRES project student experiences.

5. Broader Impacts

The proposed research will bring together students from two contrasting parts of the US, from the densely populated urban corridor of California and from sparsely populated Kansas. Students will be heavily recruited from groups under-represented in environmental science and engineering by working with multi-cultural engineering program coordinators at K-State and Cal Poly Pomona. Activities designed to promote team building and cultural sensitivity and designed to prepare the students for research in the international setting will be part of a week-long pre-departure orientation course taught in real time at both K-State and Cal Poly Pomona via Zoom technology. At least one of the participants will be in a graduate program at K-State and will share first-hand experiences about graduate school with the undergraduate participants. As part of the program evaluation and transfer of knowledge between cohorts, exit surveys and videos of the research and student perceptions will be conducted and played for subsequent cohorts. Experiences will also be logged for current and future cohorts using social media (Facebook and Twitter). Participants will present their research at UKZN in the final week and will be required to present a poster or oral presentation at REU poster sessions, local or regional research symposia, or at professional society meetings and conferences. IRES participants will also create videos about their research that will be shared with future cohorts and K-12 students. Presentations o K-12 institutions via after-school programs are also encouraged. The proposed IRES experience will provide enriching research experiences and motivate US students to pursue graduate studies and, ultimately, contribute toward greater numbers of US students, including those under-represented in the sciences, conducting research at the forefront of environmental engineering.

6. Project management

The proposed project will follow the timeline below:

Table 3. Project Timeline

Activities	Y1: 2014 - 2015				Y2: 2015 - 2016				Y3: 2016 - 2017			
	<i>Fall</i>	<i>Win</i>	<i>Spr</i>	<i>Sum</i>	<i>Fall</i>	<i>Win</i>	<i>Spr</i>	<i>Sum</i>	<i>Fall</i>	<i>Win</i>	<i>Spr</i>	<i>Sum</i>
Applications announced and student recruitment	X	X			X	X			X	X		
PI applies for orientation course through continuing education	X											
IRES application deadline		X				X				X		
IERS participants announced		X	X			X	X			X		
Accommodation and flight arrangements made			X				X				X	
Pre-departure orientation			X				X				X	
Student research in Durban				X				X				X
Student video competition				X				X				X
Research presentations at UKZN				X				X				X
Exit surveys of IRES participants				X				X				X
Oral and poster presentations at K-State and Cal Poly Pomona				X				X				X
Manuscript writing, publication					X	X	X	X	X	X	X	X
Evaluation		X	X	X	X	X	X	X	X	X	X	X

PI Mladenov will oversee the whole project including 1) leading the pre-departure orientation course, 2) disseminating applications and recruiting materials, 3) communicating with Professor Buckley and the Pollution Research Group to coordinate logistics, 4) coordinating logistics with the Study Abroad and Division of Continuing Education Offices at K-State, 5) mentoring students in the preparation of abstracts, posters and talks to disseminate their work, and 6) contributing to the research and educational manuscripts that will result from the proposed work.

Mladenov has advised and mentored 14 undergraduate students in the development of individual research projects. One of those undergraduates was the first author of a publication that is now accepted (N. Goss), and four others have contributed to peer-reviewed journal articles as co-authors. Seven of the students have presented posters or oral presentations on their research at local or regional conferences or symposia.

Dr. Palomo will be in charge of 1) recruiting students at Cal Poly Pomona to participate in the Durban South Africa project, 2) supporting K-State pre-departure orientation for international travel and 3) mentoring students in the preparation of abstracts, posters and talks to disseminate their work, and 4) contributing to the research and educational manuscripts that will result from the proposed work.

Dr. Palomo has five years of teaching experience at Cal Poly Pomona. During that period she has mentored 16 undergraduate and 2 community college students while conducting individual environmental research projects. Dr. Palomo is experienced in training and mentoring undergraduate students conducting research. She is the founder of the “Civil & Environmental Engineering Research Laboratory” (CEERLAB) group where “*Science is Applied into Engineering Solutions*”. Moreover, she has been working on recruiting undergraduate students that have potential to become independent researchers. In addition, Dr. Palomo has provided multidisciplinary research opportunities by collaborating with Community colleges in the formation of teams of non-engineering community college students and engineering Cal Poly Pomona students. Teams that have successfully development research projects while working in a multidisciplinary environment.

Professor Buckley will be the primary mentor for the IRES students during their 5 1/2 week research experience at the University of KwaZulu-Natal (see C. Buckley support letter). Ensuring the safety of IRES participants while on campus and at the field sites is the number one priority in for the Pollution Research Group. Prof. Buckley and his staff will make housing arrangements for the students at the D’urban Elephant or at one of the nearby accommodations (Chelsea Villa Guesthouse) that is a safe walk or drive to the UKZN campus. Prof. Buckley will also make arrangements and ensure safe transportation to the Newlands Mashu and Frasers field sites. In January 2013, PI Mladenov and her student Hersy Enriquez visited the Newlands Mashu site (Figs. 2a, 2b, and 2d), which is an eThekweni Municipality research site with secured entry and staffed by UKZN and municipality scientists and technicians. Prof. Buckley will also coordinate the IRES student research and will, together with PI Mladenov, pair students with the appropriate research projects based on student research interests and other materials submitted in the online application. In the final week of the research experience, Pollution Research Group staff will facilitate a poster session at UKZN in which each IRES student will present a poster to their cohort and to student and faculty researchers in the Pollution Research Group.

Prior NSF Support. OISE-1105289. Int’l Planning Visit: Investigating the interactions between DOM, microbial communities, and arsenic biogeochemistry in groundwater of a pristine delta. (Mladenov, McKnight; \$12,710, 2011 – 2013). *Intellectual merit:* Preliminary microbial and chemical data were collected; 1 publication is in press. *Broader impacts:* 2 female (one minority) graduate students and 2 female undergraduates conducted research and theses are in preparation.