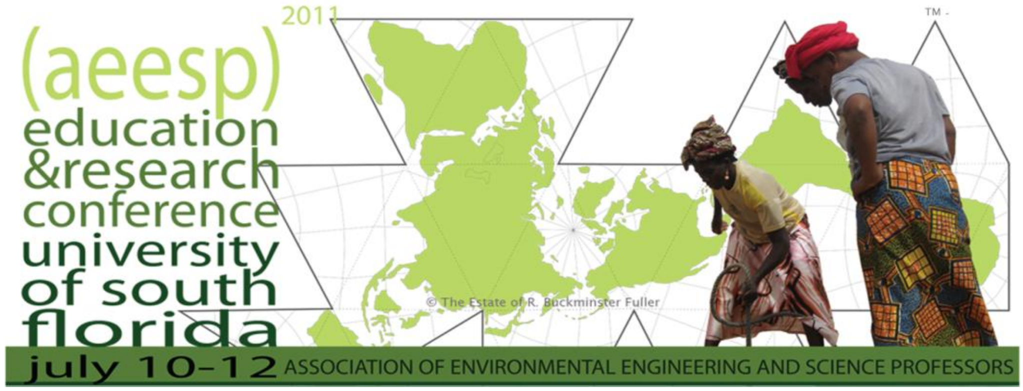
University of South Florida

July 10–12, 2011

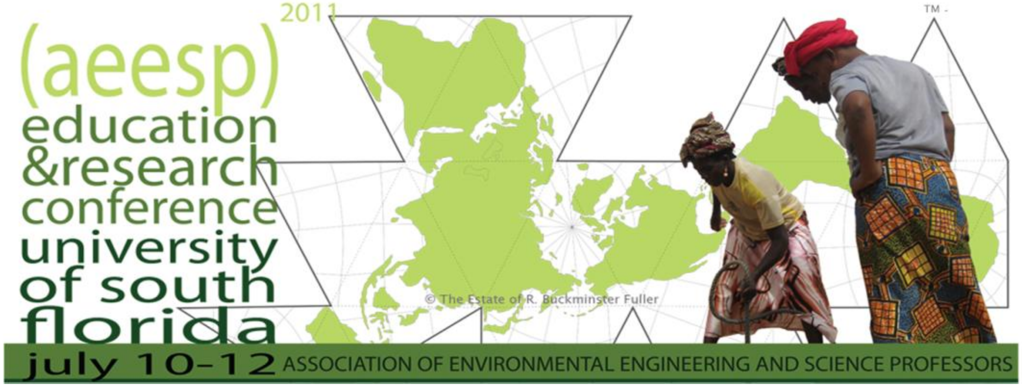
Tampa, Florida

http://www.aeesp2011.com



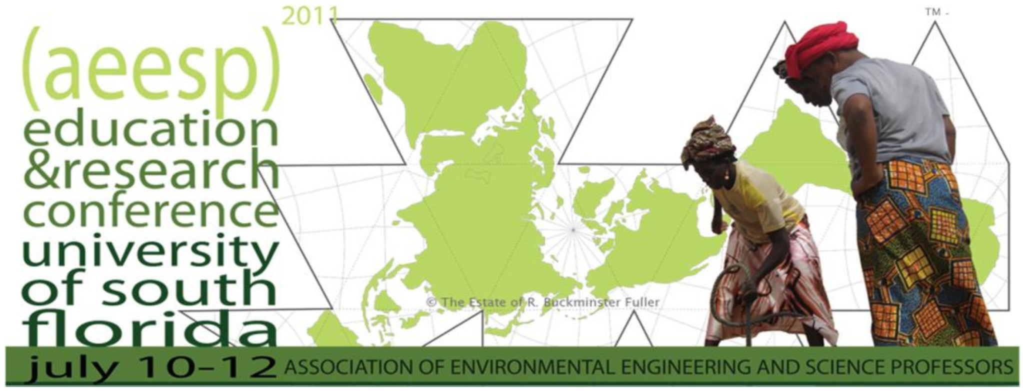
Program **O**verview

Sunday – July 10, 2011	
8:00 am	Conference Registration on the 2nd Floor Marshall Student Center (until 4:45 pm)
9:00 am to 12 m	**Workshops** 1a: NSF CAREER proposals (starts at 8:30 am) 2a: Academic job search 3a: Integrating sustainable development into engineering courses 4a: Engaging students in the classroom 5a: Quantitative microbial risk assessment 4b: Teaching using video lessons 5b: Environ. chemistry software
12:45 pm to 3:45 pm	**Workshops** 1b: Navigating the early years of academia 2b: Frontiers in environmental education 3b: Strategies for teaching writing 4c: Response to climate change 5c: Natural & eng systems in the built environ 4d: Service learning projects & sustainability
5:00 pm to 9:00 pm	**Dinner** Networking Social (Clearwater Hilton, Gulf Coast beach). Shuttles provided and depart USF at 5:00 pm. Activities to welcome new members organized by the AEESP membership committee.
Monday – July 11, 2011	
7:30 am	Conference Registration on 2nd Floor Marshall Student Center (until 4:00 pm)
7:30 am to 8:30 am	Continental Breakfast available in the Marshall Student Center (MSC)
8:30 am to 8:40 am	Welcome by **Dr. Ralph C. Wilcox**, Provost and Executive Vice President, USF
8:40 am to 9:45 am	Plenary Session *"Designing Tomorrow"* with **Dr. Paul Anastas**



Program **O**verview (cont'd)

10:00 am to 11:45 am	Research and Education Oral Presentations
11:45 am to 1:00 pm	Lunch Plenary Speaker *"The Day After Tomorrow: Changing Our View of Education"* with **Dr. James Mihelcic**
1:15 pm to 4:15 pm	Research and Education Oral Presentations
6:00 pm to 9:30 pm	AEESP Business Meeting, Awards Ceremony & Dinner at Florida Aquarium in downtown Tampa (Shuttles provided and depart USF at 5:00 pm. They return starting at 8:30 pm and ending at 10:30 pm). 6-7 pm Registrants get to tour the Aquarium. Buffet dinner starts at 6:30 pm. Welcome by: **Lisa Montelione**, Member of the Tampa city council and the owner of Sustainable Development Strategies LLC Aquarium is close to Channelside area or you can take a trolley to Ybor City if interested in going out after the meeting.
Tuesday – July 12, 2011	
7:30 am	Conference Registration on 2nd Floor Marshall Student Center (until 11:45 pm)
7:30 am to 8:30 am	Continental Breakfast available in the Marshall Student Center (MSC)
8:30 am to 8:40 am	Welcome by **Dr. John Wiencek**, Professor & Dean, USF College of Engineering
8:40 am to 8:45 am	Plenary Session *"Climate Change and Development: Avoiding the Unmanageable and Managing the Unavoidable"* with **Dr. Rosina Bierbaum**
10:00 am to 11:45 am	Research and Education Oral Presentations
11:45 am to 1:00 pm	Lunch with activities led by the AEESP government affairs committee and strategic planning committee at the MSC Ballroom. Welcome by: **Dr. Kala Vairavamoorthy**, Director, Patel School of Global Sustainability
1:15 pm to 3:35 pm	Research and Education Oral Presentations
3:45 pm to 6:30 pm	Poster Session and Social at USF Interdisciplinary Research Building Galleria -IDR
7:00 pm to 9:00 pm	Dinner & *"Legacy Celebration: Round 2"* hosted by Dr. Wayne Echelberger and Dr. Phil Singer at Embassy Suites. Announcement of contest winners.



AEESP Welcome **L**etter

Ahoy, AEESP Maties! (come to the Monday night business meeting and awards ceremony to understand the motivation for the pirate talk):

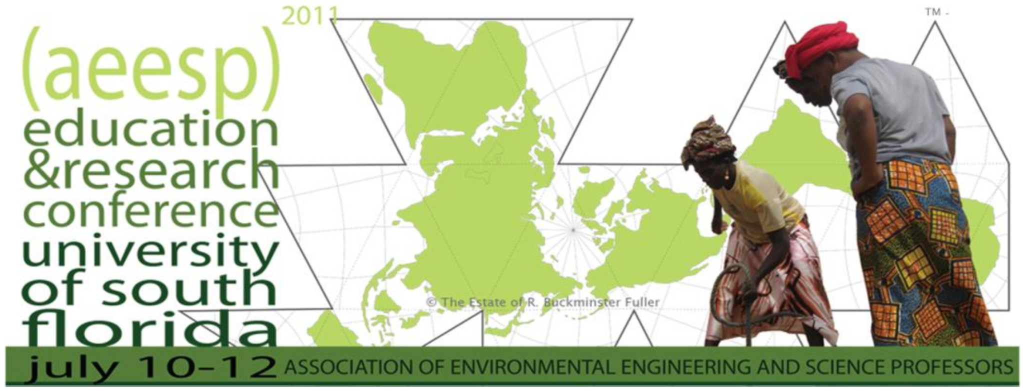
On behalf of the AEESP Board of Directors we would like to welcome you to the AEESP 2011 meeting. This is certainly an exciting time to be working at the forefront of education and research in environmental engineering and science. The conference theme "Integrating Global Sustainability into Education, Research, and Practice" captures the breadth of topics that encompass our environmental field, and the depth of our impact which occurs through educating future leaders in education, research and practice. Our field is one that evolves rapidly and dramatically, and this conference gives us the opportunity to come together and recalibrate ourselves to keep up with changing priorities for the future.

Our biannual AEESP meetings are truly unique, and are largely without peer among professional societies - something that we thank our visionary legacy members for. We are a highly collegial group of professors, practitioners and students who take the time and make the effort to convene every two years to share our most exciting research discoveries, to learn about educational and teaching strategies, and to debate the most pressing real world issues in the field. The biannual conference creates an environment where we can convene to address the needs and opportunities in environmental engineering and environmental science teaching and research, with unrestrained passion and conviction. Workshops are put on by volunteers and are designed to engage in healthy dialog about issues of importance to the field, to learn new educational strategies, to learn about work-life balance, and to share tools and skills that give everyone a chance to be successful. What a wonderful community of people!

This year's conference organizers from the University of South Florida have done a spectacular job in planning what we know will be an enriching and educational program for everyone. They are very ready to host you, and please thank them for their hard work when you see a member of the organizing committee over the next few days. We close by wishing you a wonderfully fulfilling conference. And don't forget to have fun….Shiver me timbers, we both plan to! Argh!

Nancy Love
2010-2011 AEESP President

Joel Burken
2011-2012 AEESP President



Organizing **C**ommittee ~ **W**elcome **L**etter

On behalf of the organizing committee of the 2011 Association of Environmental Engineers and Science Professors (AEESP) Research and Education Conference, we welcome you to Tampa, to the University of South Florida (USF), and to your Conference.

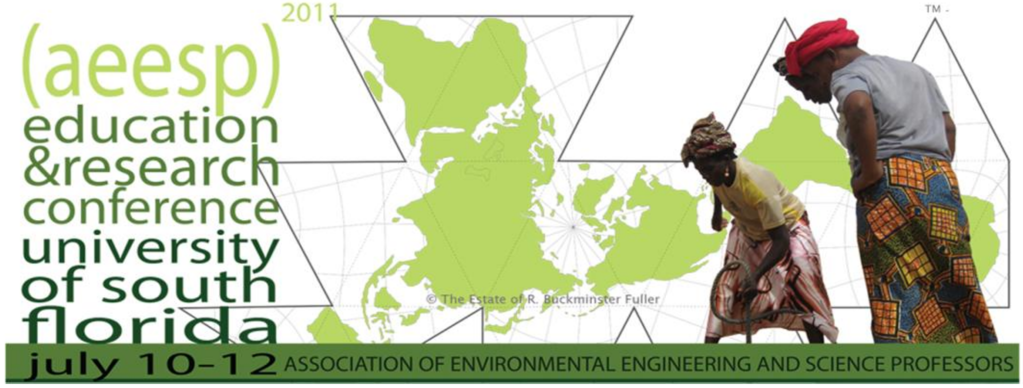
The biennial Research and Education Conference is the flagship event for AEESP members to exchange information on novel research and educational activities. We hope that this year's Conference will serve as an effective, exciting, and enjoyable forum for the exchange of information between and within the academic and practitioner communities, particularly relating to the advancement of innovative research and to the preparation of students for professional practice in environmental engineering.

While you are here, you will be able to explore the Conference's theme -- Global Sustainability: Implications for Research, Education, & Practice -- through 13 pre-Conference workshops, three presentations from invited keynote speakers, 140 poster presentations, and more than 100 oral presentations. We hope you will also enjoy other Conference features such as a photography competition, student poster competition, recorded interviews of AEESP members, and -- continuing an activity started in 2005 at the Conference hosted by Clarkson University -- a celebration of "legacy members" of AEESP.

Many people have contributed to the success of this Conference. We especially thank our sponsors: the National Science Foundation, American Water Works Association, Water Environment Federation, Environmental Research & Education Foundation, International Water Association, Springer Publishing Co., John Wiley & Sons Inc., CH2M HILL, Hazen and Sawyer, HDR Inc., Florida Water Environment Association, Tetra Tech Inc., USF College of Engineering, USF Department of Civil and Environmental Engineering, USF Office of Sustainability, USF Office of Research & Innovation, and the Patel School of Global Sustainability at USF. We also thank technical committee members, session moderators, workshop organizers, platform and poster presenters, legacy members of AEESP, judges of student posters, members of the AEESP Board of Directors and AEESP Conference Planning Committee, AEESP staff, and USF students and staff.

Once again, welcome to the 2011 Research and Education Conference!

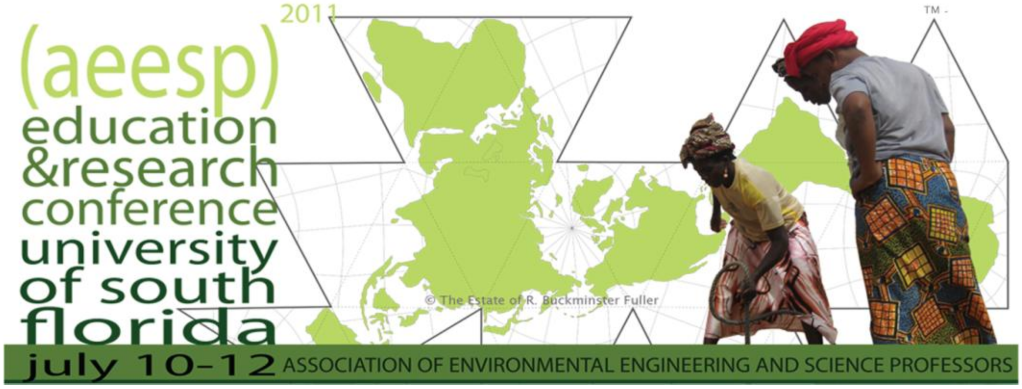
Maya Trotz & Jeffrey Cunningham
2011 Conference co-chairs



Organizing **C**ommittee

2011 AEESP RESEARCH AND EDUCATION CONFERENCE ORGANIZING COMMITTEE
DANIEL YEH, JEFFREY CUNNINGHAM (CO-CHAIR), JAMES MIHELCIC, KALA VAIRAVAMOORTHY
AMY STUART, MAYA TROTZ (CO-CHAIR), QIONG JANE ZHANG, SARINA ERGAS
MISSING FROM PICTURE: WAYNE ECHELBERGER & LINDA PHILLIPS

Jeffrey Cunningham & **M**aya Trotz (Conference co-chairs)
Wayne Echelberger
Sarina Ergas
James Mihelcic
Linda Phillips
Amy Stuart
Kala Vairavamoorthy
Daniel Yeh
Qiong Jane Zhang

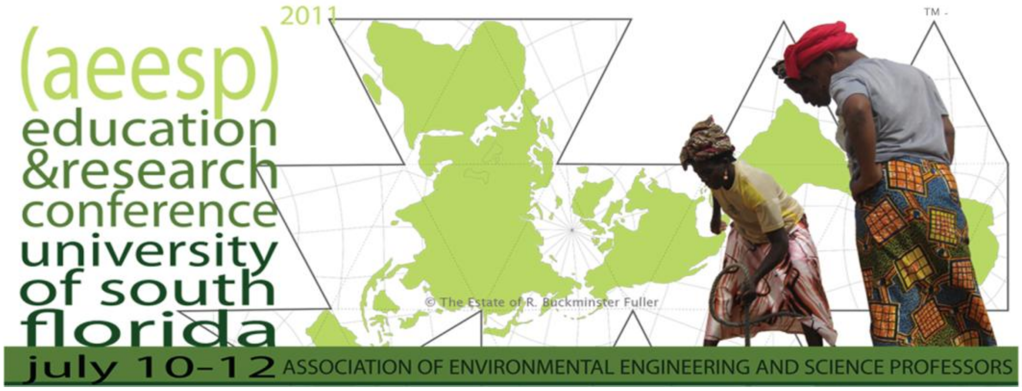


Conference **H**ost

*The **University of South Florida** (USF) is one of the nation's top public research universities and one of only 25 public research universities nationwide with very high research activity that is designated as community engaged by the Carnegie Foundation for the Advancement of Teaching. USF serves more than 47,000 students in Tampa, St. Petersburg, Sarasota-Manatee and Lakeland. USF offers 232 degree programs at the undergraduate, graduate, specialist and doctoral levels, including 89 bachelor, 97 master, two ed specialist, 36 research doctoral, and four professional doctoral programs. USF is accredited by the Commission on Colleges of the Southern Association of Colleges and Schools (SACS). The 2011 U.S. News & World Report annual college rankings placed the University of South Florida as one of the nation's "up and coming universities." USF received over $360 million in research grants and contracts in the 2007/2008 fiscal year (the most recent for which the data are available). In a 2009 ranking by the Chronicle of Higher Education Almanac, the University of South Florida was rated the fastest growing U.S. university in terms of obtaining federal research funds (a 213% increase from 2000 to 2007). Last month, USF appeared as one of only 14 universities, and the only university in Florida, on a list of 300 organizations awarded the highest number of U.S. patents last year.*

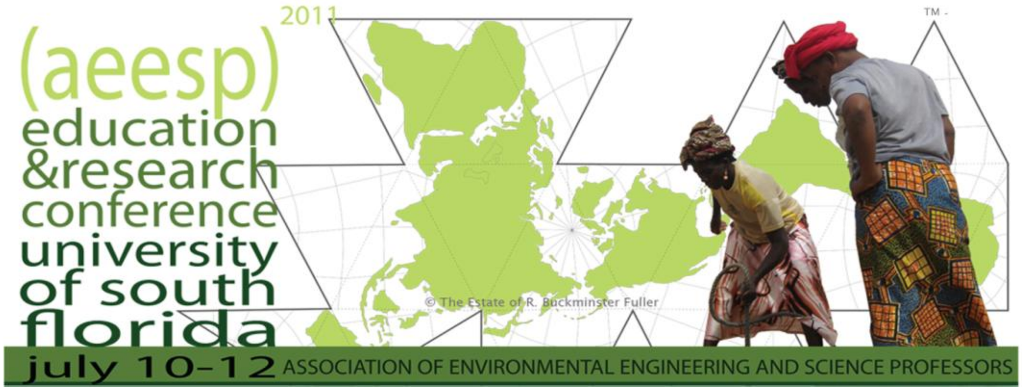
*The **College of Engineering** at USF comprises six academic departments: Chemical & Biomedical Engineering, Civil & Environmental Engineering, Computer Science & Engineering, Electrical Engineering, Industrial & Management Systems Engineering, and Mechanical Engineering. The mission of the College of Engineering is to improve the quality of life in its community by providing a high quality education for its students and practicing professionals, by creating new knowledge and solving real world problems via innovative research, and by engaging in effective community service and outreach. By providing a relevant, high quality educational experience for its students and by being a leader in innovative research in the areas of sustainability, renewable energy, and biomedical engineering, the College of Engineering aspires to be a peer among engineering programs at research-focused public universities. The College of Engineering has 17 faculty members who are NSF CAREER award recipients, including nine with active awards.*

*The **Department of Civil and Environmental Engineering** at USF graduates approximately 100 undergraduate engineers every year and has approximately 200 graduate students, about 80 who are working on a doctoral degree. Two faculty recently received distinguished CAREER awards from the National Science Foundation. Research centers in which our students are involved include the Center for Modeling Hydrologic and Aquatic Systems, the Clean Energy Research Center, and the Center for Urban Transportation Research.*



Sponsorship Level

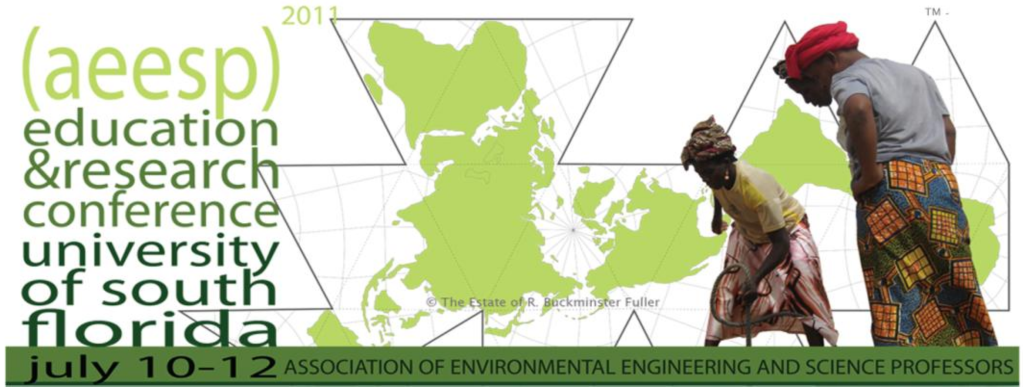
Level	Sponsor	Logo
Conference	University of South Florida (USF) USF College of Engineering National Science Foundation (NSF)	
Event	CH2MHill	
Session	Patel School of Global Sustainability AWWA	
Student	Environmental Research & Education Foundation Springer WILEY Publishers Hazen & Sawyer HDR IWA Publishing Water Environment Federation USF Office of Sustainability USF Office of Research and Innovation Florida Water Environment Association Tetra Tech	



Conference **T**echnical **C**ommittee

Jeffrey Cunningham (University of South Florida)
Maya Trotz (University of South Florida)

Lilia Abron (PEER Consultants)
Defne Apul (University of Toledo)
Daniel Cohan (Rice University)
John Crittenden (Georgia Institute of Technology)
Marc Edwards (Virginia Polytechnic Institute and State University)
James Edzwald (University of Massachusetts-Amherst)
Sarina Ergas (University of South Florida)
April Gu (Northeastern University)
Timothy Haug (AAEE Trustee, Loyola Marymount University)
Kimberly Jones (Howard University)
Young-Shin Jun (Washington University in St. Louis)
Daniele Lantagne (Harvard University & Center for Disease Control)
Heather MacLean (University of Toronto)
James Mihelcic (University of South Florida)
Shelie Miller (University of Michigan)
Debbie Niemeier (University of California-Davis)
Catherine Peters (Princeton University)
Debra Reinhart (University of Central Florida)
Diego Rosso (University of California-Irvine)
Michael Selna (AAEE Trustee, formerly Sanitation Districts of Los Angeles County)
Bradley Striebig (James Madison University)
Amy Stuart (University of South Florida)
Daniel Yeh (University of South Florida)
Qiong Zhang (University of South Florida)
Julie Zimmerman (Yale University)


2011
(aeesp)
education
&research
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ASSOCIATION OF ENVIRONMENTAL ENGINEERING AND SCIENCE PROFESSORS
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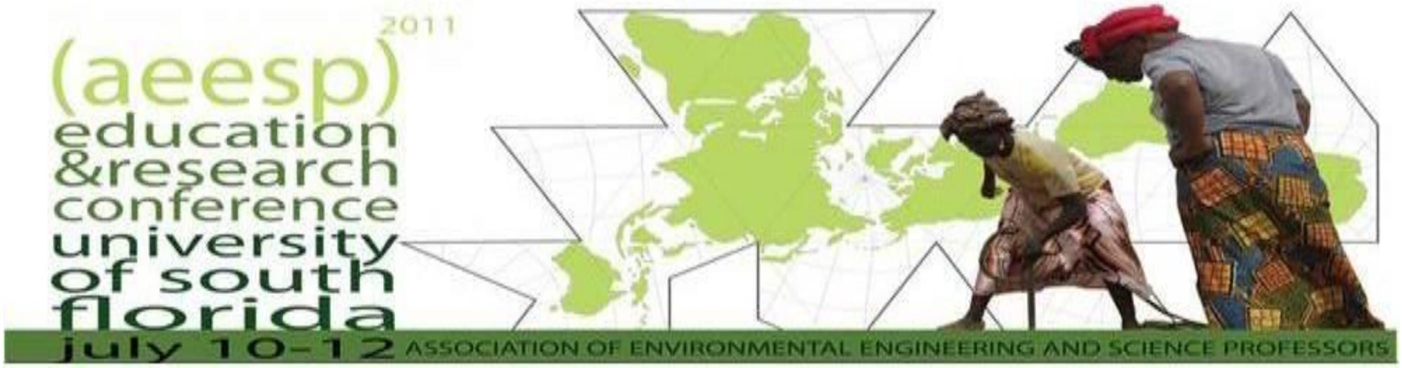
Program



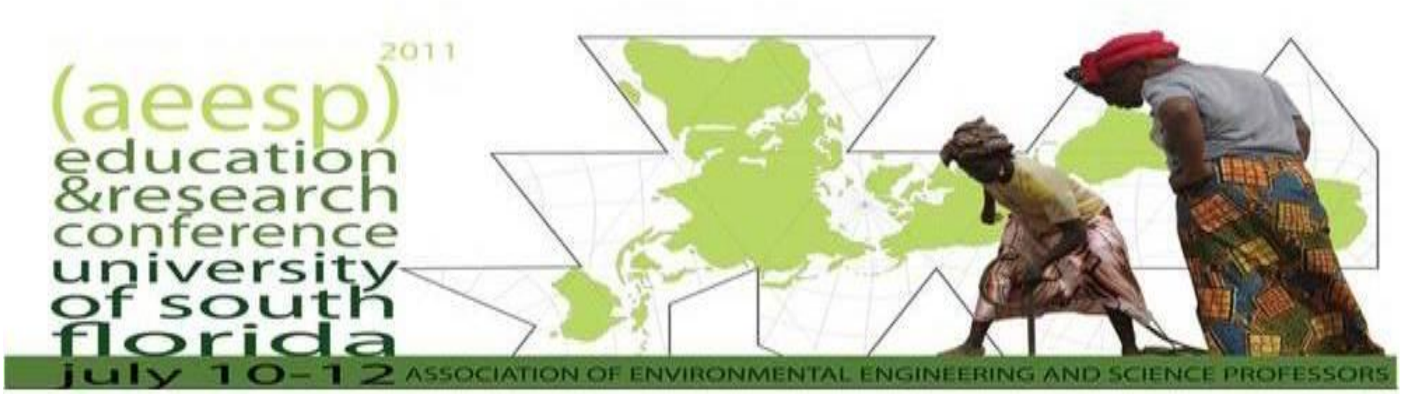
Plenary/**K**eynote **S**peaker **B**iographies

Paul Anastas, Ph.D., is the Assistant Administrator for EPA's Office of Research and Development (ORD) and the Science Advisor to the Agency. Known widely as the "Father of Green Chemistry" for his groundbreaking research on the design, manufacture, and use of minimally-toxic, environmentally-friendly chemicals, Dr. Anastas has an extensive record of leadership in government, academia, and the private sector. He earned his B.S. from the University of Massachusetts at Boston and his M.A. and Ph.D. in chemistry from Brandeis University. At the time he was nominated by President Obama to lead ORD, Dr. Anastas was the Director of the Center for Green Chemistry and Green Engineering, and the inaugural Teresa and H. John Heinz III Professor in the Practice of Chemistry for the Environment at Yale University's School of Forestry and Environmental Studies. Prior to joining the Yale faculty, Dr. Anastas was the founding Director of the Green Chemistry Institute, headquartered at the American Chemical Society in Washington, D.C. From 1999 to 2004 he worked at the White House Office of Science and Technology Policy, concluding his service there as the assistant director for the environment. Dr. Anastas began his career as a staff chemist at EPA, where he rose to the positions of chief of the Industrial Chemistry Branch, and director of the U.S. Green Chemistry Program. It was during his work at EPA that Dr. Anastas coined the term "green chemistry."

Trained as a synthetic organic chemist, Dr. Anastas' research interests have focused on the design of safer chemicals, bio-based polymers, and new methodologies of chemical synthesis that are more efficient and less hazardous to the environment. A leading writer on the subjects of sustainability, green chemistry, and green engineering, he has published ten books, including "Benign by Design," Designing Safer Polymers," "Green Engineering" and his seminal work with co-author John Warner, "Green Chemistry: Theory and Practice."

Dr. Anastas has been recognized for his pioneering work with a host of awards and accolades including the Vice President's Hammer Award, the Joseph Seifter Award for Scientific Excellence, the Nolan Sommer Award for Distinguished Contributions to Chemistry, the Greek Chemical Society Award for Contributions to Chemistry, the Inaugural Canadian Green Chemistry Award, a Scientific American 50 Award for Policy Innovation, the John Jeyes Award from the Royal Society of Chemistry, and an Annual Leadership in Science Award from the Council of Scientific Society Presidents. He was a Special Professor at the University of Nottingham and an Honorary Professor at Queens University in Belfast where he was also was awarded an Honorary Doctorate.

(Biosketch obtained from: http://www.epa.gov/ord/htm/anastas_bio.htm)



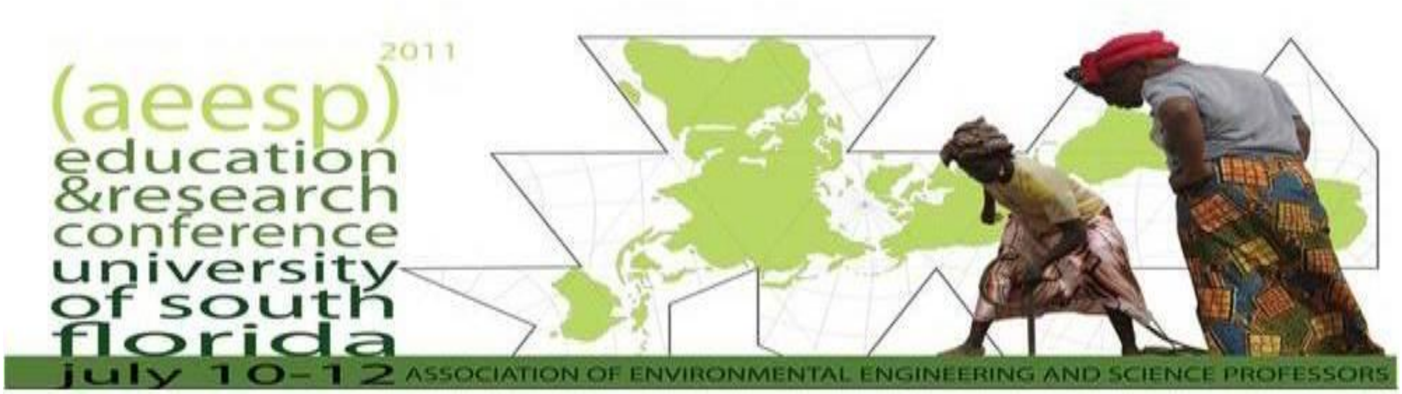
Plenary/**K**eynote **S**peaker **B**iographies

Rosina Bierbaum, Ph.D., is the Dean of the School of Natural Resources and Environment (SNRE) at the University of Michigan. She has earned a B.A. in English and B.S. in Biology from Boston College and a Ph.D. in Ecology and Evolution from the State University of New York, Stony Brook. In April 2009, President Obama named her to the President's Council of Advisors on Science and Technology (PCAST). In April 2008, Dr. Bierbaum was selected by the World Bank to co-author and co-direct *World Development Report 2010: Development and Climate Change.* Published since 1978, the World Development Report is an annual publication that focuses on a different topic each year and aims both to consolidate existing knowledge on a particular aspect of development and to stimulate debate on new directions for development policy. For the first time, this report was aimed at helping nations think about how sustainability, mitigation and adaptation to climate change and development can be achieved simultaneously.

Dr. Bierbaum is an elected Fellow of the American Academy of Arts and Science as well as of the American Association for the Advancement of Science. In 2010 she received a Distinguished Service Citation from the Ecological Society of America for her "long and distinguished service" to the scientific community and her ecological work in the public interest. She was awarded the Waldo E Smith medal of the American Geophysical Union for ‘extraordinary service to geophysics’ in 2000, and in 1999 she was awarded the Environmental Protection Agency’s “Climate Protection Award”.

She currently serves as a board member for the Federation of American Scientists, The Energy Foundation, the Gordon E. and Betty I. Moore Foundation, and the Environmental and Energy Study Institute. She is also a member of the International Advisory Board for the journal “Frontiers in Ecology and the Environment” and the Executive Committee for the Tyler Prize for Environmental Achievement. Dr. Bierbaum serves as the U.S. Scientific Expert, Permanent Court of Arbitration of Disputes Relating to Natural Resources and/or the Environment, in the Hague.

Prior to joining the School of Natural Resources and Environment, Dr. Bierbaum was acting director of the Office of Science and Technology Policy (OSTP) from January 2001, and preceding that, she directed the first Environment Division at OSTP. Dr. Bierbaum was confirmed by the U.S. Senate as Associate Director for Environment of OSTP on July 30, 1998. She served as the administration’s senior scientific advisor on environmental research and development, with responsibilities for scientific input and guidance on a wide range of national and international environmental issues. These included global change, air and water quality, biodiversity, ecosystem management, environmental monitoring, and energy research and development.

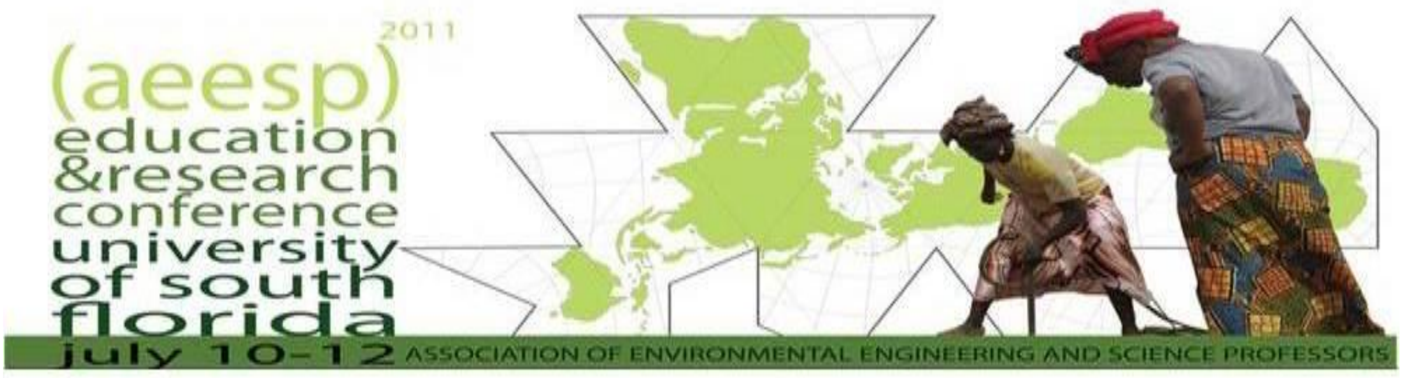


She worked closely with the President's National Science and Technology Council (NSTC), and co-chaired its Committee on Environmental and Natural Resources, which coordinated the $5 billion federal research and development efforts in this area, including the (then) $2 billion US Global Change Research Program. Bierbaum led the U.S. government reviews of the IPCC second and third assessment reports in 1995 and 2000. She also led the US delegations to the Intergovernmental Panel on Climate Change (IPCC) Plenary in Shanghai in 2001, the IPCC Plenary in Montreal in 1999, and the IPCC plenary in Costa Rica in 1998, and served as alternate head of delegation to the IPCC plenary in Mexico City in 1996. She headed the U.S. Delegation for the U.S./China bilateral on Climate Science in 2000.

Dr. Bierbaum's career in Washington began in 1980 when she was awarded a Congressional Fellowship. She then continued working in the Office of Technology Assessment (OTA) on a wide range of environmental issues, helping various Committees of the Congress tackle the emerging science and policy concerns posed by acid rain, marine pollution and mining, urban smog, ozone depletion, energy production and climate change. Her work led to 9 book-length publications and positions as Assistant Project Director for Acid Rain in 1982, Senior Analyst in 1985, and Project Director for Climate Change in 1988. In 1991, she was awarded OTA's highest honor -- Senior Associate.

In addition to publishing many articles in technical and popular journals, Dr. Bierbaum is the co-author of the report "Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable" prepared at the request of the Commission on Sustainable Development (2007). She is also the primary author of Changing By Degrees: Steps to Reduce Greenhouse Gases. This report (1991) identified a series of technical options to reduce both U.S. and worldwide emissions. In 1993, she directed and was the primary author of the two volume study, Preparing for an Uncertain Climate, which outlines a sustainable development strategy for the United States. This report was the foundation for the United States' formal submissions on Adaptation to the International Conference of Parties on Climate Change in 1995 and 1997.

(Biosketch obtained from: http://www.snre.umich.edu/profile/rbierbau)

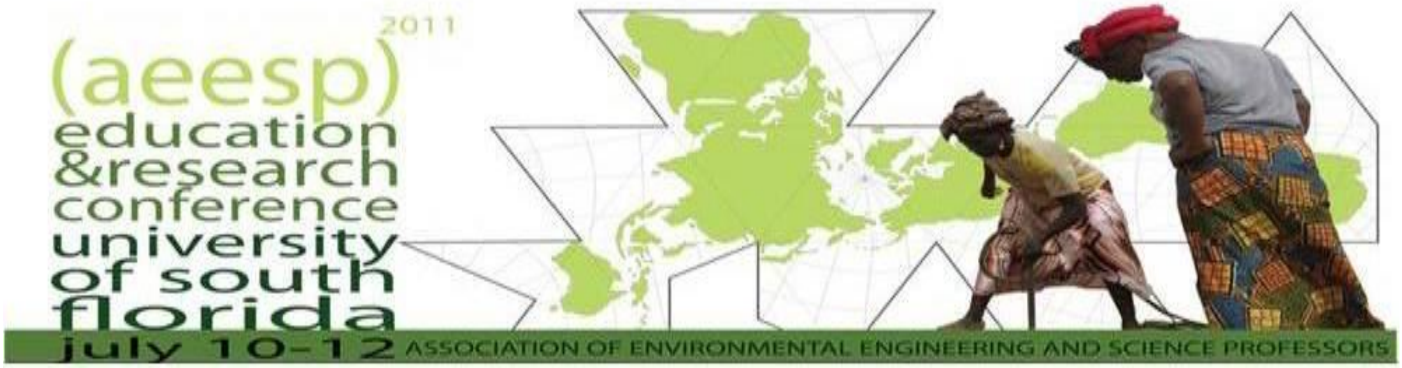


Plenary/**K**eynotes **S**peakers **B**iographies

James R. Mihelcic, Ph.D., is a Professor of Civil and Environmental Engineering and a State of Florida 21st Century World Class Scholar at the University of South Florida. He earned his B.S. in Environmental Engineering from Pennsylvania State University and his M.S. and Ph.D in Civil Engineering from Carnegie Mellon University. His teaching and research interests are in sustainability, water and sanitation, design and operation of appropriate technology, green engineering, and reform of engineering education. He directs a Peace Corps Master's International Program in Civil and Environmental Engineering. This program allows students to combine their graduate education and research with service in the Peace Corps as a water/sanitation engineer. Dr. Mihelcic is lead author for 3 textbooks: *Fundamentals of Environmental Engineering* (John Wiley & Sons, 1999); *Field Guide in Environmental Engineering for Development Workers: Water, Sanitation, Indoor Air (*ASCE Press, 2009); and, *Environmental Engineering: Fundamentals, Sustainability, Design (*John Wiley & Sons, 2010).

Dr. Mihelcic is a past president of the Association of Environmental Engineering and Science Professors. He is a current Board Trustee and Board Certified Environmental Engineering Member of the American Academy of Environmental Engineers (AAEE). He is a member of the EPA Chartered Science Advisory Board (SAB) and also the EPA SAB's Environmental Engineering Committee. He has traveled extensively in the developing world to serve and conduct research on sustainable development related to providing water, sanitation, and hygiene. Some of his recent field trips have been to Bolivia, Dominican Republic, Fiji, Honduras, and Madagascar.

He has received several education and research awards from students, AEESP, and the American Society for Engineering Education (ASEE). These awards include an AEESP Doctoral Thesis Award, the AEESP-Wiley Interscience Award for Outstanding Contributions to Environmental Engineering & Science Education, and a Best Paper Award from the Environmental Engineering Division at the American Society for Engineering Education.


2011
(aeesp)
education
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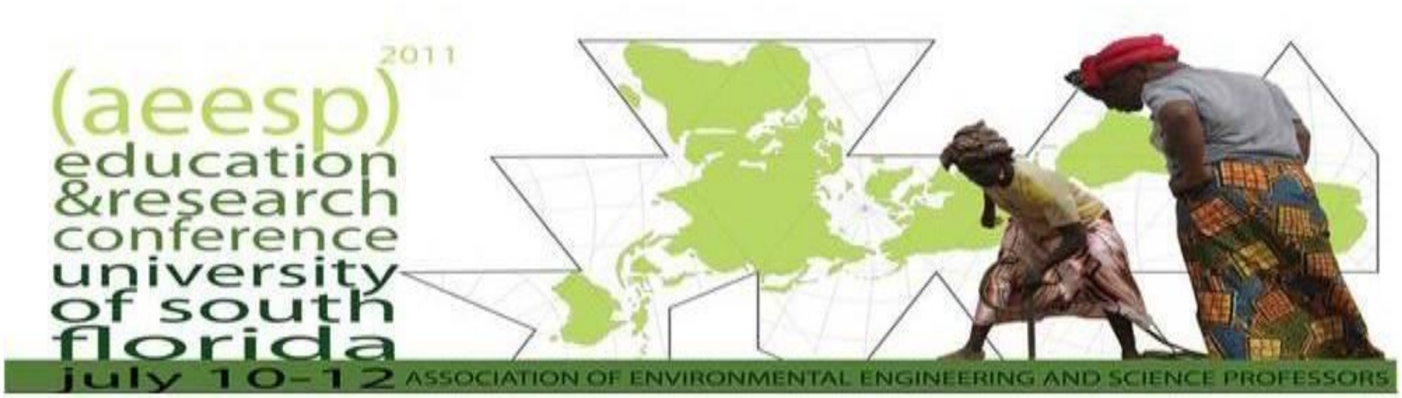
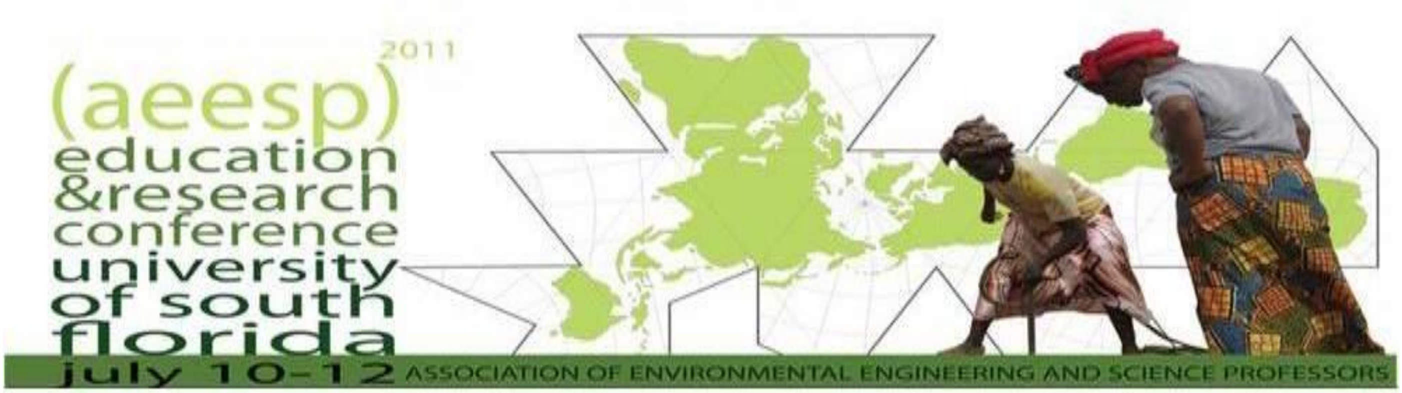
conference
university
of south
florida
july 10-12
ASSOCIATION OF ENVIRONMENTAL ENGINEERING AND SCIENCE PROFESSORS

Workshops



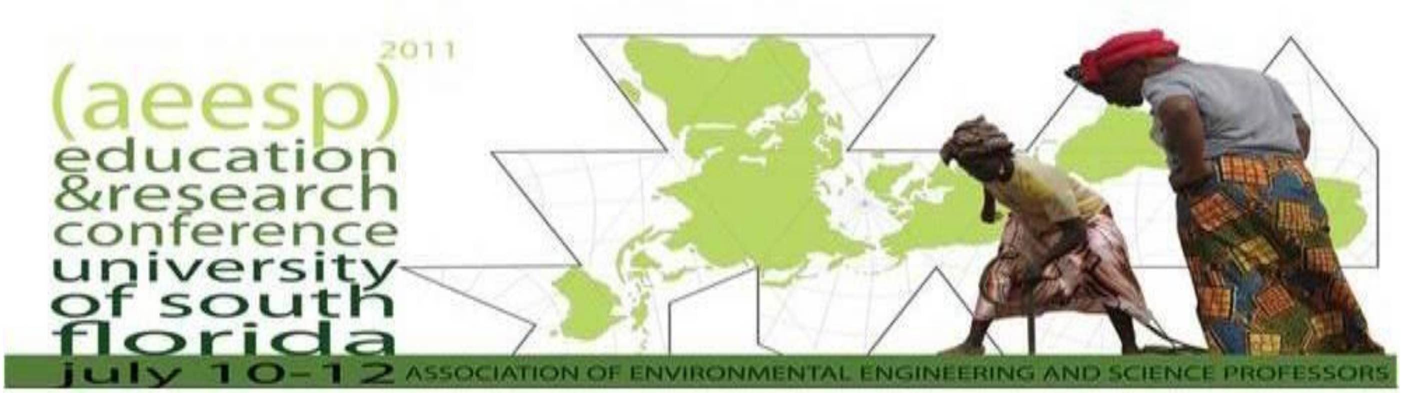
Workshop Topics

Full Workshops			
Title		**Organizers**	**Contact for more information**
1a	**N**SF CAREER proposal workshop	Jeff Cunningham, University of South Florida	cunning@usf.edu
1b	**S**tarting off right: Navigating the early years of academia	Sharon Walker & David Cwiertny , UC Riverside	swalker@engr.ucr.edu
2a	**N**avigating the Academic Job Search: A Workshop for Graduate Students, Post Docs, and Practitioners	Defne Apul, University of Toledo, Andrew J. Whelton, NIST and the AEESP student services committee	defne.apul@utoledo.edu, ajwhelton@gmail.com
2b	**F**rontiers in Environmental Education	Angela Bielefeldt, Univ. CO, Joel Burken, Missouri S&T, Joe Hughes, Georgia Tech, Sharon Jones, Lafayette College, Kurt Paterson, Michigan Tech, Deb Reinhart, Univ. Central FL	burken@mst.edu
3a	**I**ntegrating Sustainable Development into Courses throughout the Engineering Curriculum	Cliff I. Davidson, Syracuse University John C. Crittenden, Georgia Tech., Julie B. Zimmerman, Yale, Qiong (Jane) Zhang, Univ. South FL	davidson@syr.edu
3b	**G**iving your students an edge: efficient strategies for teaching writing skills	Jen Fela, Washington DC, Brian E. Whitman, Wilkes Univ., Julie Zilles, University of Illinois Urbana-Champaign	jzilles@illinois.edu

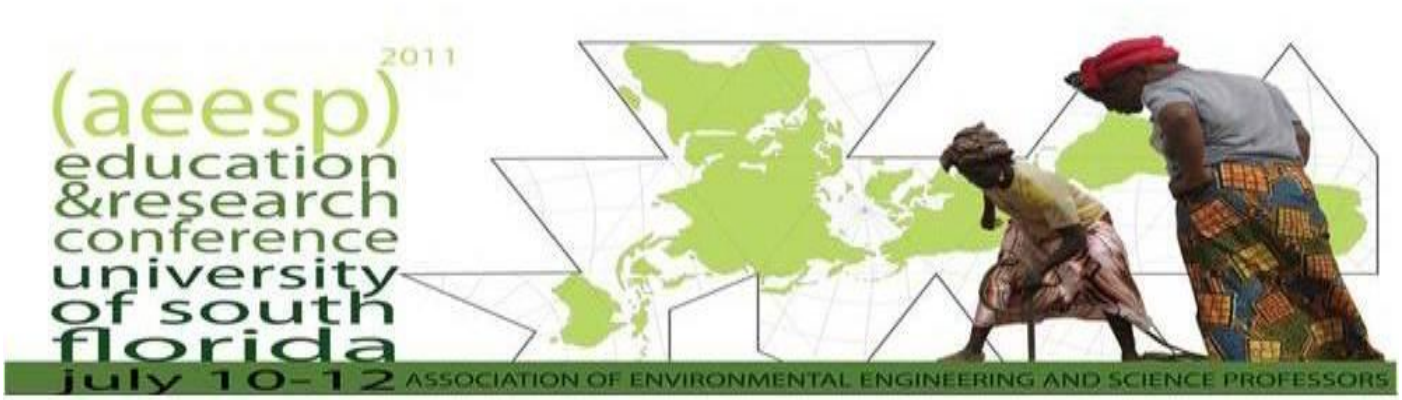


How Do I Teach…?

Title		Organizers	Contact for more information
4a	**E**ngaging Students in the Classroom Environment	Joel Burken, Missouri S&T, Jeanine D. Plummer, Worcester Polytech, Jeanne VanBriesen, Carnegie Mellon Univ.	jplummer@wpi.edu
4b	**U**sing Video Lessons to Enhance Learning and Classroom Interactions	Philip T. McCreanor, Mercer Univ.	mccreanor_pt@mercer.edu
4c	**R**esponse to climate change: adaptation, mitigation, and sustainability	Glenn Schrader, Univ AZ, Maya Trotz, Univ. South FL and Allan Feldman, Univ. South FL	afeldman@usf.edu
4d	**I**ntegrating Intensive Service Learning Projects into Sustainability Courses	Bruce Dvorak, University of Nebraska, Angela R. Bielefeldt, University of Colorado, Craig Just, University of Iowa	bdvorak@unlnotes.unl.edu
5a	**T**eaching Quantitative Microbial Risk Assessment in Environ. Engr. & Science	Charles N. Haas, Drexel Univ., Patrick L. Gurian, Drexel Univ., Mark H. Weir, Michigan State	weirma@msu.edu
5b	**S**oftware used in teaching environmental chemistry	Steve Cabaniss, Univ. New Mexico	cabaniss@unm.edu
5c	**S**ustainability – An Integration of Natural And Engineering Systems In The Built Environment	Daniel Becker, Plunkett Raysich Architects, Milwaukee WI	dbecker@prarch.com



Room	2708 Plaza	3707 Oak	2709 Hillsborough	3705 Manatee	3709 Heron
8:30	1a: **NSF CAREER proposal**				
9:00		2a: **Academic job search**	3a: **Integrating sustainable development into Engrg. Courses**	4a: **Engaging students in the classroom**	5a: **Quantitative microbial risk assessment**
Room				**3708 Sandhill Crane**	**3711 Egret**
10:30				4b: **Teaching using video lessons**	5b: **Environ. Chemistry software**
12:00	**Working Lunch (for am full workshops)**				
Room	**3707 Oak**	**3709 Heron**	**3708 Sandhill Crane**	**3711 Egret**	**3705 Manatee**
12:45	1b: **Navigating the early years of academia**	2b: **Frontiers in environ mental education**	3b: **Strategies for teaching writing**	4c: **Response to climate change**	5c: **Natural & eng systems in the built environ**
Room				**2709 Hillsborough**	
2:15				4d: **Service learning projects & sustainability**	
3:45	**Get Ready to Go to Clearwater Beach**				



Workshop Descriptions

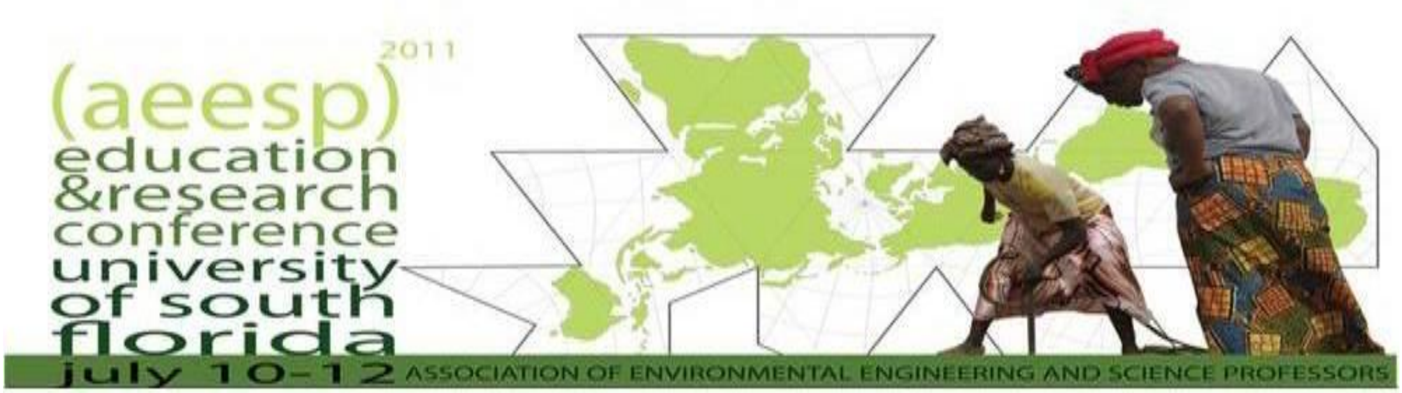
1a. NSF CAREER WORKSHOP

NSF's Faculty Early Career Development (CAREER) Program is a Foundation-wide activity that offers the National Science Foundation's most prestigious awards in support of junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations. NSF envisions that the CAREER award will help awardees to build a firm foundation for a lifetime of leadership in integrating education and research and to develop careers as outstanding researchers and educators who effectively integrate teaching, learning and discovery. Because of the importance of the CAREER program in establishing the next generation of teacher-scholars, and because of the significant opportunity that this award represents to awardees, a workshop dedicated to the NSF CAREER program will be conducted as part of the 2011 AEESP Research and Education Conference.

Objectives of the NSF CAREER workshop are:

1. Inform and familiarize participants with the NSF Faculty Early Career Development Program;
2. Inspire participants to reflect on their roles as teacher-scholars who integrate teaching, learning, research, and discovery;
3. Stimulate discussion concerning personal and professional growth as a tenure-track faculty member in environmental engineering and science; and
4. Offer practical advice to participants on preparing effective CAREER proposals.

8:30 – 8:45	Welcome and introduction	Jeffrey Cunningham (Univ. South Florida)
8:45 – 9:15	"NSF CAREER program"	Paul Bishop (National Science Foundation)
9:15 – 9:45	Panel #1: How are CAREER proposals evaluated?	Pat Brezonik (University of Minnesota), Jim Mihelcic (University of South Florida), Tom Theis (University of Illinois – Chicago)
9:45 – 10:00	Networking break	
10:00 – 10:30	Panel #2: Congratulations, you are a CAREER winner! Now what?	Ramesh Goel (University of Utah), Keri Hornbuckle (University of Iowa), Kimberly Jones (Howard University), Eric Marchand (Univ. Nevada – Reno), Kara Nelson (Univ. California – Berkeley), Amy Stuart (University of South Florida)
10:30 – 11:00	"Planning your career and your CAREER"	Nancy Love (University of Michigan)
11:00 – 11:30	"Integration of research and education"	Jeanne VanBriesen (Carnegie Mellon Univ.)
11:30 – 12:00	Lunch brought to room	



12:00 – 12:30	“My failed CAREER”	Joseph Hughes (Georgia Tech.)
12:30 – 12:45	Concluding remarks	Paul Bishop

1b. STARTING OFF RIGHT: NAVIGATING THE EARLY YEARS OF ACADEMIA

Presented by Sharon Walker and David Cwiertny, University of California Riverside

This workshop is intended to provide useful tools and insights to junior faculty working through the ranks from Assistant to Associate Professor. It should be a good follow up workshop for those participating in the morning NSF Career Award or Academic Job Search programs. Highlights of the programming will include focusing on issues relevant to the service-teaching-research obligations that we all try to balance. The session will be a combination of speakers and panelists talking on the issues of finding work-life balance, identifying funding opportunities, and navigating the tenure review process. The panel will be composed of recently tenured faculty, program directors, and department chairs.

We also will have break-out groups based upon the type of institution participants are at (research or primarily undergraduate institutions) to network and discuss relevant issues to each person’s situation. A department chair/program head and recently tenured faculty member will participate in each of these breakout groups. To link to the transdisciplinary and global theme of this year’s AEESP meeting, the speakers and panelists will also be asked to address issues related to interdisciplinary research and collaboration, working in developing countries, and community outreach and their role in the tenure process.

Speakers

- Panel members: Mark Weisner (Duke University), Nancy Love (University of Michigan), Allison MacKay (University of Connecticut), Dharni Vasudevan (Bowdoin College), Amy Childress (University of Nevada), Steve Mylon (Lafayette College),and Michelle Scherer (University of Iowa)
- Barbara Minsker (Professor of Civil and Environmental Engineering, UIUC and author of “The Joyful Professor”) to speak about how to juggle the many responsibilities of faculty and personal life.
- Mitch Boretz (Grant Writing Specialist, Bourns College of Engineering, University of California, Riverside) to speak on funding opportunities for junior faculty members trying to build their laboratory and get a solid start.

Registration

One of the goals of this workshop is to help junior faculty connect with recently tenured faculty and program heads/department chairs that can serve as mentors to them. Hence, we would like to know who is participating in advance so that the breakout groups can be “engineered” to make these important connections. Therefore, we would like to request that you send an email to Sharon Walker (swalker@engr.ucr.edu) to sign up for the workshop by June 15th. Also, when you email to register,

please include a few questions that you have on navigating the early years of academia. We will try to incorporate your questions in to the speakers' and panelists' discussion.

2b. FRONTIERS AND CHALLENGES IN ENVIRONMENTAL EDUCATION TOPICS

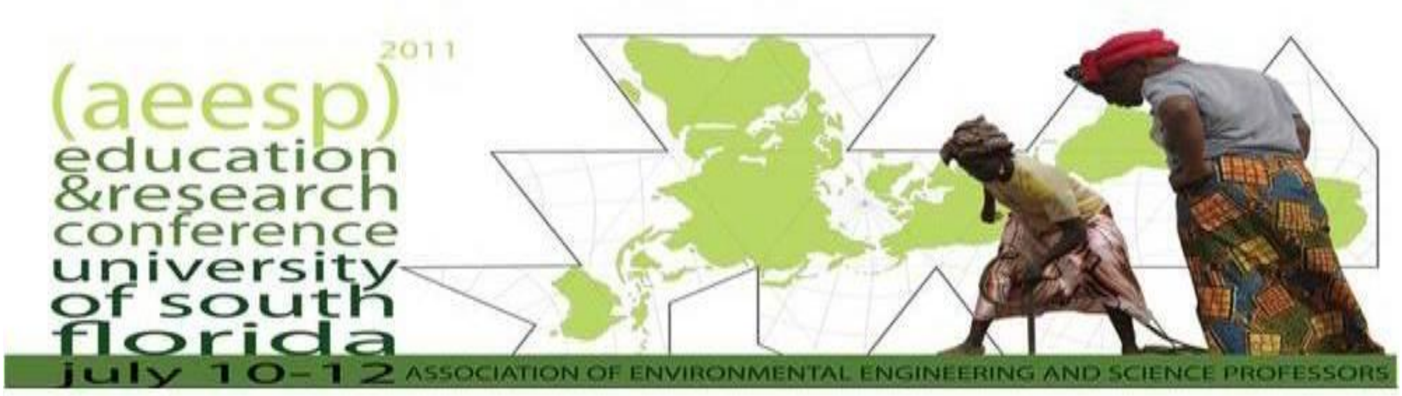
This workshop will discuss current challenges and related frontiers in environmental education topics (not methods) that are rapidly changing and expanding. At the same time our field is growing at the highest rate of any engineering and technology fields. The concurrent expansion creates unique challenges for our field.

Environmental science and engineering is rapidly expanding in scale and in professional scope. The engineering components in particular have evolved from central seeds of water and wastewater treatment, and have grown to encompass much more. Environmental and civil/environmental engineers still have primary responsibility for air pollution controls and water and wastewater treatment and conveyance infrastructure that is a large portion of the overall field in terms of workforce and project scale, however the field now encompasses tremendous workforce aspects in water resource management, remediation and protection; air pollution control; solid waste management; industrial/institutional environmental management; and even overall 'sustainability' aspects of our greater society. Our field will also be greatly impacted as climate change aspects are addressed and when considering CO_2 and all greenhouse gases to be 'regulated pollutants' is and will be transformational to our field. As we address these topical or thematic challenges we also face communications and infrastructure challenges in our broad and interdisciplinary field.

Leaders will present information to seed discussions, and also disseminate some of the materials that will hopefully result from a national 2 day 'Frontiers' workshop planned for April. The April workshop is unfortunately limited to 50 participants, and this workshop in Tampa will serve as a continuation/extension of the national discussion and advancement on these challenges and resulting frontiers.

Intended Audience

Program and departmental chairs and coordinators are particularly targeted in this workshop and a continued national dialog is expected. A direct goal of this workshop series is to develop a lasting communication platform for this group and to their faculty. Such a communication platform is lacking in our field as environmental engineering and science field has developed in a diverse manner from civil and chemical engineering, chemistry, biology etc. and now a convergence in interests is warranted. Basically, we have no national equivalent of ASCE, AIChE, ASM etc. The audience is also going to include members from organizations (AAEE, ASEE) and professional societies noted above with many goals and interest analogous to our field.



Workshop Leaders

- Angela Bielefeldt – University of Colorado-Boulder, AAEE Env. Eng Division former Chair and currently Director
- Joel Burken – Missouri S&T, AEESP –President Elect
- Joe Hughes – Georgia Tech – AAEE/AEESP Member
- Sharon Jones – Lafayette College, AEESP Board of Directors, ASEE Env. Eng. Division program chair
- Kurt Paterson – Michigan Technological University, ASEE Env. Eng. Division AEESP Educational Committee
- Deb Reinhart – University of Central Florida, AAEE – Past President

3a. INTEGRATING SUSTAINABLE DEVELOPMENT INTO COURSES THROUGHOUT THE ENGINEERING CURRICULUM

The Center for Sustainable Engineering (CSE) and the Center for Green Chemistry and Green Engineering at Yale (CGCGE) propose a 3-hour workshop at the AEESP conference July 10-12, 2010 in Tampa. This workshop is designed for engineering educators to expand their capacity to integrate sustainable development design principles into existing engineering curricula. Our strategy is to empower participants through guided practice with a set of learning activities and tools that can be applied to the learning environments distinctive to their own institutions. The intended audience is anyone involved in engineering education interested in learning more about incorporation of sustainability into their courses, including but not limited to tenure and non-tenure track faculty members, graduate students, and postdocs who are teaching or intend to teach. Participants in former CSE or CGCGE workshops will be encouraged to attend and assist in serving as breakout group moderators.

We propose the following agenda for the 3-hour workshop:

1. Introduction, goals of the workshop, and plan to achieve the goals (Cliff 10 min)
2. What is the CSE? (John 5 min) What is the CGCGE? (Julie 5 min)
3. Assignment for breakout groups (Jane 10 min): Identify the most important concepts in sustainability for engineering students to learn (either general concepts appropriate for any course, or course-specific concepts), and identify tools and metrics of sustainability that could be included.
4. Breakout groups meet (1 hour). Approximately 5-10 people per breakout group.
5. Plenary session re-convenes. Each group presents the results of their deliberations (30 min).
6. Tools and metrics of sustainability (John 10 min plus 5 min Q&A)
7. The CSE Electronic Library (Cliff 10 min plus 5 min Q&A
8. Textbook by Mihelcic and Zimmerman (Julie 10 min) plus 5 min Q&A)
9. Learning Suites (Jane 10 min plus 5 min Q&A

10. Evaluations distributed to all participants

Since a goal of the workshop is to allow educators interested in sustainability to interact with one another, we will request a list of registrants for the workshop ahead of time and prepare a list of participants with contact information, courses taught or planned, and specialty areas of research/teaching. All participants will be added to the distribution list of emails for future activities in SE that currently includes all participants in previous CSE and CGCGE workshops.

Workshop Leaders
Center for Sustainable Engineering / Center for Green Chemistry and Green Engineering at Yale
Cliff I. Davidson, John C. Crittenden (CSE)
Julie B. Zimmerman, Qiong (Jane) Zhang (CGCGE)

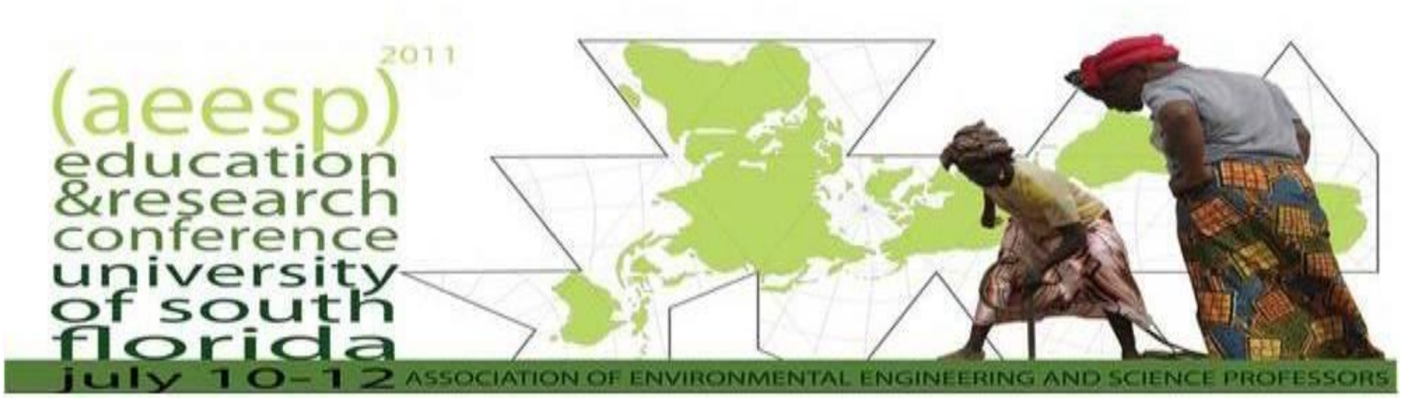
3b. GIVING YOUR STUDENTS AN EDGE: EFFICIENT STRATEGIES FOR TEACHING WRITING SKILLS

Intended audience
Environmental engineering and science professors who believe writing skills are an important component of an engineering education (whether or not they are currently emphasizing this topic in their classes).

Summary
Discover the fundamentals of good technical writing and learn methods to teach your students to write more effectively. This interactive workshop will help faculty:

1. Identify writing-based objectives for their courses or curriculum,
2. Educate themselves about writing,
3. Design assignments that are structured to help students succeed,
4. Assist students with self-correction, and
5. Provide feedback in an efficient manner.

The workshop will be hands-on, with text written in class used to illustrate the techniques presented. Case studies will be presented from undergraduate and graduate environmental engineering courses to illustrate different ways of integrating this information into a course or a curriculum. Breakout groups will allow participants to brainstorm plans for implementing changes in the specific context of their course responsibilities and broader curriculum.



Workshop organizers

- Jen Fela is a freelance science writer and editor based in Washington, D.C. As an undergraduate, she earned a B.S. in Environmental Science and a B.A. in English with a Writing Concentration from Wilkes University. She has over 10 years of experience writing and editing for scientific organizations, including the Ecological Society of America, Smithsonian Institution, and Water Environment Federation.
- Dr. Brian E. Whitman is the Chair of the Environmental Engineering and Earth Sciences Department and Associate Professor of Environmental Engineering at Wilkes University, a small private university that focuses on undergraduate education. His experience comes from incorporating writing in his courses and from leadership of a committee instituting a university-wide requirement to include writing in all undergraduate curricula.
- Dr. Julie Zilles is in Civil & Environmental Engineering at the University of Illinois Urbana Champaign. She emphasizes writing in a required graduate class on biology for environmental engineering and has developed an elective graduate class focused on scientific writing.

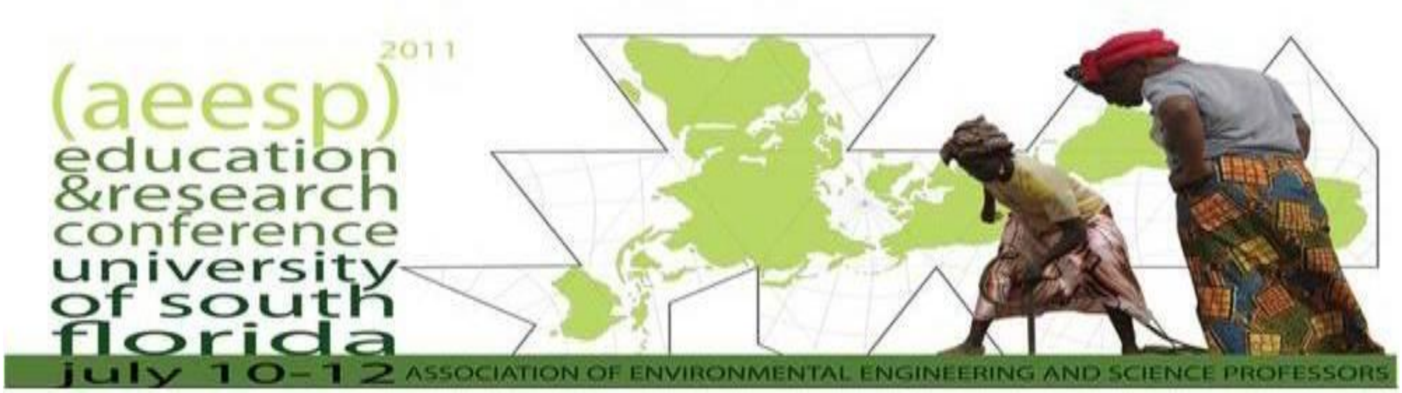
Case study presenters

- Dr. Shankar Chellam (Professor, University of Houston) has intensive writing and presentation requirements in an undergraduate introductory course in environmental engineering, developed in cooperation with Ms. Nancy Linden from the engineering library and technical communications director Dr Chad Wilson. Dr. Chellam received the W.T. Kittinger Outstanding Teacher Award in 2008.
- Dr. Laurie McNeill (Associate Professor, Utah State University) incorporates writing assignments in all of her undergraduate and graduate classes, including one with a co-requisite writing class taught by Dr. Sonia Manuel-Dupont. Dr. McNeill is the 2010 Carnegie Professor of the Year for the State of Utah.
- Janel Miller (Adjunct Assistant Teaching Professor, Carnegie Mellon University) is developing methods to integrate technical communication in the CEE curriculum. Previously, Ms. Miller was Director of Automotive Engineering for Advanced Transportation Systems at Alcoa, Inc.
- Dr. Belinda Sturm is an Assistant Professor in Civil, Environmental & Architectural Engineering at the University of Kansas. Dr. Sturm teaches required biological principles in environmental engineering course, in which she emphasizes interpretation and synthesis of primary scientific literature in class laboratory reports.

4a. HOW DO I TEACH? – ENGAGING STUDENTS IN THE CLASSROOM ENVIRONMENT

Topics

This workshop will provide participants with tools to engage students with a variety of learning styles in the classroom environment. The workshop will be divided into mini-sessions, including:



Teaching With (out) Technology: Software and hardware advances have allowed professors to introduce technologies into the classroom. Some technologies enhance the learning environment, while others are a poor substitute for innovative teaching based on more traditional approaches. This session will discuss creating a successful, engaged classroom without technology (through active learning, questioning, and the "what it means to me" factor) and with technology (using visual media such as 3-D simulations and virtual tours). Participants will learn what students mean when they comment that their professor "actually teaches" in the classroom.

Self-Directed Learning: Self-directed learning is a process in which individuals take initiative and responsibility for their own learning. While often considered in the context of informal education with adult learners, many of the components of self-directed learning can be applied to project-based courses that are typically used within environmental engineering programs. In this session, the fundamental characteristics of self-directed learning will be reviewed along with an example of implementation in an introductory engineering course at Carnegie Mellon. Methods to apply self-directed learning in many different settings will be summarized.

Personal-Choice Learning: Engaged, personal-choice learning lets students make choices in how to advance their learning through open-ended opportunities and use course fundamentals at a much higher cognitive level. Students are allowed to explore individual interest areas, which builds their desire to comprehend and apply fundamentals in solving self-selected problems. This session will discuss the use of problem-based and project-based learning in a variety of classes. Key aspects include guiding students to set individual learning objectives and the importance of peer interactions in the process. Service learning will also be discussed, specifically regarding public interactions and engagement, which are important components of our field that is concerned with protecting public health and the environment.

Intended Audience

Prospective faculty (including graduate students), early career faculty members, and faculty with significant teaching experience can benefit from this workshop. The objective is to provide faculty with tools to engage students in the classroom, including new tools they may incorporate in their teaching and new approaches for techniques they have already implemented in some capacity. The tools can be applied to classroom and project experiences at any level of education and thus this workshop is broadly applicable to undergraduate and graduate teaching environments.

Workshop Leaders

The workshop will be led by three professors with significant recognition for their teaching and research accomplishments. Most notably, they have all been awarded the AEESP Outstanding Teaching Award, which recognizes outstanding contributions, particularly in classroom performance. The leaders are:

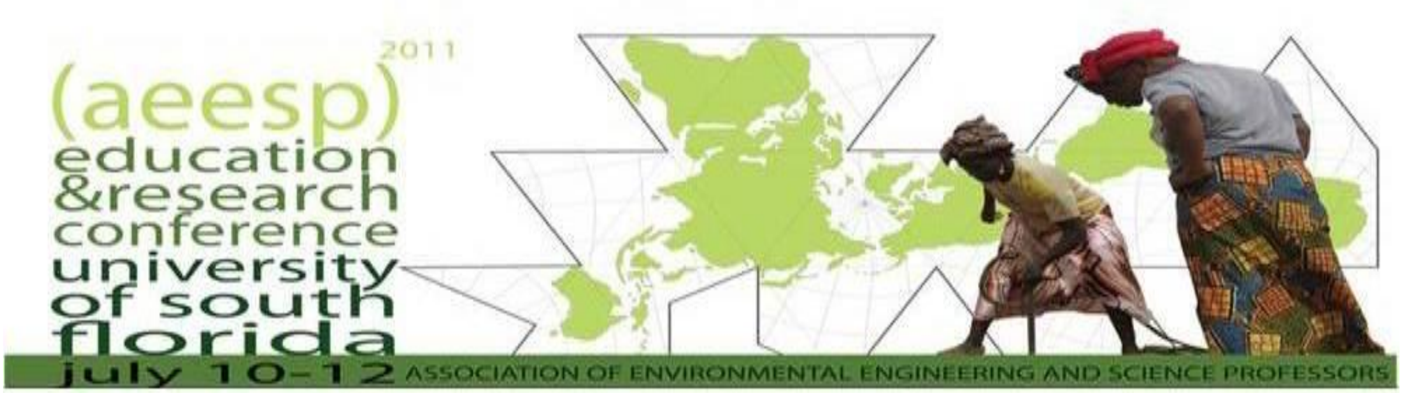
• Joel Burken, Associate Chair and Professor of Civil, Architectural, and Environmental Engineering, Missouri University of Science and Technology
• Jeanine D. Plummer, Schawber Associate Professor and Director of Environmental Engineering, Worcester Polytechnic Institute
• Jeanne VanBriesen, Professor of Civil & Environmental Engineering and Director, Center for Water Quality in Urban Environmental Systems, Carnegie Mellon University

4b. HOW DO I TEACH? – USING VIDEO LESSONS TO ENHANCE LEARNING AND CLASSROOM INTERACTIONS

In general, engineering, science, mathematics, and technology courses deliver content through classroom lecture sessions and reading assignments. Students in these courses are then expected to apply these concepts to solving problems. Classroom time in most college courses, including engineering, is used to deliver course content which may include the presentation of example problems. Engineering students are often tasked with working problems outside of the classroom environment while exams are almost exclusively working problems. Homework sets may or may not be taken up by the instructor for grading. The grading of homework assignments may or may not include feedback on where errors were made in the application of the technical concepts and the solution of the problem. Thus, engineering students are often developing their primary engineering skill outside of the classroom and often without meaningful support from their instructor.

Today's students are generally web savvy and comfortable in on-line learning environments. A significant portion of the course content in Engineering Hydrology, Groundwater Hydrology, and Contaminant Fate and Transport is now being delivered through the use of on-line course materials including video lessons on individual course topics. The on-line lessons are followed by on-line homework sets that are automatically graded upon submission. The classroom sessions associated with these courses are spent reviewing the lesson materials and questions from the homework sets. Students are then allowed to re-work missed problem and submit them for hand grading for up to full-credit. To receive full-credit, reworked problems must include a brief statement indicating why the initial solution was incorrect.

This presentation will provide an overview of the course and lesson structure including the Blackboard environment used to organize the course materials and challenges associated with creating and delivering streaming video content. The use of WebEx for in-class collaboration on software projects will be demonstrated. Student feedback on the use of this type of course structure will also be included in the presentation.



Workshop Leader

Dr. Philip T. McCreanor is an Associate Professor in the Environmental Engineering Department at Mercer University, the Director of the Engineering Honors Program, and Faculty Advisor for Tau Beta Pi. He is a member of the American Society of Engineering Educators, the Association of Environmental Engineering and Science Professors, Sigma Xi, and the Solid Waste Association of North America. He was recognized as an Outstanding Referee by the Waste Management: Journal of Integrated Waste Management, Science, and Technology in 2005, received the Mercer University / Vulcan Materials Company 2006 – 2007 Innovations in Teaching Award, and was inducted as a Georgia Governor’s Teaching Fellow in 2008.

4c. HOW DO I TEACH? – ENGINEERING EDUCATION RESPONSE TO CLIMATE CHANGE: ADAPTATION, MITIGATION, AND SUSTAINABILITY

Workshop Organizers

Glenn Schrader, Maya Trotz, and Allan Feldman Evidence for climate change has been widely investigated by the scientific community, and the projected impacts are expected to become a major influence on the world’s economy and societal structures within a few decades. In addressing how to reduce the undesirable consequences of climate change, debates over adaptation vs. mitigation approaches have ensued, especially among climate change scientists and public policy makers. The interrelation between these different avenues is regarded as being complex, but very few comprehensive discussions have been held that include engineering analysis of the considerable technological challenges. It is clear that engineering research and development must be enhanced to ensure that the key scientific discoveries, technological advances, and systems-level approaches are available to reduce future vulnerability to climate change. But for this to happen, climate change issues, including adaptation, mitigation, and the development of sustainable, resilient communities must be addressed in environmental engineering education.

Overview

The proposed workshop will build upon the outcomes of a 2011 NSF sponsored workshop, “Engineering response to climate change: adaptation, mitigation, and sustainability” organized by Glenn Schrader and Frank Princiotta, that will focus on the integration of mitigation and adaptation approaches and will emphasize the centrality of engineering in developing a sustainable technological “roadmap” for climate change. The AEESP workshop will focus on how to incorporate the findings and recommendations from the NSF workshop into environmental engineering education. Workshop participants will consider how these issues can be addressed in existing courses, such as air quality, aquatic chemistry, and water resources planning and management, as well as stand-alone courses in global climate change, both for engineering majors and for the general student population. Participants will also discuss the integration of concepts of resilient infrastructure design into courses on water and wastewater systems. Workshop

participants are encouraged to bring examples of syllabi and other educational materials that they use in their own teaching that address these issues.

Workshop Leaders

- Glenn Schrader is Associate Dean for Research and Professor of Chemical Engineering of the College of Engineering, University of Arizona, Tucson, AZ.
- Maya Trotz is Associate Professor of Environmental Engineering, University of South Florida.
- Allan Feldman is Professor of Science Education, University of South Florida.

4d. HOW DO I TEACH? – INTEGRATING INTENSIVE SERVICE LEARNING PROJECTS INTO SUSTAINABILITY COURSES

Many universities now have a family of classes related to sustainability and sustainable engineering. One valuable niche is a class with an intensive service learning component related to sustainability. Such classes are often highly valued by administrators for publicity and accreditation, and by students and potential future employers for the intensive real world experience in grappling with sustainability applications. The classes can vary from freshman level introductory experiences to capstone design. Project scope and group sizes can also vary. This workshop will share the experiences from the Universities of Colorado, Iowa and Nebraska related to several service learning classes that have practical projects with significant sustainability components. The goal of this workshop is to share lessons learned, and useful exercises and formats to help other faculty develop or re-develop their own courses with an intensive service learning component related to sustainability so participants can apply them to their own institution and class type.

The classes used as examples will include:

"Environmental Engineering Design" (University of Colorado). The senior capstone course, available for the past decade, focuses on a real-world project (such as WW treatment plant upgrade; design of sustainable drinking water treatment in a developing country).

"Design for the Developing World" and "Introduction to Sustainability" (University of Iowa). Both courses have been taught with substantial service learning components for the past several years to about 25 students enrolled in each. During the past year, enrollment in both courses tripled and each became more interdisciplinary after being included as eligible courses in the new undergraduate Certificate in Sustainability offered by the University.

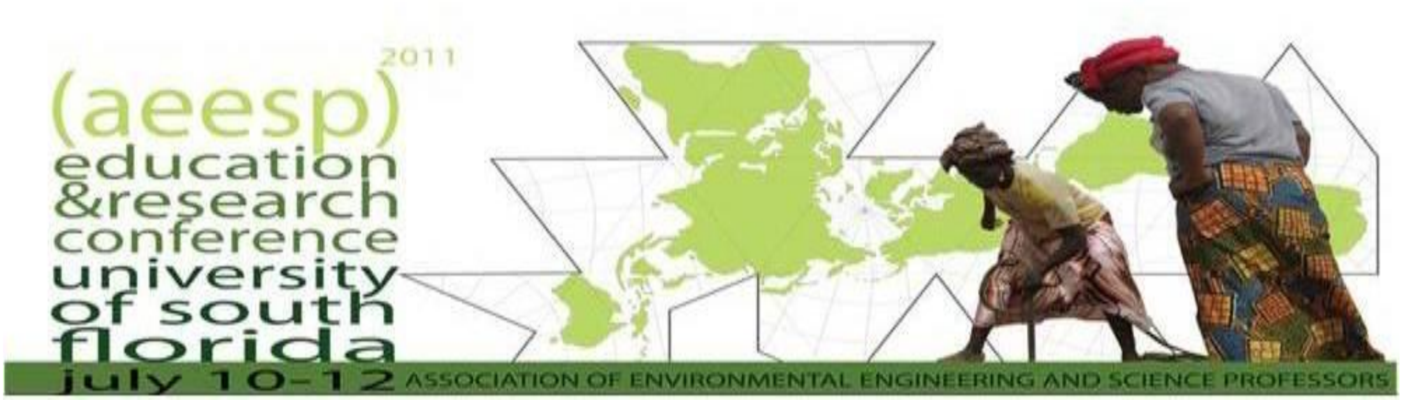
"Pollution Prevention: Practices and Principles" (University of Nebraska). For the past 14 years, students (10-20 per year) provided business management reports to Nebraska businesses (ranging from small to large) with practical recommendations how to reduce waste production and improve sustainability.

The workshop will include:

- Overview of each class syllabus, target audiences, and goals
- Discussion of the resources needed for success with the service learning project courses. A common thread with these classes is that supplemental funding from external or internal grants is essential to provide the faculty time and staff support for a successful outcome.
- Discussion of the attributes of TAs and support staff proven to be the most helpful for these projects.
- Lessons learned from each course. Examples of these include:
  - Pre-class development of service learning project(s), including tasks required and attributes of good clients and projects.
  - Attributes of students who are most successful and gain the most.
  - Challenges of scaling-up to serve large numbers of students and possible solutions.
  - Examples of valuable exercises and formats. These include report formats and example reports, student/client communication exercises, role playing exercises to help students develop skills at understanding a client's decision making process, and reflection exercises.
  - Post-class project wrap-up tasks (for clients and funding source).
  - Assessment methods used for both students and clients.
  - Examples of benefits of service learning projects to both students and clients, and how to leverage these benefits for further credit in terms of grant funding, accreditation, and publication.
- An overview of preliminary findings from an NSF funded collaborative grant to study faculty involvement in service learning
- Examples of potential supplemental funding sources, including sources not tapped by the workshop organizers.
- Participants will be provided with a CD of the examples and resources discussed.
- The workshop will conclude with a group discussion of ways these materials, exercises and examples might be used by the participants to develop or redevelop their own courses.

Workshop Leaders

- Bruce Dvorak, Professor, University of Nebraska
- Angela R. Bielefeldt, University of Colorado,
- Craig Just, Adjunct Assistant Professor, University of Iowa.



5a. HOW DO I TEACH? – TEACHING QUANTITATIVE MICROBIAL RISK ASSESSMENT IN ENVIRONMENTAL ENGINEERING & SCIENCE

Topic

Quantitative microbial risk assessment (QMRA) is a constantly evolving science, one vital to understanding the impacts of environmental engineering controls. The treatment of water directly affects the health of the public, therefore an understanding of how to assess the risks from microbial exposure must be addressed. The workshop will instruct and review the core interdisciplinary topics which are the most vital to an understanding of QMRA:

1. Basic microbiology
2. Risk frameworks
3. Data sets in QMRA
4. Dose response modeling
5. Exposure assessment and modeling
6. Risk characterization
7. Risk management

The workshop will be structured around case studies appropriate to the intended audience. For example, using QMRA to quantify the risks associated with fecal contamination in areas with poor sanitation, where shallow wells are a crucial but higher-risk source of water, particularly in developing regions. The Center for Advancing Risk Assessment (CAMRA) has 5 years of experience of instructing students in week-long as well as single day workshop formats on the basics and advanced QMRA concepts. Participants will be trained to use the "Spreadsheet Microbial Risk Assessment Tool", a library of dispersion models and dose-response parameters suitable for conducting preliminary microbial risk assessments which can be useful as a resource for problem-based learning.

Intended Audience

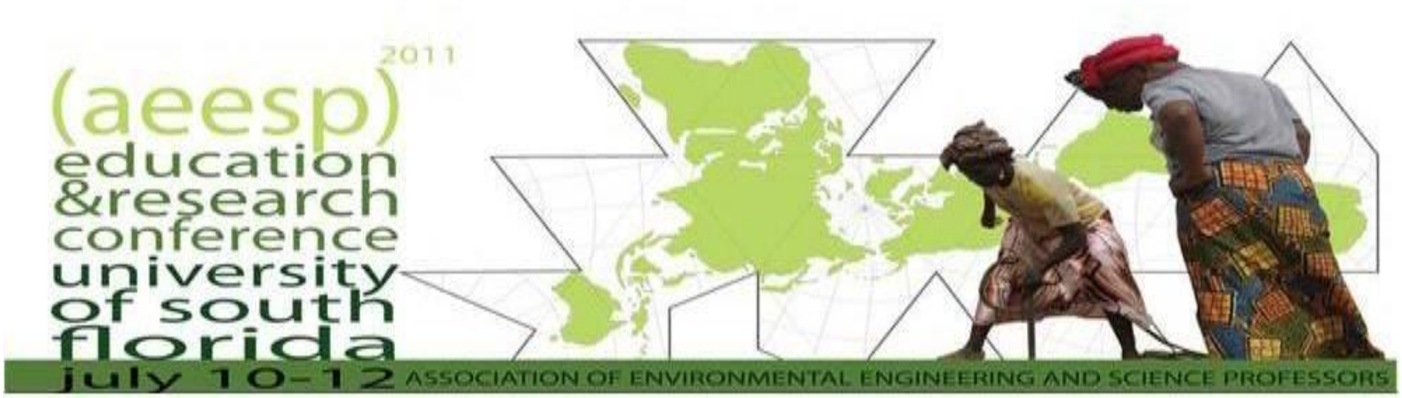
The workshop is focused towards environmental engineers and scientists who have an interest in risk assessment. Since microbial risk assessment is an interdisciplinary field, the interested parties will be a wide array of the attendees.

Workshop Organizer

Mark H. Weir, Ph.D., weirma@msu.edu

Duration of Workshop

1.5 Hours



Workshop leaders

Participant Name	Affiliation
Charles N. Haas PhD.	L.D. Betz Chair Professor of Environmental Engineering Co-Director of Center for Advancing Microbial Risk Assessment Department of Civil Architectural and Environmental Engineering, Drexel University, Philadelphia, Pennsylvania
Patrick L. Gurian PhD.	Associate Professor, Department of Civil Architectural and Environmental Engineering, Drexel University, Philadelphia, Pennsylvania
Mark H. Weir PhD.	Postdoctoral Fellow, Department of Fisheries and Wildlife Michigan State University, East Lansing, Michigan

5b. HOW DO I TEACH? – SOFTWARE FOR TEACHING ENVIRONMENTAL CHEMISTRY

Summary

This workshop will present a brief survey of free software suitable for teaching environmental chemistry- equilibrium calculators, kinetic simulators, and databases/ predictors for the physical properties of organic molecules. Recommended software will be demonstrated using environmental examples.

Proposer contact

Steve Cabaniss, University of New Mexico, Water Resources Program, Albuquerque, NM 87131 cabaniss@unm.edu

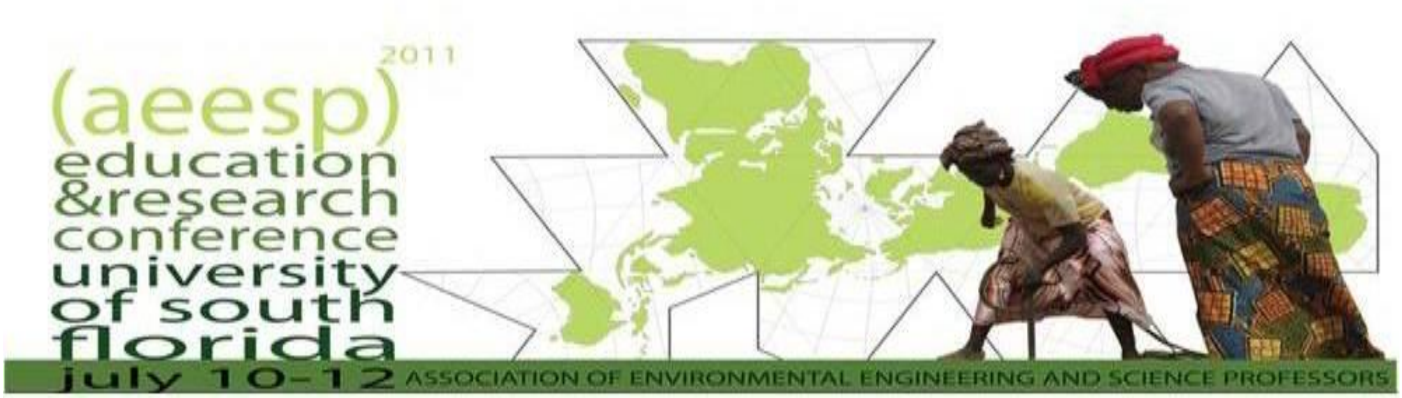
Professor Cabaniss studies organic matter and metals in the aquatic environment and has written thermodynamic and kinetic simulation software. He maintains the website “Students’ Guide to Free chemistry Software” (https://sites.google.com/site/chemistryfreeware/).

Audience

Faculty and students who are/will be teaching environmental chemistry to engineering and/or chemistry students and wish to become (more) familiar with software available.

Topics

1. Aqueous equilibrium modeling- Programs which solve aqueous equilibrium problems, including Visual Minteq, MINTEQA2, Titrator and PHREEQc. Software demonstrations will include example equilibria and questions for students.
2. Kinetic simulations- Programs which simulate reaction kinetics using either ODE solvers or stochastic algorithms, including Kintecus, CAIN, COPASI and TENUA. Brief comparison of algorithms and an environmental simulation.



3. Molecular properties- A survey of programs which provide database access and/or property prediction for small organic molecules, including EPI-Suite, SPARC, and the NIST chemistry web-book. Comparison of program scope and results with examples drawn from both hydrophobic and hydrophilic pollutant molecules.

Support required
We will need 1) speakers to display working Windows software and web browser, either from a laptop (preferred) or by installing software on local computer. It would also be desirable for participants to have Wi-Fi access.

5c. SUSTAINABILITY – AN INTEGRATION OF NATURAL AND ENGINEERING SYSTEMS IN THE BUILT ENVIRONMENT

Workshop Description:
This presentation presents an approach to the design of the built environment that utilizes the integration of natural and engineered systems.

Workshop Outline:
This presentation will give participants the resources to recognize the opportunities and limitations of utilizing geography, light, water and air as part of a design approach. Areas to be addresses are:

- The integrated design approach: how, what and why
- Designing regionally
- Daylighting theory and techniques
- Progressive approach to storm water management
- Theory and techniques of natural ventilation
- Design energy modeling and post occupancy energy evaluations.

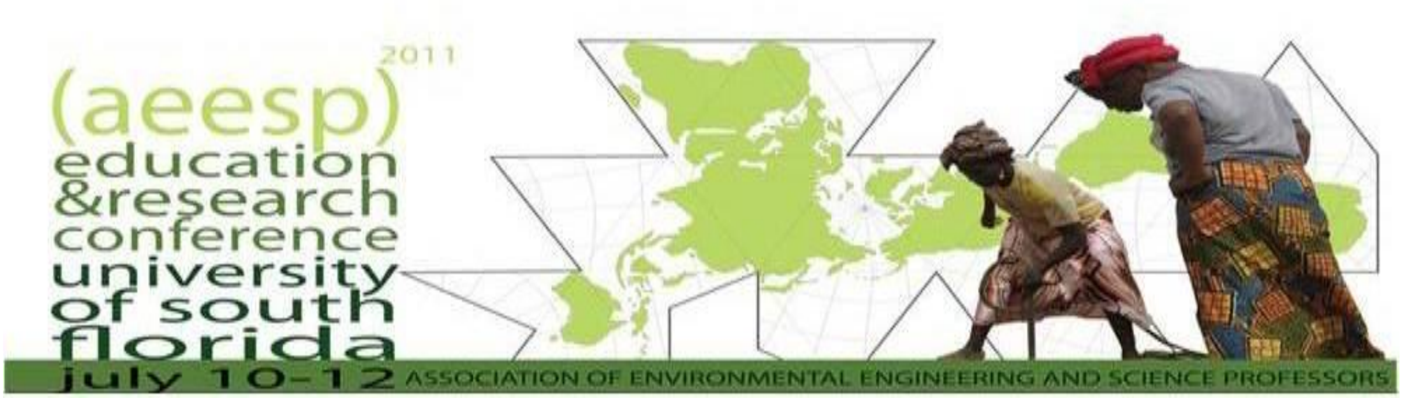
Learning Objectives:
1. Participants will be able to identify approaches to improving building and sites through integration of natural systems. This will be done through explaining basic theory behind designing with natural systems and examples of existing projects that utilize them.

2. Participants will be able to implement an integrated design approach by better understanding the design process and what key diverse consultants are required to achieve maximum benefit.

3. Participants will learn how to integrate engineered and natural building systems to achieve optimum building performance and occupant satisfaction. This will be done through a review of

the theory and applications of these systems and illustrate proven approaches to achieving high performance buildings.

4. Participants will learn how to apply metrics to evaluate the success of the implementation of sustainable strategies. This will be done by showing how to perform energy modeling early in a project and doing post occupancy energy evaluations.



Abstracts - Oral Presentations

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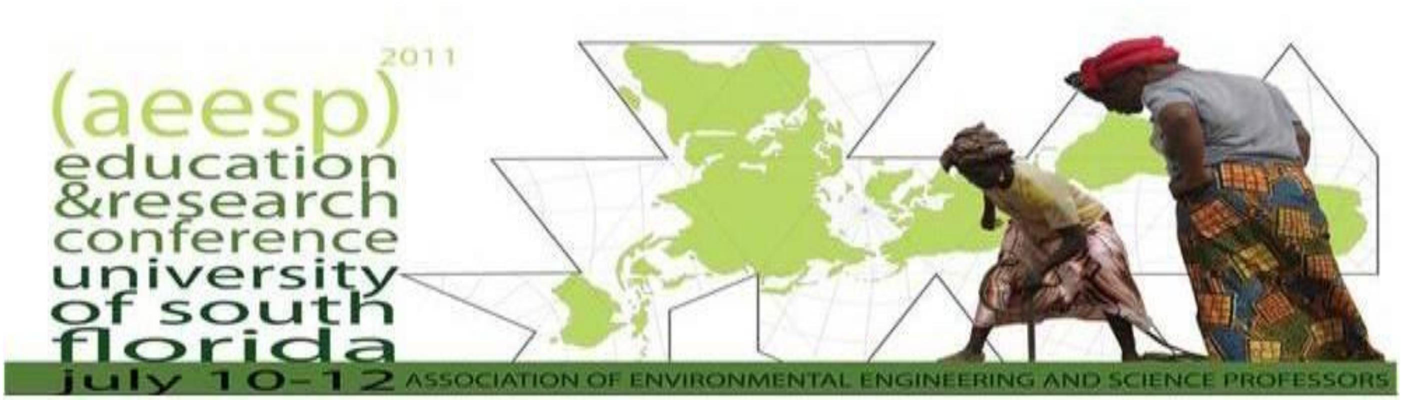

Research Category #1: ***Advances that Deal with Water Depletion and Degradation***

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Research Category # 1

ADVANCES THAT DEAL WITH WATER DEPLETION AND DEGRADATION

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OSMOTICALLY ASSISTED DESALINATION: A LOW ENERGY HYBRID DESALINATION SYSTEM

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Seawater desalination has become a common practice to supply the growing demand for water in areas having access to the ocean. Desalination technologies can be classified by their separation mechanism into thermal and membrane based desalination. In thermal desalination salt is separated from water by evaporation and condensation, whereas in membrane desalination water diffuses through a membrane, while salts are almost completely retained in the feed water. Reverse osmosis (RO) and multi-stage flash distillation are the techniques that are most widely used. The decision for a specific desalination technology is influenced by feed water salinity and required product quality as well as by site-specific factors such as labor cost, available area, energy cost, and local availability of electricity. RO has gained much wider acceptance than its thermal alternatives in recent years due to its lower energy consumption. However, there are still areas were the energy and environmental costs could be improved. High pressure pumps are necessary to overcome the osmotic pressure of the feed water (e.g., seawater) and normally this energy demand relies on fossil fuel – not renewable energy. Also, there are environmental concerns with the discharge of high concentrated brines being discharged through ocean outfalls.

Osmotically assisted desalination (OAD) can provide a solution to reduce the energy costs of RO desalination by lowering the RO energy demand and to reduce the environmental costs of RO by enabling discharge of brines at lower concentrations. OAD relies on the relatively new process of pressure retarded osmosis (PRO).

The process utilizes a high-pressure membrane desalination process (i.eRO) that in combination with a PRO subsystem achieves water desalination at lower energy expenditure. In the OAD system (Figure 1), treated wastewater, or another source of impaired water, is used as an energy source that is manifested during mixing with concentrated brine (draw solution) before ultimate discharge of the mixture back into the ocean. There are several advantages associated with the OAD system:

- The only external energy input required is to pressurize water from approximately 350 to 600 psi (ΔP = 250 psi). This is much less than the external energy input required for conventional seawater RO which requires pressurization from approximately 0 to 600 psi (ΔP = 600 psi). Otherwise, the energy for the system is supplied through pressure exchangers that convert the osmotic pressure difference in the OAD to hydraulic pressure in the desalination process (osmotic pumps). From the energy standpoint, the osmotic pressure difference between the draw solution (generated by the desalination process) and the wastewater is the source of hydraulic pressure that is used in the desalination process to overcome the osmotic pressure of the feed water to the RO process; therefore, the net energy demand of the RO process is used for the purpose of producing purified water only and not to overcome the osmotic pressure of the feed water to the desalination process. Therefore, in the OAD a booster pump is used to enhance water recovery at very low energy expenditure.

- The draw solution is used in a completely open loop and therefore accumulation of contaminants in the system is unlikely.

- The brine generated during the desalination process is being diluted in the PRO process and subsequently being discharged back to the ocean at the same ambient concentration; therefore mitigation adverse environmental impact on marine ecology/habitat. Also, being mixed with purified water from the PRO process, the diluted brine is discharged to the ocean at higher water quality compared to the ambient seawater.
- The impaired water and RO product water are in completely separate circuits so there is no contact of impaired water with drinking water.

The goal of the research was, for the first time, to develop, construct, and test a pilot scale OAD system. A pilot-scale OAD system is currently under construction and it will be deployed to the test field in spring 2011. When completed, the OAD system will be the first PRO system operating in the United States. During the presentation, details about system construction, and results from experiments and modeling will be presented.

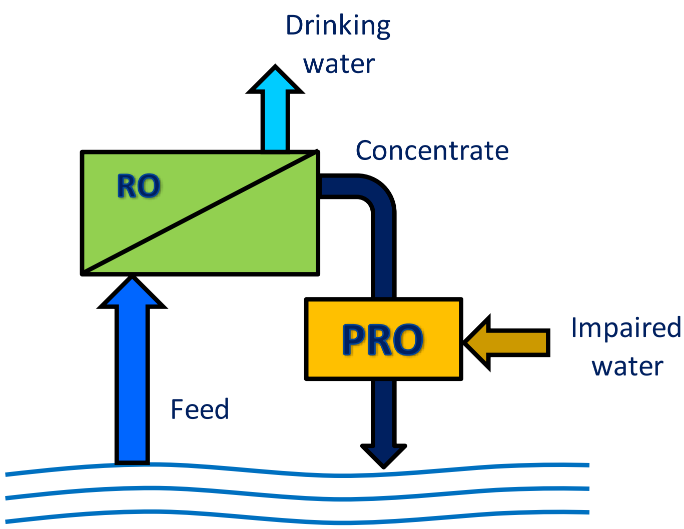

Figure 1: Schematic illustration of the OAD system.

HYPOXIA IN CHESAPEAKE BAY: MINING DECADES OF DATA FOR NEW INSIGHTS

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Anthropogenic nutrient discharge to estuaries is a global problem that is dramatically transforming coastal ecosystems. Significant resources have been dedicated to reducing point and non-point nutrient loads, yet many of the symptoms of eutrophication, such as low dissolved oxygen concentration (hypoxia) remain unabated. Recent studies have suggested that many eutrophic estuaries, such as Chesapeake Bay, the northern Gulf of Mexico, and the Baltic, have recently exhibited unexpected non-linear shifts in relationships between hypoxia and nutrient loading. Investigating alternative causes for such behavior in Chesapeake Bay has been the major focus of a team of investigators who have developed a virtual Chesapeake Bay Environmental Observatory (CBEO; http://cbeo.communitymodeling.org/) as a means to facilitate access and analysis of multi-decadal time-series data, including estuarine water quality, nutrient loading rates, regional weather records, and specialized research databases, such as several decades of calibrated simulation results from a 3-D hydrodynamic and water quality model,[1] sediment nutrient fluxes,[2] and benthic organism abundance.[3] The mining and further analysis of these data, at a variety of spatial and temporal scales, and within the context of several alternative mechanistic hypotheses, has provided us with new insights regarding the complex links between nutrient loading, hypoxia, and climatic conditions.

Background and Motivation

Chesapeake Bay has a large ratio of watershed area (164,200 km^2) to estuary surface area (~11,500 km^2) and a long dendritic shoreline that combine to make the estuary especially sensitive to land-based activities and inputs.[4] Freshwater flows (2300 m^{3}s^{-1}, including ~55% from the Susquehanna River) contribute nutrients, set up stratification, and drive a lower-layer counter-flow that acts to retain particulate and dissolved materials. In addition, the Bay's relatively long water residence time (3-6 months) serves to intensify the Bay's susceptibility to eutrophication.

Within the watershed, urban land has expanded since 1850, while agricultural land use has shrunk. Total use of agricultural fertilizers in the watershed has grown steadily since the 1950s, leveling off at ~60 x 10^6 kg N y^{-1} in 1980. And although forests are currently the largest component of the Chesapeake basin, they are declining at rates of ~100 acres per day, mostly due to development; between 1990 and 2000, the rate of land conversion from rural to urban/suburban more than doubled over the previous decade.[5] Much of the watershed has also seen rapid increases in nutrient inputs from sewage discharges,[6] with the watershed now supporting a population of well over 16 million people.

Prior research has confirmed that summer hypoxia in the Bay's main stem depends strongly on the magnitude of the river flow and spring nutrient load from the Bay's tributaries (and especially the Susquehanna River). This is illustrated by the results shown in Figure 1, which indicate that inter-annual variations of hypoxia trend in correspondence to wet and dry years. Harder to explain, however, has been an observed increase in the ratio of the estimated summer hypoxic volume per unit nitrogen load in the past 25 years relative to the preceding 30 years.[8] Especially perplexing has been the continued rise of "average-July" hypoxic volume over the past twenty-five years despite an apparent plateau or mild decline in the spring nitrogen load from the Susquehanna since about 1980.

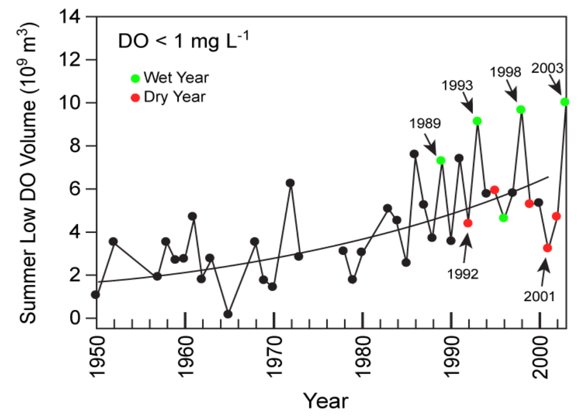

Figure 1. July average hypoxic volume over

<u>Approach and Principal Findings</u>

Over the the past four years, the project team has used the archived data within the CBEO testbed to explore a variety of hypotheses related to the above findings, including each of the following potential causes;

- Possible artifacts associated with the methods used to quantify hypoxic volume or nutrient loads;
- Possible biological feedback mechanisms associated with the changes in benthic conditions that may accompany increasing hypoxic volume;
- Decadal- scale changes in the timing of river flows;
- Decadal-scale changes in the role of phosphorus;
- Decadal-scale changes in nitrogen loadings from sources other than the Susquehanna;
- Decadal-scale changes in climatic factors that could affect the water circulation patterns in the Bay, including temperature, wind, and sea level rise.

The presented paper will briefly describe how each of these issues was investigated and will provide preliminary findings in each area. One of our most important findings has been that decadal scale trends in early-summer and later-summer hypoxia are very different, with the former following changes in physical circulation and climate, and the latter showing recent declines that are consistently correlated with nutrient load.[9] In the case of early-summer hypoxia, our results suggest that long-term increasing stratification in the Bay may have resulted in less replenishment of DO to bottom waters during late June and early July, following algal blooms induced by spring flows. Research is on-going in an effort to better understand the climatic and other factors that may be causing this stratification trend.

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THE ROLE OF SEDIMENT IN THE BIOAVAILABILITY OF STEROID HORMONES

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There is growing concern about the impact of steroidogenic compounds in aquatic systems. The primary evidence for biological effects of exogenous hormones stems from research documenting negative reproductive outcomes in fish. Other potential human health outcomes such as defective bone formation and effects on brain development have also been demonstrated. Steroids released into the environment have been shown to sorb to sediments in aquatic environments, however other studies have suggested that steroids can move through sediment beds, and that fish and other aquatic organisms can facilitate this mobility. The bioavailability of sediment-associated steroids is not well understood. In this study, we investigated the effect of sediment-associated 17β-estradiol and trenbolone on vitellogenin expression in fathead minnows, a ubiquitously distributed freshwater organism. Vitellogenin (Vtg) is an egg precursor protein produced in female fish in response to endogenous estrogen production, and when male fish are exposed to estrogenic compounds, they will inappropriately express the protein. Similarly, female fish exposed to pharmacological doses of androgens, including trenbolone, have been shown to be defeminized, as evidenced by a reduction in the expression of hepatic Vtg.

Sediment was collected from Plum Creek near Seward, Nebraska, a location identified previously as a pristine reference location. Prior laboratory exposure to this sediment resulted in no effect on gene expression in fathead minnows. Trenbolone or 17β-estradiol was equilibrated with the sediment for 24 hours and a 6 cm deep layer of the contaminated sediment was placed in a glass aquaria along with 20 sexually mature female (trenbolone) or male (17β-estradiol) fathead minnows. An additional control group of fish remained unexposed to steroid or sediment through the duration of the experiment. A positive control experiment was performed in which fish were exposed to an aqueous concentration of trenbolone or 17β-estradiol without sediment present. Ten fish were randomly collected from each tank at 7 days with the remaining harvested at 14 days. After collection, fish were anesthetized and weighed. Livers and gonads were collected from each individual and weighed. These were flash frozen in liquid nitrogen and stored at -80^{o}C until analysis. Relative hepatic vitellogenin (Vtg) expression was quantified using ribosomal L8 as a normalization standard. Hepatic mRNA expression was performed using a Bio-rad MyiQ Real-Time Polymerase Chain Reaction Detection System maintained by Optical System Software version 1.0. Relative Vtg expression observed in fish after the 14-day exposure is presented in Figures 1 and 2.

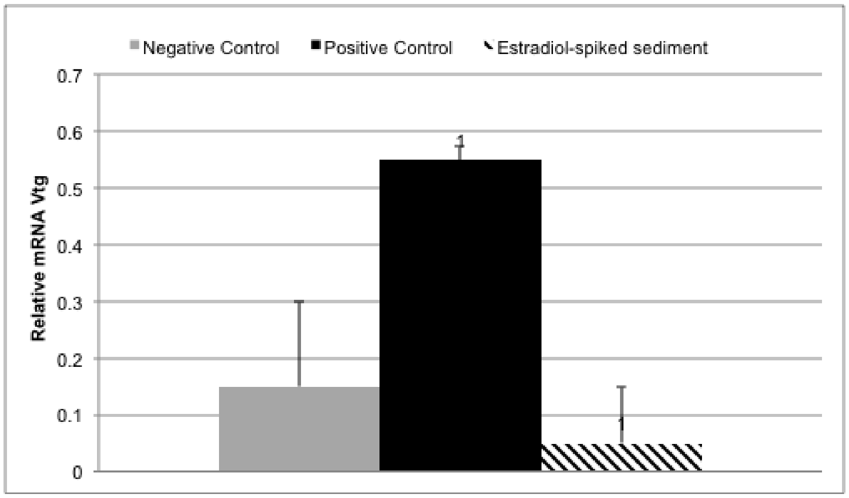

Figure 1. Relative hepatic Vtg after 14-day 17β-estradiol exposure.

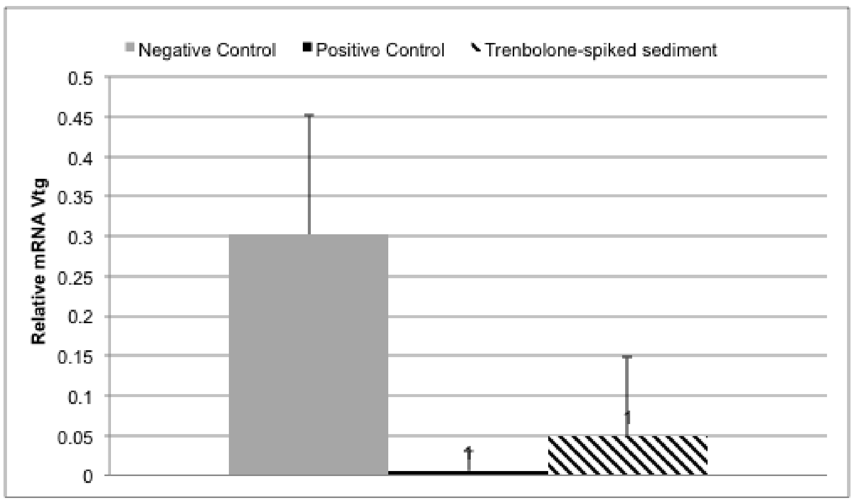

Figure 2. Relative hepatic Vtg after 14-day trenbolone exposure.

After 14 days of exposure to 17β-estradiol-contaminated sediments, male fathead minnows exhibited no inappropriate expression of Vtg relative to the negative control group (male fish exposed to laboratory water only) as shown in Figure 1. A positive control group of male fish exposed to aqueous 17β-estradiol did exhibit inappropriate expression of Vtg (Figure 1). By comparison, female fathead minnows exposed to sediment-associated trenbolone did exhibit a reduction in Vtg expression relative to negative controls (Figure 2). Female fish exposed to the positive control (aqueous trenbolone) also exhibited a reduction in relative mRNA Vtg expression compared with fish in the negative control groups. Taken together, we observed differential bioavailability for an estrogenic compound (17β-estradiol) and an androgenic compound (trenbolone) when associated with sediment. Both estradiol and trenbolone have been shown to degrade in aerobic sediments. The observed bioavailability of sediment-associated trenbolone may be due to the formation of recalcitrant metabolites such as trendione. Liquid chromatography tandem mass spectroscopy will be performed on sediment extracts and water samples obtained over the exposure period to evaluate steroid desorption and transformation over the exposure period.

MUSSELS AND NITROGEN: DAILY ROUTINES AND DISRUPTED BEHAVIOR

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One of the most widespread manifestations of anthropogenic mismanagement of nitrogen is eutrophication on the continental shelf of the northern Gulf of Mexico causing a hypoxic 'dead zone.' Excess nitrogen delivery to the Gulf from the extensively row-cropped Midwest via the Upper Mississippi River (UMR) has decreased dissolved oxygen concentrations to levels below which aquatic life can survive. To solve such problems, river ecosystem managers have started to move away from traditional engineering solutions towards more ecology-based restoration and conservation activities.

In the UMR, the lock and dam system constructed to maintain a navigation channel from St. Louis, Missouri, to St. Paul, Minnesota is being improved through the US Army Corps of Engineers Navigation and Ecosystem Sustainability Program. This program contains an ecological habitat restoration component that includes aquatic organisms such as freshwater mussels, which have significant management and conservation needs in the UMR. Thus, the goal of our study is to use freshwater mussels as a sentinel species to better understand the impacts of ecosystem perturbation on nitrogen processing in large river systems.

Freshwater mussels have been referred to as 'ecosystem engineers' because they exert control over food resources and alter habitats for other organisms. Mussels are excellent indicators of overall ecosystem health due to their reliance on host fish for their larval stages and trophic subsidies via benthic-pelagic coupling. Also, mussels and bacteria play a major role in nutrient cycling in large river systems by cycling nutrients taken up by phytoplankton and zooplankton. Under 'normal' environmental conditions, mussels appear to process nitrogen more rapidly than denitrifying bacteria.

This study was completed in a well-characterized mussel bed (assemblage) located in a 1200-m reach of the UMR in navigation pool 16 near Buffalo, Iowa. Through the use of the University of Iowa's Upper Mississippi Envirohydrologic Observatory, high frequency nitrate data was collected every 15 minutes from sensor clusters located throughout the pool in the main channel and in the water column above the mussel bed. Initial observations of the collected data suggest distinct differences in the diurnal nitrate fluxes between the main channel and mussel bed locations (see Figure 1).

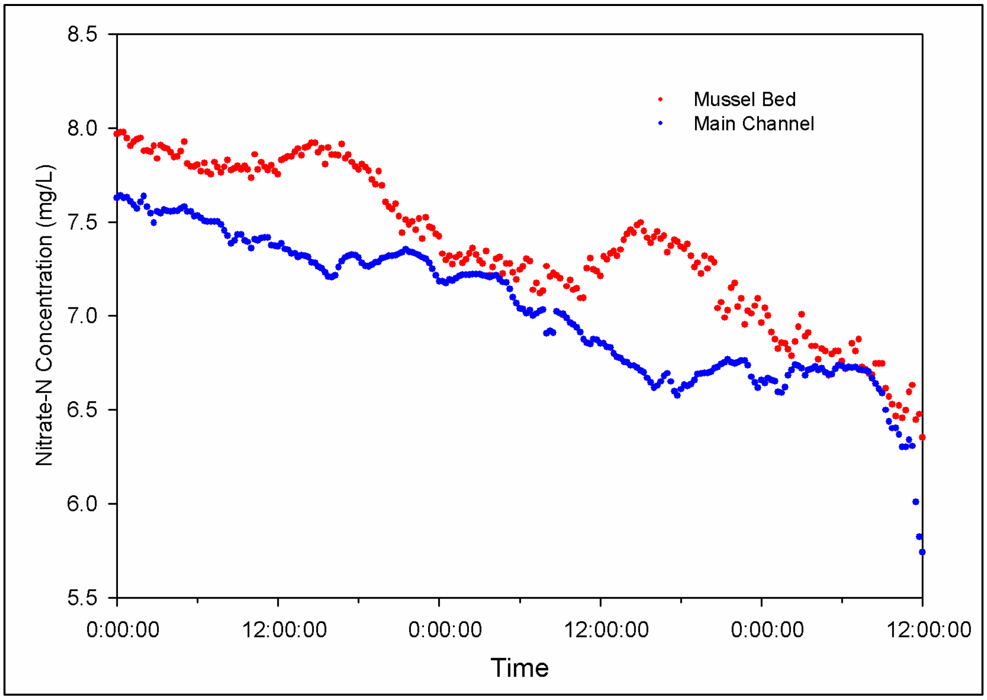

Figure 1: Evidence of differences in diurnal nitrate patterns for the mussel bed and main channel locations over two day period in August 2009.

We initially hypothesized that this phenomenon was attributed to the presence of mussels as lab studies indicated mussels exhibited diurnal behaviors in response to ecological processes such as variations in light intensity. However, calculation estimates revealed that the maximum diurnal nitrate flux attributable to mussels was likely only around 15 percent. Using a computational fluid dynamics (CFD) model, we are currently working to couple the observed nitrogen dynamics and mussel behaviors to further investigate the observed differences in diurnal nitrate patterns between the mussel bed and the main channel.

Given that freshwater mussels are inextricably linked with the hydraulics of river flow, development of models for research to improve mussel management and conservation requires the integration of mussel ecology and hydraulics (i.e. ecohydraulics). The use of CFD to model systems such as the Mississippi River is being more widely used to develop three-dimensional flow field outputs for ecohydraulics applications. Our initial CFD results demonstrate that variations in flow rates can have significant impacts on different densities of mussel beds, especially in regards to velocity magnitude and turbulent kinetic energy present in the water column above the mussel bed.

As rapid-rate filter feeders, freshwater mussels are largely dependent on obtaining suspended particles from the water column. Increased diversity of mussel species in a mussel bed has been shown to decrease current shading (deceleration of flow from upstream to downstream neighbors) and increase delivery of suspended particles to mussels. However, as our initial CFD results suggest, ecosystem perturbations such as intense flooding could significantly impact mussels' ability to obtain suspended particles, severely limiting their impact on nitrogen processing and other river ecosystem processes.

FAST, CHEAP & GREEN SITE ASSESSMENT USING *IN-PLANTA* PHYTOFORENSIC METHODS

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Plants interact with their environment, extracting all that is needed to represent 99% of the world's biomass. Plants can extract micronutrients even when present at extremely low levels. Plants concurrently collect and store chemicals and elements from the water, air, and soil in the surrounding environment, including contaminants. Using novel techniques, we can gather this data on contaminants in the subsurface environment to help in contaminated-site investigations and delineations that are too often costly and inaccurate, thereby aiding in human health protection. The methods can also be applied in conjunction with natural treatment systems and utilized as long term monitoring approaches.

This talk will highlight novel *in-planta* sampling methods have been developed to allow for high spatial resolution, and low detection level assessment of contaminated groundwater and soil. Trees have long been known to interact with groundwater, which has been exploited in numerous phytoremediation projects, due to their ability to extract groundwater and the associated contaminants via the evapo-transpiration stream. Now, we have developed specialized sampling techniques that use trees as a sampling point for contaminated groundwater. These methods are faster, cheaper, less invasive, and easier to implement than traditional well drilling. Single sites have been sampled, with up to 100 samples per site, in a single day with a team of 2 people using increment borers. These data were then analyzed within a week and the plume was mapped. Methods include tree coring with solid phase microextraction (SPME), *in-planta* solid phase samplers (SPSs), and *in-planta* SPME. SPME fibers include polydimethylsiloxane (PDMS) and composite PDMS/carboxen fibers. Different materials have been investigated for the development of the SPSs, revealing how material properties relate to sampling efficiency and sensitivity. Recent work includes direct GC-MS analysis connected to the plants themselves. The use of these advanced methods has allowed the use of multiple samples in one individual tree to gain gradient information for the root zone. The directional analysis provides even greater spatial resolution by sampling around a single tree and gaining information on azimuthal direction, even when there are a limited number of trees at a site to be sampled.

This work summarizes the advantages and disadvantages of each method, such as the ability to perform repeat sampling, increased sensitivity over headspace analysis of tree cores, and instrumentation needs of each method. Field data will be shown, demonstrating the methods in real-world settings and the benefits of the novel methods. The development of these methods will allow for improved implementation for plume delineation and monitoring to better protect human health.

STRUCTURAL ALTERATIONS INDUCED IN CYANOBACTERIA BY NANO-TITANIUM DIOXIDE EXPOSURE

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Introduction: Progress in nanotechnology has recently raised concerns on the potential environmental impact of engineered nanomaterials (NMs). In particular, the increasing applications of nanoscale titanium dioxides ($nTiO_2$) in a variety of fields, such drinking water treatment and cosmeceutical. A recent study reported effluent concentrations from wastewater treatment processes of 5-15 µgTi/L. Fundamental research on the toxicity of $nTiO_2$ to ecologically relevant organisms, such as algae and cyanobacteria, is scarce and information on $nTiO_2$ bioavailability is lacking. Preliminary studies have confirmed that the exposure to $nTiO_2$ affects algal growth and inhibits primary productivity. This study aims to assess the ecotoxic impact of $nTiO_2$ on the cellular structure of the cyanobacteria *A. variabilis*, prokaryote of significant biogeochemical importance because of the global contribution to nitrogen and carbon atmospheric fixation. *A. variabilis* is known for its ability to tolerate adverse and fluctuating environmental conditions implementing unique metabolic strategies. The specific goals were to: 1) quantify the oxidative stress caused by TiO_2 via reactive oxygen species (ROS) production analysis; 2) investigate the changes in cell surface topology and mechanical properties after $nTiO_2$ exposure; 3) identify intracellular physiological modifications caused by $nTiO_2$ and 4) reveal the fate and migration of $nTiO_2$ and potential bioaccumulation in exposed cells.

Methods: Nano-TiO_2 anatase (primary size from manufacturer was 10 nm and average size of aggregates of 192±0.8 nm) was dispersed in 1% BSA modified Mes-Volvox culture media and cup sonicated for 20 minutes prior experiments. *Anabaena variabilis* strain (UTEX #1444) was axenically cultured under a 12 h light/12 h dark regime. The fluorometric H_2DCFDA assay was used to quantify intracellular and total ROS formation. Cell surface roughness and mechanical properties were characterized via an Atomic Force Microscope. Raman Spectrometry and Transmission Electron Microscopy were applied to image and monitor the fate of $nTiO_2$ and *A. variabilis* intracellular functional biomolecules.

Results & Discussions:

Reactive Oxygen Species (ROS) production

A dose-dependent total ROS production was measured in *A. variabilis* cells exposed to $nTiO_2$ and increasing total ROS production rates from 190 to 340nM H_2O_2/h as $nTiO_2$ concentrations increased from 10 to 200 mg/L. At a given time the intracellular oxygen species are only a small fraction (<10%) of the total ROS measured. The formation of ROS highlights that oxidative stress possibly played a key role in cells structural changes and the observed membranes disruption.

Impact of $nTiO_2$ exposure on cell surface topology and mechanical properties

Nanomechanical measurements indicated that surface topography (Figure 1) and mechanical properties of *A. variabilis* cells were modified after 24 hours exposure to 50 mgTiO_2/l with increasing average roughness (from 28.6 to 45.9 nm) and shift in the cell spring constant from 0.01 to 0.5 N/m. The shift in the cells spring constant (k_{cell}) distribution towards higher values indicates that the increase of cytoplasmic turgor pressure after exposure to $nTiO_2$ is possibly a response phenomenon.

Intracellular modifications resulting from $nTiO_2$ exposure

Disruption/alteration of cellular membrane was observed in both vegetative and heterocyst cells after *A. variabilis* exposure to $nTiO_2$. The regulation of other cellular defense mechanisms was induced, such as the opening of intrathylakoidal spaces (site of photosynthetic reactions), the increase of membrane-limited crystalline inclusions (of unknown function) and the increase in the outer mucilage layer thickness.

Evidence of internalization of $nTiO_2$ in algal cells

Time sequential observations show that 500 nm size $nTiO_2$ particles disaggregate overtime possibly due to a dispersant effect of DNA or other biomolecules. Consequently, the diffusion of ~20nm size particles through the multilayered membrane occurred. RAMAN microscopy (Figure 2) combined with TEM allowed the observation of $nTiO_2$ aggregates changes and potential bioaccumulation of metal oxide nanoparticles inside *A. variabilis* cells. Although the NM entered cells whether the cell is live or dead was not clear.

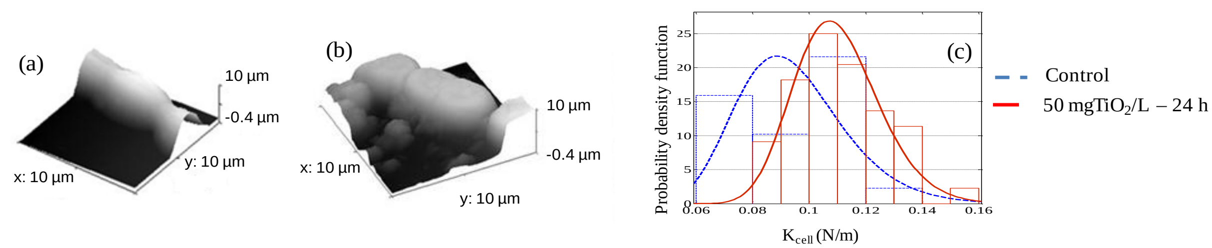

Figure 1: 3D AFM topographies showing the impact of $nTiO_2$ exposure on surface topology of control cell (a) after exposure to 50 mg/L of $nTiO_2$ for 24 h (b). Cell spring constants fitted in lognormal distributions before and after $nTiO_2$ exposure (c).

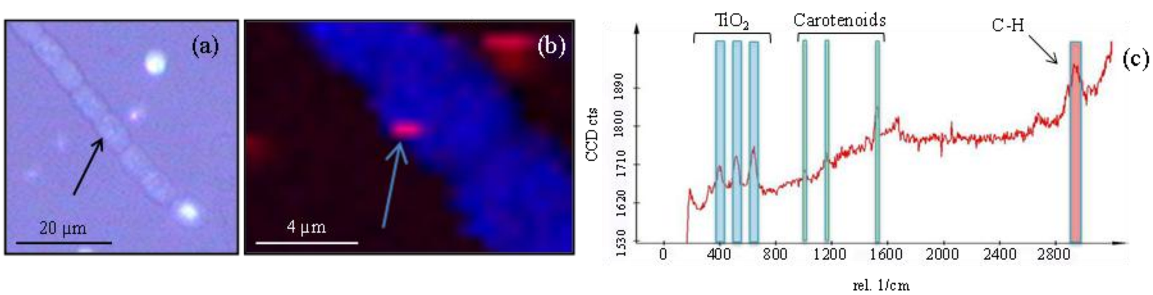

Figure 2: Microscopic image (a) and high resolution Raman image (b) of $nTiO_2$ internalization in *A. variabilis* cells, reconstructed from Raman intensities of the cell protein density (C-H stretching vibrations, blue) and the $nTiO_2$ inclusion (red, arrow). Spectrum collected at the inclusion level (c) showing characteristic $nTiO_2$ peaks and typical vibrations of cellular components (carotenoids, C-H, etc).

Conclusions: The results of this study showed that exposure to $nTiO_2$ leads to observable alterations in both cell surface topology and mechanical properties and induced a series of recognized stress responses, including production of ROS. The results revealed the possibility of aggregated nanomaterials to dissipate overtime into smaller size with likely the aid of dispersant of biomolecules such as DNA. The NMs was able to penetrate through cell membranes and therefore suggested that NMs bioaccumulation can occur in cyanobacteria, enter the ecological food web and ultimately impact important biogeochemical processes, such as the carbon and nitrogen cycle.

AMBIENT IRON-MEDIATED AERATION (IMA) FOR DIRECT POTABLE WATER REUSE

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Water reuse is a strategically significant approach to solve the global water shortage problem, and address the large energy demand associated with centralized water and wastewater treatment (US EPA 2004). However, there are technical and economical challenges involved in terms of treatment schemes for direct potable reuse capable of removing a full spectrum of possible contaminants at low energy demand. The iron-mediated aeration (IMA) process, in which wastewater is aerated in the presence of macro-scale metallic iron, represents one energy-minimal approach to the removal of a broad spectrum of molecular-scale water impurities, with no attendant increase in salinity. The earliest report regarding IMA treatment (Matsumoto and Arimitsu, 1969) demonstrated that the IMA process was able to remove 78% of 21.2 mg/L chemical oxygen demand (COD), 87% of 38 unit color, and > 99.4% of 3.6 mg/L phosphate from a secondary effluent. Recently, we further revealed the reaction mechanisms behind physicochemical treatment (Englehardt et al., 2007). Mechanisms include the production of reactive oxygen species (ROS) (most likely ferryl ions at neutral pH) capable of oxidizing certain organics (e.g. 99% of 0.09-1.78 mM EDTA, normally refractory except to advanced oxidation, and 99.9% of 0.153 mM glyoxylic acid), and Fe^0 corrosion products capable of co-precipitating a wide range of organics and inorganics (e.g. 99.996% of 0.239 mM As) (Englehardt et al., 2007). In this study, we aimed to comprehensively evaluate the performance of the ambient iron-mediated aeration for water reuse. At neutral pH, room temperature, and atmospheric pressure, bench-scale tests were conducted in a batch mode to study the treatability of IMA in secondary effluent, natural surface water, and simulated contaminated water. All experiments were carried out in a test tube reactor described in detail elsewhere (Englehardt et al., 2007), except for the nutrient removal tests conducted in a jar testing apparatus. Overall, IMA treatment followed by filtration achieved high removal efficiencies for various aqueous pollutants. Removal rates of COD and electrical conductivity (EC) in a secondary effluent in the IMA and control (no iron and no aeration) processes are shown in Fig. 1. The COD removal efficiency in the IMA reactor was dramatically increased to 44% within the first hour, and then further developed to 66% at 27 hours. In contrast, the control group achieved only 33% COD removal, probably due to organics volatilization or continuous microbiological degradation. Along with COD reduction, IMA removed 26% of 2.14 ms/cm EC, primarily through equilibrium aeration softening. Fig. 2 shows the results in IMA oxidation of two individual endocrine disrupting compounds (EDCs), di-n-butyl phthalate (DBPs) and 17β-estradiol (E2). Within 25 hours, the residual DBP and E2 were < 5% and 8% of the initial 1,000 µg/L, respectively. Moreover, the IMA treatment removed 22% of 37.4 mg/L total nitrogen (TN), 95% of 10.1 mg/L total phosphorus (TP), 99.8% of 4.71 mg/L Cr, > 90% of 0.89 mg/L Ni, and 99% of 100 unit color, as well as accomplishing 3.2 log removal of total coliform, and 2.4 log removal of *E. Coli.* Such removal of nano-scale impurities without salt addition or high-energy membrane treatment shows the promise of the IMA technology for use in direct potable reuse systems.

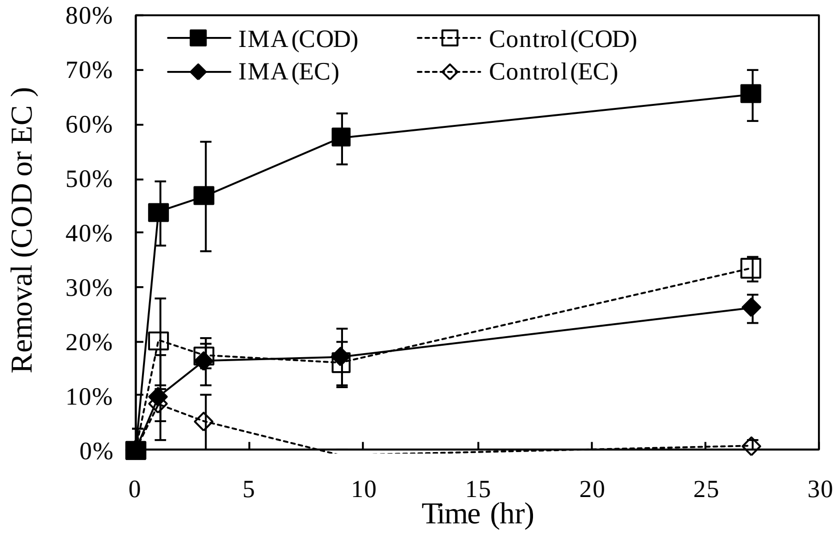

Fig. 1 Removal of COD and EC versus time at the IMA and control (no Fe^0 and no air aeration) processes [Conditions: secondary effulent collected from the Central District Wastewater Treatment Plant (Miami, Florida, USA); COD_0 = 50 mg/L; EC_0 = 2.14 ms/cm; and pH_0 = 6.92].

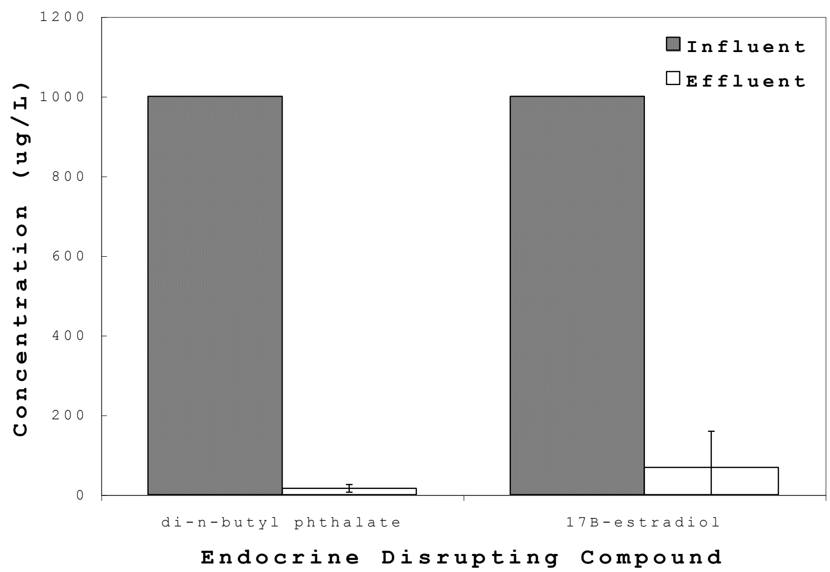

Fig. 2 IMA oxidation of di-n-butyl phthalate and 17β-estradiol from simulated natural water. [Conditions: C_0 = 1.0 µg/L; pH ~ 7.5; and reaction time = 25 hours].

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EFFECT OF BIOSTIMULATION ON INDIGENOUS TNT-DEGRADING BACTERIAL COMMUNITY

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Groundwater provides 50% of the world's drinking water and dependence on groundwater is only expected to increase as population grows. Leaching of pollutants from contaminated soils into drinking water aquifers poses a direct threat to the sustainability of groundwater resources. Energetic compounds (i.e., explosives) are of particular concern due to their toxicity and widespread contamination that has occurred during their manufacture, transport, testing, and disposal. Therefore, identifying effective remediation techniques for explosives contaminated aquifers is critical to maintain the longterm integrity of groundwater resources. Bioremediation is an attractive option, however, the microbiology driving this phenomenon is poorly understood. This work is focused on understanding the anaerobic microbial populations associated with 2,4,6-trinitrotoluene (TNT), a widely used explosive, under different biostimulation configurations.

TNT is generally believed to undergo successive reductions to products that bind more strongly to sediment than does the parent compound. All known reductive biotransformation pathways for TNT degradation involve non-specific nitroreductases that requires addition of electrons. To test if electron donor addition stimulated TNT degradation, a microbial culture was enriched from a historically contaminated, but previously unstudied, site sediment (Former Nansemond Ordnance Depot, Suffolk, VA, USA). The culture was incubated in static batch liquid microcosms spiked with TNT and amended with potentially bioavailable organic carbon (PBOC) extracted from site sediment serving as the carbon source and either ethanol or lactate as electron donor and potential biostimulants. This bench-scale feasibility study demonstrated that the indigenous microbial population at FNOD has the ability to degrade TNT and that degradation rates can be increased by electron donor addition. In particular, lactate amended microcosms exhibited superior performance relative to ethanol-amended microcosms.

A major challenge of identifying TNT-degrading bacteria is that it appears to be degraded via fortuitous metabolism, rather than serving as carbon or energy source. To circumvent this challenge, molecular tools were strategically applied to examine the relationship between bacterial community composition and the TNT-degrading performance status of the microcosms. To achieve this, denaturing gradient gel electrophoresis (DGGE) was performed to compare bacterial community dynamics between experimental test conditions and killed controls. Sub-samples of sediment were analyzed with time to monitor culture enrichment corresponding to biodegradation. DNA was extracted and bacterial 16S rRNA genes were PCR-amplified and analyzed by DGGE, providing a visual indication of the effect of the electron donor addition on the bacterial community.

Visual inspection confirmed differences in banding pattern between test conditions, indicative of differences induced by different electron donors. For example, microcosms incubated with ethanol stimulation yielded a greater number of DGGE bands than those incubated with only PBOC. For a given test condition, differences in band intensity were also noted across time, which suggests differences in abundance among the treatments of specific bacteria represented by the DGGE bands. An example of this is demonstrated in Figure 1, which compares lactate-amended microcosms over the time required for TNT to reduce below the detection limit. An increase in the intensity of Band 1 is shown over time, in non control (i.e., not killed) samples. While DNA sequence analysis is currently underway, bacteria corresponding to bands that increase in intensity corresponding to TNT degradation will be further investigated as candidate bacteria potentially driving TNT biodegradation. Bacteria unique to performing microcosms are also of interest. Bacteria with the highest similarities to the bands will also be further investigated for conserved nitroreductase gene regions to provide further evidence of the role of this gene in TNT degradation. Principle component analysis (PCA) of banding patterns and intensities will aid in unambiguous characterization of the DGGE gels.

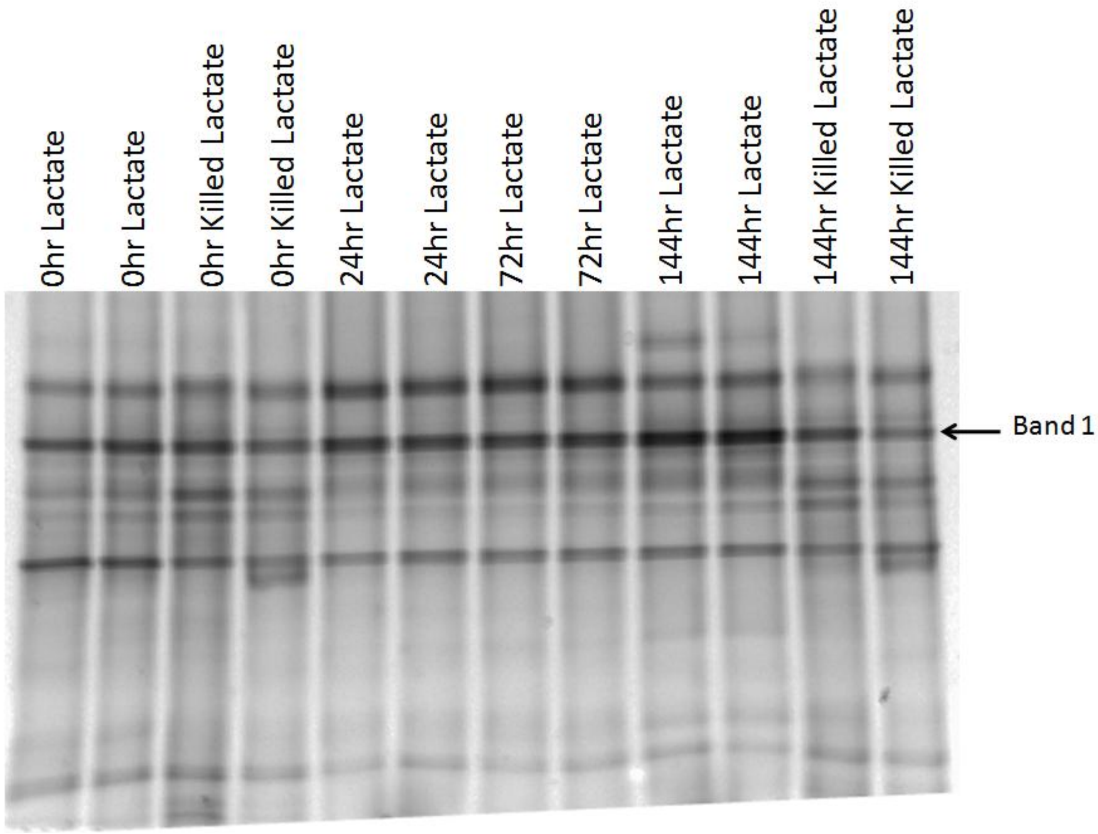

Figure 1. Example DGGE analysis of bacterial community in lactate-amended microcosms over time, indicating an increase in Band 1 intensity for non-killed samples.

Through the molecular methods pursued in this work, valuable information will be gained about the microbial community responsible for TNT degradation at a model contaminated site. Comparisons of the bacterial community at this previously uncharacterized site to the microbes already known to be involved in TNT degradation will enrich understanding of TNT degrading bacteria, possibly revealing novel TNT degraders. Few anaerobic degradation studies have identified microbes involved in TNT degradation via DNA sequencing, and many of such studies do not involve indigenous anaerobic microorganisms. Finally, the results of this study will be useful as an analogue for remediation of similarly structured organic pollutants, especially other energetic compounds. As more nations industrialize and population grows, demand for clean groundwater will increase. Learning how to effectively decontaminate groundwater aquifers will ensure continued sustainability of this invaluable resource.

TOXICOGENOMIC BASED TOXICITY ASSESSMENT

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The large and even increasing number of emerging contaminants in our water require fast, simple and reliable assessment methods, which can provide multiply information needed for regulatory decision making in order to eliminate or reduce the potential risks associated with these pollutants. Toxicogenomic research (genomic, proteomic, and metabonomic) measures the global molecular-level activity in response to environmental stressors. Its sensitive, characteristic and ability to reflect sub-lethal low dose effects of toxicant in short time frame provide a significant advance in toxicant evaluation, understanding toxicity mechanisms and pathways. However, traditionally toxicogenomic technology – microarray, has some limitations such as high cost, complex procedure, and lack of temporal resolution when apply for ecological assessment. Furthermore, accepted and transferable quantitative toxicogenomic endpoints that can be potentially applied on toxicity assessment and toxin regulation are lacking.

In this study, a whole-cell-array library consisting of 91 *Escherichia coli K12* strains with transcriptional GFP-fusions, covering most known stress genes was employed, which allowed for temporal monitoring of transcriptional activities in exposure to several engineered nanomaterials (ENMs), as nano-silver (nAg), nano-titanium dioxide anatase (nTiO2_a), nano-titanium dioxide rutile (nTiO2_r), carbon black N110 (CB), Fullerene, and single-wall carbon nano tube (SWCNT_L). All data were corrected with various controls, including blank with medium control (with and without ENMs) and promterless bacterial controls (with and without ENMs). The transcriptional effect level (I), for a given gene at each time point due to chemical exposure, is represented by the ratio of transcriptional GFP level in the experiments with ENMs exposure to that in the control condition without any ENMs exposure.

The ENMs induced transcriptional effect levels are very dynamic and complex across the stress genes examined, with most of the genes exhibiting different patterns and varying magnitudes of transcription activities over time. The temporal change in gene expression level reflected the dynamic of the cellular response involved in the stress-response mechanism. The results revealed that the oxidative stress, DNA damage, and membrane stress are the most important toxicity mechanisms for all the ENMs tested. With the analysis of detailed information of different DNA damage and repair genes, we found that different DNA repair pathways are activated by different ENMs. Carbon-based NMs led to relatively less extent of DNA stress compared to others. nAg activated Base Excision Repair (BER) and, nTiO2_a induced more on Nucleotide Excision Repair (NER) and Mismatch Repair (MR). The more severe DNA damage caused by nTiO2_a is indicated by the activation of an intensive DNA repair regulatory system, SOS system.

The gene expression profiles are not only chemical-specific but also concentration-dependent indicating that the molecular level genomic activities are very sensitive to not only the type of toxin but also the level of toxin in exposure. With a computational algorithm and methods for 2-dimensional gene-expression data clustering and similarity analysis, the NMs showed clusters based on their similarity in response to toxicants, meaning their toxicity mode of action (Figure 1). The same NM of different concentration treatments clustered together except those concentrations at detection limit or above the threshold of MOA-dependent response. The gene-expression profile of a mixture of ENMs (nAg and fullerene) most closely clustered with profiles of component ENMs (Figure 1), potentially allowing for identification of causal chemicals present in the mixture.

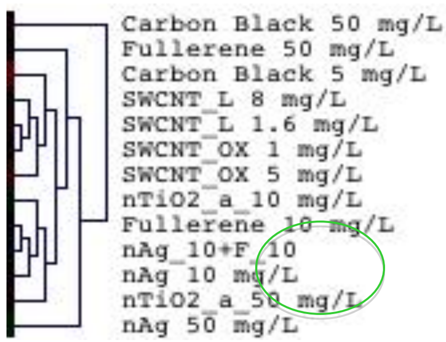

Figure 1 Cluster of toxicant specific profiling with different ENMs at various

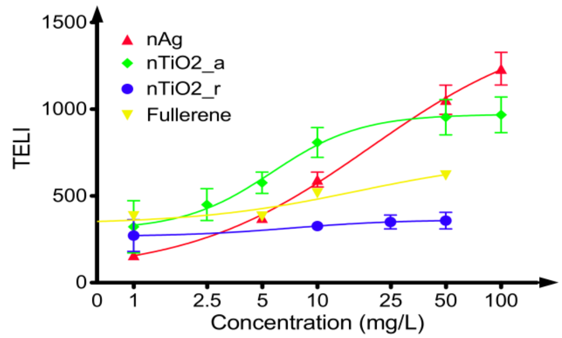

Figure 2 TELI-dose response curve allow for developing toxicogenomic endpoints.

To link the toxicogenomic results with regulatory benchmarks and conventional toxicity assessment endpoints, a Transcriptional Effect Level Indicator (TELI) that incorporates both the extent and magnitude of altered genes expression induced by toxicants as well as the factor of exposure time are calculated. Those TELI values exhibit concentration-dependent pattern (Figure 2) and allows for the establishment of dose-response curve. The parameters derived from TELI-dose response relationship, as $TELI_{MAX}$, TELI50, $NOTEL_{TELI}$ and $TELI_{slope}$, are comparable with those currently used endpoints, such as EC50, Biological Oxidative Damge (BOD) and Non Transcriptional Effect Level (NOTEL) (Table 1). These TELI-derived parameters can serve as regulatory benchmarks and toxicity assessment endpoints in environmental monitoring, toxicant evaluation, and toxic identification at low dose level exposure.

Table 1 Correlation of TELI-derived toxicity endpoints with currently used toxicity endpoints

Corrlation Coefficient	$TELI_{MAX}$	Slope	TELI50	$NOTEL_{TELI}$
NOTEL	-0.51	-0.04	0.20	*
EC50	-0.82	0.39	-0.61	0.78
BOD	0.98	-0.63	0.80	-0.95

*NOTEL and $NOTEL_{TELI}$ both represented the toxin level with non-detectable transcriptional effect, the absolute value of these two endpoints are consistent in our study (*p* values ranged from 0.92~1).

This study demonstrated the promising application of toxicogenomic information generated from quick and inexpensive in vitro or in vivo techniques, such as *gfp*-infused recominant whole-cell arrays used for screening and evaluating the environmental toxicants of concern. The Transcriptional Effect Level Indicator (TELI) proposed in this paper, for a first time, translate the toxicogenomic data into a readily useable and information rich toxicity evaluation endpoint that can be potentially link to regulation endpoints and incorporated into decision-making framework. The real-time gene expression profiling will improve our understanding of toxicant induced biological response by providing information about underlying molecular pathways that involved in response to compound exposure.

MICROBIAL COMMUNITIES IN FLOWBACK WATER IMPOUNDMENTS FROM HYDRAULIC FRACTURING OF SHALE FOR NATURAL GAS RECOVERY

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Natural gas is the fuel source for 24% of the total energy demand of the United States. This fraction is expected to rise as the U.S. turns towards its large, unconventional, domestic natural gas sources to meet growing demand. Currently, shale gas is the largest contributor to growth of natural gas production in the U.S. and is predicted to represent nearly half of all domestic natural gas production by 2035.

Shale gas refers to natural gas entrapped in shales, the fine-grained, clastic sedimentary rock composed of clay minerals and silt-sized particles as well as other minerals, such as quartz, calcite, and pyrite. The gas is held in natural fractures and pore spaces or adsorbed onto the organic material and minerals in the formation. However, shale formations lack sufficient natural porosity for recovery of natural gas at rates suitable for large-scale production. Therefore, fractures must be engineered in the formation to enable commercially-viable gas flow rates. This is made possible through the combination of horizontal drilling technology and hydraulic fracturing.

Hydraulic fracturing of horizontal wells results in large volumes of wastewater known as flowback. Flowback is a complex mixture of fracturing fluid amendments as well as salts, metals, and hydrocarbons from the subsurface and is typically impounded at the surface prior to treatment and disposal or reuse. Biological reactions in the impoundment can give rise to aesthetic problems, such as sulfide production as well as water management issues including metal precipitation. These transformations and the microbiology which drives them are poorly understood. We characterized the microbial communities, both *Bacteria* and *Archaea* in several flowback water impoundments receiving water from hydraulic fracturing of the Marcellus shale in Pennsylvania. PCR-based methods were utilized to characterize populations at different depths in the impoundments and across different pre-treatment strategies.

16S rRNA gene clone libraries show that all impoundments, treated or untreated, contained diverse microbial populations with high degrees of similarity to organisms from saline environments. The impoundment which had received pretreated water (precipitation and filtration) exhibited relatively small population changes from the surface to the bottom of the impoundment. Gene sequences recovered from this impoundment were most similar to known aerobic hydrocarbon degrading and sulfur oxidizing bacteria from the ⍰-proteobacterial clade. The impoundments receiving untreated flowback water were more diverse and featured microbial population changes between the surface and the bottom of the impoundments. At the surface, gene sequences had a high degree of similarity with well described, aerobic hydrocarbon degrading *Marinobacter* from the ⍰-proteobacterial clade. Clone libraries of the communities in deeper impoundment samples contained sequences most similar to known marine sulfate reducing members from the ⍰-*proteobacteria* and many sequences for which no similarity between known genera existed above the 90% level. Gene sequences recovered at all depths in the untreated impoundments were closely aligned with fermentative organisms from phylum *Clostridia*. Archaeal populations were only present in the impoundments which received untreated water and exhibited greatly limited diversity; all gene sequences recovered had a close similarity with the genera, *Methanohalophilus*, a salt-tolerant methanogen.

The finding of diverse microbial populations in flowback water impoundments is significant for the efforts of natural gas developers to limit microbial growth through the addition of organic biocides. Despite these controls, the microbial communities which develop are closely linked with the depth-dependent biogeochemical gradients within the impoundments. Findings of this study suggest that a better understanding of the microbial populations which develop during impoundment of flowback water will lead to better management options for natural gas developers to minimize the adverse impacts of microbial growth and result in more sustainable solutions for flowback water management.

EVALUATION OF IMPACT OF NANO- AND MACROSCALE CELLULAR SURFACE CHARACTERISTICS ON MICROBIAL TRANSPORT BEHAVIOR IN POROUS MEDIA

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Transport and migration of microbes in porous media is relevant to various environmental engineering applications such as in situ or enhanced subsurface bioremediation, filtration processes for water and wastewater treatments and protection of drinking water supplies. Microbes in subsurface, either indigenous or bio-augmented, can profoundly impact the fate and transport of contaminant by changing the geochemical conditions, transform and/or degrade the contaminant, or alter the mobility of contaminants. The search for relatively inexpensive and sustainable means to improve the quality of surface waters to be used as a source of drinking water has draw attention to the technology of riverbank filtration; however, in order to better design and operate bank filtration schemes for drinking water treatment, it is important to understand the transport and fate of the pathogenic microbes as well as microbes that have impact on the fates of pollutants. Currently, theory of colloidal transport has been most often applied for modeling microbial migration without incorporating some distinct aspects unique to microbes such as their morphological geometry, elasticity (deformable) and cellular surface composition and properties, that would affect cell-cell or cell-surface interactions, and therefore their transport. There is a need to gain fundamental understanding of the impact of these cellular-dependent properties with the microbial migration behavior.

In this study, we quantitatively assessed cell surface properties such as presence of extrapolymeric substance, contact angle, zeta potential etc. and cell-cell adhesion quantities (aggregation index), for a number of environmentally relevant microorganisms. Atomic Force Microscopy (AFM) and related mathematical framework was employed to conduct nano-scale characterization of cell surface mechanical properties, cell-cell/cell-surface contact mechanics and inter surface forces. The microbial displacement and transport in water-saturated porous media for the selected bacteria were also evaluated with flow-through column experiments, under different environmental conditions (water chemistry and fluid flowrate). Microbe breakthrough curve, retained cell profiles and attachment efficiency were also quantified. We then evaluated the impact of the cellular surface properties and aggregation behavior on the macro-scale deposition parameters determined by column testing.

-Table 1 reports the results of the cell surface characterization for selected bacteria strains studied. Different bacterial species, even different strains of the same species, exhibited differences in their surface properties. Cell aggregation index (AI), which measures the tendency of cells to aggregate was higher for *Desulfovibrio* despite its higher hydrophobicity and surface charge. This could be partially explained by the presence of EPS on *Desulfovibrio* surface, which can affect its ability to adhere to other cells by long-range forces. Different migration behavior among the microorganisms was also observed (Figure 1). The larger percentage of cell retained for *S. Odenensis* (which can be deducted by the height of the breakthrough curve in Figure 1), can be explained with the differences in size and surface characteristics of the two strains: *S. Odenensis* is slightly larger in size and have higher tendency to aggregate (indicated by its higher AI value) than *S. Putrefaciens*, so the single collector efficiency would be higher for this strain since it could be more easily intercepted or settle on the collector. In addition, *S.*

Odenensis is less electronegative than *S. Putrefaciens*, therefore the electrostatic repulsion should be lower. In accordance to DLVO theory, deposition increased for the different bacteria species with increasing ionic strength of the water (Figure 1). DLVO calculations revealed high energy barriers for all conditions except that with the highest ionic strength evaluated, indicating that the energy barrier based on conventional forces for colloids would prevent the bacteria from attaching to the sand grains. However, experimental data showed clear attachments of these microorganisms onto the column media.

The nano-scale characterization done with AFM reveals that adhesion energies increase with increasing ionic strengths whereas the repulsive energies decrease; also mechanical properties, such as the elastic modulus increases, increasing the stiffness of the cell. AFM results suggest that deformation forces might play an important role at the lowest ionic strength but might be negligible at the highest ionic strength, potentially explaining why DLVO theory is unable to predict bacteria attachment at lower ionic strength.

In conclusion, different bacteria have distinct migration characteristics and behavior, even if they are of the same species with similar morphology, making it clear that conventional colloidal theory, which consider microbes as spherical colloidal particle and, whose deposition rate is determined only by Van der Wall and electric double layer forces, may not be sufficient for predicting microbial transport in porous media. A new theoretical framework and model structure is needed to better predict the microbes transport that incorporates more microbe-dependent parameters. AFM was shown to be a powerful tool in measuring parameters and forces that can affect the bacteria transport.

Table 1. Measurements of surface properties for the strains studied. Within parenthesis the standard deviation of the measurement is also reported.

Bacteria strain	**Contact angle**	**Presence of EPS**	**AI**	**ξ-potential (mV)** 1 mM KCl	3 mM KCl	10 mM KCl
Desulfovibrio Vulgaris	45.5°(4.5)	+	0.29 (0.07)	-43.5	-37.1	-25.4
S. Oneidensis MR-1	30.3° (4.9)	-	0.21 (0.04)	-18.3	-18.4	-16.9
S. Putrefaciens CN32	15.5° (4.7)	-	0.12 (0.04)	-30	-29.9	-28.2

Table 2. Selected Nano-scale mechanical properties determined with AFM for two of the strains studied.

	S. Oneidensis MR-1			***S. Putrefaciens CN32***		
	1 mM KCl	3 mM KCl	10mMKCl	1 mM KCl	3 mMKCl	10 mM KCl
Elastic Modulus (KPa)	101 ± 17.1	218 ± 22.5	281 ± 27.6	53 ± 8.7	111 ± 14.8	148 ± 29.7
Adhesion Energy (aJ)	59 ± 3.0	154 ± 12.2	390 ± 20.8	40 ± 3.69	46 ± 3.52	74 ± 5.22
Repulsive Energy (aJ)	1330 ± 30.5	210 ± 10.3	37 ± 5.12	/	/	/

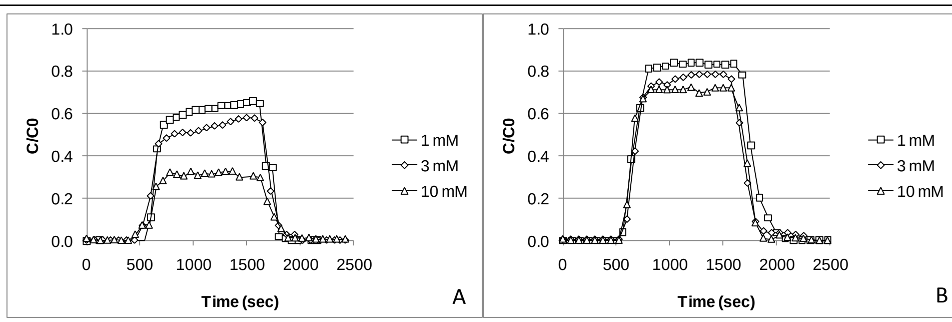

Figure 1. Representative breakthrough curves for experiments conducted with S. Odenensis MR1 (A) and S. Putrefaciens CN32 (B) cells in columns packed with silica sand over a range of solution ionic strengths.

GENETIC BIOAUGMENTATION: UTILIZING HORIZONTAL GENE TRANSFER TO ENHANCE IN SITU BIOREMEDIATION

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Bioremediation has gained considerable attention over the past few decades as an effective and relatively inexpensive method of cleaning up contaminated environmental sites. Specific methods for bioremediation could involve *ex situ* pump-and-treat processes or *in situ* treatments that add either substrates to stimulate microbial degradation of contaminants (biostimulation) or microbes that have high degradation potentials (bioaugmentation). Although *in situ* bioremediation processes generally offer more advantages than *ex situ* methods, there are concerns with the current *in situ* methods that limit their effectiveness. For example, a major concern in bioaugmentation is the effect of the addition of large quantities of microorganisms that are foreign to the site. This may lead to significant changes in microbial community structure and a long-term instability in ecosystem integrity. Furthermore, the degradative activities of such foreign microbes may be compromised when introduced into an unfamiliar environment during bioaugmentation, thereby resulting in a lower bioremediation potential.

Horizontal gene transfer (HGT) is a widespread phenomenon in the prokaryotic kingdom that occurs readily under harsh environments where genetic adaptation is required for the survival of microorganisms. HGT could be useful for bioremediation to shift microbial communities in favor of degrading xenobiotics, persistent organic compounds, and emerging contaminants. In fact, it has been noted that HGT has repeatedly occurred naturally in contaminated sites to aid in bacterial adaptation to organic pollutants. Therefore, instead of introducing large quantities of foreign microbes capable of degrading the contaminant as seen in conventional bioaugmentation, we can introduce small amounts of bacteria harboring genes encoding for enzymes that degrade the contaminant of interest and stimulate *in situ* HGT of those degradative mobile genetic elements to the native bacterial community. This proposed method is termed genetic bioaugmentation and may provide a safer way of bioaugmentation than using genetically engineered microbes. However, the mechanisms and effects of HGT must be extensively characterized prior to this application with a focus on how to enhance HGT occurrences and improve the resulting degradation potential. This method should be especially useful for the bioremediation of emerging anthropogenic contaminants.

In this study, the TOL plasmid, which includes genes for the degradation of xylenes, toluene, and related species, is used as a model system with toluene as the model contaminant. While toluene is not considered a persistent emerging organic contaminant, the TOL plasmid is an ideal model HGT system because it falls under a diverse family of degradative plasmids that frequently undergo HGT and its degradation pathways are well documented. Using a green fluorescent protein expression system, we have demonstrated that the TOL plasmid from *Pseudomonas putida* BBC443 has been successfully transferred to several γ-proteobacteria strains, e.g. *Pseudomonas fluorescens*, *Serratia marcescens*, and *Escherichia coli* DH5α. However, some transconjugants that harbor the TOL plasmid do not have the ability to degrade and utilize toluene as the sole carbon source even though all of the necessary genes have been successfully transferred. Further investigations have shown that such transconjugants require additional external factors for toluene degradation such as alternative carbon sources. For example, the effects of glucose addition on the toluene degradation rates of the various strains are shown in Figure 1.

The addition of glucose at most concentrations resulted in significant enhancement of toluene degradation rates in all transconjugants while its effect on the donor strain, *P. putida*, was not as pronounced. Similar results were obtained when varying dilutions of the nutrient-rich Luria-Bertani medium was added. Furthermore, exposure of transconjugants to different pH values and nitrogen sources indicated that pH 8 and ammonia were the most favorable conditions for gene functionality. The mechanisms of enhancement by such changes in environmental conditions are currently being studied.

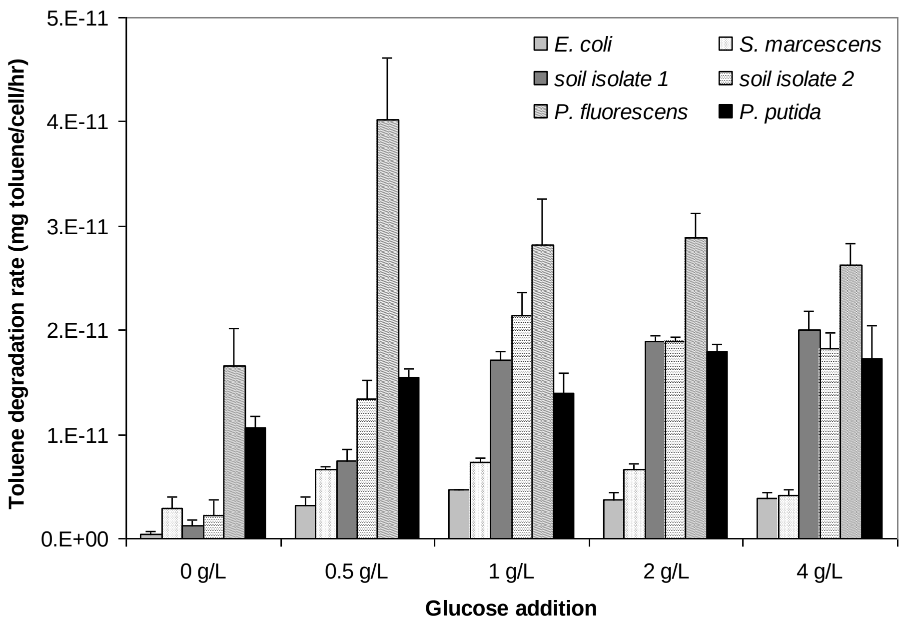

Figure 1. Toluene degradation rates of transconjugants and *P. putida* with the addition of varying doses of glucose. Error bars represent the standard deviation of triplicate samples.

Previous studies suggest that the recipient genomic guanine-cytosine (GC) content may play an important role in determining whether the transferred genes will be expressed in transconjugants. The lack of functional phenotype in the absence of alternate substrates seen in this study may be due to differences in GC content between the TOL plasmid (~59% GC) and the recipient genomes (e.g. *E. coli*: 50%, *S. marcescens*: 59%, *P. fluorescens*: 60%). Therefore, the closeness of recipient genomic GC content to the GC content of the transferred genes may be an indicator of the success rates of genetic bioaugmentation.

While other parameters should be studied in depth prior to the field application of genetic bioaugmentation, the results from this study indicate that successful HGT events coupled with the desired degradative phenotype can be promoted by small changes in environmental conditions. With further research, there is potential for genetic bioaugmentation to be applied towards remediating emerging contaminants in various environments such as groundwater and soil. Overall, this study will illustrate that genetic bioaugmentation may provide an effective but safer, cheaper and less invasive method for bioremediation.

HIGH-THROUGHPUT PYROSEQUENCING OF BACTERIAL DIVERSITY IN DRINKING WATER

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Background: Despite vigorous filtration and disinfection in water treatment operations, a small number of microorganisms, some of which are potentially pathogenic, remain present in treated water, presenting a poorly-understood public health risk. Data on waterborne disease outbreaks suggest that drinking water continues to be one of the most import media for infectious diseases worldwide. Current practices in assessing biological integrity of drinking water have relied primarily on cultivation and polymerase chain reaction (PCR)-based techniques. Since many microorganisms are not yet culturable while PCR-based techniques could only detect specific groups using previously known signature sequences, it is likely that the microbial diversity and potential health risks of drinking water remain inadequately evaluated. Therefore, the objective of this study is to thoroughly characterize the diversity of bacterial populations in drinking water with high-throughput pyrosequencing as well as conventional clone library analysis.

Methods: Drinking water (150 L) was collected from the same faucet in December 2009 and June 2010. Microbial biomass was harvested with ultrafiltration followed by centrifugal concentration. DNA was extracted for both clone library analysis and 454 pyrosequencing of the V3 region of 16S rRNA genes. OTUs were assigned with the average neighbor clustering algorithm and taxonomy was assigned by MOTHUR using the naïve Bayesian rRNA classifier of RDP. A pairwise distance matrix was constructed and all the subsequent analyses (ecological indices, rarefaction, rank-abundance, species abundance, and shared analyses) were performed using this distance matrix.

Results: Clone library analysis generated a total of 173 sequences, representing 35 unique sequences of ~900 bp. In contrast, pyrosequencing resulted in 11,248 high quality reads of ~150 bp, representing 1,463 unique sequences. As expected, rarefaction curve analyses of the observed OTUs indicate the near complete coverage of the community diversity with the unprecedented sampling depth provided by pyrosequencing. In contrast, clone library analysis evidently under-sampled community diversity. Three bacterial phyla, *Proteobacteria*, *Actinobacteria*, and *Firmicutes*, were detected by both clone library and pyrosequencing, with *Proteobacteria* as the predominant group (~90% sequences), confirming the consistency between these two methods. Over all, similar bacterial diversity was indicated by clone library analysis and pyrosequencing at the family level (Fig. 1).

However, pyrosequencing was able to detect additional phyla with low abundance such as *Acidobacteria* (0.12%), *Bacteroidetes* (0.20%), *Deinococcus-Thermus* (0.12%), and *Fusobacteria* (0.03%). Pyrosequencing also detected potential opportunistic pathogens at very low abundance, including *Aeromonas*, *Burkholderia*, *Mycobacteria*, and *Legionella*. Notably, the bacterial community structures in drinking water shifted significantly between winter and summer (Fig. 1): Populations related to *Methylobacteriaceae* were the most predominant in winter while *Oxalobacteraceae* were the most abundant in summer. Since the activities of these bacteria were unclear in drinking water, the significance of the changes in these abundant populations needs to be further investigated. The high-throughput sequencing of 6 additional drinking water samples has been completed at the time of submission. Ongoing analysis of the sequencing data will provide information on the distribution of these bacterial populations in geographically distant water distribution systems.

Conclusions: The high coverage of pyrosequencing enabled the detection of low abundance bacterial populations such as certain potential pathogens, demonstrating the advantage of this technology to adequately assess the public health risk of waterborne pathogens in drinking water. On-going investigation will further reveal the biogeography of bacterial populations in drinking water.

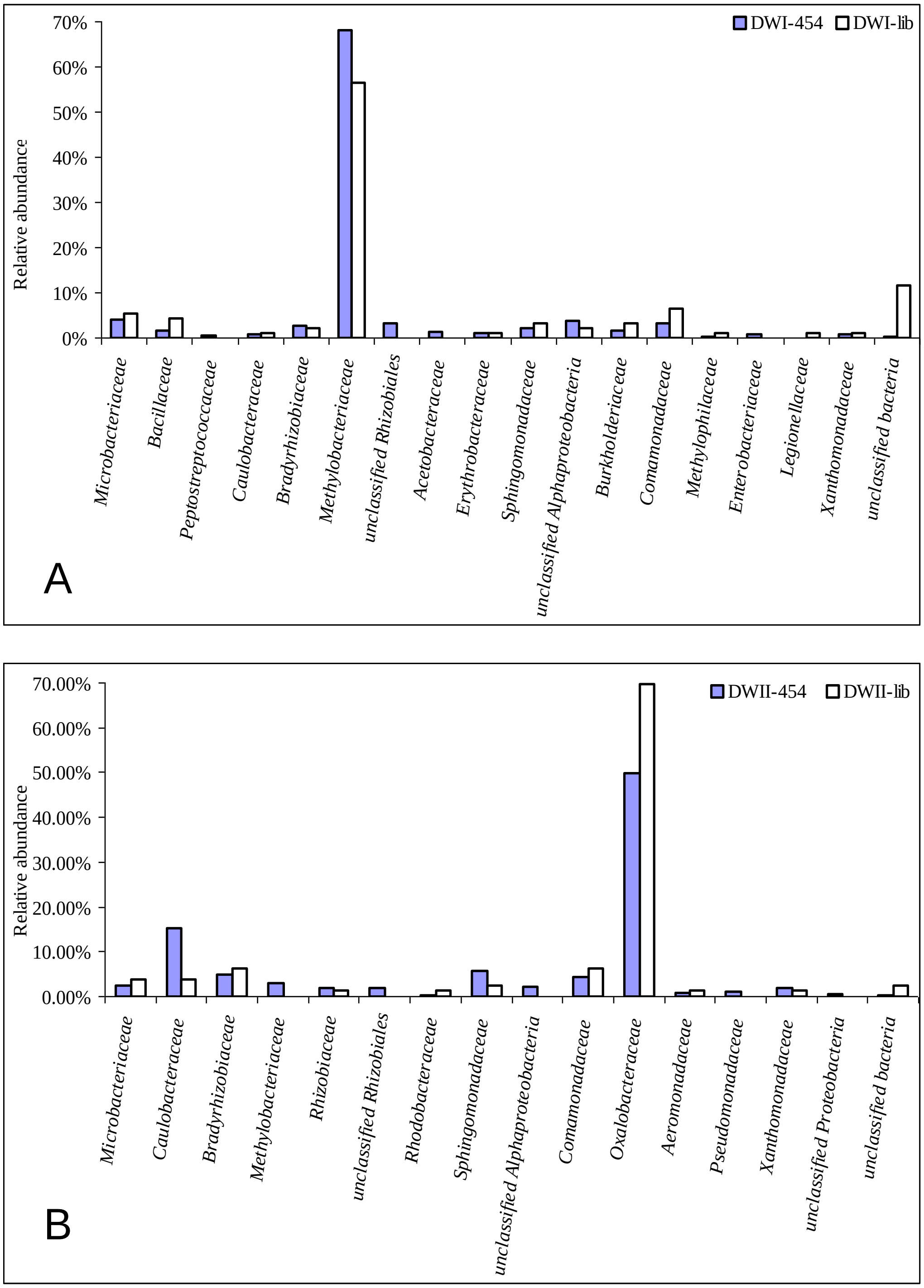

Fig. 1. Bacterial community composition at the family level as revealed by clone library (DWII-lib) and pyrosequencing (DWII-454) for drinking water sampled in winter (A) and summer (B).

BACTERIOPHAGE-FUNCTIONALIZED MATERIALS FOR SELECTIVE CAPTURE AND INACTIVATION OF WATERBORNE PATHOGENS

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Waterborne infectious diseases bring death and illness to millions of people worldwide. Rapid, effective and sustainable methods to purify drinking water can save human lives in developing countries and in disaster scenarios such as floods or earthquakes. One proposed method to control bacterial populations in potable water supplies is the use of bacteriophage-functionalized materials. Bacteriophages are viruses that exclusively infect prokaryotes and are thus innocuous to eukaryotic (e.g., human) cells. They can be used as natural biocontrol agents in water decontamination, food processing, and biomedical applications. Bacteriophages can be immobilized on substrates as simple as filter paper and serve as a means of water purification without need for any advanced or expensive infrastructure.

In this study, we have investigated the bacterial capture and inactivation capability of different phages. Five phages with different structures and genetic material were chosen and covalently immobilized onto a model substrate. The phage-functionalized substrates were subsequently tested for bacterial capture efficiency towards their host bacteria: *Salmonella typhimurium* (*S. typhimurium*) and *Escherichia coli* (*E. coli*). Furthermore, the rate of cell lysis for phage bound to the model surface was studied using fluorescence microscopy. The five selected phages (PRD1, P22, PR772, MS2, and T4) are representative of the possible structural variations for phages and allow us to evaluate the behavior of phages having completely different physical structure and mode of infection. To our knowledge, this is the first study of its kind and can help fill the gap for utilizing phage in combating waterborne infections.

The selected substrate, phages and bacterial species were characterized using several experimental techniques including scanning and transmission electron microscopy, atomic force microscopy, X-ray photoelectron spectroscopy, and contact angle goniometry. The number of captured bacteria for substrates functionalized with each of the chosen phages was quantified via fluorescence microscopy and is presented in Figure 1. Moreover, the rate of cell lysis by a phage-functionalized substrate has been monitored (Figure 2).

We will present and discuss our findings while taking into consideration the structural differences of the selected bacteriophages. Binding of the phages to the model substrate affected their biofunctionality as expressed by bacterial capture efficiency and rate of host lysis. Our results emphasize that the biology and surface properties of the phage and the bacterial target greatly influence bacterial capture and subsequent inactivation. Of the phages investigated, PRD1 (host *S. typhimurium*) MS2 (host *E. coli*) exhibited superior capture efficiencies for their host bacteria. Substrates with immobilized PRD1 were shown to actively lyse all of the captured cells within one hour of contact. The results of our study show that phage-functionalized materials are promising candidates for selective capture and inactivation of waterborne pathogens.

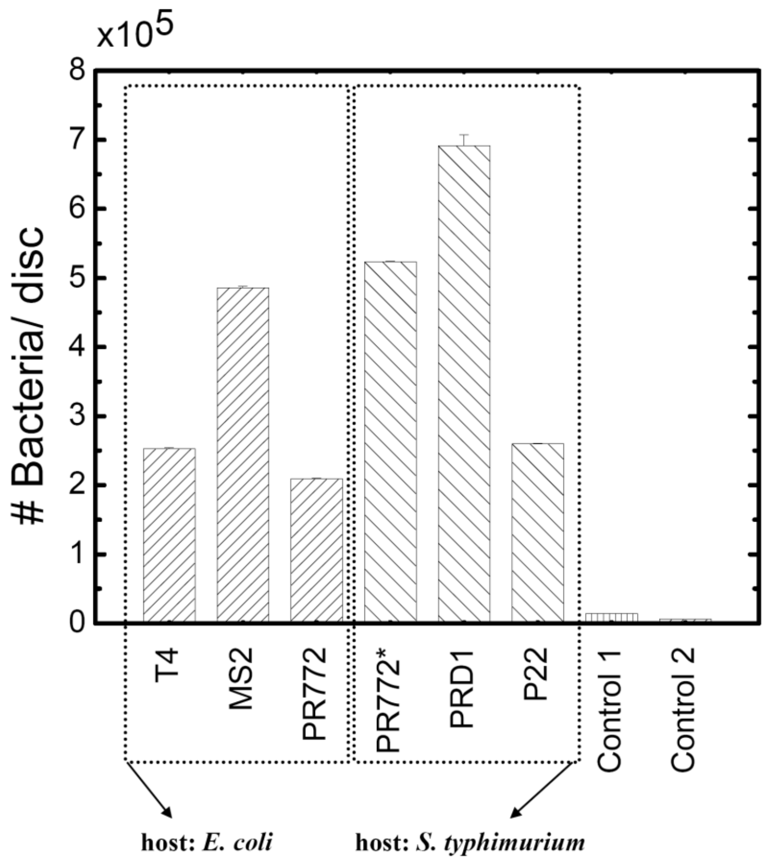

Figure 1- Number of host bacteria attached to phage-functionalized discs. Each column represents the mean of five experiments with 30 frames analyzed for each experiment. Control 1 represents APTES-coated disc and Control 2 represents blank disc (both blocked with bovine serum albumin). Controls are the average for both bacterial hosts. Data are means ± 95% confidence intervals (n = 150).

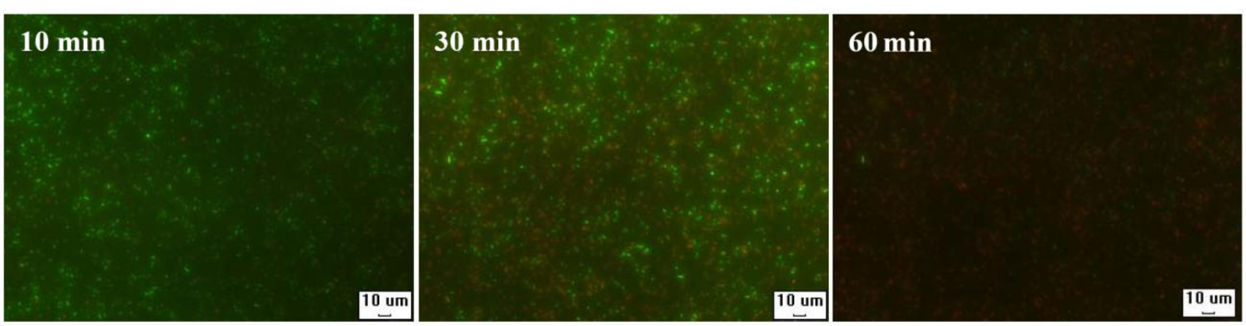

Figure 2. Representative images of cell lysis monitored by fluorescence microscopy using BacLight™ bacteria viability kit. Green dots represent live bacteria and red dots represent lysed bacteria.

NATURAL ORGANIC MATTER INTERACTIONS WITH METAL-BASED NANOMATERIALS: IMPLICATIONS FOR AGGREGATION, DISSOLUTION, AND BIOAVAILABILITY

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The environmental fate and mobility of metallic and mineral nanoparticles (NPs) can be strongly influenced by sorption of natural organics including humic substances. Organic matter is capable of modifying particle surfaces and changing the reactivity of the NPs with respect to attachment to other particle surfaces, dissolution of the NPs, and bioavailability of the metals associated with the NPs. In this work we studied two types of nanomaterials: zero-valent Ag NPs, which are widely used in consumer products for antimicrobial applications, and mercury sulfide (HgS) NPs, which occur in Hg-contaminated sediments as an intermediate of metacinnabar precipitation processes. Here, we studied multiple pathways in which dissolved natural organic matter (NOM) can alter the fate of nanomaterials in the aquatic environment. These processes include aggregation, dissolution, metal complexation, and bioavailability to microorganisms.

In the first case, we studied how dissolved organic ligands that are prevalent in aquatic systems may affect the aggregation and oxidative dissolution of metallic Ag nanoparticles. Cysteine, a thiol-containing amino acid, was chosen as a surrogate for high-affinity metal binding groups prevalent in NOM. Our research found that cysteine sorbed to Ag nanoparticles and increased NP attachment efficiencies during aggregation in diluted seawater (Figure 1a). The increase of aggregation rates depended on surfaces properties, including zeta potential and type of surfactant coating utilized to manufacture the NP (e.g., citrate, PVP). The addition of cysteine to Ag NP suspensions also increased the dissolved Ag concentration (Figure 1b). These results indicated that cysteine was simultaneously sorbing to the Ag NPs and promoting their dissolution. Furthermore, the dissolved cysteine that was observed to remain in solution was likely to persist as dissolved $Ag(cysteine)_2^-$ complexes in solution, based on calculations of dissolved equilibrium speciation. Bioavilability of silver to exposed organisms is expected to depend on dissolved Ag concentration and Ag speciation.

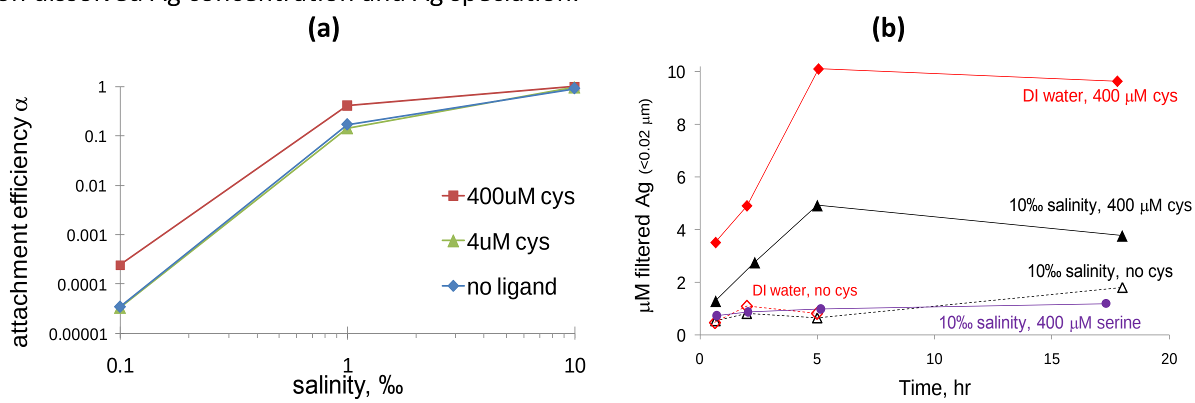

Figure 1. Influence of cysteine on the aggregation and dissolution of citrate-coated Ag nanomaterials suspended in diluted artifical seawater. a) Addition of cysteine increased the attachment efficiency between Ag nanoparticles; b) Cysteine increased the dissolved Ag concentration while the extent of dissolution depended on the salinity (and possibly the aggregation state of particles).

In the second case, we studied the precipitation of HgS and other metal sulfide nanoparticles in the presence of dissolved NOM. Such reactions are expected to occur in anaerobic sediments of mercury-contaminated systems. Hg speciation in porewater controls the bioavailability of mercury to anaerobic microorganisms that produce methylmercury (the form of mercury that bioaccumulates in food webs). Our work has shown that nanoparticles of HgS can exist in porewater if precipitation reactions occur in the presence of dissolved NOM. We observed stabilization of nanoparticulate metal sulfides in solutions with thiolate ligands and with high molecular humic substances (*1-2*). Methylation potential of HgS-humic nanoparticles were compared to dissolved and microparticulate HgS by exposing pure cultures of a sulfate-reducing bacteria (*D. propionicus*) to three different forms of mercuric sulfides. MeHg production was greatest in cultures treated with dissolved Hg-sulfides (Figure 2). In the treatments with HgS nanoparticles, mercury methylation was observed at a slower rate, but was faster than the bulk scale metacinnabar treatment. These results suggest that a fraction of inorganic mercury associated with HgS nanoparticles is bioavailable to methylating bacteria, possibly due to higher solubility and specific surface area of nanoparticles over micro-scale particles.

Overall, our work highlights the importance of metal-binding organic ligands such as NOM for modifying the surface of metal and mineral nanomaterials in environmental settings. Sorption of NOM alters the aggregation and solubility of the nanomaterials, and ultimately, will influence their persistence in the environment and bioavailability to exposed organisms.

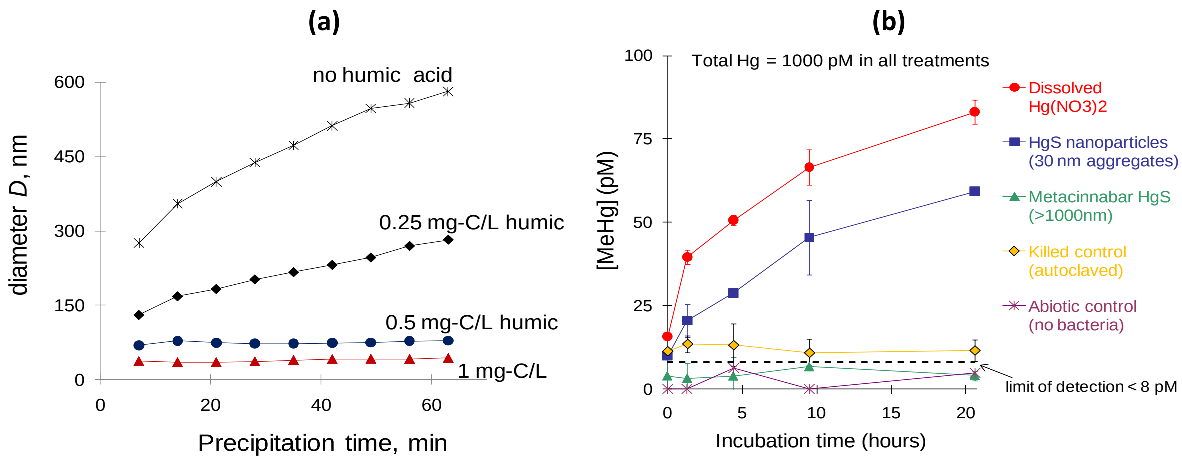

Figure 2. (a) Precipitation of 3 μM $Hg(NO_3)_2$ with 3 μM Na_2S dissolved in the presence of dissolved humic acid (pH 7.5 0.5M $NaNO_3$ electrolyte). Modified from Ref. (*1*); (b) Production of methylmercury (MeHg) in *D. propionicus* cultures exposed to 1 nM mercury in three different forms (dissolved $Hg(NO_3)_2$, HgS-humic nanoparticles, and bulk HgS particles).

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DEPOSITION KINETICS OF *E. COLI* S17 ONTO PVC AND BIOFILM IN A MONOVALENT SALT SOLUTION

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Drinking water distribution system (DWDS) can be treated as a bioreactor with microorganisms both in bulk water and on the pipe surfaces. A layer of organic matter and microorganisms formed by the attachment of bacteria on the surface of the pipe is known as biofilm. DWDS biofilm could be a public health concern because it can promote accumulation, survival, and growth of waterborne pathogens. A variety of microorganisms can enter the system through leaks, breaks, and insufficient treatment. Once microorganisms persist in the DWDS, the partition of microorganisms between bulk and pipe surface plays an important role in microorganism fate and transport in the system. The objectives of our study were to determine the attachment mechanism of *Escherichia coli* (*E. coli*) S17 on PVC and biofilm grown on PVC in monovalent salt solutions. In our study, a parallel flow plate chamber coupled with an inverted fluorescence microscope was used to monitor the real time attachment of *E. coli* S17 onto PVC or biofilm surfaces in monovalent salt solution (NaCl). Biofilm community analysis was conducted to help understand the correlation between biofilm age and the attachment mechanism.

Biofilm was grown on PVC coupons with Newmark groundwater in a CDC biofilm reactor. Biofilms with different ages (2, 6, and 8 weeks) were grown for deposition experiment in a parallel flow plate chamber with the corresponding Re of 1.24 and flow rate of 1 ml/min. The attachment of *E. coli* S17 on the biofilm surface was observed and counted every 15 sec for 30 min through the deposition experiments.

Surface potentials of *E. coli* S17 and a substratum were measured in solutions with varied ionic strength. These data were used later in calculation for energy barriers by Derjaguin-Landau-Verwey-Overbeek (DLVO) theory. Contact angles were measured for *E. coli* S17 and biofilm to calculate Hamaker's constants. Biofilm surface roughness was also measured by atomic force microscopy (AFM). Biofim community analysis was carried carried out for biofilms with different ages.

The transfer rate coefficients (k_D) of *E. coli* S17on both PVC and biofilm increased with ionic strength due to double layer compression. The positive correlation of deposition with ionic strength indicates that electrostatic interaction plays a role in *E. coli* deposition on biofilm. Van der Waals forces calculated from contact angle suggested that deposition decreased with biofilm age. However, measured deposition rate increased with biofilm age. Thus, the combination of electrostatic interaction and van der Waal interaction is not sufficient to explain *E. coli* deposition on biofilm. We hypothesized that biofilm surface roughness played an important role in *E. coli* S17 deposition. Figure 1 shows a positive correlation between the biofilm roughness measured by AFM and deposition rate coefficient k_D. The roughness increase with biofilm age, and corresponds to more varieties of microorganisms found with aged biofilm, as shown in Figure 2.

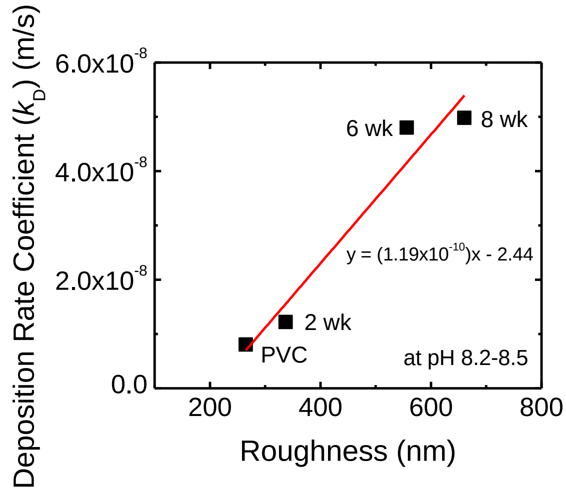

FIGURE 1. Biofilm roughness corresponding to deposition rate coefficient of *E. coli* on each biofilm. Deposition experiment was carried out at pH 8.2-8.5. k_D at 10 mM KCl was selected as a representative to include in this plot. Biofilm roughness was measure by AFM tapping mode. Scan area was 5 µm^2. Each measurement was repeated at least 3 times.

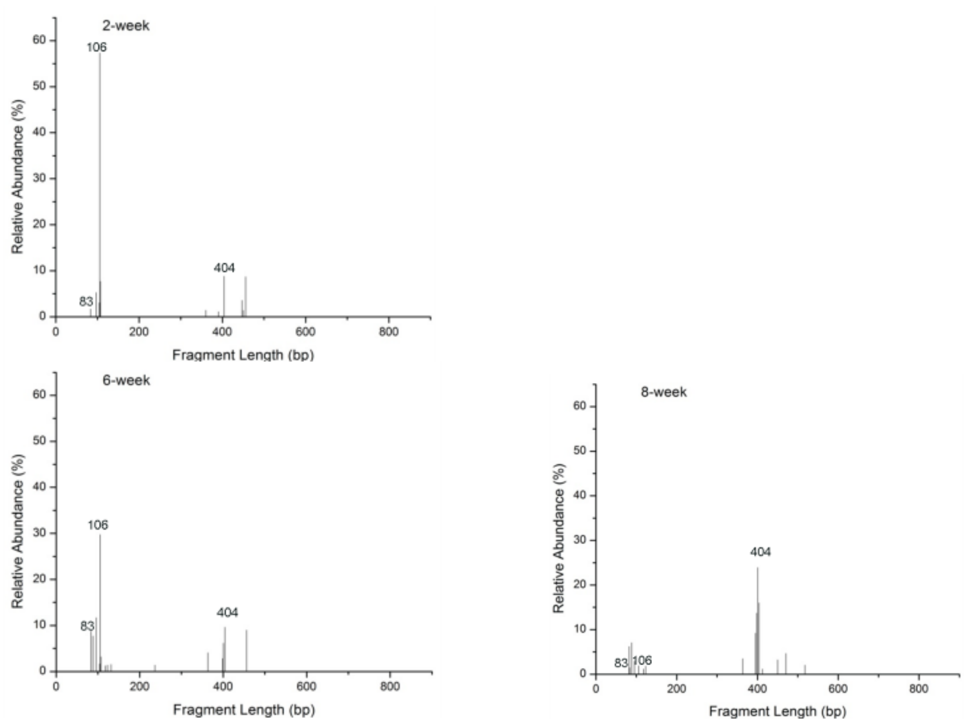

FIGURE 2. T-RFLP fingerprints of biofilm samples retrieved after 2 weeks (A), 6 weeks (B), and 8 weeks (C) of development.

OPTIMIZING THE BIOSAND FILTER FOR HOUSEHOLD DRINKING WATER TREATMENT IN DEVELOPING COUNTRIES

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The concrete biosand filter (BSF), as shown in Figure 1, is a small scale, intermittently-operated slow sand filter designed for use in households where water is carried into the house in buckets or other containers and then poured into the filter. When contaminated water is poured into the filter, the high water level in the influent reservoir provides the hydrostatic head to push water through the filter by the force of gravity. Pause periods between filter use are important because they provide time for (i) microorganisms in the biolayer to consume contaminants in the supernatant and upper layer of the sand bed and (ii) adsorption and settling of contaminants to occur in the lower layer of the sand bed. Pause periods of 6-12 hours (minimum 1 hour and maximum 48 hours) are generally recommended.

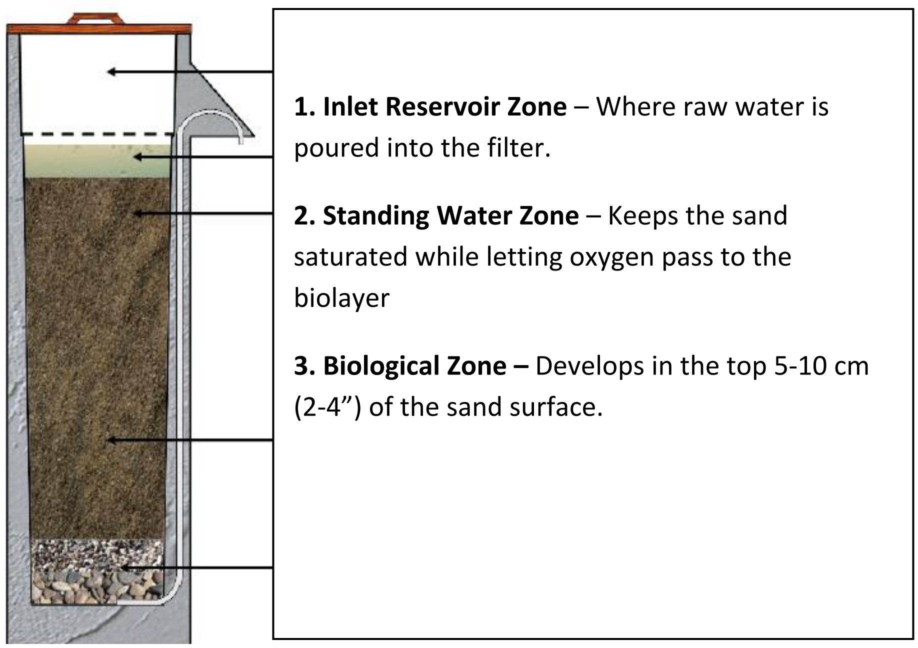

Figure 1. Cross-sectional view of the concrete biosand filter showing the internal components. Figure courtesy of the Centre for Affordable Water and Sanitation Technology (CAWST).

The concrete BSF produces high quality water but can be too costly ($10-30 USD) for some of the poorest households in the developing world. In addition, the size (0.3 m x 0.3 m x 0.9 m, w x d x h) and weight (250 lbs) of the concrete filter make it cumbersome and difficult to transport beyond the initial installation location. The current research tests the hypothesis that biosand filtration can be effective with smaller, lighter, less expensive units in order to more sustainably meet the needs of a larger global market.

We are testing two modified BSF designs, a 5-gallon bucket BSF and a 2-gallon bucket BSF, against the large concrete BSF for their efficacy in removal of turbidity, total coliforms, *E. coli*, MS2 coliphage, and *Cryptosporidium parvum* oocysts from raw drinking water supplies.
Water from a spiked tank is used to fill 12 filters: four concrete BSFs, four 5-gal bucket BSFs, and four 2-gal bucket BSFs. The 12 BSFs were constructed under the guidance of Derek Baker, technology director for the Centre for Affordable Water and Sanitation Technology (CAWST) in Calgary, Canada. Filter media (fine sand and coarse gravel) is the same for all three BSFs; the major difference is the depth of the fine sand layer (fine sand depths are 54 cm for the concrete BSF, 16 cm for the 5-gal bucket BSF, and 10 cm for the 2-gal bucket BSF). Sand was prepared according to CAWST training manuals. Supernatant water is maintained at a depth of 5 cm for all three BSFs. Raw water holding capacities (i.e., reservoir volumes) are 12 L for the concrete BSF, 3.5 L for the 5-gal bucket BSF, and 1.5 L for the 2-gal bucket BSF. Filters are currently being tested for 32 consecutive weeks over a range of pause periods (1, 2, 3, 6, 12, 24, and 72 hrs).

Since most particulate removal occurs at the surface of the sand bed, the smaller sand bed depths in the bucket filters are not expected to significantly impact filter performance with respect to turbidity, bacteria, or protozoan cysts. Virus removal, however, may suffer from the more shallow sand bed depths in the bucket BSFs. Viruses are negatively charged (which inhibits their attachment to negatively-charged sand grains) and small enough to move through the biolayer and, potentially, the entire sand bed depth. Therefore, we are also testing a modification to the three BSF designs consisting of 6 kg of small rusty iron nails (i.e., iron oxide) in the diffuser basin (two of the four filters of each type are modified with rusty nails); these positively-charged rusty nails are included to enhance the adsorption/adhesion of the negatively-charged viruses through electrostatic forces. In this way, the viruses become attached to the iron oxide on the nails and onto the sand grains where natural die-off/deactivation occurs.

Results from this work will identify whether the smaller, cheaper BSFs can provide drinking water that is comparable in quality to that produced by the traditional concrete BSF (and whether the addition of the rusty nails is a requirement to achieve virus removals in the smaller BSFs that are similar to those observed in the concrete BSF). We will also be able identify optimal pause periods recommended for use of the smaller filters.

The smaller, lighter BSFs resulting from this project will fit nicely into existing, self-sustaining channels of global distribution (ranging from charitable donations to full cost-recovery programs). Because they cost less and are easier to handle, deliver, and service, more families will be able to purchase and transport the new BSFs to their homes, full cost recovery or partial cost-recovery programs will be more feasible, and each donor dollar for subsidies will go further. The new BSFs will also open up new opportunities for social entrepreneurs to build businesses selling water treatment systems to those who can afford to pay. Theoretically, this type of social marketing can enhance the development of the "middle class" in developing nations – a necessary requirement for developing nations to evolve from poor economies to sustainable, growing economies.

Making BSF technology more accessible to a broader population will contribute to the United Nations Millennium Development Goal of reducing by half the proportion of people without access to safe water by 2015. Increasing the number of people who filter their drinking water will reduce the incidence of waterborne diarrheal disease, increase productivity (e.g., increase the number of days children attend school and adults attend work), increase the earning capacity of the average household, and help households and communities break the cycle of sickness and poverty which currently plagues billions of people worldwide.

ADVANCED TECHNIQUE FOR MONITORING BIOREMEDIATION OF VINYL CHLORIDE IN GROUNDWATER

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Bioremediation strategies can be cost effective and environmentally friendly approaches for improving the quality of groundwater that has been degraded by chemical contamination. For example, vinyl chloride (VC), a known human carcinogen, is a pervasive groundwater contaminant that can enter groundwater via poor handling and disposal practices at polyvinyl chloride production facilities. However, VC is more often formed in groundwater from incomplete reductive dechlorination of other common groundwater contaminants such as the more highly chlorinated ethenes and ethanes. We are studying situations where VC has formed under anaerobic conditions and migrated, along with some ethene, to a zone where oxygen is also present. Under this scenario, aerobic, ethene-assimilating bacteria (i.e. etheneotrophs) could either cometabolize the VC in the presence of ethene or possibly adapt to VC as a growth substrate.

Our research aims to better understand the presence, abundance, and functionality of etheneotrophs in VC-contaminated groundwater. The main goal is to develop methods that provide rapid, useful information about etheneotrophs for site managers tasked with remediating the dissolved VC plume. Culture-based microcosm tests and semi-quantitative genetic assays are currently available, but take about 60 and 14 days, respectively, to yield useful information. We have recently described a quantitative, real-time PCR (qPCR) method which can yield data within 3 days. We are now working to extend this technique in a way that reveals metabolic functionality of etheneotrophs in groundwater. This involves extracting RNA from groundwater samples and applying reverse-transcriptase qPCR (RT-qPCR). This allows us to estimate the abundance of both functional genes and mRNA transcripts associated with etheneotrophs in groundwater. This method targets the functional genes *etnC*, which encodes the alkene monooxygenase (AkMO) alpha subunit and *etnE*, which encodes the epoxyalkane:coenzyme M transferase (EaCoMT). These functional genes are known to be involved in both the aerobic VC and ethene biodegradation pathways. AkMO converts VC and ethene to epoxide intermediates, while EaCoMT transforms these epoxides into compounds that can enter central metabolic pathways.

Groundwater samples from several VC-contaminated sites were collected with Sterivex filters, preserved with RNAlater as appropriate, shipped on ice, and stored in -80^{o}C in the lab prior to processing. DNA (or RNA) extraction was performed with the protocol of MOBIO PowerWater DNA (or RNA) Isolation Kit. Luciferase mRNA (or DNA) was incorporated immediately after the cell lysis step to provide internal controls for mRNA (or DNA) loss during mRNA (or DNA) isolation steps. Previously described degenerate qPCR primers were used along with ABI Power SYBR green Master Mix Kit. Standards were constructed with purified PCR products of *etnC* (*Mycobacterium* strain JS617), *etnE* (*Nocardioides* strain JS614), and luciferase gene (cDNA from luciferase mRNA). The qPCR experiments were conducted with an ABI7000 Sequence Detection System.

Analysis of qPCR data, corrected with internal controls, revealed 2×10^{3} *etnC* and 6×10^{3} *etnE* genes per liter (L) of groundwater. In contrast, there were 1×10^{3} *etnC* and 1×10^{3} *etnE* transcripts present per L of groundwater. This corresponded to DNA and RNA recovery efficiencies of 87% and 7%, respectively. Normalizing gene expression to gene abundance showed that there were 0.5 *etnC* and 0.2 *etnE* transcripts per gene, which suggests that etheneotrophic gene expression was relatively low in this sample. Future work is focused on better understanding our transcript per gene measurements in the context of metabolic activity.

Overall, this novel RT-qPCR method shows promise for quantifying the abundance of *etnC* and *etnE* transcripts in groundwater and therefore represents an approach for demonstrating metabolic functionality of etheneotrophs and VC-assimilators therein. In the future, the study for increase of RNA recovery efficiency should be performed. For better understanding of metabolic functionality, number of transcripts per gene in microbial growth phases with pure culture should be performed.

ELECTRODIALYSIS DESALINATION POWERED BY MICROBIAL FUEL CELLS

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A microbial desalination cell (MDC) is a new bioelectrochemical technology that can be used to desalinate water while simultaneously treating wastewater. In an MDC exoelectrogenic microorganisms at the anode, coupled with the oxygen reduction at the cathode, generates electric potential energy that is used to separate ions from salty water held between two ion-exchange membranes. In a microbial electrodialysis cell (MEDC), hydrogen gas is produced at the cathode but voltage must be applied to drive desalination (although the electrical power can be derived from the produced hydrogen gas). In previous studies, desalination in an MDC or MEDC relies on the ionic transport from salty water to less salty wastewater and catholyte solution. Thus, substantial volumes of wastewater and catholyte solutions were required to improve salinity removal. For instance, to achieve greater than 90% salt removal of 1 mL seawater, more than 60 mL of wastewater and a clean catholyte solution were used in a previous design. The performance of these systems can be improved by minimizing the volumes of the desalination cell and incorporating multiple desalination cells in a MDC.

The ionic separation in microbial desalination is driven by relatively small potential energy (~800 mV under open circuit conditions) provided by the microbes and oxygen reduction. Due to this small potential energy, the performance of the MDC is very sensitive to losses in potential due to Ohmic resistance, junction potentials, and over-potentials. Ohmic resistance occurs due to the system internal resistance, which can be minimized through improved designs (e.g., reduced cell width). The junction potential is created by the salinity difference across an ion-exchange membrane, and therefore it increases as the salinity differences increase between the diluate and concentrate cells. Over-potential is the voltage loss needed to drive the electrode reactions. In addition to potential losses, relatively slow ionic separation makes a MDC vulnerable to other limiting factors, such as the osmotic water transport or perm-selectivity of ion-exchange membranes. The perm-selectivity quantifies the ideality of ion-exchange membranes, and a value of unity for a cation-exchange membrane indicates that 100% of the charge transfer through the membrane was carried by cations.

In this study, a new type of MDC was built to increase the desalination recovery without the need for an external voltage supply. The objectives were (1) to develop an MDC that used a multiple cell-paired electrodialysis stack to improve the desalination recovery, and (2) to quantify the effects of the limiting factors, such as the Ohmic resistance, junction potential, over-potential, osmosis, and membrane perm-selectivity on performance.

Methods. A MDC was built with an electrodialysis stack of 5 cell pairs as shown in Figure 1. One cell pair consists of one diluate and one concentrate cells, which are shown as the white and shaded cells in the figure, respectively. The electrodialysis stack was sandwiched with anion- and cation-exchange membranes (Asahi Glass, Japan). The inter-membrane distance (or cell width) was 1.3 mm, and the cross-sectional area of the cell was 8 cm^2. Synthetic seawater (35 g/L or 600 mM NaCl) was continuously pumped into the electrodialysis stack at 0.1 mL/min, and the corresponding mean hydraulic residence time was about 50 minutes for each MDC. The cathode and anode chambers were operated as batch reactors. For each batch cycle (~24 hours), 18 mL of the synthetic seawater was provided in the cathode chamber, and the anode chamber was filled with 30 mL of synthetic wastewater (1.0 g/L sodium acetate in 100 mM phosphate buffer solution). With 4 MDCs, a continuous flow desalination system was built as shown in Figure 2. The diluate solution flows through MDC-1, -2, -3, and -4 before its effluent is collected in a reservoir, while the concentrate solution was pumped from MDC-4, -3, -2, and -1.

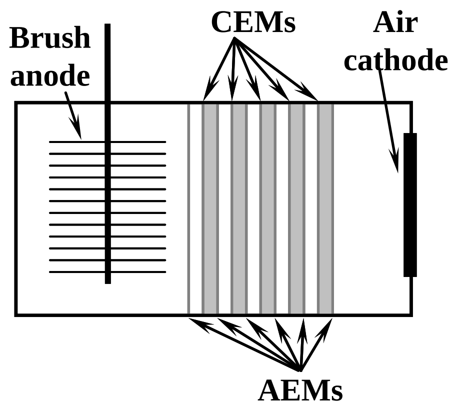

Figure 1. MDC with 5 cell-pair electrodialysis stack.

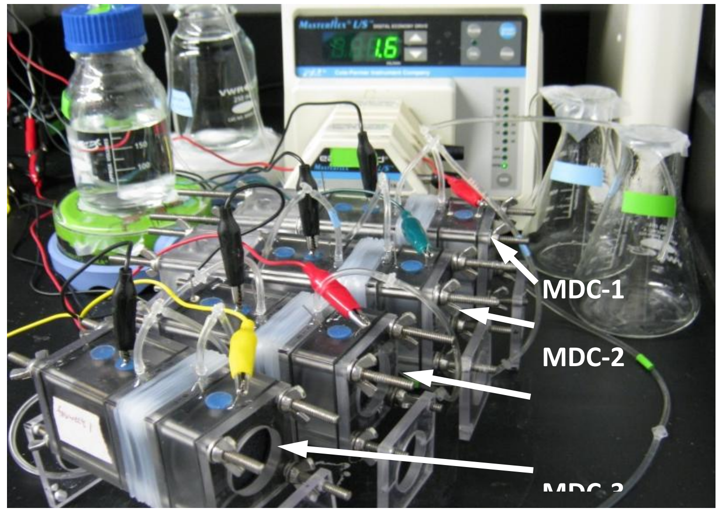

Figure 2. Continuous flow system with 4 MDCs in series.

Results and discussion. The electrogenic activity during a fed batch cycle lasted for ~12 hours at stable currents between 3 to 5 mA. The diluate and concentrate effluents were collected over that time period (except for the first 2 hours to eject the residual solution from the previous cycle). The diluate effluent showed 44% reduction in conductivity (from 56 to 31 mS/cm), while the conductivity of the concentrate solution increased from 56 to 71 mS/cm. The collected volume of the diluate and concentrate effluents was 60 and 78 mL, respectively. This difference in the effluent volume, due to osmotic and electroosmotic water transport, would result in decreased performance.

The current efficiency, defined as the rate of the ionic separation divided by the observed electric current, was 86%. This indicates the perm-selectivity of the ion-exchange membranes ranged from 80 to 90 %. Based on the solution conductivity and membrane resistivity, the Ohmic potential loss in the electrodialysis stack was found to be relatively insignificant (25 to 30 mV at 4 mA), while that in the anode and cathode chambers was ~100 mV. The magnitude of the over-potential was approximately 150 and 200 mV for the anodic and cathodic reactions, respectively. The junction potential loss was found to increase from 50 to 110 mV along the diluate flow due to the concentration reduction.

These results show that microbial desalination in an MDC could be improved with a multiple cell-paired electrodialysis stack, with the salinity removal ranging from 40% to 50%. To enhance the salinity removal, on-going research is focused on reducing the effects of the limiting factors on performance.

BENEFICIAL ROLE OF HOMOACETOGENS IN MICROBIAL ELECTROCHEMICAL AND DECHLORINATING SYSTEMS

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Organic wastes from agriculture, industrial wastewater treatment, and other feedstock can provide renewable sources for energy conversion or bioremediation via properly managed hydrolysis, fermentation, and respiration processes. The outputs of fermentation are organic acids, alcohols, and H_2 or methane (CH_4). In any process where fermentation is necessary to break down a complex substrate for its further use in environmental processes, the fate of H_2 and the organic acids determines success or failure. These fermentation products can be used as electron donors for microbial electrochemical and dechlorinating systems; however, acetate and H_2 can also be converted to CH_4, which becomes a sink of electrons. The efficiency of routing electrons to the ideal destination is usually determined by syntrophic interactions among the different microorganisms present in the system. If we want to exploit organic wastes as sources of carbon and electrons for bioenergy and remediation, understanding the microbial ecology and, specifically, the syntrophic relationships that develop is critical for the success.

In the energy realm, Microbial Electrochemical Cells (MXCs) are promising technologies that produce electricity or H_2 at the same time as organic wastes are treated and pollution is reduced. Anode respiring bacteria (ARB) transfer electrons to a solid anode, and electrical current is produced as the electrons flow to a cathode. Substrates other than acetate or H_2 are not consumed directly by ARB, and this result in low electron recovery. Higher electron recoveries are possible when the H_2-scavenging mechanism is shifted from methanogenesis to acetogenesis.

In dechlorinating systems, *Dehalococcoides* are the only identified microorganisms able to completely dechlorinate perchloroethene (PCE) and trichloroethene (TCE) to harmless ethene. Their electron acceptors are halogenated compounds, their electron donor is H_2, their carbon source is acetate. *Dehalococcoides* are obligate anaerobes, grow optimally at a near-neutral pH, and require corronoids (usually in the form of vitamin B_{12}) as essential cofactors for the enzymes in charge of the dechlorination, i.e., reductive dehalogenases (RDases). In reductive dechlorination, acetogens can be H_2 competitors, but also producers of acetate, H_2, and corrinoids. The first activity is negative for dehalogenation, while the last three are positive. Proper management of these communities means gaining the positive without incurring the negative. Lack of a deep understanding of the interactions between dechlorinators, fermenters, and the acetogens limits our ability to maximize electron and carbon flow to reductive dechlorination. We can improve dechlorination rates when we provide the optimal amount of electrons and nutrients to fermenters and/or acetogens, who contribute essential nutrients and growth factors to *Dehalococcoides* and select against members who divert electrons to other processes without providing benefit to dechlorinators.

Up to now, our research has focused mostly on the inter-relationships among microbial ecology of the ARB biofilm on the anode and MXC performance and interactions among homoacetogens and dechlorinators. To achieve this, we employ molecular, electrochemical, and microscopy methods to understand the processes occurring. We focus on understanding the interactions between ARB or dechlorinators (in two separate systems) and the other microbial communities during the consumption of fermentable substrates.

With MXCs we have shown that a significant fraction of the electrons removed from the organic fuel can be diverted away by the generation of methane gas. We found that H_2-oxidizing methanogens are responsible for this diversion and that acetate-oxidizing ARB can out-compete acetate-utilizing methanogens. Current production increased in parallel with methane generation, indicating syntrophic interactions between ARB and methanogens, and fermenters outcompete ARB that can directly consume fermentable substrates. Suppressing H_2-oxidizing methanogens and encouraging acetogens (which convert H_2 + CO_2 to acetate) increased the electron-capture efficiency from 60% to 84%. Our research also allowed us to understand the microbial community structure at the biofilm anode and to correlate it with electron distribution, which enabled us to reveal the significance of H_2 scavengers. We have also tested the potential of acetogens establishing in the anode biofilm and suspension when CO_2 and H_2 were provided instead of a fermentable substrate. We proved that acetogens make effective positive syntrophic interactions in MXC anodes for efficient consumption of H_2 to produce electrical current, leading to current densities of ~10 A/m^2, comparable to acetate-fed biofilms.

For reductive dechlorination, we have developed a dechlorinating culture, "DehaloR^2". DehaloR^2 is a novel, TCE-reducing, sediment-free, stable consortium enriched from estuarine sediments. We have maintained DehaloR^2 for over a year with fast reductive dechlorination rates. This culture contains, besides dechlorinators, a high proportion of *Acetobacterium.* The loss of reducing equivalents to methanogenesis and acetogenesis in this culture depends again on the use of fermentable substrates serving as electron donors and carbon sources. Complete dechlorination to ethene in cultures amended with lactate + methanol is not affected by adding different concentrations of Vitamin B12 a required cofactor sometime provided to dechlorinators by acetogens. On the other hand, cultures amended with acetate + H_2 dechlorinate at slower rates, are more affected in a positive way by the addition of Vitamin B12, and show substantial methane production. Electron-flow analysis of lactate and methanol-amended DehaloR^2 indicated that production of volatile fatty acids (VFAs) accounted for ~80% of the electron consumption, biomass for ~19%, and only 1% channeled to reductive dechlorination. Clone libraries revealed that *Dehalococcoides* and *Geobacter* are the main dechlorinators, and *Acetobacterium* are the main identified acetogens in the culture. Using qPCR, we monitored the dominant microbial groups during conversion of TCE to ethene. We tracked growth of *Acetobacterium*, with the acetogen specific formyltetrahydrofolate synthetase (FTHFS) gene, whose copy numbers increased until the VFAs stabilized. Due to its exceptionally fast reductive dechlorination rates, coupled with the presence of homoaceteogens and methanogens, DehaloR^2 is a great model to study microbial interactions which enhance or hinder dechlorination.

Acetogens act as efficient H_2 scavengers that channel the H_2 electrons to current or dechlorination through acetate, as long as they are not out-competed by methanogens. We are now investigating practical ways to stimulate the desired acetogens while suppressing methanogens in MXC anodes and dechlorinating systems.

MECHANISTIC AND APPLIED STUDIES OF MICROBIAL DEGRADATION OF 17β-ESTRADIOL

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Natural estrogens have been detected in wastewater treatment plant effluents and drinking water sources worldwide. 17β-estradiol (E2), a natural estrogen with high estrogenic potency, is reportedly capable of affecting the function of the endocrine system at low ng/L levels. Due to its potential adverse health effects, E2 was recently added to the U.S. EPA's drinking water contaminant candidate list 3 (CCL 3). There is a need to develop effective treatment processes to remove E2 and its common degradation products, such as estrone (E1), from drinking water. The goal of this study is to investigate the feasibility of removing these estrogens using a fixed-bed biologically active carbon (BAC) reactor and to investigate the molecular mechanisms governing microbial E2 degradation.
A lab-scale fixed-bed activated carbon reactor was constructed with a total volume of ~700 cm^3. The reactor consisted of 240 cm^3 intact Calgon F400 granular activated carbon (GAC), and was fed with synthetic drinking water containing 20 µg/L E2. In the first 178 days of operation, with no external carbon sources in the influent the reactor was able to bring down effluent E2 concentration to 200 ng/L. On Day 178, 3 mg/L NH_4^+-N was added to the reactor influent to stimulate the growth of ammonia oxidizing bacteria, which were reported to remove estrogens in wastewater treatment. Upon ammonium addition, after a transient accumulation of E1, the BAC reactor was able to lower both effluent E1 and E2 concentrations to below their detection limits (Figure 1). To better simulate of the composition of a typical surface water, ammonium was replaced by nitrate and acetic acid was added to the synthetic influent on Day 240. With acetic acid and nitrate as the respective carbon and nitrogen sources, the BAC reactor was able to completely remove E2, while a detectable amount of E1 remained in the effluent. Overall, the microbial activities involved in the BAC operation provided an effective barrier against E2 in drinking water treatment. To better understand the microbial community dynamics in the BAC reactor under various operating conditions, we are currently constructing 16S rRNA gene-targeted clone libraries using the 454 pyrosequencing technique.

To investigate the molecular mechanisms governing microbial estrogen degradation, a shotgun proteomics approach was developed to identify key metabolism responses of *Stenotrophomonas maltophilia*, an estrogen degrading bacterial species isolated from activated sludge, during E2 degradation. The quantitative proteomic study was carried out on a 2-D LC-MS/MS followed by database analyses using *S. maltophilia* R551 genome in the MASCOT software. Results showed that after 4-hr E2 degradation, a number of anabolism and catabolism pathways in *S. maltophilia* were highly impacted (Table 1). Moreover, homologs of five enzymes responsible for testosterone degradation in *Comamonas testosteroni* TA441 was also identified with three of them up-regulated by >2 folds (Table 2). Our results revealed the effects of E2 treatment on *S. maltophilia* metabolisms and suggested an overlap between the microbial degradation pathways between testosterone and estradiol. Currently, a kinetic experiment is being conducted to reveal protein expression profiles of *S. maltophilia* at different E2 biodegradation stages.

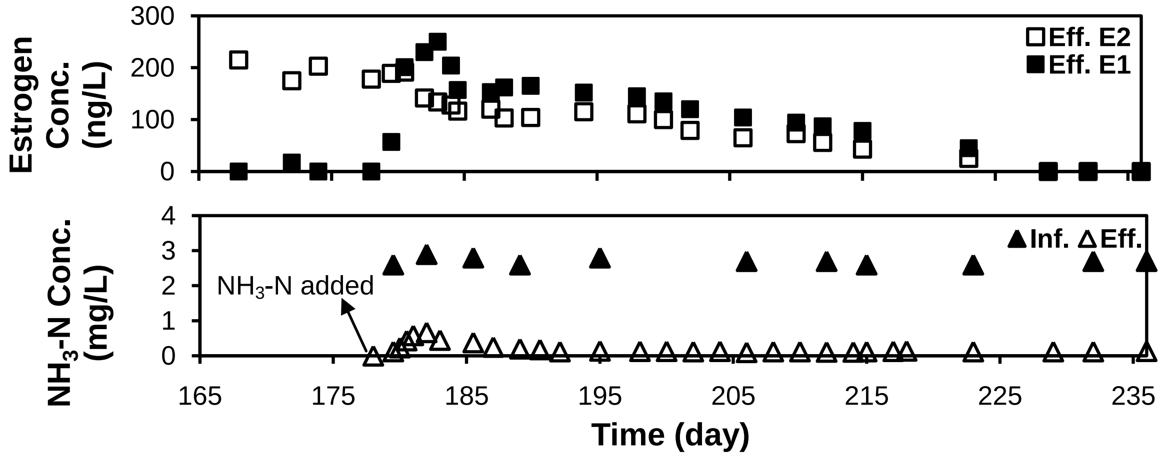

Figure 1. Improved E2 and E1 removal of the BAC reactor upon NH_4^+ addition.

Table 1. Differential expression of proteins related to ammonia assimilation, fatty acid synthesis, glycolysis, and citric acid cycle in *S. maltophilia* after a 4-hr E2 treatment.

Protein name	GeneBank accession No.	Fold change after E2 treatment	Protein description
NAD-glutamate dehydrogenase	gi|194349182	4.1	Ammonia assimilation
Glutamine synthetase, type I	gi|194346691	1.2	
Glutamate-putrescine ligase	gi|194347922	1.6	
Acetyl-CoA carboxylase, carboxyl transferase, beta subunit	gi|194349417	5.0	Fatty acid synthesis
3-oxoacyl-(acyl-carrier-protein) reductase	gi|194347454	60.0	
Phosphoenolpyruvate carboxylase	gi|194347210	0.3	
Phosphoglycerate kinase	gi|194349792	4.4	Glycolysis
Phosphopyruvate hydratase	gi|194348034	6.4	
Phosphofructokinase	gi|194349879	0.1	
Citrate synthase	gi|194349829	0.5	Citric acid cycle
Aconitate hydratase 2	gi|194348420	0.4	
Succinyl-CoA synthetase, alpha subunit	gi|194349739	4.6	
Succinyl-CoA synthetase, beta subunit	gi|194349740	1.6	

Table 2. Protein homologs of testosterone degrading enzymes in *S. maltophilia* after a 4-hr E2 degradation.

No. of predicted homolog	Testosterone degrading gene	GeneBank accession No.	Fold change after E2 exposure
1	*TesA*	gi|29603466	4
2	*TesB* (Meta-cleavage enzyme)	gi|10566463	0.7
3	*TesF*	gi|29603469	7
4	*TesG*	gi|29603470	2
5	*TesH* (3-ketosteroid-delta1-dehydrogenase)	gi|33562983	4

INFLUENCE OF SOLUTION CHEMISTRY ON HORIZONTAL GENE TRANSFER OF ADSORBED DNA INTO *AZOTOBACTER VINELANDII*

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Horizontal gene transfer affects both the capabilities of microbial communities and their rates of adaptation to new conditions. From an engineering perspective, in the soil environment, horizontal gene transfer is important for the dissemination of pathogenicity and antimicrobial resistance and for the development and dissemination of biological pathways for degradation of anthropogenic chemicals. We focus here on one mechanism of horizontal gene transfer, natural transformation, which involves extracellular DNA.

In the soil, DNA is released by dead cells or actively excreted by living organisms *(1)*. Extracellular DNA adsorbs to many common soil constituents, including sand, clay, and natural organic matter (NOM) *(2, 3)*, and once adsorbed may persist for days to years *(3)*. The adsorbed DNA provides a reservoir of genetic potential, and this reservoir can be accessed through the process of natural transformation, in which DNA is taken up, maintained, expressed and amplified in a new host microorganism and its offspring. Environmental factors that regulate DNA adsorption and natural transformation in the soil need to be identified and their effects characterized.

The work we are presenting here employed interdisciplinary techniques to monitor the transport and fate of extracellular DNA in model soil environments. The adsorption of extracellular DNA onto silica or natural organic matter-coated silica bead surfaces under different solution chemistry was monitored by quartz crystal microbalance with dissipation (QCM-D). The QCM-D data suggest that DNA adsorbed to silica surfaces has a more compact and rigid conformation in Ca^{2+} solutions than in Na^{+} solution, and that the reverse is true when DNA is adsorbed to NOM surfaces. While the amount of DNA adsorbed on a silica surface was similar for Ca^{2+} and Na^{+} solutions, the amount of DNA adsorbed on NOM-coated surface was higher in Ca^{2+} solution than in Na^{+} solution *(4)*.

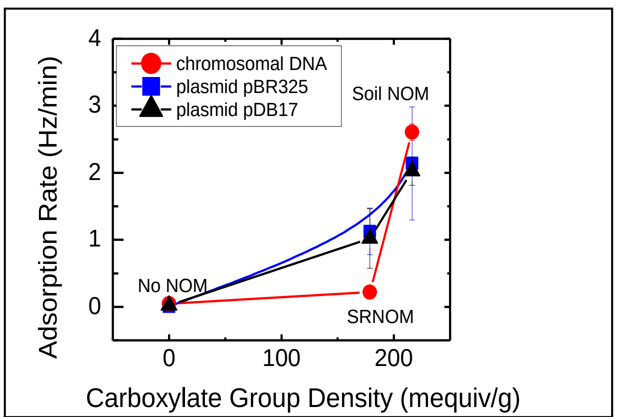

Figure 1 Adsorption rate (Hz/min) of dissolved NOM onto adsorbed DNA layer vs. NOM carboxyl group density at pH 7.2.

Since NOM is ubiquitous in the soil environment, the effects of dissolved soil or aquatic NOM were also tested. Our model soil NOM has higher carboxylate group density than the aquatic Suwannee River NOM (SRNOM). Silica beads with adsorbed DNA became more negatively charged after additional adsorption of dissolved NOM. For adsorption studies of NOM on DNA in solutions containing either 1 mM Ca^{2+} or Mg^{2+}, we observed a positive correlation between the adsorption rates of dissolved NOM on adsorbed DNA and the carboxylate group density of the NOM (Figure 1). Increased total organic concentration (TOC) of the NOM solutions also led to an increase in the adsorption rates of NOM on DNA. The correlation between NOM adsorption rates and carboxylate group density on DNA layers can be explained by divalent cation complexation with NOM carboxylate groups and DNA phosphate backbones. This hypothesis is currently being tested using Fourier transformation infrared spectroscopy (FTIR).

The availability of adsorbed DNA to transform microorganisms was assessed under different chemical conditions though natural transformation assays using the soil bacterium *Azotobacter vinelandii*. Our results show adsorbed DNA is transformed at a similar frequency to dissolved DNA (Figure 2). The conditions we tested, including salt composition and dissolved NOM, did not strongly influence the natural transformation of *A. vinelandii*. Transformation frequencies for dissolved DNA and DNA adsorbed to silica and to NOM were 6×10^{-5}, 5×10^{-5}, and 2.5×10^{-4}, respectively. An effect of salt composition was observed for NOM coated surfaces; transformation frequencies from individual experiments were 2-50 fold higher in the presence of Ca^{2+} than in the presence of Na^{+}. This was not due to the amount of DNA, which was controlled in these experiments, but could be due to the higher density of adsorbed DNA on NOM-coated surfaces in the presence of Ca^{2+}. The presence of dissolved NOM did not strongly influence transformation of dissolved or adsorbed chromosomal DNA or of dissolved plasmid DNA (Figure 2).

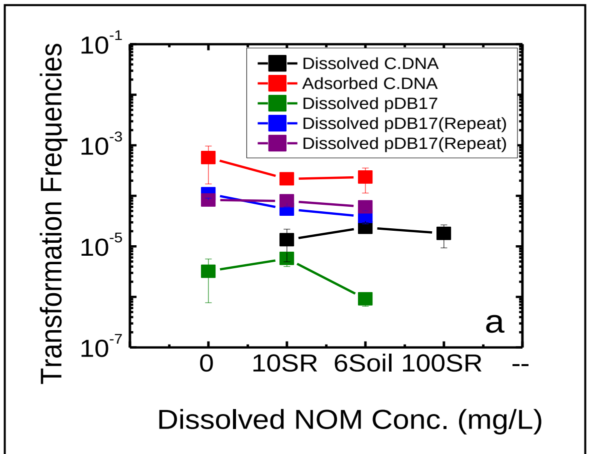

Figure 2 Natural transformation frequencies of *A. vinelandii* with chromosomal or plasmid DNA in the presence of dissolved SRNOM or soil NOM.

These results suggest that adsorbed DNA in the soil is available for natural transformation, regardless of salt composition or dissolved NOM in environmentally relevant conditions. These conditions are therefore not considered critical elements in modeling the transformation of DNA into bacteria in the soil environment. Biological properties influencing natural transformation, such as competence development and cell motility, should be assessed. Extracellular DNA could influence the composition and the capabilities of the soil microbial community through natural transformation.

Reference

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NOVEL MEMBRANE DESIGN FOR FORWARD OSMOSIS: ENABLING A SUSTAINABLE WATER TREATMENT ALTERNATIVE

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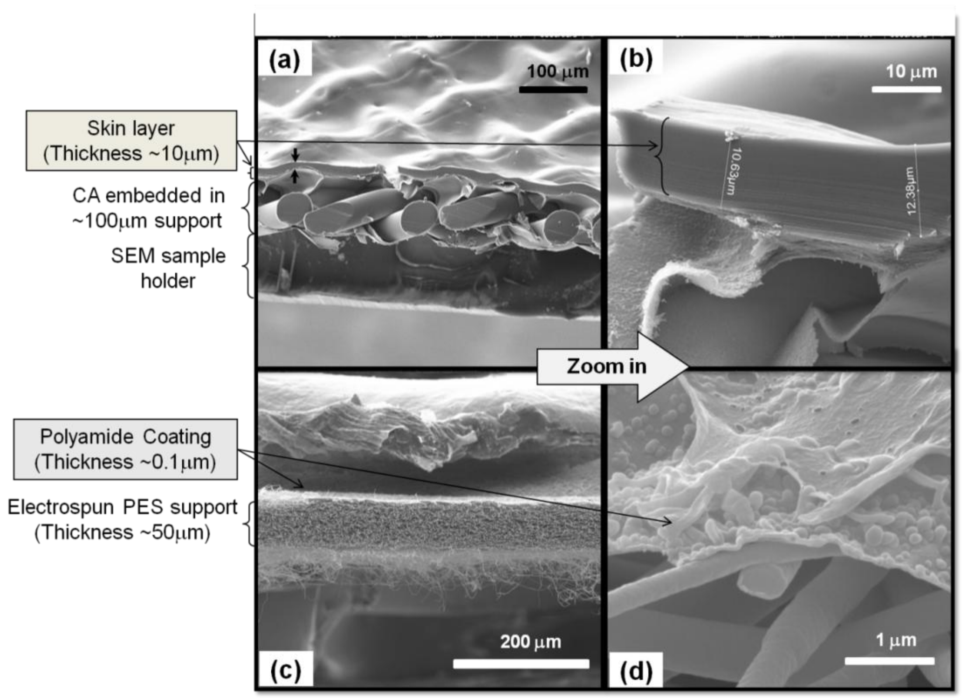
Freshwater resources are critical to public health and economic prosperity. Modernization and international development are placing new levels of pressure on world water resources, while climate change alters the distribution of water resources in unpredictable ways. Supplying water to new markets and billions of additional people will necessitate tapping unconventional and impaired water sources, including wastewater, brackish groundwater, and seawater. Distillation and advanced membrane technologies (i.e. reverse osmosis, RO) currently available for impaired source treatment require significant quantities of high value energy (electricity and/or high quality steam) produced from carbon emitting technologies. Ironically, these conventional power sources (ie. coal, oil, and natural gas) emit greenhouse gases that further exacerbate the aridity that desalination is intended to alleviate. In addition, membrane-based water treatment processes generate an environmentally harmful brine waste stream that effectively limits its use to coastal regions where discharge to the ocean is an option. Both energy use and brine management constitute a substantial portion of the *total water cost* of desalinated water. Economically viable desalination alternatives that are carbon neutral and ecosystem compatible are critical for realizing large scale water production without dramatically increasing the cost of potable water

Forward osmosis is emerging as a sustainable desalination alternative to RO and distillation. FO relies on an *osmotically-driven* water flux across a semi-permeable salt rejecting membrane. This osmotic driving force is generated by an osmotic agent, referred to as a draw solution, which consists of a thermolytic salt which can be *removed and reused* using only low-grade thermal energy. Our previous efforts identified the combination of ammonia and carbon dioxide gases in water (NH_3-CO_2) to have a competitive advantage over other draw solutes due to its capability of generating large osmotic pressures (up to 3000 psi) and easy removal and recycling using only low grade heat (as low as 40 ˚C). These efforts also concluded, however, that polymeric membranes designed for RO perform poorly in FO processes. These *thin film composite* (TFC) membranes consist of a thin selective layer and a series of porous support layers which provide mechanical integrity to the fragile selective film during handling and high pressure operation. During osmosis, these layers contribute to severe mass transfer resistance, referred to as internal concentration polarization, which results in poor water flux performance. The viability of FO hinges upon the development of FO-specific membranes with reduced resistance, increased water flux and superior selectivity.

Our work at the University of Connecticut is a two pronged effort to produce a next generation membrane specifically tailored for operation in forward osmosis. Both of these efforts involve modification or restructuring of a TFC membrane *support layer.* The first project involves the use of commercial TFC RO membranes. Previous investigations have identified that the hydrophobic nature of the support layer in these membranes prevents wetting and thus dramatically reduces osmotic flow. Our lab has employed a novel bioinspired polymer, polydopamine, to modify two TFC membrane *support layers* to increase their hydrophilicity. This resulted in increased hydrophilicity and a corresponding increase in 'wetted porosity' and reduced internal concentration polarization. The modified membranes were then characterized for contact angle, salt rejection, hydraulic permeance, salt flux, and osmotic flux. The results were promising, indicating that the modified reverse osmosis membranes exhibited an **eight to twelve fold increase in flux** performance under test conditions when compared to an unmodified membrane. This modification method, which is scaleable, has the potential to enable the use of existing thin film composite membranes for forward osmosis and thus capitalize on thirty years of membrane development which have produced desalting membranes of superior permselectivity.

However, even with the enhanced performance of these existing desalination membranes through enhanced chemistry, there will be a limit of performance improvement without also addressing the structure, specifically porosity and tortuosity. Therefore, our lab has also designed and fabricated a radically new TFC membrane structure consisting of electrospun nanofibers used as a novel support. These nanofiber fabrics, spun from polysulfone and polyethersulfone, have exceptional porosity and minimal tortuosity, dramatically improving mass transport in support layer. A polyamide layer is formed on the nanofibers *in-situ* from reacting m-phenylenediamine (MPD) monomer and 1,3,5-benzenetricarbonyl trichloride (TMC). Tests in a direct osmosis system yielded exciting results, **with fluxes near 90 liters/m^2.hr (the highest flux reported for FO at the time of this writing)**. The figure below shows scanning electron micrograph images of our new membrane (bottom) along with the only commercial forward osmosis membrane (CA from Hydration Technologies Innovations). These images show the significant differences in membrane structure of our membranes, which exhibit exceptional porosity (as high as 80% in the support layer) and low tortuosity relative to this commercial membrane.

In all, these investigations have yielded very promising results. These unique approaches to membrane modification and fabrication will continue to develop and result in a next generation forward osmosis membrane. These efforts, in combination with efforts from a growing number of academic and industrial groups, will help enable forward osmosis as an emerging membrane desalination and wastewater treatment technology.



EMERGING CONTAMINANTS AS UNCOUPLERS IN ANAEROBIC DIGESTION: THE POSSIBLE AUGMENTATION AND DISRUPTION OF METHANOGENESIS BY NONYLPHENOL AND TRICLOSAN

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Anaerobic digestion is a critical wastewater residuals stabilization process that has been used worldwide for over a century. This process relies upon the syntrophic relationship between fermenting bacteria and methanogens. While the process is beneficial, producing biogas, it is susceptible to foaming and upsets that can be costly. Emerging contaminants pose a potential threat to digesters, as their concentrations can be quite high in biosolids and several of these contaminants have biological impacts. Indeed, it has been estimated that over 250 tons of emerging contaminants are discharged to soils with biosolids every year. Two commonly detected contaminants in digester biosolids are nonylphenol and triclosan; nonlyphenol is present at levels over 100 mg/kg (~10 uM) in digested biosolids while triclosan is present at concentrations over 10 mg/kg (~1 µM). Nonylphenol and triclosan are of special interest because of their potential role as uncouplers in microorganisms.

Uncouplers have the ability to dissipate the proton motive force, resulting in higher rates of metabolism that generate less energy to fuel biosynthesis and growth. What results is excess “waste product” formation with less biomass generation. It is likely that those microorganisms that make a marginal living, obtaining little ATP per mole of substrate degraded, could die if exposed to chemical uncouplers. Microorganisms that are likely to fall into this category include methanogens, which serve as the base of the anaerobic food web in digesters. Uncoupling of this sort may result in more methane production and seemingly better digester performance; nevertheless, it could also leave the community simpler, less-resilient, and more susceptible to upset in the face of secondary perturbations (such as temperature, pH, and nutrient fluctuations). The objectives of this research are to determine i) if nonylphenol and triclosan act as uncouplers of methanogens at environmentally-relevant levels and ii) if these compounds make anaerobic digesters less resilient to secondary perturbations, and thus more susceptible to system failures.

Experiments include both pure culture and mixed culture work. Pure cultures of *Methanosarcina barkeri* and *Methanosarcina thermophila* are being cultivated to test the impacts of triclosan and nonylphenol on cell growth and respiration; 2,4-dinitrophenol will be used as a positive control. These experiments are important for understanding the direct role that these compounds have on methanogens – a key microbial group for successful anaerobic digestion. Completion of pure culture work is anticipated by March, 2011.

Three 4-L anaerobic digesters are being operated in parallel to determine the long-term impacts of nonylphenol and triclosan on digester operation. One reactor will be spiked with nonylphenol (100 µM), one with triclosan (10 µM), and one will serve as a control. The reactors have an HRT of 30 days and are kept in a 35°C room. Total solids, volatile solids, pH, volatile fatty acids, total gas production and methane production are continuously monitored. The effect of nonylphenol and triclosan addition will be assessed by changes in methane production.

The three lab-scale anaerobic digesters are also seed reactors for several serum bottle experiments in which communities will be perturbed (e.g. change in temp, pH) and functional resilience will be quantified. Preliminary results (Figure 1) indicate that nonylphenol does act as an uncoupler at 5 µM. However, the impact on resiliency is yet to be determined. These experiments should be completed by June, 2011.

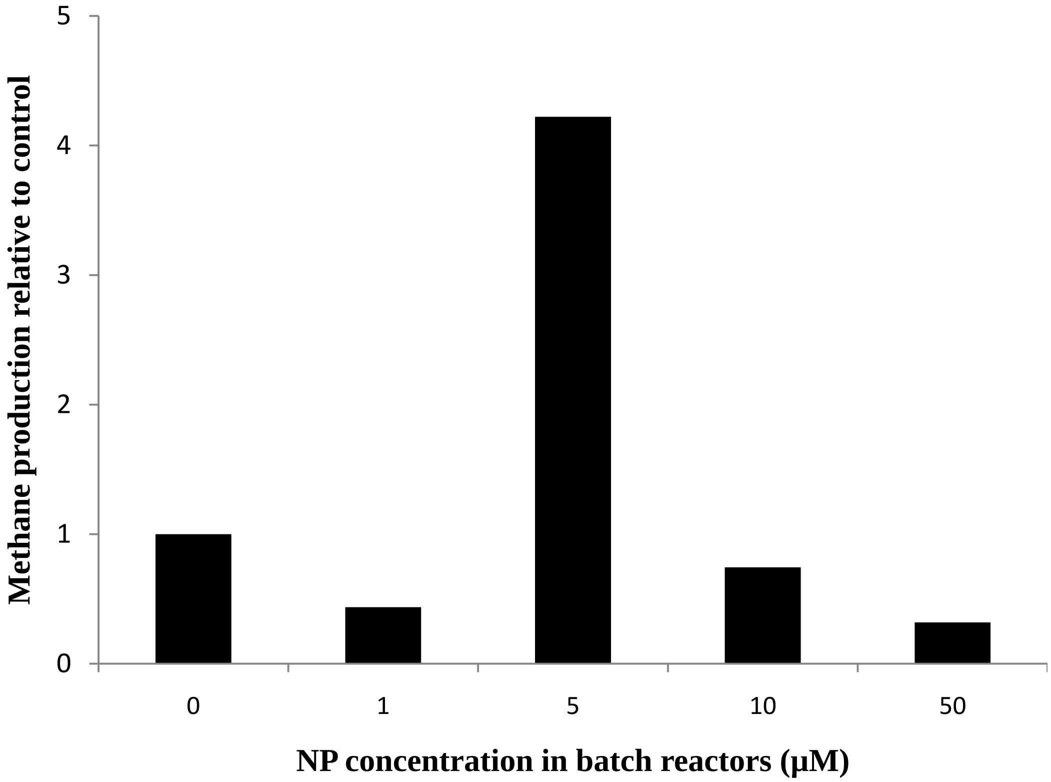

Figure 1: The impact of nonylphenol on methane production in anaerobic digester sludge.

BACTERIAL TRANSPORT IN MICROFLUDIC DEVICES: STUDY OF ENHANCED CONTAMINANT MIXING AND CHEMOTAXIS

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Understanding bacterial transport through subsurface porous media is critical both for characterizing contamination of drinking-water bodies and designing successful bioremediation strategies for contaminated sites. There has been much effort devoted to studying bacterial and colloidal transport in porous media; recently, flow cells and micro-models have been used to visualize colloidal transport in porous media to simulate bacterial transport. However, additional factors such as bacterial random motility and chemotaxis (directed migration toward a contaminant source) affect both contaminant mixing and overall bacterial transport, and need to be quantified and considered carefully in order to predict bacterial transport accurately. This study quantifies (1) enhanced contaminant mixing due to bacterial motility, and (2) the role of chemotaxis in bacterial transport through a two-dimensional micromodel with a contaminant source.

A novel bi-layer polydimethylsiloxane (PDMS) microfluidic device was fabricated using photolithography and soft lithography techniques to simulate contamination of groundwater due to leakage from an underground storage tank. This device consists of a porous channel through which a bacterial suspension is flown and another channel for injecting contaminant into the porous channel. The device facilitates visualization of both bacteria and a chemical tracer flowing through porous media and is therefore useful in determining their mutual spatial distribution in porous media.

Contaminant Mixing:
Enhanced contaminant mixing due to the presence of motile bacteria was assessed by comparing the transverse dispersion coefficient (D_{cy}) of a non-reactive conservative tracer (Dextran solution labeled with fluorescein isothiocyanate, FITC) in porous media in the presence of motile *Escherichia coli* HCB33 (wild type) bacteria, immobilized bacteria, and with no bacteria. A contaminant plume was established along the centerline of the microfluidic device while bacterial suspensions ran through the micromodel, as seen in Figure 1. Experiments

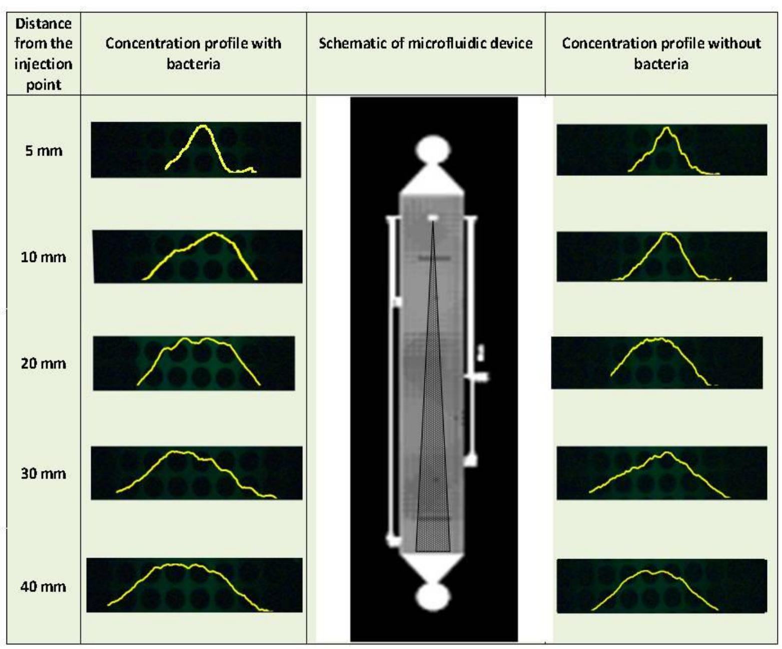

Figure 1: Contaminant plume formation in the micro-fluidic device with (left side) and without (right side) bacteria.

were run at three different velocities and fluorescent images of contaminant concentration profiles were obtained at various cross-sections along the microfluidic device. Experimental data were fitted to an analytical solution to the advection-dispersion equation to determine the transverse dispersion coefficient values for the contaminant in the presence of motile bacteria, non-motile bacteria, and no bacteria. Results for contaminant dispersion values are shown in Figure 2, and correspond to apparent dispersivity values of 0.0075, 0.0046, and 0.0037 for the porous medium with motile bacteria, non-motile bacteria and no bacteria, respectively. The presence of motile *E. coli* significantly increases the effective transverse dispersion of a contaminant.

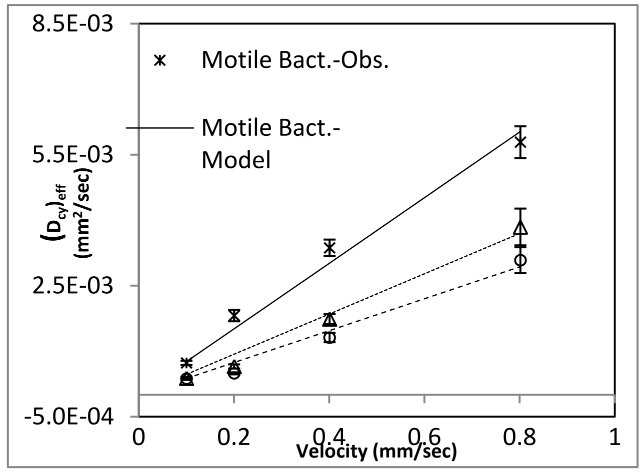

Figure 2: Best-fit dispersion coefficients for contaminant mixing with motile bacteria, non-motile bacteria and no bacteria at three flow

Chemotaxis Studies:

The chemotactic response of *E. coli* HCB33 (wild type) toward L-aspartic acid was also observed by imaging bacterial and contaminant flow at three different cross-sections downstream of an injection point in which bacteria and attractant are injected into opposite sides of the micromodel. Temporal changes in bacterial count profiles at three selected locations were quantified.

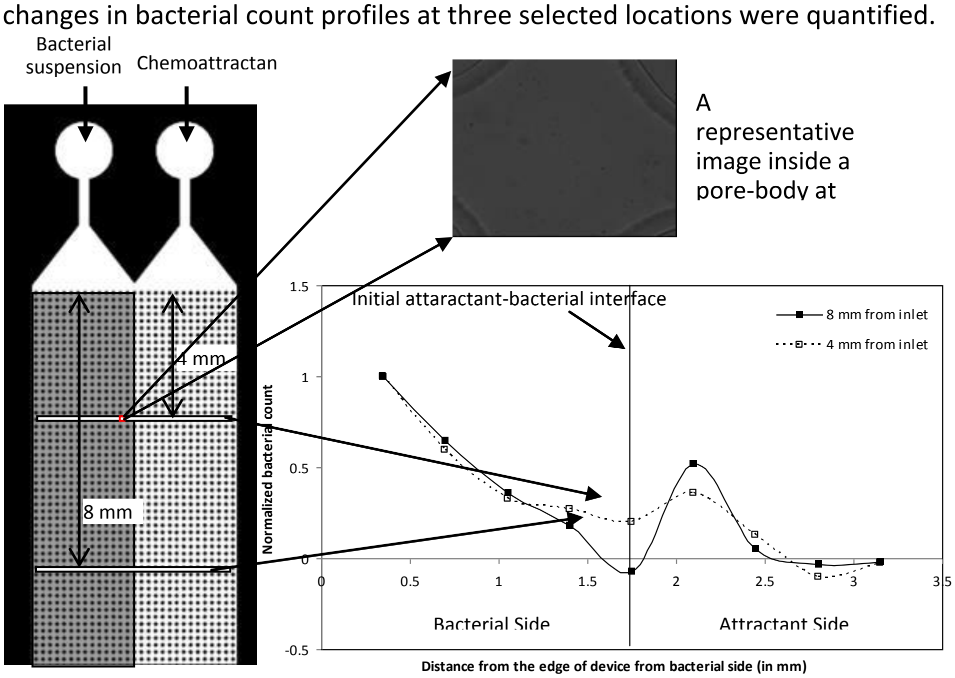

Figure 3: Chemotactic bacterial concentration profiles in a microfludic device in which a chemotactic bacterial count peak is observed in the plot on the attractant side (right) with a corresponding decrease in the bacterial count in the bacterial side (left) of the plot. Inset image shows a representative image taken in the pore body.

Experimental results from this work, as well as educational demonstrations developed with the micromodel system will be presented.

BACTERIAL INFILTRATION AND SURVIVAL IN DRINKING WATER DISTRIBUTION SYSTEMS

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Drinking water treatment plants rely on multiple approaches to minimize microbial survival, growth, and re-growth in distribution systems. These approaches include limiting the availability of substrates and nutrients necessary for microbial growth and disinfection to kill microorganisms and to inhibit re-growth. So far, few studies have used culture independent methods to catalog the phylogenetic diversity of bacterial populations in drinking water distribution systems (DWDS) (Hoeffel et al 2005, Hong et al 2010, Noguera et al 2009, Revetta et al 2010). Although these studies provide information on which microbial populations are present in DWDS, there is little information on the effect of seasonal variability and treatment processes on microbial seeding of and re-growth in DWDS. To address this, we have conducted a year-long sampling campaign of a local drinking water treatment plant (DWTP) and distribution system.

Samples were collected from the Ann Arbor DWTP and DWDS (Ann Arbor, MI, USA). The plant uses a combination of surface and ground water, with total monthly surface water:ground water flow ratios varying between 2 (January) to 8 (August). Softening, coagulation-sedimentation, ozonation, granular activated carbon (GAC) filtration, and chloramine disinfection are used to treat the source waters. Samples at the DWTP were collected from source waters, pre- and post-filtration, GAC filter bed, disinfection tank, and final reservoir. In addition, samples were obtained from 13 different monitoring points along the DWDS. All samples were analyzed for multiple water quality parameters. Water samples were filtered through 0.2 µm polycarbonate filters to collect biomass, which was used for DNA extraction. Microbial dynamics were evaluated targeting the 16S rRNA gene using a combination of DNA sequencing approaches (using both traditional Sanger sequencing and 454-based pyrosequencing). Data were also collected on the water use patterns/water age in the vicinity of the DWDS sampling points and the frequency of water main breaks to identify potential infiltration events.

Principal component analyses indicated that the treatment processes have a significant impact on water quality with distinct clustering of samples collected at different points in the DWTP and DWDS (Figure 1). Despite the independent clustering, samples collected from the DWDS exhibited variability, suggesting the possible effect of water age and use patterns on water quality. Such differences in water quality within the DWDS could be the result of biological activity and/or microbial proliferation. Trends implicating biological activity in DWDS include, among others, accumulation of nitrite, increase in turbidity, and drop in chloramine residual. 16S rRNA gene based clone library data suggest the possibility that the DWDS is seeded with bacteria that are sloughed off from the GAC filter and survive chloramine disinfection. Clone library data indicate that approximately 30% of the 16S rRNA gene sequences retrieved from the DWDS were at least 97% identical to sequences obtained from the GAC filters operated in the DWTP. Most of these sequences obtained for the DWDS and GAC filter were also identical at the 99% cut-off level (Figure 3). These data suggest that, despite chloramine doses as high as 5 mg Cl2/l at the end of the treatment process, a phylogenetically diverse group of bacteria survive disinfection and make up a significant fraction of the bacterial community in the DWDS. In addition, phylogenetic analyses indicated that the DWDS samples exhibited a high diversity of sequences that were not detected in either the GAC filter or the source water. The presence of unique sequences may be due to infiltration events from the environment surrounding the DWDS. The year-long sampling campaign will reveal the potential for season-dependent seeding of different phylogenetic groups of bacteria from the DWTP, the source water, or the surrounding environment into the DWDS.

Due to the limitations of the clone library approach, it is possible that low-abundance sequences were not detected. Therefore, we are using 454-based pyrosequencing to obtain a much better coverage of microbial populations in these samples. Samples are being processed for massively parallel sequencing targeting the V3-V5 region of the 16S rRNA gene of bacteria. These results will (1) identify the bacterial populations that survive disinfection (2) help elucidate seeding mechanisms of the DWDS, and (3) determine the effects of source water use patterns on the microbiota inhabiting the DWDS.

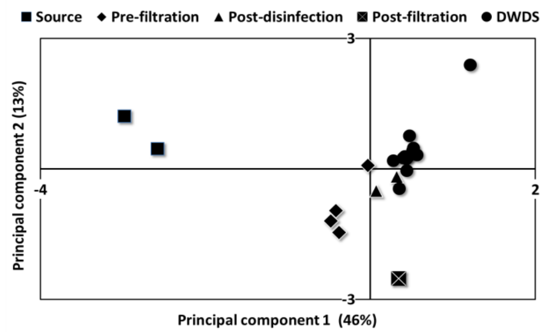

Figure 1: Principal component analyses of water quality data using the physico-chemical parameters listed in Table 1.

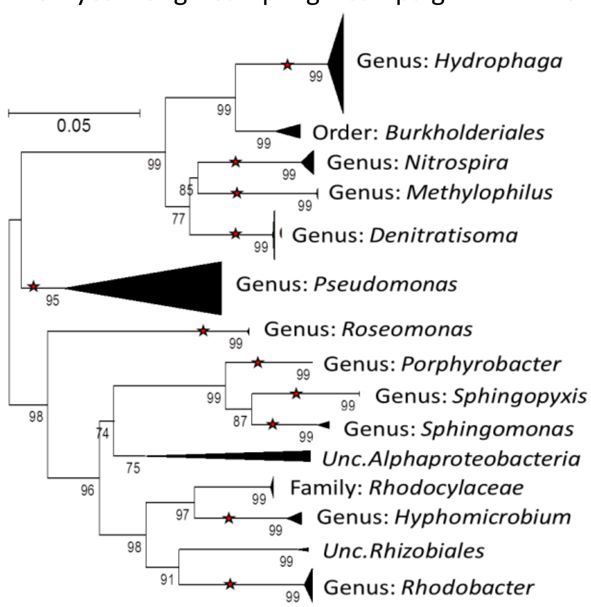

Figure 3: Phylogenetic tree of 16S rRNA gene sequences shared between the GAC filter and distribution system samples at 97% identity cut-off. Red stars indicate sequences with greater than 99% identity between GAC filter and distribution system samples.

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TOWARD SUSTAINABLE WATER: MINIMIZING ENERGY DEMANDS ASSOCIATED WITH MEMBRANE REMOVAL OF MICROCONSTITUENT ANTIBIOTIC RESISTANCE GENES

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Antibiotic resistance genes (ARG) are considered emerging contaminants, as they are associated with a critical human health challenge, propagate independently of the host cell, and are becoming amplified in human-impacted environments. ARG are often carried in clusters on plasmids and other transmissible elements, rather than as single genes. As microorganisms in natural aquatic environments reach the end of their life cycles and lyse, their DNA is released onto the surrounding environment. Perhaps more importantly, several studies have shown that DNA is constantly being expelled from several bacterial strains, and that extracellular DNA (eDNA) is an important component of the extracellular polymeric substances that bind bacterial biofilms. Therefore, eDNA can comprise a significant fraction of the total DNA found in the environment. The unique properties of ARG thus have important implications for water treatment, which may provide an ideal barrier against the dissemination of undesired genetic material.

The overall goal of this project is to explore the potential of membrane removal of ARG in wastewater treatment plant effluent, considerate of cost and energy requirements. Of particular interest is the potential effect of wastewater colloids on membrane removal of ARG, as it has been previously shown that eDNA from various sources adsorbs to various colloidal particles. Although a few studies have been carried out concerning the behavior and fate of eDNA in highly simplified systems, there exists a significant knowledge gap in the behavior of eDNA in natural systems. Such fundamental understanding is critical in optimizing the potential for ARG to be removed from wastewater treatment plant effluent.
This study explores the effect of membrane filtration on the removal of colloid-associated ARG from three wastewater treatment plant effluents. Membranes ranging from 1.2 um pore size to 1 kDa molecular weight cutoff (MWCO) (1.2 µm-pore size, 0.45 µm-pore size, 0.1 µm-pore size, 100 kDa-MWCO, 10 kDa-MWCO, and 1 kDa-MWCO) are being tested for removal efficiencies of plasmid DNA carrying two commonly found ARG: the vancomycin resistance *vanA* gene and the beta-lactam resistance bla_{TEM} gene. Quantitative polymerase chain reaction (qPCR) analysis is being used to track the quantities of these genes after each filtration step. In addition, qPCR of 16S genes serves to estimate the persistence of preexisting genomic DNA after each filtration step. The DNA quantification values will be supported by spectrophotometric analysis.

Several approaches are being employed to describe the colloidal composition of the treated wastewater effluent, including measurements of total organic carbon, protein and polysaccharide concentrations after each filtration step, in addition to scanning electron microscopy and atomic force microscopy for particle visualization and size distribution estimations. Furthermore, the rate of degradation of the plasmid DNA is tracked throughout the experiment in order to correct for background losses during experimentation.

Preliminary results demonstrate that there is partial plasmid degradation in the wastewater (Figure 1), but not in the control buffer (Data not shown); however, it was also found that the preexisting DNA present in the wastewater effluent is largely extracellular and resistant to enzymatic degradation. This supports previous findings suggesting that adsorbed DNA is more recalcitrant and persistent than its free counterpart, and suggests that the plasmid DNA is not readily adsorbed to the colloidal particles when spiked to the wastewater effluent, contrary to what has been shown in simplified systems. It was also found that eDNA is removed more efficiently when adsorbed to colloids, as revealed by the 16S rRNA gene quantities (Figure 2-left); than when present in a colloid free medium (Figure 2-right).

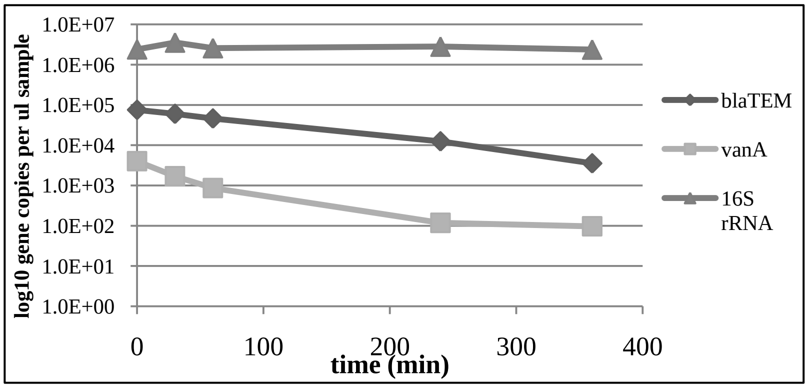
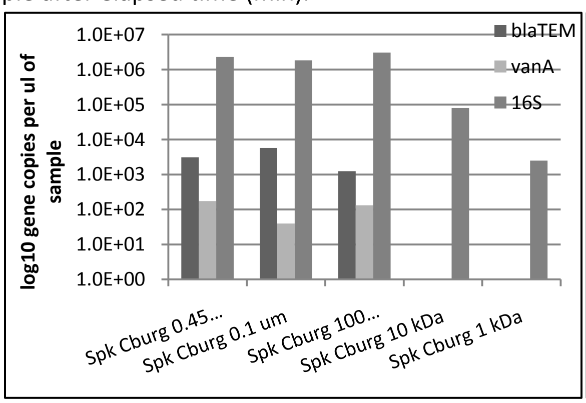


Figure 1. qPCR quantification of bla_{TEM}, *vanA*, and 16S rRNA genes present in DNA extracted from a wastewater sample after elapsed time (min).



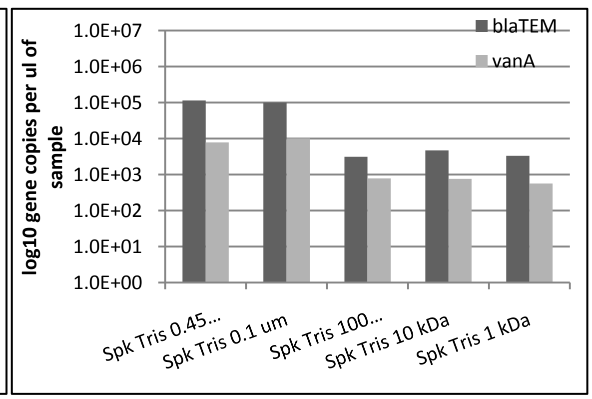


Figure 2. qPCR quantification of bla_{TEM}, *vanA*, and 16S rRNA genes present in DNA extracted from (left) plasmid-spiked Christiansburg WWTP effluent, and (right) plasmid-spiked tris(hydroxymethyl)aminomethane-HCl pH 8 buffer, after filtration through 0.45 um, 0.1 um, 100 kDa, 10 kDa, and 1 kDa membranes. 16S rRNA data for figure on right not available.

The results of this study will provide insight into the distribution of eDNA within wastewater effluents, as well as on the membrane requirements for different levels of ARG removal. Although preliminary and expected findings can provide a good baseline for the application of membrane filtration on the removal or ARG, an important aspect of the study will be to compare ARG removal in distinct wastewater effluents.

The use of membrane filtration as a polishing step in wastewater treatment is gaining momentum; and its use for the removal of ARG would not only help eliminate this microconstituent of increasing concern, but would also aid in the reduction of microbial concentrations in the water, including pathogenic bacteria and resistance gene carriers, prior to disinfection steps that could potentially select for antibiotic resistance. Other microconstituents such as pharmaceuticals and nanoparticles could also be removed either by direct membrane separation or by colloid interactions similar to that of ARG.

SIMULTANEOUS WATER DESALINATION, ENERGY PRODUCTION, AND WASTEWATER TREATMENT IN BIOELECTROCHEMICAL SYSTEMS

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Introduction

Water and energy are two critical issues facing the world. The social and economic development of society depends on a sustainable supply of both water and energy. Recently developed bioelectrochemical systems (BESs) represent one of the newest approaches for generating clean water and energy. BESs employ microorganisms to catalyze the oxidization of biodegradable materials in the anode chamber and deliver electrons to the anode. The electrons can be captured for direct energy generation, such as current or hydrogen gas production, or used to remediate groundwater contaminants. We recently developed an integrated BES system that can simultaneously desalinate salt water, produce H_2 or electricity, and treat wastewater (1). This system has significant advantages compared to traditional desalination processes, such as reverse osmosis (RO) or electrodialysis (ED), as it does not require intensive energy inputs or high water pressure.

Materials and Methods

The BES reactor was divided into three chambers by placing an anion exchange membrane (AEM) between the anode and middle desalination chamber and a cation exchange membrane (CEM) between the middle and cathode chamber (Fig. 1). The reactors were inoculated from a mixed culture by transferring the bacterial pre-acclimated anodes of active acetate-fed bioelectrochemical cells. The anodic medium contained acetate or wastewater and the cathode chamber was filled with 50 mM phosphate buffer solution. The middle chamber was filled with 10 g/L NaCl solution for desalination. The cathode chamber was designed for either electricity or H_2 production. To harvest direct current, the carbon cathode was open to air for oxygen reduction. To collect H_2, the cathode chamber was covered to block air diffusion and supplemented by a small voltage (0.6-0.8V) to boost H_2 evolution.

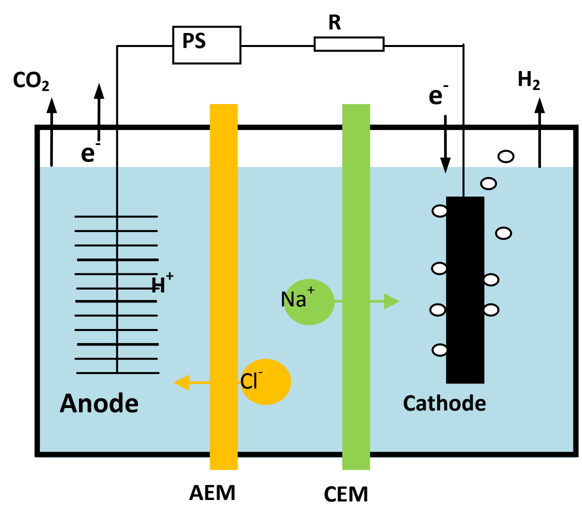

Fig. 1 Schematic diagram of the BES system for H_2 production, waste treatment, and

Results and Discussion

Desalination efficiency and hydrogen gas production were characterized in both fed-batch and continuous flow BESs. With an applied voltage of 0.8 V, the fed-batch reactor achieved a maximum H_2

production rate of 1.5 m^3/m^3 d (1.6 mL/h) and a maximum desalination rate of 0.42 mS/cm h. More than 98.8% of the 10 g/L NaCl was removed from the middle chamber within 4 batch cycles. The anode recirculation alleviated pH and high salinity inhibition on bacterial activity and further increased system current density from 87.2 to 140 A/m^3, leading to an improved desalination rate by 80% and H_2 production by 30% (Fig. 2). The energy efficiency obtained in the H_2 producing MECs varied in a range of 170 % - 181 %, suggesting that sufficient H_2 could be produced to power the system with extra energy output for additional uses. Compared to slight changes in desalination, H_2 production was more significantly affected by the applied voltage and cathode buffer capacity, suggesting cathode reactions were likely affected by the external power supply in addition to the anode microbial activity.

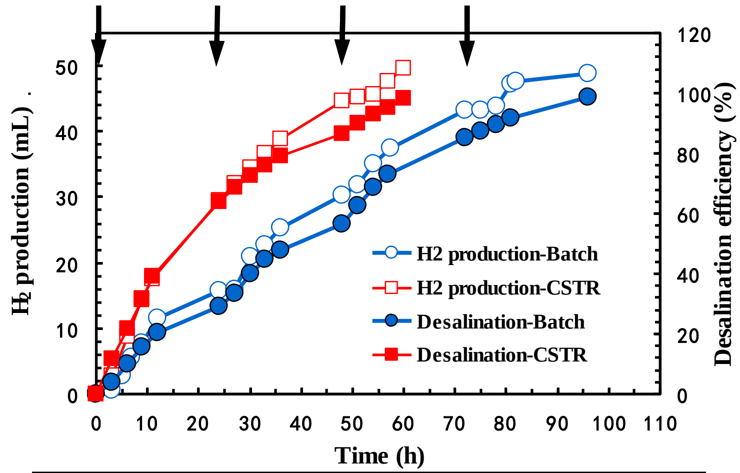

Fig. 2. Accumulated H_2 production and desalination efficiency in BES during batch and continuous operation with an applied voltage of 0.8 V. (Arrows indicate electrolytes replacement.) (1)

Wastewater has been used as substrates for energy production in BESs, but the low salinity and alkalinity in wastewater limited power output as compared to refined substrate with high buffer capacity. We characterized the benefits of integrating desalination to wastewater treatment in BESs and found the ion transferred from the saline water increased the wastewater conductivity from ~2 mS/cm to ~6 mS/cm and increased maximum power density by 168% (2).

The integration of desalination, energy production, and wastewater treatment in one reactor provides new applications for bioelectrochemical systems. But as a new multifunctional process, the BES research is facing many challenges that remain to be solved, such as pH variation in the anode and cathode chambers, increased ohmic resistance, and stack system development. In practice, the BES can be used as pretreatment of downstream RO processing to reduce energy consumption and membrane fouling, or being directly applied for direct beneficial uses such as agricultural irrigation or groundwater recharge, where higher salt limits are allowed (TDS 500-2000 mg/L).

References:

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ROLE OF NATURAL ORGANIC MATTER AND TEMPERATURE ON INACTIVATION KINETICS OF ROTAVIRUS AND MS2 BY SOLAR IRRADIATION

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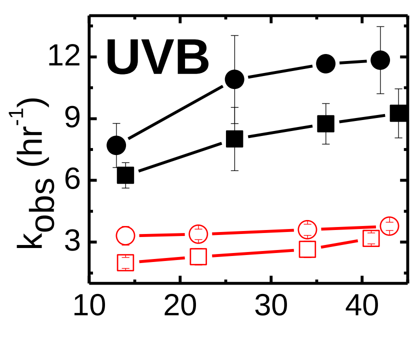
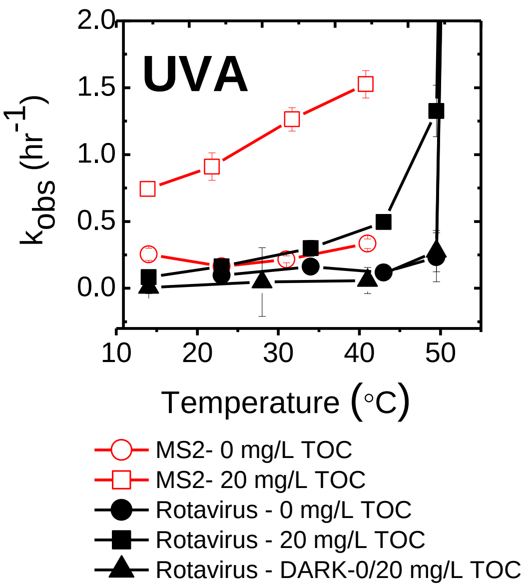
The waste stabilization ponds (WSP) method is a promising domestic wastewater treatment technology that relies solely on sunlight as the power input. The inexpensive energy requirements make the WSP technology suitable for places where construction, operation and maintenance costs exceed land costs. When properly designed, operated and maintained, WSP have been shown to provide high quality effluent able to meet the World Health Organization guidelines for safe use of wastewaters in agriculture, for example. Although WSP “natural” disinfection has been shown to achieve significant inactivation of pathogens, the disinfection mechanisms are not fully understood. The few mechanistic studies on pathogen disinfection in WSP consistently show that virus indicators display lower inactivation rates than bacteria indicators. Therefore, we need a better understanding of the sunlight disinfection mechanisms of viruses.

For sunlight disinfection of pathogens, three mechanisms have been identified: indirect (UVA-visible range) damage by exogenous sensitizers (i.e. SRNOM, methylene blue, etc.), indirect (UVB and UVA) damage by endogenous sensitizers (i.e. flavins, quinones, etc.), and finally direct UVB damage. Previous studies have shown that upon solar irradiation of the ubiquitous natural organic matter (NOM) in aqueous systems, reactive oxygen species (ROS) are produced. A recent study reported that of the ROS produced by the irradiation of NOM, singlet oxygen was the most significant MS2 virus disinfectant. Thus, inactivation of phage MS2 by the ubiquitous exogenous sensitizer NOM could serve as an important disinfection process of viruses in surface waters. Whether enteric viruses will be inactivated by sunlight following the same mechanism as for the MS2 bacteriophage is still to be determined.



This study elucidates the importance of each mechanism for the sunlight disinfection of rotavirus, an enteric virus, and MS2, a bacteriophage, in buffered water samples irradiated with a solar simulator. We also investigated the role of temperature and Suwannee River natural organic matter (SRNOM) for each disinfection mechanism and each type of virus. For MS2, the inactivation rates (hr^{-1}) for each mechanism are as follows for all temperatures considered (14-40°C for MS2, 14-60°C for rotavirus): direct UVB damage (0 mg/L TOC) > direct UVB damage + 20 mg/L TOC > indirect exogenous damage (UVA: 20 mg/L TOC) >

indirect endogenous damage (UVA: 0 mg/L TOC). For rotavirus, the inactivation rates (hr^{-1}) were: direct UVB damage (0 mg/L TOC) > direct UVB damage + 20 mg/L TOC > indirect exogenous damage > indirect endogenous damage for temperatures ~32-50°C. For temperatures below ~25°C, the indirect exogenous damage did not experimentally differ from the indirect endogenous damage for rotavirus. For temperatures > 50°C, rotavirus inactivation was primarily due to heat damage. Unlike MS2, the observed exogenous contribution for rotavirus at > ~32°C was not attributed to singlet oxygen. Quencher tests conducted at 42 and 50°C indicate that neither hydroxyl radicals nor hydrogen peroxide are responsible for rotavirus inactivation. Currently we are studying the effect of triplet state NOM as a potential damaging radical to rotavirus at high temperatures.



The experimental results presented here suggest that the direct UVB and indirect endogenous damages comparably affect MS2 and rotavirus. Inactivation rates by direct UVB and indirect endogenous are the higher and lower, respectively, for both viruses. However, the indirect exogenous damage over the temperature range considered differs for both virus models. The species responsible for the exogenous damage also differ for both viruses. Because inactivation of MS2 does not parallel the enteric viral disinfection, we conclude that it is crucial to investigate disinfection using enteric viruses.

The future work will focus on elucidating the rotavirus damaged site caused by both direct UVB and exogenous effects. TEM, gel electrophoresis, and other similar methods will be used.

DEVELOPMENT OF SUSTAINABLE CARBON NANOFIBER AND CARBON NANOTUBE SUPPORTED PD CATALYSTS FOR NITRITE REDUCTION

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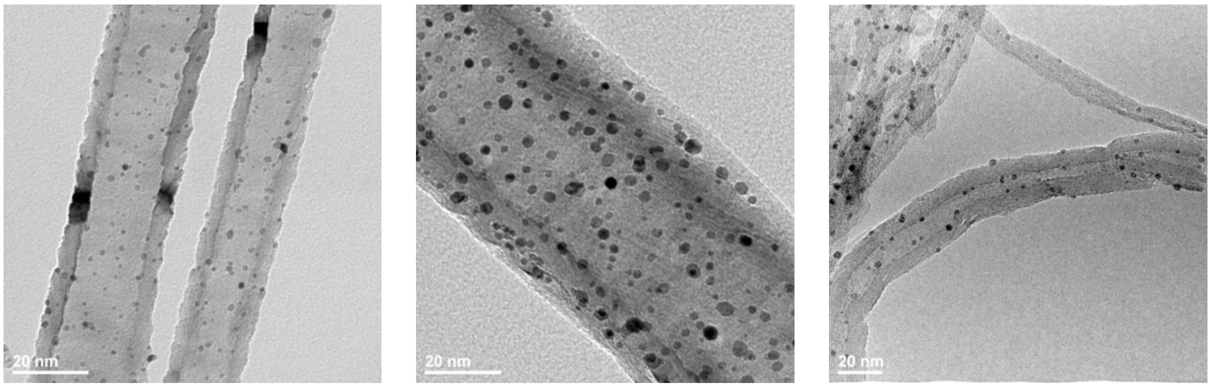
Nitrate is a wide-spread contaminant because of its extensive use in agriculture; nitrite is a reduction intermediate of nitrate in natural systems and *in vivo*. Both must be removed from drinking water to below regulatory threshold values due to their adverse health impacts. Pd-based catalytic reduction with hydrogen has emerged as a promising water treatment strategy for nitrate and nitrite compared to conventional technologies such as ion-exchange and biological denitrification. Nitrate reduction occurs on bimetallic Pd-M catalysts (M represents the promoter, e.g., Cu, In, Sn) to produce nitrite, and nitrite reduction proceeds on Pd-alone through a series of nitrogenous intermediates (e.g., NO, N_2O) to produce the end products N_2 and NH_3.

The economic advantage of catalytic reduction is still an open question. It depends on catalytic activity per unit mass of precious metal, and on catalyst longevity during fouling and oxidative regeneration. In addition, catalytic selectivity towards N_2 also determines the viability of this technology. The byproduct NH_3 needs to be minimized because of its toxicity. The objective of our research is to develop Pd-based catalysts with enhanced activity, selectivity, and fouling resistance for nitrate/nitrite removal from drinking water. Carbon nanofibers (CNFs) and carbon nanotubes (CNTs) are employed as catalyst supports because of their unique properties (i.e., high surface area with tunable functional groups, favorable electronic properties, interior versus exterior loading), and nitrite is selected as the probe contaminant because it is the key intermediate of nitrate reduction that determines selectivity for N_2 and NH_3.

The hollow structures of CNFs and CNTs allow Pd nanoclusters to be loaded on their interior and/or exterior surfaces. Selected CNF and CNT catalysts were characterized by transmission electron microscopy (TEM) as shown in Figure 1. Pd nanoclusters were loaded primarily inside CNFs, primarily outside CNFs, or proportionally inside and outside CNFs. For primary inside loading, acetone or an acetone/water mixture was used as the solvent, and its volume was precisely matched with the internal channel volume of CNFs. For primary outside loading, m-xylene was used to fill internal pores of CNFs, and Pd was loaded onto CNFs in an aqueous solution that was immiscible with m-xylene. For both inside and outside loading, CNFs were exposed to Pd in aqueous solution by the incipient wetness method. These distinct preparation methods gave Pd nanocluster interior loading percentages from 72.2±20.2% to 22.7±17.8%. We also post-heated one primarily inside loaded catalyst in N_2, and obtained Pd nanocluster diameters for all samples ranging from 1.44±0.69 nm to 9.57±3.45 nm.

Pd nanoclusters were loaded primarily inside CNTs using the same solvent approach for CNFs, but ultrasonication was necessary to promote Pd migration into the smaller internal diameter pores (3-5 nm in CNTs compared to 20-50 nm in CNFs). This method resulted in 41.0±13.1% of the Pd nanoclusters being loaded inside CNTs, with diameters of 2.08±0.50 nm.



(a) (b) (c)

Figure 1. TEM images of selected CNF (a, b) and CNT (c) supported Pd catalysts

We evaluated the activity and selectivity (i.e., N_2 over NH_3 production) for nitrite reduction by CNF supported Pd catalysts, and explored the effects of Pd nanocluster size, interior versus exterior loading, and catalyst aggregate size. Results show that nitrite reduction activity generally increases with decreasing Pd nanocluster size (i.e., increasing Pd surface area), increasing exterior versus interior loading, and decreasing catalyst aggregate size. Higher surface area yields a larger number of Pd active sites, and external versus internal loading and smaller aggregate size result in faster mass transfer. Results also show that selectivity for dinitrogen instead of ammonia generally increases with increasing Pd nanocluster size and decreasing catalyst aggregate size, but is not sensitive to interior versus exterior loading. Smaller Pd nanoclusters tend to have more Pd active sites and edges and/or corners, which are proposed to promote NH_3 production rather than N-N pairing..

We will evaluate the fouling resistance of CNF and CNT supported Pd catalysts, with interior and exterior loadings. Suwannee River humic acid standard II, Suwannee River natural organic matter (NOM), and sulfide will be studied as representative foulants. They were chosen because Suwannee River humic acid and NOM have different molecular sizes, and because sulfide is prevalent in natural waters and engineered systems under reducing conditions. Catalytic activity and selectivity will be evaluated before and after fouling and after regeneration. Catalyst will be characterized by TEM, scanning transmission electron microscopy (STEM), and X-ray photoelectron spectroscopy (XPS).

To summarize, CNFs and CNTs are used as supports for Pd catalysts for nitrite reduction, and their properties are explored to evaluate the effects on activity, selectivity, and fouling resistance. They are advantageous because their relatively simple structure allows detailed evaluation of reaction mechanisms, because they show promise as a practical support if they are produced more economically, and because they provide insights to synthesize novel sustainable Pd-based catalysts for nitrate/nitrite reduction.

PSYCHROPHILIC ANAEROBIC MEMBRANE BIOREACTOR FOR DOMESTIC WASTEWATER TREATMENT

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Water utilities are finding it increasingly desirable to reduce energy consumption and residuals production as part of a portfolio of strategies to achieve sustainable water management[1]. As part of these efforts, domestic wastewater (DWW) treatment design approaches need to move toward energy neutral operations and lower residuals production, without compromising effluent quality. Anaerobic biological treatment of DWW has been proposed as a more sustainable alternative to traditional aerobic biological treatment[2-6]. Anaerobic membrane bioreactors (AnMBRs), which combine anaerobic biological treatment and membrane separation, have the potential to improve or match the degree of treatment accomplished in current DWW treatment, while greatly improving the sustainability of the process by reducing the footprint of operations, energy consumption, residuals production, and by providing a useful end product. A few recent studies have reported the potential of AnMBRs for low-strength wastewater treatment[7-9]; however, these studies have demonstrated feasibility at elevated temperatures (≥25°C). The possibility of anaerobic treatment of DWW at psychrophilic temperatures (2-20°C) has been proposed in a few studies[10, 11] and is a critical component for attaining process sustainability. The current research assesses the feasibility of AnMBR technology for DWW treatment at psychrophilic conditions through operation of a bench-scale AnMBR, examines the role of the membrane biofilm in fouling and treatment, and is performing microbial analyses to better understand and optimize the process.

A 7-L bench-scale AnMBR with a liquid volume of 5 L and two submerged membrane housings each containing two separate flat-sheet microfiltration polyethersulfone membranes with a pore size of 0.2 µm (GE Osmonics, Greenville, SC) is being operated in this study. The AnMBR was inoculated with a combination of seed sludges providing diverse microbial communities from mesophilic (UASB and anaerobic sludge digester) and psychrophilic (anaerobic lagoon) environments. The system employs biogas sparging and permeate backflushing to mitigate membrane fouling. From days 1-350, the bioreactor was fed a synthetic wastewater representative of DWW[12]. The system is currently operated using actual DWW collected from the Dundee Wastewater Treatment Plant (Dundee, MI). Operating conditions include a reactor temperature of 15°C, a solids retention time (SRT) of approximately 300 days, a target hydraulic residence time (HRT) of 16 hours, and a membrane flux of 8.07 $L/m^2/hour$ (LMH). In actual operation, the HRT ranged from 16 to 24 hours due to membrane fouling. The organic loading rate was approximately 660 mg COD/L/day during operation with the synthetic DWW, and currently fluctuates between 180 and 430 mg COD/L/day due to fluctuating DWW characteristics. Finally, massively parallel sequencing targeting the V3-V5 hyper-variable regions of the 16S rRNA gene will be performed on each inoculum, and mixed liquor and biofilm samples to determine microbial community structure.

The bench-scale AnMBR fed with synthetic DWW achieved an average COD removal of 92 percent during approximately 350 days of operation with an average permeate COD of 36 mg/L. Although BOD_5 was not measured routinely, analyses of a limited number of samples indicated an average permeate BOD_5 of 18 mg/L. Consistent differences of approximately 100 mg/L between soluble bioreactor COD and permeate COD indicated substantial soluble COD removal across the membrane. Additionally, it was found that greater membrane fouling resulted in 10% additional COD removal across the membrane. These results suggest that a direct relationship exists between membrane fouling and soluble COD removal by the biofilm. More work is needed to determine if the mechanism of soluble COD removal is primarily biological, or if size exclusion, charge exclusion, and adsorption are involved. To this end, an experiment was conducted in which an AnMBR was operated with fouled membrane units, but without mixed liquor biomass, and fed a solution containing trace metals at levels similar to those in the synthetic DWW and approximately 55 mg/L of acetate and 10 mg/L each of the volatile fatty acids (VFA) formate, propionate, isobutyrate, butyrate, isovalerate, and valerate. The results of this experiment indicated that soluble COD removal across the biofilm is largely due to biological removal, evidenced by differential VFA degradation and the presence of soluble methane in the permeate stream. The results further suggested that hydrogenotrophic methanogenesis is favored over aceticlastic methanogenesis in the biofilm, possibly due to hydrogen's increased solubility at psychrophilic temperatures. Specific methanogenic activity assays and microbial community characterization through pyrosequencing of DNA extracted from biofilm and mixed liquor biomass samples are pursued to further evaluate these observations. Finally, microbial community characterization of the three inocula (two mesophilic, one psychrophilic) using pyrosequencing will be compared to biofilm and mixed liquor community structures from the AnMBR and used to evaluate the effect of prolonged psychrophilic operation on these communities.

During operation of the AnMBR, methane solubility limited direct biogas recovery. Extensive quantification of soluble methane[13] in the mixed liquor and permeate indicated that about half of the generated methane was removed from the reactor through the permeate rather than being collected in the headspace. Soluble methane measurements indicated supersaturation relative to Henry's law, which may be a result of transmembrane pressure gradients in the system as well as additional methane production in the biofilm. Recovery of soluble methane from the permeate will require degasification, which may impact the economic feasibility and overall sustainability of the process. Alternatively, dissolved methane can be considered an asset if it can be used directly, for example, as a substrate for denitrification.

A second bench-scale AnMBR was recently inoculated with biomass from the first AnMBR to evaluate the feasibility of treating actual DWW in this system. Preliminary results suggest that the treatment performance when feeding actual DWW is similar to that observed with the synthetic DWW. Additionally, economic and environmental assessments of AnMBR technology applied to DWW treatment are pending.

In conclusion, a bench-scale AnMBR operated at psychrophilic temperatures treating a low-strength wastewater was able to achieve a high-quality effluent suitable for direct discharge (assuming nutrient removal is not necessary). These results are suggestive that psychrophilic treatment of DWW via AnMBRs is worthy of further investigation as a direction for more sustainable DWW treatment.

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AN EVALUATION OF GROUP WORK FORMATS IN A SERVICE-LEARNING COURSE ON WATER TREATMENT

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This abstract contrasts the format of two service-learning courses on water treatment for under-privileged communities and describes advantages and disadvantages of each format for the benefit of the students and the community partner.

A new service-learning course has been offered in the School of Engineering at the University of Mississippi with the partnership of the organization Living Waters for the World (LWW). LWW is an organization that trains and equips mission groups to introduce clean drinking water to communities in need. The communities range from rural villages in Nicaragua with no access to municipal water, to neighborhoods in small cities in Mexico with low quality municipal water, to households in the U.S. with water wells contaminated with mine waste. LWW implements its clean water mission by holding four-day courses named Clean Water U in two locations in the United States. Participants attend Clean Water U in Mississippi or California and return to their mission groups with the knowledge to build successful relationships, teach hygiene, and train the receiving communities to build and operate water treatment systems composed of microfiltration and ozonation or ultraviolet (UV) disinfection (Figure 1). The two Clean Water U facilities house several the treatment systems built in different configurations for the purpose of training participants.

Figure 1. The author (left) and a student (right) discuss the water treatment system at Clean Water U in Mississippi.

This service-learning course, held in the fall semesters of 2009 and 2010, combined teaching of water treatment processes with hands-on projects to test LWW's water treatment systems at the Mississippi Clean Water U facility.

The Fall 2009 course enrolled 10 students in two engineering disciplines (civil and geological) and included two graduate students. Two main projects were carried out: (1) testing the rate of coliform disinfection along the 1-inch PVC pipe ozonation plug flow reactor; and (2) testing the effectiveness of changing the order of two unit processes in the system. The class functioned as one large project group, with the instructor as project manager directing the timing of the testing and how to report results. Each student filled a different role, which was mostly kept constant throughout the semester. Students naturally acted on roles that were comfortable to them. For example, some students conducted the colorimetric water quality analyses, others operated the treatment systems, others worked on the results in a computer spreadsheet, and so on. Roles were rarely switched among students, and the instructor kept careful watch over all activities. By the end of the semester, a small group of students took the role of report writers and completed a report submitted to LWW. Eventually, this report was revised as a manuscript that was published in the *International Journal for Service Learning in Engineering*.

The Fall 2010 course enrolled 12 students in three engineering disciplines (civil, geological, and chemical) and included eight graduate students. Four projects were carried out: (1) testing the effectiveness of different venturis for ozone injection; (2) testing the effectiveness of UV disinfection in the absence of a 0.5-micron filter; (3) testing the effectiveness of a chlorine shocking practice to disinfect the system before start-up; and (4) creating a procedure to estimate the strength of bottled bleach given limited supplies. The class was divided into four groups of three students, with each group containing two graduate students and one undergraduate. Each group worked on data collection and analysis on two of the above projects and as a peer reviewer for a third project. The instructor acted as a general guide for the activities, rather than project manager as in the previous offering of the course.

In the two offerings of the course, students collected and reported data, and wrote reports and orally presented the findings to members of LWW. The two different group work formats had advantages and disadvantages. When organized into one large group with the instructor as project manager (Fall 2009), some students did not benefit from learning the big picture of the project, and many students relied on the instructor for directions instead of taking initiative. The advantage of this format was that one detailed final report was submitted to LWW, which carefully detailed the experiments and had clear conclusions. The group format was changed in the second offering of the course (Fall 2010) to take advantage of potential leadership skills of the graduate students and to have students work outside of their comfort zone and take roles that they typically would not take. The format with small groups also had disadvantages. With three small-group projects to work on, students did not have time to be thorough in their testing and therefore did not offer as good of a service to the partner organization. In addition, students did not have time to assimilate all of the technical issues related to the three projects that they had to work on in a single semester. One advantage of this format is that students were more independent on how to conduct their testing and learned well through their mistakes.

While it appears that a next offering of the course will have a format of medium-sized groups working on at most two projects each, this method will also have advantages and disadvantages. Groups, no matter how large, will always have conflicts among students, especially on how the workload is distributed. Nevertheless, students always learn about team performance for the common goal of serving the partner organization. It is evident that the instructor must be clear to the students on the objectives and expectations of the group work.

PREDICTING THE PRODUCTION OF BIOMATERIALS IN ACTIVATED SLUDGE USING GENOMIC MODELING

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Introduction. Recovery of wastewater resources into value-added materials has recently been the subject of active research. Storage compounds such as polyhydroxyalkanoates (PHAs), triacylglycerols (TAGs), and glycogen are naturally produced by many bacteria as intracellular carbon and energy reserves under various environmental stresses including feast-famine cycles occurring during biological wastewater treatment (3, 12). PHAs and TAGs are interesting polymers for their properties as bioplastics and biodiesel precursors, respectively (11). The ability of producing these polymers in wastewater treatment plants may allow a reduction in production cost over the current industrial processes, which use pure cultures and sterile pure substrates. However, our ability to predict the metabolism of heterotrophic bacteria selected in activated sludge wastewater treatment processes and producing the various storage polymers is still at its infancy, which limits our ability to rationally develop the technologies. The goal of this paper is to develop a simulation protocol based on available genome-scale metabolic models (two models were used: *Rhodococcus jostii* strain RHA1 (this study) and *Escherichia coli* strain K-12 (9)) to predict the metabolisms selected and expressed in mixed microbial communities.

In order to study the biodiversity of heterotrophic bacteria accumulating storage compounds, we propose to study the possible metabolisms through the available genome sequences (currently 831 complete genomes are available (8)) and the genome-scale metabolic models (currently 15 models are available (5)). Genome-scale metabolic models are analyzed by flux balance analysis (FBA). In the FBA framework, the set of mass balances around each metabolite of a biochemical network constitute an underdetermined set of equations that can be optimized by linear-programming approach implementing biologically relevant objective functions.

The choice of an objective function is central to FBA. In one interpretation of the evolutionary principle, bacteria constantly optimize their metabolic activities to get competitive advantage. For growth in wastewater treatment systems, one could hypothesize that the growth rate (or yield if substrate uptakes and growth rates are coupled) corresponds to this optimum. However, storage metabolism can be seen as a sort of secondary metabolism where substrate uptake and growth is decoupled. Therefore, the selection pressure may not be at the level of maximizing overall growth rate (or overall yield). Consequently, the main objective of this study was to evaluate alternative objective functions to determine the best one to predict the metabolism that would be selected in activated sludge systems for storage accumulation. We tested two additional sub-objective functions: (i) minimizing the total metabolic fluxes (i.e., maximizing cellular efficiency) (6), and (ii) minimizing the flux differences between feast and famine growth (i.e., minimization of metabolic adjustment, MoMA) (10).

Materials and Methods. The three different objective functions were compared for their ability to predict the pairing relationship between substrates (glucose and acetate) and storage compounds (glycogen and poly-β-hydroxybutyrate (PHB)). Two genome-scale metabolic models were used: (i) an E. coli K-12 model (9) modified to allow the accumulation of PHA (glycogen can already be accumulated by E. coli), and (ii) the R. jostii RHA1 model that we constructed. R. jostii RHA1 is an environmental isolate which genome has recently been sequenced and annotated (7). Our RHA1 reconstructed network contains 1240 balanced (intracellular) compounds and 1931 unique fluxes. It also includes 329 extracellular compounds that are associated with 517 exchange fluxes. Simulations were conducted in using the COBRA toolbox of MATLAB (1).

Results and Discussion. Fig. 1 shows the variation in value of objective functions (max. growth rate, min. metabolic fluxes, or min. metabolic adjustments) with respect to the accumulation of glycogen and PHB at different fluxes for a constant carbon uptake rate (21 Cmmol/(g-DW·h)) in the form of glucose or acetate uptake. Fig. 1 only reports simulation results for R. jostii RHA1 model, but the E. coli model simulations also showed similar trends.

The three objective functions above-mentioned properly predicted the storage metabolism observed when lab-scale activated sludge reactors were operated with artificial wastewater containing either glucose (storage: glycogen) (4) or acetate (storage: PHB) (2) as the sole carbon sources (e.g., Fig. 1 for R. jostii RHA1 results with glucose as substrate). These results were independent of the assumed lengths of the feast and famine phases. Although all these objective functions properly predicted the carbon sources and storage metabolisms pairing, the MoMA objective function found the largest differences between glycogen and PHB metabolisms, suggesting a more reliable prediction.

We also analyzed the case of succinate as the sole carbon source for which we do not have experimental data yet. In this case, the three objective functions predicted the same way. However, the R. jostii RHA1 model predicted the accumulation of PHA, while the E. coli model predicted the accumulation of glycogen. We are now testing these in the lab. However, it seems that the use of lumped reactions to simplify the E. coli model may be the cause of this discrepancy.

Conclusion. The substrate-storage pairing relation of two species commonly present in activated sludge systems and taken as representatives of heterotrophs was analyzed using the genome-scale FBA. The simulation results showed glucose-glycogen and acetate-PHB pairing which is in agreement with the experimental observations. Once fully developed, this modeling approach may provide a good predicting tool for heterotrophic metabolisms found in activated sludge treatment systems and it could be used for the optimization of the production of the valuable biomaterials from wastewater resources in future.

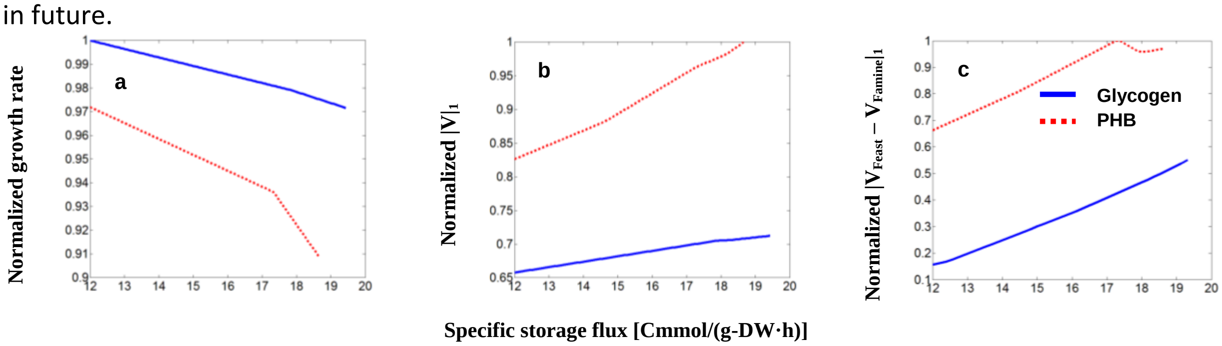

Fig. 1. Comparison of the normalized average maximum growth rates (**a**), sum of the flux vector ($|V|_1$) (**b**), and sum of the flux difference between the feast and famine phases ($|V_{Feast}–V_{Famine}|_1$) (**c**) vs. the specific storage flux of two storage compounds: glycogen and PHB for *in silico* growth of *R. jostii* RHA1 on specific glucose uptake rate of 21 Cmmol/(g-DW·h). **The ordinate is normalized with regard to the maximum value obtained for a given objective function. NOTE THE DIFFERENCES IN THE RANGES OF Y-AXES.** The results were the same for the *E. coli* model with glucose, and the simulation showed the reverse trends with acetate as substrate.

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MICROBIAL ELECTROCHEMICAL CELLS AND THEIR BIOENERGY APPLICATIONS IN THE LABORATORY AND FOR THE WASTEWATER INDUSTRY

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The concept of microbial electrochemical cells (MXCs) holds great promise for renewable energy production from wastes. Inside an MXC, anode respiring bacteria (ARB) catalyze the direct conversion of organic matter into electrical current. Electrical current has been successfully produced in MXCs from a variety of organic wastes which include wastewater, wastewater sludge, animal and agricultural wastes, sugars and alcohols, among others. The electrical current produced can be used to generate electrical power, fuels such as hydrogen (H_2), or high-value chemicals of interest to the water and wastewater industry (i.e. caustic, hydrogen peroxide).

In order to maximize the benefits of MXCs, we must select for ARB that minimize anode potential losses. By using lower anode potentials, we selectively grew ARB, enriched from wastewater sludge of the Mesa Northwest Water Reclamation Plant (Mesa, AZ), that are capable of producing high current densities at low anode potentials. We used these enriched ARB community to study their kinetics and thermodynamics and maximize electrical current production. In order to optimize the biofilm anode, we must understand the transport processes occurring inside the biofilm: substrate diffusion, proton and ion diffusion, and electron transport to the anode. Moreover, we must understand how the MXC design affects these processes and limit ARB activity at the biofilm anode. Our group has combined modeling and experimental work to study the rates of electrical current production by our ARB community. The development of these kinetic models has lead to better MXC designs and has opened new research areas in the field of microbial kinetics.

One of the new research areas that we are developing is related to the study of microbial kinetics through ARB. Our previous research on ARB kinetics has revealed that ARB can carry out extracellular electron transfer (EET) with minimal potential losses. Thus, their electrical energy production is directly measuring the metabolic rate of ARB. These electrochemical measurements, in which ARB kinetics are directly coupled to the anode, open-up new research opportunities for understanding the kinetics of metabolic processes occurring in microbial cells and biofilms. The continuous monitoring of the current generated by ARB also allows us to track respiration rates in real time at ranges below 1 millisecond. Thanks to these electrochemical measurements, we are now able to study the kinetics of microbial processes in a simpler manner and even perform studies that were not possible before.

An example of such kinetic studies measures the kinetic response of ARB to an instantaneous increase in substrate concentration after a starvation period. The MXC is first depleted of electron donor, leading to starvation and a decrease in current production by ARB. Then, a spike in substrate (H_2, acetate, ethanol, butyrate, among others) allows us to determine the microbial response to substrate availability. ARB response times to these substrate spikes occur within < 5 seconds, demonstrating our capability to measure microbial kinetics with high temporal resolution. However, not all substrates have a quick response; this approach has allowed us to characterize mixed microbial communities and determine whether a substrate is directly consumed by ARB, or if a fermentative step is occurring upstream of current generation. These experiments not only show the versatility of measuring ARB kinetics, but also demonstrate the potential to use electrochemical measurements to probe microbial and biofilm kinetics, thus expanding our knowledge of microbial kinetics related to bioenergy applications.

OCCURRENCE OF OPPORTUNISTIC PATHOGENS IN A HIGHLY CHLORAMINATED DRINKING WATER DISTRIBUTION SYSTEM

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Aims: Opportunistic pathogens residing in water systems, particularly premise (i.e., building) plumbing, are now the primary source of water-borne disease in developed countries. As populations expand and infrastructure becomes increasingly urbanized, the importance of opportunistic pathogens is poised to be of increasing concern. Opportunistic pathogens pose a new challenge for public health, requiring a paradigm shift that moves beyond disinfection of water produced by drinking water treatment plants. Of particular interest is the relationship between opportunistic pathogens and the broader drinking water system microbial ecology, which may have an overall stimulatory or inhibitory effect. Thus, the purpose of this study was to explore the occurrence of an array of opportunistic pathogens at various points within a distribution system, including premise plumbing, along with the corresponding microbial community composition. The present study focused on a distribution system that was highly choraminated, a conventional means of inhibiting certain opportunistic pathogens, while future studies will compare with other distribution systems and with laboratory models. The specific aims of this study were to **1)** investigate the occurrence of four opportunistic pathogens (*Legionella pneumophila*, *Mycobacterium avium*, *Pseudomonas aeruginosa* and *Acanthamoeba polyphaga*); **2)** investigate the influence of water age on the occurrence of pathogens and microbial communities; and **3)** explore possible relationships between microbial ecology and pathogen occurrence.

Materials and Methods: The sampling plan was designed based on a water age model of a small drinking water distribution system. Three to seven houses were selected for sampling at each water age investigated (3d, 6d, 8d, 10d, and 17d or longer). Three or four 1-L samples were collected at each sampling location: the first was collected before flushing the sampling tap (first draw sample), the second was collected after flushing the sampling tap for 3 min, and 1 or 2 water heater samples were collected from the safety valve and bottom drain valve of corresponding water heaters. The sampling procedure was performed in accordance with the EPA sampling guide with slight modification. Collected water samples were transported to the lab within 2 h and processed by filtrating through 0.22 µm-pore-size mixed cellulose ester filters (Millipore), which were subsequently fragmented and subject to DNA extraction using the FastDNA® SPIN Kit (MP Biomedicals, Solon, OH). Quantitative polymerase chain reaction (Q-PCR) was used to quantify *L. pneumophila*, *M. avium*, *Acanthamoeba*, *P. aeruginosa* and 16S rRNA genes. The microbial community composition of the water samples was profiled by terminal restriction fragment length polymorphism (T-RFLP).

Results and Conclusions: The physicochemical properties of the water samples were found to be consistent across all samples, with an average T of 19.7 (±2.4) ℃, pH of 7.85 (±0.23), NH_4^+ of 0.63 (±0.14) mg/L, NO_3^- of 0.34 (±0.05) mg/L and TOC of 2.36 (±2.96) mg/L. A high chloramine residual was verified throughout the distribution system, with an average concentration of 2.21 (±0.63) mg/L (calculated as total Cl_2).

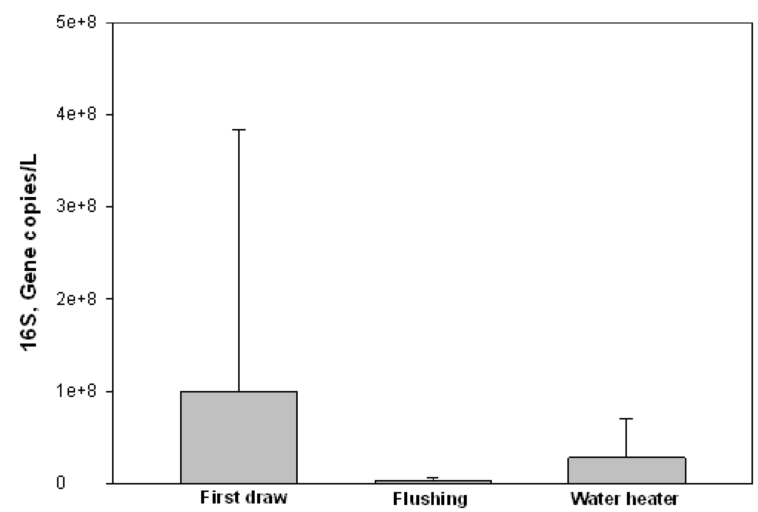

Figure 1 Average (+ standard deviation) concentration of 16S rRNA genes (indicative of total bacterial population) of first draw samples, samples following flushing, and water heater samples.

The occurrence rate of *L. pneumophila*, *M. avium*, and *Acanthamoeba* for all 93 samples were 4.3%, 8.7%, and 6.5%, which were relatively low compared to previous studies. Only one sample was found to test positive for *P. aerugniosa*, a water heater sample with a concentration of 1,859.8 (±340.1) gene copies/L. The highest concentrations of *L. pneumophila*, *M. avium*, and *Acanthemoeba* detected were 1,3748 (±5186), 1,937 (±345) and 6,804 (±2955) gene copies/L, respectively.

The low occurrence of opportunistic pathogens might be related to the relative higher disinfectant concentration by comparing to other similar studies that have higher pathogen occurrence and low disinfectant level (1.1-1.6 mg/L). 6.7% and 16.7% of first draw samples detected positive for *L. pneumopihla* and *M. avium*, respectively; while none of samples collected after flushing were positive for *L. pneumophila* or *M. avium*. This suggests that even when the distribution system itself is highly chloraminated, overnight stagnation may still permit the growth of indigenous pathogens harbored in biofilm. The results of 16S rRNA gene quantification demonstrated that the concentration of 16S gene for first draw samples is significantly higher than samples after flushing (P<0.05), supporting the potential role of biofilms harboring pathogens (Figure 1).

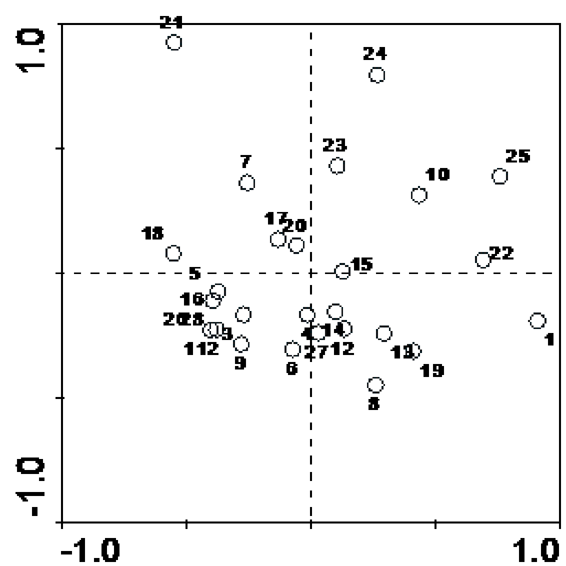

Figure 2 PCA analysis of bacterial tRFLP profiles (presence/absence of peaks) of drinking water samples taken after flushing. Labels: 1-4- water age of 3d; 5-12- water age of 6d; 13-17- water age of 8d; 18-23- water age of 10d; 24-29- water age of 17d or longer.

Principle component analysis (PCA) of tRFLP fingerprints of the bacterial and eukaryotic communities indicated that microbial community composition did not cluster based on water age (Figure 2). Weak clustering was only observed for first draw samples positive for *M. avium*. Future research will investigate in detail the role of additional factors, such as pipe material, disinfectant type, hot water heater temperature and configuration on opportunistic pathogen occurrence.

BOOTSTRAP UNCERTAINTY ANALYSIS OF K-NEAREST NEIGHBOR CLASSIFICATION FOR MICROBIAL SOURCE TRACKING

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Library-based microbial source tracking (MST) approaches require the collection of bacterial data from possible contaminating sources in a watershed or waterbody to create a library of data to which bacteria from unknown sources (*i.e.* those found in the water) are compared. Although most researchers in the MST field are moving towards library-independent methods such as identifying host-specific genetic markers, the library-dependent approach can be useful in a complex geographical area where multiple bacterial sources are influencing water quality. There are two well-established tools for analyzing library-dependent MST datasets, namely discriminant analysis and k-nearest neighbor (k-nn). Both of these methods are classification algorithms, originally developed for signals analysis and information theory. They evaluate the rate at which a specific sample is similar enough to a set of exemplars obtained from known sources, where a new isolate from a known source (*e.g.* cow) should be correctly classified to the exemplars from a similar source (*e.g.* livestock). The use of classification tools in MST has shown mixed results, and they suffer from insufficient analysis of the uncertainties in the resulting classified groups. While all classification techniques perform the same base task, there are subtle differences in technique and method which allows for preference from one form to another. Discriminant analysis attempts to compare data values to their associated classes (discrete group) using a set of lines, planes or hyperplanes cutting the data into separate classes. k-nn analysis does not attempt to force a linear relationship, as this technique compares all available data to the associated classes, and those data points nearest to specific classes are classified within that group. Figure 1 shows a graphical depiction of the two classification techniques, figure 1a being k-nn and figure 1b being discriminant analysis.

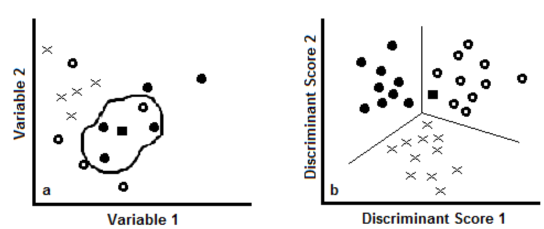

Figure 1. a) k-nn classification, showing the object of unknown origin (■) is classified by its placement to its three nearest neighbors and b) based on two discriminating variables generating distinct groupings of objects in a hyperplane.

What is of particular interest is the lack of further computational analysis of the results of these classification techniques within the MST field. While the underlying uncertainty of the classifications from each of these techniques has been analyzed in signals processing and information theory, this work has primarily focused on the errors of classification. As to the point of this work, there has not been a published effort to understand the uncertainty of correct classification. Typically the jackknife technique ("leave-one-out" analysis) is used to infer the variance and bias of the classification rate. While the jackknife is useful in classification analyses, it is not a random iterative process; therefore, it is incapable of inferring a distribution of classifications, since the same result is generated at each implementation. Therefore to expand classification results into further analyses or risk modeling, using techniques such as the Monte Carlo method, the capability of inferring a distribution of classification results is necessary.

This work is based on the data and classification information resulting from a MST case study conducted within the jurisdiction of the Philadelphia Water Department. Bacterial isolates were collected from the host species, grouped as: wildlife, waterfowl, wastewater treatment plant finished effluent, livestock, domestic animals and zoo (animals not indigenous to the watershed). Amplified DNA fingerprints for *Escherichia coli* (*E. coli*) and *Enterococcus spp.* were generated using routine polymerase chain reaction (PCR) with the BOX-A1R primer set, and used to construct the library of know source groups. This library was then used to classify the isolates into the known groups. Both discriminant analysis and k-nn were used, but since k-nn provided a better rate of correct classification, this technique was chosen for all classification work in the case study, and thereby, this uncertainty analysis. The k-nn classification was bootstrapped, which is an iterative technique that developed a vector of 10,000 rates of correct classification (thus 10,000 iterations), based on randomly sampling from the library of data. Three bootstraps were conducted overall, first where only the data from the library were sampled randomly, second where the value of k was randomly chosen (as opposed to the optimal k chosen via cross validation) and third where both k and the data were randomly sampled.

Using the data from the MST case study, the bootstrap of the classification routine (the uncertainty in the rate of correct classification) was determined by calculating the mean and quantiles of the 10,000 classification results. It is shown that the uncertainties of classifying MST data are best handled using a bootstrap of randomly sampling possible k values, and secondly, where the data is randomly sampled. While the rate of correct classification decreased due to the bootstrap, these rates can now be more effectively described within likely uncertainty bounds. Another interesting result from the bootstrap method is that while a larger number of exemplar cases was typically associated with smaller uncertainty bounds, this was not always the case for both *E. coli* and *Enterococcus*. Through all bootstrap` types, *Enterococcus* performed much better, allowing a much greater probability of correct classification as well as decreased uncertainty in this estimate. Overall the results of this uncertainty analysis for MST data demonstrate a needed expansion on the information available from classification analysis, and an ability to assess the distribution exhibited in the classification rate, rather than a general assessment of the variance and bias in the classification.

QUANTITATIVE ASSESSMENT OF VIRUS PROTEIN AND GENOME DAMAGE UPON INACTIVATION BY COMMON DISINFECTANTS

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Background. Successful disinfection of contaminated drinking waters is pivotal for ensuring public health, yet scientists and engineers lack a mechanistic understanding of how pathogens are inactivated with disinfection treatments. Even virus pathogens, which have relatively simple structures compared to bacteria and protozoa, have not been described with respect to their disinfection pathways. Infectious virus agents consist of a single or double strand of RNA or DNA encapsulated in a protein capsid (some are surrounded by a lipid envelope). Despite having similar structural components, virus strains can have widely varied susceptibilities to disinfectants. For example, Poliovirus 1 Brunhilde is twice as resistant to free chlorine as Poliovirus 1 Mahoney (*1, 2*) and Adenovirus 41 is more resistant to UVC inactivation than Adenovirus 2 or 5 (*3*). These discrepancies suggest that small differences in viral components can alter virus resistance to inactivation.

Previous studies have detected damage in viral proteins (*1, 4-9*) and nucleic acids (*5, 6, 9-11*) as the virus are inactivated. Most have focused on damage to specific viral components without probing the effects that the detected damage has on fundamental virus activities. Predictions on inactivation mechanisms have been broad and often contradictory (*6, 9, 11-13*). For instance, poliovirus inactivation by free chlorine was attributed to RNA damage in one study (*12*) and to protein damage in another (*6*).

In this study, we work towards an in-depth description of how virus composition and structure influence susceptibility to inactivation. We believe this knowledge will aid scientists and engineers in predicting disinfectant effectiveness against those virus strains that cannot be cultured. This, in turn, would aid water utilities in designing disinfection processes that ensure public health.

Methods. Bacteriophage MS2 was inactivated via UV_{254} irradiation, free chlorine, singlet oxygen ($^1O_2$) and heat. MS2 was employed as a surrogate for non-enveloped enteric human viruses as it has been extensively employed in water treatment studies. In addition, it is easily cultured and concentrated to high concentrations (> 10^{14} PFU/mL), and has a relatively simple structure with 180 identical copies of the capsid protein (13.7 kDa, 129 residues), a single copy of the assembly protein (43.9 kDa, 339 residues), and a single-stranded, positive-sense, 3.6 kb RNA genome. The damage incurred by the virus proteins and genome was tracked with quantitative MALDI mass spectrometry and quantitative RT-PCR, respectively. A binding assay and an injection assay were developed to assess the loss of fundamental virus functions due to the detected virus protein and genome damage.

Results. Damage detected in the virus proteins was most extensive with free chlorine inactivation. UV_{254} damage and $^1O_2$ damage were subtle and occurred only at specific locations in the capsid proteins. Several protein oxidation products were identified with MS-MS analysis. In the genome analysis, more damage was detected with free chlorine treatment per $\log_{10}$ loss of virus infectivity than with UV_{254} and $^1O_2$. Overall, the protein and genome damage results suggest that MS2 can withstand more damage with free chlorine than with UV_{254} or $^1O_2$ with the same loss of infectivity.

Virus activity assay results demonstrated that $^1O_2$ damage affected MS2's ability to bind with its host cell. Thus, the small amount of capsid protein damage detected with $^1O_2$ inactivation was sufficient to cause a loss of the virus binding function. On the other hand, damage by UV_{254} irradiation and free chlorine caused a loss in MS2's ability to inject viral genome into the host cell. We attribute this function loss to the damage detected in the A protein and virus genome.

Conclusions. Our results demonstrate that virions can retain infectivity despite high levels of certain types of damage and that the extent of virus protein and genome damage relative to inactivation levels varies greatly amongst the different types of inactivation.

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TRANSPORT OF MUTI-WALLED CARBON NANOTUBES THROUGH POROUS MEDIA

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During the process of production and application, CNTs are frequently dispersed in water or other polar solvent, which requires surface modification by different methods, one of which is surface oxidation through acid treatment or other means. Anticipating the possible spill or other type of environmental release for such materials, it is important to understand the effects of such treatments on CNT behavior in the natural environment, including their transport through soil, bottom sediments, and subsurface materials. In addition, sand filtration is a common process of water treatment that is possibly the most important barrier for removing multi-walled carbon canotubes (MWCNTs) from wastewater streams or water supplies. In order to better understand and design such processes, we have undertaken a study of the effect of surface oxidation on the transport of MWCNTs through porous media under different conditions of aquatic chemistry and using well-controlled and well-characterized porous media.

In this study, MWCNTs purchased from Nanolabs Technology (Nanolabs, Inc.) were oxidized with $53\%_{w/w}$ or $15\%_{w/w}$ nitric acid in order to intruduce oxygen containing functional groups onto the surfaces. The distribution of different oxygen containing functional groups was then tested using X-ray Photoelectron Spectroscopy (XPS). Colloidal suspensions of oxidized MWCNTs were then prepared by extended (20 h) sonication. Approximately 0.6 µg of colloidal O-MWCNTs was injected as a pulse into the DI water line using an injection loop. The O-MWCNTs then passed through columns packed with glass beads at diameters of 0.335 – 0.425 mm. NaCl was used for the background electrolyte, at concentrations ranging from 0.5 mM to 700 mM. Experiments were conducted at pH 4, 5.8 and 10. The water in each system was adjusted to within ±0.2 units of the target pH using 0.1M HCl or NaOH. In our experiments, the use of buffer was avoided to eliminate any unintentional effects of buffering agents on the stability of the O-MWCNTs. In order to obtain consistent and accurate results, the collectors were used only once after purchase and were cleaned thoroughly by sonication, first in base (4 M NaOH) and then in acid (0.001 M HCl). Before every experiment, the beads were sonicated for at least one hour and then repacked into the column. This final step was necessary to expel tiny air bubbles and unstable silica colloids from the surface of the glass beads -- because attachment efficiencies of colloidal O-MWCNTs are extremely sensitive to collector surface composition, the final sonication step was found to be critical to obtaining reliable and reproducible results. The pulse breakthough curves collected by UV-Vis were then analyzed using a simple one dimensional convection-dispersion transport equation that included a first order removal term for colloid deposition and collection at surfaces. The colloid deposition rate coefficient *k* is obtained from appllication of equation (1) below, and the collision efficiency α can then be calculated based on the use of equations 2 and 3.

$$\frac{\partial \mathrm{C}}{\partial \mathrm{t}} = \mathrm{D}\left(\frac{\partial^2 \mathrm{C}}{\partial \mathrm{x}^2}\right) - \mathrm{v_p}\left(\frac{\partial \mathrm{C}}{\partial \mathrm{x}}\right) - k\mathrm{C} \qquad \textbf{Eq. 1}$$

$$k = -\frac{1}{\mathrm{t_p}}\ln\left(\frac{\mathrm{C_f}}{\mathrm{C_o}}\right) \qquad \textbf{Eq. 2}$$

$$\alpha = \frac{k}{k_{\text{fast}}} \quad \textbf{Eq. 3}$$

where *C(t)* is the effluent O-MWCNT concentration, *k* is the colloid deposition rate coefficient, t_p is the average travel time of the colloidal particles through the column, *q* is the volumetric flow rate, N_0 is the total amount of colloids injected into the column, t_f is the time at which the colloid pulse has completely moved through the column, and k^{fast} is the deposition rate coefficient under favorable deposition conditions.

Transport studies in packed columns confirmed that the attachment efficiency of MWNTs is strongly affected by ionic strength, and pH in a manner generally consistent with expectations, as shown in Figures 1 and 2. Results were found to be independent of the injection amount of MWCNT dispersions (Figure 3), which indicated that the aggregation effect of MWCNTs was not significant in this experiment. Surprisingly, the oxidation degree of O-MWCNTs was also found to have comparatively little effect on the attachment efficiency (comparison of Figures 1 and 2). The possible causes of this latter behavior are still under investigation and will be discussed in the presented paper.

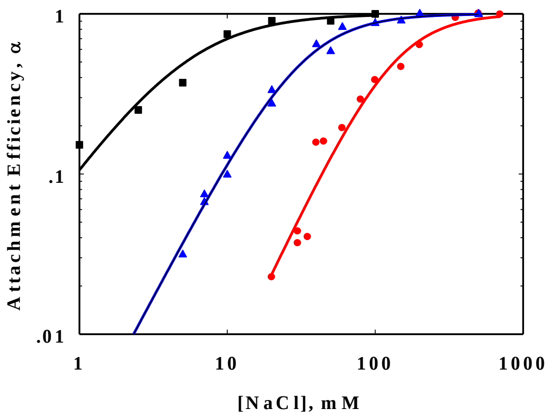

Figure 1. Critical deposition curve of O-MWCNTs treated with 53% HNO_3 at pH 4.0± 0.2, 5.8 ± 0.2, and 10.0± 0.2 at 1 mM to1000 mM NaCl.

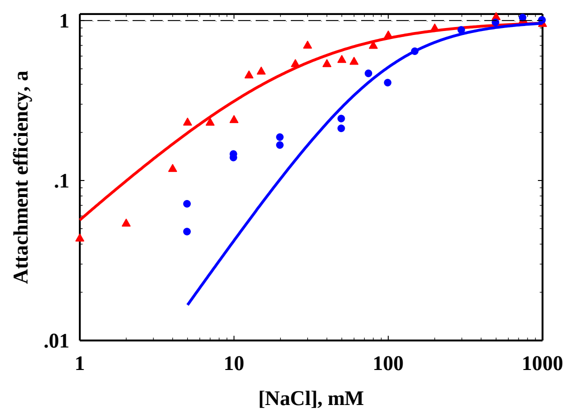

Figure 2. Critical deposition curve of O-MWCNTs treated with 15% HNO_3 at pH 5.8 ± 0.2 and 10.0± 0.2 at 1 mM to1000 mM NaCl.

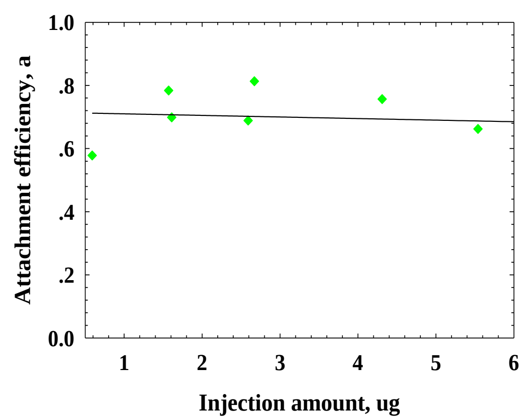

Figure 3. Attachment efficiency of O-MWCNTs treated with 53% HNO_3 at different injection amount at 40 mM NaCl. pH 5.8 ± 0.2

CHARACTERIZING THE MICROBIAL COMMUNITY RESPONSIBLE FOR NITRIFICATION USING HIGH-DENSITY MICROARRAYS

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Nitrification in drinking water distribution systems that use chloramines as a residual disinfectant is problematic because it can decrease disinfectant residual, dissolved oxygen concentrations, pH, and alkalinity. In addition, regrowth of heterotrophic organisms is also observed in sections of the distribution system where nitrification occurs. *Nitrosomonas oligotropha* is now recognized as ubiquitous ammonia-oxidizing bacteria (AOB) during nitrification episodes, although other AOB have also been detected in several studies.[1,2] In addition, preliminary evidence for the presence of ammonia-oxidizing archaea (AOA) in drinking water distribution systems is starting to emerge. Molecular methods for the identification of the microbiological community responsible for nitrification are providing greater insight than previous culture based methods.

With the objective of evaluating the diversity of nitrifying organisms in samples from water distribution systems, we have designed high-density microarrays that target subunit A of the ammonia monooxygenase (*amoA*) gene of ammonia-oxidizing bacteria (AOB) and ammonia-oxidizing archaea (AOA). Additionally, we have included the ability to evaluate bacterial diversity by detecting conserved regions of the 16S ribosomal DNA. The initial steps in the design included the collection of *amoA* sequences from GenBank, their alignment and organization in operational taxonomic units, and an evaluation of the quality of the retrieved sequences. Short sequences and potential chimera sequences were removed from the design databases, which currently contain approximately 7,000 amoA-AOB and 9,000 amoA-AOA sequences and 6,500 bacterial (16S) sequences. With a 95% similarity threshold for the definition of operational taxonomic units, comprehensive microarrays were designed to target 318 AOB, 500 AOA, and 630 bacterial taxonomic units. Next, a preliminary selection of oligonucleotide probes specific for each taxonomic unit was identified. In this process, probe length was set to 20-24 nucleotides, and the consensus sequence of each taxonomic unit was exhaustively evaluated for target locations that offered the highest degree of specificity. Potential probes were ranked according to whether they uniquely matched one taxonomic unit, or matched (with one or two mismatches) other taxonomic units. The final step in the design was the fine-tuning of probe length based on thermodynamic considerations of probe-target binding for the perfect match and the potential mismatched hybridizations.

The University of Wisconsin (Madison) pilot-scale chloraminated distribution system was operated to achieve chemical and operational parameters typical of those achieved by utilities that use chloramines as a residual disinfectant. The pilot-scale distribution system was operated to maintain a chloramine residual between 0.5 and 1.0 mg/L. Six different distribution systems were operated to understand the impact of pH (7.9, 8.3, and 8.6) and chlorite residual (0, 0.5, and 1.0 mg/L) upon the microbial community. Chlorite was included in the study as it has been reported to delay the onset of nitrification events and is used in several utilities throughout the United States.[3] Samples were analyzed to characterize the microbial community present prior to and during nitrification events. Preliminary evaluation of microarray hybridizations has confirmed the presence of a small number of operational taxonomic units detected for both AOB and AOA. With typical values of 10-12 positive AOB OTUs (out of the 318 defined) and 5-6 positive AOA OTUs (out of the 500 defined), the distribution system does not indicate a very diverse microbial community. AOB and AOA species not previously reported in chloraminated distribution systems have been detected. Additionally, the presence of different OTUs positive at different points within the treatment process offers insight into the response of specific microbial communities to different treatment strategies.

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REMOVAL AND IN-SITU IMMOBILIZATION OF ARSENATE BY POLYSACCHARIDE-STABILIZED MAGNETITE NANOPARTICLES

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We have synthesized and extensively tested a new class of stabilized magnetite nanoparticles for enhanced removal of arsenate from water and ion exchange brine, and for in situ immobilization of arsenic in soil and poultry litter. Two low-cost and "green" polysaccharides, a water-soluble starch and sodium carboxymethyl cellulose (CMC), were used as stabilizers to facilitate particle size control and enhance adsorption capacity. Our results indicated that particle size, morphology, soil mobility and arsenic sorption capacity can be controlled by manipulating the stabilizer type and concentration. For instance, at a starch concentration of <0.04 wt.%, the magnetite nanoparticles prepared at 0.1 g/L (as Fe) were present as starch-bridged aggregates, which can be easily separated from water, yet displayed a 5-fold greater arsenic removal capacity compared to conventional bare magnetite particles. Consequently, the bridged nanoparticles offer a powerful means for enhanced removal of arsenic from contaminated water or spent ion exchange brine. When applied to a simulated spent IX brine containing 300 mg/L As and 6% (w/w) NaCl, nearly 100% removal of arsenic was achieved within 1 h using the starch-bridged nanoparticles at an Fe-to-As molar ratio of 7.6, compared to only 20% removal when bare magnetite particles were used. Increasing NaCl in the brine from 0 to 10% w/w had little effect on the arsenic sorption capacity. Maximum uptake was observed within a pH range of 4-6. The Langmuir capacity coefficient was determined to be 248 mg/g at pH 5.0, which surpasses other literature-reported capacity values. The final treatment sludge was able to pass the TCLP (Toxicity Characteristic Leaching Procedure) based leachability of 5 mg/L as As.

Complete particle stabilization of 0.1g/L as Fe of the nanoparticles was achieved with ≥0.04 wt.% starch or ≥0.005 wt.% CMC. The mean particle size of stabilized magnetite was 75 nm and 34 nm for starch- and CMC-stabilized magnetite, respectively. The stabilized nanoparticles can be used either for water treatment or for in situ immobilization of arsenic in soil and groundwater. When used for water treatment, the starch and CMC-stabilized nanoparticles offered 9.3 and 5.4 times, respectively, greater arsenate sorption capacity than the commercial magnetite particles, based on isotherm tests. Compared to CMC-stabilized nanoparticles, starch-stabilized nanoparticles not only offered greater sorption capacity, but also faster adsorption rate owing to its nearly neutral surface potential. For a nanoparticle suspension of 0.1g/L as Fe, increasing starch concentration from 0 to 0.04 wt.% converted the gravity-settleable aggregates of magnetite into fully dispersed nanoparticles and increased arsenate uptake by 2.2 times. Further increasing the starch concentration to 0.1 wt.% resulted in smaller nanoparticles and a furhter increase in arsenate uptake by 14%. A weak external magnetic field was able to completely separate the spent nanoparticles from water.

Preliminary results indicated that the stabilized nanoparticels can be used for in situ injection into contaminated soil or solid waste, thereby facilitating effective immobilization of arsenic. Column breakthrough tests revealed that both starch- and CMC-stabilized magnetite nanoparticles were highly transportable through a sandy soil. For example, at a pore velocity of 0.213 cm/min and an influent nanoparticle concentration of 0.1 g/L as Fe stabilized with 0.04 wt.% of starch, the full breakthrough concentration of the stabilized nanoparticles reached 90~95% of C_0. Yet, once delivered in positions (i.e. upon removal of external injection pressure), the nanoparticels would remain immobile, serving as a permanent sink for prolonged arsenic immobilization. **Fig. 1** shows the column elution histories of arsenic from an As-laden sandy soil column. The results indicated that the magnetite nanoparticle suspension reduced leachable As from 10.5% to 1.5% during a ~30 pore volumes column run. When subjected to TCLP tests, the nanoparticle treatment reduced the TCLP leachability of arsenic by >50%% compared to the water-amended soil sample.

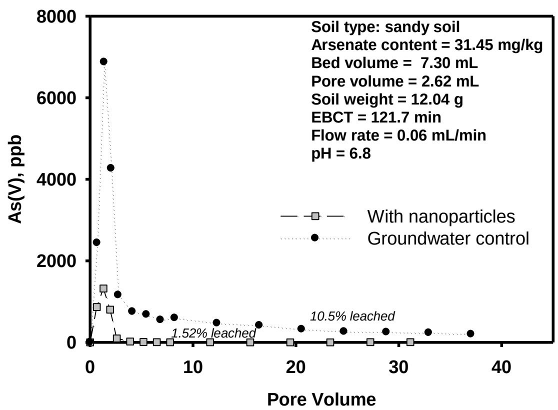


Fig. 1. Arsenic elution histories when an As-laden sandy soil was eluted with groundwater and a nanoparticle suspension (0.1g-Fe/L, 0.04% starch).

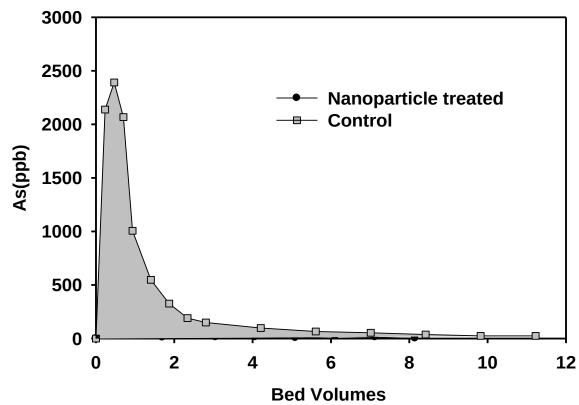
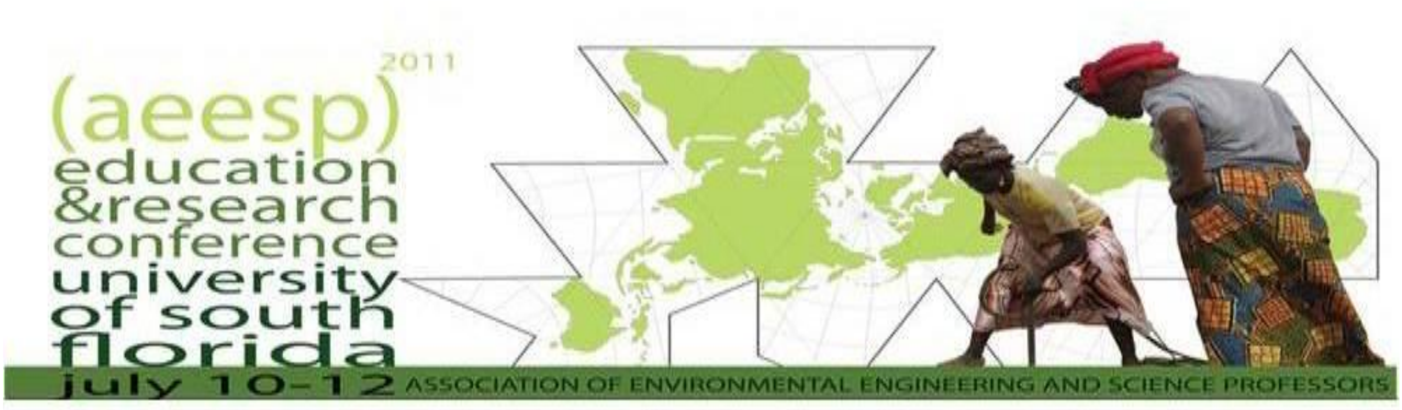


Fig. 2. Arsenic elution histories when a nanoparticle treated and a fresh poultry litter were eluted with simulated rain water.

The nanoparticels were also effective for immobilizing arsenic in a poultry litter. Batch desorption tests indicated that at a litter to particle suspension ratio of 1g to 100 ml (0.5g/L Fe nanoparticles with 0.2wt.% starch), the nanoparticles reduced the aqueous arsenic concentration from ~130 ppb (in control) to <20 ppb in 30 minutes. Column elution tests (**Fig. 2**) showed that when 2 g of the poultry litter was treated with 0.5 g as Fe of the nanoparticles, the arsenic leachability was reduced by ~88%, compared to untreated fresh poultry litter.



Research Category #2: ***Advances that Assess and Improve Air Quality and Waste Management***

Index of Oral Presentations

Research Category # 2

ADVANCES THAT ASSESS AND IMPROVE AIR QUALITY AND WASTE MANAGEMENT

THE CONTRIBUTION OF LANDFILL GAS TO RENEWABLE ENERGY PRODUCTION

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Landfills are currently the most cost-effective approach in managing municipal solid waste in the US, with more than 54% of the generated municipal solid waste landfilled in 2008. One potential revenue source for landfill owners is collecting and utilizing landfill gas (LFG) to produce energy from the methane content. LFG to energy (LFGTE) facilities can result in a positive cash flow through energy sales, carbon credit trading, and tax credits for producing and using renewable energy. Acknowledging the fact that the methane is being produced from biomass, LFG is considered a renewable energy resource in almost all US state-established renewable portfolio standards. This fact encourages landfill owners to invest in LFGTE for both environmental and economic benefits.

Changes in regulations and policies, as well as improved operating procedures, are likely to occur during the lifetime of LFGTE projects and affect their economic viability. Recent economic debates regarding controlling greenhouse gas emissions have focused mainly on two scenarios, carbon tax and carbon-trading. Although conceptually simple to understand, policy makers and public communities are currently less likely to discuss the establishment of a carbon tax due to the recent economic recession. Yet businesses have in the past shown interest in the rising carbon trading market. The US voluntary carbon trading market was valued over $0.7 billion in 2008 (compared to $0.3 billion in 2007 and $0.1 billion in 2006).

Cost and revenue factors can be analyzed to study the economic parameters affecting LFGTE projects and facilitate managerial and operational decision making. In this project, LFGTE potential was estimated for the state of Florida, as a case-study demonstration, using a modified version of the US EPA LandGEM model, with consideration of model uncertainties. Total benefit and cost, marginal benefit or cost, feasibility threshold, and return of investment were studied for a typical landfill. Costs and revenues were calculated using a modified version of the Bioreactor Landfill Economics Model (BLEM; Berge et al., 2009). Also, a sensitivity analysis was done to study the effect of changing economic parameters on the viability of LFGTE projects, considering various scenarios of policies, renewable portfolio standards, and operation procedures.

Outcomes showed that Florida landfills operators could avoid approximately 320 $MTCO_2e$ of uncollected greenhouse gases and potentially generate over 80 billion kWh of electricity from LFG during the 2010-2035 timeframe. This energy production would be equivalent to removing some 70 million vehicles from Florida highways or eliminating the need to import over 800 million barrels of foreign oil. With approximately half of Florida landfill energy potential used at present, there is high untapped capacity for LFGTE. Furthermore, studying the renewable power density of Florida landfills showed that LFGTE could provide a power density as high as 10 $W \cdot m^{-2}$, ranking above wind and ocean heat and comparable to geothermal, tidal, and hydro energy. The power density could be further increased by using the closed landfill site for other means of renewable energy production. For example, flexible membranes with photovoltaic cells have been installed at the Tessman Road Landfill, San Antonio, Texas, US, on 2.3 hectares of land to produce 182 MWh of solar electricity.

Additionally, preliminary outcomes from the economic analysis show that, landfill operation under the base-case assumptions result in a net cost, revenue from operating a LFGTE facility, as well as trading carbon credits in the voluntary over-the-counter market would make the project economically feasible. In the absence of a federal renewable portfolio standard and carbon trading scheme, the fee received for waste disposal and electricity sales are the main economic revenues for landfill owners. Evaluating net benefit under variable electricity sales prices showed that the landfill could significantly benefit from minimal increases in pricing. The most economically beneficial scenario is operating the landfill as a bioreactor cell. Bioreactor operation, revenue from LFGTE production, and trading carbon credits increase the net benefit significantly and result in a 32% return of investment, 10 years earlier than in the base case. Overall, energy sales revenue from a LFGTE facility could significantly affect the economic feasibility of landfill projects despite the fact that, in the current US voluntary carbon market, revenue from trading carbon credits is minimal. However, policies and regulations favoring carbon trading will promote the value of renewable energy production at landfills.

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INFLUENCE OF LOCAL AND GLOBAL SOURCES ON TRANSIENT AIRBORNE PARTICULATE MATTER LEVELS IN HOUSTON, TEXAS

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Background. Airborne particulate matter (PM) contributes to haze, acid rain, global climate change, asthma and other respiratory ailments, cardiopulmonary disease, and decreased life expectancy. A portion of the toxicological response of PM is thought to arise from the metals content of PM. Additionally, particulate metals concentration data can be employed as inputs to source-receptor models to identify emission sources necessary to develop effective air quality management strategies. Hence, accurately measuring metals in atmospheric PM is an important aspect of identifying their sources and impacts on human health and the environment.

Atmospheric particles originate directly from natural sources and human activities (primary particles) or condense from gaseous precursors (secondary formation). Sources of primary particles include industrial activity, combustion of biomass, coal, and oil, motor vehicles, resuspension of crustal material, etc. In addition to these local sources, trade winds carry a portion of the 160 to 760 teragrams of dust emitted from the Sahara-Sahel region in North Africa to the continental United States [1]. This research specifically focuses on transient variations in aerosol concentrations in the greater Houston area caused by industrial malfunctions, equipment start-up or shutdown, incursion of smoke from Central America, and aeolian North African dust.

Objectives. This presentation will (i) describe the development of a novel analytical method for particulate trace metals using dynamic reaction cell inductively coupled plasma – mass spectrometry (DRC-ICP-MS), (ii) provide evidence for unreported emissions of fine (< 2.5 µm) and coarse (< 10 µm) particles by petroleum refining operations, and (iii) investigate a particular North African dust episode, which increased PM levels in Houston over a 3-day period in 2008.

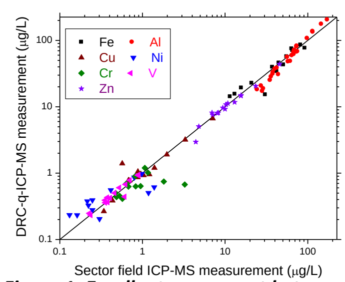

Figure 1. Excellent agreement between sector field and DRC ICP-MS. From [2].

Results and discussion

DRC-ICP-MS. PM samples were first digested using HF, HNO_3, and H_3BO_3 in two stages in a microwave oven each with set points of 200 °C, 225 psig, and 20 minutes dwell time. We recently improved measurements of key aerosol elements including Al, V, Cr, Fe, Ni, Cu, and Zn by exploiting ion-molecule reactions in a dynamic reaction cell with NH_3 [2]. Other elements (Na, Mg, Si, K, Ca, Sc, Ti, Mn, Co, Ga, As, Se, Rb, Sr, Zr, Mo, Cd, Sn, Sb, Cs, Ba, Pb, Th, and U) and lanthanoids (Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu), which are important for source apportionment studies, were also measured. Inter-laboratory comparison using sector field ICP-MS demonstrated the accuracy of DRC-ICP-MS (Figure 1).

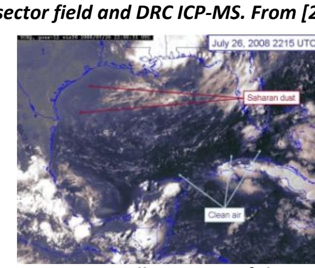

Figure 2. Satellite image of the Gulf of Mexico showing long-range transport of Saharan dust to Houston, Texas.

Monitoring industrial emissions. The novel analytical method described above was used to determine the elemental composition of over 150 PM_{10} samples collected from an industrialized site. La/Ce ratios in a small fraction of the samples were > 1 as it is in source samples from refinery cracking catalysts. Also, the heavy lanthanoids Tm and Lu were almost always below their detection limit (0.018 ng m^{-3}), but were detected infrequently. These same PM_{10} samples also exhibited elevated concentrations of all lanthanoids, typically 10 – 20 fold higher than the median value. These observations suggest episodic releases of fluidized bed catalytic cracking catalysts from petroleum refineries located in the vicinity of the sampling site that are greater than the "routine" emissions levels. Concentrations from one sample collected on May 27, 2009 between 12:00 noon and 6:00 pm Central Daylight Time were strongly and positively correlated with corresponding average values measured in refining catalysts. The abundance sequence of the major lanthanoids were identical in cracking catalysts and this particular sample (La>Ce>Nd>Pr>Gd~Sm>Dy). Enrichment factors for all light lanthanoids with respect to their average concentrations in cracking catalysts using Nd as the reference were close to unity. Therefore, fluidized-bed cracking catalysts appear to be primarily responsible for lanthanoid enrichment. Higher airborne PM concentrations can be attributed to an emissions event in one of the local refineries that released catalyst from the fluidized bed cracking unit to the atmosphere.

North African dust episode. Satellite imagery tracked the transport of dust from North Africa to Houston between July 25 and July 27, 2008 (Figure 2). During this period, Tapered Element Oscillating Microbalance samplers operated by the Texas Commission on Environmental Quality (TCEQ) measured higher $PM_{2.5}$ concentrations throughout southeastern Texas. We also measured elevated levels of coarse and fine particles collected on Teflon membranes (Figure 3). As observed, 24-hour $PM_{2.5}$ mass levels rose from 9.6 to 30.9 μg/m^3 at Channelview, TX. PM_{10} mass showed an even more substantial rise in concentration from 18.4 to 83.8 μg/m^3.

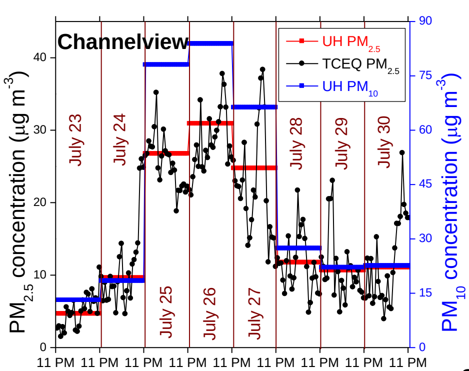

Figure 3. Elevated PM levels during July 25, 26, and 27 coinciding with satellite observations of Saharan dust transport.

48 elements, including lanthanoids, were quantified to apportion PM mass. The crustal elements (Al, Na, Mg, Si, K, etc.) consistently increased with mass, indicating their association with Saharan dust. Al and Si followed a similar pattern with mass at both sites. However, anthropogenic metals (Cu, Mo, V, Ni, Zn, etc.) stayed consistent through the dust event at both Houston sites. Elemental ratios of these elements also varied independently of the dust event. The V/La ratio five days prior to the event ranged between 9.3 – 35.2 but was only 4.0 – 17.2 during the event. Similar metal ratios demonstrate the simultaneous contributions of local and global sources. These data provide insightful information on the prevalence and nature of these long-transport aerosols, which consistently impact the local atmospheric chemistry. On-going work is focused on chemical mass balance calculations and enrichment factor analysis to better quantify the Saharan dust contribution to total aerosol mass.

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CHARACTERIZING UNCERTAINTY IN ATMOSPHERIC RESPONSE MODELING

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Atmospheric models are relied upon to simulate not merely the concentrations of various pollutants, but also their sensitivities to perturbations in conditions. Most prominent for environmental policy applications is the sensitivity of concentrations to changes in emissions. Those sensitivities underlie the relative response factors that derive the selection of emission control policies in the development of SIP attainment plans. However, whereas simulated concentrations can be evaluated against ambient observations, there is no direct gauge of model performance or uncertainty in simulating concentration-emission sensitivity relationships. Characterizing the uncertainty of those sensitivities could help inform decision-making about the amounts and types of emissions controls needed to attain air quality standards in a cost-effective manner.

This talk will review various approaches that have been deployed by the speaker and other scientists to characterize the uncertainty of pollutant-emission sensitivities in atmospheric models. The approaches utilize sensitivities computed from photochemical models using either the high-order decoupled direct method (HDDM) or brute force finite differencing. While HDDM enables more computationally efficient calculation of high-order sensitivity coefficients, it is not available in some photochemical models or for processes involving particulate matter. Although formation of ozone and secondary particulate matter are highly nonlinear, accuracy testing showed that these nonlinear relationships can be well-characterized by Taylor series expansions involving second-order cross-sensitivity coefficients. Accuracy is well maintained even in predicting the sensitivity of pollutant concentrations to very large perturbations in emissions, under very large perturbations in model input conditions (e.g., simultaneous 50% changes in emission rates and photolysis rates) from those that were used to establish the predicted relationships.

Much of the work that will be discussed here arose from an EPA STAR grant investigating uncertainties in the photochemical modeling that informs the development of State Implementation Plans. Actual modeling episodes were taken from recent SIPs to serve as the bases of those analyses. Associated papers introduced new techniques to more efficiently represent how parametric uncertainties in model inputs generate uncertainty in predicted concentrations and sensitivities. However, those studies neglected structural uncertainties in the photochemical models, which are being explored in ongoing work. For example, predictions of ozone responsiveness to precursor emissions may be strongly influenced by the choice of chemical mechanism or by method for generating the biogenic emissions inventory. Ongoing work is jointly considering parametric and structural uncertainties that could affect predictions of the responsiveness of ozone to precursor emissions. Such efforts could highlight priorities for improving the inputs to photochemical models.

Opportunities for applying Bayesian techniques using observational data to refine estimated probability distributions will also be discussed. Ongoing work in our research group is exploring how two techniques that have been utilized in previous atmospheric modeling literature—Bayesian Monte Carlo and Bayesian Model Averaging—could provide complementary information characterizing *a posteriori* probability distributions of pollutant responses to emission perturbations. Rather than assuming each parametric or structural uncertainty case is equally likely, Bayesian approaches can utilize observational data for concentrations of ozone and its precursors to assign a relative weight or likelihood to each case. Preliminary results from those efforts will be presented.

THE ARKANSAS PEOPLE PARTICIPATING IN LEAD EDUCATION (APPLE) PROGRAM: CASE STUDY IN EDUCATION, OUTREACH & PRACTICES FOR SUSTAINABLE COMMUNITIES AND LEAD MANAGEMENT

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The design of sustainable communities requires the engagement of multiple stakeholders, with unique challenges for areas with older infrastructure and multiple economic disadvantages. Lead, harmful to human health, can be found in the paint and piping materials of older buildings, posing unique challenges for especially impoverished residential areas. The Arkansas People Participating in Lead Education (APPLE) Program is a collaborative effort between six Arkansas State, National and Community Organizations to reduce lead exposure of Arkansas residents. This presentation will describe the integrated approach to reducing human exposure to lead in Arkansas, compare the educational material and outcomes from working with the multiple stakeholders/participants, and offer insights into opportunities for interdisciplinary curricular development between engineering/science and public health schools/departments based on experiences thus far.

In 2009, Arkansas was listed as one of the unhealthiest states in the country with a 25% increase in the number of children living in poverty over the last 10 years. Over half of the children in various communities live in rented housing, a majority of which were built before 1975 when leaded paint and pipes were routinely used. Many of these families must therefore rely on landlords to improve their living conditions, by safely updating homes and removing lead sources. Exposure to lead comes primarily from lead dust released during renovation activities, but also from paint chips in poorly maintained homes.

APPLE started as a 1 year grant from the EPA in 2008 to implement lead awareness, lead training and model municipal legislation to needy communities in Arkansas (Little Rock, North Little Rock, Pine Bluff, Mariana, Helena-West Helena and Conway). Table 1 summarizes the main educational components of APPLE and the corresponding target audiences. APPLE hosted hands-on, and effective "call to action" lead awareness workshops and lead-safe work practices training seminars that reached 300 local area contractors and landlords. APPLE staff worked with city officials to implement municipal legislation encouraging dissemination of information on lead-safe work practices to contractors and individuals seeking permits to renovate at-risk structures in these communities. Results from 248 respondents at these 8 hour trainings on lead –safe work practices showed that there were positive shifts in attitude and behavior towards lead-safe work practices following training as other studies have found [2], but that content clarification was desired for lead exposure sources and exposure routes to children [3]. In April 2010 the Environmental Protection Agency implemented a new Renovate, Repair and Painting Rule (RRP) [1] which requires certified lead-safe work practices training for any worker who disturbs more than 6 ft^2 of lead based paint inside and 20 ft^2 of lead-based paint outside a target home or child-occupied facility.

Since April 2010, another 380 contractors and landlords have paid for training as a part of the new EPA RRP certification requirement using updated training materials, and improved hands-on-skill sets. Two hour community seminars were also held reaching approximately 800 parents, and a one hour seminar was designed for landlord association meetings of which 100 have attended to date. Meetings with the Mayors from 5 counties resulted in the implementation of new requirements that contractors receive project information upon filing of registration forms.

Table 1: Stakeholder groups and APPLE activity with the population reached in brackets.

Stakeholders	**8 hour course**	**1 or 2 hour seminars**	**PSAs/News/ Emai /Website**	**Classes**
Contractors & Landlords	X (300*) X (380#)			
Landlord Association meetings		X (100)		
Parents		X (800)		
Mayors			X (5)	
University Students (Hazards Control Course)			X	X

*Trained for free prior to the EPA 2010's RRP rule; #Paid for certification after April 2010

Through new EPA funding, the project has been expanded to include Data Gathering and Database Development to identify and reduce lead poisoning in under-studied areas with high potential for undocumented, elevated blood-lead. Data from Head Start Centers (i.e., 19 Head Start Grantees and up to 300 small, midsize and large centers usually serving vulnerable populations) across Arkansas is being compiled into one database for easy viewing and interpretation. APPLE is providing education and outreach to doctors to increase their screening and reporting rates for Head Start patients and other vulnerable children under their care. This information will lead to the development of a Centralized State Reporting System. Sustained relationships with contractors and research into city development plans are important for identification of communities that might be at risk from exposure from lead releases from drinking water pipes [4] which is not incorporated into RRP training material. Partnering with environmental engineering programs to develop that material and solutions for the target populations we serve provides an opportunity for the creation of new curricular material, maybe interdisciplinary project based service learning courses, that educate our students whilst improving the health and sustainability of the communities in which we live. Integration of lead activities into a holistic healthy homes approach will also be crucial directional changes for improving community health.

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LIGHT-DUTY HYBRID VEHICLES: QUANTIFYING REAL-WORLD TAILPIPE ULTRAFINE PARTICLE EMISSION RATES UNDER COLD, HILLY CONDITIONS

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Very little real-world data exists in the literature on the tailpipe emissions of hybrid-electric vehicles (HEVs), especially light-duty, gasoline-powered hybrid-electric passenger cars. This is especially true for emissions and performance metrics evaluated under actual on-road driving conditions, and even more so for terrain and climate conditions routinely encountered in northern mountainous states like Vermont. In northern states such as Vermont, there are unique topography and climate factors that affect motor vehicle use and emissions and associated air quality. These factors include: (i) high road grades that increase the power-demand load placed on the internal combustion engine (ICE); (ii) low winter temperatures that limit hybrid-electric vehicle battery performance; and (iii) driver behaviors that affect aggregate “cold start” emissions (winter weather extended idling and use of engine block heaters). Thus, there is a need for real-world data on HEV use, operation, emissions and performance as a function of ambient temperature and road grade in order to better quantify . It is important to identify the environmental conditions that have significant impact on alternative vehicle performance and emissions, because the public’s perception of vehicle performance will affect their purchasing decisions and this will, in turn, affect local and regional air quality.

Ultrafine particles (diameter less than 100 nm) were quantified in the exhaust of two 2010 model Toyota Camry vehicles during repeated runs of a 32 mile route in Chittenden County, Vermont by a single driver to assess the relative particle number emissions between the conventional and hybrid-electric propulsion system. The hybrid vehicle had a 147-horsepower, 2.4 liter, 4-cylinder ICE and a 105 kW permanent magnet AC synchronous electric motor powered by sealed nickel-metal hydride batteries. The conventional vehicle was powered by a 169-horsepower, 2.5 liter, 4-cylinder ICE. Both vehicles were equipped with the same emissions control devices. Using the University of Vermont- built TOTEMS (“Total On-Board Tailpipe Emissions Measurement System”) instrumentation package, particle and gas emissions as well as vehicle location (by GPS) and engine/vehicle operating parameters were recorded second-by-second as the vehicles traveled in the real-world transportation network. Road grade was independently measured by the Vermont Agency of Transportation and joined to the vehicle emissions and performance database to enable evaluation of road grade effects and calculation of vehicle specific power (VSP) using location-specific road grade.

Particle number concentrations and emission rates (PNERs) for the city-driving portion of the route were surprising: the hybrid vehicle had cumulative and average PNERs that were 2 times *higher* than the conventional vehicle of the same Camry model year. The ability of the TOTEMS package to measure second-by-second emissions and engine parameters enabled more detailed analysis of the vehicle operating regimes that led to high particle number emissions from the hybrid. Both vehicles had elevated particle emission events during acceleration from stops and at high road grade, but the frequency, magnitude and duration of the elevated particle emissions events were all higher for the hybrid vehicle compared to the conventional (Figure 1). These particle emissions data are especially surprising given that the ICE on the hybrid vehicle was off up to 57% of the time during city stop-and-go driving.

The real-world emissions data measured in this study call into question the air quality benefits associated with hybrid-electric propulsion systems for light-duty vehicles of the Toyota planetary-combination hybrid design under the conditions studied. Further analysis of the hybrid operating parameters indicate that elevated particle number emissions events corresponded to ICE "restart" episodes that apparently involve fuel enrichment and associated particle formation.

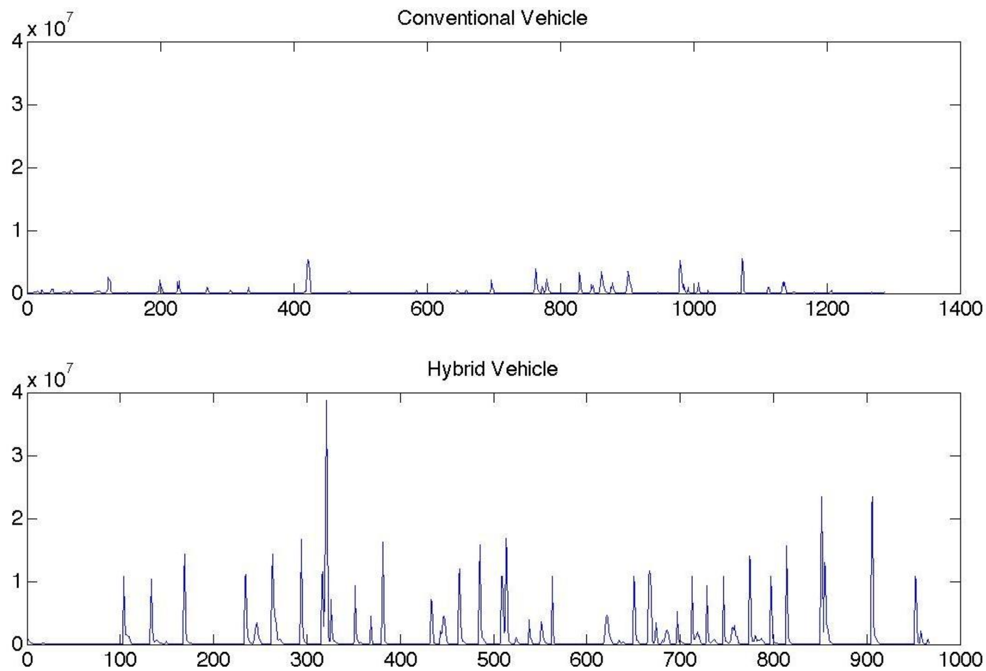

Figure 1. Particle number concentrations (#/cm^3 at 1Hz resolution) from conventional (top) and hybrid-electric (bottom) Toyota Camry vehicles over city portion of driving route.

APPLICATION OF BINARY MIXTURE OF INDUSTRIAL SOILD WASTES IN CONCRETE MIXES

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Introduction In view of the recent global demand for using sustainable materials, recycling is a logical option for materials not suitable for composition. Metal and plastic are the most common of these materials. With increasing environmental pressure to reduce waste pollution, the concrete industry has begun adopting a number of methods to achieve these goals [1]. Reuse of industrial solid waste as a partial replacement of aggregate in construction activities results in reducing the demand for extraction of natural raw materials as well as saving landfills space [2]. The quality of aggregate is highly important since approximately three-quarters of concrete volume are occupied by aggregate; it greatly affects the strength, durability and the structural performance of concrete. Iron smith processes as well as plastics manufacturing plants generate significant amounts of iron filings and plastic wastes, respectively. These types of wastes create serious environmental problems, mainly due to their non-biodegradability and the inconsistency of the wastes streams. Several studies dealt with incorporating a single type of waste in concrete mixes, none of them concerned about utilizing a mixture of waste materials. The aim of this study is to evaluate the influence of recycling mixed iron filings and granular plastic waste on the fundamental mechanical properties of concrete mixes.

Materials and methods Type I Portland cement was utilized in this study. Natural sand of 4.75 mm maximum size and crushed stone aggregate of maximum size 20 mm and bulk density of 1545 kg/m^3 were used. Waste iron filings were collected from local iron smith workshops as they normally generated in tremendous quantities from this type of industry. Granular waste plastic represents the discarded waste collected from plastic manufacturing plants. It consists of approximately 80% polyethylene and 20% polystyrene.

Experimental procedure Plain concrete mixes consisted of 715 kg/m^3 sand, 1020 kg/m^3 gravel, 380 kg/m^3 cement and a water to cement ratio of 0.53 were prepared as reference mixes (M0). Three types of waste-concrete mixes; M1, M2, and M3 were prepared using waste iron filings to replace sand by 10, 15, and 20%, respectively with the granular waste plastic to substitute the sand by 2% weight fraction. All the concrete mixes were cured for 28 days.

Test results and discussion The compressive and flexural strength tests outcome for the concretes made with iron and plastic wastes are presented in Figure 1. The results demonstrate that as the reused waste contents increase in mixes M1, M2, and M3, the tendency of compressive strength and flexural strength increase above that for the plain mix by 2.2, 4.3, and 6.4%, respectively for the compressive strength and by 6.8, 16.9, and 23.7%, respectively for the flexural strength. This tendency could be attributed to pozzolanic effect of iron filings that overcomes the retardation of hydration caused by the hydrophobicity of waste plastic.

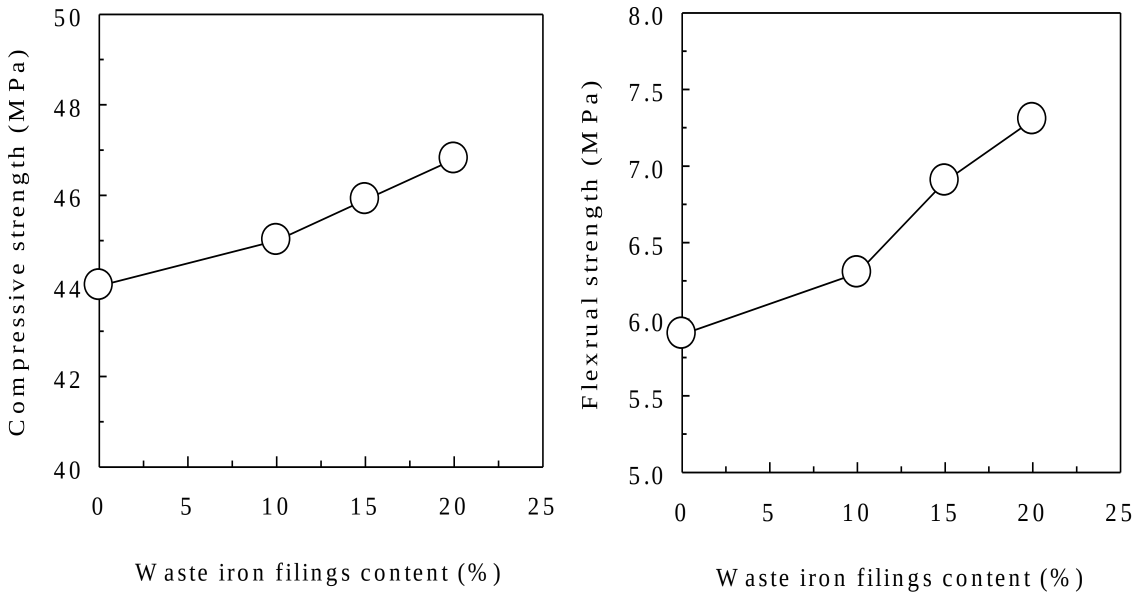

Fig. 1: Compressive strengths and flexural strength for the plain and waste-concrete mixes at 28 days curing using waste iron filings to replace sand by 10, 15, and 20% in the presence of 2% granular waste plastic.

The results of the slump tests indicate that as the waste aggregate content increase, the tendency of slump values slightly decrease below the slump of the plain mix. In spite of this decrease in the slump values, the mixes were workable. The decrease in slump values could be attributed to the assumption that waste particles are larger than sand as well as having sharper and more angular grain shapes. Moreover, as the content ratio of the mixed wastes increased, additional cement paste attached to the surface of the waste resulted in less available cement paste required for concrete fluidity.
Colors of the waste materials did not have any noticeable effect on the prepared waste-concrete specimens.

Conclusion It can be concluded that this binary mixture of solid waste materials can be used in concrete mixes without hindering its mechanical properties up to the composition range used in this study. This study is exploratory, requires further work and investigations to assess the possibility of increasing the fraction of waste materials beyond the range used in this study.

Acknowledgments This work was funded by the Ministry of Housing, Iraq.

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BRIDGING THE CAPABILITIES OF EXISTING HUMAN EXPOSURE MODELS WITH CURRENT NEEDS

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Globally, an estimated 8 million chemical substances are commercially available. International regulations requiring registration of these substances are intended to protect human health and the environment. The European Chemicals Agency (ECHA) List of Preregistered Substances includes about 143,000 substances and the U.S. EPA Toxic Substances Control Act (TSCA) inventory currently contains about 83,000 registered chemicals. About 15,000 additional substances are registered under other legislation in the U.S. and between 500 and 1000 new chemical substances are produced annually. The majority of these chemicals lack enough information to fully characterize their potential impacts on human health and the environment. Therefore, the need for new approaches has been recognized and is currently being addressed with emerging programs globally: (1) the new substances provisions of the Canadian Environmental Protection Act (CEPA) and (2) the Registration, Evaluation and Authorisation of Chemicals (REACH) in the European Union. These approaches integrate both exposure and hazard as commensurable components in the process of categorization, screening and prioritization for risk assessment. Following recommendations of the National Research Council (NRC), the U.S. EPA has also been developing systems approaches to evaluate chemicals across their entire life-cycle in a holistic framework.[1]

New efforts to manage chemical risks call for hazard information to be interpreted in the context of exposure information. Unfortunately, the exposure scenarios associated with many products are not well characterized by simple approaches to exposure assessment for a number of reasons, including: (1) the relevance of surrogate exposure estimates; (2) the number of sources and pathways through which exposure may occur; (3) the heterogeneity of concentration in multiple medium; and (4) significant spatial and temporal variability.[2] Therefore, prioritizing tens of thousands of chemicals call for advanced techniques in decision making under high uncertainty.

A key challenge to developing new models and approaches exists in establishing which information sources, criteria and metrics should be used in factoring exposure into prioritization schemes. In April 2009, the U.S. EPA issued an exposure based prioritization challenge to several exposure modelers. By evaluating the exposure-based rankings produced from these efforts, EPA can leverage knowledge across the exposure science disciplines to gain a better understanding of how existing exposure models evaluate potential exposures and subsequently rank a set of chemicals.

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In this study a gap analysis of these efforts was conducted to elicit the expert judgment of the proprietary modeling efforts. The gap analysis evaluates the assumptions, defaults, relevant data sources, and decision criteria used to rank the given set of chemicals. Based on a set of benchmarking chemicals, an expected performance level is determined for each model, and then used as a basis for comparison.

The overall gap analysis of the models addresses critical modeling components in the linked models across the exposure to effects paradigm: emissions, environmental fate and transport, distribution (i.e. concentration in environmental media) and exposure. These challenge experiments use complex proprietary models that integrate component processes across the exposure continuum. Comparing the ranking results from these efforts was challenging because of different thresholds, interactions between input factors, and the mixture of continuous and discrete inputs. Analysis of variance (ANOVA) provides a robust approach to identifying key controllable inputs as well as sources of uncertainty from independent models.[3] A preliminary analysis leads to insights regarding the factors driving the ranking results despite uncertainty. Preliminary results show agreement between ranking models for the given challenge chemicals based on the relative intake fraction for adults with constant unit emissions rates and in the absence of mode of entry information. When information is introduced on assumed or predicted routes and pathways of exposure (i.e. use scenarios), actual emissions rates and internal dose metrics (from Absorption, Distribution, Metabolism and Excretion (ADME) processes), discrepancies in estimated exposure levels are observed. Future work includes a value of information analyses to quantitatively assess the importance of these types of information as they relate to risk rankings within a priority setting decision framework.

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MICROBIAL POPULATION CHARATERIZATION TO REVEAL SOURCES OF BACTERIA IN INDOOR AIR

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Physical processes affecting the sources and character biological aerosols in indoor air are poorly understood. From particle dynamics theory, and based on findings for total aerosols, potential sources of airborne microorganisms are closely related to human occupancy (Ferro et al, 2004; Thatcher and Layton, 1995). We hypothesize that resuspension is a dominant source of airborne microbial material in indoor environments. To test this hypothesis, size-resolved concentrations of total and biological material in indoor air were quantified in classrooms under occupied and unoccupied conditions. The microbial diversity of potential bioaerosol sources (outdoor air, floor dust, and human skin) was identified via ribosomal RNA encoding gene analysis/next generation DNA sequencing to assess the similarity of indoor air microorganisms to the microbial population of potential sources.

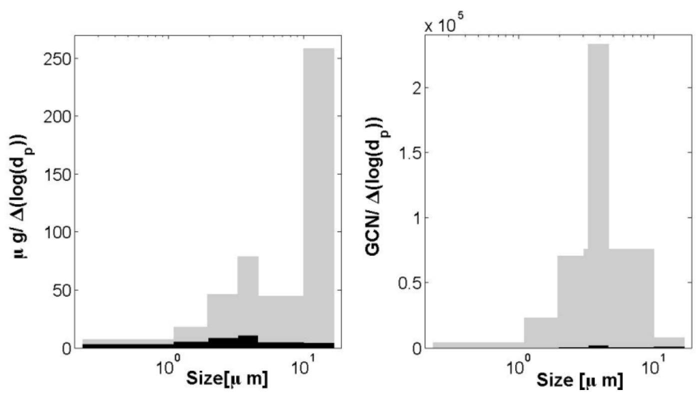

Figure 1. Indoor PSD (µg $(\Delta\log(d_p))^{-1}$) and BSD (GCN $(\Delta\log(d_p))^{-1}$). Grey bars represent concentrations during occupation and black bars represent concentrations during vacancy.

Indoor/outdoor ratios (I/O) of total particle numbers (data not shown) reveal that during the occupied period, only a minor fraction of the aerosols larger than 1 µm can be accounted for by infiltration and ventilation from outdoor air. Significant increases of indoor total particle mass and bacteria concentrations were observed during the occupied period compared to the unoccupied control case, as shown in Figure 1. These increases varied in magnitude with the particle size and ranged from 2 to 65 times greater for total mass and 13 to 2800 times greater for bacterial genome copy numbers (GCN) for the occupied case. Particle size distributions (PSD) for total aerosols in the occupied cases follow the predictions from a previous study in which larger super-micron particles are more effectively resuspended (Thatcher and Layton, 1995). Bacterial size distributions (BSD) under occupied and unoccupied cases corresponded with the physical size of bacteria (~1 to 3 μm), suggesting that most bacteria were not highly agglomerated or attached to other significantly larger particles. Less than 1% of the total aerosol mass was from bacteria during the occupied time.

Microbial ecology descriptions and analysis suggest that bacterial populations in indoor air are similar to populations in floor dust and less similar to populations in outdoor air and on human hands. These results reinforce the significance of human occupation for increased indoor air bioaerosol concentrations and suggest that under our experimental conditions, resuspension of floor dust, rather than shedding or ventilation, is the dominant source of airborne microbial material when people are present.

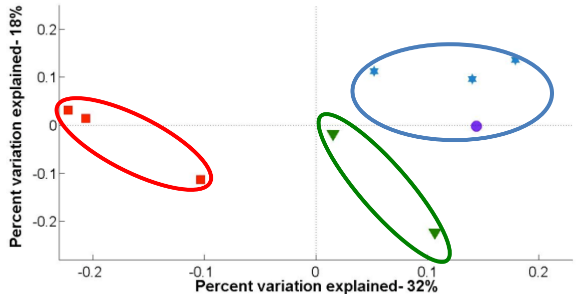

Figure 2. Phylogenetic distance-based principal component analysis of microbial communities in indoor air (blue stars), outdoor air (green triangles), floor dust (purple circle) and hand microbiota (red squares).

In conclusion, occupancy is a strong source of indoor bacterial aerosols. The marked differences between total particle size distributions and bacterial size distributions of our samples suggest that size-dependent aerosol models and exposure calculations that use total aerosols as a surrogate for microbial aerosols may incorrectly predict concentrations of and exposure to airborne bacteria. Next generation DNA sequencing and recently developed bioinformatics analyses of microbial community populations indicated that resuspension from floors, and not direct particle shedding from humans, was the dominant source for indoor bacterial bioaerosols.

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PHASE TRANSFORMATION OF METALS IN REUSING SLUDGE FOR CERAMIC PRODUCTS: EXAMPLES OF NICKEL AND COPPER

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A sustainable wastewater treatment strategy should develop a closed-loop material flow by recycling and reusing the water resource and waste materials. The sludge generated from municipal wastewater treatment plants has become an increasingly serious solid waste problem for many regions in the world, particularly for those densely populated urban areas. On the other hand, the huge quantity of industrial wastewater sludge generated from many heavily industrialized areas in the world is imposing a very high burden to the local environments. For example, landfilling is currently the only means to dispose of nearly 900 tonnes of dewatered municipal wastewater sludge produced in Hong Kong every day, and is apparently not a sustainable method in the long term wastewater treatment strategy. As situated on the spine of Pearl River Delta (PRD) region, Hong Kong is also strongly influenced by the environmental impact of industrial activities in PRD region. The PRD has become the world's workshop and is a major manufacturing base for products such as electronics, textiles, plastics, and a range of other goods. The industrial waste sludge generated from these manufacturing activities is often of high concentrations of hazardous metals and is therefore subject to stringent pretreatment requirements before being disposed in qualified landfills. Although thermal treatments (incineration, pyrolysis, gasification, etc.) have been proposed to largely reduce the sludge volume needed for disposal, the metal concentrations in the resulting incineration ash will be enriched and require further consideration in their stabilization process.

The goal of beneficially using waste sludge or its incineration ash for marketable products is to provide an opportunity to achieve a closed-loop for a more sustainable material flow. However, how the hazardous metals can be safely and reliably stabilized in the products is a major challenge for such development. In this study, the feasibility of stabilizing nickel or copper laden sludge or its incineration ash with commonly available ceramic precursors was investigated. High metal incorporation efficiency was achieved via forming $NiAl_2O_4$ and $NiFe_2O_4$, $CuAl_2O_4$ spinels through the reactions with aluminum-rich and iron-rich raw materials commonly used in construction ceramics. The $NiAl_2O_4$ was the immobilization phase produced when mixtures of NiO were sintered (>800°C) with γ-Al_2O_3, corundum, kaolinite, or mullite, as aluminum-rich precursors. Analogously, $NiFe_2O_4$ was the stable phase produced by firing (>600°C) NiO with hematite as an iron-rich precursor. The sintering experiment of CuO and alumina mixtures revealed that the optimal sintering temperature for $CuAl_2O_4$ formation was around 1000°C. Quantitative X-ray Diffraction (XRD) analysis was further applied to reveal the different nickel incorporation efficiencies in the sintering systems.

Prolonged leach tests of potential products of nickel and copper phases were carried out in acidic environments similar to TCLP to evaluate the durability of sintered products. Both aluminate and ferrite spinels proved superior to nickel and copper oxides for the immobilization of nickel or copper. The leaching behavior (congruent or incongruent dissolution) of product phases was also analyzed through the leachate composition, together with the potential reprecipitation mechanisms on the product solid surface. Furthermore, the detoxification effect of $CuAl_2O_4$ was tested through bacterial adhesion with *Escherichia coli* K12, and the comparison of bacterial adhesion on CuO and $CuAl_2O_4$ surfaces shows the beneficial detoxification effect in connection with the formation of the $CuAl_2O_4$ spinel. While current cement solidification/stabilization technologies are not generally successful in preventing metal mobilization in acidic environments (i.e., pH < 4.0), this study has demonstrated the success of stabilizing metal-laden sludge or its incineration ash from a wide-range of ceramic precursors. With the information reported, this study has demonstrated the potential of a reliable waste-to-resource strategy for the hazardous metals problem in sludge and thus may facilitate the development of a more sustainable wastewater treatment industry.

ENVIRONMENTAL AND SPATIAL FACTORS AFFECTING METHANOGENESIS INITATION IN SOLID WASTE

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Anaerobic decomposition of organic matter occurs in both natural (e.g., soil, peat bogs, digestive tracts) and engineered (e.g. landfills, anaerobic digesters) ecosystems. The primary end-products of anaerobic decomposition are methane (CH_4) and carbon dioxide (CO_2). Upon landfilling, rapidly degradable materials within the refuse anaerobically decompose resulting in an accumulation of volatile fatty acids (VFAs) and a commensurate drop in pH to a minimum ranging between 5.5 and 6. The low pH, high carboxylic acid conditions, which has been referred to as the anaerobic acid phase in solid waste decomposition, have been shown as inhibitory to methanogenic *Archaea* in analogous ecosystems such as peat and the rumen. In contrast to these findings, methanogenesis initiation occurs under these conditions, indicating the mechanism by which methane production begins in refuse is poorly understood.

There are two theories for how methane production initiates in landfills. One is that methanogenic *Archaea* (i.e. methanogens) tolerant to the low pH, high VFA conditions consume acids until the bulk pH is suitable for the establishment of methanogens that grow under pH-neutral conditions. The second theory is that spatially isolated areas of neutral pH exist while bulk pH is acidic and these localized regions of neutral pH act as initiation centers for methanogenesis. The goal of this study was to test these two theories and validate their importance relative to methanogenesis initiation in refuse.

To evaluate methanogen acid tolerance in decomposing refuse, three liquid inocula were derived: (1) refuse just entering active decomposition, (2) well-decomposed refuse and, (3) peat. Under high VFA concentrations, results showed methanogenesis initiation occurred at pH minima of 6.25, 5.75 and 5 for actively decomposing refuse, well-decomposed refuse and peat, respectively. The hydrogenotrophic *Methanoculleus* genus facilitated methane initiation in actively decomposing refuse (pH 6.25) while *Methanosarcina* triggered methane production in well-decompose refuse (pH 5.75). In peat, methanogenesis was facilitated by an uncultured *Methanosarcinales*. This suggests acid tolerance under low pH(i.e. 5 – 6.25), high VFA conditions may be relatively common provided sufficient acclimation time. However, methane production rates at lower pH were found to be 3 to 6 fold lower than those at neutral pH.

To evaluate the spatial influences on methanogenesis initiation, fresh refuse was placed into laboratory scale reactors, decomposed to the anaerobic acid phase, and destructively sampled when methanogenesis initiated. The active bacterial and archaeal populations were evaluated using RNA clone libraries, RNA T-RFLP and RT-qPCR. Measurements from eighty-one core samples from vertical and horizontal sections of each reactor showed large spatial differences in refuse pH (Figure 1), moisture content and VFA concentrations. No pH neutral niches were observed in reactors prior to methanogenesis. RNA clone library results showed most bacterial activity was attributed to the *Clostridiales* order. Methanogenic *Archaea* activity at low pH was catalyzed by *Methanosarcina barkeri*. After methanogenesis began, pH neutral conditions developed in high moisture content areas containing substantial populations of *M. barkeri*. These areas expanded with increasing methane production, forming a reaction front that advanced to low pH areas. In the absence of pH neutral niches, this study suggests methanogens tolerant to low pH, such as *M. barkeri*, are metabolically active under the low pH, high VFA conditions typically present during the anaerobic acid phase of refuse decomposition.

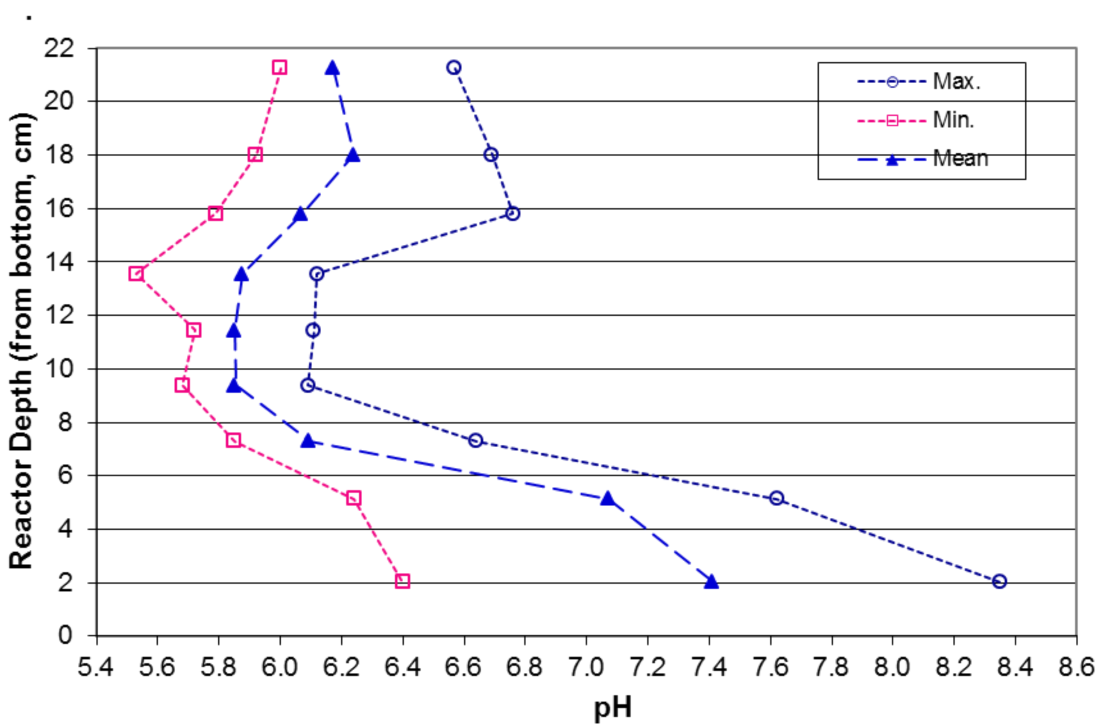
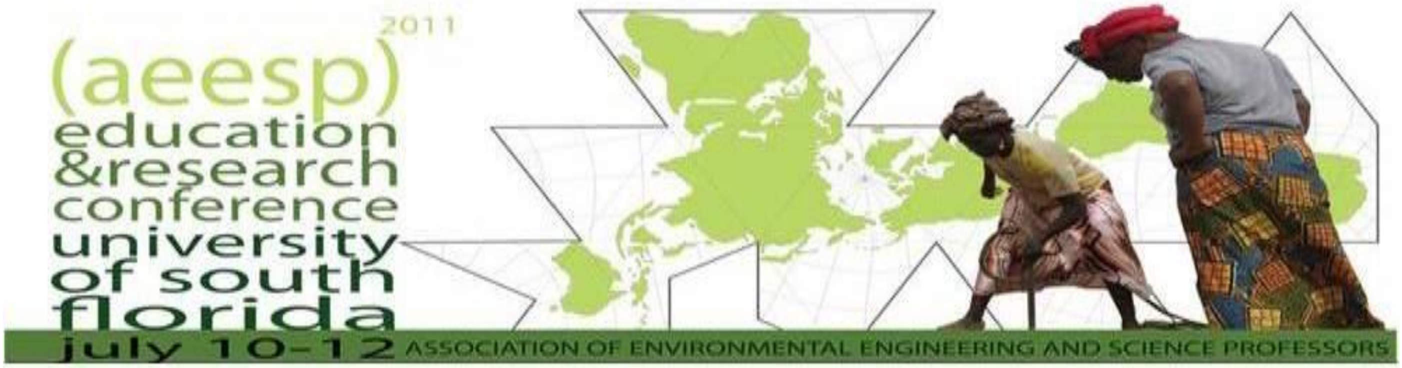


Figure 1. Summary of typical pH values measured in decomposing refuse versus reactor depth. Maximum, minimum, and average pH values are shown for clarity.



Research Category #3: ***Infrastructure that Serves an Expanding and Urbanizing Population***

Research Category # 3

INFRASTRUCTURE THAT SERVES AN EXPANDING AND URBANIZING POPULATION

IS IT TIME TO STOP USING POTABLE WATER TO FLUSH TOILETS? ECOLOGICAL DESIGN PRINCIPLES SAY YES, BUT HOW FEASIBLE IS IT?

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Today's water infrastructures are the outcome of an industrial revolution-based design that are now at odds with the current sustainability paradigm. A new vision is necessary towards developing sustainable infrastructures. In the first part of the presentation, such a vision will be presented. This vision was developed by compiling a list of 99 ecological design principles from eleven authors. These ecological principles were grouped into three themes: (1) human dimension, (2) learning from nature (biomimicry), and (3) integrating nature. Biomimicry concept was further divided into six sub-themes; (1) complex system properties, (2) energy source, (3) scale, (4) mass and energy flows, (5) structure, and function, and (6) diversity and cooperation. These themes offered new perspectives for water infrastructure design that are currently missing in today's design thinking. Decentralized or semi-centralized adaptive infrastructure, nature-inspired and more diverse ways to move and treat water, and matching water quality to its intended use are some examples of these perspectives. In addition, ecological design principles suggested that the water infrastructure should be conceptualized in a more holistic way by not only considering water supply, treatment, and storm water management services but also integrating into the design problem other provisioning, regulating, cultural, and supporting ecosystem services.

While a vision is the necessary first step towards solving a problem both in the engineering and sustainability contexts, the feasibility of implementing the recommendations should also be evaluated. For example, based on ecological design principles, the use of potable water to flush toilets is a major inefficiency and should not be practiced. Yet, are alternatives to potable water use viable in today's conditions? In the second part of the presentation, this question will be answered for existing buildings at The University of Toledo.

Toledo is located in the Great Lakes area. Water shortage is not an issue for this location, yet excessive surface runoff and combined sewers create regional environmental problems. In addition, use of potable water to flush toilets increases the energy demand and associated greenhouse gas emissions of the water infrastructure by increasing the treated volumes of both drinking and wastewaters. Use of harvested rainwater in toilet flushing can help alleviate these problems. The feasibility of implementing this strategy and its economic and environmental implications were studied for the Engineering Complex and Crossings Dormitory buildings at the University of Toledo.

The Engineering Complex is an office and classroom type building with approximately 2,200 faculty, staff, and student users. This study showed that, for the Engineering Complex, the use of rainwater in low flush toilets would have been a viable choice had this design approach been implemented at the time of building construction. Compared to the use of standard toilets, the rainwater based low flush toilet system resulted in lower cost, lower energy demand, and lower CO_2 emissions within a 10 year period. Considering building lifetimes of 50 to 75 years, the rainwater-low flush systems would therefore be the preferred option for this building.

The Crossings Dormitory is one of 9 dormitories on campus and houses 630 students. Given the five-storey, tall and narrow design of the building, the roof area for this building was not enough to meet the water demand for flushing toilets. This building was analyzed as both a new construction and a building being renovated for rainwater harvesting implementation. The renovation doubled the initial cost of the rainwater system due to tearing down of walls for pipe setting. Yet, results showed that neither one of these scenarios was a viable option for this building due to high payback periods in cost, energy and CO_2 emissions.

Our study of these two buildings also revealed some other implications. For example, the pay back periods for rainwater harvesting systems are typically highest for cost, lower for energy, and lowest for CO_2 emissions. Therefore, if greenhouse gas emission reduction is an important goal for a university, rainwater harvesting systems can play an important role in achieving this goal. From another perspective, the emissions from the water infrastructure contribute to approximately 20 % of total greenhouse gas emissions from City of Toledo and Lucas County Government operations. Since this is such a high percentage, any reduction in potable and wastewater flow rates would help considerably in reducing the emissions from these local governments and helping them meet their climate action plans.

Other implications of the study were on building design and on energy efficiency of the water infrastructure. For example, the codes for building design do not currently include any parameters relevant for rainwater harvesting systems. Similarly, LEED green building rating system would favor rainwater harvesting systems regardless of different conditions. Yet, this study showed that rainwater harvesting systems become favorable only under certain conditions. Higher roof area per occupant per flush reduces the life cycle energy of rainwater harvesting systems. Similarly, combined sewer systems make rainwater harvesting a more favorable option due to reduction in wastewater volumes treated when rainwater is harvested. Rainwater harvesting systems also become the better option when the utility rates and the energy use of the water and wastewater infrastructures are high.

Is it time to stop flushing toilets with potable water? The vision for sustainable water infrastructure would suggest yes, the time has come. Yet, implementing the vision given existing infrastructure has its own parameters that need to be considered. The economic and environmental models for toiled flushing showed that whether rainwater harvesting systems are favorable or not depends on the conditions. This study evaluated the results for certain conditions in Toledo. Further work on coupled economic and environmental analysis is necessary to document the feasibility of rainwater harvesting in other situations. Analyses as in this study will be helpful in charting the path for the sustainable water infrastructure vision.

THE NEED FOR ALTERNATIVE DRINKING WATER SUPPLIES: SOCIAL AND TECHNICAL CHALLENGES

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Overview and Objectives. *What are the salient beliefs of stakeholders about alternative drinking water supplies? What water quality characteristics of an alternative water supply are important to consider for future drinking water treatment?* These questions illustrate the social and technical challenges that regulators, utilities, planners, engineers, and non-governmental organizations must consider when evaluating alternative drinking water supplies. This research project used the St. Johns River, FL, USA as a case study for alternative water supply planning. The results of this research are also expected to be applicable to water supply issues at a global scale.

The motivation for this work is that municipalities in the St. Johns River Basin need to consider alternative drinking water supplies because groundwater sources are not expected to meet increases in regional water demand beyond 2013. Groundwater is currently the most widely used water source in the St. Johns River Basin, and alternative sources under consideration include surface water, seawater, reclaimed water, and water conservation. Accordingly, the objective of this research project was to evaluate the social and technical challenges relating to alternative water supplies. The specific objectives of the research were (1) to understand stakeholder beliefs about alternative water supplies in the St. Johns River Basin (i.e., social challenge) and (2) to collect baseline water quality and treatability data for the St. Johns River (i.e., technical challenge). Specific objective 1 was accomplished by conducting an online survey for a large group of stakeholders. Specific objective 2 was accomplished by collecting water samples from the St. Johns River and conducting laboratory analyses and treatability studies. All research for specific objectives 1 and 2 has been completed.

Methods. A list of expert stakeholders (N = 598) was compiled from lists of attendees at public meetings held to discuss water supply planning in the St. Johns River Basin. The stakeholders included federal, state, and local governments, public utilities, environmental groups, and engineering consulting firms. Ten expert stakeholders were randomly selected for an elicitation study in which open-ended questions were asked about the risks and benefits of surface water, seawater desalination, reclaimed water, and water conservation. The risk/benefit questions were framed in terms of ecological, economic, and human health impacts. The responses to the elicitation study were used to formulate questions for the online survey. The online survey was sent to all stakeholders by email and had a response rate of ~50%, which is consistent with web-based surveys in the social sciences.

Water samples were collected approximately 2 times per month for 1 year from the St. Johns River at Astor, FL. The site was chosen because it is near locations of proposed surface water withdrawals and has a U.S. Geological Survey stream gage that records bulk water quality parameters. The water samples were analyzed in the laboratory for a wide range of inorganic and organic parameters including dissolved organic carbon (DOC), UV absorbance, florescence excitation-emission spectra, bromide, chloride, iodide, sulfate, nitrate, and total nitrogen. Anion exchange treatability studies were also conducted with each batch of water to evaluate treatment performance with changing water quality.

Anion exchange treatment is a promising technology because it targets both DOC and bromide, which are precursors to harmful disinfection byproducts.

Results and Discussion. An example of the survey results pertaining to the perceived risks and benefits of surface water is shown in Fig. 1. The survey questions were framed as scenarios in which stakeholders had to decide whether a scenario was a benefit or risk and then determine the impact of the risk/benefit. The results show that stakeholders viewed the treatment costs of surface water as a risk. Nevertheless, surface water was reported by a majority of the stakeholders to be a benefit to solving regional water supply problems. The laboratory component of this research project was designed to quantify the technical challenges associated with surface water as an alternative drinking water source. Fig. 2 shows the time-varying concentrations of DOC and bromide in the St. Johns River. The concentrations of DOC and bromide are very high for a drinking water supply. For example, > 10 mg/L DOC and > 100 µg/L bromide would be considered high concentrations and a difficult-to-treat water source. *This presentation will synthesize results from the stakeholder survey and water quality analyses to highlight the social and technical challenges that must be considered when evaluating alternative drinking water supplies. The outcomes from this research include a better understanding of stakeholder worldviews, priorities, and belief conflicts, and water quality parameters and treatability necessary to transform the St. Johns River into potable water.*

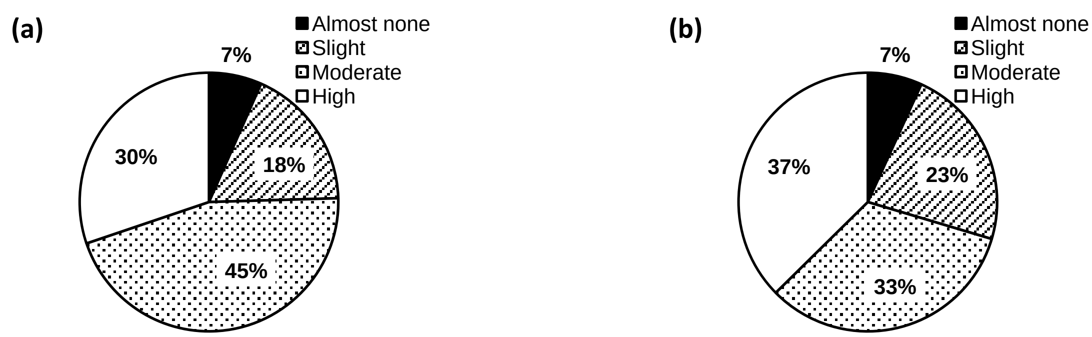

Fig. 1. ***Social Challenge* –** Example of surface water scenarios asked in online survey: **(a)** 86% of stakeholders reported that "surface water has higher water treatment costs than groundwater" as a *risk*, and **(b)** 74% of stakeholders reported that "surface water is a long-term solution to regional water supply problems" as a *benefit*. The *impact* of the risk/benefit is shown in the pie graphs.

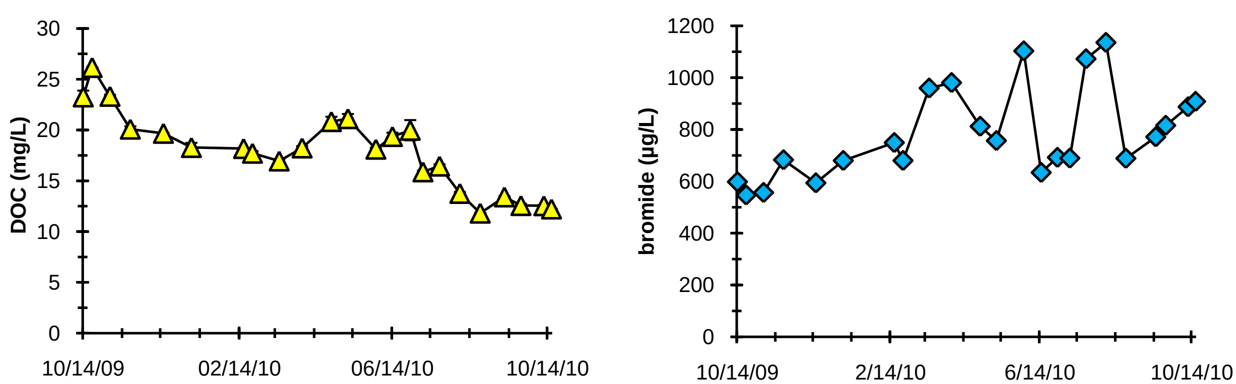

Fig. 2. ***Technical Challenge* –** Time-varying water quality in the St. Johns River at Astor, FL.

SUSTAINABLE AND RESILIENT URBAN INFRASTRUCTURE: AN INFRASTRUCTURE ECOLOGY APPROACH

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With the global urban population approaching 4 billion, provision of sustainable urban infrastructure is one of the foremost challenges in achieving global sustainability. However, the challenges faced by urban infrastructure in the developed and developing world are dissimilar in nature. While the developed world is coping with aging infrastructure, the developing world faces the challenge of keeping up with the brisk pace of urbanization and the rise in infrastructure demand. Nonetheless, sustainability needs to be addressed at all levels to ensure the existence of a bountiful Earth a few generations down the line. The goal of this research group is to develop a framework for sustainable and resilient urban infrastructure, incorporating the water-energy-land use-transportation-socioeconomic nexus. The framework will initially be developed for the test-bed cities of Atlanta and Phoenix, and then extended to other cities as well.

The approach of this research group to the challenge of sustainable infrastructure is the *"infrastructure ecology"* approach. Ecology, as defined by the Merriam-Webster Dictionary is *'the totality or pattern of relations between organisms and their environment'*. The concept of ecology has been extended to urban systems, viz. *'urban ecology,'* and to the industries, viz. *'industrial ecology'*. The concept of ecology can similarly be extended to urban infrastructure when the urban infrastructure components are not analyzed individually but analyzed as an interlinked system. Urban infrastructure can be envisioned as an integrated network of four major infrastructure components, which are water, energy, transportation and land-use patterns, or the urban form as shown in Figure 1. A systems-level integrative approach reveals many options which might be more sustainable but not apparent when approached on an individual basis.

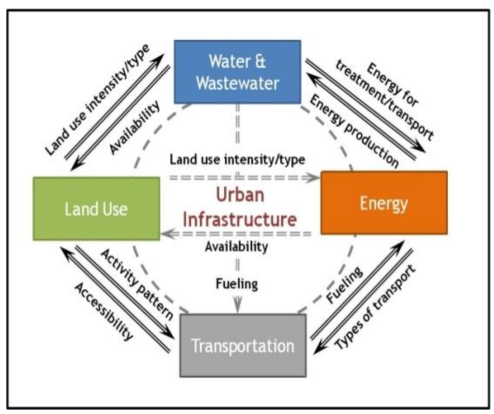

Figure 3: Urban infrastructure is interconnected. This figure shows the dependence of each system on one another, demonstrating that decisions should be made for infrastructure that considers the effect on the sustainability of a city on a holistic basis.

These interrelations are not only dependent on the infrastructure options chosen, but also vary widely with the climate and geography of the regions. For example, the connection between water and energy has been well studied; the creation of energy consumes water, and energy is used to treat water. This becomes a serious consideration in times of dry, hot summers as both energy and water demand increase, thus putting a huge strain on the water-energy interrelationship. Similarly, while biofuels have a lower carbon footprint than fossil fuels, they have a much larger water footprint than their fossil counterparts. In light of these existing dynamic tensions, prudent choices need to be tailored to fit the requirements of a particular city according to its geographic location, demographics and needs. Though the water-energy and the energy-transportation are more prominent, these inter-relations are prevalent between all individual infrastructure components like water, energy, transportation and land use.

One of the key hypotheses of the research group is that sustainable and resilient urban infrastructure can be better addressed through compact living spaces and distributed water and energy production. While compact growth enables the adoption of low-impact development (LID) techniques for storm water management, and the use of distributed energy generation through combined heat and power and other sustainable alternatives, distributed water and energy production are hypothesized to be more resilient due to their inherent redundancy. Agent-based models were developed to examine the adoption for compact living by future residents. The material and energy requirements to build and operate urban systems for both compact growth and 'business as usual' scenarios are also being evaluated. Preliminary results for Atlanta, GA, as shown in Figure 2, suggest that the sprawl case would cause substantial levels of deforestation, dispersion of residential and employment activities across the metropolitan area, an increase of the commuting distance, and consequently, a significant increase of additional water and energy demands in the system. The model is now being refined to produce a more detailed land use forecast and then link that forecast to a life cycle cost analysis. In addition, various alternative scenarios of distributed water and energy production are being evaluated at the system level to optimize the sustainability of the system. Transportation alternatives are also being assessed to determine their energy and water footprints.

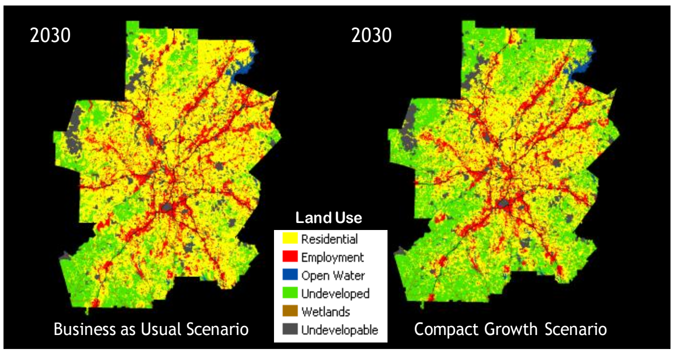

Figure 4. The urban growth scenarios of the Atlanta area by 2030. Business as usual shows more sprawl. Compact growth keeps a much larger portion of the land as undeveloped green space.

The infrastructure ecology approach would provide exciting insights for the researchers of this realm into the potential benefits and alternatives that are obtained through addressing the challenge of urban sustainability at the systems level. In addition, it would provide a better comprehension of the interactions between the various infrastructure components, which would aid the decision making process for urban planners.

A UNIT PROCESS APPROACH TO URBAN STORMWATER MANAGEMENT

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Water quality impairment from urban stormwater is one of the few growing water environmental problems. Increased land development for growing populations and infrastructure create impervious surfaces such as building rooftops, parking lots, and roadway systems. These impervious areas alter the water and pollutant mass balances in urban areas by directing these fluxes to surface waters. Current management of urban runoff via stormwater control measures (SCMs) is highly empirical and the scientific databases are immature with minimal fundamental scientific support. Most regulatory agencies will specify stormwater management techniques and technologies with little consideration of local conditions, including soils and geology, climate, and watershed location. Much of the current regulatory framework emphasizes "one size fits all" and percent pollutant removals as performance metrics. Both of these focal points have major problems when challenged with scientific and engineering rigor.

Urban SCMs are generally classified based on specific technologies, such as ponds, swales, bioretention, wetlands, sand filters, and others. Increasingly, greater emphasis is being placed on nature-based SCMs that utilize soils and vegetation. However, these technologies function via the same unit processes exploited in drinking water, wastewater, and other water treatment operations. These processes include sedimentation, filtration, adsorption, ion exchange, and myriad biological reactions. With proper consideration of the water and pollutant balances, combined with the pertinent treatment unit process, predictable performance should be possible for SCMs under conditions and designs unique to every situation. This work discusses some of these challenges and progress being made to address these challenges.

Foremost, the water balance must be understood. Water balances in SCMs require consideration of input, storage, and several output pathways. Most SCMs will include a storage component and many new technologies emphasize infiltration into the native soils. Evapotranspiration is expected to be important in the long-term water balance. Both infiltration and evapotranspiration emphasize site-specific performance

Unit treatment processes pertinent to SCMs have been known and studied for decades or more. Theory has been developed and tested and can be applied to stormwater situations. Removal of particulate matter will require understanding of sedimentation and filtration mechanisms. Long-term buildup of sediments and possible re-suspension requires attention. Many of the toxic compounds found in urban stormwater runoff are affiliated with particulate matter and the removal of particles will contribute to toxics removal. Adsorption is a major reaction pathway for dissolved metals (lead, copper, zinc), hydrocarbons, and dissolved phosphorus in infiltration SCMs. Understanding and exploiting specific adsorbent properties that may enhance the adsorption can lead to greater performance. An example is to increase amorphous iron and aluminum contents via amendments to filtration/infiltration SCMs to enhance inorganic phosphorus removal. Nitrogen is a pollutant of major concern in many waterways.

Nitrogen speciation and cycling in nature-based SCMs is complex, yet is similar to those in soil and related systems. Creating conditions that favor denitrification is challenging in urban stormwater management, yet possible.

These various unit processes, nonetheless, must be evaluated in the complex, highly dynamic environment of urban stormwater runoff. Runoff is manifest as highly unsteady flows, with unsteady, variable pollutant concentrations. Dry conditions will exist between rainfall events, so a continuous flow will not exist. Seasonable effects will be demonstrated via changes in temperature (viscosity impacts on flow and evapotranspiration, chemical reaction thermodynamics and kinetics, and associated biotic conditions) and possibly rainfall patterns.

Because of the highly dynamic conditions inherent to urban stormwater runoff, proper performance metrics must be developed and integrated into the existing regulatory structure. Most stormwater regulations and existing databases emphasize a "percent removal" for a particular SCM: a simple metric valid only for steady state performance. This metric ignores the high variability of pollutant inputs to SCMs and is overall unprotective of water quality. For a high input concentration, a high percent removal may still result in a high, unacceptable discharge. For a very low input, even a low percent removal may result in a satisfactory discharge. Performance must consider the variability in water quality inputs and desired low discharge pollutant concentrations and mass loads.

STATE OF THE SCIENCE OF STORMWATER MANAGEMENT: CRITICAL REVIEW AND NECESSARY STEPS TO DEVELOP RESILIENT URBAN STORMWATER INFRASTRUCTURE

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"Just as built infrastructure like roads and utilities is necessary for modern societies, green infrastructure provides the ecosystem services that are equally necessary for our well-being… cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, sequestering carbon, protecting areas against storm, flood damage, and maintaining hydrologic regimes" (Weber et al., 2006).

The National Academy of Engineering has identified urban infrastructure one of the "Grand Challenges for Engineering" in the 21st century (NAE, 2009), and the American Society of Civil Engineers assigned a D- grade to our nation's stormwater infrastructure (ASCE, 2009). The USEPA estimates that over $500 billion will be needed to upgrade water systems by 2020, based on the current mode of water infrastructure design. Failure to invest in infrastructure upgrades now risks public health and environmental damage as well as increases in upgrade costs by orders of magnitude. Urban areas are particularly at risk as populations become denser, especially those located at the mouth of waterways where agricultural, industrial, and other anthropogenic pollutant sources are concentrated. Green infrastructure technologies and strategies link water cycles and reduce contaminant loads while potentially reducing implementation and operation costs by maintaining or restoring natural hydrology (USEPA, 2010). Green stormwater infrastructure is emerging as a new paradigm in stormwater management: one where water is viewed as a recoverable and recyclable resource and material and natural systems are incorporated for storage, reclamation, reuse, storm impact reduction and other ecosystem services.

In this paper, the state of the science of stormwater infrastructure is reviewed. Grey infrastructure has been the conventional mode for removing stormwater from urban landscapes throughout the history of stormwater management. 1950's suburban development focused on efficient water removal through curb and gutter drainage, followed by integration of detention systems to reduce localized flooding, and management focused on moving water quantity off-site. In the early 1990's, urban areas were shown to be important sources of non-point source pollution and water quality became important. Now it is clear that grey infrastructure alone does not hold the complexity, flexibility or resilience required to protect other infrastructure from increasingly large and frequent storms/flooding, or waterways and aquatic life from urban contaminants. Incorporation of green infrastructure may add the resilience of natural systems and ecosystem services.

The provision of ecosystem services is a differentiating factor between grey and green infrastructure, and quantifying the benefits provided by green infrastructure allows us to understand life cycle benefits achieved by green versus conventional systems. Recent studies have shown that green infrastructure can reduce urban temperatures, provide building thermal insulation, and decrease the warming of runoff into sensitive environments. Preliminary cost/benefit and life cycle cost analysis show that green infrastructure is only slightly more costly than conventional stormwater controls, and the added cost is quickly recovered through ecosystem benefits (e.g. aesthetic space, improved air quality, reduced urban temperatures, and pollution reduction) during the design life of the project. Additionally green practices can be significantly more modular than conventional approaches, allowing decentralized implementation one site at a time, or systematic implementation for whole neighborhoods. Hydraulic performance of green infrastructure, especially when combined with engineered forecasting storage controls, shows that best management practices (BMPs) have the potential to retain storm flows and peak times even further than pre-development conditions. Green stormwater infrastructure can actually perform better than low impact development (which mimics pre-development conditions), which should allow a systematic resilience to be designed into the urban space, where mixed grey and green infrastructure can provide resilience function for the overall design.

However, there is little mechanistic understanding of water quality performance of many BMP designs, geospatial distribution, or economies of scale to optimize cost and hydrologic/treatment performance and therefore no clear path for optimal investing in mixed green and grey infrastructure. Stormwater modeling studies can generally be split into a) large-scale (regional) hydrologic modeling and b) single technology mechanistic modeling. Recently, researchers have explored the concept of spatial aggregation of modeled BMPs, pollutant removal simulation through completely mixed flow reactors in series, and specific hydraulic or biogeochemical processes (e.g., infiltration capacity; phosphorus removal). Some models have addressed the integration of stormwater into overall urban water management, opening opportunities for onsite stormwater use (Zoltay et al. 2010). Very recent model developments have considered systematic BMP selection and placement for sites to cities, optimized for cost or stormwater treatment capacity (Shoemaker et al. 2009). These models have yet to link ecosystem services with cost optimizations, are limited to empirical relationships for simulating pollutant removal by BMPs, and cannot optimize a “mix” of green and grey infrastructure.

Gaps in the science of stormwater management lie in the question of how to design resilience into infrastructure in the face of urbanization and climate change. We need to systematically design stormwater infrastructure to 1) match demand for its service with minimal deviation regarding urban drainage, flood protection and pollutant removal; 2) link it to other urban water infrastructure and green space to increase functionality and resource cycling; 3) maintain efficiency in water resource use and reuse through decentralized solutions; and 4) allow for highly coordinated management to respond quickly to disruptions. Systematic design requires understanding of what conditions may require various mixes of green and grey infrastructure. For example, system conditions may prevail where only grey infrastructure can be applied, such as very high population densities where no space exists for green infrastructure. BMPs may have cascading and nonlinear effects in this systematic design and simulation processes such as system dynamics may further our understanding. Finally, further investigation into the cost-effectiveness and optimized design will allow us to invest in appropriate and resilient stormwater management systems.

In summary, this paper defines grey and green infrastructure as a means of addressing resilience in stormwater management, critically reviews the stormwater literature to assess the current state of knowledge for application to resilient infrastructure, and provides a path forward to address knowledge gaps in systematic urban stormwater infrastructure design.

(Citations are not complete due to space limitation, but available upon request/in full paper)

COST EVALUATION OF DECENTRALIZED VS. CENTRALIZED WATER DISTRIBUTION SYSTEM CONFIGURATION

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Water scarcity is a worldwide problem that is driven by the rising population, water pollution, and limited water resources. Coping with the problem of water scarcity requires comprehensive understanding on the interaction and interdependence of water infrastructure with the natural and socio-economic systems and other engineered systems, such as energy infrastructure. Recently, there is an emerging interest in decentralized water system, which refers to a system based on the utilization of local resources for improved energy efficiency and less environmental impacts. Decentralized water system could be of more interest due to local control over the system characteristics such as system security; robustness; augmenting centralized system; and economic viability for a longer term. Significant work has been done in evaluating and designing a traditional (centralized) water distribution system (WDS); however, the evaluation of decentralized systems is still at infancy, which is the main priority of the current paper.

As a starting point, cost analysis of a simple centralized system and its counterpart decentralized system (Figure 1) was carried out using EPANET2.0 and a unique *hybrid* cost estimation model (Equation (1)) .

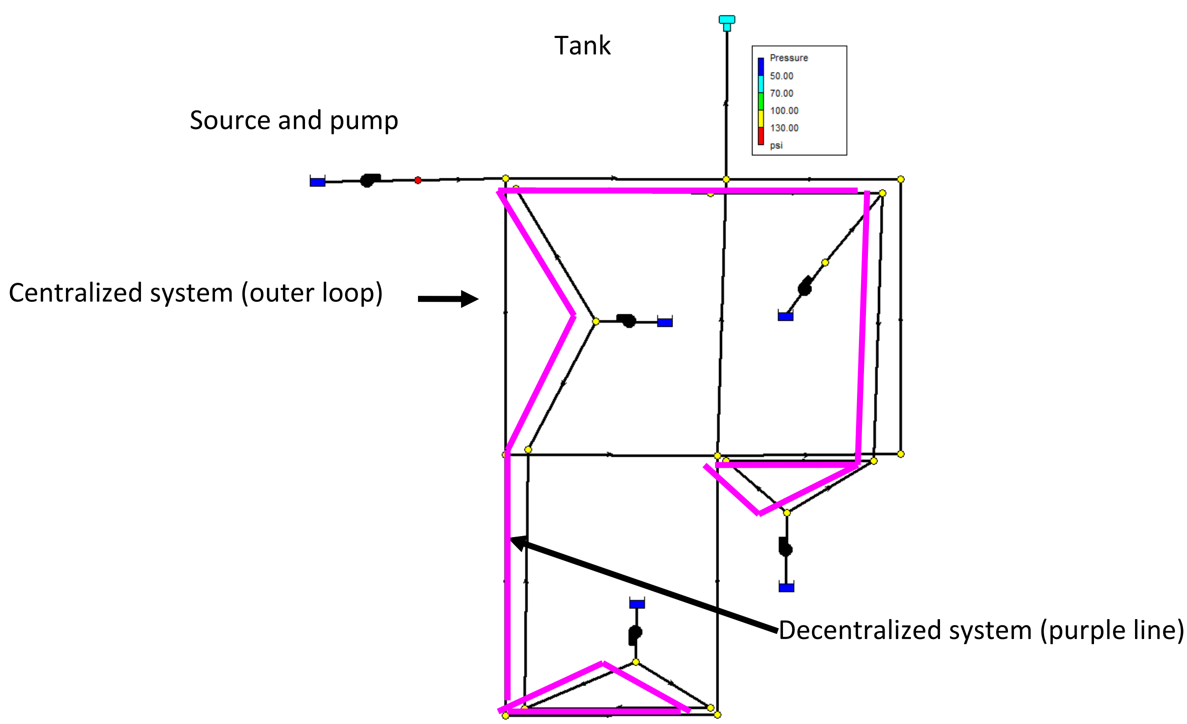

Figure 1: Hypothetical decentralized water system designed from a hypothetical centralized system (created and modified from Example data files of USEPA (2000) (in the caption, color coded pressure distribution.)

The cost model incorporates the capital cost of both water distribution and water treatment infrastructures. The combination of two components provides a picture of total cost of a WDS.

$$TIC = \sum_{i}^{2} TC_i \qquad (1)$$

Where, TC_i is the capital cost for the two major components of a WDS: (i) water treatment plant costs (includes raw and finished water pumping station costs, treatment processes costs, and building maintenance), and (ii) distribution network (pipes and fittings). The pipe installed costs; trenching and excavation; and embedment, backfill, and compaction costs were included in pipe costs analysis. Note that the installed costs include the pipe, the gasket, and joining materials, as well the labor and equipment costs. The operation and maintenance (O&M) costs depend on many factors such as treatment technology, pipe materials, and raw water quality; however O&M costs were not included in this analysis. The capital costs for pipes and fittings were estimated as shown in Equation (2):

$$TC_1 = I + T + B \qquad (2)$$

where, installed costs, *I;* trenching and excavation costs, *T*; and embedment, backfill, and compaction costs, *B*; for main pipe lines and service lines were determined based on Clark et al. (2002) (Equation (3)):

$$I,\ T,\ or\ B = a + bD^c + dE^e \qquad (3)$$

Where, parameter, *a*, *b*, *c*, *d*, and *e.* are different for different type of pipe costs. *E* is the indicator variable of ductile iron pipe used in a WDS and *D* is pipe diameter.
The costs of water treatment plant mainly depend on the raw water quality, treatment standard, technology selected, and treatment capacity. Accordingly, TC_2 were estimated based on McGivney and Kawamura (2008) (Equation (4)).

$$TC_2 = \sigma Q^{\beta} \qquad (4)$$

where, σ and β are parameters dependent of a specific treatment technology, and *Q* is the capacity of the treatment plant, (in MGD).

While the unit production cost for centralized system is lower than the decentralized one, the latter could be beneficial due to the saving on transmission energy and wise use of locally available resources. Preliminary results of cost analysis showed that the decentralized system could be economically viable for a longer term due to potential savings in water usage. The cost model could aid engineers and water utilities in evaluating the economic viability of centralized and decentralized water supply options. The net present value benefits of the decentralized WDS will be evaluated for a range of service life in the future.

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RESIDENTIAL GRAYWATER IRRIGATION: AN ENVIRONMENTAL SERVICE-LEARNING PROJECT

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Fifty to seventy percent of the wastewater generated by a single family residence comes from laundry and bathing activities. This wastewater is commonly referred to as gray water and will have significantly lower BOD5, COD, solids, and microbial counts than the wastewater discharged from toilets, dishwashers, and garbage disposals. The quantity and quality of gray water produced by a residence make it an attractive source of water for on-site re-use including both toilet flushing and irrigation. The on-site re-use of gray water is regulated at the state level. In the State of Georgia, gray water irrigation systems are regulated by the Department of Human Resources, Division of Public Health, Land Use Program as septic systems. The definition of gray water irrigation systems as septic systems prohibits installation at properties serviced by a municipal sewer system and requires gray water reuse system utilizing drip emitters to include an aerobic treatment unit (ATU). Given the differences between the water quality characteristics of gray water streams derived from laundry, bath, and shower sources and mixed wastewater streams which include flows from toilets, kitchen sinks, and dishwasher in addition to the gray water flows this treatment requirement may be excessive. The goals of this project are to

- Evaluate the design issues associated with the use of gray water for landscape irrigation,
- Evaluate the maintenance issues associated with the use of gray water for landscape irrigation,
- Assess the treatment techniques and levels appropriate for a gray water irrigation system, and
- Support the development of regulations that are more favorable to the implementation of residential gray water irrigation systems in Georgia.

These objectives will be accomplished through the installation of gray water irrigation systems at residences in Bibb County. The first system was installed at a 5-bedroom, 7-occupant Macon Area Habitat for Humanity home (Figures 1 and 2). Future systems will be installed at Macon Area Habitat for Humanity homes as permitted by regulatory approval, funding, and timing.

Prior to being discharged to the lawn area via sub-surface drip emitters, the gray water will be treated through filtration; aerobic and/or anaerobic treatment; and chlorination. Above ground plastic tanks will be used as the treatment vessels and for storage prior to dosing of the irrigation field. The use of above ground tanks will enable the research team to quickly and easily change the treatment method and/or the treatment time prior to dosing. Chlorination will be accomplished using septic chlorine tablets in a flow over system. Filtration will include tub/shower drain guards, bristle-type septic tank filters, and screen filters. A series of tests will be used to evaluate the performance and utility of the gray water irrigation systems. The primary goal of these tests is to collect information that can be used to aid regulatory decision makers. The tests to be performed include system functionality, operating pressure and flow rate, drip emitter performance, free chlorine, pH, BOD5, COD, solids analysis, and maintenance requirements.

This system was designed by senior environmental engineering students, installed by engineering students from a variety of disciplines and levels, and will be monitored by senior and/or graduate students. Future systems will use the same basic design with modifications to the drip system layout. Installation of future systems will be a service learning component of environmental engineering, sustainability, and/or environmental science courses.

The goal of this presentation is to provide the information necessary for a faculty member to consider incorporating the design and installation of a residential gray water irrigation system as a service learning project in one of their courses. This presentation will cover the design of a gray water irrigation system installed for use at a five-bedroom residence in Macon, GA and preliminary results from operation of this system. The general design process for a gray water irrigation system as well as the design of a simple direct discharge system will be included in the presentation. The potential for collaborating with a local Habitat for Humanity chapter will also be discussed.

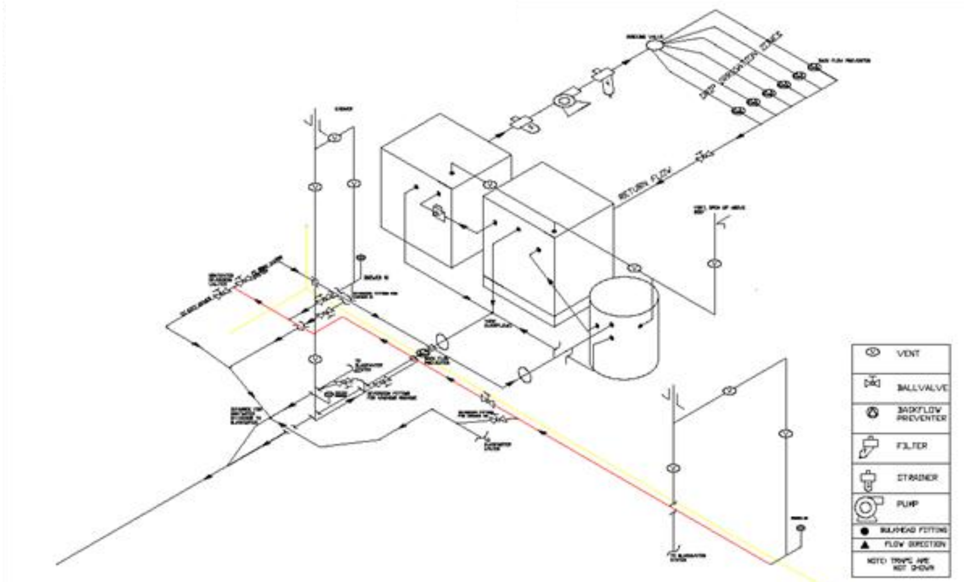

Figure 1. Plumbing and treatment system for a residential gray water irrigation system.

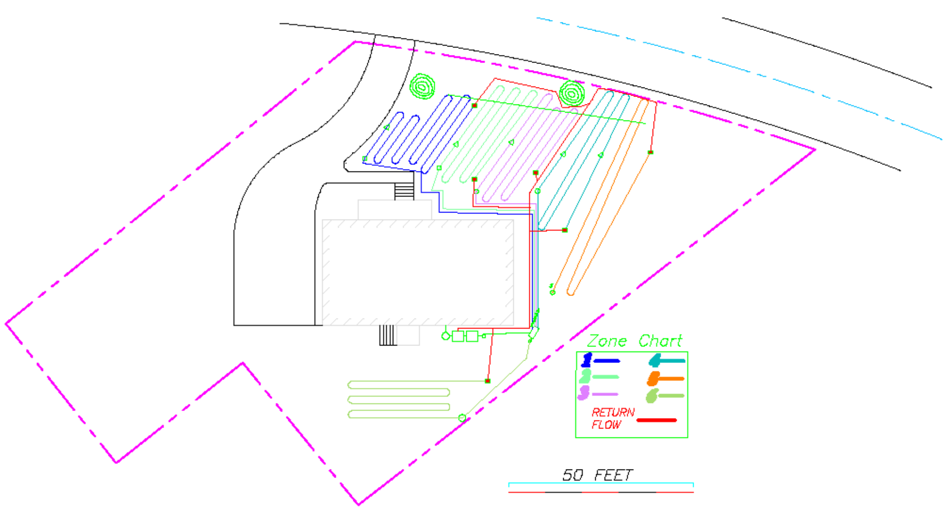

Figure 2. Layout of gray water irrigation drip zones for a 5-bedroom Macon Area Habitat for Humanity home.

URBAN FUTURES – SUSTAINABILITY (RESILIENCE) EVALUATION OF WATER INFRASTRUCTURE

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Owing to uncertain future coupled with emerging concerns associated with climate change and population growth/shift to urban areas, a twin track approach of both mitigation and adaptation measures is required to plan, design and operate urban services to maximise resource efficiency, minimise redundency of the available infrastructure (through urban regeneration) and explore sustainbility optimisation options. Sustainability, by default, is a subjective term and its evalution and implementation does require negotiating trade offs between conflicting goals. The incorporation of future influnces must be an integral part of any evalution exercise aimed at achieving long term sustainability aspiration. Within this context, a 4 year muli disciplinary and multi institutional project, *Urban Futures*, was undertaken with support from the UK Engineering and Physical Scinces Reserach Council.

This paper breifly introduces the *Urban Future* Project and lists the outcome of an extensive exercise to crystalise wide ranging (probable to plausible) urban future scenarios (Part A) and mainly describes the methodology applied to assess the future scenario implications on water infrastructure (Part B).

Part A: The high level goal of the *Urban Futures* project is to test resilliance of today's 'sustainable solutions' and explore strategies and options for infrastructure future proofing. This is addressed through a focused (but integrated) investigation of key urban services (including water and wastewater). The reserach work was organised in 8 distinct work packages. These and interactions between them are outlined in Figure 1.

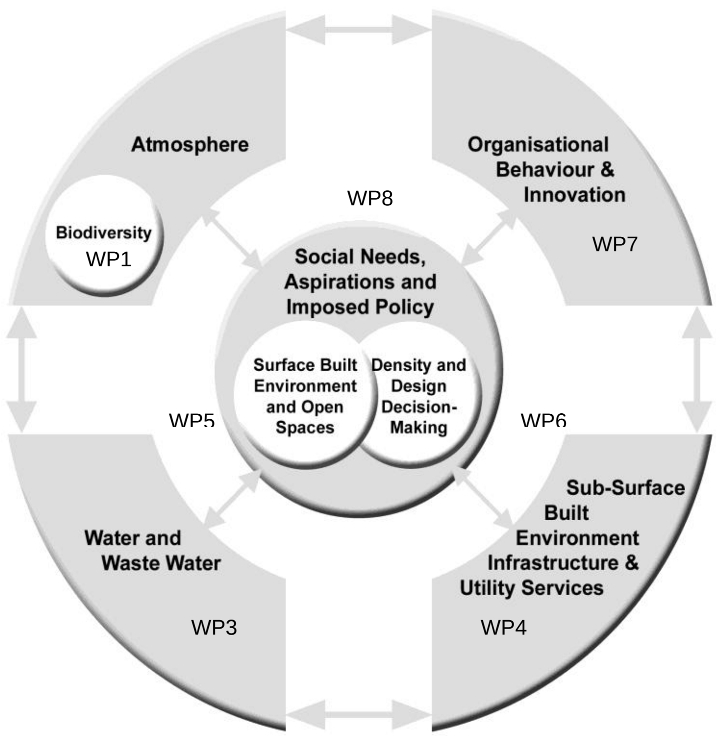

Figure 1 Urban future project work packages and interactions

As a function of societal values and the nature of regulatory/policy regimes, four future scenarios have been adopted: Market Forces (MF), Policy Reform (PR), New Sustainability Paradigm (NSP) and Fortress World. The scenarios extraction process, their definitions and interpretations for water related aspects of the project are summarised in Hunt *et al* (2010).

Part B: This part describes the methodology, developed to implement urban futures interpretations for water infrastructure, comprising the development of an urban water optioneering tool (UWOT?) and a water distribution network simulation.

In order to investigate the impacts of the above mentioned future scenarios and the influnce of currently available (sustainble) technologies on water (demand) consumption patterns and implications for water cycle mangement, *UWOT?* has been developed. The tool consists of a technology library and a user interface. The library is populated with a wide range of technologies for potable water consupmtion reduction, alternative non potable supply and reuse at different scales (centralised and decentralised) and surface water managment. For each technology, the library also includes information associated with sustainbility indicators (including water saving potential, cost, energy consumption and social acceptability). The tool is coupled with a multi-objective optimisation solver and produces automated optimal composite strategies, their respective sustainbility evaluations and water demand patterns for any of the above mentioned or user defined future scenarios.

The resilience, of existing water distribution networks, to fluctauting water demands and urban growth patterns could vary signficantly for different future scenarios. For example in the MF scenario, demand is envisaged to increase signficantly and sections of a network are likely to become vulnerable at satisfying the minimum surplus head requirement. On the other hand, under NSP scenario demand will reduce considerably and therfore water age in the network is likley to incease and in turn could prompt water quality deterioration.

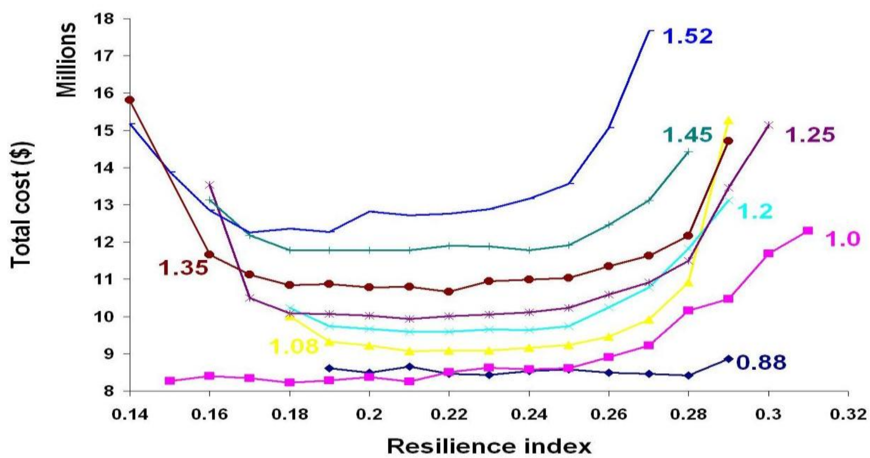

Figure 2 Resilience index relationship with demand mulipliers & rehabilitation investments

To analyse the above mentioned and related operational issues, quantify network resilience to future scenarios and propose optimal network rehabilitation strategies, simulations were carried out using a benchmark network (Anytown). An example simulation output (Figure 2) shows the influence of network rehabilitation investments and water demand multipliers (future scenario combinations) on resilience index (i.e. surplus hydraulic power in the network). The figure suggests that for certain scenarios, even higher investments do not necessarily guarantee improved resilience index.

The project, currently in its final stage, is testing the developed methodology using a number of national and international case study sites.

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INTRODUCING A NEW ENGINEERING RESEARCH CENTER: RE-INVENTING AMERICA'S URBAN WATER INFRASTRUCTURE

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In urban centers of the U.S., massive centralized infrastructure is typically used to provide drinking water and treat the resultant waste water before discharge. While this strategy may be viable for many metropolitan regions, an adequate supply of imported water is no longer available in many of the fastest growing regions in the western and southeastern United States. The response of cities to the imbalance between water supply and demand is complicated by a lack of investment and a reluctance to adopt new technologies. In most locations, urban water infrastructure looks much as it did in the 1960s, with centralized water and wastewater systems delivering water over long distances. In addition, large utilities still provide water of extremely high quality (*i.e.*, potable water) for applications including landscape irrigation, toilet flushing, fire-fighting, and industrial activities. While acceptable in an era of inexpensive energy, abundant water supplies, and unrecognized aquatic habitat needs, these systems are ill suited for meeting our future needs. It is increasingly clear that these kinds of unsustainable infrastructure projects do not represent the best approach to meet the needs of society. In addition, climate change represents a potential threat with significant uncertainty, thus complicating evaluation of the resilience of water infrastructure and identification of appropriate adaptation responses. Rather than replace existing infrastructure systems with more of the same, we have an opportunity create something better.

In order to investigate transformation of urban water infrastructure into more sustainable systems, an NSF-sponsored Engineering Research Center (ERC) has recently been recommended for funding. The ERC joins four leading universities in the West: Stanford University, Colorado School of Mines, New Mexico State University and University of California-Berkeley. Although increased demands on water supplies occur throughout the country, these demands are acute in the arid West, where the ERC partner universities have special capabilities and access to unique test beds. Furthermore, each campus has strategic collaborations with members of the professional community and international universities at the forefront of urban water infrastructure research that will help us to translate our research into tangible results. The goal of the ERC is to advance new strategies for water/wastewater treatment and distribution that will eliminate the need for imported water, recover resources from wastewater, and generate rather than consume energy in the operation of urban water infrastructure while simultaneously enhancing urban aquatic ecosystems. While many existing approaches could be used to transition urban water infrastructure to this more sustainable state, their implementation currently is limited by uncertainties about their long-term performance, life cycle costs, institutional impediments and public concerns about unfamiliar technologies. In some cases, the technologies needed to realize our vision do not yet exist and technological breakthroughs are needed. To meet these challenges, our strategic planning process identified key research projects within three thrust areas:

(1) **Engineered Water Systems:** Decrease reliance on inefficient centralized treatment systems by employing distributed treatment systems that embrace water conservation, local use of alternative supplies, energy management, nutrient recovery, and that integrate with existing infrastructure;
(2) **Managed Natural Systems:** Integrate managed natural systems into water infrastructure to fully realize the potential benefits that natural systems can provide with respect to water storage and improvement of water quality, while simultaneously rehabilitating urban hydrology and aquatic habitat; and
(3) **Urban Water Systems and Resource Management:** Support the integration and management of decentralized and more diverse and stochastic system components by developing engineering-economic models, and addressing barriers to innovation (such as institutional barriers, public perceptions of water risks, etc.).

The ERC's educational efforts will build a pipeline of diverse, well-prepared students who eventually pursue and complete water-related degrees at the undergraduate and graduate level to become leaders and support significant change in the Nation's water infrastructure in a manner guided by scientific knowledge and supported by an informed public. This effort will begin at the elementary level and continue through graduate education. To ensure the involvement of under-represented minorities, the ERC is partnered with American Indian Tribal Colleges and Universities, and K-8 and high schools that target districts that serve primarily Hispanic, Pacific Islander and African American populations.

CONTROLLED ENVIRONMENT HIGH RISE FARMING FOR LOCAL FOOD PRODUCTION IN COLD CLIMATES

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Feeding our earth's population has become increasingly difficult. By the year 2050, the population of Earth is expected to rise by 3 billion people. Approximately 10^9 hectares of additional traditional farmland will be needed to feed them. However, it is estimated that 80% of the arable land on Earth suitable for farming is presently in use and roughly 15% of this land has been rendered unusable for farming due to poor management. Climate change has claimed additional land. Locally, the produce industry of the US is both inefficient and insufficient. Populations in the northeast buy produce for at least 6 months out of the year from farms that are over 3,000 miles away. This produce has been engineered to survive the long trip and extend shelf life in stores. Better tasting locally grown produce of high quality is only available for a few months out of the year, and in a relatively limited quantity. Crop yields are also highly dependent on weather. A single poor growing season can cause thousands to starve in many areas of the world. In the US, this at minimum causes a significant rise in imported produce, resulting in higher prices and dollars leaving the local economy.

Current farming practices are not sustainable and inadequate for feeding our growing population. Industrialized farming has depleted top soil and its nutrients, requires substantial additions of fossil energy and agrichemicals, and results in food production in a few geographic areas that requires processing and long-distance transport to consumers. An alternative agriculture model for local food production is proposed that utilizes a smaller land area, has a longer growing season and provides steady year-round employment. This new approach will help to sustain the nutrition needs of our population while reducing the environmental impact associated with the increase in our current agricultural practices.

The basis of the project presented here is the hypothesis that growing plants in a high-tech, high-rise controlled environment would help regions with cold climates to grow food for their local needs while reducing cost and environmental impacts. The CEHRF (Controlled Environment High-Rise Farm) is a new organic farming model based on recent innovations in the respective areas of crop growth, artificial lighting and HVAC efficiency. The use of high-tech plant growth and lighting components within this food production system will greatly reduce water, nutrient, land and transportation energy requirements.

A student team at Clarkson University designed and built a 450 sq. ft. pilot greenhouse to test the CEHRF concept, focusing especially on maximizing yields while minimizing energy requirements for local food production in cold climates. The student project has been coordinated though Clarkson's SPEED (student projects for experiential engineering design) program and senior capstone design classes with funds from the EPA P3 design competition. Students worked on the technical design of the pilot and full scale CEHRF, environmental impacts, and business planning for the overall project.

The technical design required students to understand plant growth needs and the innovative engineered systems available to provide to meet the required growing conditions. Plant growth requires both ample daylight and warm temperatures. The pilot-scale greenhouse building is designed to balance daylighting from a southern-facing light transmissive wall with the others being highly-insulated to minimize heat requirements. An innovative lighting system based on red and blue LED lights with an advanced control system will limit the use artificial lighting to the minimum specific lighting conditions required for plant growth. An opportunity to maximize the efficiency of the greenhouse and reduce fossil fuel consumption has been accomplished by integrating its operation with a biomass-solar thermal heating system and an anaerobic digester for waste management and heat and power production. Collectively, these coupled systems will represent an opportunity to demonstrate an approach to maximize mass and energy efficiencies as the "waste" resources (heat, plant matter, nutrient rich digester effluent, CO_2) are shared among the building facilities.

Ultimately, operation and analysis of the pilot greenhouse will enable the design of much larger vertical growing systems for cold climates. Preliminary studies suggest that a seven story 70,000 sq. ft. facility to grow lettuce in an area that will support the prices for organic produce will generate an annual profit of $2.5million. If the facility utilizes biomass heat and electricity, it will generate minimal greenhouse gases, require only 7.3% of the water and only 13.5% of the nutrients compared to traditional farming and transportation. Improvements in the lighting and heating systems that were made to the pilot structure after these preliminary estimates were made should improve the overall efficiency of the lettuce production even more.

The objective of this presentation is to describe the technical features of a CEHRF that were developed and proven to make this concept economically and environmentally sustainable and describe the educational logistics and benefits of addressing a real-world, ill-defined project with an approach that couples research, coursework and student activities.

COST-ENERGY ANALYSIS OF OPTIMIZED WATER DISTRIBUTION FOR A THEORETICAL URBAN SETUP: A CASE STUDY

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The recent study on national wide infrastructure by ASCE ranked the nations' drinking water infrastructure as D- and estimated more than $2 trillion investment needs for the infrastructure renovation. It is a challenge as well as a good opportunity for us to build our future infrastructure in a more resilient and sustainable manner. The challenge lies in the complex interactions and the interdependence of water/energy system within the natural and built environment in which the infrastructures are embedded. The efficiency of water infrastructure depends not only on the infrastructure configurations but also on the urban form, population density, climate, and resource availability. While a comprehensive understanding of the pros and cons of decentralized and centralized water supply system is still a problem to explore, it is goes beyond doubt that a combination of the two is necessary for different urban settings. In order to understand the impact of urban form on the efficiency of different water distribution network, in the preliminary studies, the performance of a few water supply scenarios was studied under three typical urban forms: centralized city, polynucleated city, and uniform density (or complete sprawling) city. It is expected that a general city can be simulated by the combination of the three urban forms.

A synthetic city with a median population and area of US cities was created on ArcGIS platform. Using the US Census Bureau data, the median population was calculated to be 170,000 people, and the area covered by this population was approximated as 432 sq.km. The city is divided into grid system with a resolution of 1km×1km for the water distribution network simulation. The above mentioned urban forms were differentiated by the population densities in the grid system. The uniform distribution urban form assumes that the population is evenly distributed within the whole city. The polynucleated urban form assumes five core areas in the city with twice the density than the evenly distributed form. The centralized urban form assumes that the population is concentrated in the central area with a density as three times higher than the evenly distributed form.

For each urban form, distributed and centralized water supply network scenarios were designed using water network software based on EPANET2.0. The centralized water supply consists of one treatment plant and a looped water distribution network with a central storage tank. On the other hand, the distributed supply network consists of multiple water treatment plants with purple line options. Based on the population, 100 households with an average of 3 inhabitants have been assigned to a single junction. For the hydraulic simulation of the water network, the product of 660 L/d (the average per capita water use per day) and 1.80 (maximum daily demand), with the population, was used to calculate the peak water demand of 2423.5 L/s. Also, to ensure water availability even under extreme peaks in water demand, the fire-flow demand of 391.6 L/s for 6 hours was summed up with the peak water demand. Thus, the total water demand (inclusive of the required fire-flow demand) was calculated to be 2815.2 L/s. This total water demand was then inputted for calculating the loads for each of the junctions in the network, and at the same time, the pressure head in the system was maintained within the range of 14 to 70 meters of head. A 24-hour time demand pattern or a diurnal curve was applied to make the system more realistic. The central storage tank was also simulated to meet the demands of the population over the 24-hour period simulation. Initially, for the base-case scenarios, the elevation of the entire water distribution was assumed to be at zero elevation. For the comparative study, each of the water systems' pump horsepower and tank minimum and maximum water levels and its elevation were modified and simulated. The alteration of the pump horsepower and tank characteristics were modified to maintain acceptable system-wide pressures in every urban form.

Each of these three ideal water network models developed would present a deterministic approach to define its urban water infrastructure. In the future research, the energy use and cost analysis for the three types of systems will be performed. For each urban form, water network configurations are to be compared for its efficiency in terms of the recorded energy and cost factors. The comparison of the cost and energy factors involved in developing an urban water distribution system will direct the urban planners in making important network decisions at the planning stage itself. Thus, this research is focused on serving as a platform for urban water infrastructure developers/planners to decide the water distribution network their City/Town plan requires based on its population needs while keeping their energy requirements as low as possible.

MINERAL DEPOSITION BEHIND WATERLESS URINALS

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Background and Objectives

In an attempt to conserve water, many institutions, commercial establishments and municipal facilities have installed waterless urinals in men's restrooms. These urinals do not require flushing. Accordingly, they are touted as saving an average of 40,000 gallons of fresh water per urinal per year, and are becoming increasingly popular as water-saving devices.

One of the problems associated with these waterless urinals, however, is precipitation of mineral deposits in the pipes behind the urinals. Because no water is employed to flush the urinal, some remnants of the urine remain in the drainage pipe after each use until they are displaced by urine from the next user. Urea in these remnants hydrolyzes to release ammonia and carbonate. This raises the pH of the urine, causing it to become oversaturated with respect to struvite (magnesium ammonium phosphate) and various calcium phosphate minerals (e.g., calcium hydroxyapatite), leading to precipitation of these solids and potential plugging of the drainage pipes.

The objective of this presentation is to provide examples of the extent of mineral deposition in such waterless urinals, discuss the relevant chemistry associated with the phenomenon, and to suggest approaches for overcoming this potential problem.

Methodology

The University of North Carolina at Chapel Hill installed approximately 300 Falcon Waterfree urinals on its campus about five years ago (see Figure 1). These urinals have a disposable cartridge that must be replaced after about 70,000 uses (every 4-6 months). The cartridge contains a polymer sealant that covers any urine remaining in the cartridge between uses. The urinal cannot be flushed with tap water for cleaning because the water would cause the sealant to deteriorate.

The UNC maintenance department experienced problems with these urinals and noted appreciable mineral deposition in the drainage pipes behind the urinals. Accordingly, they replaced most of the Falcon cartridges with alternative cartridges. These cartridges are fitted with a flexible rubber tube which allows for discharge of the urine during use and folds up between uses to prevent the release of odors back into the bathroom. The alternative filters allow for the urinals to be rinsed with water by housekeeping staff so that urine is not allowed to accumulate in the system between uses and mineral deposition is minimized.

For this study, we pulled several of these Waterfree urinals off the wall and examined the drainage pipes behind the urinals. Locations with the following attributes were selected: locations where only the Falcon cartridges were used, locations where the Falcon cartridges had been used for two years and then replaced by the alternative cartridges, and locations where only the alternative cartridges had been used. In each case, high use and low use locations were chosen. The extent of mineral deposition in the drainage line was captured with photographs, and samples of the mineral deposits were collected. The deposits were sterilized (autoclaved), dried, powdered with a mortar and pestle, and submitted for x-ray diffraction (XRD) and scanning electron microscopy (SEM) analysis.

Additionally, the underlying chemistry associated with these deposits was analyzed using chemical equilibrium calculations. Starting with the average chemical composition of urine (total dissolved calcium, magnesium, sodium, potassium, ammonia, chloride, sulfate, carbonate, phosphate, oxalate, citrate), its pH and acidity, we calculated the pH change accompanying the production of ammonia and carbonate arising from urea hydrolysis. The resulting pH, along with the increase in ammonia and carbonate concentrations, was used to calculate the mineral deposition potential (degree of oversaturation) with respect to struvite, calcite, calcium hydroxyapatite, and other calcium phosphate minerals.

Results

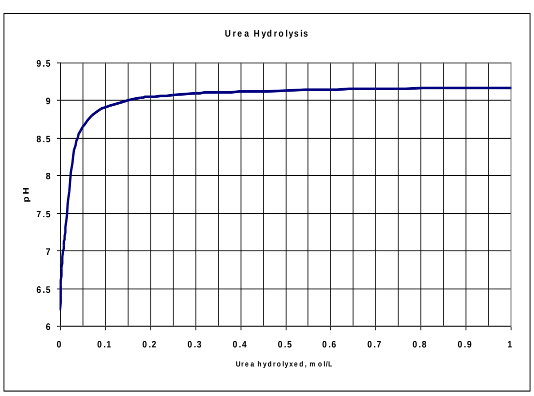
Figure 2 is a photograph of deposits observed in the pipe behind a Waterfree urinal fitted with a Falcon cartridge that was installed 6 months earlier in a high use location. Equation 1 illustrates the release of ammonia and carbonate associated with the hydrolysis of urea.

$$NH_2(CO)NH_2 + 2H_2O \rightarrow 2NH_4^{+} + CO_3^{-2} \qquad (1)$$

Figure 3 shows the calculated change in the pH of urine as urea hydrolyzes. The increased pH approaches pH 9.25, the equilibrium pH of an ammonium carbonate solution. Figure 4 shows the XRD pattern for several mineral deposits taken from pipes behind Waterfree urinals compared to that of struvite.

Figure 1 (left). Photograph of the Falcon Waterfree urinal

Figure 2 (right). Mineral deposit behind a Waterfree urinal.



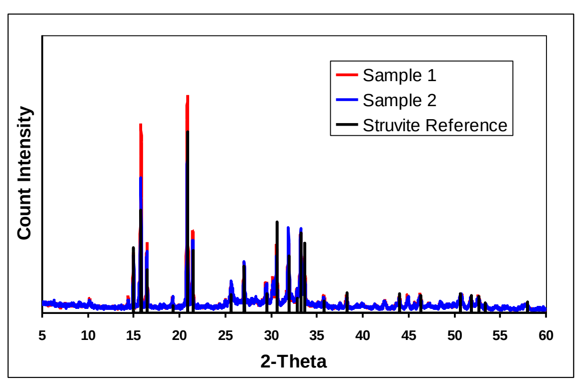


Figure 3 (above, left). Calculated change in pH of urine resulting from hydrolysis of urea.
Figure 4 (above, right). Comparison of XRD patterns of deposits with struvite reference pattern.

SUSTAINABLE POLYMERIC WATER PIPE INFRASTRUCTURE: WHAT WE KNOW AND DON'T KNOW ABOUT LEACHING

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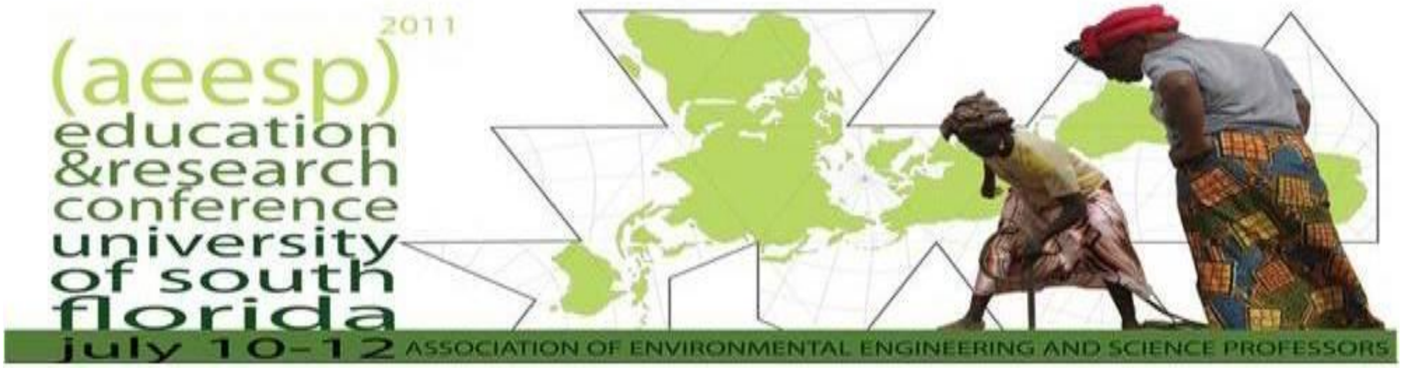
Polymeric potable water pipes are progressively becoming the new interface between the water treatment facility and the customer's tap. These organic pipes are considered sustainable, have estimated 50-100 year service-lives, and are being used for buried water pipe replacement and new building construction globally. With major shifts in planning, urbanization, and infrastructure construction on the horizon, engineers and researchers need to better understand the impact of these increasingly popular materials on drinking water quality and safety. The goal of this project was to examine how North American polymeric pipes are manufactured and identify to what extent polymer manufacture impacts contaminant migration from in–service and new potable water pipe. Results showed that while ten different types of polymer pipe have been installed in North America (roughly 2-8 vendors per material), only a handful of chemical migration studies are publicly available. As a result, the scope of this work was expanded to include investigations conducted in 15 different countries. More than 150 regulated and unregulated contaminants were identified leaching from different polymer drinking water pipes. Almost all inorganic and organic contaminants identified were either polymer pipe ingredients or manufacture byproducts. Compounds were grouped to include: (I) Unreacted monomer and resin, (II) Additives such as antioxidants, stabilizers, pigments, processing aides, initiators, lubricants, curing agents, crosslinking agents, flame retardants, fillers, plasticizer, accelerants, solvents, (IIII) broken polymer chains that in general have oxygen functional groups containing alcohol, ketone, aldehyde, and carboxylic acids, and (IV) primary or greater derivative degradation products of ingredients. uPVC pipe has received the greatest scrutiny for two contaminants (lead and VCM), while other materials such as other PVC types, PEs, multilayer pipes, and FRPs have received less scrutiny. Several contaminants identified have regulated MCLs (e.g., lead, VCM), are being considered for regulation on USEPA's 2010 Contaminant Candidate List 3 (e.g., MTBE), and have received public and regulatory interest (e.g., bisphenols and phthalates) **(Table)**. This presentation will provide the audience an overview of existing polymeric drinking water pipe migration knowledge and outline several major knowledge-gaps inhibiting advancement of polymeric pipe as a sustainable infrastructure material.

Table. Known Contaminants that Migrate from Polymeric Pipes that have USA Federal Regulatory Drinking Water Limits and those being considered for Regulation

Contaminant	Pipe Types	Regulated Concentration, µg/L
Barium	uPVC	2000
Benzene	HDPE, PEX–AL–PEX[unspecified]	4
Cadmium	uPVC	5
Ethylbenzene	HDPE	1000
Lead	uPVC	15
Styrene	HDPE, FRP–Poly(ester)	700
Trichloroethylene	HDPE	5
Toluene	HDPE, PEX–AL–PEX[unspecified]	200
VCM	uPVC	2
Xylenes	HDPE, PEX–B, PEX[unspecified]	100
n–Propylbenzene	HDPE	Proposed on CCL3
MTBE	PEX–A, PEX–C, PEX[unspecified], PEX–AL–PEX[unspecified], PEX–C–AL–PEX–B	Proposed on CCL3
TBA	PEX–A, PEX[unspecified], PEX–AL–PEX[unspecified]	Proposed on CCL3
Bisphenol compounds	uPVC, FRP–Poly(ester)	Under consideration
Phtalate compounds	HDPE, uPVC, FRP–Poly(ester)	Under consideration

Suspect that all HDPE pipes are unimodal PE materials since no studies reported resin modality and pipes used before the 1990s were generally all unimodal, not bimodal PE; Some PEX studies did not declare the type of PEX examined. The State of California has a drinking water MTBE regulatory limit of 13 µg/L (health based) and secondary MCL of 5 µg/L (aesthetics based).



Research Category #4: ***Vulnerability and Adaptation to Climate Change***

Research Category # 4

VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

POTENTIAL FOR CARBON CAPTURE AND SEQUESTRATION (CCS) IN FLORIDA

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It has been proposed that carbon dioxide (CO_2) could be captured from large stationary sources, such as fossil-fuel-fired power plants, and then stored underground in geologic repositories, as a means of removing CO_2 from the atmosphere and thereby mitigating global climate change. This proposed technology is often called "carbon capture and storage," or CCS. Our team at USF is working to investigate three aspects of CCS. First, we are developing new technologies to capture CO_2, which may be more cost-effective than existing technologies. Second, we are conducting a geologic investigation of what subsurface formations in Florida might be most suitable for CO_2 storage. Third, we are developing models to predict how CO_2 will behave when injected underground, including geochemical models to predict what chemical reactions will occur when CO_2 dissolves into the native brine of deep saline aquifers. Our work so far suggests that CCS in Florida appears feasible.

For carbon capture, our team is investigating a material composite, specifically a film of calcium oxide (CaO) impregnated on the fibers of a ceramic fabric. CO_2 is captured by the fiber during a carbonation cycle in which CaO is converted to $CaCO_3$, then released and recovered during a carbonation cycle. The process is repeatable through multiple cycles, as shown in Figure 1 (below), with only a slight loss of effectiveness in the first few cycles.

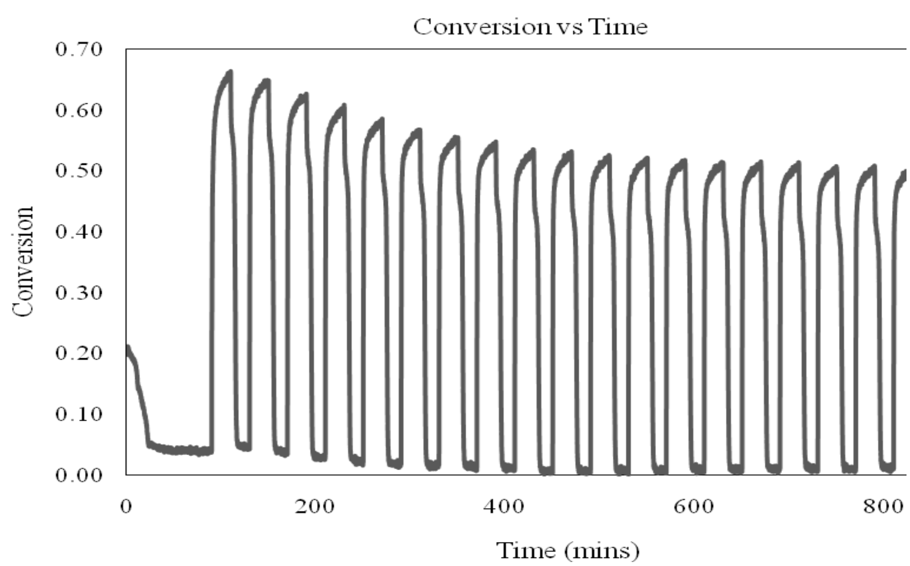

Figure 1: Capture and release of CO_2 by impregnated ceramic fabric

If CO_2 can be captured and recovered from stationary sources within Florida, a potential repository is the Cedar Keys / Lawson geologic formation. This formation is a deep saline aquifer, approximately

3,000–5,000 ft (1,000–1,500 m) below ground surface, which underlies much of the Florida peninsula. The formation is deep enough for CO_2 to be in the supercritical phase and is not considered an "underground source of drinking water" (USDW) because it is too saline. This formation has a significant capacity for CO_2 storage, as shown in Figure 2, below.

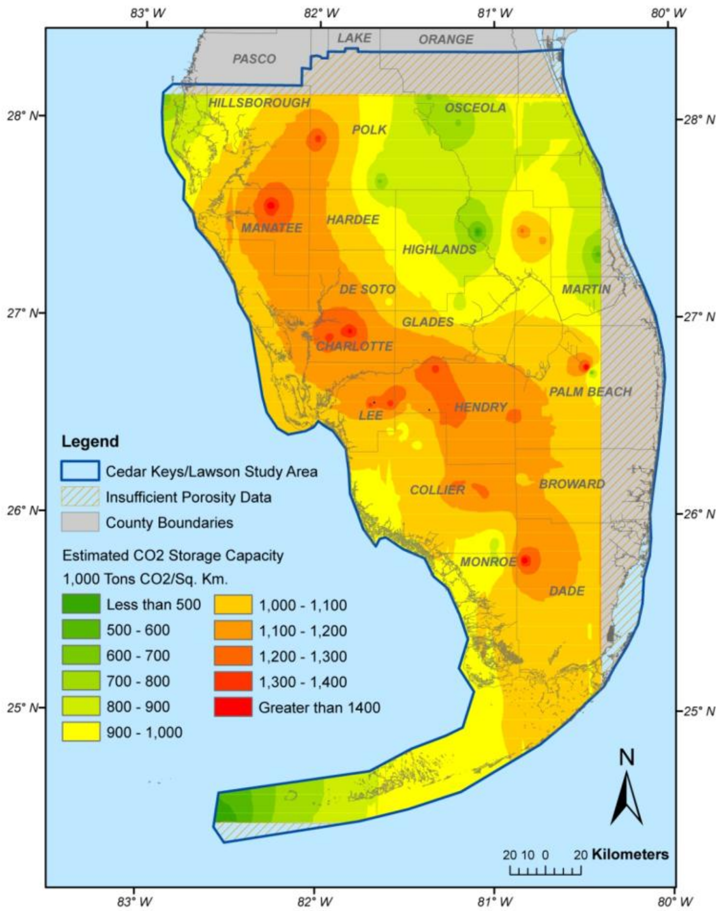

Figure 2: Capacity of the Cedar Keys / Lawson formation for CO_2 storage

The proposed Cedar Keys / Lawson repository is comprised of carbonate rocks, i.e., limestone and dolomite. Injection of CO_2 into the saline brine is likely to induce a drop in pH, which may in turn cause dissolution of the carbonate rocks in the formation. Therefore, we have developed a geochemical model to predict the extent of mineral precipitation and dissolution induced by CO_2 injection. Commercially available "off-the-shelf" software already exists with this capability, but by developing our own model we were able to assess the sensitivity of the model's predictions to different thermodynamic sub-models that have been proposed in the literature. We found that all proposed thermodynamic sub-models yield similar predictions, but that predictions are sensitive to the method used for estimating the fugacity coefficient of supercritical CO_2. Furthermore, all models tested predict that calcite and dolomite will dissolve and that gypsum will precipitate when CO_2 is injected, but that the resulting changes in porosity will be small. The extent of precipitation and dissolution is sensitive to the temperature and the salinity of the brine, but not sensitive to the initial pH of the brine, nor, surprisingly, to the injection pressure of the supercritical CO_2.

CLIMATE CHANGE AND CARIBBEAN CORAL REEFS

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The Caribbean encompasses a region consisting of the Caribbean Sea, surrounding islands (most of which enclose the sea) and the adjoining coasts. The region is located between the Gulf of Mexico, North America, Central America and South America. The Caribbean lies mostly on the Caribbean tectonic plate and comprises of over 7000 islands, islets, reefs and cays. These islands form an archipelago that extends from the tip of South America along the eastern and northern edges of the Caribbean Sea, to the southern coast of North America. Geographically, the Caribbean lies in a region around the equator, classifying it as a tropical region experiencing only two (2) major seasons (wet and dry) with a hurricane season from June to November.

Changes in climate are directly affecting the Caribbean region. The region's economy, largely dependent on "sun, sea and sand" is gradually being destroyed. More importantly, the livelihood of many who survive on tourism and fishing is being dramatically affected. Increasing carbon dioxide levels have resulted in rising earth temperatures with concomitant high levels of coral reef bleaching. Increases in storm and hurricane activity have caused destruction of coastal systems. Increased rainfall and tremendous flooding have brought havoc to the fishing industry. In short, Caribbean progress is being stifled by changes in climate. The paper which will be presented zeroes in on the extent to which climate change is affecting coral reefs and beaches in the Caribbean. Reefs and beaches have been targeted because they are invaluable sources of food and income for several countries in the region. The original paper is divided into four parts which will be made more effective in the presentation by the use of illustrative slides.

Part 1 shows the importance of coral reefs to the Caribbean. Their significance to marine ecosystems and the vital relationship between these organisms and their surroundings are factors which are explained. In this section also, financial statistics surrounding five (5) coral reefs chosen from the region are used in support of economic importance. In Part 2, the sensitivity of coral reefs to environmental changes is examined. Changes in various factors such as rising sea levels, rising sea temperatures, changing salinity levels, light intensity and upwelling of nutrients, will be explained. Part 3 delves into anthropogenic (manmade) forces of human activity as a major contributor to climate change. While it is a known fact that varying levels of damage to coral reefs occur through the forces of nature, the harm is exacerbated by human action. Human impact has been divided into four categories, climate change being shown to be the most important. This part continues with a discussion on El Niño Southern Oscillation and how climate change is affecting the intensity of this phenomenon. The connection with hurricane activity and intensity in the region will be demonstrated. Spin off effects that threaten the existence of coral reefs and beaches in the region will also be shown. Part 4 concludes with suggested mitigation and adaptation strategies and policies to counteract the effects of climate change in the Caribbean. Some of these strategies range from practices that North Americans see as everyday and normal, e.g. reducing, reusing and recycling, to huge endeavours that require regional effort, e.g.

research into different energy sources for the region. Some of these practices seem somewhat alien to people of the Caribbean, in light of the fact that our economies have never focused on sustainability but more on survival and development. The intention is not to throw out the baby with the bath water but to bring equilibrium and balance. In terms of infrastructure, tourism and overall development, we have reached thus far and must continue the growth process. The objective of the paper is to heighten awareness and appreciation for our environment, by increasing education levels in local communities, fostering new respect for our marine ecosystems and advancing the discussion on responsibility, whether locally or at a governmental or regional level.

CLIMATE CHANGE AND DEVELOPMENT IMPACTS ON THE SUSTAINABILITY OF SPRING-FED WATER SUPPLY SYSTEMS IN THE ALTO BENI REGION OF BOLIVIA

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Sustainability of spring-fed gravity distribution systems depends on recharge that accommodates present and future water needs. In addition to a planned increase in agricultural area in the region, climate change may also result in changes to the water cycle. A daily water balance model is used to predict recharge rates in eleven watersheds, with incorporation of the NRCS curve number method to separate recharge from runoff. Low cost field methods and publicly available satellite-derived products were used to collect all data required to calibrate the model. The recharge is then modeled under scenarios of climate change and agricultural expansion. The annual average temperature, derived from an ensemble of 14 downscaled outputs for the A1B scenario (Maurer et al. 2009), is expected to increase by about 3.5 degrees. The ensemble mean precipitation anomaly is positive 34 mm (range -290 to +570) from the current annual precipitation of about 1300 mm. Because of the uncertainty in the precipitation anomaly, climate impacts are modeled using the ensemble mean, plus and minus the standard deviation. Initial results suggest climate change impacts are may be larger than those from agricultural expansion, contrary to perceptions that spring flow will decline further primarily because of agricultural growth. Finally, the current and projected water use resulting from planned improvements in water and sanitation coverage is compared with recharge to the springs to evaluate impacts of changes in population, land use, climate, and water infrastructure development on the sustainability of continued reliance on natural springs for domestic water supply.

FORECASTING CLIMATE CHANGE OF SEA LEVEL RISE IMPACTS ON SALT WATER INTRUSION IN THE BISCAYNE AQUIFER, THE SOLE SOURCE OF WATER SUPPLY TO MIAMI-DADE COUNTY, FLORIDA, AND EVERGLADES SUBSURFACE

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Forescasting the effects of climate change on salt water intrusion in coastal aquifers and their use as groundwater supply is crucial in the planning and implementation of timely preparedness and actions by regional and community water users. In the United States sea level rise estimates by the Intergovernmental Panel on Climate Change (IPCC) could annihilate 43 percent of coastal wetlands and increase coastal flooding. The question herein addressed is the potential impact (e.g., vulneravility and resilience) of sea level rise on salt water intrusion in the unconfined Biscayne Aquifer, a part of the surficial aquifer system in Florida, and a sole-source of water supply for the southeastern Florida region. Impacts are expected on both the Everglades ecosystem and the populated coastal urban environment.. Salt water intrusion has been a recurring concern in Miami-Dade County due to increasing levels of salinity in coastal well fields as a result of pumping groundwater (Fish & Stewart, 1991). The objective of this effort is to provide an assessment framework for the extent of salt-water intrusion, including shifts in the halocline location (i.e.,fresh-saline groundwater interface), from scenarios based on the IPCC and regional historical trends.

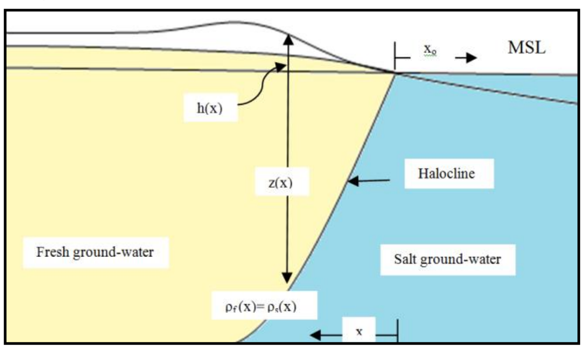

Figure 1: Conceptual Schematic of the GHB Relation

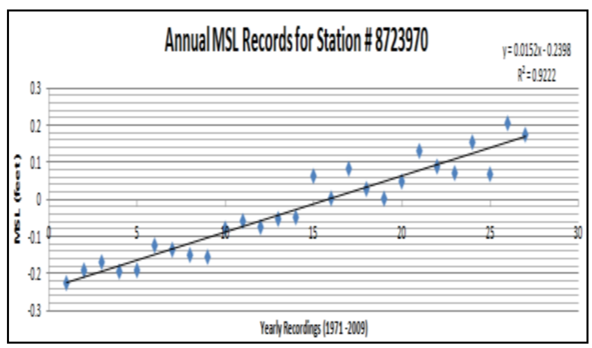

Figure 2: SLR Linear Projection for NOAA'S Station # 8723970

The Ghyben-Herzberg (GH) relation (Figure 1) and variations (e.g., to account for freshwater recharge and discharge into the sea) is used as the mathematical and computational tool to define scenarios of impact. The GH relation is an analytical solution for a homogenous aquifer at coastlines that is based on hydrostatics and the Dupuit approximation for flow in an unconfined aquifer.

The target systems in this study are the Biscayne Aquifer and the Everglades of southeastern Florida, mainly, Miami-Dade County. Both systems are expected to be subject to much stress from the potential climate changes. The GH relation is herein presented by Equations (1) to (6) for the case of no freshwater discharge in the sea. Equation (3) represents shifts in the existing halocline as a function of sea level rise with respect to time. The application is also modified by incorporating Equations (4) and (5) (Werner and Simmons, 2009) and Equation (6) from (FEMA, 1991).

$$Z_s(x) = \sqrt{\frac{2\alpha(q(0))(x)}{K}} \qquad (1)$$

Where,

$$\alpha = \frac{\rho_f}{\rho_{f-}\rho_i} \qquad (2)$$

$$(x) = \alpha\left(h_f(x)\right) \qquad (3)$$

$$Z_s^{'}(x) = Z_s(x) + SLR(t) \qquad (4)$$

$$\alpha = \frac{Z_s(x) + SLR(t)}{h_f(x)} \qquad (5)$$

$$SLR(t) = (0.0039 + M)t + bt^2 \qquad (6)$$

Variables α, ρ_f, ρ_i, $Z_s(x)$, $h_f(x)$, $Z_s^{'}(x)$, $SLR(t)$, $M$and b respectively represent the density ratio, the density of freshwater, the density of salt water, the height of the water table at a location x inland, halocline depth as a function of the inland location, sea level rise and site specific factors to estimate sea level rise. Figure 2 illustrates trends of sea level rsie along the southeatern Florida coastline from a NOAA station.

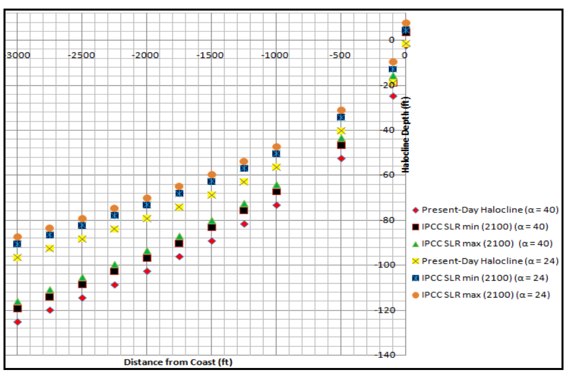

Figure 3: Inland variations on halocline depths based on IPCC predictions

The assesment focused on the impact of sea level rise on the Biscayne Aquifer in Miami-Dade County, Florida. Scenarios are predicted and analyzed as a function of aquifer properties (e.g., hydraulic conductivity), spatial variability of aquifer hydraulic conductivity (e.g., along northern and southern transects in the county), density ratio α, estimation of recharge and discharge in the sea and, as an major independent variable, the range of predicted sea level scenarios.

Assumptions were made to account for the limitations of the analytical relation in, for instance, density ratios for limestone and hydraulic conductivity variability in the aquifer. Results are analyzed and conclusions and recomendations scoped as to the expected range of effects on the Biscayne aquifer water table, halocline shifts on the freshwater availability and realted stress on the Everglades environs. Figure 3 exemplifiess predictions for the halocline location for various estimates of seal level rise along in-landtransects in the county.

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A SYSTEMIC APPROACH TO VULNERABILTY ANALYSIS OF PYRAMID LAKE INDIAN WATER RIGHTS UNDER CLIMATE CHANGE

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Climate change and variability brings new challenges to the arid and semi-arid region of the Western United States. Increased frequency and duration of climatic extreme, particularly drought, will put regional water and environmental management system under unprecedented stress thus increasing the need for climate change adaptation (CCA). The first fundamental step in CCA is a climate change impact assessment, however the conventional CCA approach has two major shortcomings: 1) lack of integrated and holistic assessment of physical and social vulnerabilities, and 2) lack of a participatory approach. In particular, CCA assessment focuses primarily on hazards or physical vulnerabilities, such as water availability, floods, drought impact, amongst others. Furthermore, it is often derived from an expert driven approach that involves downscaling and incorporating future climate change scenarios into hydrological models (e.g. rainfall-runoff model), and coupling the hydrologic model with a reservoir or environmental system model. However, in addition to such physical vulnerabilities, important intrinsic vulnerabilities, such as socio-cultural and legal vulnerabilities, that play a major role in determining the overall impact and burden of climate change needs be considered especially since the weaker strata of society is likely to be most impacted by climate change. The motivation of this research study is to formulate and implement a systemic approach for a holistic assessment of vulnerabilities of downstream users and identify critical components for negotiation, successful collaboration, and adaptive management that address climate change impacts. The research study focuses on the Pyramid Lake Paiute Tribe (PLPT) in Truckee River Basin and involves a complex and multi-stakeholder system with a century long history of conflict and negotiation over values and usages of water and a recently negotiated settlement, the Truckee River Operating Agreement (TROA) of 2008.

TROA sets up operating arrangements for water allocation and management in the Truckee River Basin by establishing equitable apportionment of water between urban, rural, and tribal water users. Within TROA, tribal water rights of the Pyramid Lake Pauite Tribe (PLPT) are devoted to protect endangered fish (such as Cui-ui or *Chasmistes cuius*), and the ecosystem of Pyramid Lake. PLPT is uniquely posed, in contrast to urban and other rural water users, because PLPT culture and livelihood is closely tied with the Pyramid Lake ecosystem services and cultural values of water. While TROA sets up arrangements for water management, it does it without explicitly consider climate change impacts, and thus there is a need to look into the potential of TROA for CCA considering downstream water users. In this research, we propose collaborative planning that accounts for plural perspectives in an uncertain climatic terrain resulting in a great potential for basin-wide acceptability and success. In this regard, the present study aims to take the first fundamental steps by building feedback loops and constraints of a conceptual collaborative system dynamics model.

Vulnerability and Adaptation to Climate Change

Our proposed approach of a systemic assessment includes an a) investigation of physical (both technical and perceptual) and intrinsic vulnerabilities; b) analysis of the evolution of stakeholders' power relations, conflict, negotiation, and implications for climate change impacts; and, c) establishment of first fundamental steps in system dynamics modeling by eliciting cognitive map of individuals from major stakeholder groups through interviews, forming aggregated causal loop diagram or cause map through group discussions, and developing conceptual climate-environment-society feedback loop for individual groups.

Three major steps of the research have been conducted to evaluate the physical, socio-cultural, and legal vulnerabilities and future research includes implementing and analyzing a participatory approach. First, as in conventional vulnerability assessment, we analyzed technical physical vulnerability in Truckee River Basin against climate change through climate scenario assessments. Standardized precipitation index (SPI) derived from ensembles of 36 scenarios of 16 CMIP models under different emission scenarios for the basin showed that there are potential for moderate ($-1.49 < SPI < -1.0$) and even severe ($-1.99 < SPI < -1.5$) or extreme ($SPI \leq -2.0$) droughts. Progressive increase in projected average monthly temperature is expected for both lower and upper Truckee River Basin with much higher monthly rise in the later part of the century. Second, a survey was conducted to explore perceptual vulnerabilities to climate change on Pyramid Lake Paiute tribal members and managers. Preliminary results from 110 tribal member surveys and 21 managers' surveys revealed that drought, water availability, lake water quality, fisheries, and livelihood are some of the key concerns of PLPT tribal members and environmental managers under the face of climate change. Third, an analysis of power relationships was performed to evaluate relative stakeholder influence through conflicts and negotiations over Truckee River water. This illustrated the development of water sharing strategies and changing power relationships between stakeholders. Results showed that PLPT has transformed from a marginal user to one of the most powerful groups in the basin. Persistence of PLPT for seeking legal recourse to safeguard their water rights, bolstered by enforcement of the Endangered Species Act of 1973, appears to be key contributing factor to their power position. Ongoing research activities include one-on-one open-ended interviews that will be conducted to build individual cognitive maps for two main groups of environmental managers and leaders: 1) PLPT stakeholders and experts and 2) non-tribal stakeholders and experts (e.g. Bureau of Reclamation, Fish and Wildlife Services, Truckee Carson Irrigation District, and Truckee Meadow Water Authority). Then, two separate and larger group discussions will be conducted to synthesize a group casual loop diagram by involving indvidually interviewed stakeholders. Finally, these casual loop diagrams will be developed into system dynamics influence diagram for future collaborative modeling purpose. These research steps provide a holistic assessment of vulnerabilities of downstream users and identify critical components for negotiation, successful collaboration, and adaptive management that address climate change impacts.

In conclusion, while climate data analysis showed potential climate change impact in Truckee River Basin, preliminary results show that PLPT has emerged from a historically weak power position (with high level of interst/importance but low level of influence) to high level of interest and influence. In view of this, it appears that PLPT is in a better position to safeguard its water rights in the face of climate change. However, future collaborative modeling exercise is needed for trust building, adaptive planning, and management to address climate change impacts.

SUPERCRITICAL CO_2-INDUCED CLAY MINERAL DISSOLUTION AND SECONDARY MINERAL FORMATION: IMPLICATIONS FOR GEOLOGIC CO_2 SEQUESTRATION

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Carbon dioxide sequestration in deep saline formations is an attractive option among geologic CO_2 sequestration (GCS) strategies (1-2). However, dissolution of rocks and secondary mineral formation induced by CO_2 injection could potentially change the physical properties of the geological formations, and thus influence the transport and injectivity of CO_2 (3-4). Although the injection phase of GCS could last as long as 25 years or more (3), recent studies have shown that supercritical CO_2 ($scCO_2$)-induced dissolution and precipitation can change the rock's porosity and permeability after a short time (5-6).

To ensure the viability of geologic CO_2 sequestration (GCS), we need a holistic understanding of reactions at supercritical CO_2 ($scCO_2$)–saline water–rock interfaces and the environmental factors affecting these interactions. This research investigated the effects of various environmental factors (such as salinity, temperature, pressure, and the extent of water) on the dissolution and surface morphological changes of clay minerals. Phlogopite [$KMg_{2.87}Si_{3.07}Al_{1.23}O_{10}(F,OH)_2$], biotite [$K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$], and muscovite [$KAl_2(Si_3Al)O_{10}(OH,F)_2$] were used for model clay minerals in potential GCS sites. In this work, both fluid/solid chemistry analysis and interfacial topographic studies were conducted to investigate the dissolution/precipitation on clay mineral surfaces under GCS conditions (368 K, 102 atm) in high salinity systems.

For example, for phlogopite, dissolution was the predominant process. Salinity enhanced the dissolution of clay minerals and affected the location, shape, size, and phase of secondary minerals. In low salinity solutions, nanoscale particles of secondary minerals formed much faster, and there were more nanoparticles than in high salinity solutions. Although the bulk solution was not supersaturated with respect to potential secondary mineral phases, interestingly, nanoscale precipitates formed. Atomic force microcopy (AFM) was utilized to record the evolution of the size, shape, and location of the nanoparticles. Nanoparticles first appeared on the edges of dissolution pits and then relocated to other areas as particles aggregated. In 1 M NaCl, amorphous silica and kaolinite were identified as the secondary mineral phases, and qualitative and quantitative analysis of morphological changes due to phlogopite dissolution and secondary mineral precipitation are presented. The effect of water extent was investigated by comparing $scCO_2$–$H_2O(g)$–phlogopite and $scCO_2$–$H_2O(l)$–phlogopite interactions. Experimental results suggested that the presence of a thin water film adsorbed on the phlogopite surface caused the formation of dissolution pits and a surface coating of secondary mineral phases that could change the physical properties of rocks.(7)

For biotite, on the basal planes, numerous macroscopic fibrous illite formed after only 3 h reaction, although the bulk solution was undersaturated. After longer reaction times, microscale cracking (22 h) and disintegration of biotite basal surface (96 h) occurred. These morphological evolutions increased the surface area in contact with solution, and accelerated biotite dissolution. Meanwhile, a greatly diminished amount of fibrous illite was observed on the cracked biotite basal plane. Significant Al-substituted goethite preferentially precipitated on biotite edge surfaces, resulting in lower net dissolved Al and Fe than Mg and Si after reaction for 44 h.(8)

These results provide new information for understanding reactions at scCO_2–saline water–rock interfaces in deep saline aquifers, and will help design secure and environmentally sustainable CO_2 sequestration projects.

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SAFE AND EFFECTIVE GEOLOGIC SEQUESTRATION OF CO_2: PARTNERSHIPS FOR MULTI-SCALE EXPERIMENTAL STUDIES

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The UN Intergovernmental Panel on Climate Change (IPCC) has concluded that to limit global-average temperature rise to less than 2.4°C, global CO_2 emissions will need to be reduced by 2050 to at least 50% relative to 2000 levels. The International Energy Agency projects that geologic carbon sequestration should account for as much as 19% of the needed emissions reductions, second only to end-use efficiency increases. For the U.S., a similar analysis by the Electric Power Research Institute estimates that geologic sequestration could account for one third of the needed reductions, surpassing even end-use efficiency. In geologic carbon sequestration (GCS), CO_2 is captured from large point sources, and transported to sites where it is injected into deep geologic formations. To enable the safe, effective and reliable advancement of GCS, we need to better understand the possibility of CO_2 leakage from target formations. This means understanding the integrity of caprocks as seals for injection formations and the mechanisms that govern CO_2 migration away from the injection formation.

Partnerships between Princeton, the University of Virginia, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory and the University of Provence are coordinating the study of these processes at multiple scales. Experiments span length scales from microns to 100's of meters, and the processes studied range from geochemical reactions to the physics of flow in porous media. (See Figure 1) In this presentation, we summarize the suite of experiments that are planned and underway and we present recent findings. We seek to demonstrate that this coordinated multi-disciplinary, multi-scale research collaboration will produce transformative contributions to GCS and ultimately advance carbon management on a global scale.

At the largest spatial scale, there is LUCI, the *Laboratory for Underground CO_2 Investigations*, an experimental facility planned for the DUSEL laboratory in the former Homestake goldmine in South Dakota. LUCI is designed to study vertical flow of CO_2 in sedimentary media over length scales representative of leakage scenarios in GCS. LUCI construction is projected to start in 2013, take 2 ½ years, and cost between \$40 and \$60 million. The scale and accessibility of this facility will permit measurements that cannot be done in a conventional lab and observations that cannot be made in the field.

Additional experiments isolate relevant physical and geochemical processes to generate the fundamental understanding needed to interpret larger-scale observations. At intermediate scales, demonstration column experiments are being planned. A LUCI prototype of ~35 m length is planned for the *Laboratoire Souterrain à Bas Bruit* (LSBB), the premier underground lab for geosciences research, located in France. To guide the design of these experiments, we are planning a 6 m column and have already built a 1 m column at the University of Virginia. These experiments are designed to resolve competing hypotheses about multiphase flow of a partially miscible and highly compressible fluid in a heterogeneous porous medium.

At the bench-scale, experiments are underway to study CO_2 properties and reactions in porous and fractured sedimentary rocks. Inferences are drawn with the benefit of a suite of imaging methods including X-ray computed microtomography (μCT), back-scattered electron (BSE) SEM imaging, energy-dispersive X-ray spectroscopy (EDX), and synchrotron-based X-ray spectroscopy and diffraction imaging.

At Princeton and Brookhaven, an important finding comes from an experiment with a limestone specimen from a caprock over a CO_2 injection site in Michigan. In a core-flooding experiment, we exposed this specimen to CO_2-acidified brine at temperature and pressure conditions corresponding to 1 km depth. Extensive degradation of the specimen occurred after 7 days, leading to the conclusion that caprocks that are carbonate rocks, if fractured, can erode quickly, which could compromise seal integrity. We also found that differential dissolution of calcite and dolomite produces uneven aperture growth, complicating prediction of flow permeability.

At the University of Virginia, the aim has been to characterize the balance of interfacial forces at mineral/supercritical-CO_2/brine boundaries and the shear drag forces in the bulk bubbly liquid. Existing models have neglected to consider how bubble deformation will impact its flow through small pores. Contrary to previous work, our work suggests that at lower pressures, e.g., for leaking CO_2, carbonic acid solution could become less viscous during upward migration, potentially accelerating leakage. This understanding will contribute to more accurate predictions of shear drag force and, ultimately, the processes governing bubble rise.

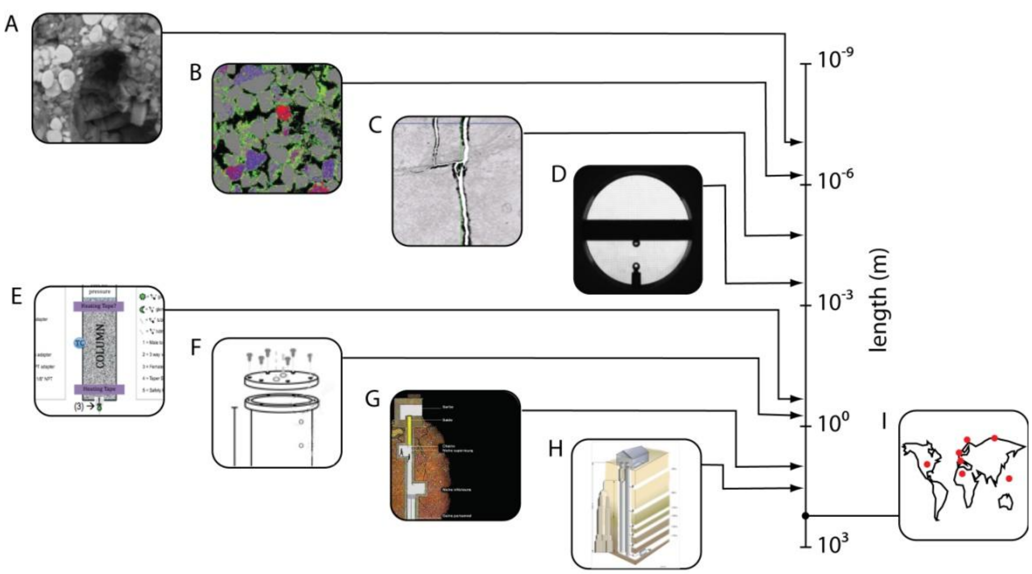

Figure 1. The span of the multi-scale experiments (A through H) in relation to existing field-scale GCS demonstration projects (I). A – Submicron-scale study of CO_2 reactions at mineral surfaces; B – pore-scale study of reactive surface areas in consolidated rocks; C – micron-scale study of reactive flow in fractured caprock; D – mm-scale study of interfacial effects on supercritical CO_2 transport; E - bench-scale column studies; F & G – multi-meter-scale column studies; and H - field-scale experimental columns

EVALUATION OF PORE-SCALE MINERAL PRECIPITATION AND PERMEABILITY REDUCTION OF RELEVANCE TO GEOLOGICAL CARBON SEQUESTRATION

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Geological carbon sequestration involves the capture of CO_2 from stationary power sources, compression of CO_2 to its supercritical state, and injection of the supercritical CO_2 into deep subsurface reservoirs, including saline aquifers. During injection, prior model simulations indicate that a plume of supercritical CO_2 migrates upward and out from the injection point, and dissolves into water along the plume boundaries. In pore water, CO_2 reacts with minerals and results in mineral precipitation. Mineral precipitation can blocks pores, reduce permeability, and potentially affect injection efficiency.

We performed mixing experiments using calcium and carbonate in a flow-through microfluidic pore network to explore precipitation rates, the stability of minerals formed, and permeability reduction. A schematic of our experimental system is shown in Figure 1.

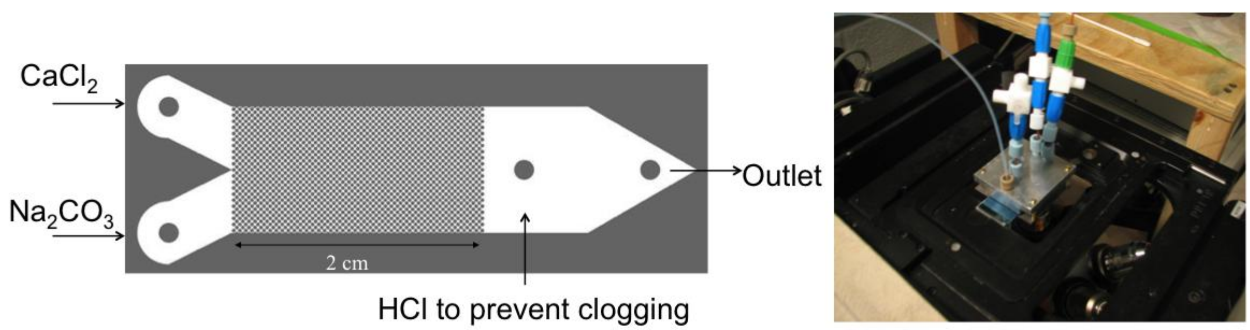


Figure 1. Schematic of the microfluidic pore network (micromodel) including inlet and outlet ports (left), and back of the micromodel manifold mounted on a microscope stage (right).

Four different concentration loadings of calcium and carbonate were evaluated ($[Ca^{2+}]=[CO_3^{2-}]$=6.5, 10, 25, or 50 mM). We found that the amount of $CaCO_3$ precipitation initially increased to a maximum and then decreased to a steady state value. We also found that the extent of precipitation increased with decreasing concentrations, in contrast to our expectations. Reflected differential interference microscopy and fluorescent microscopy were used to visualize precipitation, and to evaluate the corresponding effects on the flow field. Results showing $CaCO_3$ precipitation in the pore network for the 25 mM experiment are shown in Figure 2.

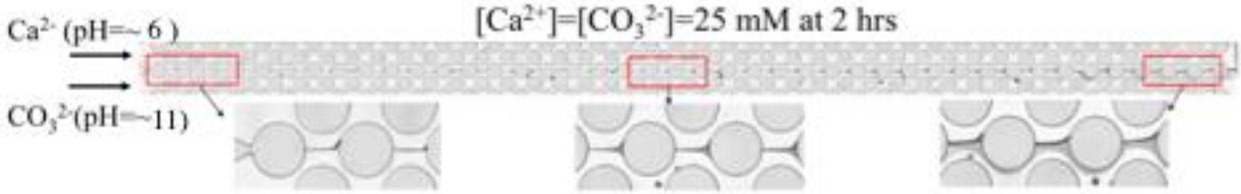


Figure 2. Image of $CaCO_3$ preciptation along the center mixing line of the microfluidic pore network, with enlargements of precipitation in selected pores.

We then developed a two-dimensional pore-scale model to simulate mixing and mineral precipitation using the Lattice-Boltzmann code for water flow, and a finite volume code for reactive transport. Only Ca^{2+}, H^+, OH^-, and three carbonate components were considered. We matched the experimental data by adjusting the reaction rate, the reactive surface area, and the effective diffusion coefficient. We found that the best match of the experiments was obtained when the effective diffusion coefficient was decreased in proportion to the square of porosity at the local grid scale (i.e., 5 micron), and the reactive surface area included all micromodel and calcite surfaces in the flow cell. An illustration of our best match to the imaging data for the 25 mM experiment is shown in Figure 3. These results, as well as those evaluating mineral precipitation for different water chemistry scenarios will be presented. The impacts of the results on sequestration of CO_2 in geologic formations will also be explored.

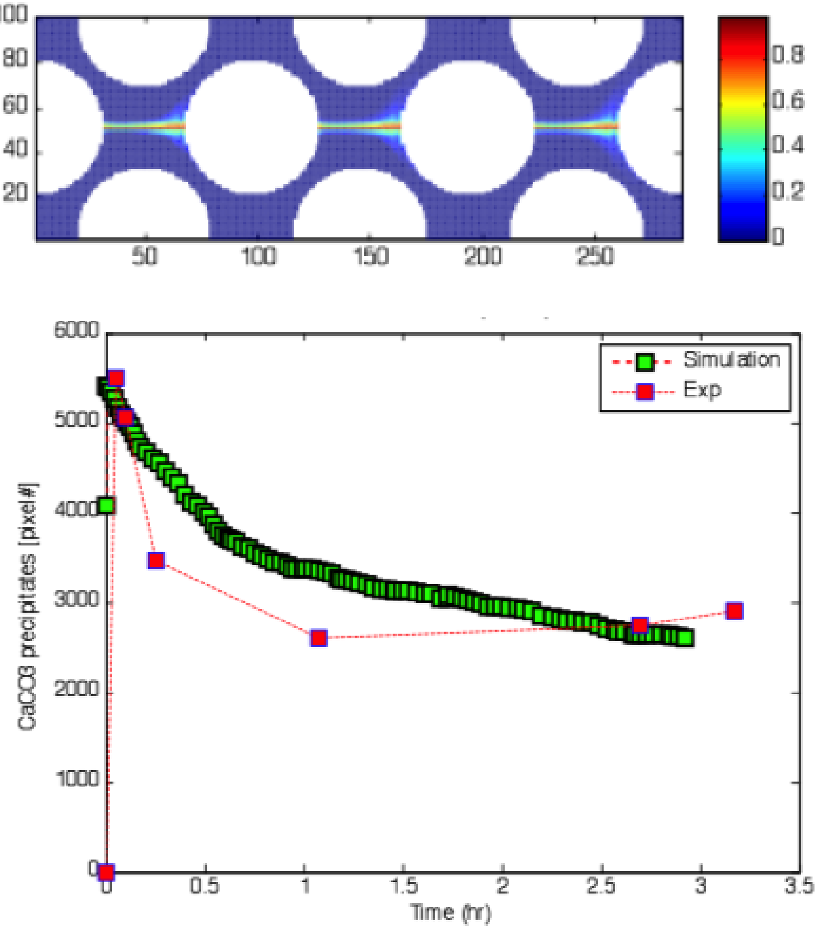
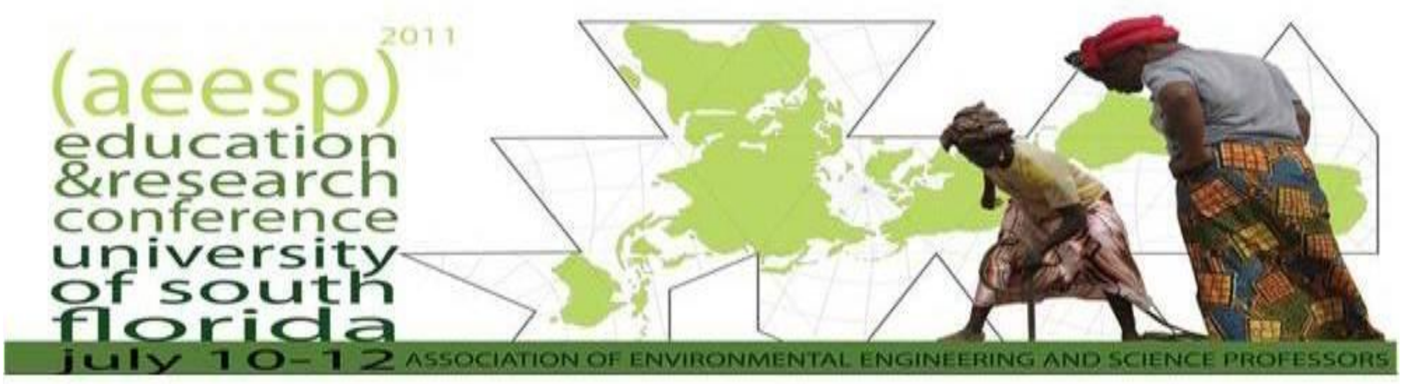


Figure 3. Images of simulated (top) calcite precipitation after 13 minutes, and experimental and simulated cumulative area that contains calcite precipitation over time (bottom).



Research Category #5: ***Global Issues in Environmental Engineering***

Research Category # 5

GLOBAL ISSUES IN ENVIRONMENTAL ENGINEERING

INTEGRATING ECONOMIC AND FINANCE PRINCIPLES IN ENVIRONMENTAL ENGINEERING RESEARCH AND EDUCATION

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Decisions regarding society's most challenging environmental problems are made with attention to both scientific and economic arguments, with economic criteria playing an ever-larger role. Economic terms and concepts are now ubiquitous in environmental policy debates, with discussions over climate change mitigation often revolving around "discount rates", while concerns over "equity" frequently play a prominent role when considering activities designed to promote sustainability. Economic principles also play an increasing role in the development of new market- or incentive-based approaches receiving more attention. Similarly, financial theory is being increasingly employed in the development and deployment of innovative solutions to environmental challenges. Examples include the application of portfolio concepts to environmental risk management (e.g., water supply), the use of real options theory for improving long-range infrastructure planning (e.g., mitigation strategies for climate change) and assessments of the value of information in developing regulatory monitoring networks. Financial concepts also have important implications for the implementation of various environmental policies in the developing world (e.g., microfinance) and in emerging economies (e.g., project financing).

This presentation will report out on an NSF-sponsored AEESP workshop on *"Integrating Economic and Finance Principles in Environmental Engineering Research and Education"* in Washington, DC (January 26-28, 2011). The objectives were to: (i) Identify new research opportunities for the environmental engineering community with an improved understanding of economic and financial principles; (ii) Discuss the principles and tools that would be most useful in allowing the environmental engineering community to take advantage of these research opportunities; (iii) Develop opportunities for adaptation of environmental engineering and science curricula to introduce students to these principles and tools; and (iv) Advocate the use economic and financial concepts to highlight the intellectual and economic value created by the environmental engineering community, while increasing its influence on society's environmental choices. We focused the conversation around six themes, including:

1. <u>Innovation in Environmental Regulatory Institutions</u>. Command-and-control regulatory approaches have been the traditional approach to limiting pollutant releases from both point and stationary sources, typically through concentration-based limits or technology-based standards. Increasingly, more flexible, performance-based, regulatory strategies are being adopted (e.g., SO_2 cap-and-trade program, nutrient credit trading). Engineering research can play an important role in expanding opportunities for this type of institutional innovation, by linking incentives, asymmetric information and behavioral economics to more realistic assumptions about the users of engineered systems.

2. <u>Informing the Design of Environmental Engineering Systems using Benefit-Cost Analyses</u>. The annual cost of complying with environmental regulations in the U.S. is estimated at about 2% of GDP, giving rise to questions regarding the benefits that society derives from these investments.

While it is difficult to quantify all of the costs and benefits associated with environmental regulations, benefit-cost analysis (BCA) has become a common and sometimes mandated, part of many regulatory debates, including social cost of carbon, climate mitigation strategies, and the like. A greater awareness of the principles of benefit-cost analysis will put environmental engineers in a position to better identify constraints on the design of engineering solutions and better contribute to environmental policy debates.

3. Using Economic and Financial Concepts to Improve Environmental Risk Management. Many research themes within environmental engineering are pursued with the objective of reducing environmental risk. These risks are associated with physical phenomena, such as flooding and drought, as well as contaminant release/exposure, both of which can impact human health and ecosystem conditions. Economic and financial theory can play an important role in structuring and informing risk management decisions in these areas. Examples of potential applications would involve climate change, water supply planning, flood risk mitigation, and establishing ambient criteria and emission limits for non-toxic contaminants in both water (e.g., nutrients, sediment) and air (e.g., CO_2, methane).

4. Assessing Actions and Investments that Promote Sustainability. Although the concept of sustainability is difficult to firmly define, all agree that it involves environmental, economic and social elements. Key challenges include (i) selecting metrics, both technical and economic, to evaluate the sustainability of various technologies and policies (e.g., metrics typical in a life-cycle assessment); (ii) identifying the range of methods for assessing actions or investments with costs and benefits accruing over different time horizons (e.g., climate change); (iii) incorporation of ecosystem services in design, and (iv) linking better understanding of financial concepts (e.g., real options) to the development of new implementation strategies for sustainable development.

5. Environmental Engineering in the Developing World. Within the community there is a growing awareness of the tremendous demand for environmental engineering skills in the developing world. While scientific and technical knowledge are important factors in improving the sustainability of societal practices, it is also critical that this knowledge be applied with an understanding of the economic and institutional realities in these countries. As one example, increased emphasis on the lifetime costs of a system (e.g., drinking water) would enhance the sustainability of solutions, as projects are often undertaken without full consideration of ongoing operational and maintenance costs, thereby leading to system failure.

6. Integrating Economic and Financial Concepts into Environmental Engineering Education. The trend that decisions for innovative engineering solutions increasingly encompass cost-benefit analysis, carbon finance and microfinance, venture investment and public finance, and consider economic break-even timeframes, is apparent. The National Academies invoked the importance of economics and finance in areas such as ‘Solar Energy’, ‘Clean Water’, and ‘Urban Infrastructure’. Whether as researchers or educators, as entrepreneurs or knowledge workers in corporate R&D, or by engagement with non-governmental organizations (NGOs), or as an investor, the capacity for students to incorporate economic and finance principles in their research and communication skills will help move the needle in the adoption of solutions for sustainability, and contribute to the education of a globally competitive US work force.

THE EFFECT OF URBANIZATION ON URBAN RIVERS- SEDIMENT WATER INTERACTION

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Introduction: Urban growth is recognized as one of the major environmental concerns in today's society. By 2050 the global urban population is expected to increase from the current 3.5 billion (6.6 billion total) to 6.5 billion (9.1 billion total), whereas the urban population in China, India, and the United States is estimated to increase by 67%, 300%, and 44%, respectively over this same period of time. **Urbanization directly affects the water quality of surface waters due to a variety of anthropogenic activities. Water management is now regarded as the key to the survival of the global population and sustainable societies.** Organic enrichment and contaminant inputs from urban and industrial discharges, aquaculture waste, stormwater and agricultural runoff have become obvious stressors to surface water bodies. Surface water quality deterioration due to nutrients, organic carbon and other inputs is a widespread problem which is threatening the sustainability of global water resources. Surface water resources are most convenient for human use and yet, many surface water bodies have been badly contaminated with nutrients, organic material and other pollutants. Addressing surface water quality is now a key research area recently recognized by president Obama's administration.

Utah's 52-mile Jordan River connects the remnants of historic Lake Bonneville by draining the shallow Utah Lake through the urbanized Wasatch Valley, a complex of wetlands managed for waterfowl and migratory binds, and eventually discharging into the terminal Great Salt Lake where all pollutants and inputs are either retained, biogeochemically recycled, or released into the atmosphere as gases following various transformations. The Jordan River has been heavily manipulated and affected by anthropogenic activities including channelization, flow control, diversion, riparian/wetland removal, and the pollutant and sediment loadings associated with an urbanizing valley. Recently, a Total Maximum Daily Load (TMDL) studies have been initiated for the Jordan River, the upstream Utah Lake, and potentially the downstream managed wetlands and Great Salt Lake in attempts to better understand and manage these valuable surface waters as a watershed complex. As part of the Jordan River TMDL, Sediment Oxygen Demand (SOD), has been seasonally monitored at 7 primary sites and 15 supplementary sites along the length of the Jordan River. However, in our past and ongoing research efforts, we have noticed that unaccounted processes such as hyporheic zone exchange, periphyton respiration and organic carbon speciation (coarse versus fine particulate matters) play an important role in DO dynamics in the urban Jordan River.

In this transformative and highly applied research, we have adopted traditional methods and have developed new techniques to quantify the contributions of hyporheic zone exchanges, sediment-water column interactions, and periphyton respiration. **The primary objectives were** to: *(1) evaluate seasonal SOD to determination temperature effects (2) evaluate the contribution of periphyton on Reach based stream metabolism (3) explore the contributions of hyporheic exchanges and nutrient fluxes.*

Results and Discussion: SOD was determined *in-situ* using 36L open bottomed aluminum chambers that encapsulated a sediment area of 0.16 m^2. One closed bottom Control chamber containing ambient river water was used to subtract the oxygen demand associated with the water column. Average measured seasonal SOD values greater than 1 g DO/m^2*day have been observed throughout the river as shown below in Table 1.

Table 1. Average Reach based measured SOD values for the Jordan River

Reach #	Seasonal Avg (g DO/m^2*d)	Std Dev	Number
1	2.52	0.72	24
2	2.03	1.04	11
3	1.28	0.53	26
4	2.81	1.82	23
5	2.64	2.31	8
6	1.44	0.73	9
7	1.90	0.33	2
8	1.51	0.86	4
LR 1-3	1.90	0.90	61
UR 4-8	2.36	1.72	46

Note: All values presented as measured rates, not normalized to 20°C

It should be noted that all SOD values are presented in their measured form (minus oxygen demand associated with the water column) due to the large amount of inconsistencies noted while normalizing SOD rates to 20°C. Winter SOD values measured during 2009 & 2010 were routinely as high, or higher than summer and fall measurements. This was attributed to various other factors more influential than temperature, such as turbidity, river flow rates, shifts in the benthic communities, changes in sedimentation, and seasonal fluxes of CPOM.

The sections located within Reaches 1-3 are considered the Lower Jordan River (LR) due to the diversion of the majority of the rivers flow and stream energy away from the mainstem of the Jordan River for flood control in Salt Lake City. Reaches 1 and 2 have experienced DO infractions and SOD rates are undoubtedly influenced by the large amount of silty-muck sediments present resulting from low flow velocities, decreased reaeration rates, and an abundance of course and fine particulate material (FPOM and CPOM) originating from both allochthonous and autochthonous sources. Sources of organic material originating as leaf litter and upstream autotrophic biomass are assumed to be the driving force behind SOD in the Lower Jordan River. This has been informally confirmed by the observation of large amounts of flammable swamp gas that are liberated from these sediments upon disturbance. Further attempts to qualify and quantify the sources of organic material, gas emissions and the diffusion of reduced ion species are ongoing.

Although no DO violations have been observed in the Upper Jordan River (UR), which is characterized by faster flowing waters, elevated reaeration rates, and sediments composed of sands, gravels and cobbles, high SOD rates have been continually observed. These high SOD rates are assumed to be driven by both heterotrophic and autotrophic respiration in addition to hyporheic exchanges. Three additional 36L chambers constructed from clear lexan with an enclosed bottom were used to measure SOD and primary production (PP) rates using buried trays filled with sediments and left in the river for 6 weeks to allow benthic colonization. SOD was initially measured in the clear chambers by surrounding the chambers with black garbage bags and PP was estimated by removing the bags and measuring the rate of oxygen production until saturation was achieved. Preliminary results show the existence of an autotrophic benthic community at many of the sites and SOD/nutrient flux comparisons with the open bottom aluminum SOD chambers suggest that multiple of the UR sites are influenced by hyporheic exchange. We have nearly finished all needed experiments and in the process of analyzing the data. **Detailed results on how the aforementioned affects the sustainability of surface waters will be presented in the conference**. This is also one of very few research efforts to evaluate the effect of hyporheic zone on surface water quality. This research has tremendous benefits to decision makers and local municipalities in their dialogue exchange about TMDL process and in general about **the sustainability of surface waters**.

QUANTITATIVE SUSTAINABLE DESIGN OF WASTEWATER INFRASTRUCTURE

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Introduction
Wastewater treatment plant (WWTP) design has traditionally been driven by effluent permit requirements and cost, with minimal consideration for broader environmental and social factors that influence system sustainability. Social factors can, to a degree, be addressed with qualitative tools and stakeholder participation. Environmental, economic, and technical aspects of design, however, require a quantitative approach capable of embracing conventional design objectives while addressing emerging concerns for environmental sustainability. The <u>objective</u> of this work is to develop a transparent quantitative sustainable design methodology to economically reduce meaningful environmental impacts of wastewater management. Using life cycle assessment (LCA), present worth analysis, and deterministic WWTP process modeling we are evaluating the design implications of broader environmental impact constraints (e.g., life cycle global warming potential) on WWTP design. Although this quantitative sustainable design framework can be applied to any number of engineering challenges, it will be demonstrated here through its application to a WWTP upgrade in the Hampton Roads Sanitation District (HRSD) in Virginia, USA.

Quantitative Sustainable Design – Problem Formulation
For a given WWTP design challenge, be it an upgrade or a completely new plant, engineers must account for locality-specific factors in their design process. These factors range from wastewater composition to the professional experience and preferences of project stakeholders. In addition to dictating which configurations shall be considered, locality-specific factors will also influence the selection of each configuration's decision variables – elements of the design that may be adjusted (solids residence time, SRT; hydraulic retention times, HRTs; recycle flow rates; etc.). In order to advance the sustainability of WWTPs, what is required is a tool that can optimize <u>decision variables</u> (***x***) given <u>locality-specific factors</u> (***s***) while addressing both traditional and emerging design objectives.

In order for wastewater utilities to continue to provide vital services to populations in the face of increasingly stringent performance requirements, the goal of both traditional and (arguably) sustainable WWTP design will be the minimization of <u>life cycle costs</u> (*cost*). To this end, we have developed a design methodology that operates as a single objective optimization (the minimization of *cost*) subject to traditional (effluent permits) and emerging (local, regional, and/or global environmental impacts) performance constraints.

Additional Design Constraints for Environmental Sustainability. In order to protect the local (or downstream) aquatic environment, WWTPs are required to achieve certain effluent quality standards. <u>Permit requirements</u>, therefore, are included as constraints in the traditional design process (*permit*). These constraints, however, do not address emerging concerns for local, regional, or global environmental sustainability. In order to address this deficiency, we are adding <u>life cycle environmental impact constraints</u> (*life_cycle_envi*) to the design process in the form of mid-point indicators (e.g., global warming potential) determined via LCA to evaluate their impact on life cycle costs, WWTP design and performance. The inclusion of life cycle environmental criteria as constraints rather than an objective function has three advantages: (i) it is more consistent with today's practice of including performance constraints, (ii) it more accurately represents the environment as a limiting factor that requires us to operate within a set of impact boundaries, and (iii) it avoids the direct comparison of environmental versus economic trade-offs, as well as trade-offs across environmental criteria that may be incommensurable or incompatible.

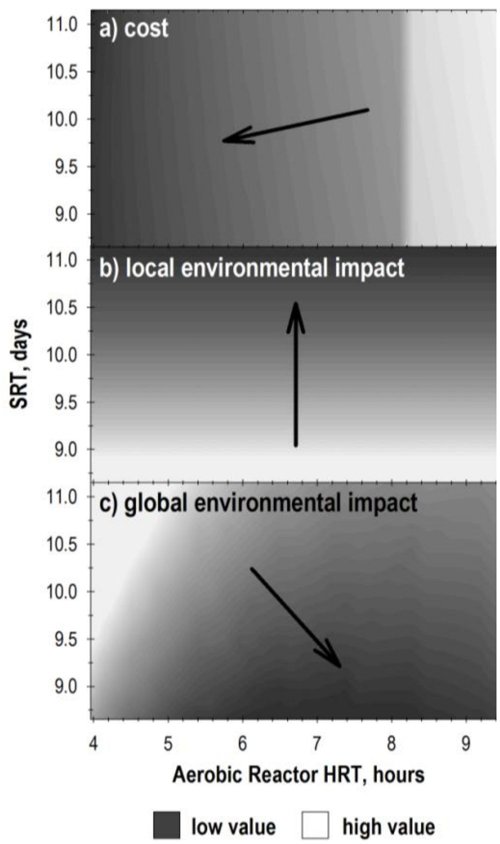

Figure 1. Influence of MLE decision variables solids residence time (SRT, y-axis) and aerobic reactor hydraulic retention time (HRT, x-axis) on (a) present worth, (b) effluent total nitrogen, and (c) life cycle global warming potential. Arrows indicate desirable traits: (a) decreasing cost, decreasing (b) local and (c) global environmental impacts.

Optimization Problem. With this problem formulation, the sustainable design of a given WWTP configuration can be represented as a single objective optimization problem:

minimize *cost*(***x***, ***s***)
subject to: *permit*(***x***, ***s***) = TRUE;
life_cycle_envi(***x***, ***s***) = TRUE

Preliminary Results

Preliminary results have been generated from the application of this methodology to the design of a Modified Ludzack-Ettinger (MLE) process. As seen in **Figure 1**, decision variables that reduce local environmental impacts (i.e., improve WWTP effluent quality) may, at times, result in greater global environmental impacts across the WWTP's life cycle (see differing trends in **Figure 1b** vs. **1c**). A reduction in life cycle cost (**Figure 1a**), however, may at times be aligned with either a reduction in global environmental impacts or local environmental impacts depending on the specific situational variables, ***s***, and the WWTP configuration under consideration. Although an idealistic target would be to develop technologies that simultaneously reduce present worth in addition to local and global environmental impacts, we expect that most (if not all) traditional biological processes used in industry will require trade-offs among these design characteristics.

Presentation Content & Outcomes

The work presented in July will be a comprehensive demonstration of the application of this quantitative sustainable design methodology in the context of a 20 million gallon per day (MGD) WWTP upgrade being planned in the HRSD. Although this methodology will be discussed in the context of WWTP design, this framework can be applied to a wide range of engineering challenges and disciplines to evaluate the economic and engineering implications of design and policy alternatives aimed at reducing local, regional, or global environmental impacts.

STAKEHOLDER PRIORITIES FOR WATER AND SANITATION DEVELOPMENT IN LEOGANE, HAITI

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The importance of incorporating local knowledge and preferences into development plans has been acknowledged for decades but has often proven difficult to achieve. Evaluation of different strategies to eliciting local input may help address this challenge. This study conducted a survey of residents of Leogane, Haiti to ascertain their water and sanitation needs and preferences. The study then conducted and evaluated a participatory workshop to elicit local knowledge and preferences for water and sanitation redevelopment in Leogane, Haiti, the epicenter of the January 2010 earthquake. Workshop participants developed proposals for reconstruction in breakout groups, and these proposals were voted on by all participants to develop a ranked list of redevelopment priorities. These projects were overwhelmingly physical (construction) projects with only two projects including an explicit organizational component (e.g., organizing committee). None of the projects received votes from a majority of participants even though each participant was allowed three votes. This dispersion of preferences is seen as evidence of a process that has not yet reached equilibrium. This interpretation is supported by a pre- and post-survey in which a majority of participants indicate that the community is not ready to act but requires more time to assess the situation. Proposed projects in some cases aligned with and in some cases diverged from expert conceptual models. For example, proposals to tap the artesian aquifer, repair and extend existing pipe networks largely agree with governmental and international aid organizations planned activities. However, several proposals emphasized reservoir development, which does not appear to be a technical requirement given the storage capacity of the available aquifers. The highest ranked projects did not have serious conflicts with technical understanding. Some divergence in attitudes may exist, as one proposal emphasized extending service to all homes while another stated that payment should be required for services. The proposal indicating that payment should be required was ranked above the proposal indicating that service should be extended to all homes. This is consistent with the results of the survey which found that 76% of respondents were willing to pay for access to safe drinking water and 65% were willing to pay for a reliable sanitary system.

A second round of breakout groups was then conducted in which participants identified strategies to implement the previously identified redevelopment projects. As with the first round, votes were dispersed among a large number of projects. The highest ranked second-round breakout group ideas all involved substantial roles for international organizations. Pre- and post-survey results indicate that many participants see outside aid as important for redevelopment, although most also see some progress as being possible through local efforts. Survey results also suggest that many see government as having an essential role in convening local development efforts. Local and central government are preferred by many as the appropriate authorities to own, operate and/or regulator water supplies (Figure 1). This may be problematic given current governmental capacity, and is at odds with current government policy that envisions a large role for regional government and private contract operators.

While a single workshop cannot achieve consensus priorities, it does reveal key decisions for which technical input could be acquired and fed back into the participatory process. In this case these inputs would likely consist of costs and pricing of different infrastructure options, as well as experience with different management and governance structures for infrastructure systems. The workshop results also suggest a role for capacity building for local entities to implement such participatory methods in order to help the process proceed further towards the identification of actionable plans for redevelopment.

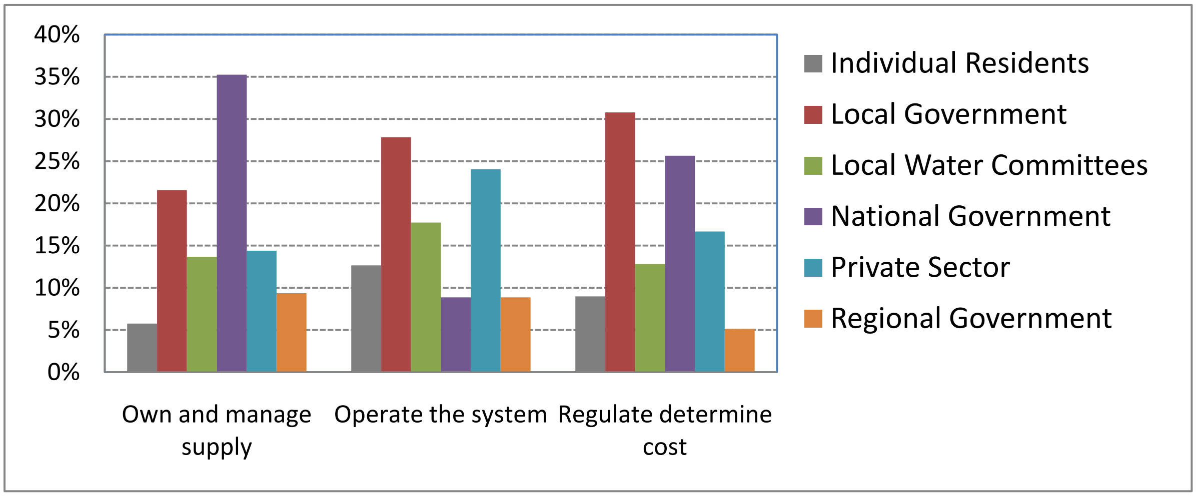

Figure 1: Survey respondent preferences for different management options for water supply (N=166)

SUSTAINABILITY ENGINEERING EDUCATION: A BRIDGE TO INTEGRATION INTO PRACTICE

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As sustainability goals are being recognized as critical components for the development of our world, there is also a need to incorporate sustainability engineering education into the curricula at our universities. However, sustainability engineering is not a topic that can be contained in a single course, or adequately covered in many of the traditional educational settings. By nature, sustainability is interdisciplinary, complex and multidisciplinary. In addition, many of the technologies and policies that might afford a more sustainable world are rapidly developing or not even imagined yet, so the methodologies for incorporation must be flexible and dynamic, responding to new research directions and differences in practice as sustainability criteria are established and accepted. Both students and practitioners need educational opportunities to more effectively integrate sustainability concepts into practice and research for future technologies.

Various aspects of sustainability are being integrated into Civil and Environmental Engineering curricula across the country, in many formats and focusing on many of the sustainability tracts, from energy to water, and from infrastructure needs to climate issues. This work represents a summary synthesis of many of the techniques and case studies of incorporating sustainability engineering education in higher education. It then details two applications that directly aid in integrating sustainability engineering education into practice. It is being submitted in response to Track 7: Integration of Sustainability into Practice.

The first application represents a major addition of a course with the introduction of a multi-disciplinary full year Interdisciplinary Design Experience (IDeX) class at Washington State University. The experience is in its second year. The first year focused on an organic farm project, bringing together engineering, agricultural, architectural and construction management students at the University campus. The second year experience has expanded to a green development design in conjunction with a city in Washington, with interactions extending to many of the professionals and practitioners in that community. Course questionnaires and interviews have indicated the effectiveness in the communication contributions that the IDeX experience can result in, both for the students and the faculty involved.

The second application is the introduction of a mini-consulting service project for graduate students who are taking a dedicated sustainability class. The mini-consulting service projects allow the students to work with many other disciplines that they may then collaborate with in practice for a more sustainable infrastructure. Some of the projects are for service in other classes, such as in an architectural studio. Many of the projects are support for facility, operations, or construction projects on campus or at the student's place of employment. These include surveys on the effectiveness of water reduction features, estimates of sustainability improvements with changes to lighting fixtures or paper towel use, and work on various planning projects such as bicycle maps or landscaping needs. These mini-projects have been developed since the demand for sustainability classes has resulted in large enrollments, for which there is still a need for interdisciplinary interactions, especially for the development of interdisciplinary communication skills, but which cannot be accomplished in dedicated course team projects due to limited resources. Preliminary survey instruments have indicated that these mini-projects are effective in developing interdisciplinary communication skills and furthering understanding of the contributions that other disciplines provide in sustainability design.

GLOBAL HIGH RESOLUTION FRESHWATER EUTROPHICATION IMPACT CHARACTERIZATION

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Providing adequate food supplies to a growing global population while minimizing environmental impacts will be one of the grand challenges of the first half of the coming century (Lupien and Menza 1999; Tilman 1999). An increase in population to nearly 8 billion by 2025 could be accompanied, for example, by 3-fold increases in application of synthetic fertilizers. Fertilizer, in turn, may have implications for ecosystem health and human health – and food supply – via eutrophication, the oversupply of nutrients and subsequent oxygen depletion in a water body.

In Life Cycle Assessment (LCA) methods, eutrophication has classically been treated on a non-spatial basis, or has been at the relatively broad resolution of countries or states, such as in the TRACI and ReCiPe models (Norris 2003; Struijs et al. 2009). However, the location of an emission can strongly affect the expected eutrophication impact. In this project, freshwater eutrophication due to phosphorus emissions was modeled on a global scale with a 0.5 degree resolution. For this purpose, a new fate model was developed that 1) estimates phosphorus fate and transport for point and non-point emissions, and 2) estimates the environmental damage, in terms of species affected, for these emissions.

The hydrological component of the model, which routes water from grid cell to grid cell, as well as estimates of main water bodies and sub-grid water bodies, uses the global river network and attributes developed by Vörösmarty et al. (2000). Mass balance differential equations for phosphorus were based on Harrison et al. (2010). Loss of phosphorus in water bodies is modeled by outflow to the downstream grid cell, retention in water bodies, and water use by humans (Wollheim et al. 2006), and removal by humans. Effect factors for phosphorus are derived from macro fauna data converting a concentration into a species effect (Payet 2006; Struijs et al. 2010).

Sensitivity and scenario studies of the fate model have confirmed its robustness and show that local hydrological properties have the most influence on fate factors for phosphorus. Cells with high residence times, e.g. due to lakes, contribute the most to the total eutrophication impact. The resulting characterization factors are the first to enable a global life cycle impact assessment of freshwater eutrophication for worldwide phosphorus emissions. Such a tool allows for the consistent assessment of the impacts of globalized production, e.g. in the case of complex products whose components are manufactured in several locations, countries or continents.

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THERMAL AND OPTICAL MEASUREMENTS FROM COOKSTOVE EMISSIONS

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An estimated three billion people in developing countries obtain their primary energy needs (e.g., for cooking and space heating) largely by burning indigenous solid fuels (e.g., wood, coal, charcoal, crop residue, and dung) on "three-stone" open fires and inefficient cookstoves. Indoor and outdoor burning of solid biomass releases large amounts of particulate matter, carbon monoxide, and other toxic pollutants that affect human health and contribute to global climate change. While "three-stone" open fires are the predominant means of producing energy, a large government effort is underway to have 100 million homes adopt clean and efficient stoves by 2020—that uses less fuel and produce less pollution. However, information on the performance and carbon emissions of many of these improved cookstoves and their potential impact on climate are limited. Carbon-bearing compounds impact climate by absorbing and reflecting incoming solar radiation. Combustion efficiency, the carbon dioxide-to-carbon monoxide (CO_2/CO) ratio is a major primary indicator of stove performance. Incomplete combustion produces carbon pollutants that fall into two general categories—gaseous phase: CO_2 and CO, and particulate phase: organic carbon (OC), elemental carbon (EC), and black carbon (BC). The proportions and the species of carbon released are influenced by several factors, that include cookstove type, fuel type, fuel moisture content, and combustion conditions. Forty-six (46) aerosol filters obtained from a cookstove study performed by Jetter and Kariher (2009) were analyzed using thermal-optical analysis (TOA) for OC/EC and EC/TC ratios (Khan *et al. in review*). These ratios are important for air quality, dispersion, and climate models to forecast regional and global weather patterns (Hansen *et al.,* 2000; Jacobson, 2001). The aerosol filters represented 10 stove/fuel combinations using a modified version of the Water Boiling Technique (WBT) (Bailis *et al.,* 2004) (Table 1). Results from the TOA showed that OC concentrations can be as much as 2.5 times greater than EC concentrations. A summary of the EC/TC ratios, as illustrated in Figure 1, for the different stove/fuel combinations shows that (i) EC can account for over 80% of the total carbon (TC) in the particulate phase and (ii) stove type is a major factor in carbon speciation distribution.

A more current, more comprehensive study was conducted in 2010, in which aerosols from 24 stove/fuel combinations using the WBT were (i) collected on quartz-fiber filters and analyzed for the OC/EC content by thermal-optical analysis (TOA) and (ii) measured continuously *in situ* (not on filters) for light absorption and scattering using a photoacoustic soot spectrometer – three wavelengths (PASS-3). Data analysis on this study will focus on comparing the distribution of carbon species emissions among the different stove/fuel/combustion combinations and the relationships between TOA and PASS-3 measurements. Results of this study will provide carbon emissions data from a variety of cookstoves types that can offer useful insight when addressing near- and long-term actions for climate change at the local, regional, and global level.

Table 1. Cookstove/Fuel/Heating Phase of the WBT combinations. The WBT involved collecting aerosols during three heating phases: (1) C - cold start with water at room temperature with the stove operated until water reaches boiling temperature, (2) H - hot start commences immediately after the completion of cold start. The pot is refilled with room temperature water and the stove operated until water reaches

boiling temperature, and (3) S – simmer phase begins immediately after hot start with the stove, pot, and water hot. The stove is operated until water temperature is just below boiling point.

No	Cookstove	Fuel	Heating Phase*
1	Open fire (3-stone)	Kiln-dried Douglas fir	S
2	GTZ	Charcoal	H S
3	Philips	Kiln-dried Douglas fir	C H S
4	Philips	Seasoned oak	C H S
5	UCODEA rocket	Seasoned oak	C H S
6	UCODEA rocket	Charcoal	H S
7	VITA	Kiln-dried Douglas fir	C S
8	VITA	Seasoned oak	S
9	WFP rocket	Kiln-dried Douglas fir	C H S
10	WFP rocket	Seasoned oak	C H S

**WBT: C – cold, H- hot, S-simmer (Bailis et al., 2004)*

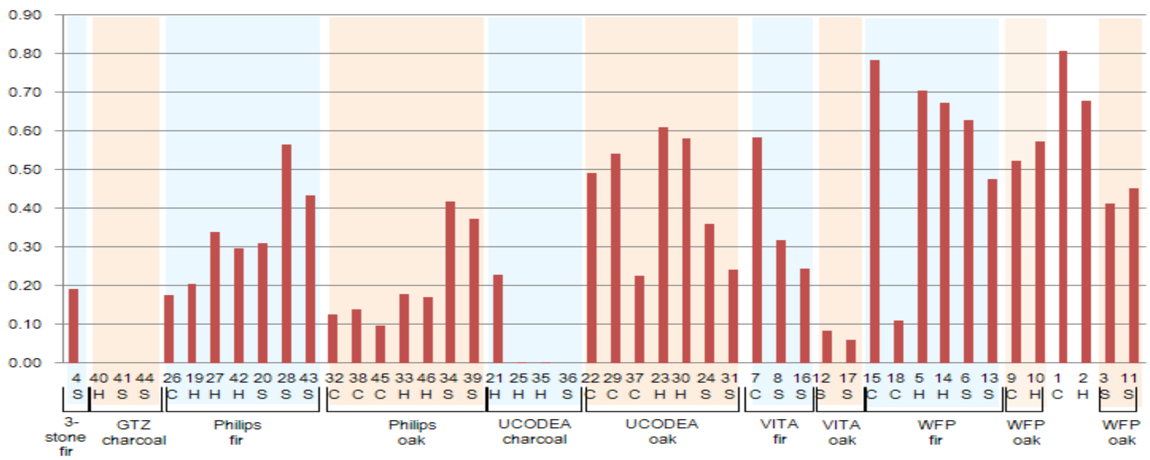

Figure 1. EC/TC ratios for different cookstove/fuel/WBT combinations using TOA.

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INTEGRATING SUSTAINABILITY EDUCATION AND RESEARCH THROUGH GLOBAL EXPERIENTIAL LEARNING

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Significant sustainability challenges face our global society today, including the rising costs and insecurity of non-renewable energy sources; the social, economic, and environmental toll of poverty and disease across the globe; and the depletion and disruption of the natural resources upon which our civilizations depend. In 2009, the University of Illinois ("Illinois") created a vision to simultaneously promote a high quality of life for **all** people and healthy and diverse ecosystems[1] through community- and campus-based education, research, and engagement, both locally and across the globe. This paper summarizes how Illinois is implementing this vision through a core strategy around global experiential learning. The following components of the strategy are summarized below, along with the status and next steps: (1) define sustainability learning objectives; (2) inventory current courses and programs and identify gaps; (3) develop sustainability curriculum to fill gaps; and (4) create long-term experiential learning sites, both locally and globally.

As a first step in this process, a campus-level committee created a set of sustainability learning objectives that define what every Illinois graduate should know about sustainability. These objectives serve as a guide for units to adapt to the unique needs of each field and for students to better understand the knowledge and skills required to address sustainability. The Department of Civil and Environmental Engineering (CEE) has adapted these objectives to the six learning outcomes shown in Table 1, which are guiding our curriculum development efforts. The CEE effort is defined more broadly on multidisciplinary and global education, but has a strong sustainability focus.

Table 1. CEE Multidisciplinary and Global Educational Outcomes
Understand how their lifestyle, wellbeing, and professional practice are interconnected with diverse communities and ecosystems around the world
Develop a personal and professional vision for local, regional, and global sustainability of natural and built environments.
Understand interactions between real-world engineering solutions and the environment, society (including cultural, governance, and ethical issues), and economy, in both global and domestic arenas.
Ability to function on a team with other disciplines (within and outside CEE).
Understand how to be effective leaders in advancing the frontiers of CEE.
Design holistically by coupling expertise in their specialty with an understanding of system-level interactions and issues that affect their designs.

The second step in the experiential learning strategy is to inventory current courses and programs to identify gaps that limit achievement of the outcomes. At the campus level, a Web site search and

[1] Here we use the term "ecosystems" broadly to include the entire living and non-living Earth system that supports human and non-human life.

department survey were completed to inventory available courses and programs across all disciplines and prepare a single Web page summarizing the findings. Many of the relevant courses and programs were not specifically called "sustainability," yet met many of the learning objectives. At the CEE department level, a faculty survey produced a similar inventory of courses that achieved the learning outcomes identified in Table 1. A new primary specialty area in Sustainable and Resilient Infrastructure Systems and three secondary specialty areas in Sustainability, CEE in a Global Context, and Custom Multidisciplinary were also created to better prepare students to integrate technical depth with a broad understanding of system-level interactions. Increased efforts to coherently publicize the many and diverse sustainability activities are now being pursued at both the department and campus level.

The third step is to develop sustainability curriculum to fill the gaps identified in the second step. The campus launched the Prairie Project Curriculum Development Program in 2010. Initially modeled after the Piedmont and Ponderosa Projects that are taught in the Association for the Advancement of Sustainability in Higher Education (AASHE) Sustainability Across the Curriculum Leadership Workshops, significant modifications are now being made to focus more heavily on hands-on curriculum development, integrate with the Illinois Climate Action Plan, increase formal assessment, engage campus leadership to encourage faculty to participate, and celebrate faculty successes. A campus-wide Scholarship of Sustainability Series has also been created, with public discussions on the seminal sustainability literature and debates linked to courses across campus, which engaged hundreds of students, faculty, staff, and community members in its first offerings. At the department level, two new faculty awards are being created. The first award, CEE Global/Multidisciplinary Fellow, would provide funding and recognition for modifying or creating new courses to address the outcomes given in Table 1. The second award, the Global/Multidisciplinary Teaching Award, would recognize faculty who have brought significant global and multidisciplinary innovation into the CEE curriculum.

Lastly, but most importantly, the above efforts identified a clear need to increase hands-on learning on real-world sustainability problems, both locally and globally, which is necessary for students to understand the complexities and interconnections that drive sustainability problems. However, developing partnerships, obtaining relevant data and models, and investing in needed infrastructure, such as instrumentation and cyberinfrastructure, can be time consuming and difficult for individual faculty. Therefore we are creating long-term experiential learning sites that integrate research and education through hands-on learning in close collaboration with external partners. In Spring 2011, a CEE graduate course in Environmental Systems Analysis is exploring two emerging experiential learning sites in the Upper Embarras Watershed, which includes Illinois' experimental farms, and the Shiyang River Basin in China, which is a partnership with a similar graduate class at Tsinghua University. Students are working in teams to define the sustainability problem through stakeholder interviews and research, delimit system boundaries, define methodologies for addressing the problem, and implement their approaches. The students are supported by a virtual environmental observatory that contains available geospatial data and metadata and an online course management system (Moodle). Lectures and discussions are recorded for viewing by the Tsinghua students. Both classes will visit the Shiyang River Basin to interview stakeholders in March 2011 and the results of their work will help guide the next 5-year management plan for the basin. Results will be reported at the conference. Future plans are to expand these sites to allow multiple courses from different disciplines to interact in advancing sustainability of the watersheds and their supporting infrastructure, as well as creating other experiential learning sites.

INTEGRATION OF RESEARCH, EDUCATION AND ENTREPENEURSHIP IN A RURAL PERUVIAN COMMUNITY

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The goal of this paper is to present the results of a binational effort that has synergistically integrated engineering education, entrepreneurship and research to promote the sustainable development of a rural community in Peru. This work is presented as a case study for engineering educators who continue to search for new models of education that seek to engage students in life-long learning, civil engagement and sustainability. A variety of projects have been performed in a period of four years and have involved students from the United States and Peru as well as members of the Andean community of Langui, Peru.

The multidisciplinary team leading this effort has formal training in Mechanical and Environmental Engineering as well as Environmental Health, Sociology and Economics. Notably, this team has included members of the local community from the beginning. Dr. Montoya has led this effort from the United States as faculty member in two different institutions (Rensselaer Polytechnic Institute and the University of Colorado at Boulder) and Ms. Harman as Social Projects Coordinator of Support Group to the Rural Sector (Grupo de Apoyo al Sector Rural), a unit within the Engineering Department at the Pontificia Universidad Católica del Perú (PUCP).
The small town of Langui is located in the Canas province in the Cusco region of Peru. With an average monthly income of about $60 USD per capita, families in this area are amongst the most socioeconomically disadvantaged in Peru. Consequently, a main goal of this collaboration has been to develop appropriate technologies that provide sustainable sources of energy, water and air for this rural population while providing avenues for business enterprises based on the introduced technologies. These technologies have been developed and implemented through interdisciplinary student design teams with the participation of the community. The technologies developed through this collaboration have been implemented on our flagship project, the *Andean Ecological Home* (Casa Ecológica Andina) in the town of Langui. A recent (Spanish) video produced by Grupo about this project can be viewed at http://www.youtube.com/watch?v=yHgF1YzKqyY. This home is a center for training and technology transfer where our team now conducts workshops for the local communities to promote the adoption of these appropriate technologies. Such workshops have also been offered in response to local demand.

More recently, our efforts have focused on promoting the local dairy industry and to assist the community in the certification of their products and accessing the larger markets. Under this project, we have conducted surveys to determine the local dairy production and the potential market in Cusco city, the largest city in the region and a world tourist destination. These surveys determined that the average local dairy production is low and does not merit the pursuit of certification on an individual household basis. Additionally, the market survey determined the existence of a demand and identified specific impediments for the local producers to access this market. This work is now being incorporated into a PhD thesis in Ecological Economics at Rensselaer Polytechnic Institute.

Another major research effort has been evaluating the indoor air quality in Langui as part of a PhD thesis in Environmental Engineering at the University of Colorado at a Boulder. This research focuses on the characterization of both (biomass) combustion and biological aerosols present in these environments since previous studies have found them to synergistically worsen respiratory health. Pilot studies have been conducted to determine indoor $PM_{2.5}$ levels in the summers of 2009 and 2010 involving 17 and 30 households, respectively. Results showed that the levels of $PM_{2.5}$ in the majority of these households regularly exceeded the World Health Organization guidelines for 24-hour $PM_{2.5}$ and the largest emissions occurred within the first hour of stove use. Significant reductions in indoor $PM_{2.5}$ and black carbon concentrations were achieved after improving a traditional stove using local materials. Carbohydrate and protein levels were also measured to evaluate bioaerosol contributions to $PM_{2.5}$ and PM_{10}. Though significant improvements were made with stove modifications, additional appropriate technologies will be required to limit demand for biomass combustion indoors and minimize biological sources of indoor air pollutants. Such technologies can be developed, implemented and evaluated as part of these ongoing research, education and entrepreneurship efforts.

WATER QUALITY IN THE INTERMITTENT, PIPED WATER SUPPLY OF HUBLI-DHARWAD, INDIA

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Most piped water supplies in the developing world provide water intermittently. In India alone, over 150 million people are served by intermittent water supplies. Intermittent supply leaves the pipes vulnerable to contamination during periods of low or negative pressure; in addition, households must invest in additional infrastructure, such as storage containers and pumps. Recently, upgrading municipal systems to provide continuous (24x7) water supply has gained significant interest in India. However, the costs and potential benefits of upgrading to 24x7 water supply have not been well characterized. Although there is a rich literature characterizing the complications arising from intermittencies in N. American and European piped water systems, it does not provide much insight for India because the context is quite different.

The city of Hubli-Dharwad, Karnataka, India is one of the first cities in South Asia to upgrade to continuous water supply. Currently, 10% of the city receives continuous water supply through a World Bank funded pilot project, while the rest of the city receives water for a few hours once every 5-10 days. We are conducting an assessment of the intermittent versus continuous supplies in terms of water quality and quantity, health impact, and economics. The focus of this presentation will be on water quality, including data on the spatial and temporal variability in water quality parameters, mechanisms of contamination, and recommendations for improving water quality in intermittent and 24x7 supplies.

To characterize water quality, grab samples are collected from locations throughout the distribution system, including storage reservoirs, household taps, and household storage containers; analyses include *E. coli* (IDEXX Colilert Quantitray), chlorine residual, and turbidity. In addition, parameters that may correlate with contamination are being monitored at household taps using in-line sensors (YSI), including conductivity, turbidity, and chlorine residual. Upstream of continuous measurements, high-frequency pressure sensors are installed.

The presentation will report the results from six months of data collection, which is currently underway (approximately 2000 grab samples and 500 h of continuous water quality and pressure measurements). Preliminary results indicate that the water quality that enters the piped distribution system in Hubli-Dharwad is typically of good quality; the two supply reservoirs are fairly well protected, and the two treatment plants provide treatment via coagulation, sedimentation, rapid sand filtration, and chlorine disinfection. There is evidence of water quality degradation in the intermittent supply network, but not as much as might be expected given the poor condition of the infrastructure. Many potential sources of contamination have been identified, including water pipes lying in or adjacent to open sewers, in contaminated groundwater, submerged taps, and cross connections with contaminated stored water. Analysis of the continuous sensor measurements and pressure data is ongoing. In the 24x7 zones, a major impediment to realizing the benefits of improved water quality is that most low-income households continue to store water in containers, often uncovered, leaving them vulnerable to recontamination.

SYNCHRONICITY AS AN EFFECTIVE PEDAGOGY FOR STUDENTS' LEARNING ABOUT THE MILLENIUM DEVELOPMENT GOALS

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In the transition to a knowledge economy, faculty are challenged with adapting away from a transmittal model of instruction (i.e., 'sage on the stage') and engaging students as adults through active learning pedagogies (i.e., 'guide on the side') (a). Problem-based learning (PBL), where teams collaboratively solve challenges with expert guidance, has been shown to be an effective means of knowledge generation within engineering, science, and technology students. For faculty, two major challenges include: (1) identifying authentic problems that suitably serve the needs of the students; and (2) integrating diverse areas of academic scholarship (i.e., teaching, research, and service) to teach a PBL course effectively. This presentation argues that synchronicity, or "the meaningful coincidences between inner states of mind and outer events to which they are not causally related", is an effective pedagogy that solves both of these challenges (b). In other words, a successful course is achieved when the apparently random developments in the classroom and the guidance of the instructor converge to grow knowledge in the consciousness of the students; whereas an unsuccessful course fails to achieve convergence and appears to students as a collection of unrelated exercises (i.e., a disorganized instructor or course).

In the case of this presentation, four seminal events over a period of six years were instrumental in the development of a body of scholarship that included a dual-level, term-length course (CE600/601 MDG7: Ensuring Environmental Sustainability); the formation of an award-winning, extracurricular student organization (University of Cincinnati Chapter of Engineers Without Borders); the growth of four non-government organizations (Village Life Outreach Project, Shirati Health and Education Development Foundation, Sadguru, and Hechos 2:8); and Federal funding opportunities (US Environmental Protection Agency People, Planet, and Prosperity Program; US Department of State Fulbright Program; and the National Science Foundation). Through synchronicity, 80 baccalaureate and 40 graduate students have gained classroom knowledge about the United Nations Millennium Development Goals (especially target 7c, "reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation); 50 students have travelled abroad to Guatemala, India, Kenya, or Tanzania; three students have lived abroad for more than six months; and safe water and sanitation have been provided to more than 15,000 villagers on three continents. Student knowledge was measured through recognition assessments tests before learning and comprehension assessment tests after learning, as well as likert-scale assessments of ABET outcomes (i.e., both engineering and professional skills), aggregated responses to open-ended questions regarding preferences, and faculty evaluation of electronic portfolios.

This work is original because it is neither a report of a case-study nor an example of well-described pedagogical approaches (i.e., PBL). Rather this work introduces the construct of synchronicity as a solution for faculty challenged with the unfamiliar needs of providing instruction without following the traditional transmittal model. The status is complete as this presentation reflects the successful work of six years. Because rigorous assessment was employed as part of the project, the quality content has benefit for the AEESP audience, and teaching the Millennium Development Goals to students is significant for the field and the central theme of "Global Sustainability" adopted for this conference.

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GLOBAL DESIGN PROJECT EXPERIENCES FOR ENVRIONMENTAL ENGINEERING STUDENTS

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Environmental engineers are increasing involved in projects that take place in the global community. Educating students in the cultural and societal issues that affect engineering solutions in such settings is paramount to preparing students to enter the global marketplace professionally. At Worcester Polytechnic Institute (WPI), significant team project experiences are a requirement for graduation. The project requirements total over a semester worth of credit in three distinct projects – the first in the humanities and arts, the second an interdisciplinary project linking social sciences and technology/engineering, and the third a capstone project in the students' major. To provide students with global awareness, WPI launched the first off-campus project center over 35 years ago. Since then, WPI's global network has grown to more than 25 locations on five continents. Some 7,000 students have completed off-campus projects in that time. Unlike many U.S. students who study abroad, WPI students become immersed in the local culture as they tackle important problems for sponsors, local organizations and agencies that receive solutions to the important issues they face.

The WPI global program has traditionally focused on international opportunities for third year undergraduate students completing their interdisciplinary projects. Through this program, WPI has developed extensive knowledge and practice informing international project centers, training faculty, managing risks, and ensuring top quality projects and well prepared students. This wealth of experience has now been used to develop high quality international capstone projects for fourth year students. This presentation will focus on environmental engineering capstone projects at global sites.

The author has been involved in development and advising of international capstone projects for environmental engineering students at four locations – the Turks and Caicos Islands, Panama, South Africa and Ghana. In three cases, the projects were logistically handled as "one-time" opportunities for students (though South Africa has involved students in multiple years). In one case (Panama), the objective was to develop a sustainable global project center that offers project opportunities on a yearly basis. Table 1 summarizes these recent project opportunities.

The impetus for projects in Turks and Caicos was based on support from a successful alumni in Civil and Environmental Engineering. While living and working on a tropical island during the wintertime provided an incentive for students to participate, the educational goal was to demonstrate to students the impact that tourism development has on environmental quality, and the engineering controls that are – and are not – appropriate in an island environment. The project on restoration of salt ponds was both a technical project on water quality and hydraulics, as well as an opportunity for students to understand the balance between development (for tourism) and ecosystem impacts.

Table 1. Recent Global Project Opportunities in Environmental Engineering at WPI

Location	Site description	Year	# of students	Example project topics
Turks & Caicos	Caribbean islands with tourism	2005-06	5	Restoration of water quality in salt ponds
Panama	Latin country with extensive development	2009-present	9	Drinking water treatment for Smithsonian Research Institute island, located in Panama Canal
South Africa	Less developed country; public health challenges	2008-present	4	Design of water and sanitation facility for informal settlement
Ghana	Less developed country; public health challenges	2010	3	Public health control of schistosomiasis in rural village

In Panama, the objective was to collaborate with consulting, industry and government organizations to expose students to the challenges and opportunities of working in a Latin country undergoing extensive construction and development. In particular, it was desired to expose students to the Panama Canal Expansion project which was started in 2006 and is estimated to span eight years and cost over $5 billion. This massive civil and environmental engineering project to widen and deepen the canal channels is intended to increase the canal capacity and provide economic benefits to the country. However, negative environmental impacts – such as water quality degradation – have resulted from dredging activities in the canal. Through development of the project center, it was found that in-country support is critical to ensuring good project pedagogy and arranging logistics for the students.

The projects in Africa represent opportunities for work in less developed countries facing serious public health challenges. The Ghana project arose from a collaborative association between WPI and Tufts University, and between faculty in environmental engineering and biology. The students worked in a rural village with high prevalence rates of urinary schistosomiasis and were involved in the design, construction and implementation of an alternative water recreation facility to lessen disease transmission rates. A challenge and opportunity for the students was to understand resource constraints that engineers face in less developed countries when implementing technical solutions. The South Africa project provided similar opportunities for students but is part of a multi-year initiative in Cape Town that brings together interdisciplinary projects, capstone design projects and research. The undergraduate projects formed the foundation for a Mondialogo Engineering Award from Daimler and UNESCO.

While the country environments and scope of each project were substantially different, the overall educational objectives were similar – to provide students with the opportunity to understand the practice and application of environmental engineering solutions in settings that differ from their home experience. Achieving these project goals in a relatively short period of time (students are on-site at the project location for 2 months) requires a structured approach to project advising and pre-travel preparation. In addition, it was important that project outcomes were carefully crafted to ensure useful results for the sponsoring organizations as well as high standards and expectations for academic performance. Lastly, careful selection of student participants is needed, as they are representatives of the university.

A STUDY OF NOVEL FLUORIDE REMOVAL TECHNOLOGIES AND THE USE OF SOCIAL ENTREPRENEURSHIP FOR SUSTAINABLE IMPLEMENTATION IN ETHIOPIA

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One of the key global issues faced at this time is a lack of safe drinking water. The health issues resulting from inadequate safe drinking water contribute to other social issues such as education, maternal health and economic development. The United Nations University and UNESCO estimate that 900 million people currently lack access to potable water and 1.4 billion people are living on less than $1.25 (US) per day. In an effort to mitigate the world water crisis, The United Nation's Millennium Development Goal, ensuring sustainable development, was set to "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation." To achieve this goal, sustainable solutions must be developed. Beyond the environmental engineering development of novel technologies, implementation methods must be assessed and improved upon in order to work towards technologies that are sustainably implemented and used on a regular basis.

Microbial pathogens are the most pressing issue contributing to a lack of global safe drinking water. After pathogens, fluoride is the next water quality issue impacting human health. Fluoride has the potential to cause detrimental health affects to over 200 million people in areas where it exists above the World Health Organization (WHO) recommended limit of 1.5 mg/L. Fluoride is naturally occurring in the drinking water sources of many areas of the world, including the Rift Valley of Africa, areas of China and India and parts of the southwestern United States. The health effects of fluoride include dental and skeletal fluorosis. Skeletal fluorosis can cause bones to become deformed or stiff to the point where mobility is limited and/or painful. This is particularly troubling in rural areas where people depend on their physical labor in order to farm or earn a living.

This presentation will discuss laboratory research on aluminum coated bone and wood chars for fluoride removal from drinking water. Bone char has previously been shown to be effective at removing fluoride from drinking water in both household and community scale treatment systems. Additionally, activated alumina is one of the most successful technologies for filtering fluoride from water. However, activated alumina is expensive and not always readily available in developing areas. Therefore, it is helpful to study the fluoride removal potential when bone char, with its high surface area, and aluminum based materials, with their positive surface charge, are combined. It is also helpful to investigate aluminum coated wood char for use in areas where waste wood products are more prevalent and/or communities are not amenable to using bone char as a water treatment technology.

These aluminum coated technologies have the potential to remove fluoride to meet the WHO standard, be inexpensive, and be locally available and easy to use. This presentation will discuss the isotherms resulting from removal of fluoride from water at various pH values and with competing ions such as phosphorous and sulfate. Specific surface area, point of zero charge, chemical composition, surface morphology and results from column studies will also be discussed.

Selecting an effective fluoride removal technology is important to the success of an implementation project. However, in addition to the technology, the implementation must be done in such a way that families and/or communities maintain ownership of the treatment technologies and are motivated to maintain and use it in the long term. One potentially effective way to accomplish this is through the use of social entrepreneurship. Social entrepreneurship organizations have two simultaneous goals: to obtain a profit in order to be economically sustainable and to help solve a social problem. For example, an entrepreneur could develop a business in which they would produce and sell the appropriate fluoride filtration media. Utilizing social entrepreneurship for fluoride removal will be discussed and a student-created business model of implementation for bone char as a fluoride removal mechanism in Ethiopia will be shared.

TRANSFORMING ARSENIC CRISIS INTO AN ENGINE FOR ECONOMIC GROWTH: EVIDENCE FROM THE DEVELOPING WORLD

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Although unknown nearly twenty five years ago, natural arsenic contamination of groundwater has emerged as a major global crisis affecting over fifty countries. In the United States, nearly seven thousand communities are now required to introduce additional treatment to reduce the arsenic level in groundwater in order to be in compliance with the current Safe Drinking Water Act (SDWA) promulgated by the USEPA in 2006. However, the adverse health effects resulting from drinking of arsenic contaminated groundwater are most apparent in south and southeast Asia, namely, Cambodia, Bangladesh, Laos, Nepal, Vietnam and the eastern region of India. Rainfall in this region is quite significant and often exceeds 2000 mm/year. Ironically, however, arsenic-free surface water is practically unusable due to poor sanitation practices in the region and consequent potential for an outbreak of water borne diseases. According to World Health Organization (WHO), over 200 million people are threatened with arsenic-inflicted health impairment (i.e., arsenicosis) including cancer of the skin, lungs, kidney and urinary bladder. The use of groundwater in these regions is favored because of its easy availability, microbial safety and the absence of proper infrastructure for the treatment and distribution of surface water. Arsenic is by far the most toxic contaminant present in groundwater and it enters into the aqueous phase through biogeochemical leaching of soil. Recently, widespread arsenic poisoning of large population in rural areas of Argentina and Chile have also been reported.

The United Nations Millennium Development Goal (UNMDG) to provide safe drinking water to the people in the developing world is receiving a major jolt due to natural geochemical arsenic contamination of groundwater. The crisis is further aggravated by the fact that most of the arsenic-affected population lives primarily in the rural areas and contaminated groundwater is often the only viable source of potable water. To this end, during the last fifteen years, we have installed nearly 250 Sustainable Arsenic Removal System in Affected Communities (SARSACs) in the bordering region of India and Bangladesh, and Cambodia where over 250,000 villagers and school children currently drink arsenic-safe water. The key pertinent attributes of SARSAC that have evolved during the last decade are as follows:

- The community based arsenic treatment employs regenerable and reusable arsenic-selective adsorbent which helps reduce the volume of disposable arsenic sludge by nearly two orders of magnitude;
- Arsenic sludge is stored in an oxidative environment, thus minimizing arsenic leaching;
- Once installed, SARSACs are run, operated, financed and maintained by villagers in every location.

Socio-economic management of each SARSAC unit at the community level has contributed to the continued success of the systems for many years. **Figure 1** depicts the relationship among the input conditions of an arsenic-affected community, development of technology and the benefits accrued through the community. The entire system has evolved as a viable business model where arsenic-affected villagers are also stakeholders of each unit installed and required to pay a small monthly tariff. **Figure 2** shows an easy-to-operate SARSAC unit in a remote village in Kandal province, Cambodia where arsenic level in contaminated groundwater is consistently brought down from over 600 µg/L to less than 10 µg/L.

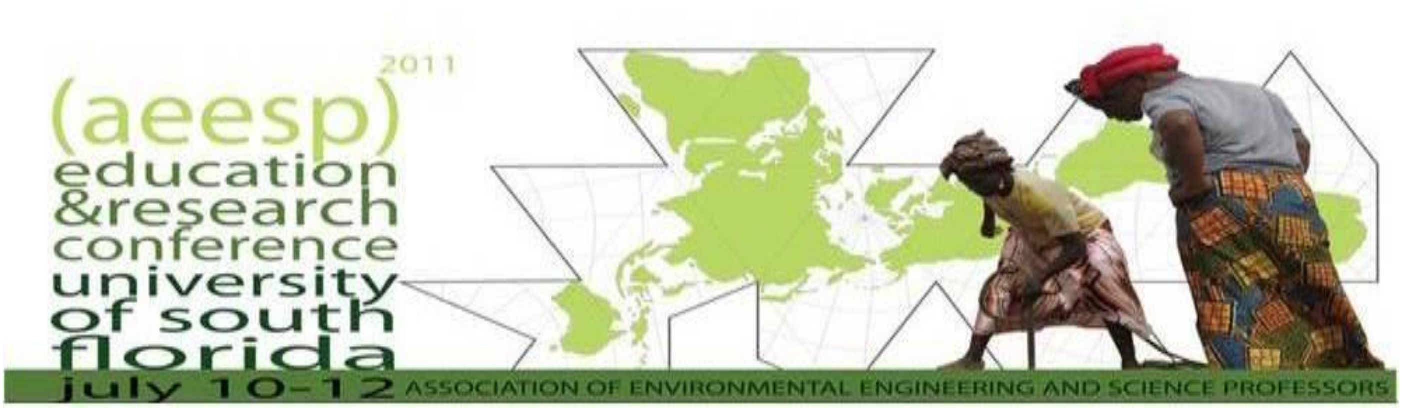
Figure 3 provides continued increase in revenues generated by a specific unit in India for a period of five years. This economic growth has consequently motivated many other affected villages to pursue the arsenic removal technology and the management practice.

Figure 1 Schematic illustration of relationship among arsenic-affected community, development of technology and benefits accrued through the community

Figure 2 An easy-to-operate SARSAC unit in Kandal province, Cambodia (Input arsenic >600 µg/L and arsenic at the exit of removal unit <10 µg/L)

Figure 3 Example of continued increase in revenue generation from a specific community based arsenic removal unit installed in Nabarun Sngha village.

The observed approach is not necessarily limited to arsenic contamination alone. Currently we are planning to apply similar community based technology and business model to abate fluoride contamination in groundwater in Africa. According to our findings, the appropriate choice of technology is the single most important factor for attaining long-term economic sustainability.



Research Category #6: ***Energy as a Cross-Cutting Theme***

Research Category # 6

ENERGY AS A CROSS-CUTTING THEME

GROWING STUDENT INTEREST IN RENEWABLE ENERGY

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Over the past five years an increasing number of incoming undergraduate environmental engineering (EVEN) students at the University of Colorado at Boulder (CU) have been interested in renewable energy. However, many are unsure if their interest in energy-related issues is best served by majoring in environmental engineering or another discipline. This paper presents the trends in student interest and changes that have been made within courses and the curriculum to enable students to explore energy interests.

At CU all incoming first-year engineering students are required to take a 1-credit introductory course to their major. The first assignment of the semester in the EVEN course requires the students to define environmental engineering, list four major sub-discipline areas, select one sub-discipline of most interest, and find an example of this type of project in the news. Figure 1 shows the sub-discipline areas of primary interest to the students over the past five years. The total enrollment in the course has increased substantially, and interest in energy increased from 0 in 2006 (three students interested in energy dropped the course prior to the first assignment due date; 9%) to 35% in 2008 and 2009.

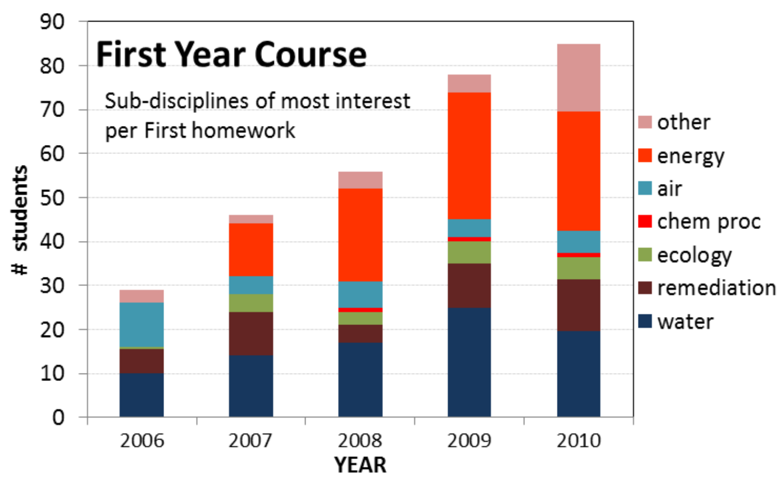


Figure 1. Primary sub-discipline interests of first year EVEN students on the first homework assignment

The course content has been modified over time to emphasize energy related issues (Table 1).

Table 1. Homework (HW) Assignments in the First Year EVEN Course in Different Years

2000-2003	2004-2005	2006	2007	2008	2009	2010
Skill evaluation	Why EVEN paper	Define EVEN and Overview				
Study strategies	Silent Spring book review	Waste-water Case Study		Drinking Water (DW) Evaluation	Sustainability	
Time management	Our Stolen Future book review			Team DW Evaluation	Biofuel LCA	
Ethics	Ethics Case Study	Ethics: NSPE code, case studies, moral exemplar, student honor code				
		Course Plan to Graduation with ABET/BOK mapping				
DW treatment plant tour		Team Project: Solid Waste Generation and Recycling – Landfills – LandGEM – Waste-to-Energy				Team Fuel LCA project
Guest Speaker write-up		HW7: Guest Speaker Discussion and Final Reflective Essay				

At the end of the semester on HW7, the students discuss environmental engineering and if they plan to major in EVEN. Many students in the course were not declared EVEN majors (Table 2); some were engineers who had not yet selected a major and others were from the College of Arts & Sciences and potentially interested in switching into EVEN. In 2007 when very little course content focused on energy, a much smaller percentage of the students interested in energy intended to remain EVEN majors compared to all EVEN students; in later years the intended persistence of energy students was more similar to all students (Table 2). The most popular majors for energy-interested students not planning to stay in EVEN were environmental studies and electrical, mechanical, and chemical engineering. The actual retention of EVEN majors interested in energy was similar to all EVEN students.

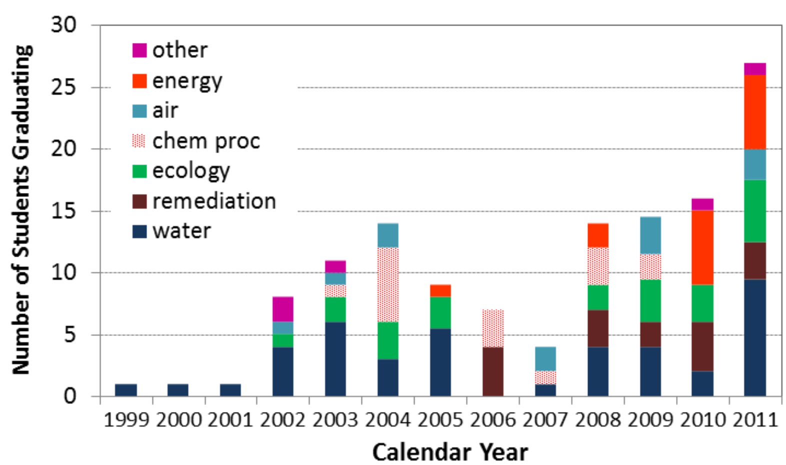
Table 2. Retention of students in the first year course with an interest in energy

YEAR:	2007		2008		2009		2010	
	EVEN majors	Non-EVEN majors	EVEN majors	Non-EVEN majors	EVEN majors	Non-EVEN majors	EVEN majors	Non-EVEN majors
Number of students in course*	25/24	23/20	37	22	48/47	30/25	52/48	31/30
% with $\geq$50% intent to major in EVEN on HW7	79	60	91	59	81	48	73	50
% majoring in EVEN 1 / 2 yrs later	52/48	13/13	70/62	14/18	79/NA	23/NA	NA	NA
% energy-interested students with $\geq$50% intent to major in EVEN	63	50	93	30	69	50	69	50
% energy-interested students majoring in EVEN 1 / 2 years later	50/33	0/0	83/67	13/38	82/NA	8/NA	NA	NA

** initially enrolled and completed homework 1 / completed homework 7; NA = not available*

Students majoring in EVEN at CU select a specialization option for 9 credits of technical courses in their junior or senior year. A specialty track for energy was officially added in fall 2008; previously students could create an energy focus via petition. The number of graduates from various sub-discipline areas is shown in Figure 2; the year 2011 data are projected.

Figure 2. Specialization options of EVEN students graduating from CU.



The courses in the energy option are drawn from electrical engineering (Circuits, Energy Conversion), mechanical engineering (sustainable energy, thermodynamics 2, wind energy), civil engineering (Building Energy Lab, Building Energy Audits, Solar Design), physics (Energy and the Environment), and environmental studies (Energy Policy) (http://www.colorado.edu/engineering/even/energy.htm). Recent senior design projects have also focused on energy (LEED certified CU dormitory; waste-to-energy options for CU; Halliburton Environmental Footprint Challenge; biodiesel waste processing and use; http://www.colorado.edu/engineering/civil/CVEN4434/projects.html).

THE TOP FIVE THINGS THAT ENVIRONMENTAL ENGINEERS CAN TEACH US ABOUT ALGAE-TO-ENERGY TECHNOLOGY

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Music lovers are fond of assembling top-five lists (e.g., "albums for a desert island") to help catalog their libraries and, frequently, to make a statement about what they think have been the most important contributions in a particular genre. During this talk, we will sort through recently published work on the topic of algae-to-energy systems, including our own, in order to compile a top-five list of ways in which environmental engineers could contribute to the advancement of this rapidly emerging alternative energy sector. Algae are considered by many to be a promising source of next-generation bioenergy. They are not a traditional food crop and can be cultivated on marginal land; thereby minimizing both direct and indirect competition with food supply. Their growth yields are higher than most terrestrial crops, and they can be converted into various usable energy carriers. Despite these advantages, algae-bioenergy is a nascent industry with as-yet unclear economic and environmental benefits. Our work suggests that five areas of traditional environmental engineering expertise could be brought to bear in deploying sustainable algae-to-energy systems. These areas, summarized in Figure 1, include: 1) environmental life cycle assessment (LCA); 2) nutrient management in wastewater streams; 3) emerging contaminants management in wastewater streams; 4) anaerobic digestion; and 5) biomass dewatering. This talk will touch on each of these five areas, using up-to-date information from ongoing work by the authors and others.

Area 1 – Environmental LCA. The environmental impacts of large-scale algae cultivation have been the subject of extensive research and debate over the past several years. This interest is accelerating, as made evident by at least eight different algae LCA papers to appear in the last twelve months alone. These papers have had largely divergent results, fueling the debate about whether algae-to-energy systems offer an improvement over transportation fuels derived from fossil sources or terrestrial plants. At issue are a number of assumptions about how algae cultivation would look since no commercially viable facilities exist today. Our own work has highlighted the importance of functional unit and system boundaries selection on overall LCA results. This had led to significant discourse on the role of procurement, residual biomass handling, and opportunity costs associated with selection of a particular energy carrier. This portion of the talk will present recent results from an algae LCA meta-analysis, in which selected assumptions have been standardized across previously-published algae LCAs, as means to address larger policy questions such as: Are algae-derived transportation fuels more or less environmentally preferable than selected benchmarks?

Area 2 – Wastewater Nutrient Management. Having demonstrated the significant extent to which N and P procurement impacts the burdensomeness of algae cultivation, we and others have suggested that treated effluents could be used to offset upstream fertilizer impacts. Still, our calculations suggest that the fraction of algae nutrient demand that could be offset using municipal effluent is quite small. This portion of the talk will recap these calculations and highlight recent research into wastewater treatment at commercial animal farms, as a means to evaluate algae-mediated nutrient management schemes within the context of centralized and decentralized wastewater treatment systems.

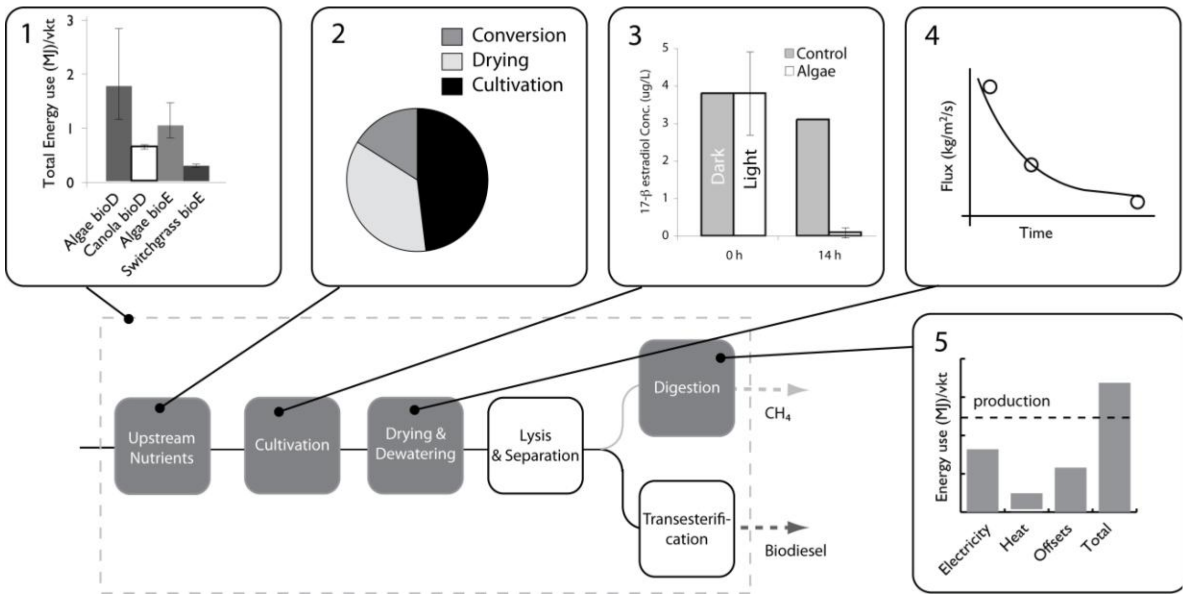

Figure 1. Generalized flow diagram for an algae-to-energy system, with special emphasis on "top-five" areas of overlap with environmental engineering (highlighted): 1) environmental life cycle assessment; 2)

Area 3 – Emerging Contaminants Management. A second attractive function of combined algae farming/wastewater treatment operations could be improved management of so-called "emerging contaminants"; i.e., wastewater constituents that are physiologically active even at very low concentrations (ng/L). It seems reasonable to expect that algae-mediated degradation and/or sorption reactions in effluent-irrigated ponds may engender significant removal of these compounds and thus mitigate contamination of downstream receiving waters. For the special case of systems in which algae biomass is combusted to produce bioelectricity, algae-mediate effluent polishing could mediate "dead-end" removal of certain emerging contaminants. This portion of the talk will present recent laboratory results from algae growth experiments with selected estrogens, as means to highlight previously unidentified environmental services of algae-to-energy systems.

Area 4 – Dewatering. LCA results point to a clear need for more energy-efficient dewatering technologies to concentrate algae suspensions from ~ 0.1% to 20% dry solids (m/m). Since many of the technologies that have been proposed for algae systems have been used for decades in municipal wastewater solids management (e.g., belt filter pressing, conveyor drying, etc.) it seems that environmental engineers are uniquely poised to make an important contribution in this field. This portion of the talk will focus on what marginal improvements in the overall algae fuel cycle energy use could be achieved per unit increase in dewatering efficiency, to emphasize the importance of dewatering/drying on overall favorability.

Area 5 – Anaerobic Digestion of Algae. Digestion has been widely touted as means to facilitate nutrient recycling and energy production from the non-lipid fraction of algae biomass. Still, there has been direct comparison of anaerobic digestion to other algae conversion processes. Thus it remains unclear whether digestion is really a viable option. This portion of the work will present a detailed energy balance for anaerobic digestion (within the context of an algae-to-energy system) and also highlight the dramatic differences in overall favorability resulting from use of theoretical vs. empirical algae digestability and methane yield parameters, as means to spur targeted research in this area.

A NEW BRIDGE BETWEEN WASTE MANAGEMENT AND ENERGY: SOLID FUEL PRODUCTION BY MEANS OF TORREFACTION OF AGRICULTURAL RESIDUES

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This presentation will cover a novel method of converting waste biomass such as agricultural residues into a convenient solid renewable fuel that is a direct replacement for coal. The presentation will include an overview of the process known as torrefaction, and will provide results of laboratory studies of the torrefaction of selected materials into 'biocoal'.

The use of biomass as an energy source is as old as the discovery of fire. The industrial revolution led to the extensive use of fossil fuels in the form of coal and later petroleum. Now we search for alternative fuels which not only are more carbon neutral, but which are also available domestically and can be produced with energy and economic efficiencies. In all of those aspects, biomass is an attractive possibility to compliment other renewable energy sources. However, the utilization of biomass as a fuel presents several technical and economic challenges. Some of the disadvantages of using fibrous biomass such as wood and timbering residues as a fuel are that it is fibrous, therefore requiring considerable energy to pulverize, it is bulky, and it contains considerable moisture. The moisture not only increases shipping costs, but also robs energy from the combustion chamber, resulting in a lower boiler temperature. Each of the other forms of biomass, such as biosolids, manures, food wastes, and the vast variety of other organic wastes generated by our society has its own unique challenges when considered as a solid fuel.

One relatively new approach that addresses many of these issues is torrefaction, i.e., the controlled thermal conversion of organic matter into a more convenient and cleaner burning fuel (Bergman and Kiel 2005). When organic matter is heated in the absence of oxygen, a series of changes occur as the treatment temperature increases (Lange 2007). Residence time at a given temperature is also a factor in these changes. At lower temperatures (200° C to 400° C) mild decomposition occurs with the evolution of some volatile hydrocarbons while most of the material remains in solid form. At higher temperatures (400° C to about 1,000° C), liquid pyrolysis oils are generated along with gases and solid residues. At higher temperatures, gasification largely predominates while some material remains as ash.

A number of studies have recently been reported in the engineering literature (Bergman and Kiel 2005, Bridgeman, et al 2008, Chen and Kuo 2010, Deng et al 2009, Gassner and Marechal 2009, Uslu et al 2008,), describing this process and methods of accomplishing these conversions, mostly with fibrous plant materials. Depending on the method followed and the nature of the feedstock, the energy yield and materials composition changes. Volatile gases are always released once the temperature is sufficient to begin the breakdown of hemicellulose and then later cellulose; only at higher temperatures does lignin begin to decompose (Chen, 2010). These are flammable gases, and can be captured and used to provide the heat for the process. Thus the process of thermal decomposition is essentially energy self-sufficient other than the minor energy requirements for pumps, blowers, control systems, etc. Bergman and Kiel (2005) report that up to about 87% of the dry weight of the material can be retained containing up to 95% of the original energy content when using willow as a feedstock.

The laboratory study to be presented is still underway. The materials being studied include animal manure (equine), switch grass, glycerin, and fruit pomace. Pomace is the solid residue left after pressing certain fruits for their juice, such as apples and grapes. In this case, grape pomace obtained from a Welch's Foods juice processing plant is being studied. Each material is being heated in a thermal reaction chamber under an inert atmosphere (to prevent combustion) to various temperatures for varying lengths of time. The objective of the experimental plan is to determine the time and temperature profile that yields sufficient flammable hydrocarbons to power the process without depleting the product of any more energy content than is necessary. The physical characteristics of the feedstock change during this heating process. Depending on the final upper temperature reached, the material changes in color from a dark brown to black. Also, the tough fibrous nature of the plant-based material is lost and the material becomes friable and is no longer hygroscopic (Bergman, 2005). The final physical characteristics are important because they relate to the ease of pelletization of the transformed feedstock. Pelletization success may be a function of the temperature of the product material as it is fed to the pelletization process and thus must be evaluated.

Another feature of this study is to evaluate product characteristics after blending the test materials in combination with glycerin. Glycerin is a by-product of biodiesel manufacture. Now that biodiesel production has increased, unpurified glycerin resulting from that production has become plentiful and almost worthless. We hypothesize that the addition of an appropriate dosage of glycerin during the thermal conversion process will result in an improved product with high heat content.

By mid-summer 2011, we will have results worthy of presentation to the AEESP conference attendees, and we request the honor of doing so.

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A LOW-ENERGY TREATMENT SCHEME FOR AUTONOMOUS NET-ZERO WATER BUILDINGS

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Current estimates suggest that >20% of total power is consumed solely for conveyance of water and wastewater in California (California Energy Commission 2005). In contrast, in-home direct potable water reuse offers the prospect of energy-efficient use of a stable freshwater source, generally free of pesticides and industrial chemicals.

The purpose of this work is to describe a new low-energy treatment system under development and construction at the University of Miami, to be installed at an autonomous net-zero water residence hall with support from the National Science Foundation (NSF), Emerging Frontiers in Research and Innovation (EFRI) program. All wastewater from the 20-bed dorm will be treated to drinking water standards beginning Fall 2011, for return to the dorm beginning January 2012. To circumvent the need for high-energy membrane treatment, all drinking and cooking water will be supplied by a rainwater cistern. Wastewater treatment will comprise aerobic biological treatment with nitrification/denitrification, followed by iron-mediated aeration (IMA) (Englehardt et al. 2007; to be described in detail in a parallel talk at this conference), parallel cloth and fine-screen filters, H_2O_2-mediated electrocatalysis, and activated carbon filtration (Figure 1). Moving parts beyond pumps and blowers will be eliminated, to support a goal of one scheduled maintenance call per year. Additional carbon and alkalinity will be dosed to the aerobic plant, if necessary for denitrification. However, alkalinity addition in particular is not expected to be necessary, because IMA experimental and modeling data indicate that alkalinity will stabilize via aeration softening (Peng and Westerhoff 2006) at 50-100 mg/L as $CaCO_3$. Goals for IMA treatment are 1-log removal of COD and phosphorus, and 2-log removal of metals. Fine screen and cloth filtration technologies, now replacing granular media filtration in centralized wastewater treatment plants, are being adapted for low flows to complement IMA treatment. Remaining organics will then be mineralized in parallel antimony-doped tin oxide and boron-doped diamond electrocatalyzers with hydrogen peroxide addition. Activated carbon treatment will provide redundancy and remove excess hydrogen peroxide and any remaining contaminants.

Electrocatalysis has recently been shown cost-effective for the oxidation of organic pollutants in conductive industrial wastewaters. Preliminary data developed at the University of Miami suggests that the process can be extended profitably to the treatment of low-conductivity organic wastewater. In particular, these data suggest that the addition of hydrogen peroxide, as both supporting electrolyte and reactant, and air to the electrocatalytic oxidation of low-strength organic wastewater on Sb-doped SnO_2 electrodes results in effective in mineralization of organics. Initial tests showed 70-80% mineralization of phenol after 8 hours of treatment [conditions: 1 mM initial phenol, 5 V square wave AC potential, 1 Hz and 1MHz, 4 mM H_2O_2, pH 7.3-8.3]. Further, COD in aerobically-treated municipal wastewater was oxidized below detection limits (Figure 1). Further tests showed >72% removal of COD in 8 hours from such secondary effluent after ~1000 hours of electrode use [conditions: 8 hour treatment, 7 mM H_2O_2 addition, 5 V, 1 Hz AC current, 1 L/min aeration]. Efficiencies are expected to increase and required H_2O_2 concentration decrease substantially, with reduced electrode spacing and increased electrode surface area, at negligible electrical energy requirement. Mechanistic experiments indicate major contributions to oxidative degradation by both singlet oxygen and hydroxyl radical, with a lesser but significant contribution by H_2O_2 (Figure 2). The new process will be evaluated for safety and cost-efficiency versus ozone, as one component of treatment for autonomous net-zero water buildings of the future.

Figure 1. Left panel: Schematic of dorm treatment system. Right panel: Oxidation of aerobically-treated municipal wastewater COD by H_2O_2-Sb-SnO_2 electrocatalytic process [Conditions: pH 7, 22^{o}C, $[H_2O_2]_0$ = 14.2 mM, 10 Hz AC, 5 V, 1.5 mA, 5.9 L air/L-min]

Figure 2. Oxidation of RNO in the reactor, with and without ethanol and/or histidine, with (from top left to bottom right): (a) applied voltage, H_2O_2, and aeration (b) applied voltage only (c) applied voltage and aeration, and (d) applied voltage and H_2O_2 [Conditions: 7 mM peroxide, 5 V and 1 Hz AC current, 5.9 L air/L-min].

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EFFECTS OF TURBULENCE ON OXYGEN TRANSFER AND BUBBLE CHARACTERISTICS IN DIFFUSED AERATION

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Aeration is an essential and energy intensive process for most wastewater treatment plants, accounting for 45 to 75% of plant energy costs (Reardon, 1995). Higher oxygen transfer efficiency can be achieved by increasing liquid velocity in oxidation ditches using mixers for liquid displacement (Da Silva-Deronzier et al., 1994; Déronzier et al., 1998). Based on mass transfer theory, turbulence at gas-liquid interfaces can promote oxygen transfer and affect aeration efficiency. In this research, the effects of liquid-side turbulence on oxygen transfer were studied in a controlled environment within the range of gas and liquid velocities correspondent to the field. This presentation will include the methodology and results of our experiments as well as a visual investigation of the bubble-liquid interactions.

To quantify turbulence effects on gas transfer, 5 fine-pore mini panel diffusers were set-up in a transparent lab-scale flume equipped with a 2-D Acoustic Doppler Velocimeter (ADV) (Fig. 1). A flow conditioner was placed at the beginning of the flume to stabilize flow. Macro photography was employed as an educational tool to engage junior students in the process of learning advanced interfacial gas-transfer phenomena. Photography, as a research tool, was also used quantitatively to demonstrate the existence of a secondary bubble plume transported horizontally off the primary bubble plume, potentially contributing to part of the oxygen transfer.

Triplicate clean water oxygen transfer tests (ASCE, 2007) were performed at 3 liquid velocities (0.12, 0.16, 0.23 m/s) and 4 air flow rates (0, 0.6, 1.2, 1.8 SCFM/diff) for a total of 36 tests, and results were reported as standard oxygen transfer efficiency (SOTE, %) and standard oxygen transfer rate (SOTR, $mass_{O2}$/time). Effective gas velocity (U_g, i.e. air flow rate / diffuser area) was measured. The liquid velocities were recorded by the ADV at 5 locations for 3 min each and averaged to determine the mean liquid velocity (U_l). The ADV locations were roughly 2 in (5.08 cm) upstream of each mini panel at the approximate channel mid-depth. At these locations, the ADV reliably predicted average and turbulent velocity without the interference of the bubble plume. The RMS of the liquid velocity component perpendicular to the channel length (RMS_y) was used as a predictor of turbulence, as it excludes the longitudinal velocity component.

The results confirm that oxygen transfer is enhanced by increasing either or both liquid and gas velocities (Fig. 2). SOTR increases sub-linearly with increasing U_l, and increases at a greater rate with U_g. Typically, increasing U_g (i.e. increasing blower AFR) is an easier task to accomplish than increasing U_l in activated sludge processes. Also, with the exception of oxidation ditches, increasing U_l would reduce the hydraulic retention time and substrate removal effectiveness of an aeration basin. Figure 3 shows that RMS_y increases with either increasing U_l (represented by changing colors) or increasing U_g (represented by bubble size). Higher SOTR was observed under conditions with higher RMS_y. The results suggest that the degree of turbulence in the system, whether induced by gas or liquid velocity, promotes oxygen transfer. Interestingly, the SOTR obtained at high U_l and medium U_g can also be obtained at medium U_l and high U_g. To determine the more suitable option for aeration system design or expansion, the costs and benefits must be considered between increasing blower power in the case of high U_g or increasing mechanical mixing or pump power in the case of high U_l.

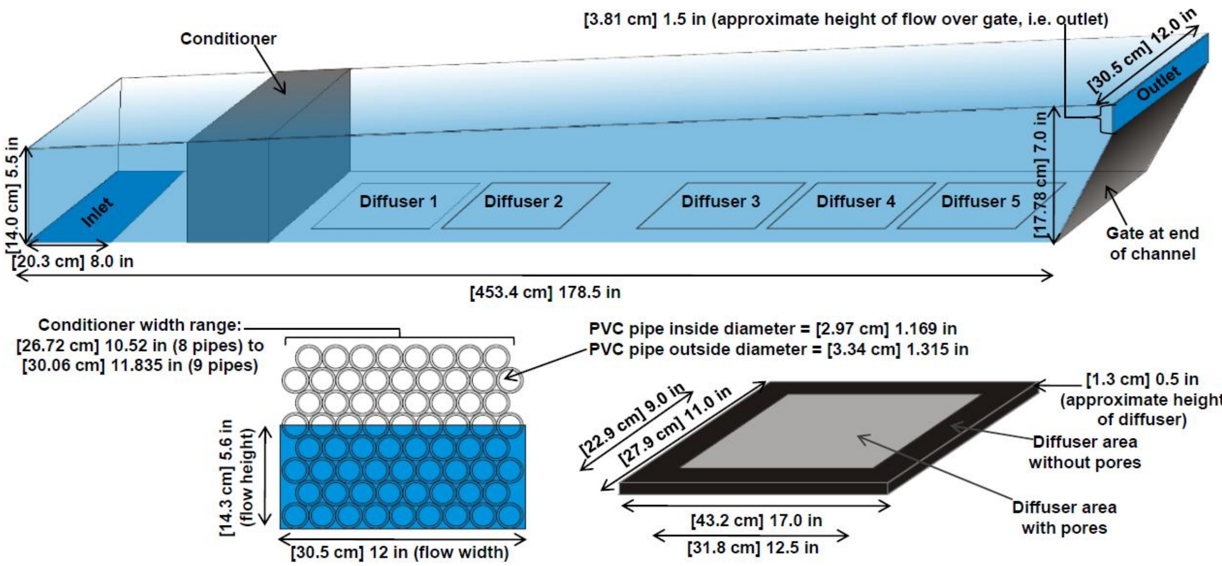

Fig. 1. Schematics of the flume (top), flow conditioner and panel diffuser (bottom details)

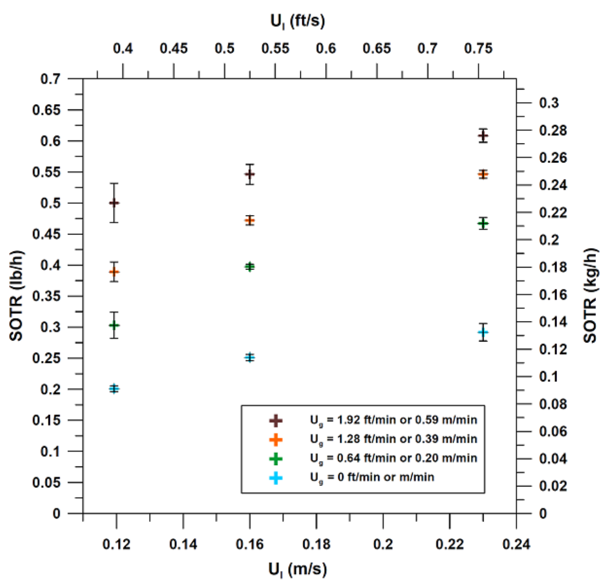

Fig. 2. Standard oxygen transfer rate vs. longitudinal liquid velocity and gas velocity

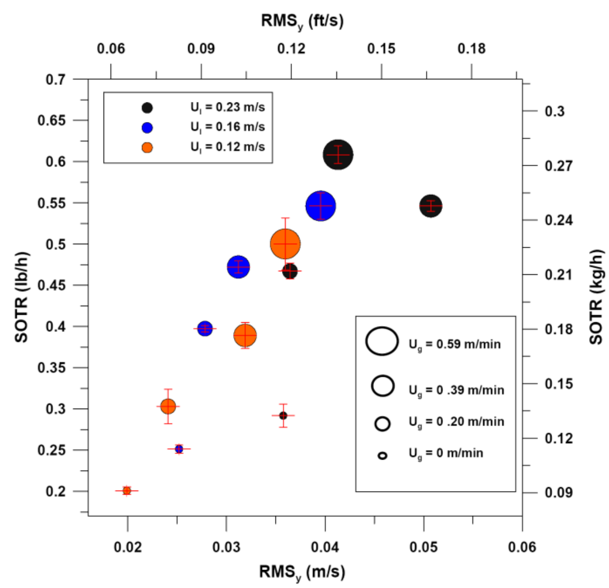

Fig. 3. Standard oxygen transfer rate vs. root-mean-square of the turbulent velocity component perpendicular to channel length

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ISOBUTANOL PRODUCTION BY GENETICALLY MODIFIED AMMONIA OXIDIZING BACTERIA

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Introduction – Biofuel production via non-fermentative pathways has been recently documented [1]. In this approach, reduced organic matter (e.g. glucose) is converted to high chain alcohols (> C_4) by bacterial strains propagating heterologous enzymes required for biofuel production. Since reduced organic feed-stocks are expensive and non-renewable, biofuel production efficiency using this model is not effective as a long term solution.

A more attractive option is to use phototrophic or chemolithoautotrophic organisms, in which renewable resources (e.g. carbon dioxide and inorganic substrates (e.g. ammonia)) become the primary carbon source and electron donor for biofuel production. Along these lines, we propose that it may be possible to genetically engineer autotrophs like ammonia oxidizing bacteria (AOB) to propagate enzymes required for non-fermentative production of biofuel or biofuel precursors. In this work, we report progress on the construction and maintenance of a genetically modified strain of *Nitrosomonas europaea* ATCC 19718 for producing isobutyraldehyde and isobutanol through modification of the L-valine biosynthesis pathway (**Figure 1**).

Methods – Hydroxylamine oxidoreductase (HAO) promoter-green fluorescent reporter (*gfp*) gene fusions are being constructed and propagated in *Escherichia coli* DH5α . The purified plasmids have been electroporated into stationary phase *Nitrosomonas europaea* ATCC 19718 and kanamycin resistance has been used to select for cell lines retaining the promoter/reporter construct. The mutant strain was then cultured under batch conditions (data not shown). Short term experiments were also performed with wild-type *N. europaea* to determine isobutyraldehyde/isobutanol toxicity and whether native alcohol dehydrogenase activity is sufficient to reduce isobutyraldehyde to isobutanol.

Results and Discussion – Both isobutyraldehyde and isobutanol exhibited high toxicity that was manifest through reduced cellular respiration rates (oxygen uptake) (**Figure 2**). Fifty percent inhibition (IC_{50}) was achieved at 110 mg isobutyraldehyde and 60 mg isobutanol/L, suggesting that isobutanol is more acutely toxic than isobutyraldehyde. Future efforts will focus on minimizing prolonged exposure to both compounds.

Isobutanol production (0.72 to 1.1 mg isobutanol/L-hr) due to oxidoreductase activity by endogenous alcohol dehydrogenase was also observed in wild-type *N. europaea* (**Figure 3**) fed exogenous isobutyraldehyde. This low production rate is not unexpected since reductase activity by this enzyme is associated with anaerobic metabolism. These findings suggest that high isobutanol production rates in this system will be dependent on inducing plasmid borne alcohol dehydrogenase.

Project Status – Ongoing work is focused on creating a HAO promoter- 2-ketoacid decarboxylase (Kivd) from *Lactococcus lactis* fusion product. Upon confirmation that the insert is intact, we will transform the wild-type with the new plasmid. The mutant strain will then be cultured under batch and chemostat conditions (solids retention time (SRT = 2.2 day); V = 1 L) using elevated ammonia concentrations (1 M) and elevated CO_2 concentration (1% v/v) to characterize isobutyraldehyde and isobutanol production rates.

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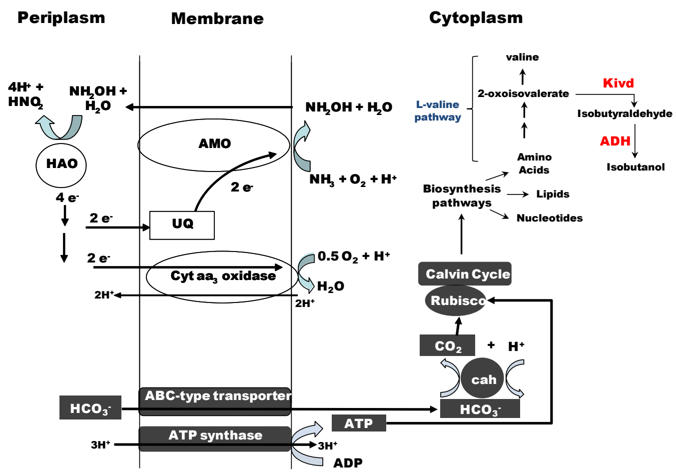

Figure 1. Overview of proposed isobutanol production pathway in *Nitrosomonas europaea*. AMO - Ammonia monooxygenase; HAO - hydroxylamine oxidoreductase; UQ – ubiquinone; Cah - carbonic anhydrase; Rubisco - ribulose 1,5-bisphosphate carboxylase/oxygenase; Kivd – 2 keto-decarboxylase; ADH – alcohol dehydrogenase. Adapted from Yu et al., 2010.

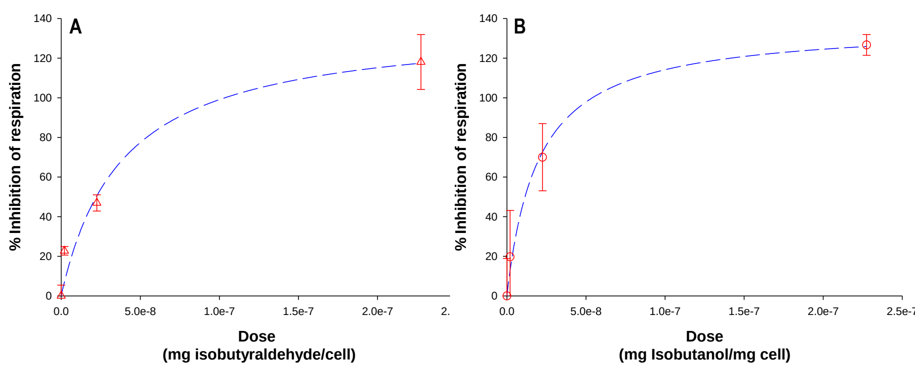

Figure 2. Inhibition curves for wild-type *Nitrosomonas europaea* exposed to exogenous stressors. A*:* isobutyraldehyde, B: isobutanol.

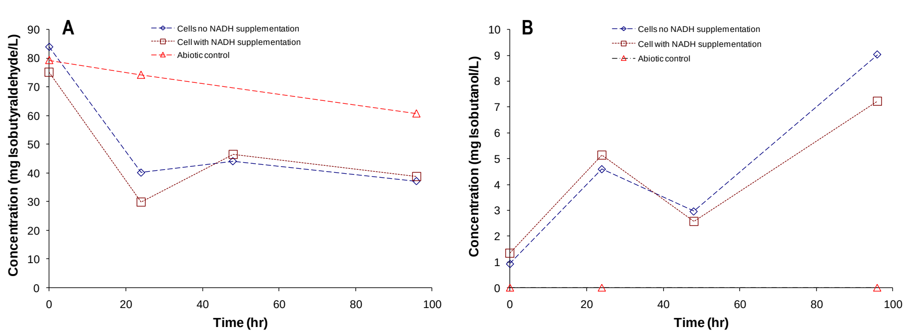

Figure 3. Chemical profiles for wild-type *Nitrosomonas europaea.* A*:* isobutyraldehyde, B: isobutanol.

DETERMINING THE EFFECT OF LAND USE CHANGE ON THE ENVIRONMENTAL IMPACTS OF BIOENERGY

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Bioenergy has the potential to reduce carbon emissions relative to fossil fuels; however potential negative tradeoffs exist with respect to nitrogen and phosphorus cycles, water use, and changes in land use patterns. Life cycle assessment (LCA) is a tool that helps quantify the environmental impacts of products. Historically, LCA has been used to analyze industrial processes, where systems are well-developed, inventory flows can be reasonably measured and are generally constant over time, and the majority of emissions can be translated into established impact metrics, such as Global Warming Potential (GWP). Conversely, agricultural systems for bioenergy production are highly variable, pose measurement difficulties due to the non-point nature of emissions, and have impacts that are not easily integrated into traditional LCA impact metrics. In addition, some systems such as perennial grasses for cellulosic ethanol are only in the development stage, and inventory data must be estimated rather than measured.

This research seeks to quantify some of the tradeoffs associated with bioenergy production. Switchgrass is a native perennial expected to be a significant contributor to future bioenergy markets. Even though it is highly abundant in natural systems and used in some conservation practices, switchgrass has never been cultivated at a large scale. Earlier data, as shown in Figure 1, suggests that switchgrass-derived bioenergy is often preferable to bioenergy derived from other sources, when land use change is not taken into account.

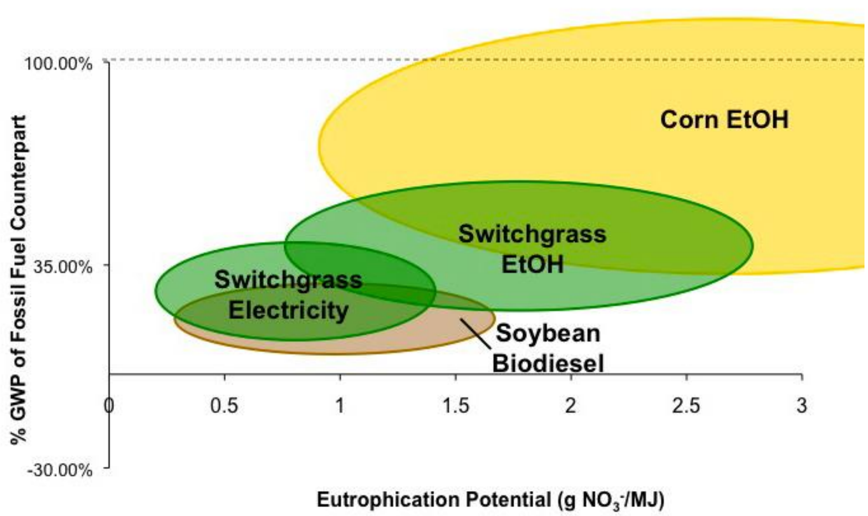

Figure 1. Carbon and nitrogen tradeoffs for a variety of biofuels. Adapted from Miller, S.A.; Landis, A.E.; Theis, T.L.; Environmental Tradeoffs of Bio-based Production *Environmental Science and Technology*, 2007, *41*(15), 5176-5182

Our research indicates that the environmental impacts of switchgrass are highly dependent on prior land use patterns. Although the general trends in Figure 1 are expected to remain, the relative change in carbon sequestration and non-point source runoff from one land use to another is significant. In general, it is expected that carbon sequestration and water quality with respect to nitrogen, phosphorus, and erosion will improve from a baseline land use, providing that switchgrass is grown on lands that previously supported intensive agricultural activities, such as corn or cotton. Alternatively, these metrics will be negatively impacted if Conservation Reserve Program or forested lands are converted to bioenergy production. Our work quantifies the differences in these metrics using the DAYCENT and SWAT agricultural models to estimate changes in land use in the Southeastern region. The research is conducted at multiple scales. The results of field-scale modeling are extrapolated to understand watershed-level impacts. The expectations of how bioenergy will expand within a region allows determination of whether overall water quality will improve or decline relative to current land use patterns.

THE OPTIMAL DESIGN OF WATER SUPPLY SYSTEMS FOR ENERGY EFFICIENCY

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INTRODUCTION

With the growing population and demand, water supply is becoming a more and more important energy consumer in the United States. Water systems need not only a lot of energy onsite for pumping and aeration, but also indirect energy for producing chemicals and providing administrative services. This total amount of energy involved with the construction and the operation phases of water supply systems was recognized as the embodied energy of water supply systems. In order to reduce the resource consumption and to improve sustainability, studies have been carried out on estimating the embodied energy of individual water supply systems (Stokes et al., 2006&2009; Mo et al., 2010). Indirect energy associated with material and service supplies has been considered a significant part of the total embodied energy in those studies. Additionally, studies have also been carried out on optimizing water supply infrastructures based on a variety of objectives, such as relieving water scarcity, improving quality allocation, minimizing cost, etc. (Lim et al., 2009; Mugisha, 2008). The optimization, however, has not been studied based on minimizing the total embodied energy.

In this study, an optimization model will be established in order to minimize the total energy embodied in the construction and operation phases of a selected water supply system. The Tampa Bay Water has been selected as the case study for this model. It has three main water supply sources: surface water, groundwater and desalinated water. These three types of water are obtained, treated, and mixed before being distributed to the customers. Currently, the Tampa Bay Water provides water to more than 2.4 million people in the Tampa Bay area and the daily flow in the system is around 180 MGD. The Tampa Bay Water has evolved haphazardly over time responding to the growing water demand. Hence, studying how the system can be possibly better designed can help to provide important aspects for the decision makers on future planning. Results from minimal total embodied energy, minimal direct energy and minimal cost scenarios will be compared and analyzed.

METHODOLOGY

The total embodied energy is the product of energy intensity (energy per economic activity) and total economic activities (costs) in a water supply system. The energy intensities for constructing and operating the surface water, groundwater and desalinated water supply systems were adapted from Mo et al. (2010) and Stokes et al. (2009). System operation includes both water facility operation and maintenance, and water delivery. Cost estimate equations involved in the construction, operation, and water delivery will be obtained from literatures, including Gumerman et al. (1979), Mickley, (2001), Traviglia et al. (2008) and McGivney et al. (2008). Those equations and energy intensities will then be put into the model for optimizing embodied energy. To optimize the embodied energy, a mixed integer non-linear model will be developed using quadratic integer programming with the assistance of CPLEX.

Within the service area of the Tampa Bay Water, its customers were divided into 10 groups according to their locations. Possible locations of the potential groundwater, surface water and desalinated water treatment plants were selected based on their locations and suitability. Potential desalination plants will be placed on the shoreline and with direct access to open waters. Groundwater well fields need to be in rural places, and undeveloped lands. Surface water plants have to have access to surface water sources such as rivers, springs or canals. Moreover, all the treatment plants have to be located within 5 miles of major distribution network.

After selecting the locations of the potential water treatment facilities and customer groups, coordinates information will be obtained from GIS maps of the Tampa Bay Water, and they will be put into the model for optimization. The results will show which of the potential locations of the surface water, groundwater and desalinated water treatment plants would be used to minimize the embodied energy and their capacities. These results will then be put back into the GIS maps for visual demonstration.

EXPECTED RESULTS

Through this study, a theoretical optimization model will be established for water supply infrastructures. The potential locations of the surface water, groundwater and desalinated water treatment facilities will also be selected and the infrastructures will be optimized for minimal embodied energy consumption. A comparison will be performed for the results of minimal embodied energy, minimal direct energy and minimal cost to look for any potential tradeoffs. This study will also provide recommendations for future system planning.

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NEXT GENERATION DNA SEQUENCING AND ANNOTATION OF THE *DUNALIELLA TERTIOLECTA* TRANSCRIPTOME: GENE DISCOVERY FOR BIOFUEL PRODUCTION

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The global demand for petroleum as a transportation and heating fuel is predicted to increase 40% by the year 2025 (Hirsch *et al*., 2005). Domestically produced liquid biofuel from plants and microalgae feedstock is a renewable and potentially sustainable alternative to petroleum energy as greenhouse gases released during the combustion of these biofuels are partially neutralized by the carbon dioxide required for their growth. The greatly minimized acreage estimates, high lipid or starch content, and biomass production rates that surpass those of terrestrial plants suggest that biodiesel or ethanol derived from lipids or starch produced by microalgae may circumvent many of the limitations ascribed to petroleum fuel and first generation plant-based biofuels (Christi, Y., 2007). However, the limited availability of genome sequences for nonmodel microalgae that are promising candidates for fuel production preclude the adoption of a rational approach to metabolic engineering-based biofuel feedstock optimization studies (Radakovits *et al*., 2010). To address this gap in knowledge, we described the nucleic acid sequencing, *de novo* transcriptome assembly, and metabolic pathway construction for the lipid and starch enriched marine microalgae *Dunaliella tertiolecta*.

D. tertiolecta was grown under varying nitrogen and osmotic-inducing stress conditions and transcribed gene sequences were extracted during log and stationary growth phases. These transcripts were converted to cDNA, normalized, and then sequenced using 454 Life Sciences pyrosequencing technology. Approximately 1.4 million high quality reads with an average length of 400 bases were produced. Following various quality and size trimming of the raw sequences, reads were assembled into 33,307 putative transcripts with a 31-fold coverage. Assembled sequences and singletons were subjected to Basic Local Alignment Search Tool (BLAST) searches available through the National Center of Biotechnology Information (NCBI) databases and annotated with Gene Ontology (GO) and Kyoto Encyclopedia of Genes and Genomes (KEGG) orthology (KO) identifiers. These analyses resulted in the identification of the important biosynthesis and catabolism pathways in *D. tertiolecta* (Table 1).

Table 1. Essential metabolic pathways annotated in the *D. tertiolecta* transcriptome.

Pathway	Enzymes found	Known enzymes
Photosynthetic carbon fixation (Calvin cycle)	12	13
Glycolysis / Gluconeogenesis	10	10
Pentose phosphate	5	5
Citrate cycle	10	10
Fatty acid biosynthesis	6	6
TAG biosynthesis	3	4
Starch biosynthesis	4	4

Pathways for carbon fixation, glycolysis, the citric acid cycle, fatty acid biosynthesis, triacylglycerol (TAG) synthesis, starch synthesis, and several value added products (b carotene, vitamin A, C, and E, and phyosterols) have been constructed for this nonmodel microalgae. Figure 1 depicts the TAG biosynthetic pathway. TAG is the main precursor for biodiesel production.

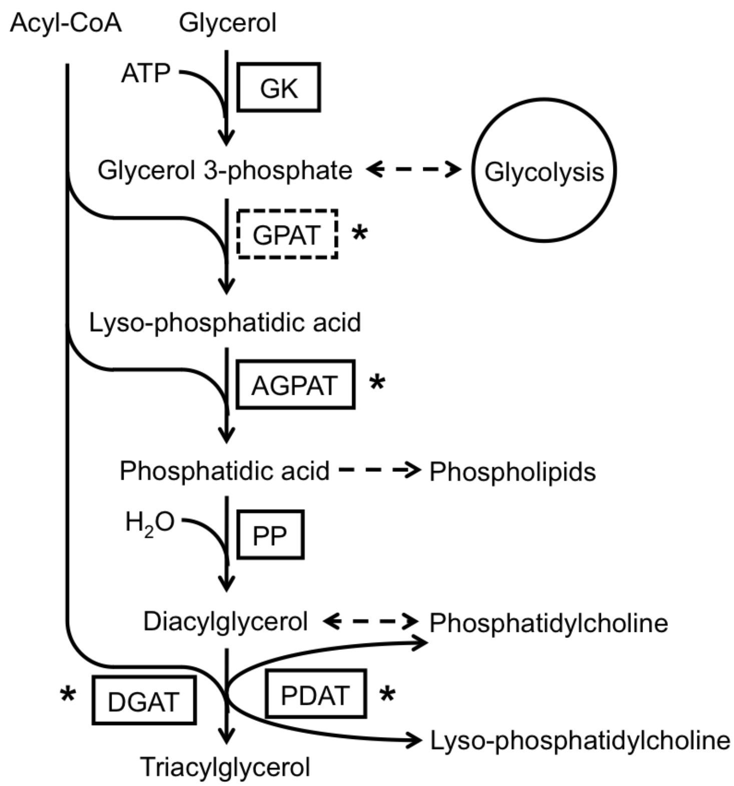

Figure 1. Triacylglycerol (TAG) biosynthesis pathway reconstructed based on the *de novo* assembly and annotation of *D. tertiolecta* transcriptome. Identified and unidentified enzymes are shown in solid and dashed boxes, respectively, and include: GK, glycerol kinase (EC: 2.7.1.30); GPAT, glycerol-3-phosphate O-acyltransferase (EC: 2.3.1.15); AGPAT, 1-acyl-sn-glycerol-3-phosphate O-acyltransferase (EC:2.3.1.51); PP, phosphatidate phosphatase (EC: 3.1.3.4); DGAT, diacylglycerol O-acyltransferase (EC: 2.3.1.20); and PDAT, phopholipid:diacyglycerol acyltransferase (EC 2.3.1.158). Key enzymes are shown with an asterisk next to the boxes, and dashed arrows denote reaction(s) for which the enzymes are not shown for simplicity.

The construction of metabolic pathways involved in the biosynthesis and catabolism of fatty acids, triacylglycerols, and starch in *D. tertiolecta* as well as the full assembled transcriptome provide a foundation for the molecular genetics and functional genomics required to direct metabolic engineering efforts that seek to enhance the quantity and character of microalgae-based biofuel feedstock.

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CORRELATING BIOMASS RESOURCES WITH THE "BEST" CHOICE IN ENERGY PRODUCT FOR LOCAL NEEDS

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Federal energy policy strongly supports the use of biomass to make liquid fuels for transportation use. Although biofuels can effectively reduce the consumption of fossil fuels and have other benefits, the benefits associated with ethanol as a transportation fuel source have been widely criticized. Unfortunately, the use of the same biomass resources for other consumer energy needs is rarely introduced into the policy discussions. The policies push all biomass towards liquid fuels, while biotechnology developers are eyeing the same resources for wood chips for combined heat and power or wood pellets for residential and small institutional heating. Effective ways to evaluate these choices have not yet been developed and used to address the question – What is the best use of a region's biomass resources to meet local energy needs? Energy consumption in Northern New York highlights the need for such an evaluation. Residential heating in the state consumes 33% of the state's natural gas and 12% of the state's petroleum consumption. On average, 2½ times more energy is consumed for space heating than water heating. Thus, residential heating exists as a sector that could benefit from the use of renewable heating fuels to displace fossil fuels.

The objective of this study was to quantitatively compare the value of utilizing Northern New York biomass for residential wood pellet heating use versus cellulosic ethanol options. Three biomass resources were considered: coppiced willow crops, grasses and logging residues. A life-cycle methodology was used to provide a holistic approach to evaluate energy and environmental impacts throughout the biomass growth, collection, conversion, and use aspects of the system. New process models were developed for wood pellet production and combustion in residential pellet stoves. Other components of the LCA inventory were derived from the GREET transportation fuels model developed at Argonne National Laboratory. Sustainability metrics examined include life cycle fossil fuel consumption, petroleum consumption, greenhouse gas emissions, particulate matter emissions and respiratory health impacts.

In general, all types of biomass used for either solid or liquid fuel that were considered in this work effectively reduce fossil fuel consumption and greenhouse gas emissions compared to our current energy sources, although they have the potential to have greater impacts on human health. Differences between how the biomass is used (pellets versus E85) were greater than among the three different feedstocks considered here. For example, results show that employing willow as a residential heating fuel displaces 1.4 times the quantity of fossil fuels compared to cellulosic ethanol solutions, but 1.9 times less petroleum is displaced. Additionally, biomass heating emits less greenhouse gases and fulfills more per capita energy demand than if that same biomass was converted to cellulosic ethanol.

The results of this analysis identify several trade offs that must be weighed in determining appropriate uses of biomass from the perspective of environmental impacts. Utilizing solid or liquid biofuels reduces greenhouse gas emissions relative to conventional fuels, but at the expense of higher quantities of emitted particulate matter. Heating options can reduce greenhouse gas emissions more than cellulosic E85 solutions, but with conventional pellet stoves, particulate matter emissions are higher. This tradeoff must be considered as renewable fuel use becomes more prominent, and decision and policy makers are faced with determining which biomass should be used and how to most appropriately use it.

ANALYSIS OF DIURNAL VARIATIONS IN ENERGY FOOTPRINT AND ITS CARBON EQUIVALENT FOR UNIT OPERATIONS IN WATER REUSE

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Water reuse is becoming a more accepted contribution to water supply portfolios worldwide (Asano et al, 2007). Impacts of current and projected population growth in arid and semi-arid regions (United Nations, 2003), potential regional water shortage (USGS, 1984; Adams, 1998), global water shortage (WHO, 2000), and water scarcity (Falkenmark and Widstrand, 1992; Postel, 2000) make water reuse an imperative alternative to current water resources like surface water or groundwater. Hence, cost-effective, energy-efficient, and reliable water reclamation technologies are vital to the successful implementation of water reuse projects.
Since the applied technologies in water reuse are typically energy intensive, any energy efficiency improvement during operations provides an opportunity for energy and carbon footprint minimization on a large scale. Also, since each energy source has its own carbon-equivalent (i.e., kg_{CO2}/kWh), and within the day the power companies vary their portfolio of employed power sources (SCE, 2010), the carbon-equivalent for power generation is time-dependent (Fig. 1). This, in turn makes the carbon-equivalent of the process energy-footprint a dynamic function. The ultimate goal of this study is to understand the effects of daily variations of hydraulic load, temperature, and specific carbon-equivalent for power generation on process efficiency, by using a dynamic predictive model for the energy footprint in a water reuse system.

The considered processes in this study inclusive of: activated sludge, microfiltration, reverse osmosis, advanced oxidation with UV/ H_2O_2. The energy equation (Eq. 1) is to be minimized to decrease energy footprint:

$$E(t) = E\left[Q(t), T_w(t), \kappa(t)\right] = \kappa(t) \cdot \sum_{j=ASP,MF,RO,AOP} E\left[Q(t), T_w(t)\right]_j \qquad (1)$$

where, $E(t)$ = energy footprint, kWh/m^3

$Q(t)$ = influent flow, m^3/min

$T_w(t)$ = water temperature, ^oC

$\kappa(t)$ = carbon-equivalent emission for power generation, kg_{CO2}/kWh

As an example, in Fig. 2 we show the AOP contribution to energy footprint normalized per unit flow treated and the carbon footprint of the AOP energy (as CO_{2eq}). This figure shows that the carbon footprint varies when the employed energy sources for energy production change in a diurnal period. This is due to the type of source employed by power plants to provide power during peak hours. Thus, carbon footprint is much higher during peak periods in comparison to the nighttime. Therefore, even though the consumed energy could be the same during different diurnal periods, carbon footprint could vary significantly. This suggests that flow equalization, when possible, would be a solution to mitigate carbon-equivalent emission, while leaving the energy-footprint and process throughput unaltered.

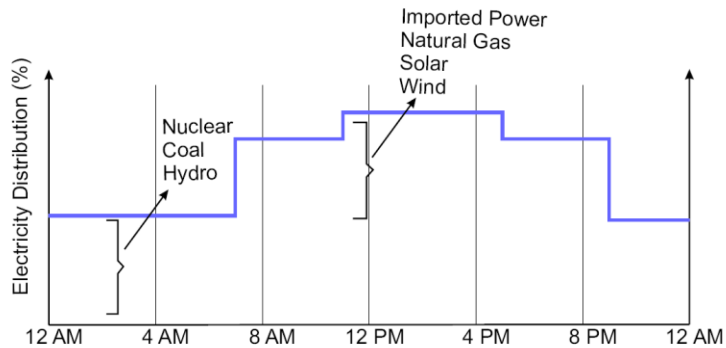

Figure 1. An estimation of diurnal power distribution and related power sources. The results are provided based on the data provided by the State of California power generation resources (CEC, 2010).

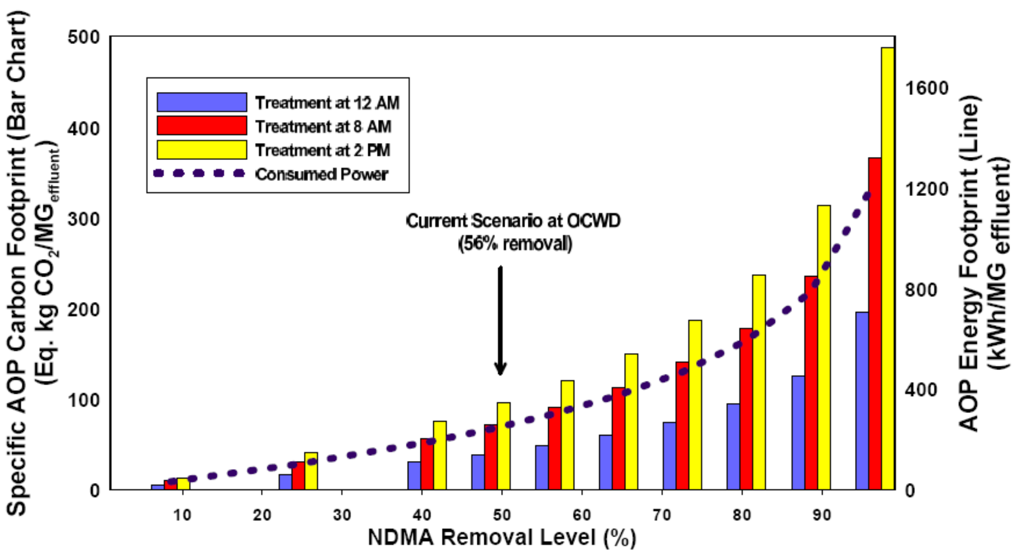

Figure 2. AOP energy requirements for increasing NDMA removal with constant E_{EO} and hydraulic load and the correspondent carbon footprint in different diurnal periods.

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MICROBIAL ELECTROCHEMICAL CELLS AND THEIR BIOENERGY APPLICATIONS IN THE LABORATORY AND FOR THE WASTEWATER INDUSTRY

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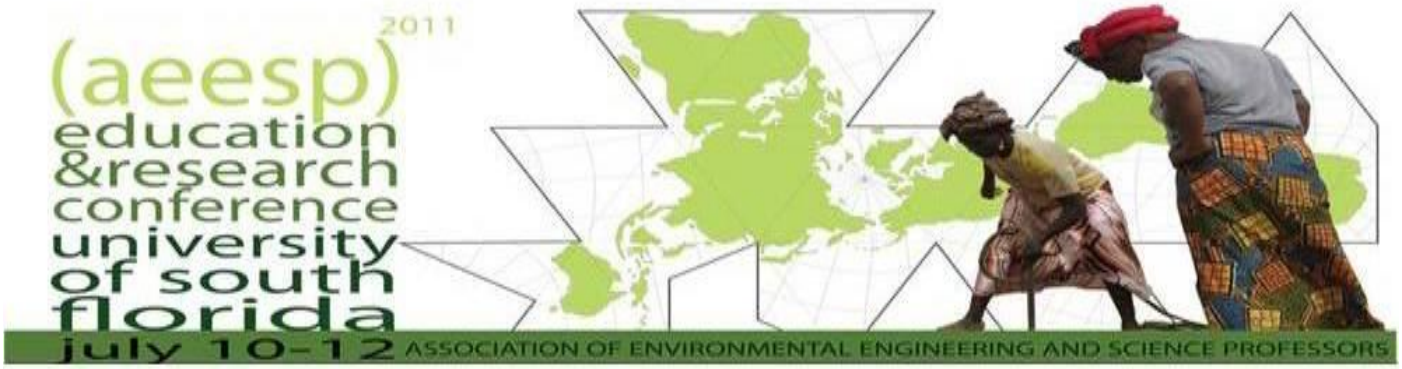
The concept of microbial electrochemical cells (MXCs) holds great promise for renewable energy production from wastes. Inside an MXC, anode respiring bacteria (ARB) catalyze the direct conversion of organic matter into electrical current. Electrical current has been successfully produced in MXCs from a variety of organic wastes which include wastewater, wastewater sludge, animal and agricultural wastes, sugars and alcohols, among others. The electrical current produced can be used to generate electrical power, fuels such as hydrogen (H_2), or high-value chemicals of interest to the water and wastewater industry (i.e. caustic, hydrogen peroxide).

In order to maximize the benefits of MXCs, we must select for ARB that minimize anode potential losses. By using lower anode potentials, we selectively grew ARB, enriched from wastewater sludge of the Mesa Northwest Water Reclamation Plant (Mesa, AZ), that are capable of producing high current densities at low anode potentials. We used these enriched ARB community to study their kinetics and thermodynamics and maximize electrical current production. In order to optimize the biofilm anode, we must understand the transport processes occurring inside the biofilm: substrate diffusion, proton and ion diffusion, and electron transport to the anode. Moreover, we must understand how the MXC design affects these processes and limit ARB activity at the biofilm anode. Our group has combined modeling and experimental work to study the rates of electrical current production by our ARB community. The development of these kinetic models has lead to better MXC designs and has opened new research areas in the field of microbial kinetics.

One of the new research areas that we are developing is related to the study of microbial kinetics through ARB. Our previous research on ARB kinetics has revealed that ARB can carry out extracellular electron transfer (EET) with minimal potential losses. Thus, their electrical energy production is directly measuring the metabolic rate of ARB. These electrochemical measurements, in which ARB kinetics are directly coupled to the anode, open-up new research opportunities for understanding the kinetics of metabolic processes occurring in microbial cells and biofilms. The continuous monitoring of the current generated by ARB also allows us to track respiration rates in real time at ranges below 1 millisecond. Thanks to these electrochemical measurements, we are now able to study the kinetics of microbial processes in a simpler manner and even perform studies that were not possible before.

An example of such kinetic studies measures the kinetic response of ARB to an instantaneous increase in substrate concentration after a starvation period. The MXC is first depleted of electron donor, leading to starvation and a decrease in current production by ARB. Then, a spike in substrate (H_2, acetate, ethanol, butyrate, among others) allows us to determine the microbial response to substrate availability. ARB response times to these substrate spikes occur within < 5 seconds, demonstrating our capability to measure microbial kinetics with high temporal resolution. However, not all substrates have a quick response; this approach has allowed us to characterize mixed microbial communities and determine whether a substrate is directly consumed by ARB, or if a fermentative step is occurring upstream of current generation. These experiments not only show the versatility of measuring ARB kinetics, but also demonstrate the potential to use electrochemical measurements to probe microbial and biofilm kinetics, thus expanding our knowledge of microbial kinetics related to bioenergy applications.



*Research Category #7: **Integration of Sustainability into Practice***

Research Category # 7

INTEGRATION OF SUSTAINABILITY INTO PRACTICE

A SUSTAINABLE HOUSING PROGRAM IN SOUTH AFRICA DEMONSTRATES THE INTEGRATION OF SUSTAINABILITY INTO PRACTICE

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Sustainability discussions have been more centered more around improving civil society in developing countries. Sustainability issues, however, are global and applicable worldwide. The elements of sustainability are varied. Sustainability work done by PEER over the last 15 years in South Africa has highlighted the following as the most important elements in these discussions in the developing world: energy, environment, economic development, housing, social stability, capacity building, and governance. Sustainability in the built environment will not occur if one of these is not considered and built into the planning and implementation equation.

Decent, safe, sanitary and affordable, energy efficient housing should be the mantra for all sustainable development professionals regardless of their specialty – architects, engineers, developers, policy specialists, and environmental managers. The house is really the basis for sustainable economic development in developing countries, as has already been proven in the US. Houses if built properly can sustain life, provide a livelihood, promote economic development, and capacity building. From the perspective of PEER Africa, while a house does all of this, we also look at the house as an appliance. It is a tool that is used to accomplish a specific objective. For the purposes of this paper, the house is used to promote sustainable economic development. It is the epitome of integrating sustainability into the practice of engineering.

This paper discusses the utilization and application of affordable energy efficient technologies and philosophies, and the utilization of environmental best management practices to control municipal household wastes, community trash, and stormwater runoff in the transformation of shanty towns to sustainable, affordable, energy efficient and environmentally responsive communities. Over 5,000 energy efficient, formal homes have replaced shacks in about 8 townships in South Africa. These passive-solar designed homes have demonstrated an average reduced energy costs in the homes by 70%. This energy efficient housing program has stimulated an awareness in the improvement of the environment through more responsive environmental management in the communities, implementation of affordable, appropriate technologies for lighting and cooking which have led to a healthier indoor air environment, and utilization of green infrastructure technologies for control of storm water leading to lowered use of potable water for gardening and more productive gardens and cleaner streams due to lowered content of pollutants and trash entering the waterways.

This program is an original research, demonstration and development project. It was started and initially funded by PEER 15 years ago, and continues to be implemented by PEER and its South Africa collaborators and many Township Associates. Since 2002, this program has been embraced by communities and local governments throughout South Africa, and the national government has rewritten its housing codes, rules and regulations to insure that more reliance is placed on the utilization of sustainability practices in projects utilizing government funds. This program has received commendation from the United Nations Framework on Climate Change being a best practice paradigm in affordable, energy efficient housing in the world. In 2009, the Witsand Project, a Greenfield of 2,200 homes, won the coveted Eskom eta award. The award recognizes companies and individuals who have designed innovative ways to promote efficient use of energy, and to improve business competitiveness.

APPROPRIATE MANAGEMENT OF WASTEWATER AND STORMWATER FROM A RUBBER PROCESSING FACILITY IN LIBERIA

Nicholas Albergo, P.E., DEE
President & CEO of HSA Engineers & Scientists

In 1987, a report by the United Nations World Commission on Environment and Development (also known as the Brundtland Commission) described the concept of "sustainability." The term has no legal definition; rather it has been simply defined "*to meet the needs of the present without compromising the ability of future generations to meet their own needs.*" Unsustainable activities such as uncontrolled waste disposal and environmental degradation are replaced through global actions such as agreement on goals, appropriate incentives and controls, and effective institutions to support sustainable activities such as improved use of technology and resource management, adequate minimum living standards, and the protection and long-term restoration of the environment. **Global sustainability** requires the integration of three principles: (1) economic growth; (2) environmental protection; and (3) social equity, wherein all citizens share equally in the benefits of natural resources.

Whereas the primary role of science is to help us understand the world that we live in, the role of the engineer in sustainability is more fundamental, as it is he/she who solves problems within the constraints applied by time, money and available knowledge.

The nation of Liberia, located in West Africa, is richly endowed with natural resources. Unfortunately, uncontrolled exploitation of these resources has failed to improve the lives of most Liberians, to the point that the natural environment is nearing the point of collapse. **HSA Engineers & Scientists** was hired by the Firestone Natural Rubber Company to create conditions, in connection with their latex and rubber processing facility, for the adoption of a long-term approach to sustainable development. In this regard, HSA was required to develop practical applications of available science and technology, combined with experience and then adapt those approaches through innovation in a country without a reliable energy source, availability of modern equipment or tools, and a largely uneducated labor force.

Rubber production is the second single largest economic activity in Liberia. Foreign concessions account for nearly 600,000 hectares of land usable for rubber production, while Liberians own less than 40 hectares. Rubber is one of the main exports in Liberia, with production estimated at 99,569 metric tons in 2002. Firestone represents the largest employer in Liberia, where unemployment is at its highest 85% of the labor force.

Public sanitation services (*i.e.,* public toilets and garbage collection) are absent in most parts of the country. Only about 11% of households have access to flushing toilets; 25% use latrines, most of which were constructed by aid agencies. The remaining 64% of households dispose of their human excrement in bushes, streams, rivers, ponds, beaches or a hole in the ground. About 26% of households dispose of their solid waste in public rubbish heaps; 34.6% in private rubbish heaps; and about one in every three households dispose their waste by throwing it in bushes and streets. Although supplies of water in Liberia seem to be abundant, it is actually a scarce resource as water bodies have been used as dumpsites. Open toilets are built along river banks, polluting it for those living downstream.

Integration of Sustainability into Practice

As part of its contribution to global sustainability, Firestone hired HSA to design and construct a wastewater and storm water treatment system to treat effluent and runoff discharges at their rubber processing plant. With limited access to consistent power, antiquated tools, and an inexperienced local population of workers, HSA designed and constructed a wastewater facility to treat rubber and latex process effluent from the facility, in lieu of the historic disposal (since 1926) of all wastewater and surface water runoff to the neighboring river shared by many small fishing villages.

The effluent was collected via gravity through a series of trenches and collection sumps, and then transferred to the head of the treatment system which was designed and constructed for a flow of up to 3.5 MGD and to reduce BOD/COD concentrations from up to 3,500 mg/L to below 50 mg/L, with a 98 percent removal efficiency.

The process water treatment system included flow equalization, activated sludge, clarification and used the ecological ("Green") solution of a natural wetland for removing residual sediments and pollutants, such as nitrogenous compounds, from the water prior to final discharge. Throughout the process, waste was minimized; the by-products from the latex/rubber processing were recovered resources (as fertilizer), and much of the wastewater could be recycled for use.

The impact of HSA's design and activities has served to minimize waste, assist in environmental management and restoration of the adjoining river, and better overall resource management. The local population was trained and now operates the facility full-time.

HSA Engineers & Scientists is a 300-person environmental and geotechnical engineering firm with its corporate headquarters located in Tampa, Florida. HSA was founded by two principals, both receiving their undergraduate and graduate engineering degrees from the University of South Florida.

SUSTAINABLY DIMINISHING MATERIALS USE, AIR POLLUTION, ENERGY, AND COSTS IN FOUNDRIES

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For 15 years, our Penn State team has been committed to increasing foundry efficiency by introducing novel technologies that transform wastes and pollutants into resources and value. Much of this work has proceeded through NSF, DOE, EPA, and USDA grants. We have come to realize that we can make a huge transformative impact on the whole foundry industry by (a) devising bindered anthracite bricks as a replacement for coke, (b) using low-emission biomaterial binders in lieu of phenolic urethane binders for making cores, (c) using advanced oxidation-ultrasonic-cavitation to reclaim the sand, clay, and coal in waste green sand; and we are now avidly pursuing multiple avenues to advance the numerous facets of these innovative opportunities. The components of these that we have moved to proven technologies have been installed in some of America's largest foundries that together have the capacity to melt 1/10 of America's cast iron. A comprehensive paradigm shift of this magnitude involves interlocking facets that borrow from many fundamental disciplines and occupations. Cannon, Voigt, and Furness have been the cornerstone of the Penn State Foundry team for fifteen years. Komarneni and Brown have joined this team in the last 4-9 years to bring expertise in inorganic and biomaterials, respectively. The team has worked to increase foundry efficiency by introducing novel technologies that transform wastes and pollutants into resources and value. With nearly $5 million of NSF, EPA, DOE, state, and industry grants, the team has made technical advancements which have saved collaborating foundries more than $30 million. If all of the innovations that we have collectively devised and researched were to be included in a single cupola iron foundry, the enhancements would cut 7% of the foundry's overall costs, 15-35% of its life cycle energy, 15-35% of its life cycle greenhouse gas foot print, and 80% of its VOC pollution. Collectively, our team has directly worked with 13 of the largest US foundries, in 11 states.

In some of our more recent research, we have appraised using hybrid binders for both foundry cores and anthracite bricks. These two developments pertain to sustainability in that most of the materials used in the bindered anthracite bricks and core binders are otherwise wasted. The collagen comes from animal hides and tendons, and there is not much other use for it than in lip stick (a limited market). The lignin is merely burned in pulp and paper mills; and the very fine anthracite grains have little market, and are sometimes discarded into silt ponds.

The bricks could replace some of the coke in foundry cupolas; and this is important, because there are only two coke manufacturers left in America that make foundry grade coke. To make coke, one pyrolyzes bituminous coal at 950^{o}C for 1 ½ days, and this inherently consumes 15-20% of the raw coal energy while also releasing that amount of green house gases. At ambient temperature, when testing anthracite briquettes in our lab, the collagen plus cross linking additive binders created a product that withstood drop-shatter abrasion (95% retained) better than did conventional coke (85% retained). Tests also appraised when anthracite fines plus silicon metal were bindered with collagen, then heated under N_2 gas to 1100-1400^{o}C, then cooled. The product contained silicon carbide nanowires, which gave these thermally-stressed briquettes an unconfined compressive strength of 550 psi (3600 kPa). This strength exceeded that of coke (300-400 psi). The silicon carbide nanowires formed in less than 7 minutes; as seen in real-time / real-temperature x-ray analyzes. Slight evidences of SiC formation was observed even when the binder included

5% rice hull silica ash and 5% silicon metal. The collagen-silicon-anthracite briquettes initially burned faster than did coke, when placed in a 900^{o}C oven with air; and these bricks offered the same fuel content as coke.

In more recent lab trials, our Penn State team has observed that when 5-10% lignin is included in the bindered briquettes, unconfined compressive strengths of 700-1000 psi have been reached after 900^{o}C pyrolysis for 30 minutes. Following this 900^{o}C pyrolysis, higher strength occurred with no silicon metal included than when 5-10% silicon metal was included. In comparision, following 1400^{o}C pyrolysis, including both 10% silicon with the 10% lignin yielded 320 psi strength, whereas 10% lignin with no silicon yielded 110 psi strength. These very favorable results were achieved with either hardwood lignin (mostly eucalyptus) that had been extracted from Kraft black liquor by Innventia AB via the Lignoboost™ process, or hardwood lignin (mainly oak) from the Appleton integrated paper mill (Altoona, PA). The Penn State team precipitated this oak lignin from the mill's black liquor via H_2SO_4 acidification. Also, briquettes made from anthracite, collagen, and hardwood lignin gave the same fuel content as coke. For the NSF work herein, we will aim to balance the proportions of lignin, collagen, and Si that offer unconfined compressive strengths that equal coke's throughout the array of thermal regimes in a cupola.

The Penn State team, in collaboration with Furness-Newburge, has also conducted two full-scale demonstrations of the collagen-silicon-anthracite bricks (but with no lignin yet at that time). These were demonstrated at Ward Foundry (Blossburg, PA). In the first of these trials, we prepared 500 pounds of 4" diameter x 3" high bricks; and these replaced 10% of the conventional coke and silicon that was charged into Ward's production cupola for an hour. The replacement fuel achieved the same high quality gray iron product, which was sold, with no change in the composition of Fe-Si-C or other metals; and the product remained within spec for Burnell hardness, etc. During this charging, the cupola upper stack temperature rose by 30-100^{o}C. We observed no bricks that broke apart during the rough cupola charging process, where the bricks and chunks of scrap iron were dropped 8-feet onto each other. We were also able to look into the cupola melt zone through the tuyere windows. In this zone, we observed 10 of the red-hot solid pieces that exhibited the distinct man-made 4" circular shapes of the anthracite bricks, even while molten iron cascaded down onto them. These trial results offered promise that the bindered anthracite bricks could hold their own in the very rough handling and thermally challenging cupola environment.

We also conducted a second demonstration for 4 hours at Ward with collagen-silicon-anthracite bricks (but with no lignin yet included). Unfortunately, during 3 months storage before this, mold had grown on these bricks; and they did not hold their strength in the trial. None-the-less, under these adverse conditions, the product gray iron remained within the high quality composition and Burnell hardness specifications. Also, the bag house dust collectors exhibited no more volume of dust collected during this 4 hours than at other times, indicating that the anthracite grains did not escape to the bag house. When we add lignin into these bricks (as proposed herein), we anticipate far less biogrowth (see below). We learned from this trial that we must continue to conduct fundamental research and practical development for this bricking to be always reliable; and that is what this GOALI project herein is all about.

The Penn State team has also been developing a line of collagen-silicate binders for foundry cores that release 80% less pollution than do conventional phenolic urethane core binders. As much as half to two thirds of the VOC air pollution from foundries originates from these core binders when phenolic urethane is used. These collagen-silicate bindered sand cores create the iron's hollow shapes when molten iron is poured into green sand molds. Our Penn State team has devised binders of collagen, alkali silicates, and other additives that held up against molten iron erosion as well as phenolic urethane binders did, when molten iron was poured onto them in Penn State's pilot foundry. Yet they also later exhibited the same favorable shake-out propensity as did the phenolic urethane (as measured by post-thermal hardness). Our Penn State team aims to soon demonstrate these core binders in full-scale trials in a foundry.

APPLICATION OF MOLECULAR TOOLS TO ENGINEERING PRACTICE TO INCREASE PROCESS SUSTAINABILITY IN WATER RECLAMATION

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Aerobic biological treatment is one of the most energy-intensive options for COD and nutrients removal in water reclamation (Rosso and Stenstrom, 2005). For the past 50 years, to optimize aeration many studies have focused on oxygen transfer efficiency (OTE, %) (e.g., Eckenfelder and Ford, 1968) and oxygen uptake rate (OUR; e.g., Mueller and Stensel, 1990). A better understanding of aeration parameters provides an excellent basis for sustainable practice. Volatile solids or substrate removal are key components in the traditional calculations of oxygen transfer rate (OTR, $kg_{O2}\ h^{-1}$) and oxygen uptake rate (OUR, $mg_{O2}\ l^{-1}\ h^{-1}$). Activated sludge flocs are composed mainly of biomass (i.e., active and inactive microorganisms, debris, extracellular polymers, and particulate substrate) but also contain abiotic compounds. Due to all the components in addition to active microorganisms, calculations using solid-based metrics (such as mixed-liquor volatile suspended solids, MLVSS, or its apportioned fractions) may lead to inaccuracy and uncertainty during calculation of microbial oxygen requirements. The objective of our study is to compare OTR and OUR calculated using biomass values generated from the molecular analysis (qPCR) of the bacteria involved in COD and nitrogen oxidation with modeled data calculated using both MLVSS- and stiochiometric- based formulas (Metcalf and Eddy, 2003; Leu et al., 2009). We also compare our qPCR-based OUR results with concurrent off-gas measurements in the same water reclamation plant.

We sampled weekly for 1 year, a local water reclamation plant operating full NDN (average sludge age = 8 d; Q = 16 MGD). Total OUR can be divided as: $OUR_{TOT} = OUR_{Heterotrophs} + OUR_{AOB} + OUR_{NOB}$ (highlighted in Fig. 1). In Fig. 1, the gray shaded area represents the difference between the total oxygen transferred and the fractions of OUR we accounted for. Therefore, the gray area includes oxygen used by other microbial species (e.g., protozoa) and oxygen wasted through excessive aeration. Further investigation of the biomass using qPCR indicated heterotrophic bacteria, AOB, and NOB occupied an average of 96.2%, 3.2%, and 0.6% of the total bacteria population, respectively. The oxygen transfer calculations indicated that total oxygen transferred was in excess by a mean of 46.9%. Heterotrophic bacteria contributed the greatest demand for oxygen with an average 50.2 $mg_{O2}\ l^{-1}\ h^{-1}$, while the oxygen demand of NOB was minor. By calculating the OUR components for AOB and NOB using qPCR-based measurements, we plot in Fig. 1 only a minor contribution to the overall OUR while the process studied oxidized all the incoming ammonia ($NH^{+}_{4,in}$~ 30 mg/l; $NH^{+}_{4,out}$<0.1 mg/l). This discrepancy is an interesting point of discussion, as it could include ammonia assimilation by microorganisms, a factor largely neglected in most calculations. Three sampling dates were subjected to off-gas measurements to validate the OUR calculations. OUR calculations using specific biomass were an average of 92.7% (SD = 13.0%) of the off-gas analysis method. Although the off-gas dataset was restricted, these results demonstrate preliminary agreement between the two methods. In sum, our qPCR-based OUR calculations agree with the OUR directly measured via off-gas testing, although the apportioned OUR fractions appear discrepant from the traditional stoichiometry-based breakdown of oxygen requirements.

Our results demonstrate the capacity of biomass characterization using molecular analysis to accurately partition the total OUR. The time required to obtain qPCR results is less than 8 hrs, another improvement over the duration of traditional VSS measurements. Earlier work by Leu et al. (2009) determined the relationship between OTE and OUR to optimize aeration and minimize power usage by coupling Monod's kinetic model with equations for oxidation of carbonaceous substrate and ammonia. Our study expands on the concept to include dynamic fractions of the bacteria responsible for treatment and clearly indicates the potential energy cost savings associated with fine tuning aeration control according to the biomass requirements.

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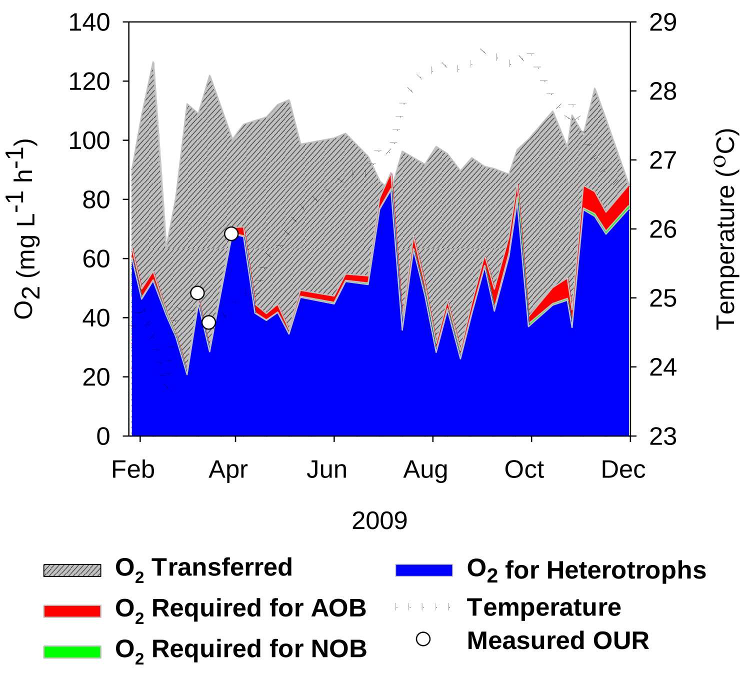

Figure 1. Oxygen requirements calculated from biomass measured with molecular genetics tools and kinetic parameters (using the same equations as in Leu et al 2009). The white points show the concordance of this model with direct off-gas measurements.

INTEGRATION OF THEORY AND PRACTICE IN WASTEWATER ENGINEERING: BENEFITS IN ENERGY SAVING, EFFLUENT QUALITY, AND PROCESS STABILITY

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The activated sludge process (ASP) is the most common method of secondary municipal wastewater treatment, and the solids retention time (SRT) is the key control parameter (Rosso et al, 2005). Normally operating at long SRT is considered only for nitrification, but there are additional benefits of high SRT operation (Soliman et al, 2006). In the past, treatment plant managers have resisted the increase in treatment level to provide nitrification, due to the commonly held belief that energy costs and capital expansion required are not economically justified (Rosso and Stenstrom, 2007).

This paper presents experimental evidence from aeration and power measurements from three treatment plants that show that: the continuous monitoring of aeration efficiency through off-gas can be used to quantify and minimize aeration energy wastage (Fig. 1); and the variation in power cost when comparing conventional with nitrifying-denitrifying processes is moderate (Fig. 2). The potential increase in aeration cost when compared to low SRT operation is partially offset by increased oxygen transfer efficiency, decreased diffuser fouling rates, denitrification credit, and reduction in biosolids processing cost.

The paper also discusses the two major additional benefits of long SRT operation: increased oxygen transfer efficiency; improved biomass particle size distribution, which results in more efficient clarification with fewer effluent particles and suspended solids; and enhanced removal of many emerging contaminants such as pharmaceuticals, personal care products, and endocrine disrupting compounds. The paper presents experiment results from 26 other treatment plants showing the benefits of longer SRT operation on effluent quality of treatment plants through larger biosolids particle size. The emerging evidence from the literature documenting improved removal of trace contaminants is also reviewed, with observations from three treatment plants in southern California.

A long-term survey of three treatment plants concludes that operating at higher SRT is not as energy- and cost- intensive as conventionally assumed, and has additional benefits. This work shows how a collection of observations from different research areas combined with plant observations can result in a new paradigm for treatment plant operation.

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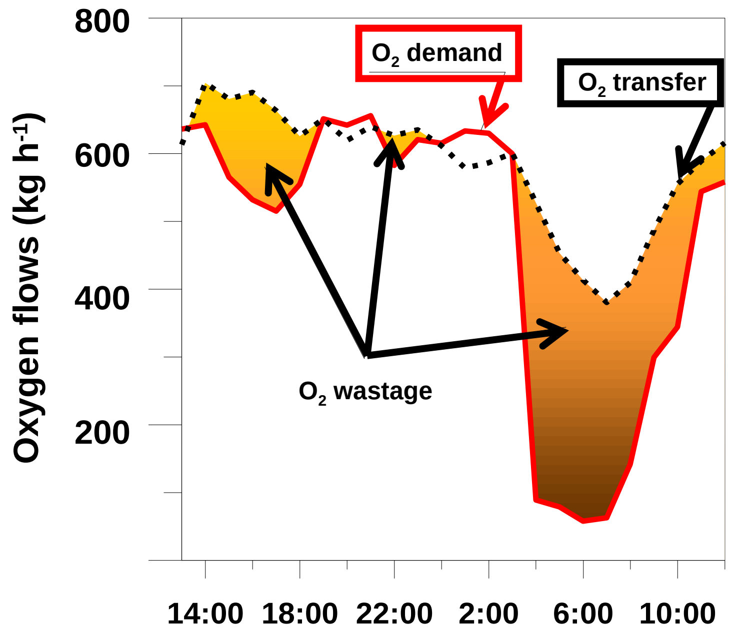


Figure 1. Oxygen flows over a 24hr period for a water reclamation plant operating full nitrification and denitrification in Southern California. The shaded area is the difference between oxygen demand (calculated from the process load) and the oxygen transferred (measured directly with the off-gas technique). The minimization of the shaded area results in more sustainable process operations.

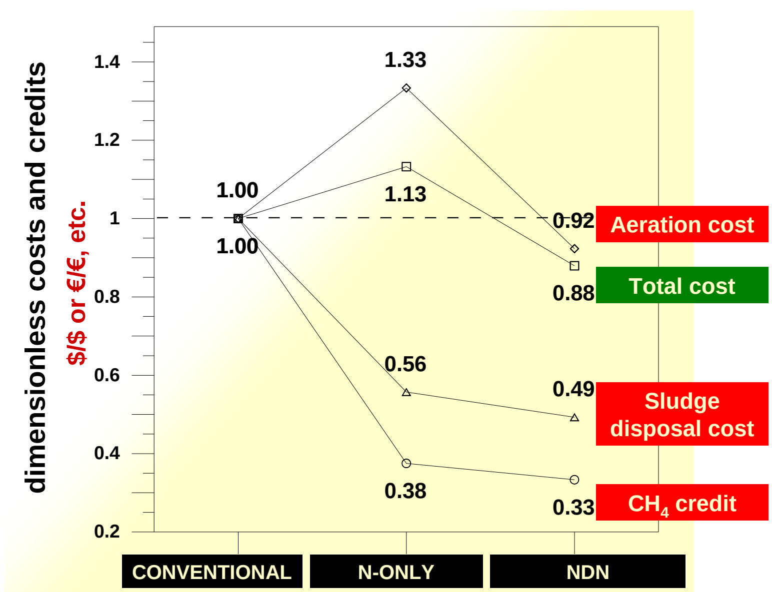


Figure 2. Results of a comparative cost analysis between typical conventional, nitrifying-only, and nitrifying-denitrifying plants in Southern California. Costs are normalized against the conventional process scenario, thereby canceling time-dependent effects such as inflation.

INCORPORATING SUSTAINABILITY INTO ALTERNATIVE WATER SUPPLY AND SEAWATER DESALINATION PLANNING

Scott C. Shannon, Christopher P. Hill, Douglas M. Owen
Malcolm Pirnie, the Water Division of ARCADIS-US, Inc.

Centered in Flagler County, the Coquina Coast gets its name from the unique geological features of the northeastern coast of Florida (USA). The Coquina Coast Project Partnership currently includes four municipal and county water agencies. In an effort to meet increasing water demands and address limitations in future groundwater usage, the Partners, together with the local water management authority (the St. Johns River Water Management District), are evaluating seawater desalination as a potential future source of drinking water.

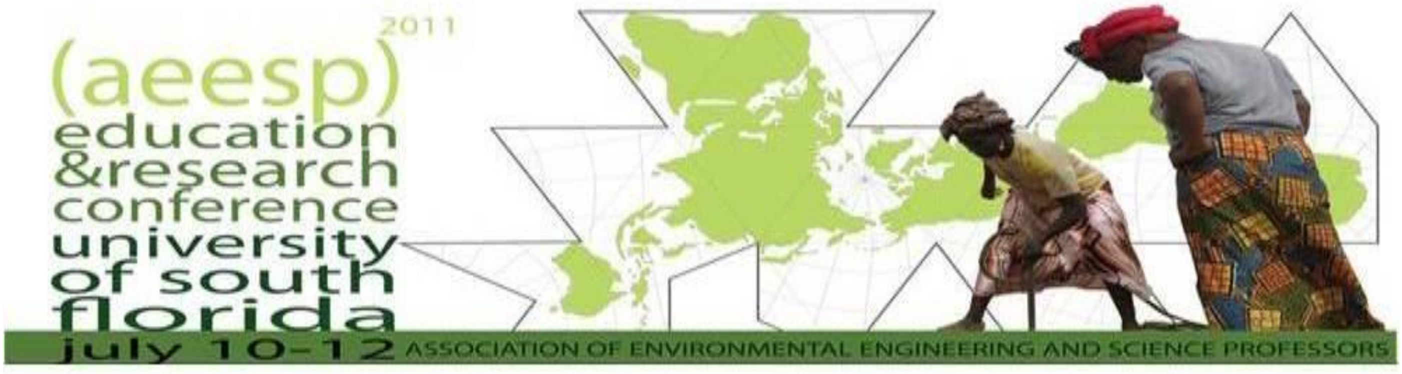
The Coquina Coast Seawater Desalination Project includes several unique features, including the incorporation of sustainability into the planning process, evaluation of vessel-based desalination (VBD), considerations affecting seawater intake alternatives, and planning for a large regional transmission system. The Project is still in conceptual engineering and planning stages, and as such there is still much to be defined with regard to the final project, including its location and capacity. When completed, however, the project is anticipated to provide between 20 and 50 million gallons per day of drinking water

Determination of the most appropriate seawater desalination alternative (land-based or vessel-based facilities) for the region began with a Sustainability Workshop, wherein Partners and members of the public identified their goals and objectives for this project. Those objectives were used to develop project evaluation criteria which then were used to evaluate every project alternative considered, including the determination of whether the land-based or vessel-based desalination provided the most sustainable water supply solution for the region.

This paper will discuss in detail the need for additional, sustainable water supplies that lead to the Partners' decision to pursue seawater desalination. It will provide great detail regarding the Partners' incorporation of the concept of "sustainability" into the planning process and how sustainability shaped not only the evaluation of land-based and vessel-based desalination, but also how sustainability principles will continue to shape the project as it moves forward to design, construction, and operation.

Abstracts – Poster Session

At the USF Interdisciplinary Research Building Galleria - IDR



Research Category #1: ***Advances that Deal with Water Depletion and Degradation***

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Research Category # 1

ADVANCES THAT DEAL WITH WATER DEPLETION AND DEGRADATION

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PROCESS CONTROLS FOR A PERCHLORATE REDUCING FLOW THROUGH BIOREACTOR IN PRESENCE OF ZERO-VALENT IRON

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Perchlorate, a byproduct of munitions, has been found to contaminate groundwater across the nation at toxic levels. The EPA announced in February it plans to regulate perchlorate in the coming years. An efficient technology must be developed in order to treat contaminated waters below regulated levels. Process control parameters of a flow-through reactor for microbial perchlorate reduction with zero-valent iron were investigated to optimize the engineered system for perchlorate removal in water. Mixed perchlorate reducers were obtained from aerobic activated sludge process as well as anaerobic digesters and inoculated into the reactor without further acclimation. Examined parameters include hydraulic retention time (HRT), pH, nutrients requirement, and both chemical and microbial kinetics. The optimum HRT for our system was concluded to be 8 hours. When the pH was not controlled to be neutral, perchlorate removal was reduced by 60%. As pH was determined to be an important parameter for microbial perchlorate reduction, a viable alternative of pH buffer was also investigated. Interestingly unlike other systems with lab cultured microorganisms our system needed no additional nutrients to completely reduce 10 mg/L of perchlorate in water, and it is likely due to the plethora of nutrients available within activated sludge based seed cultures. The system follows both chemical and microbial (Monod) kinetics. The chemical reaction follows the first order kinetics, with a rate constant (K) of 0.761 hr^{-1}. The maximum growth rate (μ_{max}) and the half saturation constant (K_s) in the Monod model were determined to be 0.55 hr^{-1} and 15.4 mg/L, respectively.

A METHOD TO CHARACTERIZE THE INACTIVATION RATE OF ATTACHED BACTERIAL PATHOGENs IN MODEL AQUATIC ENVIRONMENTs

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Groundwater contamination by microbial pathogens is recognized as an important water supply problem. Experimental techniques for the evaluation of pathogen transport in model subsurface environments and for assessing the inactivation of suspended bacteria have been reported widely; however, the inactivation of bacteria when attached to sand grain surfaces in groundwater aquifers has not been thoroughly studied. The aim of this study was to develop an experimental technique for evaluating the extent of bacterial inactivation when attached on model sand surfaces under conditions relevant to groundwater environments. The loss of bacterial membrane integrity and respiratory activity of attached bacteria were investigated as a function of time by fluorescence microscopy. Gram negative, non-pathogenic *Escherichia coli* D21 and pathogenic *E. coli* O157:H7 and Gram positive pathogenic *Enterococcus faecalis* 29212 were used as the test organisms. Two different measures of bacterial inactivation used here showed comparable trends in bacterial inactivation confirming the validity of the experimental technique that we developed. The viability of adhered cells decreased with time and the Gram positive organism *E. faecalis* exhibited a lower inactivation rate than the two *E. coli* strains examined.

USE OF ABANDONED MINE DRAINAGE FOR WATER MANAGEMENT IN THE MARCELLUS SHALE GAS PLAY

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The Marcellus Shale gas play located in northeastern US represents a tremendous potential source of natural gas, however, to avoid any adverse environmental impacts careful exploitation is paramount. Shale gas extraction requires the use of hydraulic fracturing, *i.e*. the injection of large amounts of fresh water mixed with chemicals under high pressure to fracture the rocks, increasing well permeability. After pressure release, only 15% of the injected water flows back to the surface. Because it is contaminated with extremely high concentrations of inorganics and organics dissolved from the shale, water treatment is extremely challenging. Fresh water supply and flowback water management are the key issues for the development of this natural gas resource.

Reusing flowback water for hydrofracturing, which is the most sustainable solution, requires removal of major well-scaling cations (Ba, Sr, Ca). Abandoned Mine Drainage (AMD), ubiquitous in the area of the Marcellus Shale, can serve the dual purpose of providing the make-up water for subsequent hydraulic fracturing operations and the source of sulfate for barium and strontium precipitation. The goal of this project is to understand the water chemistry when mixing AMD and flowback water. Precipitation kinetics, composition of the liquid phase at equilibrium, comparison with equilibrium models (*i.e*., ion association, ion interaction and solid solution models) and characteristics of the precipitates are studied for various Pennsylvania flowback waters and AMDs. Barium is effectively removed by precipitation while only a small portion of strontium co-precipitates. Ideal solid solution theory fails in predicting the equilibrium when carbonate precipitation occurs.

REPLICATION EFFICIENCY OF SOIL-BOUND PRIONS VARIES WITH SOIL TYPE

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Prion diseases impact a number of economically important domestic and wild animal species, and include bovine spongiform encephalopathy (BSE or 'mad cow' disease), sheep scrapie and chronic wasting disease (CWD) of deer, elk and moose. CWD is spreading at an alarming rate in the United States. CWD was first identified in mule deer in the 1970s in Colorado that later spread to Wyoming in the 1980s. Since the mid 1990s, CWD has been identified in captive or wild cervids (whitetail deer, mule deer, elk or moose) in Colorado, Illinois, Kansas, Michigan, Missouri, Montana, Nebraska, New Mexico, New York, North Dakota, Oklahoma, South Dakota, Utah, Virginia, West Virginia, Wisconsin and Wyoming. Within captive and wild populations of deer, the incidence of CWD has been reported to be as high as 90% and 30%, respectively. Based on the detection limits of current ante mortem tests, this is certainly an underrepresentation of the incidence of disease. Efforts to control the spread of CWD through selective harvest of wild populations have not been successful. In wild populations, CWD is horizontally transmissible. Experimentally it has been demonstrated that CWD can be transmitted to whitetail deer via environmental exposure to the CWD agent alone. It is not known if the host range of CWD includes humans, however, human exposure to CWD will certainly increase due to the expanding geographical range and incidence of this emerging prion disease.

Prion diseases are unique in that the infectious agent is comprised of PrP^{Sc}, a misfolded isoform of a non-infectious host encoded protein (PrP^{C}). PrP^{Sc} enters the environment through decomposition of infected carcasses and host shedding via blood or saliva, urine, feces, and birthing matter. Once in the environment, it is believed that prions are predominantly associated with soil, and it is known that prions can remain infectious for decades. Prion sorption to soil is thought to play an important role in the transmission of chronic wasting disease (CWD) via the environment. Sorption of prions to soil and soil minerals is influenced by strain and species of PrP^{Sc} and physicochemical soil properties, however, the ability of soil-bound prions to convert PrP^{c} to PrP^{Sc} remains poorly understood. The objectives of this study were to evaluate the infectivity of soil-bound prions and to determine if binding to soil inhibits the ability of prions to replicate.

In this study, brain homogenate obtained from hamsters infected with the hyper strain of transmissible milk encephalopathy (HY TME) were equilibrated with various soils and soil minerals, and then subjected to animal bioassay and protein misfolding cyclic amplification (PMCA) analysis to investigate the infectivity and replication efficiency of soil-bound prions. Soil and soil minerals used include sand, a sandy loam soil, a silty clay loam soil, sodium bentonite clay, silicon dioxide powder, and humic acid-coated silica gel particles (SiO_2-HA). In bioassay experiments, a pellet containing a silty clay loam soil with bound PrP^{Sc} was resuspended in phosphate buffer to 0.1 mg soil/µl. Intracerebral inoculations of male golden Syrian hamsters with soil and brain homogenate samples were conducted as described previously. The incubation period was calculated as the length of time in days between inoculation and the onset of clinical signs that include ataxia and hyperactivity to external stimuli. PMCA is a recently developed method for studying prion replication (i.e. conversion of PrP^{c} to PrP^{Sc}). It has been used to amplify low levels of prions, which makes it beneficial for studying prions in environmental samples. The PMCA method is somewhat analogous to polymerase chain reaction (PCR). It consists of cycles of sonication followed by incubation at 37°C. In this manner very small amounts of PrP^{Sc} can be amplified and detected by normal western blotting.

Intracerebral inoculation of groups of 5 hamsters with either HY TME or soil-bound HY TME resulted in all animals succumbing to disease with an incubation period of 62±3 and 74±3 days respectively. The titers for the unbound and SCL-bound HY TME inoculum were $10^{7.5}$ and $10^{6.2}$ i.c. LD_{50}/25µl, respectively, representing a 1.3-log decrease in HY TME titer upon binding to soil (data not shown). In general, binding of PrP^{Sc} to soil corresponded with a decrease in PMCA replication efficiency (Figure 1). Compared to the unbound HY control, sorption of HY TME to a silty clay loam soil resulted in a 92% reduction in the abundance of amplified PrP^{Sc} (Figure 1). The PMCA efficiency of bound prions varied with soil type, where prions bound to clay and organic surfaces exhibited significantly lower replication efficiencies while prions bound to sand exhibited no apparent difference in replication efficiency compared to unbound controls. PMCA results from hamster (HY TME) and CWD-elk prions yielded similar findings. The exact circumstances of prion entry into the soil environment, including N-terminal truncation of PrP^{Sc}, the time of PrP^{Sc} and soil contact, the biological matrix containing PrP^{Sc} and the soil to PrP^{Sc} ratio and soil type, can influence prion fate. Thus, the overall balance between prion adsorption affinity and replication efficiency for the dominant soil types of an area may be a significant determinant in environmental transmission of CWD.

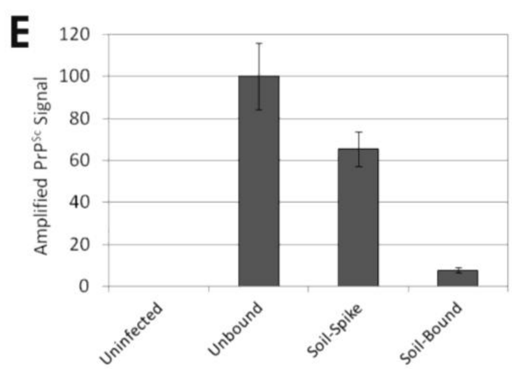

Figure 1. Representative results showing PrP^{Sc} Western Blot signal after PMCA. An unbound HY control co-spiked with soil (soil-spike) was less than the unbound HY control but significantly ($p<0.01$) greater than the silty clay loam soil-bound sample.

CHELATION OF IRON AND NICKEL METAL IONS FROM AQUEOUS SOLUTIONS USING POLY (AMINOAMIDE) DENDRIMERS

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In this study, removal of different Fe and Ni metal ion concentrations from contaminated water was achieved by using fourth generation poly-aminoamide (PAMAM) dendrimer with terminal hydroxyl groups (G4-OH) in aqueous solution. Dendrimers are well defined and highly branched polymers with controllable architecture that consist of a core, interior and terminal branch units, and they can be used as a nanoscale container for toxic metals ions in aqueous solution. The chelation process between $Fe^{(+3)}$ and $Ni^{(2+)}$ metals ions and the internal tertiary amine groups of the dendrimers was monitored visually and recorded using digital imaging. To quantify the results, time resolved UV-Vis absorption spectroscopy was used. Transmission Electron Microscopy and X-ray absorption spectroscopy were used to measure the size and distribution of the zerovalent metals after reduction of the coordinated metal ions to investigate the dispersion of the metal ions uptake by the usage of dendrimer. The results indicates the formation of mostly monodisperse metal clusters with diameter in the range of 1 to 2nm (40-400 atoms/cluster), which is consistent with the mole equivalent of the original metal ion to dendrimer concentration.

EVALUATION OF NATURAL SURFACTANTS: IMPLICATIONS TO OIL SPILL EMULSIONS AND CLEAN UP OPERATIONS

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When oils are spilt at sea different weathering processes take place, which change the volume and the chemical properties of the oil. One of these processes is the dispersion of oil droplets in water (O/W emulsions) that is aided by the addition of dispersants to efficiently dissolve the oil from the sea surface into the water column for rapid its biodegradation. Emulsification is caused by the stirring of an oil/emulsifier/water system resulting in the production of droplet populations. This mixing process also generates dynamic equilibrium of the droplets inducing their rupture and coalescence, which depends primarily on the formulation and composition variables, mixing characteristics, and preparation conditions. In this research we evaluate the effectiveness of three fractions of the Opuntia ficus-indica cactus mucilage as a natural surfactant in the formulation of such systems on O/W emulsion properties. We have determined the amount of emulsifier needed to obtain optimal emulsion stability. We have also determined the droplet size and size distribution of the dispersed phase. Such characteristics are important to understand the effective use of natural dispersants and its intrinsic character to modify interfacial properties and to improve dispersion efficiency. This research has direct implications to Deepwater Horizon Oil Spills such as the recent event at the Macondo rig in the Gulf of Mexico. We expect the use of natural dispersants will have a positive environmental and societal impact in crude oil cleanup operations.

EFFECT OF CATIONS ON URANIUM MOBILIZATION FROM URANINITE IN GROUNDWATER

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Contamination of soils and groundwater with soluble uranium as a consequence of anthropogenic activities (e.g. nuclear fuel production, weapon manufacturing, mining, etc.) is a major concern for water degradation as it can cause detrimental health effects. *In-situ* bioremediation has been proposed as a solution to mitigate uranium contaminated sites. Uraninite (UO_2) is the most desirable product of *in-situ* bioremediation because it is orders of magnitude less soluble than most other U species. Abundant ions ubiquitous in groundwater can affect the stability of UO_2. Therefore, it is of special interest to study the dissolution of UO_2 to understand the viability of microbial bioremediation strategies for groundwater.

The dissolution of UO_2 in a continuous stirred-tank reactor (CSTR) in the presence of Ca^{2+} and Zn^{2+} was investigated. The experiments were performed under anoxic and oxic conditions to evaluate the effect of oxygen in the system. Zn^{2+} had a much greater effect on inhibiting UO_2 dissolution than Ca^{2+}. This inhibition effect was mostly noted under oxic conditions where the experimental rate of UO_2 dissolution in the presence of Zn^{2+} was two orders of magnitude lower than that of Ca^{2+}. Complementary sorption experiments performed in batch indicated that Zn^{2+} adsorbed more strongly than Ca^{2+} to UO_2. This result suggests that the inhibition effect of these cations on UO_2 dissolution is related to their adsorption affinity. Adsorbed surface complexes or precipitates of Ca^{2+} and Zn^{2+} can block the access of oxygen to the UO_2 surface, in this way inhibiting the oxidative dissolution of UO_2.

DEVELOPMENT OF REACTIVE ELECTROCHEMICAL MEMBRANES FOR WATER TREATMENT

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Membrane filtration is one of the key advances in water treatment in the past 30 years. However, the most significant issue affecting the utility of membrane filtration for water treatment is associated with membrane fouling. Physical and chemical cleaning procedures are necessary to maintain membrane performance, but result in increased costs associated with operation and disposal of spent chemical reagents.

In order to overcome membrane fouling, work is underway in our laboratories to develop a novel reactive electrochemical membrane (REM). The REM utilizes a conductive, porous Ti_4O_7 membrane that can maintain a clean membrane surface utilizing two main mechanisms: 1) electrostatics and 2) electrochemical oxidation. Initial results will be presented that illustrate the effectiveness of the REM for *E. coli* filtration. The REM was used to filter solutions containing ~ 5 x 10^4 CFU/100 mL of *E. coli* in an electrochemically inert 10 mM $NaClO_4$ background electrolyte. Results indicate that in the absence of an applied current, an approximate 1-log removal was observed between the feed and the permeate solutions, as a result of filtration alone. The placement of a small current (0.25 mA/cm^2) on the REM resulted in the complete removal of all cells in the permeate solution by a combined process of electrochemical inactivation and electrostatic repulsion. Additional electrochemical characterization of the REM by electrochemical impedance spectroscopy indicates that this technique can be used to investigate the role that electrode potential has on the mitigation of fouling at the REM surface.

IMPACT OF PROTOZOA IN WWTP EFFLUENT ON MICROBIAL ECOLOGY OF RECEIVING WATER BODIES

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The objective of this work is to examine how the release of activated-sludge-associated protozoa from wastewater treatment plants (WWTP) impacts the microbial communities of receiving water bodies. Activated sludge protozoan community structure exerts strong controls on process parameters, e.g., settling efficiency, COD, and ammonia removal. However, little is known about protozoa in WWTP effluent; studies on the fate of microbiological indicators focus only on pathogens (*Giardia*, *Cryptosporidium*). The impact of protozoa in treated effluent on microbial communities downstream has gone almost entirely unexamined. Protozoa in effluent have the potential to impact water quality by altering the eukaryotic community composition, which in turn has a significant controlling influence on the rate of trophic transfer of both nutrients and anthropogenic contaminants in receiving waters.

We use microfluidic trap arrays as a method of isolating and concentrating sediment and water column protozoa. Our novel methodology provides integrated isolation, observation, and molecular analysis capabilities, as well as pH and DO measurements at millimeter-scale resolution. We deploy baited traps at several locations upstream and downstream of the University of Connecticut's WWTP effluent release point in the Willimantic River and in the effluent stream itself. We compare the resulting isolated protozoa using an inverted microscope to observe form and behavior of living cells, then extracting DNA and indexing observations to molecular identification of ciliate species.

This research offers a radical departure from existing approaches to study microbial eukaryotic communities in the field by allowing form, function, and phylogeny to be placed within a single micro-scale context.

IMPACT OF COPPER STRESS ON NITRIFICATION PERFORMANCE AND THE AMMONIA OXIDIZER COMMUNITY STRUCTURE IN ACTIVATED SLUDGE

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This research seeks to elucidate the effect of copper stress on the performance of a nitrifying activated sludge wastewater treatment process. The specific focus is the effect of the copper shock on ammonia oxidizing bacteria (AOB). This will be assessed by measuring the nitrification performance before, during and after successive copper shocks to determine the extent of inhibition, the speed of recovery, and the change in susceptibility to copper upon repeated exposure. The change in AOB community structure and expression levels of the ammonia monooxygenase (*amoA*) gene will also be evaluated as a function of copper perturbation.

Preliminary studies have been performed in which nitrifying chemostats were spiked successively with copper to achieve 25 and 50 percent (IC_{25} and IC_{50}) AOB inhibition. The ammonia concentration increased briefly but recovered to pre-perturbation levels within one day during both copper spikes, and the IC_{25} and IC_{50} values increased from 10 mM to 50 mM and from 50 mM to 100 mM, respectively, between the first spike and the second. This indicates an increase in the copper tolerance of the AOB community with a history of repeated copper perturbation. A new copper shocking experiment will be performed soon, in which reactor performance will be correlated with AOB community structure and *amoA* gene expression levels. AOB community structure will be studied based on both *amoA* gene clone library and pyrosequencing targeting the 16S rRNA gene.

ELUCIDATION OF INTRINSIC PAH BIOREMEDIATION POTENTIAL AND EFFICACY IN THE OIL-IMPACTED GULF OF MEXICO

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The Deepwater Horizon blowout has resulted in a massive environmental catastrophe that is still to be measured for years to come. Short term remediation techniques like chemical dispersion and physical removal of oil deposits cannot fully address contamination by polycyclic aromatic hydrocarbons (PAHs). PAHs are of great interest due to their toxicity and persistence in the environment. Biodegradation of PAHs has been widely studied and numerous bioremediation programs have had limited success in the decontamination of PAH contaminated sites. However, high molecular PAHs degradation remains recalcitrant. Research is being conducted to determine the viability of natural attenuation for PAHs as an alternative for the restoration of the Gulf Shore ecosystem after the oil-spill. The sea water and sediments collected from the Sandy Beach (Alabama) and the surrounding marsh area, were used for microcosm experiments. PAHs analysis of the crude oil tar-ball collected from Orange Beach (Alabama) was performed by GC/MSD. Five significant PAHs including high molecular PAHs were selected based on their abundance in crude oil. Aerobic microcosms reactors were used to monitor PAHs biodegradation in the presence of indigenous microbial communities and the dispersant (Corexit 9500), which was recently used for the oil spill cleanup. The efficacy of bioremediation via bio-augmentation of PAHs degrading enriched culture (e.g., *Pseudomonas putida*) was also investigated.

CHANGES IN THE PORE NETWORK STRUCTURE OF HANFORD SAND AFTER REACTION WITH CAUSTIC TANK WASTES

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Radioactive wastes stored in underground tanks at the former nuclear weapons production site in Hanford, WA have been leaking since the 1950s. The caustic nature of this waste causes dissolution of quartz and aluminosilicates, and precipitation of secondary minerals sodalite and cancrinite. These minerals have been shown to uptake radionuclides and thus may retard their migration off-site. Also, these minerals have been shown to cement quartz grains, which may induce changes in flow permeability. This work examines micro-scale patterns in mineral precipitation and changes in the pore structure in reacted Hanford sediments. A reactive column experiment flowing simulated waste through Hanford sand was performed at PNNL. Before, periodically during, and after reaction, the column was imaged in 3D using synchrotron-based X-ray computed tomography at BNL. At last, at Princeton, the column was flooded with epoxy, sectioned, and imaged using backscattered electron microscopy and energy-dispersive X-ray spectroscopy. Here, we summarize the findings from the 2D imaging. It was found that precipitation occurred evenly on exterior surfaces of all grains. A pre-precipitation scenario was created by digitally removing precipitation. Using a 2D erosion/dilation image analysis method, pore and throat size distributions were computed and bias-corrected. It was found that the precipitation had decreased the sizes of all pores and throats, both large and small, implying no hydrodynamic conditions favoring reaction. Also observed was the substantial extent of cancrinite precipitation in the pore space inside grains, which may provide an important hydrologic trapping mechanism for radioactive contaminants.

INTEGRATED NANOCOMPOSITE MEMBRANES FOR BIO-ORGANIC FOULING

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The goal of this study was to modify commercially available polyethersulfone (PES) membranes (0.1 µm) in order to prevent or reduce organic fouling and biofouling. The PES microfiltration membranes were modified by the standard layer-by-layer (LbL) polyelectrolyte deposition method; layers of polystyrenesulfonate (PSS), poly (diallyldimethylammonium chloride) PDADMAC and silver nanoparticles capped with PSS were alternatively assembled by electrostatic deposition. Multilayers of PDADMAC and PSS (PSS as the top layer) create a negative charge on the membrane surface thereby increasing its hydrophilicity, while multilayers of PDADMAC and PSS capped silver nanoparticles impart biocidal characteristics. Films were kept thin (1.5 bi-layers of polyelectrolyte) in order to minimize the flux decline resulting from the increased thickness of the modified membranes. Each layer added a thickness of about 10 nm resulting in an added thickness of 30 nm for each modified membrane. Aqueous solutions of humic acid (20 mg/l) and of *E.coli* suspension (10^6 CFU/ml) in PBS buffer were filtered separately through both the virgin and modified PES membranes under stirred, batch microfiltration conditions. Humic acid filtration and cleaning studies confirmed that the modification reduces the fouling of the membranes and increases the flux recovery by 6.4 and 16.5 percent for the membranes modified with and without nanoparticles after cleaning with 0.2 M of sodium hydroxide (NaOH). After biological fouling and cleaning with 200 ppm of sodium hypochlorite (NaOCl), the recovery increased by 8.5 and 11.8 percent respectively for the membranes modified with and without nanoparticles. Filtration of a mixture of humic acid and *E.coli* was performed and the results obtained confirmed that the modified membrane with nanoparticles have the lowest degree of both organic as well as biofouling in addition to significant bactericidal effects. Similarly to the organic and biofouling studies, an increase in the flux recovery after chemical cleaning was noted during the bioorganic fouling studies. The flux recovery increased by 14.7 and 23.3 percent for the membranes modified with and without nanoparticles. Manual plate counting and epifluorescence microscopy studies show that membranes modified with silver nanoparticles have remarkable biocidal effect on the *E.coli*. Membrane characterizations confirmed the increased surface charge (Zeta potential measurements), the even distribution of nanoparticles and integrity (Scanning Electron Microscopy) and the chemical modification (Fourier Transform Infra Red) of the modified membranes. Both the commercially received silver nanoparticles and the laboratory synthesized silver nanoparticles performed equally well in controlling the bacterial growth and killing.

NOVEL TiO_2-BASED NANOTECHNOLOGY BASED ON SOLAR LIGHT TO TREAT DRINKING WATER IN A SUSTAINABLE WAY

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A wide range of technologies and processes have been proposed and evaluated to tackle current challenges regarding water availability and energy conservation. Nanotechnology, with the outstanding capacity of control over the extrinsic and intrinsic properties of the material, can assist in the quest for more sustainable technologies for environmental remediation and energy storage. Nanostructure crystalline titanium dioxide (TiO_2), conventionally activated under UV light, is considered an environmentally friendly catalyst for water remediation. This technology is capable of treating non-selectively contaminants, even at very low concentrations, which are difficult or expensive to treat using other conventional methods. Therefore, it is proposed as a sustainable alternative to achieve drinking water purification. Activation of TiO_2 under visible light by non metal doping is of great interest in order to extend its adsorption capacity and design effective and sustainable solar-driven water treatment technologies. In this study, self-assembling surfactant strategies using novel sol-gel approaches were employed to synthesize and immobilize nitrogen and fluorine doped TiO_2 (NF-TiO_2) with enhanced physicochemical and optical properties. Emphasis will be given on three aspects of solar light-activated NF-TiO_2 photocatalyst: (i) synthesis and characterization of NF-TiO_2, (ii) photocatalytic evaluation of NF-TiO_2 for the destruction of emerging organic contaminants, in particular cyanobacterial toxins that include different isoforms of microcystins and cylindrospermopsin, in water under solar light, and (iii) effect of inorganic and organic water parameters in the performance of NF-TiO_2 using synthetic and real water samples.

PH DEPENDENCE ON MOBILITY OF RADIOIODINE PLUME AT SAVANNAH RIVER LOW LEVEL NUCLEAR WASTE DISPOSAL SITE

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The Savannah River low level nuclear waste disposal site (SRS) has an iodine-129 plume approaching an off-site wetland. Following the site's 1988 cleanup efforts which included addition of furnace slag and limestone and installation of a low permeability cap, the pH of the system increased by approximately 0.7 pH units. In 1993 the concentration was measured at 200 pCi/L while the current concentration range of iodine-129 is 400-1000 pCi/L. The modest pH increase may have led to the concentration increase.

The focus of this work was to quantify the pH dependence of iodine sorption to SRS sediments. Experiments were performed under oxidizing and reducing conditions to examine possible reduction of iodate to iodide. Batch sorption studies were performed with iodate and iodide in both wetland and clayey sediments in 25 g/L sediment suspensions over a period of 12 weeks. Iodate, iodide, and organo-iodine species have all been observed within SRS groundwater samples.

The data show that the iodate species sorb more strongly to the wetland soils under oxidizing conditions than the iodide species, while both species exhibit greater sorption in the lower pH range relative to the higher pH range. The rate of iodate sorption to the wetland sediment in the presence of oxygen was modeled assuming pseudo-first order kinetics and determined to be of order 0.044 with respect to the hydrogen ion concentration for the pH range of 3.6 to 6.3. The overall reaction rate constant was calculated as $k_{rxn}=10^{-0.3076}$x $(mol^{-1}L)^{0.044}(day^{-1})$.

PILOT SCALE BIOREACTOR STUDIES USING A NOVEL SULFUR OXIDIZING PERCHLORATE REDUCING BACTERIAL CONSORTIUM

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A novel sulfur-utilizing perchlorate reducing bacterial (SUPeRB) consortium was successfully used in prior batch and bench-scale packed bed reactor (PBR) studies for biological perchlorate (ClO_4^-) reduction. This study examines the scale up of the SUPeRB process for treatment of water from a ClO_4^-, nitrate (NO_3^-) and RDX contaminated aquifer in Massachusetts. A pilot-scale PBR (~250-L) was constructed with elemental sulfur and crushed oyster shell packing media. The PBR was inoculated with SUPeRB cultures enriched from a wastewater seed. Sodium sulfite provided a good method of dissolved oxygen removal in batch cultures, but was found to promote the growth of sulfate reducing bacteria, which inhibited ClO_4^- reduction in the pilot system. After terminating sulfite addition, the PBR successfully removed 96% of the influent ClO_4^- in the groundwater at and empty bed contact time of 12 hours (effluent ClO_4^- of 4.2 µg L^{-1}). Simultaneous ClO_4^- and NO_3^- degradation was observed in the lower half of the reactor before reactions shifted to sulfur disproportionation. Analyses of water quality profiles were supported by cluster molecular analysis showing distinct groupings of ClO_4^- and NO_3^- degrading organisms in the bottom of the PBR, while sulfur disproportionation was the primary biological process occurring in the top of the reactor. In addition, functional genes, *cld* and *pcrA*, were found in the bottom half of the reactor where ClO_4^- degradation was the highest.

FUNCTIONALIZATION OF MEMBRANE SURFACES TO IMPART DESIRABLE PROPERTIES

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An active area of research involves creating fouling-resistant membranes through post-synthesis surface modifications, which takes existing membranes and changes their surfaces. Some of these modifications reduce fouling by creating a more hydrophilic surface that allows water to flow more easily and prevent the hydrophobic interactions between organic and/or microbial foulants with the membrane surface. Others reduce roughness, change membrane charge, or combinations of these. However, all of the methods involve static membranes surfaces; that is, membrane properties are fixed after modification. On the other hand, a dynamic membrane surface would be able to reduce accumulation and limit the amount of fouling, reduce cleaning frequency, reduce operating cost and extend the life of the membrane. Stimuli-sensitive polymers are a way to create a dynamic membrane surface.

HIGH RESOLUTION TEMPORAL STUDY OF PHYTOESTROGEN/MYCOTOXIN CONTENT IN WASTEWATER IMPACTED AND NON-IMPACTED AQUATIC SYSTEMS

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Phytoestrogens and mycotoxins are naturally occurring compounds that are derived from a range of plant and fungal species. To a varying degree these chemical species can act as endocrine disrupting compounds (EDCs) and in high enough concentrations they have the potential to negatively impact humans as well as wildlife. At natural levels it has also been found that phytoestrogens can play a key role in the reproductive cycle of wild birds. To date no extensive temporal studies have been conducted to determine the natural fluctuations that exist in non-impacted aquatic systems. Determining if these natural fluctuations exist in the environment could potentially hint at a larger role these compounds play in the overall breeding ecology of aquatic systems. The objectives of this study are to i) determine the concentration of the phytoestrogen/mycotoxin in both wastewater impacted and non-impacted aquatic systems located in Minnesota, and ii) establish the potential for biodegradation of these compounds in the aquatic systems. Currently the yeast estrogen screen (YES) assay is being used to estimate the total estrogenicity in the studied aquatic systems. Furthermore the specific concentration of several phytoestrogen/mycotoxin compounds in the overall system is being quantified by LC-MS/MS. Initial results indicate that genistein, diadzein, biochanin A, and formononetin levels exist in the 0.5-1.5ng/L range. Preliminary batch degradation tests demonstrate that non-impacted waters are capable of rapidly degrading Genistein at 100µg/L levels. Further degradation tests will be done on genestein and diadzein at concentrations ranging from 100-1000ng/L. A substantial portion of this work will be completed by June, 2011.

CACTUS MUCILAGE AND IRON FOR THE REMOVAL OF ARSENIC FROM DRINKING WATER

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Arsenic contamination of groundwater used for drinking continues to present a global public health threat, particularly in developing communities without conventional, centralized water treatment facilities. Accessible technologies are needed which are easy to implement, operate and maintain and require little or no fossil fuel energy to work.

Cactus mucilage, extracted from the *Opuntia ficus-indica* (also known as Nopal and Prickly Pear cactus), is a natural flocculant shown to interact with dissolved arsenate. Ferric ions were introduced to the system to capitalize on the strong affinity of arsenate for ferric hydroxides. In batch experiments, ferric (Fe(III)) ions were contacted with arsenate (As(V)), then treated with cactus mucilage in a cylindrical column. After equilibration, sample aliquots were taken from the top and bottom of the column and tested for As and Fe. The mucilage accelerated precipitate formation and settling within 15 min of addition, achieving better than 90% arsenic removal as indicated by difference between initial and final dissolved As concentration in the column. Arsenic removal is affected by both mucilage concentration and Fe concentration. The role of the mucilage was demonstrated by untreated solutions showing no concentration difference and remaining stable to precipitation for more than one week. The mucilage is thought to assist the precipitation by providing a matrix for stable floc formation and remove both iron and arsenic simultaneously providing safe drinking water. This mucilage-based technology has the potential to be relatively inexpensive, and an environmentally sustainable alternative to synthetic polymer flocculants for removing arsenic from drinking water.

OPTIMAL INDOOR WATER CONSERVATION PLANNING FOR SINGLE FAMILY HOMES

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Traditional water supplies are reaching their sustainable limits in Florida. Several areas in the state are currently looking at alternative water supplies, reuse water, and water conservation to ensure that ample future water is provided. Although this initiative is a step in the right direction, current water conservation plans are often qualitative and do not measure how well the plan is working, nor how much water was saved from implementing it.

Residential water use is normally measured using a single meter that records total water use that is the sum of indoor and outdoor water use. Indoor usage can be analyzed by analyzing measured data or through an end use inventory. Several datasets are used to analyze indoor usage, compile end use inventories and determine indoor usage coefficients in Florida. Some of these datasets provide macro-scale data available to every utility in Florida, while other datasets provide micro-scale data of individual customers that are site specific and not publically available.

The purpose of this study is to provide a methodology for determining an optimal indoor water conservation plan for single family homes within any utility in Florida. This methodology describes ways to select which fixtures to retrofit within specific homes in a cost-effective manner to achieve a water savings goal. This methodology has been incorporated into the Conserve Florida Water conservation analysis tool called the EZ Guide 2.0 beta. Illustrative case study results will be included.

IMPACTS OF GLOBAL CLIMATE CHANGE ON THE WATER BUDGET ACROSS THE GREAT LAKES REGION: APPLICATION OF THE WBM MODEL

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Although the Great Lakes Region is generally perceived to be water rich, climate change is likely to impact water availability, potentially resulting in altered distribution of of available water and of water resource types across the region. To investigate the impacts of climate change we are using the Water Balance Model(WBM) (Vörösmarty et al. 1998), which quantifies water budget components at a 0.5-degree spatial resolution. Downscaled GCM outputs (Maurer et al. 2009) are used to formulate ensemble predictions of precipitation and temperature anomalies, which are then used to drive the WBM model simulations. Under the B1, A1B, and A2 SRES scenarios, greater increases in both summer and winter precipitation will occur in the eastern part of the basin, while summer precipitation will decrease in much of the western part of the basin. Temperature increases will be higher in the northeast part of the basin in winter months, but higher in the southwest part of the basin in the summer months. This gradient across the basin, along with gradients in ensemble prediction uncertainty, will be investigated using the water balance model. At a minimum, such regional-scale modeling can serve as a screening tool to identify locations for more focused research into the impacts of climate change on ecosystem services provided by water resources of the Great Lakes Region. Because of reduced complexity of the large-scale model, it is also amenable to participatory modeling with stakeholders to develop management strategies.

THERMOCLINE EFFECTS ON PERSISTENCE OF PETROLEUM HYDROCARBONS IN SHALLOW AND DEEP GULF WATERS AFTER OIL SPILLS

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The persistence of the heavy fractions of oil in the water column depends on external factors (i.e., temperature and salinity) as well as their distribution profile in the water column and sediments. The Gulf of Mexico (Gulf) has significantly high levels of salinity (about 35,000 mg/L) and significant changes in temperature due to the existence of a sharp thermocline. The purpose of this study is to characterize the persistence profile of selected crude oil fractions (PAHs) in the ocean environment depending on the temperature and salinity profile of the water column as well as water-sediment interactions. Degradation rates of selected persistent hydrocarbons in crude oil were analyzed based on the geophysical characteristics of the Gulf. The Gulf has significantly varying depths which includes 38% shallow and intertidal zone (< 20 m), 22% continental shelf (<180 m), 20% continental slope (180-3,000 m), and another 20% deeper than 3,000m. Due to the significant depth variation in the Gulf, there is also a significant temperature variation in the water column. For the analyses, the water column characteristics between 20 m and 1,600 m are of particular interest as this range encompasses the continental shelf and the continental slope. The bottom of the Gulf consists of soft sediment on the north, from the Mississippi River, and carbonate sediment on the east, from the Florida Carbonate Platform with different organic fractions. Analyses were performed for selected PAHs to visualize their persistence profile with depth in deep and shallow waters in the Gulf. Analyses for mass transfer and transformation kinetics were performed using depth and salinity based calibrations corresponding to specific regions in the Gulf.

EVALUATION OF MICROORGANISM-CONTAMINANT INTERACTION USING COLLOID-FACILITATED SOLUTE TRANSPORT MODEL

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The distribution of dissolved contaminants in subsurface porous media is of realistic importance to the protection and remediation of aquatic environments. Previous researches have indicated that the microorganisms, often simplified as colloid in current studies, could affect the transport of the contaminants through a variety of processes, which are commonly conceived as colloid-solute interactions. It has also been recognized that transport behavior of microbes deviate from those of colloids, due to the unique characteristics of the cells such as surface properties, heterogenic morphology, elasticity and deformation. The resulting associated fates of these with increasing complexity call for both comprehensive studies and powerful tools on the exploiting and simulating upon the processes governing their transports. Numerical models have been proved to be essential in predicting the distribution of contaminants alone. However, the behaviors of microbial transport and the mutual interactions among microbes, solute and subsurface media are less studied and understood. In this study, we employed Hydrus 1D model to evaluate the potential effect of microbial attachment behavior on contaminant transport, such as the microbial adsorption to the solid phase, the adsorption of contaminant to the microorganism and porous media. The Hydrus 1D model incorporates equations describing colloid and solute transport, serving for the mimic of microorganisms and contaminants, respectively. Colloid transport equations are based on modified advection-dispersion theory for colloid filtration. And solute transport equations with the presence of the colloid are formulated in similar manners for the mass balance of total solute, including dissolved solute in the liquid phase, and those adsorbed onto solid porous media and colloid. In the scenario of our study, a sand column was spiked on the top with continuous Cd^{2+} input, and then a flow of bacteria (*Shewanella oneidensis* MR-1) was added. This bacteria strain was chosen to represent microorganisms that do not bio-transform Cd^{2+}, but interact with Cd^{2+} via adsorption. The impact of key parameters dictating the interactions between the contaminant and the microorganisms were evaluated, and they include adsorption of microorganisms to porous media (k_{ac}), adsorption of contaminant to microorganism that was mobile in solution (k_{amc}) and to those that were attached to the media (k_{aic}). We found that in the absence of microbial adsorption to porous media, the bacteria would exert little impact on the transport of contaminant for this specific solute-microorganism pair studied. It was also shown that the contaminant tended to interact with the bacteria when the latter resided on the media surface. We then changed the adsorption coefficient of contaminant to these immobile bacteria, and the result showed this process could impact the solute transport significantly. In comparison, similar order of magnitude change in the adsorption of contaminant to the mobile bacteria led to relatively less changes in the breakthrough curve. This study demonstrated that the fate and migration of microorganisms influence the contaminant transport not only via bio-transformation but also via facilitated transport, therefore highlighting the necessity of study on the cell-cell or cell-surface interactions between microorganism and porous media.

APTAMER BASED OPTICAL BIOSENSOR SYSTEM FOR RAPID AND HIGH-SENSITIVE DETECTION OF 17β-ESTRADIOL

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Endocrine disrupting compounds (EDCs, such as 17β-Estradiol) are contaminants of emerging concern due to their harmful effects on endocrine function of human and aquatic organisms. They have been found frequently in natural water sources and in wastewater effluents. The EPA Unregulated Contaminant Regulation (UCMR3) has proposed to require monitoring of a number of EDCs, including 17β-Estradiol. Considerable research interests, therefore, have risen for the detection of EDCs, such as advanced instrumental analysis and biosensor methods. High-performance liquid chromatography with UV absorbance detection is frequently used to detect 17β-Estradiol in complex environmental samples, however, the labor-intensiveness and relative high-cost associated with the analysis limit its more frequent and on-line real time monitoring applications. Biosensor is a self contained integrated device consisting of a biological recognition element which is interfaced to a transducer sensor and can reversibly respond in a concentration-dependent manner to a chemical species. Using aptamers, artificially synthesized nucleic acid ligands, as biological recognition elements, have been recently proposed for biosensor development due to its higher stability (e.g. longer shelf-life) and selectivity, lower-cost for generation. There are virtually no limits of targets for aptamers such as small molecules, proteins and antibiotics. Due to these properties, the researches on aptamers used as therapeutic, diagnostic, and analytical reagents have increased in recent years *(G. D. Huy et al., 2010*).

In this study, we applied a fluorescence-labeled specific aptamer for binding 17β-Estradiol on a compact, inexpensive, and easy-to-use evanescent wave fiber-optic biosensor platform. This sensor system employs a novel single–multi-mode fiber optic coupler for exciting and collecting fluorescence emission from the same fiber optic probe. The principle for detecting 17β-Estradiol is illustrated in Figure-1. First, β-Estradiol 6-(O-carboxymethyl)oxime-BSA probe was immobilized onto the optical fiber tip. Then, water samples contain various concentrations of 17β-Estradiol was mixed with a known concentration of aptamer. The mixture was automatically pumped into the sensor to flow through the optical fiber, where the residual aptamer that was not combined with the 17β-Estradiol in the water sample would then bind to the 17β-Estradiol immobilized on the fiber, producing fluorescence signal. Thus, the higher the concentration of 17β-Estradiol in the solution, the less the fluorescent signal in this competitive mode of sensing. To regenerate the sensor, the regeneration solution (0.5% SDS, pH 1.9) was sent to the cell and then the sensor can be reused again. In the whole experiment, the fluorescence signal was recorded in real-time.

To detect the selectivity and specificity of the sensor, we used a non-specific fluorescence labeled DNA sequence instead of EDC-aptamer. Figure-2 shows that the aptamer can bind to the EDCs specifically and selectively, whereas, the non-specific DNA could not bind to the 17β-Estradiol probe and therefore had no signal. Figure-3 shows the dose-response curve of 17β-Estradiol detection ranged from 10 nM to 75 nM (2,7 ng/L to 20.4 ng/L). The results demonstrated a linear relationship of the fluorescent signal with 17β-Estradiol concentrations and the detection limit was about 3.0 nM (0.8 ng/L). The detection limit we obtained initially is comparable to those reported in the electrochemical detection of 17β-Estradiol using DNA aptamer immobilized gold electrode chip (*Y.S. Kim et al.2007)* which has the detection limit 0,3 ng/L, and the disposable amperometric immunosensor for the detection of 17β-Estradiol using screen-printed electrodes (*D. Butler, G.G. Guilbault, 2006)* which has the detection limit 5 pg/ml*.* Our detection limit is also within the range of 17β-Estradiol concentrations (<0.2 - 3 ng/L) detected in natural waters *(Hansen et al, 1998).* This portable compact sensor, therefore can potentially be applied to detect 17β-Estradiol in environmental samples without pre-concentration on site. Comparing to HPLC-MS based analysis method, this biosensor system is comparably sensitive, but with much faster and easier analytical procedure. Further research is focusing on further improvement of detection limit, evaluation of matrix interference in real water samples. Furthermore, this sensor platform can be applied to other studies for detection of various biomolecules as long as aptamers are available for the molecules of interest. Finally, multiplexed detection might be possible through the use of different aptamers for various target molecules on a single optic fiber probe.

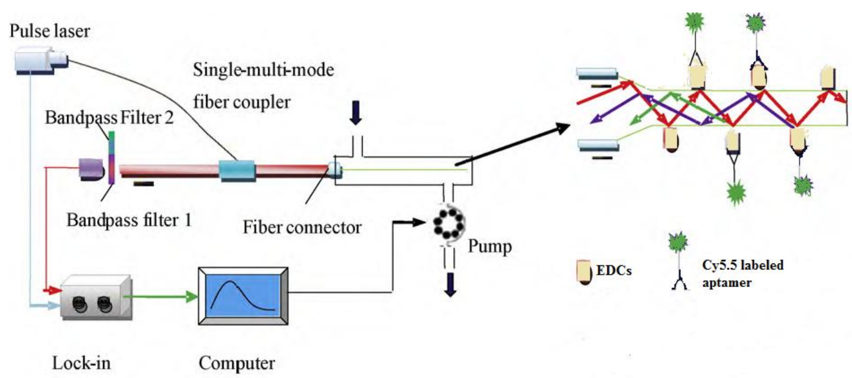
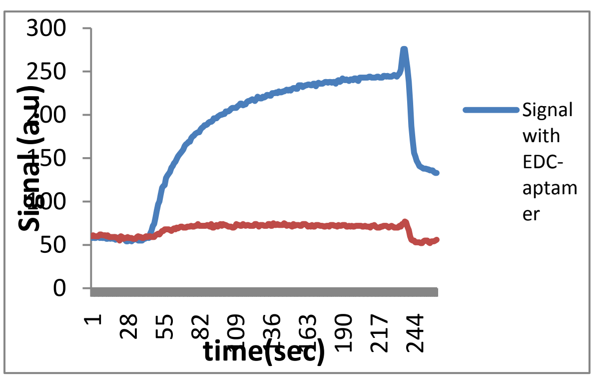


Figure 1. Detection scheme of EDC-aptamer optical biosensor system *(F. Long et al. 2010).*



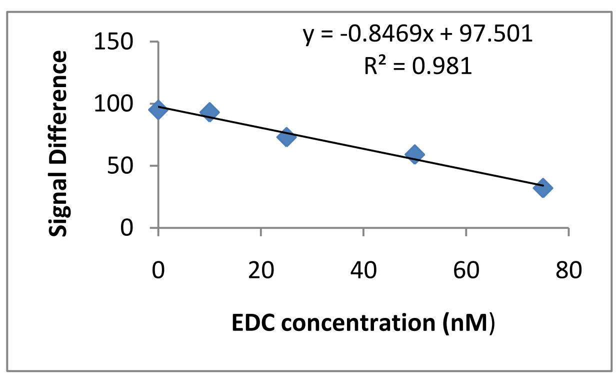


Figure 2. Specificity of the binding between aptamer and 17β-Estradiol.

Figure 3. The dose-response curve for 17β-Estradiol.

EFFECTS OF CHLORINATED PHENOLS ON *PSEUDOMONAS AERUGINOSA*

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Pseudomonas aeruginosa is an opportunistic pathogen. It has an array of mechanisms conferring resistance to antibiotics. The multidrug resistance efflux pump, MexAB-OprM, is prominent among its antibiotic resistance mechanisms. This pump effluxes structurally unrelated antibiotics and chemicals. We found that chlorinated phenols, including the commonly used antibacterial triclosan, bind a transcriptional regulator of MexAB-OprM and induce expression of the pump. This leads to higher levels of resistance to antibiotics in *P. aeruginosa* in the presence of chlorinated phenols. The presence of chlorinated phenols also increases the production of biofilm and pyocyanin, a redox active compound involved in virulence, in *P. aeruginosa*. Currently, we are studying the mechanisms behind these observations. Understanding the effect of chlorinated phenols on *P. aeruginosa* is important because some of the chlorinated phenols are widely used as general antiseptics. Additionally, they are also used in healthcare as antibacterial cleaners and as antiseptics on prosthetic medical devices.

DEGRADATION OF CARBON TETRACHLORIDE USING SURFACE-MODIFIED NANOSCALE IRON

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Subsurface contamination by chlorinated aliphatic hydrocarbons such as carbon tetrachloride (CT) is of great concern worldwide. Here we synthesized nanoscale zerovalent iron by sodium borohydride method that was stabilized with carboxymethyl cellulose (called CMC-nZVI) to investigate its potential to reductively dechlorinate carbon tetrachloride. Batch-scale experiments were conducted and rapid CT degradation by CMC-nZVI was observed, while negligible CT degradation was observed in control experiments by CMC and by sodium borohydride. Control experiments were also carried out with nZVI without stabilizing it with CMC. In the batch experiments with CMC-nZVI, CT was quickly transformed to chloroform and dichloromethane. The poster presentation will include the results of investigations currently in progress. The ongoing investigations are intended to examine how experimental variables such as CMC concentration, aging of CMC-stabilized nZVI, etc. can affect: (a) the kinetics of CT transformation and reaction products, and (b) CMC-nZVI size and its aggregation behavior.

EVALUATION OF METABOLIC DIVERSITY OF FUNCTIONALLY RELEVANT POPULATIONS IN ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL PROCESS VIA RAMAN MICROSCOPY

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Introduction: Enhanced biological phosphorus removal (EBPR) process is a widely applied process to achieve low effluent P levels and control eutrophication. But, great knowledge gap still exists in the fundamental understanding of EBPR metabolism, population diversity, process performance and stability. Unsuccessful attempts of obtaining pure isolates of polyphosphate accumulating organisms and glycogen accumulating organisms have obstructed from gaining better and complete understanding of metabolic details and necessitate the use of additional tools to quantify and monitor the metabolic states of these populations. Recently we have demonstrated the application of Raman Microscopy method in simultaneous cellular level identification and quantification of the key functionally relevant polymers in EBPR process, namely polyphosphate (polyP), polyhydroxybutyrate (PHB) and glycogen. As EBPR population characterization has so far been relying upon the genetic-target based methods such as fluorescence in situ hybridization (FISH), polymerase chain reaction (PCR) etc., Raman microscopy promises an alternative powerful tool for monitoring the functionally relevant populations in EBPR process based on their metabolic state rather than their phylogenetic identities. This study, for the first time, revealed the metabolic diversity of the functionally relevant populations in EBPR process based on Raman polymers spectrum analysis and enlighten upon the EBPR metabolic details that was captured by intracellular measurements of polymers indicative of metabolic activities.

Methods: A laboratory-scale continuous flow EBPR system was established to evaluate P removal performance and enrich for organisms that could be used for the analysis of intracellular polyP, PHB and glycogen inclusions. The HRT and SRT of the system were maintained at 18 hours and 8 days, respectively. Raman microscopy method was applied to quantify the intracellular polymer spectrum for individual cells, which allowed for potential PAO/GAO identification. Presence of PAOs in the reactor was confirmed with phosphate removal performance evaluation, Neisser staining and FISH probes targeting *Accumulibacter* and *Actinobacter* PAOs and *Competibacter* GAOs. Raman spectra were acquired using a WITec, Inc. (Ulm, Germany) Model CRM 2000 confocal Raman microscope. Excitation was provided by a Helium/Neon laser (Melles Griot, Carlsbad, CA). In order to study the dynamics of inclusion of polymers in the cells and assess the EBPR populations, P release and uptake test was performed which consisted of 90 minutes of anaerobic phase with acetate addition (50 mg-acetate/L) followed by 240 minutes of aerobic phase. Samples were taken throughout the test at 15-90 minutes interval and were analyzed for Raman analysis and for chemical analysis.

Results & Discussions:
Metabolic identification of EBPR-relevant populations based on Raman spectrum: Different combinations of the intracellular inclusions of polyP, PHB and glycogen represent different metabolic stages that PAO or GAO cells undergo during the EBPR process. Based on the current understanding of metabolic pathways of PAOs and GAOs in the EBPR system, abundance of PAOs and GAOs can be determined based on their unique Raman spectrum of combination of intracellular polymers. Table 1 shows the comparison of population abundance determined using Raman methods as proposed with

those determined by Staining and FISH method (Table 1). The consistent results validated the rationale of Raman analysis-based identification and quantification of PAOs and GAOs.

Table1: Comparison of population abundance determined by Raman and by molecular techniques

Type of method employed	**Population type**	**Population fraction ± standard deviation**
Conventional Methods		
Neisser staining	Total PAOs	67.5 ± 9.2
Raman Method		
Polymeric inclusion/Raman	Total PAOs	63 ± 3.6
Polymeric inclusion/Raman	Total GAOs	33 ± 1.4

Metabolic State Diversity among PAOs and GAOs in EBPR: Raman based identification and quantification of PAOs revealed the distribution of different sub-PAOs groups among the total PAO populations based different intracellular polymer inclusions, indicative of varying phenotype and metabolic state (Figure 1). Cells that had polymer combinations different from what would be expected based on current understanding of the biochemical pathways were elucidated. For example, polyP-containing cells with only PHB or glycogen was found to be relatively abundant, whereas PAOs with all three polymers as current EBPR model assumes are only a small fraction of the total PAOS.

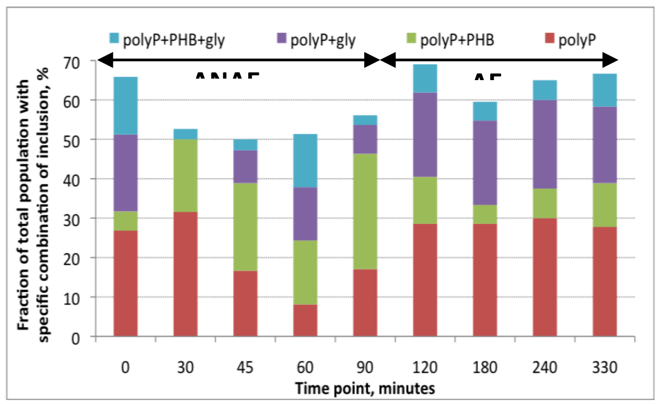

Figure 1: Distribution of PAOs with different combinations of intracellular polymers during the different metabolic stages of the EBPR cycle.

Insights into the metabolic pathways: The above results provided evidence for the hypothesis that different PAOs may employ different extent of combination of glycolysis and TCA pathways for reducing power and energy generation and that some PAOs may use TCA solely without glycolysis. The results indicated that the current observation and understanding of EBPR pathways based on mixed enrichment culture that consists of diverse populations may not accurately reflect the actual mechanism and pathways employed by different PAO and GAO populations. But rather, it represents the "apparent" mechanism as a sum of phenotypes and metabolic activities of the mixed populations, which was further evidenced by the differentiated polymer abundance associated with each populations group during EBPR (data not shown).

Conclusions: It was demonstrated that the proposed Raman method to identify and quantify functionally relevant populations in EBPR system using Raman microscopy is generally valid and the metabolic state-based measurements of active PAOs and GAOs provide a new alternative approach for monitoring the ecological dynamics of EBPR process. This method, combining with the traditional genetic-target based methods, has great potential in obtaining a complete system level and individual cellular level evaluation of EBPR process.

SOLAR DISINFECTION OF ROTAVIRUS IN THE PRESENCE OF DIFFERENT TYPES OF NATURAL ORGANIC MATTER

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Waste stabilization ponds (WSP) have been widely used as a “natural” low-cost method for the removal of pathogens and nutrients in waste water treatment. WSP consists of shallow man-made basins which take advantage of sunlight and temperature as key factors for the efficiency of the removal processes, making it suitable for tropical and subtropical areas. Previous studies have investigated the production of reactive oxygen species (ROS) by Suwanee river natural organic matter (SRNOM) in aqueous systems upon solar irradiation, capable of inactivating MS2 bacteriophage and rotavirus. However, this current study investigated the difference in reactive oxygen species production by different types of aquatic NOM. The NOM samples and SRNOM were first analyzed with fluorescence correlation spectroscopy resulting in very similar diffusion coefficients ranging from 261 to 316 $\mu m^2/s$. Batch reactors containing MS2 or rotavirus and 20 mg/l as TOC were prepared at pH~8 and temperatures ranging from 25 to 40^oC and compared with control experiments containing 0 mg/L as TOC. The solution were then exposed to simulated sunlight and sampled over time for 12 hours for virus infectivity while reactive oxygen species were monitored. Preliminary data showed that the production of reactive oxygen species is dependent on temperature, NOM concentration and type. Inactivation rates of MS2 were increased at least 2-fold in the presence of Colorado River, Loire River and Suwanee River NOM; been SRNOM the cause of the highest rate (2.5-fold) at 40^oC. However, the presence of Daon river, Blavet river and membrane bio-reactor (MBR) sample in solution did not influence the rate of inactivation of MS2.

STIMULATING GENETIC BIOAUGMENTATION IN SOIL: IMPACT ON TOL PLASMID TRANSFER RATES AND TOLUENE BIODEGRADATION

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Horizontal gene transfer (HGT) is a widespread phenomenon in the prokaryotic kingdom that occurs readily under harsh environments where genetic adaptation is required for the survival of microorganisms. HGT could be useful for bioremediation to shift microbial communities to promote the degradation of xenobiotics and emerging contaminants. Specifically, we propose a novel in situ bioremediation method termed genetic bioaugmentation in which the HGT of degradative genes and the resulting functional contaminant-degrading phenotype are enhanced. In this case study, the transfer of the TOL plasmid, which includes genes for the degradation of toluene and related compounds, is used as the model system. The presence of transconjugants is verified using a green fluorescent protein (GFP) expression system on the TOL plasmid. In pure culture experiments, small changes in environmental conditions such as additions of glucose enhanced the functionality of the TOL plasmid. To further our understanding, the TOL plasmid transfer and the change in toluene biodegradation rates was analyzed in soil and biofilm matrices with known recipient communities. *Pseudomonas putida* BBC443 harboring the TOL plasmid was added as the donor along with toluene and the occurrence of GFP-positive cells and the changes in toluene concentrations were monitored over time. Preliminary results indicate that the presence of glucose significantly increases the transfer rates of the TOL plasmid. Results from biofilm flow cell reactors and soil batch and column reactors will both be presented.

NANOMATERIALS: BRIDGING PROPERTIES AND BEHAVIOR AT INTERFACES

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The commercialization of products containing nanomaterials has begun. How widespread this process will be remains unknown, but increasing numbers of patents filed and journal articles published indicates long-term interest and investment. Research on environmental risks of these materials has recently intensified, but in order to provide good inputs into risk models environmental engineers must bridge the gap between fundamental properties and behavior in the environment. A critical problem is fundamental chemical behavior of an individual nanoparticle (NP) rarely, if ever, carries over faultlessly into the aqueous environment. Primary NPs often are engineered with organic macromolecule coatings or become coated after release affecting environmental interactions. Transport properties of NPs depend on coating type (e.g., M_W, charge density) and the underlying NP surface chemistry (e.g., hydrophobicity and surface charge). The aim of this work was to distinguish the relative roles of particle and coating chemistries on interactions with environmental surfaces. Column experiments with three types of underlying NPs (Ag, TiO_2, and C_{60}) and four types of surface coating (extracellular polymeric substances, bovine serum albumin, poly(acrylic acid), and humic acid) were undertaken for this purpose; breakthrough curves allow for the calculation of attachment efficiencies (α) for each NP/coating combination. In addition Ohshima's soft particle electrophoretic mobility analysis was performed to determine NP coating thickness. We conclude that coating chemistry type alone does not dominate column attachment efficiency, but rather the interactions between the coating and the NP are critical to understanding transport potential of the underlying material in the environment.

CATION EXCHANGE PRETREATMENT TO REDUCE MEMBRANE FOULING: UNDERSTANDING INTERACTIONS BETWEEN NATURAL ORGANIC MATTER AND ALKALINE EARTH METALS

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Membrane technology is expected to play a critical role in future water treatment design becasue of depletion and degradation of existing water sources. It has been shown that natural organic matter (NOM) and alklaine earth metals can cause irreversible fouling and scaling on membranes. This research focuses on the removal of NOM and alkaline earth metals as a pretreatment to membrane technologies to reduce fouling. The goal is to understand the behavior and relationships between NOM and alkaline earth metals using cation exchange reactions. A novel approach is the use of cation exchange as a tool to understand the behavior of the ions in solution with NOM by varying the mobile counter ion on a cationic magnetic exchange resin (MIEX). All experimental work is complete.

A major result was that NOM, a negatively charged molecule, was removed with a cation exchange resin. This was due to NOM-metal complexation (including complexation with iron oxide exposed from the MIEX). Other results showed sulfate was reactive during these reactions due to precipitation. The dissolved organic carbon (DOC) removal was relatively the same for each water with hardness (regardless of the calcium to magnesium ratio); however, there was significantly less DOC removed in the abscence of these cations. This phenomenon was observed with two NOM isolates.

This work provides new knowledge about NOM-metal complexation with alkaline earth metals during cation exchange reactions which is expected to decrease membrane fouling and be an innovative approach for treatment of membrane concentrate.

FLUORESCENCE QUENCHING: A METHOD FOR MONITORING WATER QUALITY AND ENCHANCING DRINKING WATER TREATMENT IN ORGANIC-RICH SURFACE WATER

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Surface waters rich in dissolved organic matter (DOM) are being increasingly considered as alternative sources of drinking water. As a result, utilities require methodologies to monitor influent DOM chemistry, as fluctuations in DOM affect all aspects of drinking water treatment. Such tools would allow facilities to modify their processes in response to variations in DOM, as well as help elucidate factors, such as land use and climate change, that affect DOM composition.

The goal of this work is to provide a method for monitoring DOM using fluorescence quenching and Parallel Factor Analysis (PARAFAC), a tool for separating fluorescence spectra into independent components. The overall approach is to measure the change in fluorescence intensity for PARAFAC components as synthetic and real waters are titrated with quenchers. It is expected that the relationship between a quencher and the fluorescence of a DOM component will vary depending on the DOM source. By using several well studied quenchers, the affinity of a quencher for a DOM component can be associated with the component's source specific chemistry.

Fluorescence characterization of DOM is important because changes in DOM could be quickly addressed, such as those that occur during a toxic algal bloom or increase disinfection byproduct formation. Subtle changes in PARAFAC components measured over time or space are expected to be more easily identified due to the inclusion of quenchers. These changes may prove to be slight with regard to fluorescence, but significant to the status of an aquatic ecosystem or the quality of treated water.

BIODEGRADATION OF BISPHENOL-A AND 17β-ESTRADIOL IN SOIL MESOCOSMS UNDER ALTERNATING AEROBIC/ANAEROBIC CONDITIONS

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Soil-aquifer treatment (SAT) has been proposed as a method for reusing treated municipal wastewater. SAT is characterized by alternating cycles of aerobic and anaerobic conditions in the subsurface, in response to alternating cycles of flooding and drainage of a surface impoundment. It is not yet known how these alternating redox conditions affect the removal of harmful endocrine-disrupting compounds (EDCs) from treated effluent. To address this question, we constructed mesocosms in 4-L reactors with 500 g of sediment (collected from a wetland) and 3 L of treated effluent from a municipal wastewater treatment plant; then we spiked the mesocosms with bisphenol-A (BPA) and 17β-estradiol (E2), two common EDCs often found in treated wastewater. Redox conditions in the mesocosms were controlled by switching the gas in the head space between air (to induce aerobic conditions) and nitrogen (to induce anaerobic conditions); we varied the length of the anaerobic cycles to determine how this affects biodegradation of the target EDCs. Mesocosms were also spiked with either nitrate or sulfate to serve as a potential electron acceptor during the anaerobic cycles. In addition to monitoring the concentrations of the target EDCs in the mesocosms over time, we also monitored the concentration of dissolved oxygen in the water; the redox potential; the concentrations of nitrate, nitrite, and sulfate; and the concentration of bacteria in the water (estimated via flow cytometry). Important observations included the following: (1) BPA was biodegraded only during aerobic cycles, but E2 was biodegraded during both aerobic and anaerobic cycles; (2) Whenever the redox conditions in the system were switched, there was a temporary drop in the bacterial population, followed by a recovery of the population; (3) When redox conditions were switched from anaerobic to aerobic, biodegradation of the target EDCs commenced after a lag period during which no biodegradation was observed; (4) The lag time for biodegradation in the aerobic cycle was longer when the anaerobic cycles were longer duration; and (5) More biodegradation of E2 was observed under denitrifying conditions than under sulfate-reducing conditions. The principal goal of this project is to assist in optimizing the operation of SAT systems for re-use of treated municipal wastewater, but the information gained may also assist the operation of other systems which are characterized by time-varying redox conditions.

USING MICROELECTRODES AND LIVE/DEAD BACLIGHT TO COMPARE PENETRATION, ACTIVITY, AND VIABILITY WITHIN NITRIFYING BIOFILM SUBJECTED TO FREE CHLORINE, MONOCHLORAMINE, AND PHOSPHATE

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Many utilities have used monochloramine as a secondary disinfectant for regulation compliance. Along with the addition of chloramine comes the risk of nitrification. Nitrification in drinking water distribution systems may result in degradation of water quality and non-compliance with existing regulations. It is well known that nitrifying bacteria biofilms are involved in nitrification episodes in water utilities. Unfortunately, our understanding of distribution system nitrification biofilm and its control is incomplete. In addition, orthophosphate (PO_4^{3-}) is often used to prevent corrosion in drinking water distribution systems. However, relatively little is known about its effect on nitrifying biofilm. The purpose of this research is to address knowledge gaps in our understanding of biofilm control in chloraminated drinking water distribution systems experiencing nitrification.

The research primarily used microelectrode sensors (~10 µm diameter), which are capable of probing the full depth of a model distribution system biofilm, determining the profile of the relevant water quality parameters (e.g., monochloramine (or total chlorine), phosphate, ammonia, dissolved oxygen, nitrate, and pH), and enabling calculations of the relative contribution of biofilm activity. Combined with confocal laser scanning microscopy observation using LIVE/DEAD BacLight, this research demonstrated monochloramine's greater penetration than free chlorine, the quantification of possible nitrifying biofilm recovery, and the positive act of phosphate on nitrifying biofilm development and nitrification. Overall, this research provide an improved insight into nitrifying biofilm subjected to free chlorine, monochloramine, excess ammonia, and phosphate, thus allowing further development of better strategies to prevent and control nitrification in water utilities.

FATE AND TRANSPORT OF *ESCHERICHIA COLI* O157:H7 IN SOIL AND GROUNDWATER

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Groundwater is a major source of water supply in the United States and across the world. Microbial contamination of groundwater has become a major threat to public health as a result of increasing land application of animal waste and water reuse. Currently, understanding of the fundamental mechanisms governing the fate and transport of pathogenic microorganisms in soil and groundwater systems is still lagging despite federal regulatory efforts being made to boost drinking water quality and public health security through the introduction of Ground Water Rule by Environmental Protection Agency (EPA) in October 2006. *Escherichia coli* O157:H7 is a notorious bacterium of public health concern and its infection can cause severe bloody diarrhea especially in elderly people and children. In recent years several large outbreaks of *E. coli* O157:H7 were associated with waterborne contamination. Understanding the factors governing the fate and transport of *E. coli* O157:H7 in soil and groundwater systems will help to reduce the risk of infection. In our study, *E.coli* O157:H7 surface properties were characterized by measuring cell zeta potential, cell hydrophobicity, cell size, cell aggregation and cell motility. Chemical factors such as ionic strength, pH and chemical composition; biological factor such as lipopolysaccharide (LPS) have been investigated for their roles in mediating *E. coli* O157:H7 transport in laboratory column experiments. Phosphate contents and LPS have been found to have a profound impact on the mobility of *E. coli* O157:H7 over a range of ionic strength. DLVO theory was used to elucidate the deposition behavior of the bacterial strain.

TRANSPORT MECHANISMS OF *CRYPTOSPORIDIUM PARVUM* OOCYSTS IN SUBSURFACE ENVIRONMENT: A MULTI-SCALE STUDY

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Cryptosporidium parvum oocysts, the resistant stage of a diarrhea-causing protozoan pathogen, have been a public health concern. Protection of drinking water quality and public health requires understanding of oocyst transport and fate in both natural and engineering environments. A radial stagnation point flow (RSPF) cell and a 2-dimensional micromodel consisting of an array of cylindrical collectors were used to determine transport mechanisms of *Cryptosporidium parvum* oocysts in granular porous media.

The role of oocyst surface macromolecules on oocyst deposition was investigated by comparing deposition of original oocysts with that of oocysts modified with proteinase K and/or mixed glycosidases in RSPF setup. The results showed that a fluffy outer layer of glycoproteins, which led to weaker van der Waals interaction and stronger steric repulsion, enhanced oocyst mobility. Deposition and detachment with lower ionic strength solution experiments suggested that oocysts entrapped in secondary minimum energy well were either transferred to primary minimum deposition or released by bypass flow. Deposition and detachment with high pH solution experiments indicated that surface charge heterogeneity allowed more oocysts deposited but those oocysts were remobilized when solution chemistry was disturbed.

Observation of oocysts transport in micromodel showed that oocyst attached to the forward portion of clean collectors, where the flow velocity was lowest. These oocysts were not observed to migrate along the collector surface towards the backward stagnation point of the collectors. When the collector was covered by more than 15 oocysts, oocysts were able to attach onto already attached oocysts. As a result, the region available for flow was reduced and straining increased. The observation of oocyst deposition from clean bed to straining implied two stage oocyst transport. In addition, oocysts distribution in the pore network was corresponding to the flow field distribution, which suggested that more oocysts may accumulate where flow condition varied.

BIOSTIMULATION DISRUPTS AQUIFER EUKARYOTE COMMUNITIES

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Enhanced anaerobic bioremediation of pollutants in aquifers via electron donor amendment is an attractive strategy for site clean-up as a cost effective method utilizing in situ microorganisms. Diametrically, long term consequences of the bioremediation approach on water and environmental quality are poorly understood. Our objective was to determine if electron donor amendment is a disturbance to aquifer microbial communities.

The aquifer is in southeast Iowa near the Iowa Army Ammunition Plant. It is contaminated with the explosive 1,3,5-trinitro-1,3,5-triazine (RDX) at 150 µg/l or less. Acetate was periodically injected into the groundwater to sustain RDX reducing conditions. Organisms were collected during this time and community rRNA genes (from eubacteria and eukarya) were PCR-amplified from whole community. Denaturing gradient gel electrophoresis was performed to identify proportions of taxa in the groundwater samples. Differences in profiles were visualized using detrended correspondence analysis (DCA)

Eukaryotic Shannon diversity significantly decreased as dissolved oxygen concentrations decreased ($R^2 = 0.72$, $p < 0.001$) during biostimulation consistent with observations in disturbed surface waters. Additionally, DCA indicated eukaryotic community structure irreversibly shifted from native conditions in contrast to prokaryotic community structure observed to recover within 7 weeks. The eukaryote shift was manifest as replacement of the nine most abundant taxa following biostimulation.

Our data indicates adding carbon to this aquifer disturbed the eukaryotic community. These results expose aquifer eukaryote sensitivity to pollution with potential unknown consequences to long term groundwater quality. Reactivity of eukaryotes to environmental change may also prove useful as an indicator of aquifer state and health.

COMMUNITY INTEGRATION INTO SUSTAINABILITY SOLUTIONS: A PILOT FOR STORMWATER MANAGEMENT IN URBAN COASTAL ZONES

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Commonly practiced engineered solutions to stormwater control systems often fail to meet the new numeric nutrient standards and TMDL's set by the EPA and FDEP for many coastal regions. This is mainly due in part to non-point source pollutants at the individual homeowner scale. These systems are part of the urban infrastructure, designed and implemented by engineers, and therefore community involvement in managing and understanding the importance of stormwater is typically minimal or non-existent. Educating community members through information kiosk, local meetings, and integrated K-12 curriculum allows local stakeholders the ability to make informed decisions about their personal practices that affect their natural environment. Through this educational outreach platform, members of the community are more likely to understand how runoff from their property significantly degrades the water quality of nearby surface waters and as a result implement decentralized Low Impact Development (LID) systems. In addition to enhancing their environment, economic factors (property values; local tourism; fishing industry) can also be relayed to members of the community to demonstrate the significance of LID systems.

Water Awareness, Research, and Education (WARE) and East Tampa is a model for university/K-12 community partnerships that promote the development of sustainable healthy communities through formal and informal science education centered around accessible community resources. It began with the University of South Florida, Young Middle Magnet School, and the East Tampa Community Revitalization Partnership and has shown to provide sustainability solutions through conventional engineering practices. Here, the engineered project goes beyond the physical structure and holistically encompasses the social setting in which the project is located, allowing for the people within the community to operate, manage, and benefit from the project. This fits within the vision of the Environmental Engineering Body of Knowledge that "environmental engineering problem formulation and solution must be accomplished in the context of sustainability, must meet societal needs and must be sensitive to global implications."

A NOVEL BIOMARKER TO MONITOR WASTEWATER TREATMENT PROCESS

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Activated sludge systems are the most common treatment process for domestic and industrial wastewaters. However, toxic chemicals entering the system represent a significant concern for treatment performance, which lead to effluent permit violation and the receiving water quality impairment consequently.

In this study, active bacterial diversity was used as a biomarker to measure system health. Cr (VI) was selected as a representative since it is a common industrial pollutant. Active bacteria are defined as the ones that actively synthesize ribosome and are monitored by change of precursor 16S rRNA levels. Reverse transcription and primer extension assay coupled with the novel denaturing high performance liquid chromatograph (DHPLC) was developed, optimized and applied in activated sludge samples from two wastewater treatment plants owned by Metropolitan Sewer District of Greater Cincinnati. The results showed that precursor 16S rRNA clone library is a more sensitive indicator for active bacteria in engineered environmental samples and can be used as a biomarker for system health.

This study is **SIGNIFICANT** because it provides a sensitive way to monitor the physiological response of bacterial population to toxic shock loading. With this novel technique, it provides us with a link between active bacterial structure and biological treatment performance. It is expected that the approach reported here can be used to establish a database of bacteria capable of withstanding toxic shock loading in activated sludge systems. This also provides a baseline condition in evaluating the treatment plant performance and helps the biological system recover following the upset event.

SEBAGO LAKE, ME – SCIENCE TO SUPPORT WATER QUALITY MANAGEMENT AND EDUCATION

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Sebago Lake is the second largest lake in Maine and drinking water supply to approximately 200,000 people in the greater Portland area. It is also used for recreational purposes and is dammed at the outlet for electric power generation. Sebago has been identified as a vulnerable drinking water supply because of the large amount of privately owned land in the watershed and development pressures in the area. Statistical analysis of water quality data has been conducted in conjunction with land use analysis and hydrologic modeling to provide a better understanding of the system and develop tools to help predict the outcomes of management decisions.

Currently the water quality in this large, deep lake is high enough to allow a filtration waiver for the drinking water supply. Residents, businesses, the dam owner and the water district would like to see the water quality remain high, but with a minimum of effect on their activities. The analyses described here were undertaken to try to help area residents and managers better understand system vulnerabilities to climate and land use change, and predict how activities will affect water quality to prioritize water quality protection strategies.

There is some weak evidence that water quality has recently been declining. This apparent change is coincident with less variable water levels and increasing impervious surface. Development in the watershed is approaching the 10% threshold above which water quality tends to become degraded. Efforts continue to determine the relative importance of water level and development.

ALGAL GROWTH ON CENTRATE FOR BIOFUEL FEEDSTOCK AND NUTRIENT REMOVAL

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The continued use of fossil fuels is widely regarded as unsustainable both economically and environmentally; as such there has been much interest in biofuels derived from alternative and renewable sources. One of the most promising alternatives is microalgae because they can easily grow provided sunlight and a CO_2 and nutrient source. However, water and nutrient supply add significant costs to microalgae production. Centrate is a nutrient-rich liquid byproduct of wastewater solids treatment that facilities currently spend millions of dollars a year to treat. The aim of this study was to identify how well two strains of freshwater microalgae could grow on centrate, determine the level of nutrient removal achievable, and develop a model to describe nutrient removal.

Neochloris pseudostigmata and *Neochloris conjuncta* were the two strains studied; the selection of these strains was based off their ability to grow off of high concentrations of centrate during preliminary studies. Triplicates batch experiments were carried out at 4% and 25% centrate concentrations. The best results came from *N. conjuncta* in 4% centrate (results are average of triplicates). *N. conjuncta* reduced the NH_3-N concentration by 69% from 42.1 mg/L to 13 mg/L and the PO_4-P concentration by 42% from 9.15 mg/L to 5.29 mg/L with a final algal concentration of 252 mg/L. Nitrogen and phosphorus accounted for 11.5% and 1.5% of the algal mass respectively (N: P = 7.7:1). Continuous flow experiments are currenlty being carried out in order to more closely mimic a system that would be used on a commercial level.

THE USE OF A HYBRID OZONATION-MEMBRANE FILTRATION SYSTEM FOR DRINKING WATER TREATMENT

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As a consequence of the water scarcity and the increased demand for water there is a need for more effective, economical and energy efficient processes for the treatment of surface and contaminated water sources. Membrane processes have attracted much interest in this regard. This poster describes the development of an innovative hybrid ozonation-ceramic membrane filtration system for drinking water treatment. The performance of a commercial membrane with a titanium oxide filtration layer and this membrane coated with iron oxide or manganese oxide are compared. In the absence of ozone, the manganese oxide coated fouls the least rapidly and the Fe oxide coated membrane the most rapidly. The fouling behavior observed in these experiments can be explained by the electrostatic interaction between the negatively charged NOM and the membrane surface. If ozone is applied the flux initially decreases, but after about 2 hr the flux recovers. This recovery is due to oxidation of foulants on the membrane surface. The rate of flux recovery is greatest for the Mn oxide coated membrane, which probably reflects the fact that Mn oxide is a good catalyst for the oxidation of organic compounds by ozone. For the Mn oxide coated membrane, the removal of trihalomethane (THM) and haloacetic acid (HAA) precursors is significantly higher than for conventional filtration (at the 95% confidence level). For the Fe coated membrane the removal of HAA precursors is significantly higher at the 95% CL, but the removal of THM precursors is only is significantly higher at the 90% CL.

SIZE DEPENDANCE OF METAL COMPLEXATION EXPLORED – SIZE EXCLUSION CHROMATOGRAPHY (SEC) WITH ONLINE ICP-MS

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Natural organic matter (NOM) is ubiquitous in the environment and complexes metals and other contaminants of concern. Molecular size is an important parameter that affects the fate, transport, and effects of the NOM – e.g. smaller molecular size is associated with increased mobility and greater bioavailability – and these effects also apply to the complexed constituents. Approximately 50% of assessed surface waters were deamed to be impaired by the U.S. E.P.A. and metals and NOM were among the top reasons for degraded surface water. In this study, metal-NOM complexation and the dependence on molecular size were explored using size exclusion chromatography (SEC) with online inductively coupled plasma mass spectrometer (ICP-MS), where SEC is used to separate NOM based on molecular size. Samples from four land-uses were analyzed and interestingly, many of the metals exhibited similar metal-OM size distributions. Fe and Pb were associated with molecules >10 kDa. Absorbance (254 nm), as a measure of conjugated NOM, was typically observed for molecules 3-6 kDa; Cu, Ni, Pb, and Zn were also commonly detected for this size range. Cr, Mn, Co, and Ni were commonly detected as dissolved constituents (<138 Da).

BOTTOM-UP APPROACH FOR EVALUATING WATER CONSERVATION OPTIONS IN THE COMMERCIAL, INDUSTRIAL, AND INSTITUTIONAL SECTORS

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The commercial, industrial, and institutional (CII) sectors are significant contributors to public water demand. For estimating CII water use, utilities have historically relied on water use coefficients developed through studies in the literature. Typically, these water use coefficients use number of employees or a variety of other measures of size. However, it is difficult to get this information in a fine enough resolution with consistent databases to differentiate between individual water users and adequately evaluate water conservation options. To overcome these challenges, this poster presents a bottom-up methodology by which to estimate CII water use through publicly available (from the Florida Department of Revenue (FDOR)) spatial, physical, and economic property attribute information for every one of the 326,000 CII parcels in Florida. By estimating water use at the parcel level, this methodology provides baseline water use estimates to prioritize CII water conservation options and allows utilities to compare their utility profile with other utilities. FDOR data are available in a standard format, and include land use classification of 55 CII subsectors. Water use data for 3,172 CII parcels from two utilities were linked with FDOR data to develop average and peak water use coefficients normalized by heated building area. The parcel-level information from FDOR allows for the development of pertinent relationships to estimate the number, efficiency, and frequency of use of water using devices in the 55 CII subsectors. This bottom-up approach allows for benefit-cost analysis and subsequent optimization of water conservation options.

IDENTIFYING CONTAMINANTS OF CONCERN FOR GROUND WATER MONITORING AND WATER SUPPLY PLANNING

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The research objective of this project is to update and expand a ground water quality monitoring report that is used by the Florida Department of Environmental Protection (FDEP) to assist in permitting and planning. The report contains contaminant information and recommends ground water monitoring parameters for 20 pollution sources prevalent in Florida. This project will provide contaminant information for 28 industries; some of the wastewater streams include citrus fruit, egg producers, and juice concentrate processors. This document will be utilized for permitting and ground water contaminant site investigations. It will also examine emerging contaminants and provide information to make planning decisions in the future.

Our first task was to identify information sources to use to determine contaminants of concern for the industries. These included previous FDEP reports, U.S. EPA Sector Notebooks and Development Documents, and peer-reviewed journal articles. The second task was to identify contaminants of concern and indicator parameters. Contaminants of concern are chemical compounds that would be found in wastewater effluents of the select industrial processes. Key contaminants of concern will be selected as indicator parameters because they are characteristic of ground water contamination by a particular industrial process. The third task is to describe each industry and its processes, give typical chemical compositions of the wastewater effluents, and lists contaminants of concern and indicator parameters. This poster will highlight the results of contaminants of concern and indicator parameters found in a wide range of industrial processes and their wastewater streams.

MULTI-SCALE BIOFILM CHARACTERIZATION TO COMPREHEND EARLY STAGE MEMBRANE BIOFOULING

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Despite the remarkable advantages of membrane separation technologies, the drastic reduction of water flow due to membrane fouling and the high cost of membrane replacement pose a significant problem. This research investigated the impact of feed water characteristics (i.e., conductivity and pH), conditioning layer, and activity level of biofoulant on the surface adhesion forces (i.e. hydrophobic attraction) and membrane morphology. Experiments were performed on cellulose acetate ultrafiltration membranes in crossflow filtration. Fouled membrane characterization from the macro- to nano-scale was effectively carried out using fluorescence microscopy for microbial activity, image analysis for biofilm surface coverage, AFM for fouled membrane height analysis, and CFM for surface adhesion forces.

As feed water conductivity increased and membrane surface roughness increased, the magnitude and range of the adhesion force increased and the permeate flux decline increased suggesting that feed water chemistry impacted membrane fouling potential. Comprehensive biofilm characterization, specifically AFM, revealed that bacterial cells deposited, and then formed a consolidated biofilm, on the low shear rate areas of the membrane surface. Additional experiments were carried out to determine the contribution of abiotic fouling (conditioning layer and inactive cells) to cell activity and built up resistance on CAUF membranes in early stages of membrane biofouling (<12 hours). Regardless of the degree of abiotic fouling, biotic fouling contributed most significantly to permeate flux decline. However, abiotic fouling supported biotic fouling, by acting as a food source. This research used emerging biofilm characterization techniques to better understand early stages of biofilm formation given varied feed water characteristics.

LONG-TERM TRENDS IN CHESAPEAKE BAY SEASONAL HYPOXIA, TRATIFICATION, AND NUTRIENT LOADING

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Depleted dissolved oxygen (i.e., hypoxia) is a recurring harmful summertime condition in Chesapeake Bay. Although scientists have long understood the connections between excessive nutrient loads, increased phytoplankton blooms, and hypoxia, other investigators recently have observed a shift in the relationship between the nitrogen loads into Chesapeake Bay and the hypoxic volume in July. We explored the hypothesis that this shift is the result of changes in Bay physical conditions by performing a detailed spatial and temporal analysis of both hypoxia and stratification using 60 years of data. Previous research focused only on July hypoxia. Consequently, by analyzing oxygen observations throughout the entire year, we discovered that there are major intra-summer differences in long-term hypoxic volume trends. In particular, early summer hypoxic volumes have increased substantially in recent decades, whereas late summer hypoxic volumes have slightly decreased in a manner that correlates well with nitrogen loads. Furthermore, the early summer increase in hypoxic volume can be explained by an increase in water column stratification. Additional findings show that the duration of Bay hypoxia in summer is correlated with winter/spring nitrogen loads. Our findings confirm the detrimental role that excessive nutrient loads play in hypoxia, and reveal that the disconnect between long-term nitrogen loads and hypoxia is an early summer phenomenon due to increased stratification. Causes for the stratification trends are being explored and may relate to large-scale climatic changes. Overall, our results demonstrate the importance of investigating the subtleties in a data set by trying different analysis approaches.

TOXICITY EVALUATION OF FERROUS SULFIDE IRON NANOPARTICLES ON *ESCHERICHIA COLI* GROWTH UNDER ANAEROBIC CONDITIONS

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In situ, passive technologies for remediating contaminated groundwater offer potential economic and environmental advantages over *ex situ*, active extraction methods. Most *in situ* technologies involve emplacing reactive materials in the path of a contaminant plume with the goal of transforming or sequestering contaminants in the reactive zone. Approaches to effectively create the reactive zones, known as permeable reactive barriers (PRBs), have typically involved the use of reduced iron materials, such as zero valent iron (ZVI), but more recently other iron mineral nanoparticles, such as ferrous sulfide, have been investigated. Ferrous sulfide readily forms as mackinawite nanoparticles at ambient temperature and offers similarly reactive capacity as ZVI. Although incorporating nanoparticles into PRBs is potentially beneficial due to their high reactive surface area, their release risk and toxicity have not been extensively tested. In this study, the toxicity of nano FeS particles to model bacteria, *Escherichia coli*, was evaluated in terms of their effect on growth rates in anaerobic cultures. The experiments demonstrate that *E. coli* growth is inhibited by the presence of FeS, however, the inhibition is not significantly different than that observed in particle-free sodium sulfide solutions at FeS-sulfide saturation concentrations. Growth inhibition, therefore, was not directly caused by the particulate nano-FeS itself.

OCCURRENCE AND REMOVAL OF PPCPS IN URBAN SURFACE WATER AND DRINKING WATER

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Pharmaceutical and personal care products (PPCPs) are contaminants of emerging concern in source and finished drinking water which have received world-wide attention recently due to their adverse health effects including endocrine disruption, antibiotic resistance, and alteration of chemical communication. This study examined the occurrence and removal of thirty representative PPCPs in a drinking water treatment plant (DWTP) for the period of one year to evaluate seasonal variability and treatment efficacy of DWTP processes.

Results obtained thus far show that the average total PPCP concentration in surface water is around 420 ng/L with coefficient of variation of 118%. DEET was detected at highest concentration (up to 1,000 ng/L) and showed an order of magnitude increase during summer. Overall, 19 PPCPs were detected in surface water during first nine months of monitoring while 12 of those survived treatment processes to be detected in drinking water. Those include nonylphenol, DEET, bisphenol-A, triclosan, TCEP, atrazine, caffeine, diclofenac, clarithromycin, erythromycin, trimethoprim, and cotinine (in the order of decreasing concentrations).

The removal efficiency by the drinking water processes varies greatly among different PPCPs. The overall removal rate for PPCPs was observed to be 75 ± 18%. Sedimentation and ozonation were efficient in removing ~50% of PPCPs while chlorination and filtration were found to be responsible for removal of ~25% of PPCPs. The data indicates a seasonal dependence, with higher PPCP removal rate in warmer weather. Information obtained in this study will be useful for water treatment utilities to modify treatment processes for enhancing PPCPs' removal efficiency.

FLUORESCENCE AS A SURROGATE MEASUREMENT OF MIEX TREATMENT EFFICIENCY

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Growing populations are stressing water supplies in many parts of the world. As a result, alternative water sources must be incorporated to meet demand. Dissolved organic matter (DOM) is a major concern in alternative water sources because of its deleterious effects, such as the formation of carcinogenic disinfection by-products. With the development of new treatment technologies, such as magnetic ion exchange (MIEX) resin, detailed monitoring is important to understand the treatment efficiency on the full profile of DOM. Past work has proven the effectiveness of MIEX in removing DOM, but new monitoring processes are needed to further improve treatment performance.

In practice, dissolved organic carbon (DOC) and UV absorbance are measured to determine MIEX treatment efficiency. These methods provide useful but limited information about complex DOM. Fluorescence spectroscopy has been shown to be an effective technique to characterize DOM, while its use in drinking water processes is an active research area.

This study investigates the use of fluorescence spectroscopy as a monitoring technique for MIEX treatment efficiency. Synthetic, natural, and waste waters were studied to explore the differences among the source characteristics and treatability. Following MIEX treatment, the location of the fluorescence maximum shifted to shorter emissions wavelengths, indicating a change in DOM chemistry. The maximum fluorescence intensity is positively correlated with DOC concentration and the wavelength location provides insights into the treatability of DOM. Thus, a single fluorescence measurement can be used as a surrogate to measure the concentration, chemistry, and treatability of DOM by MIEX.

DETECTION OF VIRAL PATHOGEN DIVERSITY IN AN ENVIRONMENTAL SAMPLE USING METAGENOMICS

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Environmental matrices that have been contaminated by fecal pollution have the potential to contain a diverse array of pathogens. Traditional pathogen monitoring techniques have either focused on indicator organisms, thought to be indicative of actual pathogen presence, or pathogen specific assays. However, given the large diversity of pathogens that may be present in the environment, the directed monitoring of specific agents may neglect important, dominant pathogens and lead to an underestimation of exposure or infectious risk. Viral metagenomics, enabled by next generation DNA sequencing, has the potential to remove the uncertainty associated with the monitoring of selected pathogens. By deep sequencing of viral DNA and RNA in an environmental sample and using bioinformatic techniques to identify the source of these sequences, it is possible at one time to identify all highly enriched viral pathogens present in an environmental sample. These identifications may then be used to more knowledgably direct quantitative and/or infective viral pathogen monitoring.

The goal of this work was to develop and test a metagenome-based method for describing virus pathogen diversity in an environmental sample. Viral DNA and RNA (cDNA) extracted from municipal sewage sludge residuals (termed biosolids) were considered. Biosolids are ideal for demonstrating virome pathogen recovery as this waste stream originates from the solids residuals of wastewater treatment plants serving up to one million people, their pathogen content is not well documented (Gerba, Pepper et al. 2002; Viau and Peccia 2009), and growing public opposition to the land application of biosolids as a soil conditioning product has initiated an expressed desire for comprehensive viral pathogen surveys (NRC 2002).

To create a viral metagenome, viruses-sized particles were eluted from the biosolids, DNA and RNA (cDNA) were extracted and sequenced using 454 pyrosequencing technology with Titanium chemistry (454 Life Sciences, Roche, Branford, CT). Prior to classification of the sequence data, a bioinformatic *in silico* experiment was conducted to determine the most appropriate classification approach. This experiment classified simulated short sequence reads of 10 known viral pathogens and demonstrated that classification via tBLASTx, viral only nucleotide databases and >200 nt read lengths produce a greater than 99% certainty in human virus classification.

After replicate filtering, sequencing provided 123,893 raw sequences. Reads were assembled into 1,028 contigs that averaged 874 nt and 46,153 singletons that averaged 260.7 nt. Through tBLASTx comparison with the NCBI viral-nt database, 51,925 total sequences were annotated and classified as being of viral origin. Within these viral classifications, ten different human pathogen viruses (16 strains) representing 113 sequences were identified and included 94 DNA virus sequences and 19 RNA virus sequences. Overall, annotated viral sequences consisted of 33.8% eukaryotic viruses and 66.2% bacteriophages, while human pathogenic viruses comprised less than 0.1% of total sequences

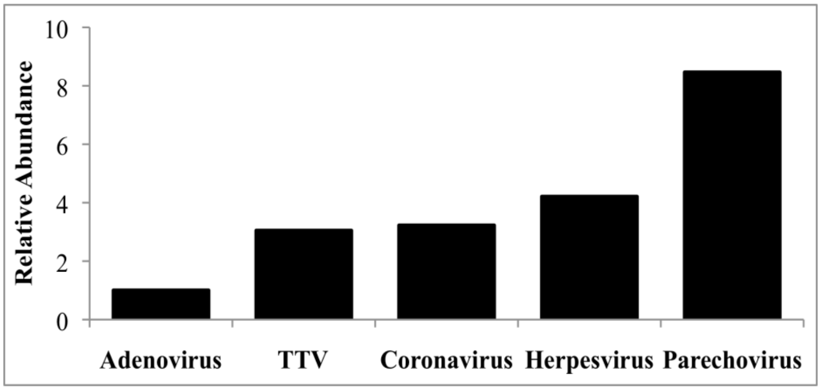

Figure 1. Relative Abundance of Select Pathogens

When using shotgun sequencing techniques, it is recognized that the likelihood of a viral fragment being identified is a function of both the virus' abundance and genome size (Angly, Willner et al. 2009). Figure 1 shows the potential number of virus genomes relative to adenovirus content after correction for virus genome size. This study identified several viral pathogens with a greater relative abundance than adenovirus, including the highly enriched parecho and corona RNA viruses, and the endemic human herpes DNA virus.

In conclusion, through an *in silico* study of simulated viral pathogens reads and an initial biosolids virome sequencing effort, this work has demonstrated the utility of next generation DNA sequencing for identifying human viruses in environmental samples of concern. Several viruses not previously identified in biosolids, including coronavirus, herpes virus, torque teno virus (TTV), and parechovirus, were identified and ranked as highly abundant compared to adenoviruses. These results indicate the importance of obtaining an unbiased view of viral pathogen diversity as a guide for subsequent cell culture and specific quantitative PCR investigations required to fully understand biosolids pathogen content.

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MOBILITY OF METAL OXIDE NANOPARTICLES SUSPENDED IN NATURAL AND ARTIFICIAL GROUNDWATER MATRICES

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Increased commercial use of metal oxide nanoparticles (NPs) will augment the risk of their potential release into natural aquatic environments. To improve our current understanding of metal oxide NP stability and mobility in natural and engineered water saturated granular systems, laboratory-scale column experiments were conducted with bare and polymer-coated cerium dioxide ($n\mathrm{CeO_2}$), titanium dioxide ($n\mathrm{TiO_2}$) and zinc oxide (nZnO) NPs. The columns were packed with clean sand and the particles suspended in artificial or natural groundwater solutions. NP suspensions were characterized with multiple complimentary techniques including dynamic light scattering, nanoparticle tracking analysis, scanning electron microscopy and transmission electron microscopy.

In general, uncoated (bare) NPs exhibited high retention within the water saturated granular matrix and dynamic (time-dependent) deposition behavior. While bare particle deposition was in qualitative agreement with the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory of colloidal stability at low ionic strength (IS), enhanced NP aggregation and physical straining within the granular matrix completely altered deposition behavior at high IS. In contrast to bare particles, polymer-coated NPs were highly stable in monovalent salt suspensions, demonstrating considerable transport potential. However, with the exception of polymer-coated $n\mathrm{CeO_2}$, the polymer-coated NPs exhibited limited mobility in divalent salt suspensions at high IS and in natural groundwater. The contrasting behaviors observed illustrate the need to consider both NP surface modification and aquatic matrix composition when evaluating metal oxide contamination potential in granular aquatic environments.

IMPACT OF DIVALENT CATIONS ON FOULING POTENTIAL OF BICARBONATE-FORM ANION EXCHANGE RESINS

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Increasing water demands and decreasing supplies of high quality water sources have led to the use of alternative water sources for potable supplies; with new water sources bringing new treatment complications. Ion exchange (IEX), frequently used for water softening, also has potential for removing dissolved organic matter (DOM) from water. Currently chloride-form resins are used for most IEX processes that target DOM, the use of which generates a concentrated brine solution that is difficult to dispose. Work done by the authors has demonstrated that bicarbonate-form resins are as effective at removing DOM. Despite the potential of bicarbonate-form IEX, little published work exists exploring it.

It is well known that many divalent cations form precipitates in the presence of carbonates. The goal of this work is to quantify the fouling potential of bicarbonate-form resins in the presence of divalent cations. To determine the fouling potential, resins will be used to treat solutions containing Ca^{2+}, Mg^{2+}, or Co^{2+}, which have carbonate species with varying solubility products. It is expected that DOM removal will decrease with increasing solubility product due to precipitation causing fouling of fixed charged sites on the resin surface. Resins will be used and regenerated multiple times to investigate how the progressive fouling of resins impacts the capacity of the resin and the kinetics of the IEX process.

This study is expected to show the impact of divalent cations on bicarbonate-form IEX, which will provide new information about water chemistry conditions that are favorable for bicarbonate-form IEX.

EFFECT OF PHENOTYPIC VARIATION OF *PSEUDOMONAS AERUGINOSA* ON BIOSORPTION OF NATURAL ORGANIC MATTER (NOM) UNDER SIMULATED DRINKING WATER DISTRIBUTION SYSTEM CONDITIONS

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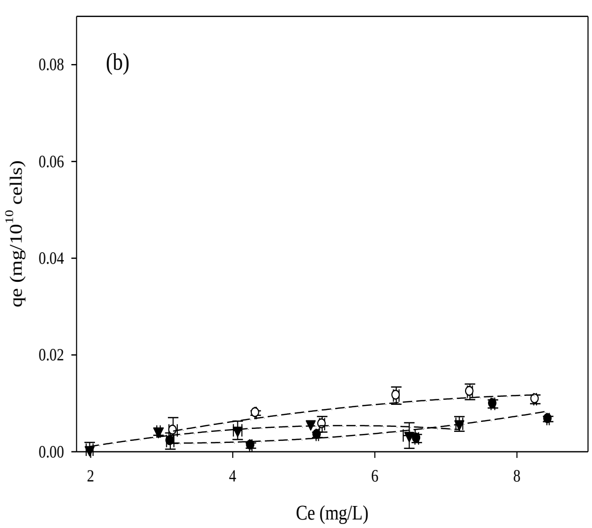
Water utilities in the US have experienced persistent biofilm formation in water distribution systems. Now, it is well accepted that biofilm extracellular polymeric substances (EPS) play a significant role on reducing the efficacy of disinfectants by providing a protective barrier to EPS embedded bacteria. In addition to sequestering disinfectants from bacteria, biofilm EPS and other portion of biofilm may adsorb available natural organic matter from aquatic environments, which can be sub-sequentially utilized by biofilm. In this study, the influence of bacterial EPS on biosorption of natural organic matter (NOM) was examined. Three representative NOM, Suwannee River NOM, humic acid (HA) and fulvic acid (FA) were used as absorbate. Three culture variants, which secrete different amounts of EPS, were investigated to elucidate adsorption kinetics and capacity of NOM to planktonic cell biomass. Divalent ions (Ca^{2+} and Mg^{2+}) were considered on the influence of biosorption because water distribution systems are impacted by water hardness as measured by ionic strength. The results indicated that biosorption under divalent ions were more obvious than the counterparts without divalent ions.

Our data suggests that biomass sorption capacity under divalent ions was higher than biomass without divalent ions. The reason may be explained by colloidal chemistry theory and the Derjaugin, Landau, Verwey, and Overbeek (DLVO) theory. Divalent ions can compress the electron double layer of NOM and bacteria, which promote a closer approach between biomass and NOM. EPS has no preference for biosorption under the condition of divalent ions.



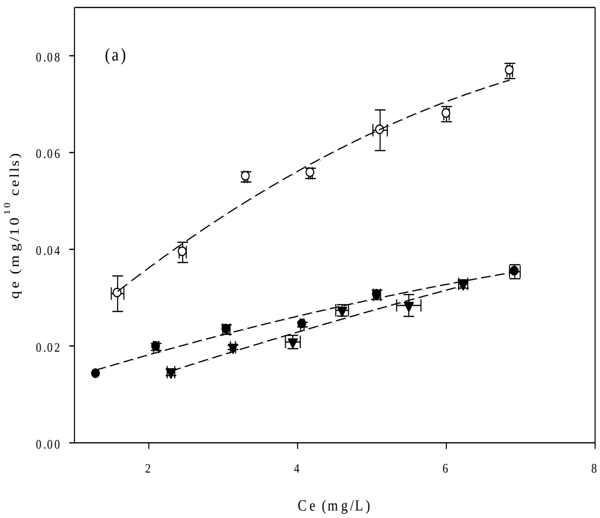


Fig. 2. Biosorption of SRHA on three cultures with and without divalent ions**.** (a) SRHA biosorption on three cultures with divalent ions. (pH=7, c(Ca^{2+}) =2 mM, c(Mg^{2+}) = 1 mM) (b) SRHA biosorption on three cultures without divalent ions. (pH=7, c(Ca^{2+}) =0 mM, c(Mg^{2+}) = 0 mM, curves were fit by quadratic equations) Error bars represent standard deviation (SD) of triplicate samples. (○-mucA, ●-PAO1, ▼algT)

CHARACTERISTICS AND APPLICATION OF A COBALT-BASED PHOSPHATE MICROELECTRODE

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The *in situ* monitoring of phosphate has received increased attentions for many environmental applications, particularly those involving biological wastewater treatment processes and eutrophication monitoring.

Cobalt-based phosphate microelectrodes were constructed, calibrated and tested for *in-situ* monitoring applications. The performance of microelectrodes was evaluated for response time, detection limit, and interference with ions or dissolved oxygen (DO). Subsequently, the phosphate microelectrodes were employed to investigate phosphate gradient in lake water and sediment samples under different environmental conditions. The phosphate concentration was measured at different depths in the sediment samples under different DO conditions. The diffusivity of the phosphate in sediment was also monitored. Concentration profiles of phosphate in sediment were well observed in these experiments. The experiments suggest that this cobalt-based microelectrode can be a useful tool to monitor phosphate transport in microenvironment.

FACTORS MODULATING WATER BIOLOGICAL STABILITY IN A MODEL DISTRIBUTION SYSTEM

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The biological stability of water in distribution systems is a major concern of drinking water quality control. At least 95% of the total bacterial biomass in drinking water was found as biofilm facilitated by the production of extracellular polymeric substances (EPS). In this study, strains from an opportunistic pathogen, *Pseudomonas aeruginosa* (both wild type and mutant strains) with different EPS secretion capabilities were used to cultivate single species biofilms. Despite increasing recognition that biofilm EPS offer resistance to disinfectant, the reaction kinetics of EPS with disinfectants, the impact of EPS content on biofilm structure, factors modulating biofilm susceptibility and behavior of biofilm detachment remain elusive. We therefore quantitatively compared susceptibility of these three single species *P. aeruginosa* biofilms and their detachments under chlorine disinfection. Biofilms were grown in a continuous flow system with a limited nutrient concentration simulating drinking water distribution system. Biofilm was visualized using confocal laser scanning microscope (CLSM) with a Live/Dead stain and EPS stain. CLSM images were processed by image analysis software to quantify biofilm structural characteristics and the spatial distribution of viability. The effect of EPS content on biofilm structure, such as surface roughness, average diffusion distance and surface area to volume ratio, was studied and related to biofilm viability. The survival rate of detached cells from biofilm was analyzed by flow cytometry to differentiate live, dead and membrane compromised cells. Both biofilm and detachment viability were confirmed by plate count method.

EVALUATION OF CHEMICAL AND PHYSICAL PARAMETERS AFFECTING MICROBIAL RESISTANCE TO ADVANCED OXIDATION PROCESSES IN WATER-BORNE BACTERIAL DISINFECTION

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Advanced oxidation techniques have been researched and suggested as an alternative to conventional disinfection. Photocatalytic titanium dioxide nanoparticles show great promise as an antimicrobial agent for water treatment applications. Application of this material requires ultraviolet photoactivation of the nanoparticles, leading to the production of reactive oxygen species (ROS) and subsequent cell membrane oxidation of the microorganism through potent oxidative reactions. Although extrinsic variables to maximize the effectiveness of the process, such as effective nanoparticle concentration and UV light intensity can be standardized for application, intrinsic variation in microorganisms and oxidative barriers can limit the effectiveness of this disinfection procedure.

In this study, we investigated the role of capsular extracellular polymeric substances on reducing the efficacy of photoactivated nano-TiO_2 water disinfection. As a model pathogen, a wild type *Psuedomonas aeruginosa* strain, PAO1, and two mutant strains that either overproduce or under produce alginate EPS were evaluated to investigate its role as an antimicrobial barrier to the oxidizing effects of photoactivated nano-TiO_2. A fluorescent cell viability assay was used to assess membrane integrity of each culture variant, based upon particle concentration, EPS production, and presence of ROS scavengers in the system. To assess chemical changes in cell structure as result of membrane oxidation, FTIR was utilized to monitor variation in signature peaks and peak intensities over the course of disinfection. Furthermore, ROS production was monitored in each reaction schematic to evaluate the influence of ROS on cell deactivation. Similarly, the physical adsorption of nanoparticles on the microbial cells was evaluated utilizing electron microscopy to visually examine the interaction of nano-TiO_2 and microorganisms, as well as qualitatively compare cell morphology and capsular EPS over disinfection time.

EVALUATING ADVANCED OXIDATION PROCESSES FOR THE TRANSFORMATION OF ORGANIC PHOSPHORUS INTO BIOLOGICALLY LABILE COMPOUNDS

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Phosphorus (P) remains a primary pollutant in natural waterways. Phosphorus in agricultural and residential fertilizers, cattle feed, and reclaimed water, eventually finds its way into surface waters. Excessive P loads can cause eutrophic or hyper-eutrophic conditions in surface waters or significantly alter an ecosystem's nutrient balance. This latter phenomenon has been documented in the Florida Everglades, where high P loads have promoted the growth of *Typha latifola* (cattail) at the expense of previously abundant *Cladium jamaicense (sawgrass).* Accordingly, *the main objective of this research is to develop an innovative combination of chemical and biological treatments for P removal from surface waters. The research will focus on understanding the* P processes within algae scrubbers and developing treatment technologies that will enhance their P uptake. Three specific objectives are being explored: (1) using advanced oxidation processes to transform dissolved organic P and particulate P to more biologically labile compounds; (2) understanding Ca-P co-precipitation and natural organic matter interactions within algae scrubbers; (3) testing different operating conditions and potential chemical amendments to maximize algae scrubber P uptake. Preliminary data for Objective 1, using hydrogen peroxide + UV, sodium percarbonate + UV, and sodium perborate + UV, showed conversion (20-100%) of both dissolved organic P and particulate P to more biologically available, soluble reactive P. This presentation will highlight results for Objective 1 in the context of the larger research project aimed at increasing P uptake from algae scrubbers.

IMPACT OF MANUFACTURED AND BIOLOGICAL NANOCOLLOIDS ON ACTIVATED SLUDGE AND TERTIARY MICROFILTRATION PROCESS

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Due to increased use of nanomaterial in everyday products there is growing concern about the fate of certain nanomaterial in wastewater streams. This research performed bench-scale studies to determine the impact of nano zinc oxide and nano copper in the biological treatment process. Toxicity results using multi-tube MPN test and respiration rates showed that neither nanomaterial had toxic effects but ionic copper, at equivalent concentrations, did inhibit microbial growth. The toxicity of copper seems to be a function of concentration and characteristics of copper remaining in solution. When either nanomaterial was spiked to activated sludge samples more than 90% was removed within an hour. The removal mechanism appears to be due to agglomeration and settling rather than by biosorption.

Due to the small size of nanomaterial they have a high potential to cause pore plugging which fouls membranes more permanently and increase energy usage. This study analyzed particles size distributions of nanoparticles in three different treatment plants. An activated sludge process with a longer mean cell residence time had a better removal of nanomaterial while trickling filters appear to have the least removal and in some instances, produced nanomaterial. Membrane flux analysis was conducted on various nanoparticle size ranges (450, 200, 100, 3.5, 2.5nm) and found that while smaller particle sizes improved filtration performance, the membranes were still significantly fouling. Pre-treatment with coagulants appeared to help filtration performance.

ALTERNATIVE TREATMENT USING A CACTUS MUCILAGE TO TREAT DRINKING WATER: FOCUS ON AREAS IMPACTED BY EARTHQUAKE

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Keywords: Earthquake, water treatment, remediation, *Opuntia ficus-indica*

Earthquakes cause serious damages in the drinking water systems, mainly in areas with high population density. The earthquake on January 12, 2010 in Port-au-Prince, Haiti, created severe problems to local residents including low access to safe drinking water, and widely spread of water borne diseases.

The purpose of this study is to investigate an alternative treatment for drinking water using cactus mucilage extracts. The mucilage is produced by several cacti species. We use the *Opuntia ficus-indica* because it is readily available and inexpensive. Extensive research in our group has shown that the mucilage is efficient at removing turbidity, bacteria and arsenic from contaminated water. In this study we are investigating the conditions that the cactus mucilage will provide better results to improve the water quality in post-earthquake scenarios.

Samples of tap, well, surface and distributed water were collected from 10 locations at Port-au-Prince. Turbidity, total suspended solids, total coliforms, biochemical oxygen demand, conductivity, pH, and trace metals were analyzed to establish the water quality and type of contamination. Batch experiments were performed with two different extracts of the mucilage, a gelling extract (GE) and a no gelling extract (NE). Samples from the top and bottom of the water column with and without mucilage were taken and analyzed by ICP-MS to determine efficiency removal of heavy metal content. Similarly, since 50% of the evaluated samples have positive presence of coliforms, optical techniques has been utilized to determine levels of bacteria and sediments from experimental water columns treated with cactus mucilage extracts.

ENVIRONMENTAL ABIOTIC DEGRADATION OF IONOPHORE ANTIBIOTICS

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Ionophores are polyether antibiotics routinely used in livestock industry as growth promoters. Much of the ingested ionophores is excreted in animal waste and may enter the environment via land applications of manure. Preliminary results show that ionophores in manure can be transported via rainfall to agricultural runoff, leading to contamination of downstream water sources. Environmental processes such as hydrolysis and photolysis may contribute to elimination of ionophores from water, but have not yet been investigated in-depth. This study examines the abiotic transformation of widely used ionophores (monensin (MON), salinomycin (SAL), narasin (NAR) and lasalocid (LAS)) in aquatic systems. Results show that ionophores can undergo hydrolysis at mildly acidic conditions with faster transformation rates at lower pH. Among the selected ionophores, SAL and NAR degrade more rapidly at acidic conditions than MON, and the kinetics follow pseudo-first-order decay. Isomeric and breakdown products observed by LC/MS support a proposed acid-catalyzed spiroketal ring-opening mechanism. Experiments also found that ionophores are susceptible to direct photolysis under UV light at ~254 nm. MON exhibits the most persistence under UV irradiation, while SAL, NAR and LAS all degrade readily. The photolysis follows pseudo-first-order kinetics with no apparent influence by solution pH. Preliminary product evaluation indicates bond breakage by photolysis to yield lower-molecular-weight substructure products. Significant inhibitory effect on the photolysis occurs when co-solutes such as nitrate are present. Further studies to evaluate ionophores' reactive sites, transformation products, pathways, and the influence of water constituents are currently underway with the aim to elucidate the reaction mechanisms.

THE EFFECT OF ORGANIC CARBON ON DEGRADATION OF STEROID ESTROGENS

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The performance of conventional activated sludge (CAS) in removing estrone (E1) has been shown to vary significantly between systems and between different sampling periods for a single system. Substrate competition by organic matter in wastewater may be an important factor for determining the removal rate and extent of biological degradation of estrogens in wastewater. The effect of organic matter on the biodegradation of E1, 17β-estradiol (E2), and ethinylestradiol (EE2) was studied in batch reactors seeded with activated sludge pellets, using a synthetic wastewater as the carbon source. Preliminary results suggest that transformation of E1 and E2 is hindered by the presence of other biodegradable organic matter. Removal of EE2 was not observed. These findings could indicate that maintaining low concentrations of biological oxygen demand in AS tanks is an important factor for efficient biodegradation of E1 and E2 in CAS systems.

SEQUENTIAL O_3-MBR AND (O_3+H_2O_2)-MBR TREATMENT OF LANDFILL LEACHATE

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Due to the negative environmental impacts of landfill leachate along with the increased volume of landfill leachate generated annually in the US, novel approaches to leachate management are needed. In this study, laboratory experiments were conducted to investigate O_3 and O_3+H_2O_2 treatment of mature landfill leachate. The pretreatment of mature landfill leachate by O_3 and O_3+H_2O_2 was intended to increase the overall biodegradability of organics present in the water matrix prior to advanced biological treatment. The biodegradable fraction of dissolved organic carbon (BDOC), ammonia-N and a model Endocrine-disrupting compound (bisphenol-aor BPA), were analyzed to track overall improvements in water quality of the studied landfill leachate water. The experiments conducted showed that Ozone and the *peroxone* process (O_3+H_2O_2) had the ability to degrade EDC's present landfill leachate. Higher degradation of BPA (the EDC chosen for this research) was achieved in DI water when compared to leachate water, this is due to large quantities of OH radicals scavengers present in the leachate matrix. Second-order rate constants for the degradation of BPA by O_3 and O_3 + H_2O_2 in leachate were calculated. When dealing with ozone alone the second order rate constant was measured to be -7.99 +/- .93x10^{-5} L mg^{-1} sec^{-1}. In addition, the second order rate constant for the degradation of BPA by the combination of ozone and hydrogen peroxide was measured to be -4.28 +/- .73x10^{-5} L mg^{-1} sec^{-1}.

At high concentrations, ammonia is one of the strongest scavengers of oxidants found in leachate water matrices. Both pre-treatments, O_3 and O_3 + H_2O_2, were found effective for the degradation of a fraction of the ammonia concentration present in the leachate, experimental procedures and results will be discussed. TOC was also used to assess the overall improvement in water quality of the treated leachate. Pre-treatment by the mentioned AOP had the ability to remove a fraction of the total TOC found in the leachate, but most importantly these treatments have been proven to alter the structure of organic compounds, breaking down large molecules into smaller less complex compounds. Due to this fact, when the pre-treated leachate was biologically treated, degradation was enhanced and the removal of TOC was greatly impacted. After the biological treatment, leachate samples were analyzed for TOC concentration, the results showed that the leachate pre-treated by 7.5ppm of O_3 and 7.5ppm of O_3 in combination to 5ppm of H_2O_2 showed a 93% and 95% reduction of TOC respectively. Results of conducted experiments show tretreatment of mature landfill leachate by ozone and the peroxon process has the ability to increase biodegradability, decrease ammonia and TOC concentration and degrade a fraction of the total EDC concentration present in landfill leachate.

SELENIUM REMOVAL BY NANO-MAGNETITE IMPREGNATED DIATOMACEOUS EARTH

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Selenium (Se) is an emerging contaminant for surface waters in many regions. The objective of this study was to modify the surfaces of diatomaceous earth (DE) by nano-magnetite and to evaluate the effectiveness of nano-magnetite modified DE in removing Se anions from water and wastewater. Batch adsorption experiments were conducted to evaluate the effects of pH, temperature, adsorbent concentration, selenium speciation, and presence of competing anions on selenium removal efficiency in conjunction with studies on adsorption kinetics, isotherms, and adsorptive thermodynamics. Rapid adsorption occurred within 30 min and selenium uptake decreased with increase in temperature. Low pH values (i.e., 2 – 4) favored selenium adsorption as expected for anion adsorption but the adsorption of selenate (Se(VI)) was more strongly dependent on pH than that of selenite (Se(IV)). It was observed that selenate adsorption was significantly affected by the presence of competing anions such as chloride, nitrate and sulfate, whereas selenite removal was mostly affected by the presence of sulfate in solution. Column adsorption tests using nano-magnetite impregnated DE showed higher adsorption efficiency for selenite anions compared to selenate. In conclusion, it was found that nano-magnetite impregnated diatomaceous earth is a promising low-cost adsorbent to treat aqueous solutions containing low levels of selenium. Besides, this new adsorbent is porous and stable, making it suitable for adsorptive filtration in column applications.

A WATER QUALITY STUDY: HOW ABSOLUTE CONCENTRATIONS AND RATIOS OF CHLORIDE AND SULFATE IMPACT LEAD LEACHING

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Even before the enactment of the EPA's Lead and Copper Rule in 1991, utilities and researchers have been concerned about elevated levels of lead and copper in potable water. Changes made to water treatment processes in order to improve overall water quality have been found, in some cases, to actually decrease water quality by triggering unintended consequences such as lead leaching. Modifications which have received recent attention include coagulant and disinfectant type and anion exchange treatment. In addition, blending of waters with different characteristics in the distribution system may also have an effect on lead leaching, a topic which has significant importance as the use of alternative sources for potable water becomes more common. Studies have shown that high chloride to sulfate mass ratios (CSMRs), greater than 0.58, yield higher rates of lead corrosion. This research examined the effects of varying absolute concentrations of these ions while maintaining a constant CSMR of ~0.58. An 8-week batch study was employed to examine lead release from C83600 Brass alloy coupons exposed to model waters with low (approx. 10 mg/L Cl^- and 20 mg/L SO_4^{-2}) and high (approx. 50 mg/L Cl^- and 100 mg/L SO_4^{-2}) concentrations of chloride and sulfate. In addition to the above parameter, the effects of pH, alkalinity and natural organic matter (NOM) on lead leaching were also evaluated. Testing will be complete by mid-April. Preliminary results show release of Pb, Cu and Zn for all model waters with the NOM-containing model water showing the greatest short-term Pb release.

FATE AND TOXICITY OF MELAMINE IN ACTIVATED SLUDGE WASTEWATER TREATMENT SYSTEMS

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Recent melamine-adulterated food safety issues raise a question about the fate and toxicity of melamine in wastewater treatment systems. Two types of activated sludge systems, a Modified Ludzack-Ettinger bioreactor (MLE) and a continuously stirred tank reactor (CSTR) with identical volume were operated for 250 days to determine the biodegradation potential of melamine and its impact on treatment performance and microbial community structure. Both systems were operated at a hydraulic retention time of 0.75 d and a target solids retention time of 15 day. The activated sludge was exposed to melamine at a constant influent concentration of 3 mg/L from day 124 to 227. The prolonged period of adaptation appeared to be ineffective in facilitating melamine biodegradation in both bioreactors. Short-term batch degradation studies confirmed that the activated sludge from the bioreactors could not degrade melamine.

Continuous melamine dose showed significant inhibition on nitrification and bacterial growth resulting in a prolonged period of deterioration of effluent water quality. The deterioration of water quality was linked to the reduced autotrophic bacterial activities and changes in nitrifying bacterial population. In the MLE, *Nitrosomonas* and *Nitrosospira* species were the dominant ammonia-oxidizing bacteria (AOB) and *Nitrospira* was the dominant nitrite-oxidizing bacteria (NOB) before melamine dose, but AOB decreased substantially after one month of melamine dose. *Nitrosomonas* and *Nitrobacter* were the dominant AOB and *Nitrospira* was the major NOB in the CSTR before melamine dosing. After one month of melamine dosing, *Nitrosospira* and *Nitrobacter* population were reduced, as indicated by terminal-restriction fragment length polymorphism profiles.

IMPROVEMENT OF MICROBIAL FUEL CELL PERFORMANCE USING A NOVEL CATHOLYTE SOLUTION

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Microbial fuel cells (MFCs) are devices that can be used to generate electricity from wastewater while simultaneously treating wastewater. The main challenges for constructing practical MFCs include increasing power and recovery of electrons from the substrate (Coulombic efficiency). Oxygen crossover from the cathode to the anode in single-chamber MFCs can significantly decrease the performance and power production in air-cathode MFCs, as well as prevent the use of lower cost carbon mesh anodes. Two-chamber MFCs can achieve less oxygen crossover than single-chamber systems, but they previously have produced much less power.

A two-chamber MFC with improved performance was constructed using an anion exchange membrane and a high NaCl concentration catholyte solution. Use of the high salt concentration in cathode chamber resulted in a low ohmic resistance and high oxygen mass transfer resistance. Chloride and hydroxide ions helped to maintain charge balance between anode/cathode chambers. The maximum power output with 240 mM of NaCl catholyte was 491 mW/m^2. This is only slightly less than that obtained with a single chamber MFC (577 mW/m^2). The coulombic efficiency was greatly improved (77~109%) with NaCl catholyte due to the high O_2 transfer resistance. Electrochemical impedance spectroscopy (EIS) data showed that addition of 240 mM of NaCl in the cathode chamber decreased the sum of membrane resistance (R_m) and solution resistance (R_s) from 52 Ω to 23 Ω, which resulted in a lower total resistance than a single-chamber MFC.

Our results show that high concentration of NaCl can significantly increase the performance of an air-cathode MFCs by reducing oxygen cross-over from cathode to anode chamber as well as lowering internal resistance in cathode chamber.

SIMULTANEOUS NITRIFICATION AND DENITRIFICAITON WITH ELECTRICITY GENERATION IN DUAL-CATHODE MICROBIAL FUEL CELLS

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Nitrogen removal using microbial fuel cells (MFCs) is of strong interest due to the potential benefits of low energy consumption and bioenergy production. In this study, we investigated the simultaneous nitrification and denitrificaiton in MFCs with dual cathodes. The proposed pathway is that wastewater containing both organics and ammonium is supplied to the anode where organics are oxidized by microorganisms that release electrons to both cathodes; the anode effluent with remaining ammonium flows into the aerobic cathode where nitrification occurrs and nitrate is produced; and then nitrate is reduced to oxygen in the anoxic cathode by accepting electrons from the cathode electrode.

We have examined this process with lab-scale H type MFCs. Our study demonstrated the feasibility of using dual cathodes to accomplish simultaneous nitrification and denitrification with bioelectricity generation in MFCs. The results suggested that the present dual-cathode MFC could achieve better performance at lower nitrogen loading rates and more than 90% of total nitrogen could be removed. It was found that through an adjusted connection to produce high power from the anode/aerobic cathode and high current from the anode/anoxic cathode, nitrogen removal was also improved significantly, possibly due to a better distribution of carbon source between two cathodes. Diffusion of nitrogen and carbon species between compartments may be controlled by using different ion exchange membranes but a detailed understanding of the process will be required.

STUDY OF THE FLOW IN OZONE REACTOR USING CFD

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The major objectives in water and wastewater industry are to meet quality requirements and improve treatment process efficiency within the constraints of investment and operating costs. This implies the use of powerful predictive modeling and simulation tools which capture the relationships between water quality and process design parameters and are capable of providing the optimum designs. Computational Fluid Dynamics (CFD) modeling tools have already been widely used in other industries but their application in water industry is quite recent.

The starting point of CFD modeling is the flow model. The equations that describe the flow of fluids are the continuity equation and Navier-Stokes equations. The most difficult part of CFD modeling is turbulence modeling. Modeling turbulent flows is a complicated issue because turbulent motions stretch out over a large range of length scales. Solving all the turbulent length scales on a computational mesh requires prohibitively high computational resources. Therefore, turbulence models are used to reduce the computational demands. Two types of turbulence models are considered here: a turbulence model based on the Reynolds-averaged Navier-Stokes equations (RANS), such as a standard k-ε turbulence model, and a subgrid-scale model for large-eddy simulation (LES). The standard k-ε model is most often used for engineering applications. The time-varying turbulent motions are captured in the averaged parameters k and ε, denoting turbulence kinetic energy (TKE) and dissipation rate of TKE. Reasonable results can be obtained at acceptable computational costs. Thus, these types of models are most often used for the design or optimization of large-scale installations, such as ozone contactors. A large-eddy simulation has much higher computational costs, but results in more detailed and accurate results, because the time-varying turbulent motions are resolved. LES is often used as a research tool for a better understanding of local transport mechanisms. Knowledge on the local and instantaneous concentrations is particularly important for simulations with chemical or microbiological reactions, because the localized areas of high concentration may result in a higher reaction rate than that calculated from an averaged concentration obtained via the RANS approach. LES resolves the large scale turbulent eddies (of the order of the mesh cell size and larger), whereas the small scale turbulent eddies are modeled using a subgrid-scale model. A filtered Navier-Stokes equation is therefore solved with an additional subgrid-scale stress term, which accounts for the unresolved turbulent scales by means of an eddy viscosity.

The objective of this talk is to present computations of the turbulent flow in a 3-D ozone contactor numerically using LES and RANS modeling approaches. In order to compare LES with RANS results, a flow analysis will be conducted providing understanding of the characteristics of the flow in terms of turbulence levels, shear and mixing. Various baffle designs for improving the disinfection efficiency of contactors will be tested using LES and RANS. Figure 1 shows velocity contours at the center plane of a 3-D ozone contactor in a RANS calculation. Residence time distributions (RTD), as shown in Figure 2 and obtained from our RANS calculation, will be compared for different designs to show the performances of the improved reactors. In future work, turbulent flow including ozone chemical reactions will be simulated for further study.

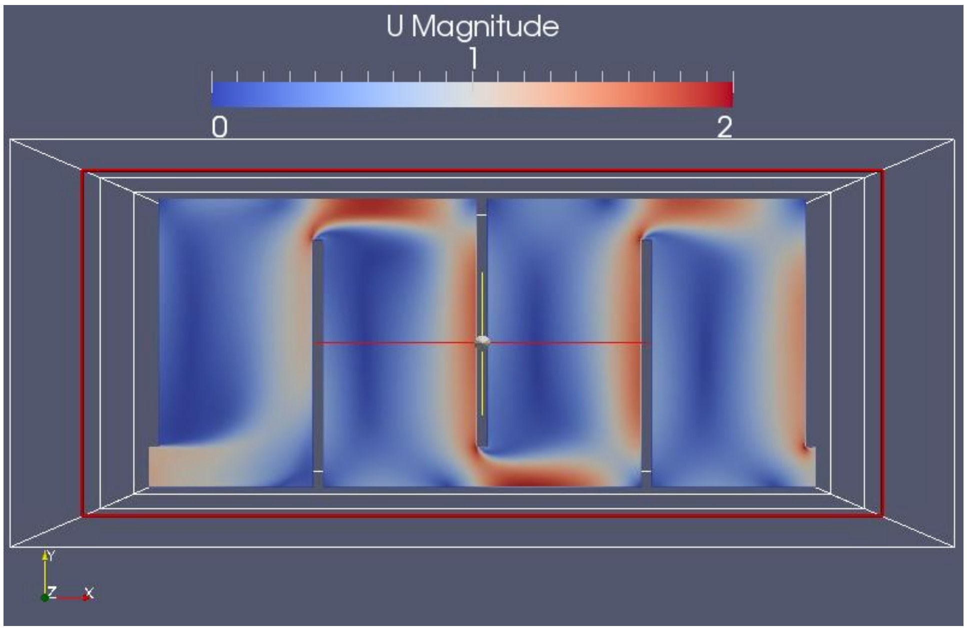

Figure1: Velocity contour at center plane of ozone contactor. Flow enters left and exits right.

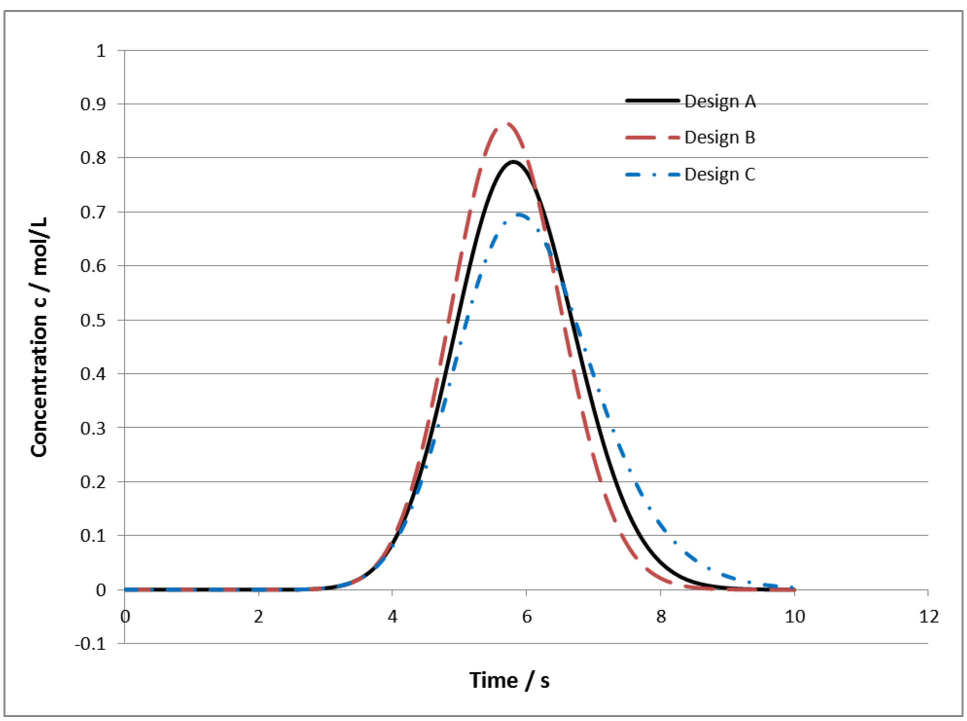

Figure 2: Residence time distribution of a passive tracer in different contactors.

CONTROLLING *PSEUDOMONAS AERUGINOSA* BIOFILM GROWTH USING BACTERIOPHAGES AND CHLORINE DISINFECTANT

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Bacterial biofilm growth is a concern in water distribution and sometimes wastewater treatment systems (e.g. biofouling in membrane bioreactors). In this study, bacteriophages isolated from municipal wastewater were used to control biofilm formation. The results showed a mixture of isolated *Pseudomonas aeruginosa* phages inhibited planktonic and biofilm growth of *P. aeruginosa* by 27 ± 4% and 62 ± 10 % after 72 h treatments, respectively. The phages also reduced the amount of pre-existing biofilms by over 50%. Compared to chlorine treatment alone, a combined use of phages and chlorination treatment inhibited biofilm formation and destroyed pre-existing biofilms to a greater extent. Biofilm growth was reduced by 50.3% at a free chlorine concentration of 21 mg/L while the reduction was increased to 86.7% with the addition of the phages. Free chlorine at a concentration of 210 mg/L did not eradicate pre-existing biofilms, but a combined use of phages and chlorine at this concentration removed 82.4% of the biofilms. In a drip flow reactor system, the combined use of bacteriophages and 200 mg/L chlorine reduced pre-existing biofilm density by 99.8 ± 0.1% while chlorine treatment alone reduced only by 34.6 ± 0.4%. Laser scanning confocal microscopy was also used to observe the effect of phage treatment on biofilms after live/dead staining. After phage-chlorine treatment, biofilms with less thickness and lower fraction of viable bacterial population were determined. The study suggests that a combined use of phages and chlorine disinfectant could be a promising method to control specific bacterial biofilms from various surfaces.

IN SITU DECHLORINATION IN SOIL AND GROUNDWATER USING POLYSACCHARIDE STABILIZED ZERO VALENT IRON NANOPARTICLES

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While dechlorination with zero valent iron (ZVI) nanoparticles have been studied for over a decade, little is known on the effectiveness for degrading soil-sorbed contaminants. To facilitate in situ destruction of chlorinated solvents in the subsurface, Auburn university developed and patented (US7,887,880 B2) a new class of stabilized ZVI nanoparticles using carboxymethyl cellulose (CMC) as a stabilizer. Long-term bench- and field-scale experimental results revealed some unique attributs of CMC-stabilized ZVI nanoparticles: 1) they are more deliverable in soil than other ZVI particles reporeted; 2) they offer much greater dechlorination reactivity than the counterparts; and 3) the particles can effectively degrade soil-sorbed TCE. Lab-column tests and field injection studies confirmed that CMC-stabilized ZVI nanoparticles can be delivered into porous media even in the presence of 200mg/L Ca^{2+}. The presence of 40-80mg/L NOM as TOC had insignificant effect on breakthrough profiles of the nanoparticles, whereas metal oxides on sand grains (4.1mg-Fe/g and 3.6mg Al/g) increased particle deposition by ~10%. At a ZVI:TCE mass ratio of 1:3, soil-sorbed TCE was degraded by 44% for an OM-rich soil and 82% for a sandy soil. Field tests confirmed the much improved soil deliverability and reactivity of the stabilized nanoparticles. Our research also revealed some technical constraints of the technology. For instances, soil sorption can limit the rate and extent of dechlorination especially for OM-rich soils, and dissolved orgaic matter can inhibit the degradation rate. Anioinc surfactants were able to aid in overcome these limitations, however, the effectiveness varied markedly with soil type and dosage.

IMMOBILIZATION OF MERCURY IN WATER, SEDIMENT AND SOIL BY STABILIZED IRON SULFIDE NANOPARTICLES

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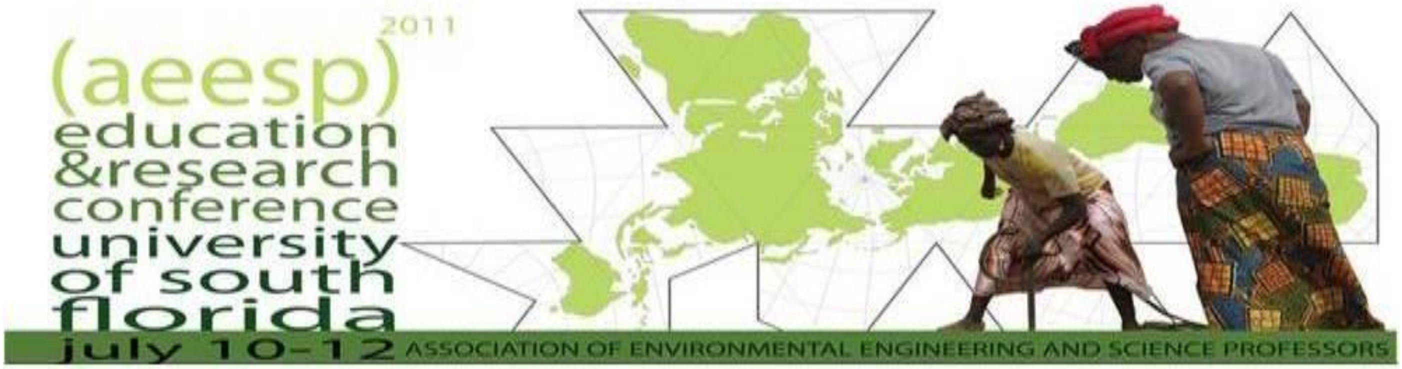
Mercury (Hg) is one of the most pervasive contaminants in the environment. Yet, effective in situ Hg immobilization technology is lacking. Auburn University developed and tested a new class of stabilized FeS nanoparticles with carboxymethyl cellulose (CMC) as a stabilizer. The nanoparticles offer the following unique advantages: 1) highly effective sorption of Hg^{2+}; 2) good deliverability into sediment or soil, and ability to facilitate in situ Hg immobilization; and 3) controllable particle size and mobility. The presence of 0.06 wt% of CMC (M.W.=90k) was able to completely stabilize 0.5g/L FeS nanoparticles, resulting in a mean size of 34.3±8.3 nm. Batch studies revealed that at a nanoparticle dosage of 18mg/L, >99.5% of 40 mg/L Hg was removed from water within 48 h, and the Hg sorption capacity remained high at pH>6.2. The high Hg removal efficiency was also demonstrated by treating two mercury-contaminated field groundwater samples, which contained high concentrations of Cl^- and DOM. XAS analysis showed that metacinnabar, cinnabar and mercury iron sulfides were formed during the Hg removal process. When applied to a Hg-laden sediment at an FeS-to-Hg molar ratio of 92:1, the water-leachable Hg was reduced by 95%. Column breakthrough tests confirmed the deliverability of the nanoparticles in sediment and soil under elevated pressure; yet, once delivered, the nanoparticles remained within 1.1 m under typical groundwater conditions, acting as a nearly immobile sink for Hg. When a Hg-laden sediment column was treated with 100 pore volumes of 0.5 g/L FeS nanoparticles, the leachable Hg was reduced by 93%.



Research Category #2: ***Advances that Assess and Improve Air Quality and Waste Management***

Research Category # 2

ADVANCES THAT ASSESS AND IMPROVE AIR QUALITY AND WASTE MANAGEMENT

EFFECTS OF SURFACTANTS AND REDUCTIVE AMENDMENTS ON THE GROWTH OF *SHEWANELLA ONEIDENSIS* MR-1

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In situ remediation strategies involving water-based delivery of remedial amendments such as calcium polysulfide (CPS) to the vadose zone or groundwater have the potential to mobilize contaminant plumes in the environment. In addition, preferential flow paths observed in the vadose zone can limit the distribution of the remedial amendment, often bypassing low permeability zones in which majority of contaminants might be located. Foam-based delivery of remedial amendments can be used to evenly distribute the remedial amendment throughout the vadose zone and potentially saturate low permeability zones. However, little is known about the effects of various proposed surfactants and remedial amendments on the indigenous microorganisms at contaminated sites. In this research, a series of bench-scale experiments were used to determine the effects of these components on bacterial cells. *Shewanella oneidensis* MR-1 was chosen as a candidate organism for these studies because of its ability to respire metals and radionuclides anaerobically, as well as its ability to inhabit environments with varying redox conditions, such as the vadose zone targeted in this study. *S. oneidensis* MR-1 cultures were amended with different surfactants and remedial chemicals to assess their affects on growth. The preliminary results show that at low concentrations, some of these chemicals are not inhibitory and may, in fact, have a stimulatory affect on growth.

ACTIVATED CARBON AMENDMENT IN GRASSE RIVER, NY TO REDUCE SEDIMENT PCB BIOAVAILABILITY

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Legacy toxic pollutants such as polychlorinated biphenyls (PCBs) persist in sediments and bioaccumulate in the aquatic food web. Remediation of contaminated sediments remains a technological challenge because traditional approaches such as sediment removal by dredging do not always achieve the risk reduction goals for human health and ecosystem protection and can even be destructive for natural resources. Recent work has shown that uptake in the food web is strongly influenced by the nature of contaminant binding, especially to black carbon surfaces in sediments. We demonstrate for the first time in a contaminated river that application of activated carbon to sediments in the field reduces biouptake of PCBs in benthic organisms. After treatment with activated carbon applied at a dose similar to the native organic carbon of sediment, bioaccumulation in freshwater oligochaete worms measured in both laboratory (Figure 1) and field exposures was reduced by 62-99% and concentrations of PCBs in water at equilibrium with the sediment by >95% compared to measurements with unamended background sediments in each year. Polyoxymethylene (POM) passive samplers were also used in lab and field applications to show that the chemical activities in pore waters of treated sediments were reduced in comparison to untreated sediments, indicating a lower potential for contaminant flux to the overlying water column. Although aggressive remedies may be appropriate for some highly contaminated sites, we show through this pilot study that PCB exposure from moderately contaminated river sediments may be managed effectively through activated carbon amendment in sediments.

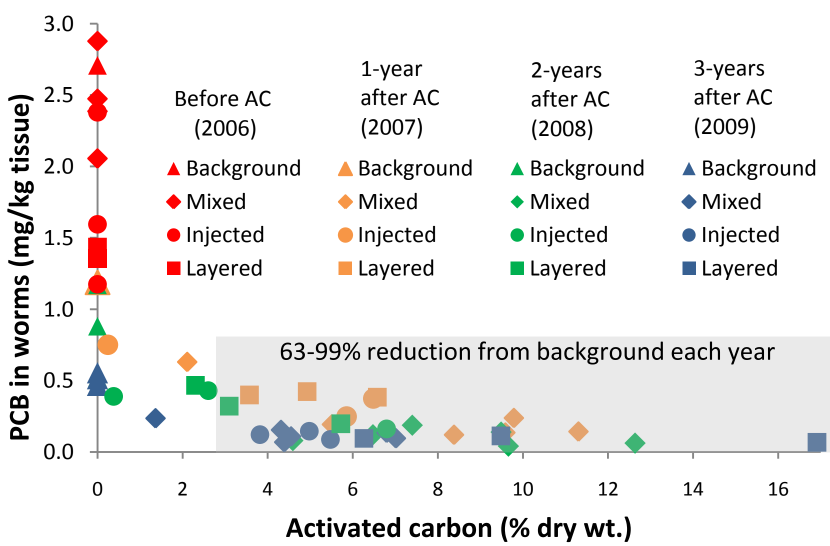

Figure 1. Relationship between laboratory bioaccumulation in *L. variegatus* and activated carbon content of sediment at different treatment area sites in each year show increasing effectiveness with activated carbon dose.

FATE OF NANOMATERIALS IN MUNCIPIAL SOLID WASTE LANDFILLS

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Nanomaterials (NMs) have been the key to advancements in drug delivery, technology, biomaterials, and energy production. Nanomaterials are widely used due their large surface area, and exhibit unique properties such as: electronic, optoelectronic, thermal, and catalytic. An inventory completed by Project on Emerging Nanotechnologies (Nanotech-Project, 2009) reported that 1,015 nanotechnology consumer products are currently available. NMs have been incorporated in cosmetics, clothing, and personal care products. As consumer products containing NMs increases, so will the quantity of these products being disposed of at landfills at the end of their useful life. It is estimated that the production of NMs will increase from 1000 tonnes, as reported in 2004, to 58,000 tonnes yearly from 2011 to 2020 (Royal Society and Royal Academy of Engineering, 2004).

To date there are no regulations pertaining to the disposal of NMs, and their fate in MSW landfills is still unknown. This research will focus on understanding the fate of NMs within waste environments. The impact on landfill biological processes and fate of ENPs upon exposure to leachate are being evaluated. Four main NMs will be assessed; Ag, ZnO, TiO_2, and SiO_2. These materials were selected based upon their large presence in consumer products. Understanding the behavior of landfilled NMs is critical in assessing potential particle releases from landfills. The overall goal of this research is to provide valuable information concerning any potential risks associated with the disposal of NM containing products in landfills.

CHARACTERIZING THE BIODEGRADATION PROCESS IN MUNICIPAL SOLID WASTE LANDFILLS

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Municipal solid waste (MSW) bioreactor landfills are equipped with leachate recirculation systems to allow the introduction of liquids in the waste matrix. The presence of moisture stimulates microbial activities thus accelerating biodegradation of MSW and achieving rapid leachate stabilization and high MSW volume reduction.

This research aims to understand the effects of biodegradation processes by monitoring the changes in leachate quality and correlating them to changes in geotechnical properties of actual MSW in a 40 L laboratory-scale landfill simulator. Settlement induced by biodegradation was recorded continuously. Leachate was recirculated every 24 or 72 hours and changes in total organic carbon (TOC), chemical oxygen demand (COD), pH and alkalinity were monitored over time.

SPATIAL VARIATIONS IN AMBIENT BENZENE CONCENTRATIONS AT HIGH RESOLUTION

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Benzene is an urban air toxic that is known to cause cancer in adults and has been associated with leukemia in children. However, the lack of characterization of variations in environmental benzene levels at high spatial resolution currently impedes understanding of human exposures and health effects for susceptible subgroups, such as school children. To investigate these spatial variations, a pilot study of benzene concentrations over the scale of a school grounds was conducted. Based on a literature review, Radiello model RAD130 passive samplers with an activated charcoal sorbent were chosen for this study. Sampling and analysis protocols were developed and tested for sampler elution with carbon disulfide, separation via gas chromatography, and quantification with mass spectrometry (GC/MS). For the pilot field study, samplers were placed at 12 sites with approximately equal spacing throughout the study area, with 2 replicates and 2 field blanks. The samples were exposed for a seven-day sampling period, and then retrieved for subsequent analysis. The spatial heterogeneity in measured concentrations was explored using a spatial distribution plot and calculation of the coefficient of variation over the study area. To assess potential impacts of spatial variations in measured concentrations on estimated health risks, lifetime cancer risks for each measurement site were also calculated and compared. Results from this study will be used to design and carry out a large passive sampling campaign to characterize intra-urban variations in benzene levels in Hillsborough County, Florida.

TIME-ACTIVITY PATTERNS AND AIR POLLUTANT EXPOSURES USING 2009 NATIONAL HOUSEHOLD TRAVEL SURVEY DATA

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Understanding of human exposures to mobile source air pollutants requires characterization of distributions of both people and pollution in time and space. However, current studies of exposure and health effects are typically limited in the temporal and spatial resolution of both. Here, the 2009 National Household Travel Survey (NHTS) dataset is used to characterize human activity patterns for Hillsborough County, Florida and to assess impacts of these patterns on estimated exposures to two important urban air pollutants with substantial mobile source emissions: oxides of nitrogen (NOx) and benzene. Specifically, the diurnal location (in time and space) of a sample of the 1650 county residents in the dataset is derived from the NHTS data. Socio-demographic characteristic data are also used to categorize the data for subsequent inter-group comparisons. Individual time-location activity data are combined with concentration distributions of NOx and benzene derived from CALPUFF dispersion modeling results for the study area. Individual exposures and group average exposures are estimated and compared in order to assess the impacts of the use of time-activity data on estimated exposures. Differences in exposures between socio-demographic groups and impacts of the use of the resolved data on estimated differences are also investigated. Expected outcomes include a better understanding of population time-activity patterns and exposures in the study area and improved methods for air pollution exposure analysis, with implications for transportation design and environmental equity.

LINKING THE NITROGEN AND ONE-CARBON CYCLES – INTERACTIONS BETWEEN NITRITE AND CARBONIC ANHYDRASE FROM AMMONIA OXIDIZING BACTERIA

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Introduction - Ammonia oxidizing bacteria (AOB) are a key microbial community involved in the microbial N-cycle. AOB fix carbon dioxide (CO_2) via the Calvin cycle for cell synthesis and utilize ammonia (NH_3) as their primary electron donor for energy synthesis. Since NH_3 oxidation and CO_2 fixation in AOB are intrinsically linked (**Figure 1**), understanding the interactions between these two metabolic cycles may yield strategies that boost AOB kinetics by optimizing carbon fixation which can then allow facilities to operate at shorter retention times, thereby reducing costs and increasing process efficiency.
During carbon fixation in AOB, carbonic anhydrase (Cah) delivers CO_2 to ribulose 1,5-bisphosphate carboxylase (Rubisco). Recent work has shown that mammalian isoforms of Cah (de)hydrate nitrite, resulting in the formation of nitric oxide (NO) and nitrogen dioxide (NO_2) [1]. Since nitric oxide is a regulator molecule in bacteria that is thought to be exclusively produced through denitrification pathways [2], nitric oxide production by Cah presents a previously undocumented source for this molecule in autotrophic organisms. In this study, we report findings that characterize nitric oxide production from crude AOB cell extracts containing Cah activity. Given that Rubisco activity is positively correlated with CO_2 concentrations, it is plausible that non-specific reactions by Cah can reduce CO_2 availability, thereby decreasing carbon fixation rates in AOB. Along these lines, we will also report findings on the effects of nitrite on Cah and Rubisco activity in AOB. Results from this study will inform future work into biological nutrient removal systems employing partial nitrification.

Methods – Biomass from chemostat cultured *Nitrosomonas europaea* ATCC 19718 (solids retention time (SRT) = 2.2 day; V = 7 L) was washed twice and concentrated in growth media minus ammonia. Carbonic anhydrase (Cah) activity of cell free extracts (five cycles of sonication at 80% output, duty cycle of 60% using a Branson Sonifier 250 (Danbury, CT, USA) followed by centrifugation at 16,100 x g at 4^0C for 1 hour) was determined by measuring the rate of protonation [3]. The effect of nitrite on Cah activity was evaluated by supplementing cell free extracts (CFE) with multiple nitrite concentrations (0 to 1000 mg NO_2^- -N/L). Abiotic (no enzyme) and positive control experiments were also conducted with purified Cah (from bovine erythrocytes) that was purchased from MP Biomedicals (U.S.A).

Results and Discussion – Preliminary results show that protonation activity of Cah from bovine erythrocytes was slowed in the presence of high nitrite concentrations (**Figure 2A**). Conversely, Cah activity from *N. europaea* CFE was stimulated in the presence of nitrite (**Figure 2B**). Since multiple Cah isoforms were used in these experiments (bovine erythrocytes extracts contained type II isoform while *N. europaea* CFE contained type II and prokaryotic Cah), interpretation of this result is difficult. Further work with isolated extracts is needed to properly diagnose whether nitrite inhibits or stimulates Cah activity. Nevertheless, these preliminary results imply that Cah activity is prone to changes in presence of high nitrite concentrations.

Project Status – Our ongoing experiments seek to characterize the inhibitory/stimulatory effects of nitrite on isolated AOB Cah as well as nitric oxide production by isolated AOB Cah. We will also monitor NO production in chemostat cultured AOB. In these experiments, we will examine gene and protein expression of the key enzymes involved in NO production from autotrophic denitrification (*nirK*, *nirS*, *norB*) and carbon fixation (*cbbL*, NE1926, NE0606, NE0448) pathways. In performing these experiments, we will reveal the extent to which nitric oxide production in AOB is due to carbon fixation pathways and whether high nitrite concentrations inhibit carbon fixation.

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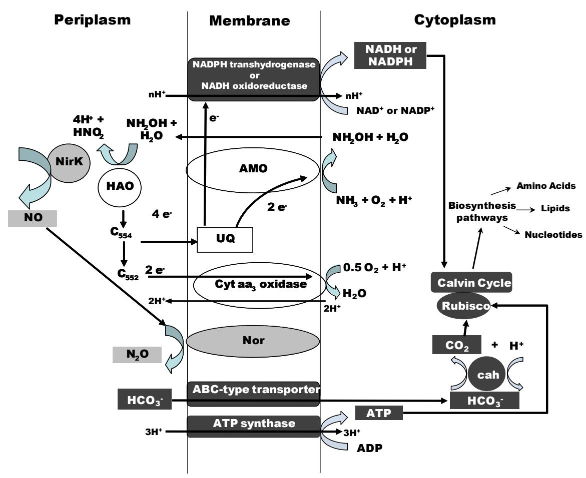

Figure 1: Diagram of energy procurement (un-shaded), denitrification (lightly-shaded) and carbon fixation (heavily-shaded) systems in *Nitrosomonas europaea*. AMO - Ammonia monooxygenase; HAO - hydroxylamine oxidoreductase; UQ – ubiquinone; Cyt. aa_3 oxidase - cytochrome oxidase; Nor - nitric oxide reductase; NirK - nitrite reductase; Cah - carbonic anhydrase; Rubisco - ribulose 1,5-bisphosphate carboxylase/oxygenase. Adapted from Yu et al., 2010.

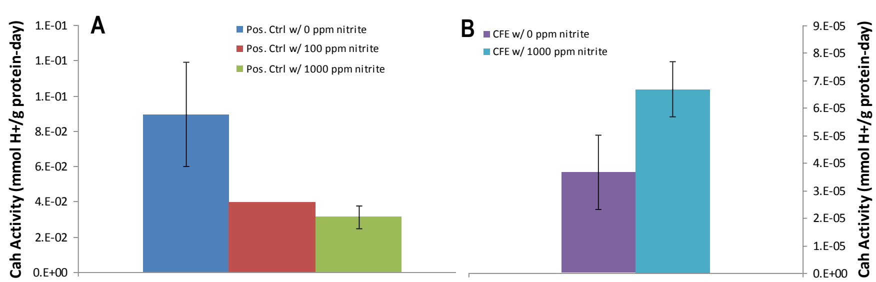

Figure 2: Relationship between carbonic anhydrase activity and nitrite concentration. A – Purified Cah from bovine erythrocytes; B – Cell free extract from *Nitrosomonas europaea.*

A MATHEMATICAL PROGRAMMING LIFE-CYCLE ASSESSMENT MODEL FOR SOLID WASTE MANAGEMENT DECISION MAKING

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Solid waste management (SWM) is an integral component of civil infrastructure that has wide array of costs and environmental impacts. In 2008, U.S. SWM systems processed approximately 250 million tons of waste, resulting in 129 Tg of CO_2e emissions, which represents 13% of non-energy related greenhouse gas (GHG) emissions. Landfills, which received 54% of municipal solid waste in 2008, represented the second largest source of anthropogenic methane in the U.S. Future national energy and climate policies (e.g., renewable portfolio standards and cap-and-trade systems) are expected to cause significant changes in energy supply and prices, which will in turn have a strong influence on the SWM system, potentially including a price on GHG emissions. Systematic analysis of SWM—from unit processes to integrated programs is necessary to identify opportunities for cost-effective GHG mitigation. The resulting changes in SWM programs could have latent consequences, so it is imperative to evaluate the environmental sustainability of SWM by performing a multi-pollutant analysis.

The complexity of climate change mitigation can potentially lead to significant unintended consequences. Given that future SWM is likely to be driven by the price effects of a GHG policy, it is essential to know how GHG emissions and other pollutant discharges will be affected and what the key tradeoffs are among them. An integrated modeling framework is being developed to enable rigorous analysis of SWM system response under a GHG mitigation policy. This framework links detailed SWM process-level operations to an aggregate SWM strategy and to the larger energy system.

To illustrate this integrated modeling framework, a stage-wise optimizable life-cycle assessment model was developed for a simplified SWM system to analyze how energy and climate policies could affect the optimal SWM process choices over the next 25 years. This system was based off of the city of Cary, NC assuming national average waste generation and composition. A base case landfill scenario was analyzed to compare costs and environmental impacts against. Additional sensitivity analyses were performed to analyze the uncertainty of the input values and to assess where more data would be most valuable. The presentation will describe the integrated modeling framework and the illustrative results.

ENERGY EFFICIENCY FOR CAPTURE AND RECOVERY OF ISOBUTANE USING ELECTROTHERMAL SWING ADSORPTION AND POST-DESORPTION LIQUEFACTION

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Several industrial processes use liquefied organic gases as inert feedstocks resulting in the production of low concentration organic gas streams that are emitted into the atmosphere. The organic gases, which have low boiling points, are typically not reused in the process and are instead thermally oxidized or captured by carbon adsorption[1]. The ability to capture, concentrate, and reuse the effluent organic gas will increase the sustainability and improve the economics of industrial processes that emit organic gases.

A bench-scale gas recovery system (GRS) was developed to capture, recover, and condense low concentration organic gases using activated carbon fiber cloth (ACFC) and electrothermal swing adsorption with post-desorption liquefaction using compression and cooling. The GRS was tested with isobutane to determine the collection efficiency and energy requirements for recovering liquid isobutane from a 2,000 ppm_v isobutane in air stream.

The energy required to capture and recover isobutane increased with ACFC temperature during desorption and ranged from 1,800 – 2,000 kJ/mol recovered. This energy consumption is 1.3 – 2.1 times that to recover acetone using the Vapor Phase Removal and Recovery System[2], which is similar to the GRS, but does not include compression and cooling and thus cannot liquefy low boiling point organic gases. Therefore, using this new GRS technology, it is now possible to capture low concentration organic gases, such as isobutane, and recover them as liquids with a reasonable energy input. These results suggest that the GRS could be implemented to improve the sustainability and economics of industrial processes.

[1] Control of VOC Emissions from Polystyrene Foam Manufacturing. EPA-450/3-90-020. 1990.
[2] Dombrowski, K.D., et al. J. of Environ. Eng. 2004, 130:3, 268-275.

SOURCE INFLUENCES ON DEPOSITED MERCURY IN TAMPA

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To mitigate human exposures to mercury, attribution of levels found in affected watersheds to sources is needed. Long-term (1996-2009) monitoring data from the mercury deposition and PM2.5 speciation networks were first analyzed to discern trends and cycles in deposition of mercury in Florida. To investigate the Tampa area specifically, precipitation data from March 2000 - 2001 for a special site fromthe Bay Regional Atmospheric Chemistry Experiment were used. Precipitation event data were first categorized by precipitation depth. HYSPLIT back-trajectory modeling was applied to compare air mass transport paths contributing to events with comparatively high versus low mercury concentrations for similar precipitation levels. Receptor analysis using positive matrix factorization was performed for diagnosis of source influences on deposited elements. The wet deposition network data show no apparent long-term trend in mercury deposition over the period studied. However, the highest precipitation depths and mercury deposition amounts were observed during the summer months at all sites in Florida. Data from the Tampa special site show a strong correlation of precipitation depth with mercury deposition (r = 0.79), and low correlation with mercury concentration (r = 0.17). Back-trajectory transport paths indicate that events with high mercury concentrations often traversed Florida during the previous 24 hours prior to deposition, whilst those with lower mercury levels did not. Statistical receptor analysis indicates that the source types contributing most to the mercury mass were medical waste incineration and coal combustion. These categories also provided the highest emissions rates of local inventoried sources during the period studied.

URINE TREATMENT IN WATERLESS URINALS: CATION EXCHANGE AND PRECIPITATION POTENTIAL

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Waterless urinals provide a way to reduce water consumption and an opportunity to treat wastewater at the source. However, these units are hindered by clogging due to mineral precipitation triggered by urea hydrolysis, a process catalyzed by the enzyme urease which decays the urea into ammonia and bicarbonate. The two most common mineral precipitates are hydroxyapatite (HAP), a calcium phosphate mineral, and struvite, a magnesium phosphate mineral. Preliminary experiments were conducted to examine the removal of magnesium and calcium from synthetic urine using a cation exchange resin with the goal of preventing the formation of HAP and struvite. Cation exchange treatment showed good removal of both calcium and magnesium from the urine, with a preference for calcium. However, calculations showed that HAP and struvite were still supersaturated in the treated urine, which motivated subsequent precipitation studies. The goal of the precipitation studies was to study the rate and extent of mineral precipitation. A synthetic urine mixture was prepared to simulate urine after it had undergone cation exchange treatment and urea hydrolysis. Two batches of "aged" synthetic urine were made: magnesium only and calcium only. The aged urine was dosed with different amounts of phosphate to observe the amount of calcium and magnesium precipitated from the urine. Results from the precipitation studies agreed with the stoichiometry for struvite precipitation (1:1 Mg:P) and HAP precipitation (5:3 Ca:P). This research is important because it provides new information about precipitation reactions in urine which is expected to improve the performance of waterless urinals.

IMPACT OF SILVER NANOPARTICLES ON ANAEROBIC DIGESTION UNDER BIOREACTOR LANDFILL OPERATIONS

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An anaerobic digestion study lasting more than 250 days was carried out to determine the potential effects of silver nanoparticles (AgNPs, nanosilver) on bioreactor landfill operations. The municipal solid waste was distributed in three identical bench-scale landfill bioreactors (9 L each) and then exposed to AgNPs (average particle size = 21 nm) at the concentration range from 0, 1 and 10 mg/kg). There was no significant difference of the cumulative gas volume or gas production rate between the bioreactor exposed to nanosilver at the concentration of 1 mg/Kg AgNPs, and the control bioreactor. However, landfill solids exposed to AgNPs at 10 mg/Kg resulted in the reduced biogas production and the accumulation of volatile fatty acids with the leachate pH consistently maintained at between 5 and 6 during the period of study. Total Ag in the leachate of the bioreactor treated with 10 mg/Kg AgNPs reactor decreased rapidly from initial 14.8 mg/L to below 2 mg/L on day 112. Quantitative PCR results after day 100 indicated that the total methanogen number was in the range of 2.56×10^5-7.85×10^5 (copies/mL) in the bioreactor treated with 10 mg/Kg AgNPs. For comparison, the total methanogen numbers were 0.90×10^7 - 1.22×10^7 and 1.81×10^7-2.21×10^7 (copies/mL) in the bioreactor treated with 1 mg/Kg AgNPs and the control bioreactor respectively. The results suggest that the level of AgNPs at 1 mg/kg has negligible impact on biogas production, but the concentration at 10 mg/kg or above may result in reduced biogas production and inhibition of methanogenic assemblages.

IMPACTS OF THE MIAMI-BROWARD I-95 HOT LANE PROJECT ON AIR QUALITY: EMISSION ESTIMATION AND DISPERSION MODELING USING TRAFFIC MICRO-SIMULATION DATA

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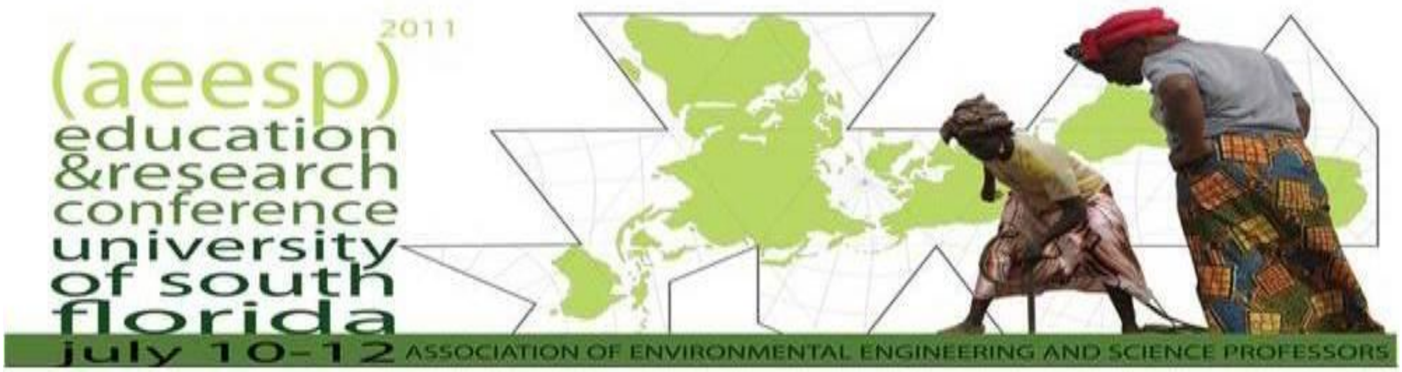
High occupancy / toll (HOT) lanes are currently receiving attention as a highway lane management option. Since transportation systems can contribute substantially to air pollutant emissions, evaluation of the impacts of such strategies on air quality is needed. Here, changes were studied in pollutant emissions and ambient concentrations resulting from recently implemented HOT lanes on a corridor of I-95 between Miami and Fort Lauderdale. Temporal trends in ambient concentrations of air pollutants associated with vehicle emissions were first assessed using available network monitoring data. Changes in emissions of carbon monoxide (CO), oxides of nitrogen (NOx), coarse particulate matter (PM_{10}), hydrocarbons (HC) and benzene due to the HOT lane implementation were then estimated using MOBILE6.2 emission factors. Transportation activity data and characteristics (vehicle volumes, speeds, and fleet mix) were derived from the results of CORSIM corridor micro-simulation modeling. Using five years of local meteorological data, the AERMOD dispersion model was applied to simulate pollutant concentrations. Results of the monitoring data analysis indicate that sites near I-95 have some of the highest observed concentrations of pollutants with substantial primary emissions (CO, NO_2, and PM_{10}). Total emissions after the implementation of the HOT lane project were estimated to increase slightly for CO, NOx, PM_{10} and benzene and decrease slightly for HCs. Simulated ambient concentrations of select pollutants (CO, NOx, and benzene) due to corridor emissions were slightly higher throughout much of the study area, with reductions at some locations near the northern end of the corridor resulting from spatial redistribution of emissions.



Research Category #3: ***Infrastructure that Serves an Expanding and Urbanizing Population***

Research Category # 3

INFRASTRUCTURE THAT SERVES AN EXPANDING AND URBANIZING POPULATION

INFLUENCE OF ROADWAY PROXIMITY ON METAL ACCUMULATION AND POPULATION DYNAMICS IN A WETLAND-DWELLING AMPHIBIAN

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As ubiquitous elements of land development, roads are distributed pervasively throughout much of North America. Runoff from impervious surfaces, an indirect effect of roads, contributes contaminants to roadside wetlands and waterways with stormwater management being a critical element of sustainable development. Heavy metals such as copper (Cu), zinc (Zn), lead (Pb) and chromium (Cr) from vehicle use can accumulate in aquatic biota that depend on roadside wetlands for breeding habitat, including engineered stormwater wetlands. However, the degree to which the salinization of waterways with development may interact with metallic contaminants to influence the chemical speciation and potential bioavailability of trace heavy metals, including mercury (Hg), particularly at sub-lethal levels, is lacking. Many investigations focus on lethal doses of single chemical exposure. However, our burgeoning understanding of the influence of rapid evolution on ecological patterns suggests that sub-lethal geochemical processes and demographic processes may interact, resulting in outcomes that vary among local populations. Understanding the impact that these interactions may have on trace metal fate and impacts in urbanized systems is critical as our society moves forward with evaluating sustainable development approaches.

We examined the potential influence of road proximity and development on the chemical characteristics of five forest and five roadside temporary wetlands located in northeastern Connecticut. In roadside wetlands, specific conductance—a close proxy for road salt—was approximately 25 times that of forest pools, demonstrating the influence of impervious road surfaces. Hg species, Cu and Zn along with base cation, anion and DOC content were analyzed from water samples collected in April, May and early July 2009. To investigate biological outcomes, we used a reciprocal transplant experimental design in which spotted salamanders embryos were grown out in field enclosures in each of the ten wetlands to parse the influence of the environment and the population on bioaccumulation. Trace metal content values in late-stage larvae in roadside ponds increased 69, 39, 6, 169 and 25% for Cr, Cu, Zn, Pb and Hg, respectively, relative to forested ponds. Average larval content was 2.5, 5.3, 160, 0.8 and 0.10 ppm, respectively. Native versus transplanted populations did not differ consistently in trace metal accumulation. While Cu and Zn aquatic concentrations increased, Hg concentration decreased for roadside ponds relative to forested ponds, possibly reflecting the shift in dissolved organic carbon affecting Hg bio-uptake potential. Subsequent sampling has involved adult salamanders returning to the Connecticut ponds as well as characterizing more developed ponds associated with the Baltimore LTER

To further elucidate potential mechanisms affecting amphibian populations, we examined the potential impact of maternal transfer on the reproductive success of amphibians, particularly relating to Hg. Low-level Hg exposure may influence reproductive success or exert sub-lethal influence on survival due to food web uptake in the larval stage. We collected adult woodfrogs in Spring 2010 returning to select roadside and forested vernal pools in the Yale Experimental Forest, CT. Pairs of amphibians were bred in captivity. Following reproduction, mating adults and a subsection of the fertilized eggs were collected and analyzed for Hg content. Reproductive success was documented by hatchling success and larvae were reintroduced into cages in the respective natural pools. Two replicates (12 larvae each) of each of four reciprocal pairs were reintroduced, allowed to grow, and harvested in early June following 2 months of food web accumulation and analyzed for total Hg. Adult females contained higher Hg concentrations (176 ng/g) relative to males (130 ng/g), with slightly higher content in forest specimens. While egg content increased with female parent Hg content for both roadway and forest specimens, maternal transfer of Hg was only significantly related (α=0.05) for the forested samples. CHECK THIS SYMBOL – should be either α or p

CAPTURING EMBODIED ENERGY IN CHINA'S NEW URBAN LANDS BY REMOTE SENSING

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Current estimates indicate that urban areas are responsible for 76% of the world's final energy use, but current estimates do not generally account for the energy and material requirements of new urban infrastructure, making it difficult to understand the full impact of urbanization processes, particularly in rapidly developing cities. This paper outlines an integrated framework for analyzing urban embodied energy using a combination of life cycle assessment and remote sensing and applies the framework to investigate the energy embodied in urban growth across China from 1990-2000.

This study combines Landsat remote sensing data, provincial apparent consumption of building materials, new construction statistics, and energy use data for building materials production to develop spatially explicit estimates of the energy embodied in new urban areas across China during this period of tremendous urban growth. This is a spatially explicit, dynamic model and also accounts for temporal aspects in the life cycle assessment component, as Chinese industry has become increasingly energy efficient since 1990.

The main results of the work are a series of urban maps that show the distribution of embodied energy in selected major Chinese cities. These results are specific to time period and location and show the effects of land cover dynamics, advances in energy efficiency, and variation in the material composition of buildings and infrastructure. This method can be used to develop accurate estimates of urban embodied energy across challenging city, provincial, and national boundaries and represent a significant methodological improvement upon conventional bottom-up techniques.

EFFECTS OF ALUMINUM SOLIDS ON PITTING CORROSION OF COPPER PLUMBING UNDER VARIABLE FLOW CONDITIONS

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Pitting corrosion of copper plumbing can result in pinhole leaks, which not only represent water resource losses, but may also lead to severe water damage and harmful mold growth. Thus, homeowners can be faced with costly and frustrating repairs and mitigation efforts. It has been proven that pinholes can be caused by aggressive potable water chemistries, which were initially characterized by a particular combination of high pH, free chlorine residual, and aluminum solids [i.e., $Al(OH_3)$]. However, recent studies have shown that aluminum solids are not required for rapid pitting to occur in high pH water with free chlorine, if continuous flow conditions exist.

To elucidate the role of aluminum solids in copper pitting, we first conducted a comprehensive review of all relevant investigations of pitting in aggressive waters. Upon synthesis of results, we determined that the net effect of aluminum solids may be dependent on water flow conditions. To test this idea, we designed a matrix of re-circulating pipe-loop experiments in which flow velocity and frequency were varied. Results indicate that in systems with slow or infrequent flow, aluminum solids adhere to copper surfaces in non-uniform mounds, underneath which pit growth is catalyzed, relative to systems without aluminum solids. Conversely, in systems with fast or continuous flow, deposition of the solids appears to be more uniform, and pit growth rates are unaffected or even decreased. These results help to explain a range of practical field observations and prior laboratory experiments, and may aid in engineering more sustainable potable water infrastructure.

RESEARCH OPPORTUNITIES IN URBAN WATER DEMAND MANAGEMENT

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Urban water demand management is a relatively new field for environmental engineers and scientists. Interest in this topic in Florida has been stimulated by recent droughts and findings from water supply assessments that growing groundwater pumpage and surface water withdrawals are causing detrimental impacts on the resource. In such cases, Florida water management districts are required to develop regional water supply plans that focus on alternative water supplies including reuse of wastewater and stormwater, water loss reduction, and programs that reduce current water demand patterns using a variety of best management practices. Some water utilities have made significant investments in water demand management during the past 20 years. Statistical analyses of water use time series data indicate that significant changes in per capita water use are occurring but the causes are elusive. Indoor water use rates are declining due to the introduction of more efficient water using devices. However, outdoor water use is increasing due to the growing popularity of in-ground sprinkler systems. Water use restrictions and the introduction of water conservation rate structures appear to reduce water use but the evidence is spotty. A process level understanding of urban water use is essential if it is to be regarded as a reliable substitute for increasing supplies, the traditional solution for a supply-demand imbalance. This presentation will highlight research opportunities in urban water demand management based on recent experience of the Florida Water Conservation Clearinghouse research team at the University of Florida.

QUANTITATION AND CHARACTERIZATION OF DRY AND WET WEATHER PCB LOADS IN THE URBAN HOUSTON ENVIRONMENT--HOW MUCH DOES THE URBAN STREAM SUFFER DURING A STORM, AND WHERE EXACTLY IS IT COMING FROM?

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Polychlorinated biphenyls (PCBs) are persistent contaminants often associated with locally sourced or globally transported legacy pollution. What is sometimes less understood concerning PCBs, however, is their quantitative contribution from the urban environment during the storm due to its unique sources (e.g. wastewater, urban surfaces, and consumer waste). PCBs in urban runoff are somewhat difficult to collect and quantify, especially in high enough number to allow statistical and trend analyses.

In this work, nine in-stream wet weather samples were collected and analyzed for all 209 PCB congeners. Dry weather samples (25) were also collected to compare differences in conditions. Chemical results revealed loadings that by median are 8.2 times higher in wet weather over dry with some increases of over 100-fold. Water concentrations were fairly similar despite higher loadings (0.82-9.4 ng/L wet vs. 0.46-9.0 ng/L dry), and the increased load was shown to come from large quantities of suspended matter in the urban watershed. Loads were modeled according to rainfall intensity and land use type using multiple linear regression, and source apportionment using principal component analysis revealed on-going non-traditional PCB sources such as building materials and non-Aroclor PCB 11 which contribute to a common urban PCB fingerprint in separate and independent watersheds. The work provides a basis for understanding the water quality impact of persistent organic pollutants from high density developed areas. Such understanding will be necessary to improve, retrofit, and build urban infrastructure that does not contribute to future water quality degradation.

BICYCLE INFRASTRUCTURE EVALUATION: WHY THE STREETS DON'T LIKE MY BIKE? CINCINNATI, OH; ST. LOUIS AND ROLLA, MO CASE STUDIES

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Multi-modal transportation development is the type of development where public transportation efficiency is maximized by the implementation of different transportation modes that complement each other, including being a pedestrian and a cyclist.

Bicycle infrastructure is a serious component of urban planning because the type of infrastructure required for implementation is a commodity that is always compared economically to high-range private vehicle related investments such as highways, parking lots, gas stations and roadways, in general.

The goal of this project is to evaluate the bicycle infrastructure of three cities' street network from the users point of view using the BLOS (Bicycle LOS) and use a modified BCI (Bicycle compatibility index) to evaluate the physical attributes of the streets.
The original BCI considers only two types of land use (residential/non residential) and does not include the economic impact of bicycle traffic. The author's version of the BCI incorporates relevant land uses (residential, small retail, retail, office space) and economic impact represented as tax payments per parcel.

A series of surveys will be handed to volunteer bikers riding fixed routes around the three cities. An average length of 9.5 miles is ridden and includes different street types, traffic volumes, surrounding land use areas, steeps and other physical characteristics that are considered to affect users perception of satisfaction.

As a result, street segments will receive two numeric attributes: a BLOS and a mBCI, combined to obtain a final grade to represent the adequacy of existing infrastructure. Information is developed and displayed as GIS maps.

MAKING URINE USEFUL: USING ION EXCHANGE TO REMOVE NUTRIENTS AND HARDNESS AT THE SOURCE

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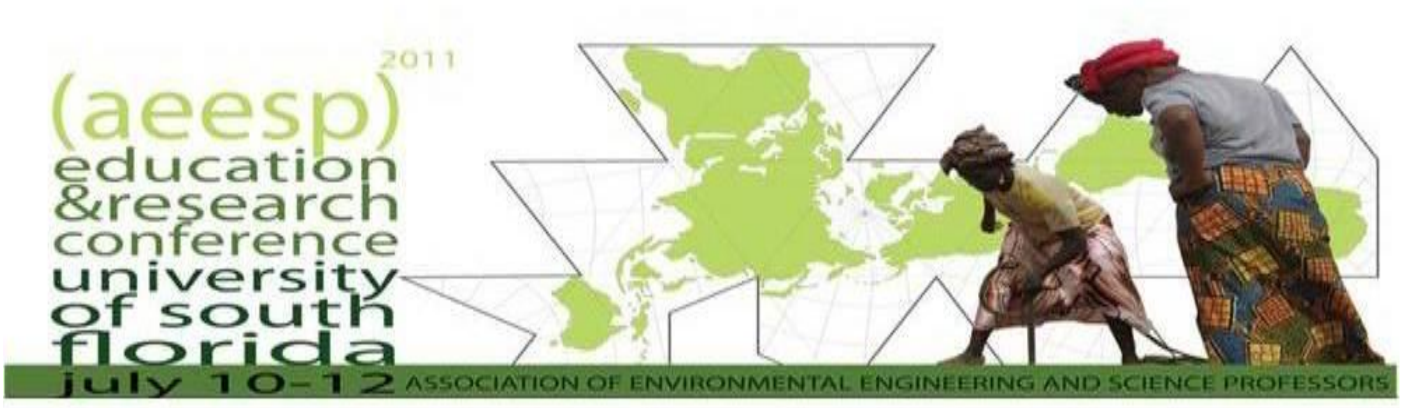
Urine comprises less than 1% of the total volume of wastewater received by a wastewater treatment plant, yet accounts for nearly 80% of the nitrogen and 50% of the phosphorus, exemplifying an all-too-common theme of inefficient wastewater management. With diminishing freshwater resources and increasing population density, it is imperative that we implement sustainable ways to treat water. Using ion exchange (IX) technology to treat toilet and urinal wastewater is one such water- and energy-saving solution with broad implications for source-water treatment, particularly in no-flush systems.

Currently, water-conserving bathroom utilities like waterless urinals, are prone to clogging due to the hydrolysis of urine that causes calcium and magnesium minerals to precipitate in the pipes. Cation exchange resins, which are electrostatically attractive to species that carry positive charges, could remove these minerals, while anion exchange resins could remove phosphates and micropollutants such as pharmaceuticals, the majority of which are excreted in human urine. This research will examine the efficiency with which IX resins, installed in the drains of waterless urinals, can remove calcium, magnesium, phosphate, and diclofenac. Synthetic urine prepared in the lab will be poured through the drain in incremental volumes (220 mL/simulated urination) representing high and low frequency urinal usage, demonstrating real-world utility. Various packing densities of IX resin will be compared based on removal efficiency and hydraulic retention times of synthetic urine. Treated samples will be examined for remaining concentrations of targeted species, using standard analytical methods, such as colorimetric titrations, UV absorbance, and ion chromatography.



Research Category #4: ***Vulnerability and Adaptation to Climate Change***

Research Category # 4

VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

PORE-SCALE MODELING OF REACTIVE MULTI-PHASE FLOW FOR CARBON CAPTURE AND STORAGE

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Physical and geochemical processes at multiple scales are yet to be understood for the storage of carbon dioxide (CO_2) in aquifers and the concomitant mitigation of CO_2 concentration in the atmosphere. In deep saline aquifers, the pores in the potential aquifers for CO_2 storage are initially filled with saline water (brine). The entrapment of brine in pores after injection of CO_2 is controlled by capillary forces and by the inertial force driving CO_2 inside the carbonate aquifer. The entrapped/residual brine will be a site for geochemical reactions which could alter the pore network and/or the permeability of the formation. Therefore, a pore-scale understanding of displacement of resident brine by CO_2 is critical to evaluate the storage efficiency of carbonate aquifers and to quantify any dissolution or precipitation of minerals (e.g., gypsum, calcite, dolomite). In this project, we have developed a multi-phase flow model, based on the lattice Boltzmann equation, which can describe pore-scale displacement of brine by invading CO_2. The multiphase flow model is applied to two different pore networks saturated with brine. We also examine the effects of CO_2 density and viscosity (which depend on formation temperature and pressure) on the amount of entrapped brine. Only by resolving the flow at the pore scale can we predict the residual brine saturation and other parameters which control CO_2 sequestration in deep saline aquifers. The amount of brine trapped after invasion of the domain by CO_2 is strongly dependent on the pore network and viscosity ratio between brine and CO_2.

MEASURING THE ANTIBACTERIAL IMPACTS OF SILVER NANOPARTICLES

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The unique antibacterial properties of silver nanoparticles (AgNPs) have led to their increased presence in a wide range of consumer products, including food storage products, wound dressings, and fabrics. As the use of AgNPs in consumer products continues to increase, the exposure of natural environments to AgNPs is a growing concern. For this reason, it is important to monitor the fate and environmental impacts of AgNPs in natural and engineered systems. The objectives of this study were to: 1) assess the antibacterial potential of pure AgNPs as well as AgNP containing consumer products and; 2) quantify the impact on environmentally relevant bacterial functions.

First, microbial growth inhibition of pure cultures of *Escherichia coli* K12, *Bacillus subtilis*, and *Pseudomonas aeruginosa* was determined by exposing cultures to AgNPs with three different coatings (i.e., citrate, gum arabic and polyvinylpyrrolidone) in concentrations ranging from 0.2 to 20 mg/L. Optical density and total protein analysis were performed to quantify differences in growth. Effects on growth were also tested in mixed cultures of wastewater bacteria originating from activated sludge. Significant growth inhibition was observed at concentrations of 20 mg/L of PVP AgNP and 2 mg/L of Ag^+. Microbial community analysis using denaturing gradient gel electrophoresis demonstrated that microbial community diversity was greatly reduced when PVP AgNP concentrations were greater than 20 mg/L (Figure 1). A similar community shift was noticed at 2 mg/L Ag^+. ICP measurements show that total dissolved silver concentrations were similar in both sets of experiments suggesting that the degree of inhibition is linked to the total dissolved silver concentrations in the media.

The antimicrobial effects of AgNPs on the ammonia oxidizing bacterium (AOB) *Nitrosomonas europaea* were also measured by comparing nitrite production rates in a dose response assay and analyzing cell viability using the LIVE/DEAD® fluorescent staining assay. AOB were selected as a model organism in this study because of their high sensitivity to wastewater contaminants. Their inactivation pathway has been established as the suppression of the membrane-bound enzyme ammonia monooxygenase (AMO) and heavy metals are known to cause this inhibition [1]. The percentage of nonviable cells was compared between control cells not exposed to AgNPs and cells exposed to AgNPs with three different coatings (citrate, gum arabic and PVP) in concentrations ranging from 0.2 to 200 ppm. Concentrations of nitrite were also monitored during the dose response assay. Media samples were collected and ionic silver levels were measured using ICP-MS. Nitrite production of *N. europaea* varied depending on the AgNP coating and size. PVP coated AgNPs reduced nitrite production by up to 15% at 20 mg/L, while the same reduction was observed with gum arabic AgNPs at concentrations as low as 2 mg/L (Figure 2). Surprisingly, the membrane integrity tests on *N. europaea* with 2 ppm gum arabic coated AgNPs showed no loss in viability, indicating that the mechanism, which reduced nitrite production, may not be the same as that of ionic silver, which did have a significant loss of cell viability (Figure 3). Experiments are ongoing to assess the toxicity of several other AgNPs with a variety of coatings on wastewater bacteria.

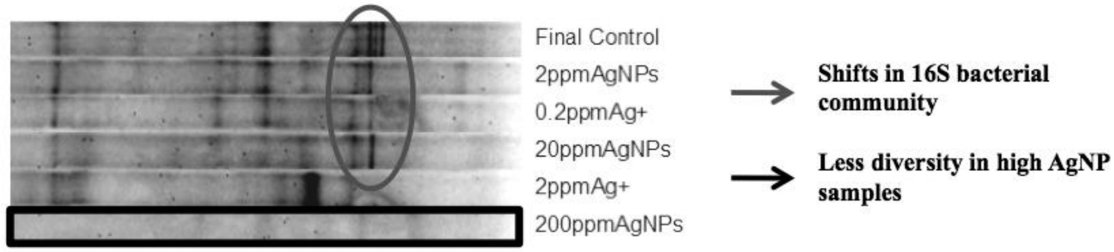

Figure 5: Changes in DGGE bacterial community profile with the addition of PVP coated AgNPs. There is a noticeable lack of bands in the highest concentrations of silver.

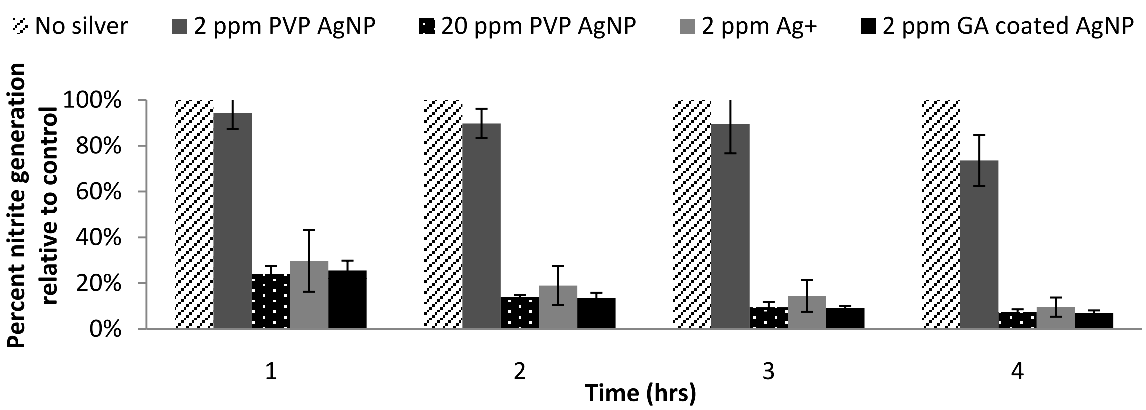

Figure 6: Percent reduction in nitrite production relative to control in *Nitrosomonas europaea*.

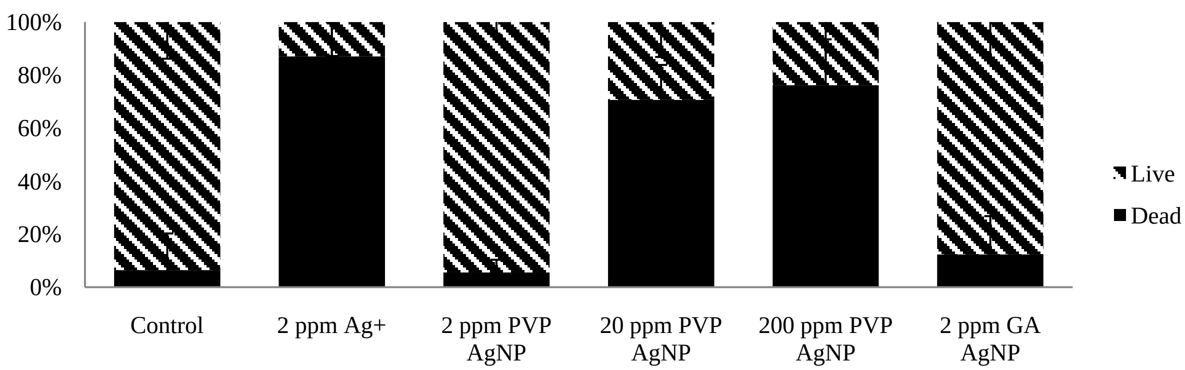

Figure 7: LIVE/DEAD analysis of *Nitrosomonas europaea*. Highest toxicity is noticeable at 200 ppm PVP coated AgNPs.

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COMBINED ION EXCHANGE AS AN INNOVATIVE APPROACH TO DECREASE MEMBRANE FOULING: EFFECT OF SOLUTION CHEMISTRY

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Climate change and population growth are exhausting water resources. Thus, alternative water sources are needed to supplement current supplies. However, alternative sources typically have elevated levels of dissolved organic matter (DOM) and total dissolved solids (TDS), making these waters more difficult to treat. High-pressure membrane filtration is an advanced treatment process commonly used to treat alternative sources. However, two of the major challenges associated with membrane processes are: 1) fouling of membrane elements due to DOM and TDS, and 2) management of membrane concentrate. The overall goal of this work is study combined ion exchange treatment of groundwater and membrane concentrate for the removal of DOM, sulfate, and hardness.

All experimental work is complete. Bench-scale experiments used 3 groundwater samples and 2 membrane concentrate samples from water treatment plants in Florida. Water samples were chosen based on high dissolved organic carbon (DOC) and hardness (i.e., divalent cations) concentrations. Preliminary experiments were performed with groundwater samples using magnetic ion exchange resin (MIEX), Amberlite 200C, and Purolite C107E. MIEX and Amberlite 200C were chosen for the remaining experiments based on preliminary results. Single-use and multiple loading jar test procedures were investigated.

The following conclusions can be drawn: 1) the multiple loading procedure, which is a better representation of the full-scale process, achieved higher removals compared to the single-use procedure, 2) combined ion exchange is an effective process for DOM and hardness removal for both types of water, and 3) combined ion exchange treatment would reduce the membrane fouling potential of the treated water.

IMPACT OF CHLORINATED WASTE SOLVENTS ON THE STRUCTURE OF CLAY IN SUBSURFACE LOW PERMEABILITY ZONES

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Dense non-aqueous phase liquids (DNAPLs) stored in low permeability subsurface zones serve as long-term sources for dissolved phase contaminant plumes in groundwater. Current models consider the movement into and out of low permeability layers to occur through transverse diffusion. Yet, field evidence suggests higher transport rates of contaminants than can be accounted for by diffusion alone. The objective of this work is to consider possible changes in the structure of the low permeability zones as a contributing factor to these higher rates of transport; specifically to examine the impact of DNAPLs on the structure of clay. DNAPLs are not pure organic liquids, so the impact of both the chlorinated solvent matrix as well as the surfactant additives must be considered. To quantify the impact, the basal spacing of clay minerals was measured in contact with chlorinated DNAPLs such as trichloroethylene (TCE) and tetrachloroethylene (PCE), aqueous surfactant solutions, as well as DNAPL wastes obtained from field sites. The changes in the basal spacing were found to be related to the type of clay and the dielectric constant of the solvent, with the basal spacing decreasing with decreases in the dielectric constant. On the other hand, contact with cationic surfactant solutions caused an increase in the basal spacing, with the impact increasing with the solution concentration. Contact with field DNAPL wastes caused a decrease in the basal spacing similar to that with the pure chlorinated solvents, suggesting that the impact is dominated by the solvent matrix.

INVESTIGATION OF CAPROCK FRACTURE EVOLUTION AFTER CO_2-BRINE FLOW

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Reactive flow experiments were performed on artificially-fractured caprock samples to investigate fracture evolution during simulated leakage of CO_2-acidified brine. The core samples are from the Amherstburg limestone, the caprock for a CO_2 storage demonstration project in Michigan. Fracture evolution was examined non-destructively via high resolution micro X-ray computed tomography. The cores were also sectioned and examined via backscattered electron and energy dispersive X-ray spectroscopy. Temperature and pressure conditions were 40°C and 10 MPa, corresponding to a depth of 1 km. The initial brine was designed to represent a brine having previously reacted with the injection formations minerals and had a starting pH near 4.7.

Results from two experimental trials will be discussed. The first case showed rapid dissolution of calcite leading to an increase in fracture volume 2.7 times that of the initial fracture. This extent of fracture deterioration occurred after only seven days of flow at a rate of ~17 pore volumes hr^{-1}. Mineral spatial heterogeneity coupled with preferential dissolution of calcite led to uneven degradation of the fracture surface. In contrast, results for the second specimen showed decreased flow permeability over the course of the experiment, which suggests mineral precipitation rather than dissolution. Unlike the first experiment, the input brine composition was closer to calcite equilibrium and had a smaller initial fracture aperture of ~125 μm. The stark difference observed in the two experiments, for rocks from the same formation, suggests caprock fracture evolution is highly sensitive to variations in mineral spatial heterogeneity, brine composition and flow conditions.

EFFECTS OF LONG-TERM PERFORMANCE VARIATIONS AND GLOBAL TEMPERATURE CHANGE ON THE ENERGY FOOTPRINT OF WASTEWATER AERATION SYSTEMS

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Aerobic biological treatment is the most common process for municipal wastewater treatment in developed areas of the world (IWA, 2008). Fine-pore diffusers are installed and operated in the majority of municipal wastewater treatment plants because of their higher aeration efficiency (Rosso et al, 2008a). Two parameters used to characterize diffuser performance are the process-water standardized oxygen transfer efficiency (□FSOTE), and the net head loss across the membrane, known as dynamic wet pressure (DWP). Fouling is inevitable and inexorable for all type of fine-pore diffusers: the efficiency decline is reflected by a declining F in □FSOTE, while concurrently the DWP increases by a factor □□(USEPA, 1989). Since the power requirements for aeration blowers (Metcalf and Eddy, 2003) are dependent on both air flow rate (hence, F) and discharge pressure (hence, □), both effects contribute superlinearly to increase aeration energy footprint. Therefore, it is crucial to understand the variation in F and □ to curb the decline in overall process efficiency and the increase in energy footprint. Ambient temperature affects this process, since blower energy is dependent on the density of displaced air (Metcalf and Eddy, 2003). Moreover, ambient temperature affects variations in the microbial activity and physiochemical properties of the mixed liquor in activated sludge, leading to higher metabolic and endogenous rates (*inter alia*, IWA, 2008). Therefore, global temperature change will affect not only blower energy but also process dynamics. The objective of this paper is to present our year-long study on F and □ dynamics, and its integration in a dynamic model that predicts aeration energy footprint after time in operation. The ultimate goal of this research is to include long-term temperature variations (i.e., multi-year scale) in the model, thus quantifying the effects of global climate change on process energy footprint.

We analyzed four fine-pore diffusers in clean- and process- water (protocols in ASCE, 2007 and ASCE, 1997) for one year at a local BNR water reclamation plant (8.5d sludge age; 16MGD; full NDN). Our results are reported in Fig. 1 as F(t) and □(t). For all diffusers, F(t) declines with time in operation. □(t)□increases for all diffusers except one, due to materials property changes, previously discussed (Rosso et al, 2008b). This compounds in the adiabatic blower power formula (Metcalf and Eddy, 2003), leading to much increased aeration energy footprint. The model illustrated in Fig. 2(A) calculates these effects dynamically, since □SOTE is a function of air flow rate and vice versa. In the model, the effect of ambient T variations is illustrated and will be included in the full-presentation. Fig. 2(B) shows a selected result for a chosen T. The grey shaded area is the energy footprint increase due to F while the orange area shows the □□effects. A multiplicative function of both F and □ contribute to energy footprint increase.

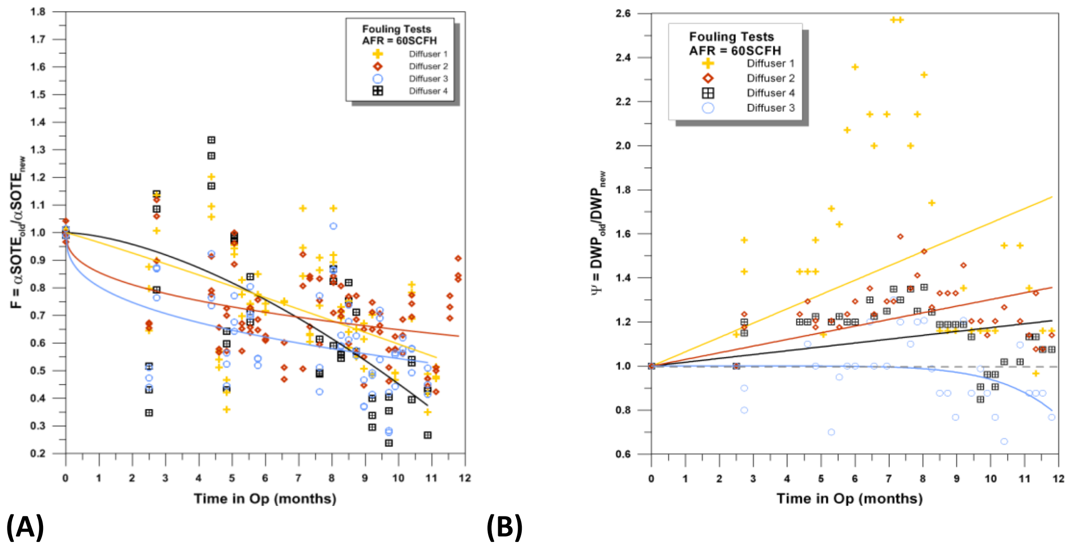

Figure 1. Summary of all fouling results for all diffusers. Plot of **(A)** F(t), **(B)** ⍰(t).

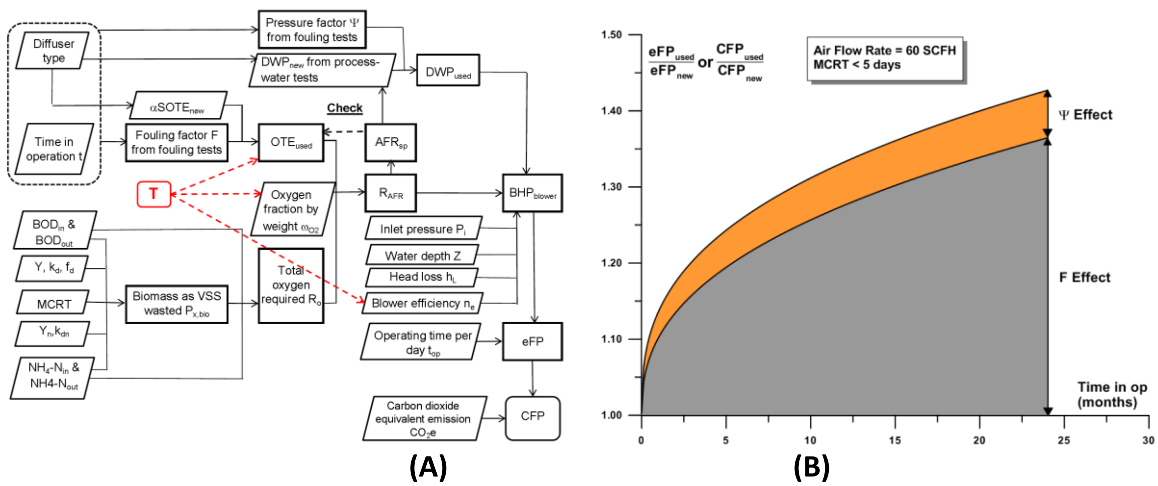

Fig. 2. (A) Dynamic energy footprint model flowchart (T effects highlighted in red); **(B)** Sample results showing the energy footprint ratio of used vs. new diffusers against time.

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NANOGENOTOXICITY ON DNA DAMAGE-COMPARATIVE STUDY BETWEEN PROKARYOTES AND EUKARYOTES

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Background: Nanomaterials (NMs) have been reported to induce DNA damage, which is responsible for mutation generation and may lead to cancer and heritable changes in ecosystems. Traditional methods for genotoxicity evaluation such as comet assay and Ames test are time-consuming with relatively low sensitivity and reliability. Application of gene expression profiling for mechanistic and rapid genotoxicity assessment has been shown to be promising. Here, we conducted genotoxicity assessment of several NMs in both prokaryotic cells and eukaryotic cells through gene expression. Genes involved in prokaryotic DNA damage and repair regulation system including SOS system and specific genes indicative of DNA damage recognition in repair pathways for eukaryotic cells were examined in response to NMs exposure.

Methods: We applied a real time gene expression profiling method using a whole-cell-array library of GFP-fused *E.coli* K12 strains for genotoxicity assessment with prokaryotic cells. For genotoxicity in eukaryotic cells, gene expression was carried out by RT-q PCR method using human lung epithelial cell line A549. In addition, cytotoxicity test was applied as well for comparison. The NMs evaluated include nTiO_2-anatase, carbon black, SWCNT (single wall carbon nanotube) and fullerene. MMC (mitomycin C) was used as a positive genotoxin control.

Results: Doses chosen for gene expression test were under LD_{50} for each material determined by cytotoxicity test, which will not cause significant cellular damage. At such dose levels, genotoxicity and DNA damage by most of these NMs were detected with both prokaryotic and eukaryotic cells. Table 1 summarizes the comparison of extent and pathways of DNA damages among the NMs studied. Relatively higher genotoxicity of nTiO_2_a was demonstrated by the altered gene expression in a number of SOS regulator genes as well as genes in the repair pathways. It also induced up-regulation of genes involved in double strand break (DSB) repair pathways in A549 cells. Carbon black (CB) led to significant up-regulation of gene *ada* in *E.coli* and up-regulation of MPG in A549 cells. Both of these genes are responsible for base alkylation, suggesting possible damage of CB through base alkylation pathway. However, the extent of gene expression alteration and the specific DNA-repair pathway related genes showed difference between prokaryotic and eukaryotic cells: Both carbon nanotube (CNT) and fullerene showed relatively low genotoxicity level with *E.coli* library test, as indicated by the moderate level of gene expression alteration of the SOS genes. In comparison, both of them induced higher magnitude of gene up-regulation in DSB, suggesting that eukaryotic cells may be more sensitive for double strand break damage. On the other hand, CNT induced Rad51 up regulation for homologous recombination, while fullerene induced Ku70 for NHEJ, a different repair way of DSB. The difference may be due to different mechanism of damage, suggesting the gene expression is sensitive to detect damage difference and specific pathways involved.

Table 1. DNA damage induced and repair pathways activated (as "+" sign) by NMs and MMC in *E.coli* and in epithelial human cell

Damage type	Repair pathway	Genes P	Genes E	MMC P	MMC E	$nTiO_2$_a P	$nTiO_2$_a E	Carbon black P	Carbon black E	SWCNT P	SWCNT E	fullerene P	fullerene E
single strand >30nt	SOS response	*recA, lexA*	not valid	+		+							
Base alkylation	Direct repair	*ada*						+					
Base alkylation	base excision repair	*mutT*	MPG	+	+	+			+				
Base oxidation	base excision repair	*mutT*	OGG1				+						
Single strand damage*	nucleotide excision repair	*uvrA*	XPC	+	+	+	+						
Double strand break	double strand break repair	*recA*	Rad51 Ku70	+	+	+	+				+		+

*Single strand damage includes cross links, single strand break, pyrimidine dimers and bulky adduct.
P: Prokaryote, *E.coli*; E: Eukaryote, Human cell A549
+: genes significant up-regulated in A549 or induction factor over 1.5 in *E.coli*.

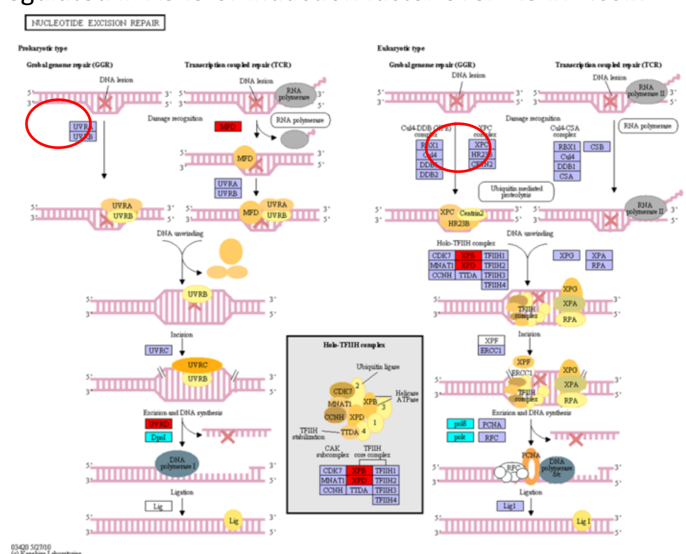

Figure 1 Nucleotide excision repair pathway in prokaryote and eukaryote. UvrA and XPC work at the recognition stage. Their up-regulation results in activation of the repair pathway.

Conclusions: The doses for gene expression test did not lead to detectable cytotoxicity on A549 cell (by viable cell counting) or *E.coli* (by turbidimetric method) in 24h for all the NMs. However, gene expression related to DNA damage and repair changed significantly at these doses, suggesting the gene expression method is more sensitive. The expression change occurred in 4 hours, which makes it possible for rapid test. Among the nanomaterials tested, $nTiO_2$_a displayed highest genotoxicity, including single and double strand damage, as well as oxidative damage on bases. NMs that have genotoxicity induced altered expression in genes involved in DNA damage and repair for both prokaryotic and eukaryotic cells, suggesting consistency between the two cell types. However, eukaryotic cell displayed more sensitivity towards NMs genotoxicity, especially to more severe double strand break, likely due to the differences in their cell wall/membrane structure and therefore different susceptibility to DNA damages, directly or indirectly.

WATER RETENTION CHARACTERISTICS OF UNSATURATED PEAT SOILS IN THE SHARK RIVER SLOUGH ENVIRONS OF THE EVERGLADES NATIONAL PARK (ENP): EXPERIMENTS AND MODELING DEVELOPMENT TO SUPPORT ENVIRONMENTAL RESTORATION

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Development and intensive drainage of the Everglades National Park ("the Everglades") has led to alterations in the physical characteristics of peat soil. Soil is a key defining compartment of the Everglades ecosystem, and soil preservation is important in ecosystem protection. There are two major soil types in the Everglades: the wetland soil, which is primarily peat formed by slowly decaying plant matter; and calcitic mud or marl, commonly found in the shallower peripheral marshes of the Everglades. The knowledge of the physical characteristics and behavior of peat soil in the vadose zone is needed to support the understanding and modeling of unsaturated flux and its role in plants competitive water needs and survival.

Two important characteristics of water in soil are the amount of water *(water content)* and the energy status of the water *(water potential)*. These two variables affect many soil processes, including soil temperature, oxygen storage and transfer and other gas movements, water and solute movement, runoff and infiltration, and plant uptake of water.

Ongoing studies characterize the soil-moisture characteristic behavior for Everglades soils in support of the development of unsaturated soil flow and transport models to simulate water storage, flow, and plant water uptake by vegetation (i.e., both native and invasive) to best understand the competition by plants for available water and the role of water availability in their survival. Both modeling and experimental work is being conducted with emphasis on the Tree Islands environs. Figure 1 illustrates patterns and differences in the soil-moisture characteristics of various types of peat soils. Figure 2 exemplifies the estimation of different water uptakes by a native plant in comparison to an invasive one. Experiments use an odometer-type pressure plate apparatus that is generates data to develop soil-moisture characteristic curves for various types of Everglades soils.
For modeling the S-shaped retention curve the van Genuchten (1980) model is used:

$$S_e = [1 + (\alpha h)^n]^{-m} \qquad (1)$$

where S_e is the water content (sometimes called effective saturation), and α, n and m represent empirical parameters that are unique to a soil type and condition
.

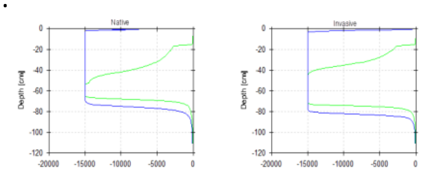
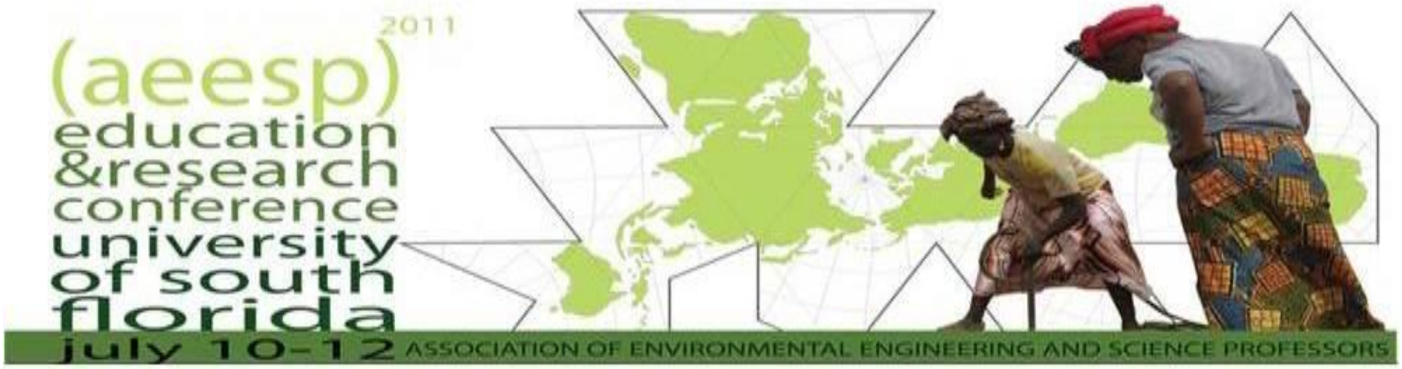


Figure 2. Differences in the predicted wetting soil profile for peaty muck (green) and marl (blue) soil samples in the Hardwood Hammock of the Everglades Satin Leaf tree island of the Shark River Slough



Research Category #5: ***Global Issues in Environmental Engineering***

Research Category # 5

GLOBAL ISSUES IN ENVIRONMENTAL ENGINEERING

SEDIMENT AND BACTERIA AGGREGATION USING MUCILAGE GUM

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The use of coagulants in water purification reduces turbidity and allows for easy removal of colloidal particles. The use of these chemicals in developing countries that lack proper sanitation methods and rely on contaminated water sources could greatly increase the quality of life and health. Case studies focusing on the implementation of water purification systems in developing countries revealed problems associated with community acceptance and maintained usage over time. In an attempt to circumvent problems accompanying robust treatment systems, the use of mucilage gum extracted from the *Opuntia ficus-indica* cactus is being studied as indigenous knowledge suggests its past use in household water treatment. Two fractions of mucilage gum were extracted from the cactus and utilized in the removal of the sediment kaolin and several strains of bacteria suspended in synthetic hard and soft waters. The addition of mucilage was observed to increase kaolin settling rates from 0.5 to 13.2 cm/min using standard column tests. In high cell concentration bacteria tests, increased coagulation time and settling with removal rates >98% were achieved. Alterations in the contaminant type and concentration as well as the water type (such as salt addition) were studied to determine the mechanism utilized by the mucilage to coagulate particles. The mucilage from the *Opuntia ficus-indica* is an ideal material for applications in water treatment because it is readily available worldwide, inexpensive and easy to process. In addition, it is accepted and commonly used by many communities that could benefit from its use in water purification.

BIOREMEDIATION IN EXTREME CLIMATES: PETROLEUM HYDROCARBON BIODEGRADATION IN CONTAMINATED ARCTIC SOILS UNDER SEASONAL FREEZE-THAW TEMPERATURES

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Petroleum hydrocarbon contamination in the Arctic has been a significant environmental concern due to uncontrolled discharges of petroleum fuels at former military and oil production sites. To date, little quantitative evidence exists on the extent of petroleum hydrocarbon biodegradation and associated microbial response during the semi-frozen post- and pre-summer temperature regimes of Arctic sites. Controlled pilot-scale biodegradation experiments were carried out in soil tanks (1 m×0.65 m×0.3 m) over 160 days with aged, contaminated soils from a large, contaminated Arctic site at Resolution Island site, Canada. The experiments were carried out in a cold room which was set at time-varying temperatures representative of post- and pre- summer seasons of the sites. The experiments showed that when the field aged-contaminated soils amended with N-P-K nutrients and maintained under aerobic conditions, semi-volatile hydrocarbons (F2:C10-C16) and non-volatile hydrocarbons (F3:C16-C34) were biodegraded up to 52% and 16%, respectively. Of this, a 32% removal of the F2 hydrocarbons was achieved under the sub-zero temperature regimes. The change in composition of the different petroleum hydrocarbon compounds due to biodegradation was determined with respect to the conserved biomarker, bicyclic sesquiterpanes. Microbial respiration was observed at sub-zero temperatures, but only when some unfrozen liquid water was present. An increase in 16S rDNA copy numbers was observed at temperatures down to -5 ºC. Hydrocarbon-degrading populations related to *Corynebacterineae*- and *Alkanindiges*-strains emerged only in the nutrient-amended soils during the freezing and thawing periods, respectively, and thus extremophile hydrocarbon-degraders were effectively stimulated, and responded selectively to specific temperature regimes.

THE EFFECT OF ENVIRONMENTAL HEALTH FACTORS AND HOUSEHOLD DEMOGRAPHICS ON THE OPERATION AND MAINTENANCE OF THE BIOSAND FILTER AND DIARRHEA HEALTH BURDEN IN RURAL GUATEMALA

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Public health policy and environmental interventions must recognize the complex interactions that influence individuals' contact with disease-causing pathogens and how household habits may impact adoption/acceptance of new technology. Understanding these interactions and habits is important for prioritizing expenditures and initializing programs. In August 2008, a water filter construction program was initiated by a non-profit organization near Playa Grande, Ixcán, Guatemala utilizing the Biosand Filter, promoted by the Centre for Affordable Water and Sanitation Technology (Calgary, Alberta, Canada).

The goal of this study was to measure the effect of various environmental health factors and household demographics on the operation and maintenance of the Biosand Filter and diarrhea health burden in the region. In August 2010, household surveys (n=286) were completed in the study region detailing water access, sanitation availability, hygiene practice, socio-economic status, education level, filter operation and maintenance and diarrhea health burden of the home.

A structural equation model was created based on accepted public health practices, a review of published research, and the researcher's previous knowledge. Model-derived parameter estimates indicated that: a) proper hygiene practices significantly promote proper filter operation and maintenance; and b) household education level, proper filter operation and maintenance, and improved water supply significantly reduce diarrhea health burden. The results from this study demonstrate the value of structural equation modeling approaches to show how public health policy decisions regarding diarrhea health or technology intervention should consider the characteristics of the people the policy will impact.

MOUSE GUT MICROBIAL COMMUNITIES ASSOCIATED WITH OBESITY

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With thirty percent of adults obese, sixty percent of adults overweight, and a growing concern for obesity among children, there exists an urgent need to evaluate potential environmental determinants of the obesity epidemic. Conventional wisdom points to a positive energy balance (i.e., too many calories consumed and too few calories catabolized) as the major causative factor, yet recent advances in pyro-metagenomics and deep sequencing with 16S rDNA approaches have suggested that the microbiota of the gastrointestinal (GI) tract in concert with the immune system and metabolic regulatory pathways are co-contributors. Molecular approaches have identified the predominant microbial genes in the GIs of humans as well as animal models.

In the current study, wild type (C57B16J) and transgenic (ob/ob; P2Y2 receptor knockouts) male and female mice were exposed to variations in diet (including standard chow AIN-93G, high fat diet D12942, and AIN-93G amended with an experimental neutraceutical). Caloric mass balances were determined through measurements of food intake, exercise, and changes in fat tissue and weight in replicate animals. Gluocse and insulin tolerance were also determined in fasting and fed animals. Cecum and ileum samples were collected from euthanized animals, and shallow and deep 16S rDNA sequencing were performed. The quantitative results from real time PCR targeting specific microbial populations were compared to the rank abundance observed in collector curves of operational taxonomic units.

The results of this study support a positive, statistically significant relationship between diet, the composition of the gut microbial community in mice, and obesity.

COMPARATIVE STUDY OF ACTIVE CAPPING MATERIALS FOR SEQUESTERING SEDIMENT CONTAMINANTS

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Sediment remediation and restoration is best accomplished using a combination of both removal and in place technologies due to the large volumes of sediments and the wide range in sediment contaminants and their concentrations. This research focused on capping, an in place technology. Active capping materials are increasingly being used to mitigate contaminant migration, cap recontamination, and contaminant bioavailability via reaction, sorption, or transformation. In this research, active capping materials were synthesized by amending clay minerals (e.g. sodium bentonite and organoclay) with selected active materials (approx 5% by wt) including powder activated carbon (PAC) and chemisorptive media. Sorption studies were performed for metals (2mg/L of Hg, As, Se, and Pb) and PAHs (100ug/L phenathrene and pyrene) in fresh and salt water microcosms. Treatment efficacy was determined by calculating the percent removal (and Kd) of the various materials selected for testing alone and in combination with clay minerals. The chemisorptive media performed the best at removing all metals (~100%) except Pb (<30%) and performed almost as well when combined with sodium bentonite. The organoclay alone and in combination with PAC was most effective at sequestering Pb (~40%). PAC alone or in combination with the clays was most effective at sequestering both PAHs in fresh and salt water. However, PAC performance was reduced in combination with clays. This research supports the development and broader application of active capping materials which will target the sequestration or destruction of specific sediment contaminants including heavy metals, nutrients, and pesticides.

ALTERNATION METHODOLOGY OF RENEWABLE ENERGY TO REDUCE CO_2 EMISSIONS

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To shift attention to Renewable Energy Sources people do believe that the launches pollutant of burning fossil fuels can be guilty of causing climate change associating global warming challenges on earth; whereas World has the enormous resources for natural gas though the country is experiencing crisis with the alternative fuel source. Consideration for solar power, wind turbines, energy from ocean waves and tidal flows, biomass, and geothermal heat sources are the possible options that can be taken on proper ground.

Possible alternative methods of renewable energy sources either do not emit carbon dioxide and dangerous greenhouse gases, or produce greatly reduced amounts of emissions. Combine these factors with the rising prices of oil, the shrinking of available fossil fuel resources issuing situation that begs for alternative energy production. The goal of every country is to be self-sufficient in the energy sector and to be able to export products or technologies to those who aren’t self-sufficient.

Our world is experiencing problems with this alternative fuel source having the resources for natural gas. There are many different ways to respond to energy needs and the crisis of utilizing fossil fuels for energy. Solar power, wind turbines, energy from ocean waves and tidal flows, biomass, and geothermal heat sources are all options that are on the table to consider. To minimize global warming threats by establishing Carbon sequestration aspects in renewable energy level can be an additional progressive approach issuing advantage of solar technology.

Carbon sequestration approach deals with Climate Change where discussion on the empirical scientific records and climate projections can be made considering human societies and ecosystems. How CO2 and methane emissions continue to rise; hundreds of coal plants and superhighways remain on the drawing boards, and international consensus on a new global climate agreement are represented and appeared sharing ideas and views by standing a common solution in devastating climate crisis situation; building progress towards a sustainable future by the Carbon sequestration project.

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World has a huge potential to take advantage of solar technology with the wonderful tropical climate that the country enjoys. Solar power has the benefit of great success when it is employed in an area that receives many days and months of sunshine. It is now estimated that one-third of electricity use is lost or wasted due to misuse. With solar panel technology, each panel owner will be accountable for the amount of power used.

It is also widely believed that world would be a good candidate to utilize wind power due to its monsoon winds and strong trade wind flows. Advantage of these natural occurrences to harness the energy associated with this renewable resource should be taken to benefit the world newly. Ten to twelve sites have already been identified as having definite potential with regard to wind flow for the possibility of installing wind turbines to help generate power. All renewable energy resources should be evaluated and analyzed, and the ones with the best match to the resources of the country should be pursued.

Committed Output:

Track #	Outputs:-
1	To take the advantage of natural occurrences to harness the energy associated with this renewable resource.
2	To respond to the energy needs and the crisis of utilizing fossil fuels for energy developing Carbon sequestration process.
3	To experience solutions with this alternative fuel sources.
4	To take advantage of solar technology.
5	To minimizing Global warming threats by establishing Carbon sequestration aspects in energy level.
6	To utilize wind power due to its monsoon winds and strong trade wind flows.
7	To experience solutions with this alternative fuel sources

INFLUENCE OF SOLUTION CHEMISTRY ON THE DEPOSITION KINETICS AND REMOBILIZATION OF OXIDIZED MULTIWALLED CARBON NANOTUBES

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Carbon nanotubes (CNTs) are increasingly used in commercial and industrial applications because of their superior mechanical and electronic properties. With CNT-containing products already available in the market, it is inevitable that some CNTs will be released into natural aquatic systems. In order to predict the fate and transport of CNTs in surface water and groundwater systems, it is important to understand the interaction between CNTs and natural surfaces. In this study, we investigate the deposition and remobilization of oxidized multiwalled carbon nanotubes (MWNTs) on silica surfaces with a quartz crystal microbalance with dissipation monitoring (QCM-D). The distributions of oxygen-containing surface functional groups for two MWNTs are determined using X-ray photoelectron spectroscopy in conjunction with vapor phase chemical derivatization. Deposition kinetics of lowly oxidized MWNTs (LO-MWNTs) and highly oxidized MWNTs (HO-MWNTs) are compared in monovalent (NaCl) and divalent ($CaCl_2$) electrolytes. HO-MWNTs are found to be more stable to deposition than LO-MWNTs in the presence of NaCl. However, in the presence of $CaCl_2$, the attachment efficiency profiles of both MWNTs are comparable, which is possibly due to Ca^{2+} cations having a higher affinity to form complexes with adjacent carboxyl groups on HO-MWNTs than with isolated carboxyl groups on LO-MWNTs. Additionally, the deposited MWNTs can be released from silica surfaces when they are rinsed with low ionic strength solutions. The degree of nanotube release was observed to be dependent on the ionic strength and pH of rinsing solutions.

PHOSPHORUS FRACTIONS IN ADVANCED WASTEWATER EFFLUENTS AND THEIR BIOAVAILABILITY

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INTRODUCTION: To address water quality problems, state environmental agencies and the U.S. Environmental Protection Agency (EPA) are requiring dischargers to reduce and achieve total phosphorus effluent concentrations as low as 0.009 to 0.05 mg/l. Advanced technologies are required for achieving ultralow effluent P levels, because the conventional P removal technologies only target at eliminating ortho-phosphate in the solution, whereas, for achieving low level of P, the residual effluent P fractions, which are resistant to conventional treatments and include refractory organic P or other refractory forms, have to be removed. A few previous studies showed that dissolved (soluble) organic P (DOP) becomes the dominant component in these highly treated effluents as the ortho-P being nearly completely eliminated. Because the removal of the final residual P, demands for alternative treatment technologies and significant investments, it is of great interest to both facilities and regulators to make a better understanding of the characteristics of the residual DOP in advanced effluents and their bioavailability to water quality-relevant algal species. Currently, little information is available for the bioavailability of wastewater derived DOP and this study aims to fill in this knowledge gap.

MATERIALS and METHODS: In the C pilot plant, three processes are operated and they are secondary system membrane bio-reactor (MBR), tertiary membrane filtration (MF) and tertiary continuous upflow sand filtration (BW-DSBP). The MBR influent is the main plant's primary effluent, and the MF and BW-DSBP share the same influent from the main plant's secondary effluent. Samples, before and after UV disinfection unit which is downstream of the tertiary process, were also evaluated. According to Standard Methods 4500-P, samples were filtered and analyzed for soluble/dissolved reactive P (sRP), soluble/dissolved acid-hydrolysable P (sAHP) and soluble/dissolved total P (sTP). Soluble/dissolved organic P (DOP) was calculated as DOP=sTP-sAHP-sRP. Bioavailable P (BAP) was determined using the bioassay method described in Standard Method 8111, using *Pseudokirchneriella subcapitata* (formerly *Selenastrum capricornutum*) for incubation of 14 days. In this study, we only focused on the evaluation of the bioavailability of dissolved P fractions since particulate phosphorus was considered not readily utilizable to algae. Original samples were filtered through 0.45 µm filter and filtrate was used for algal growth assay.

RESULTS and DISCUSSION: Figure 1shows the level and fractions distribution of effluents before and after algal bioassay. For MBR effluent with initial sRP concentration of 26µg/L, 85% of sRP was utilized by algae. For both media filtration and membrane filtration effluents, the sRP was near detection limit and it remained at detection limit level after the algal growth assay. Figure 2 shows that the concentration of DOP in the advanced effluents was between 0.012 -0.014 mg/L and majority (67% to 90%) of the DOP were bioavailable to algae. And the remaining DOP after algae growth incubation ranged from 1 to 4 µg/L. Soluble acid hydrolysable phosphorus (sAHP), presumably consists mainly of polyP and condensed P, was only detected in MBR effluent but not in the effluents from the BW-DSBP and MF processes (Figure 3).

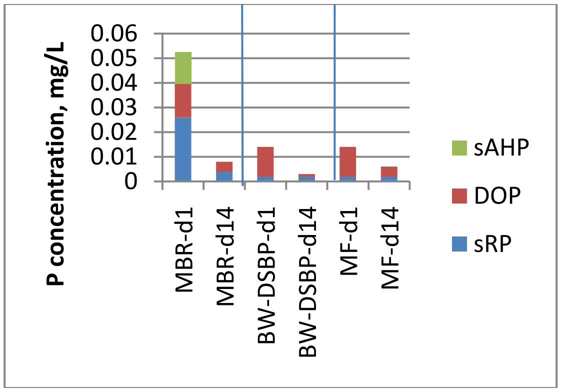

Figure 1. Bioavailability of various P fractions in different advance treatment process effluents

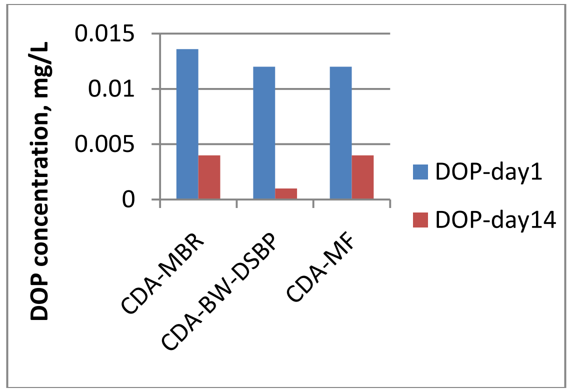

Figure 2. Bioavailability of DOP in different advance treatment process effluents

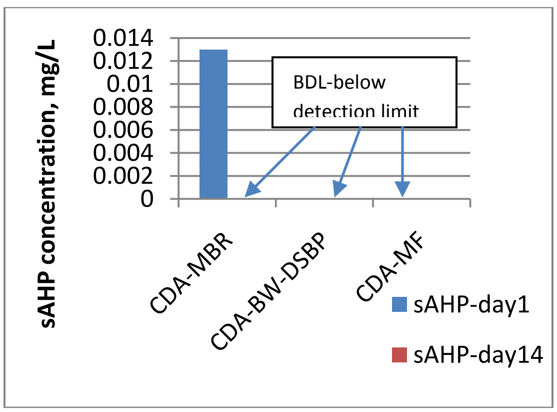

Figure 3. Bioavailability of sAHP in different advance treatment process effluents (BDL-below detection limit of 0.002mg/L)

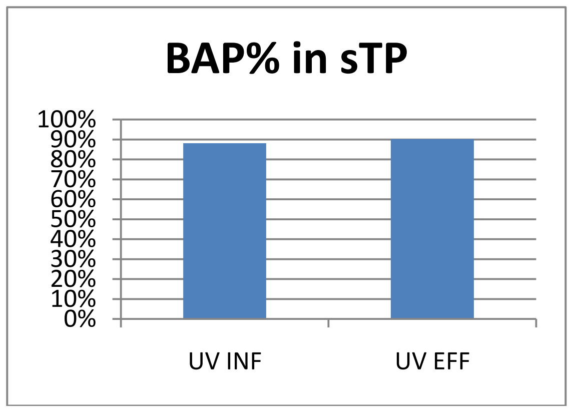

Figure 4. Percentage of BAP as of sTP in UV influent and effluent.

At least part of the sAHP in the MBR effluent is possibly associated with enhanced biological P removal (EBPR) process which enriches for a special group of PAOs bacteria (e.g.Accumulibacter) that intracellularly store polyphosphate granules, and the intracellular poly-P can be potentially released under certain conditions to produce soluble polyP. The fact that no sAHP was found with MBR effluent after 14 days incubation with algae either indicates that either sAHP itself can be utilized by algae or, during the incubation period, sAHP was hydrolyzed into sRP to be uptake by algae. Therefore, sAHP can be considered bioavailable to algae. UV disinfection process didn't seem to impact the bioavailable P level (Figure 4).

CONCLUSIONS: 1.Membrane filtration and advanced tertiary filtration processes can remove the effluent sTP to be as low as 0.015mg/L. The advanced tertiary processes can nearly completely eliminate all the ortho P (sRP), leaving the residual P consisting mostly of DOP and sAHP. 2. Fractionation analysis combined with algal bioavailability assay showed that most (almost 100%) of the residual sAHP and DOP (67-90%) in the final effluent are bioavailable to algae.

WATER QUALITY IMPROVEMENT OF IMPAIRED SURFACE WATERS WITH THE AIDE OF SELECTED COAGULANTS

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Point of Use (POU) water treatment technologies, such as the biosand filter, have gained interest as an effective tool to provide affordable potable water for households located in developing countries. The uniqueness of the biosand filter is its ability to be operated intermittently and provide biological treatment. The schmutzdecke layer in the biosand filter plays a critical role in the biological removal process. The schmutzdecke layer is known to be a mix of sediment and biological organisms. However, the formation of the schmutzdecke layer usually begins at least one week after the biosand filter has been in use. This project will focus on how the addition of coagulants can accelerate the formation of the schmutzdecke layer by adhering to and containing bacterial organisms where the schmutzdecke layer forms (in, on, or at the top of the filter column). In order to better understand the amount of organisms that can be contained through this process, jar tests will be performed with selected coagulants (cactus mucilage; alum; ferric chloride). Water quality data will be obtained from the surface water, the surface water with the initial addition of the coagulant, and the surface water at the end of the jar tests. Water quality tests will include: turbidity, total coliform counts, escherichia coli counts, CPR analysis, chlorine demand, UV absorbance, and heterotrophic plate counts. We expect to find the treatment efficiency of cactus mucilage comparable to the more commercialized coagulants of alum and ferric chloride. Alum is expected to have the greatest treatment efficiency.

NANOTECHNOLOGY AND SUSTAINABILITY: IMPACT OF CERIUM OXIDE NANOPARTICLES ON PLANTS

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Cerium oxide has found many uses in commercial products and the most notable application is probably as an additive in the gasoline. Previous study has shown that cerium oxide nanoparticles are relatively benign and only affect plant germination and elongation at very high concentrations (>1000 ppm). However, seed germination and root elongation represent only the earliest two growth stages of plants and much prior research has indicated the insensitivity of these two parameters to engineered nanoparticles. In the actual environment, cerium oxide could persist throughout the life cycle of plants at lower concentrations than the acute toxicity threshold. Therefore, it is more important to evaluate the developmental toxicity of cerium oxide nanoparticles to plants at environmentally relevant concentrations. It is also important to evaulate how they may affect crop yield and food safety after agricultural crops are exposed to these nanoparticles. Tomato plants (*Solanum lycopersicum*) were exposed to three concentrations of cerium oxide nanoparticles throughout their life cycles. Preliminary results indicated that cerium oxide nanoparticles at 100 µg/L could alter the growth stage of this plant. Plant biomass appeared to be unaffected by cerium oxide nanoparticles. However, tomato yields were lower for plants exposed to cerium oxide nanoparticles and the influence was concentration dependent. Heightened cerium oxide was detected in tomato fruits, suggesting increased dietary exposure to cerium oxide nanoparticles through consumption of tomatoes. The result showed high impacts of cerium nanoparticles at the disposal stage and has strong implications on sustainable development of nanotechnology.

EFFECT OF VARIOUS SLUDGE DIGESTION CONDITIONS ON TETRACYCLINE, SULFONAMIDE AND MACROLIDE RESISTANCE GENES AND CLASS I INTEGRONS

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Antibiotic resistance has been recognized as a major public health concern of our time. While previous efforts to study and control this problem have focused on pathogens in the clinical setting, there is increasing attention on the role of environmental reservoirs, because the majority of antibiotic resistance is more likely the case of acquired resistance, through horizontal transfer of antibiotic resistance genes (ARG). Wastewater treatment plants (WWTPs) are suspected to have the potential in disseminating ARG into the natural environment, considering that a wide range of ARG has been detected in effluent waters and waste sludge. This highlights the need to critically evaluate existing WWTPs treatment processes for their potential to attenuate ARG and limit their dissemination. Thus this study examines the effectiveness of a range of sludge digestion processes for eliminating ARG.

In this study, responses of nine ARG encoding sulfonamide, erythromycin and tetracycline resistance (*sul(I)*, *sul(II)*, *erm(B)*, *erm(F)*, *tet(O)*, *tet(W), tet(C)*, *tet(G)* and *tet(X)*), as well as the integrase gene of class 1 integrons (*int(I)*) were tracked by quantitative polymerase chain reaction (Q-PCR) in mesophilic anaerobic digestions at 10 and 20 day SRT, thermophilic anaerobic digestion at 47 °C, 52 °C and 59 °C, and a combined process incorporating thermal hydrolysis pre-treatment with downstream sequential anaerobic (37 °C, 15 day SRT) and aerobic digestions (32 °C, 5 day SRT). The bacterial communities representative of the various treatment conditions were characterized by denaturing gradient gel electrophoresis (DGGE) and relative diversity was calculated using the Shannon diversity index (H).

Mesophilic anaerobic digestion was found to effectively reduce *sul(I), su(II), tet(C), tet(G) tet(X)* and *int(I)* genes, but *tet(W), erm(B) and erm(F)* increased in response to treatment (Fig.1). Thermophilic anaerobic digestion operating at 47 ºC, 52 ºC and 59 ºC generally reduced all ARG and *int(I)* effectively except *tet(C)* at 52 ºC and 59 ºC and *tet(X)* at 47 ºC and 52 ºC with large standard errors (Fig. 1). During the combined process, thermal hydrolysis was observed to reduce all the ARG and *int(I)* to very low level, but they unfortunately rebounded during the following anaerobic digestion at 37 ºC (Fig.2). The final aerobic digestion at 32 ºC generated a distinct effect: while *sul(I)*, *sul(II)*, *tet(C)*, *tet(G)*, *tet(X)* and *int(I)* genes continued to increase, *erm(B)*, *erm(F)*, *tet(O)* and *tet(W)* genes decreased (Fig.2).

DGGE analysis revealed a decrease in bacterial diversity in thermophilic anaerobic digesters (H= 1.17, 1.22 and 1.19 for 47 °C, 52°C and 59 °C digesters respectively) compared with mesophilic anaerobic digesters (H = 1.45 and 1.51 for 10 and 20 day SRT digester respectively). Following thermal hydrolysis pretreatment, the sludge posseses very low bacterial diversity (H= 0.69), indicating that most bacteria and corresponding DNA was destroyed by this treatment. Bacterial diversity of anaerobic and aerobic digestions following thermal hydrolysis pretreatment were less than mesophilic digestion without pretreatment but higher than thermophilic digestions (H= 1.31 and 1.33 respectively).

The results of this study indicate that ARG encoding sulfonamide, erythromycin, and three classes of tetracycline resistance, generally respond similarly to digestion within each class, with some distinctions among classes. The reason for this distinct behavior may be relevant to host range of ARG, physiological characteristics of host bacteria under certain treatment conditions, such as temperature and present of oxygen, and rate of horizontal gene transfer under various treatment conditions. Bacterial community patterns in DGGE analysis provides evidence supporting this hypothesis. For example, mesophilic anaerobic digestion, which had a higher bacterial diversity, failed to disinfect some ARG, as compared to thermophilic anaerobic digestion. The rebound of ARG in anaerobic and aerobic digestion following thermal hydrolysis pretreatment may also relate to the increase in bacterial diversity. By comparing efficiency of the three treatment methods, this study indicates promising utilization of thermophilic anaerobic digestion and thermal hydrolysis pretreatment as a potential practical strategy for limiting the dissemination of undesired ARG.

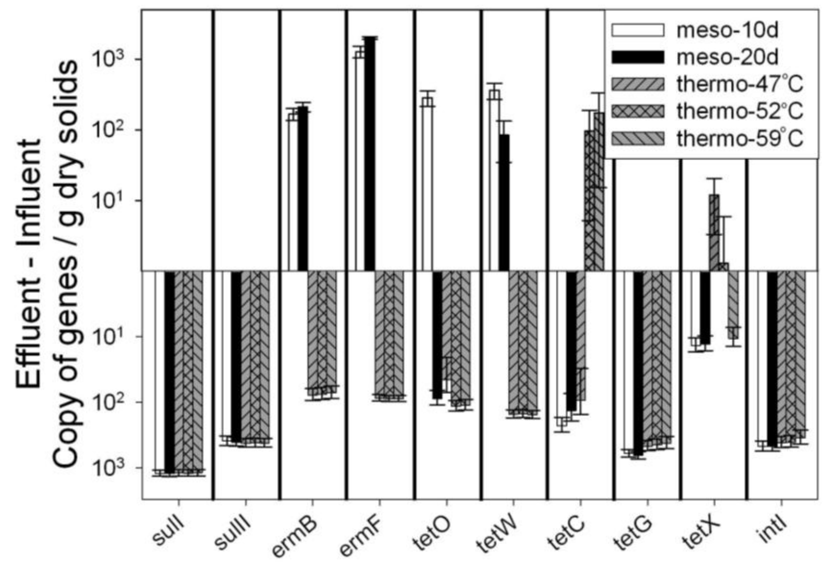

Fig. 1 – Net difference of ARG and *intI* concentrations in the effluent versus the influent of mesophilic anaerobic digestion with 10 day (meso-10d) and 20 day (meso-20d) SRT, and thermophilic anaerobic digestion (thermo) at 47 ºC, 52 ºC and 59 ºC. Error bars indicated standard deviation of each sample analysis.

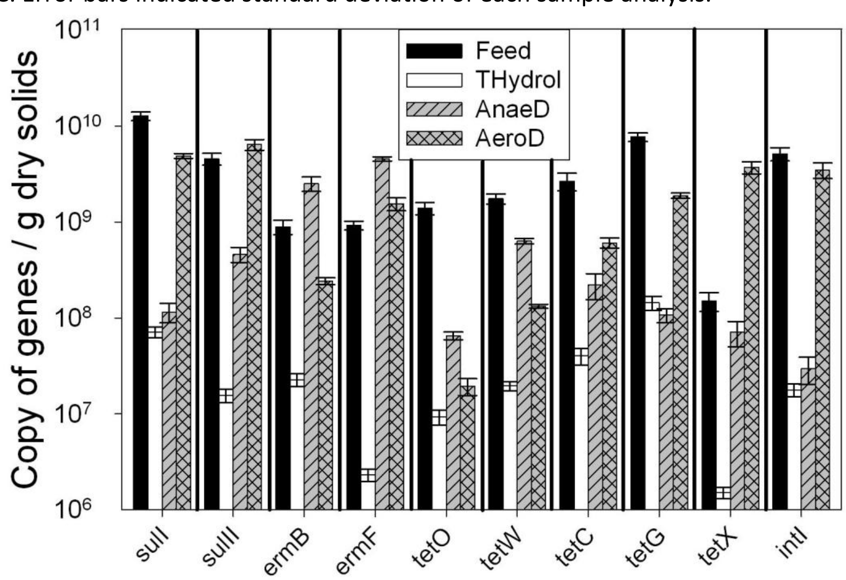

Fig. 2 – Quantities of ARG and *int*I in feed sludge (Feed), product of thermal hydrolysis (THydrol), effluent of following anaerobic (AnaeD) and aerobic digestion (AeroD). Error bars indicated standard deviation of each sample analysis.

MANUAL DRILLING OF WATER WELLS: USE IN INTERNATIONAL DEVELOPMENT, ACADEMIC RESEARCH, AND TEACHING

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Manual water well drilling techniques are increasingly being promoted to help provide water for drinking and irrigation purposes to developing communities throughout the world. The low cost of manually-drilled wells, compared to machine-drilled wells or hand dugs wells, as well as the low cost and relative portability of their equipment, make them an attractive water supply option when hydro-geological conditions are favorable. Manual drilling techniques include the basic categories of hand auguring, percussion, sludging, and jetting. Hybrid techniques consisting of use of more than one of these techniques, alternatively or simultaneously, often allow for increased drilling efficiency and depth in well drilling.

The presented research consists of an assessment of hand auguring, percussion, and percussion-jetting manual drilling equipment, designed for use in developing communities. As part of the study, the equipment set-ups are additionally assessed for relevance in academic field research, where collection of hydro-geologic data is often limited due to the expense of conventional machine drilling. While basic manual drilling techniques (e.g. hand auguring) are commonly used in academic field research, the use of hybrid manual drilling methods offer potential for significantly greater data to be obtained with minimal economic resources. Lastly, the research considers how the use of manual drilling techniques can be used to effectively teach essential aspects of groundwater hydrogeology to engineering, science and public health students, with manual drilling field labs being developed and taught at the University of South Florida over the past two years.

AID EFFICACY FOR POINT-OF-USE WATER TREATMENT: FOLLOWING INTERVENTIONS FROM INCEPTION THROUGH IMPLEMENTATION TO EVALUATION

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The provision of safe drinking water to improve health in developing countries has been a major focus of concern and action for decades. Point-of-use (POU) technologies have emerged in this context as highly visible and well-supported options with the reputation of being simple and low-cost. Many proposed technologies have passed rigorous laboratory and field-tests, but they still fail to achieve sustained, long-term use by the target populations. Such failures suggest that the processes by which technologies are developed, selected, implemented, and evaluated require further refinement. Evidence also suggests that the long-term success of technological interventions such as POU technologies will depend strongly on the extent of control that the user has over its use, repair, and replacement.

Through a case-study approach, we explore how specific POU technologies are taken from inception through implementation. Further, we evaluate what factors affect decision-making at each step of the process and what features of a technology promoters focus on most. We present findings from the comprehensive review of documents bearing on this process as well as open-ended interviews with stakeholders. Through this research, we will obtain a more in-depth understanding of the factors that determine how the international development community approaches the provision of safe drinking water. From this understanding, we can develop recommendations on how to incorporate these realities into decision-making and planning.

TRANSPORT STUDIES OF *NANO*-TITANIUM DIOXIDE IN POROUS MEDIUM

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Column studies were performed in order to determine the attachment and transport characteristics of of titania nanoparticles, *nano*TiO2 through iron oxide-coated (IOC) silica beads under different conditions of pH and ionic strength.The *nano*TiO_2 was dispersed by sonication in an aqueous medium, and the average particle size and zeta potential were measured at various pH values using a DLS zetasizer. The sizes of the unsonicated nanoparticles in aqueous media ranged from 300-500 nm, whereas after sonication the range decreases to 150-200 nm. The isoelectric point (IEP) of *nano*TiO_2 was 5.5.

Column studies were conducted to elucidate the sorption behavior of *nano*TiO_2 onto IOC beads as a function of pH (4, 5.5 and 8.3), ionic strength (0.001, 0.01, 0.03 M), adsorbent (bead) characteristics, and adsorbate (*nano*TiO_2) feed concentrations. The *nano*TiO_2 feed concentrations were chosen to be environmentally relevant and ranged from 100 to 500ppb. At a solution pH of 4, the affinity of the *nano*TiO_2 for the IOC-silica beads was the highest, whereas affinity for the IOC decreased with higher pH values, as the surface charge of both materials became increasingly negative, as expected from DLVO theory. At pH 4 and 5.5, the attachment efficiencies increased with increasing ionic strength, whereas, as pH 4, the attachment efficiency did not change significantly with increasing ionic strength,. In slightly acidic soils it can be expected that *nano*TiO_2 will not travel as far, whereas *nano*TiO_2 is expected to be highly mobile at pH 8.3, the pH of many aquatic environments.

PULACLOUD: A FRAMEWORK FOR CROWDSOURCING HUMAN COMPUTATION TASKS FOR DATA ANALYSIS TO ENABLE ECONOMIC DEVELOPMENT

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This research outlines a new paradigm for scientific problem-solving, by engaging a previously excluded and marginalized group in the scientific endeavor through a process called crowdsourcing. The crowd of interest is in the developing world: a great number of people who are unemployed; who, simply by possessing human brains and sensory organs, have the ability to do a number of tasks that are beyond the capabilities of computer programs but are nonetheless repetitive. These are "human computation" tasks. Such tasks, being repetitive and time-consuming, are typically not performed by developed-world researchers either, and so various forms of data analysis are either accepted as being performed poorly by computer programs or not done at all. The new approach described herein is to use this new resource to enable new kinds of data analysis to address new problems or old problem in new ways. Such an approach has the additional benefit of empowerment for development at a grassroots level, circumventing the traditional (and largely unsuccessful) approach of large-scale infrastructure interventions. Preliminary work on the three dimensional protein folding problem, using the Foldit game, has demonstrated the feasibility of the approach and work is ongoing on two pilot projects: feature recognition in microscope images to accelerate progress in a series of biofilm reactor experiments, and image classification and knowledge extraction from journal article figures to enable biochemical pathway mapping.

A LONG-TERM STUDY OF MICROBIAL EFFICACY AND USER ACCEPTABILITY OF TWO CERAMIC WATER FILTERS DESIGNS USED IN THE DOMINICAN REPUBLIC

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Research has suggested that ceramic water filtration may be the most effective point of use option due to the ability to achieve significant pathogen removal in turbid waters where other options, such as chlorination or UV disinfection fail (Sobsey et al, 2007).

Silver is added to improve microbial efficacy (Oyanedel-Craver and Smith, 2007). Leaching over time decreases efficacy and increases health risks to consumers (Bielefeldt et. al, 2009). Silver segregation to the surface of the filter during the drying stage could expedite the loss of silver, calling into question the most effective silver application method (Larimer et al, 2010). To date no long-term field studies of the efficacy of filters or comparisons of silver loss by application method have been conducted.

Therefore research beginning September 2010 in a rural Dominican community of 58 households will evaluate the microbial efficacy and acceptability of two ceramic filter designs 1) Potters for Peace (PFP) flower pot-shaped design with soaked-in silver and 2) Filter Pure (FP) round-bottomed lemon-juicer shaped design with fired-in silver over a minimum of two-years.

Survey data collected after 6 months shows that although 100% of respondents (n=15) reported using the filters for all their drinking water needs 20% (n=3) had dry filters at time of the survey. Users filled the filter an average of every 2.4 days producing approximately 2.8 L/day confirming exclusive use of water for drinking needs. The filtration rates were significantly lower than the minimum design specifications (1L/hr). Average turbidity reduction of 58% and 84% PFP and FP while e-coli and total coliforms were reduced 80% and 78% for PFP and 56% and 70% for FP respectively. Monthly breakage rates were 1.1%-FP while no PFP filters were broken. With the broken filters the change in silver concentrations over time will be qualitatively evaluated, beginning in April, using a scanning electron microscope with EDS. Hydraulic laboratory testing initiated in March will be compared to field measurements and used to develop mathematical models to represent the different filter geometries that may then be used to improve filter performance.

USING "COLLAPSE" TO TEACH SUSTAINABILITY

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Sustainability and sustainable development are concepts that increasingly drive environmental engineering and science education and practice. This is appropriate, and yet these terms are inherently ambiguous. These concepts can be "operationalized" for students and practitioners by using the tools of industrial ecology and associated methodologies. However, the potential negative future outcomes associated with our problems of nonsustainability and the choices we make as a society remain vague and remote for students. One possible solution for overcoming this challenge is to look critically at what has happened to societies that took a nonsustainable path and what became of them. Therefore, the goal of this work is to use the book, "Collapse: How Societies Choose to Fail or Succeed," by Jared Diamond (2005), as an alternative approach for examining the factors that contribute to a society being sustainable or unsustainable. Selected societies and problems leading to non-sustainability will be examined using simple quantitative tools and critical thinking. For example, the role of population growth, environmental damage, and climate change in the collapse of Norse Greenland can be examined using the exponential and logistic models, and their modifications (e.g., Lynnerup, 1996, Arctic Anthropology, Vol. 33, No. 2, pp. 122-136). This examination could be done in a workbook fashion, allowing for active, group, learning, with supporting mini-lectures as necessary, similar to the approach used by McConnell and Abel (2008) in "Environmental Issues: An Introduction to Sustainability, 3/E." In this presentation, the example of Norse Greenland will be provided as a sample module.

SEASONAL POPULATION CHANGES OF AMMONIA-OXIDIZING ORGANISMS AND THEIR RELATIONSHIP TO WATER QUALITY IN A CONSTRUCTED WETLAND

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Nitrogen removal in constructed wetlands mainly relies on autotrophic nitrification followed by heterotrophic denitrification. Two major microbial groups are now believed to be involved in ammonia oxidation during the first step of nitrification: ammonia-oxidizing *bacteria* (AOB) and ammonia-oxidizing *archaea* (AOA). We determined the abundance and composition of ammonia-oxidizing organisms and their seasonal population changes in a constructed wetland over a two year period to define the potential links between the water quality and nitrifying microbial population. Real-time quantitative polymerase chain reaction (q-PCR) targeting the specific *amoA* genes resulted in AOA as more dominant in wetland soils and water in both summer and winter. The AOB were more sensitive than AOA to low temperature. Terminal restriction fragment length polymerization (T-RFLP) analysis confirmed low peak intensities for the AOB species in the winter. There were links between the wetland water quality parameters and the abundance of AOA and AOB. The removal efficiencies of NH_4^+-N in wetland water in the summer and winter were 96% and 93%, respectively, while the wetland effluent NO_3^--N concentrations increased from 4 mg/L in the winter to 11 mg/L in the summer. Although more complete nitrification was correlated with higher abundance of ammonia-oxidizing organisms in summer.it was further correlated with a substantial increase of AOB population whilst the number of AOA in soils remained unchanged. These results suggest that the improved nitrification in the summer is mainly driven by AOB in the constructed wetlands treating ammonia-laden wastewater.

WAVE INDUCED STRIPPING OF VOCs IN THE OCEAN MIXING LAYER AFTER OIL SPILLS

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Air stripping is a mass transfer process which is used to remove volatile organic compounds (VOCs) from water. The rates at which VOCs are transferred from water phase to air phase can be characterized by mass transfer coefficient and the concentration gradient across the air/water interface. The amounts of VOC transferred are controlled using different air to water ratios (A/W) to achieve desired removal efficiencies. In oceans and seas, wave action results in significant mixing effects. Fresh oil slicks could be significantly reduced in size due to the stripping phenomena depending on the sea conditions and intensity of mixing. The objective of this study is to characterize the stripping profile of benzene and naphthalene as a model for VOCs and non-VOCs in fresh oil slicks in relation to sea conditions. Stripping parameters (i.e., stripping factor, number of transfer unit) were analyzed in relation to the wave characteristics and mixing intensity using horizontal stripping theory. Characteristic A/W ratios, stripping factors, and stripping times were estimated in relation to mixing layer parameters. The water column was analyzed with specific air to water ratios (A/W) corresponding to layers, depending on the sea conditions. The mixing intensity was defined in terms of Reynolds Number corresponding to specific sea conditions. Characteristic mixing profiles in the water column were developed and corresponding wave-induced stripping effects were analyzed for the water column with depth. The amounts of entrapped and released air, and quantities of compounds released from the water column were estimated depending on sea conditions.

EXTRACELLULAR POLYMERIC SUBSTANCES CHARACTERIZATION AND INTERACTION WITH ANTHROPOGENIC MICROPOLLUTANTS IN ACTIVATED SLUDGE

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Extracellular polymeric substances (EPS) are produced by microorganisms present in wastewater treatment processes and have an essential role in floc formation, though the composition and quantity of EPS vary with treatment processes (Frølund *et al.*, 1996; Yang and Li, 2009). Due to their organic nature, EPS interact with the hydrophobic micropollutants present in wastewater during treatment and thus can play a role in their removal. A plethora of anthropogenic micropollutants such as pharmaceuticals, fragrances, and endocrine disrupting compounds have now been detected in domestic wastewater worldwide (*inter alia*, Murray *et al.*, 2010). It has been shown that activated sludge processes (ASP) operating at elevated sludge retention time (SRT) are associated in general with better performance at removing anthropogenic micropollutants (Soliman *et al.*, 2006). Therefore, it is important to test whether the EPS play a role in removing anthropogenic micropollutants. The goal of this study is to characterize EPS and correlate it with the removal of anthropogenic micropollutants in different wastewater treatment processes. In this study, we categorized EPS into a tightly-bound (TB-EPS) and a loosely-bound (LB-EPS) fractions. These fractions could potentially affect the interactions of EPS with micropollutants and micropollutants' fate if released differently by the biomass to the secondary effluent.

We performed lab-scale experiments using ASP biomass from local biological nutrient removal (BNR) treatment plants. EPS measurements included protein, carbohydrates (DuBoi *et al.*, 1956), and fatty acids concentrations. We also measured the ASP specific surface area and surface hydrophobicity. Samples were obtained from the Irvine Ranch Water District (IRWD) water reclamation plant (16 MGD, 8.5d SRT, full NDN). Wastewater samples were analyzed immediately after sampling. We compared two methods for EPS extraction: thermal extraction and extraction with cation exchange resin (CER). LB-EPS and TB-EPS were obtained from thermal extraction (Yang and Li, 2009), whereas total EPS were extracted with CER (Frølund *et al.*, 1996). Biomass samples were analyzed for EPS and micropollutants (SPE, C18, Alltech) on GC/MS (Thomas *et al.*, 2009). We are currently focusing our investigation on a synthetic fragrance, galaxolide (CAS No. 1222-05-5), commonly present in municipal wastewaters.

Our results show that the Lowry (1951) method was the most suitable for EPS protein analysis, compared to the methods of Bradford (1976) and Smith (BCA) (1985). EPS protein composition varies among samples (Figure 8), although the total protein concentration was consistently around 200 $\mu g \cdot mL^{-1}$, and LB-EPS also consistently had lower protein concentrations than TB-EPS. Fatty acids in the form of fatty acid methyl esters (FAME) (Sasser, 1990) were detected in the EPS fatty fraction. Carbohydrate concentrations in TB-EPS and LB-EPS were in the range 35-39 $mg \cdot L^{-1}$ and 0.70-0.78 $mg \cdot L^{-1}$, respectively. Again, TB-EPS had higher carbohydrate concentration than LB-EPS. This means that most of the organic substance is tightly associated with the bacterial surface. Galaxolide was detected in TB-EPS (concentrations > 130 ppt) whereas for LB-EPS it was below detection limit. According to our extraction method, the recovery of galaxolide was higher than 70%. Our results suggest that higher EPS mass in activated sludge flocs corresponds with higher galaxolide removal from the water phase.

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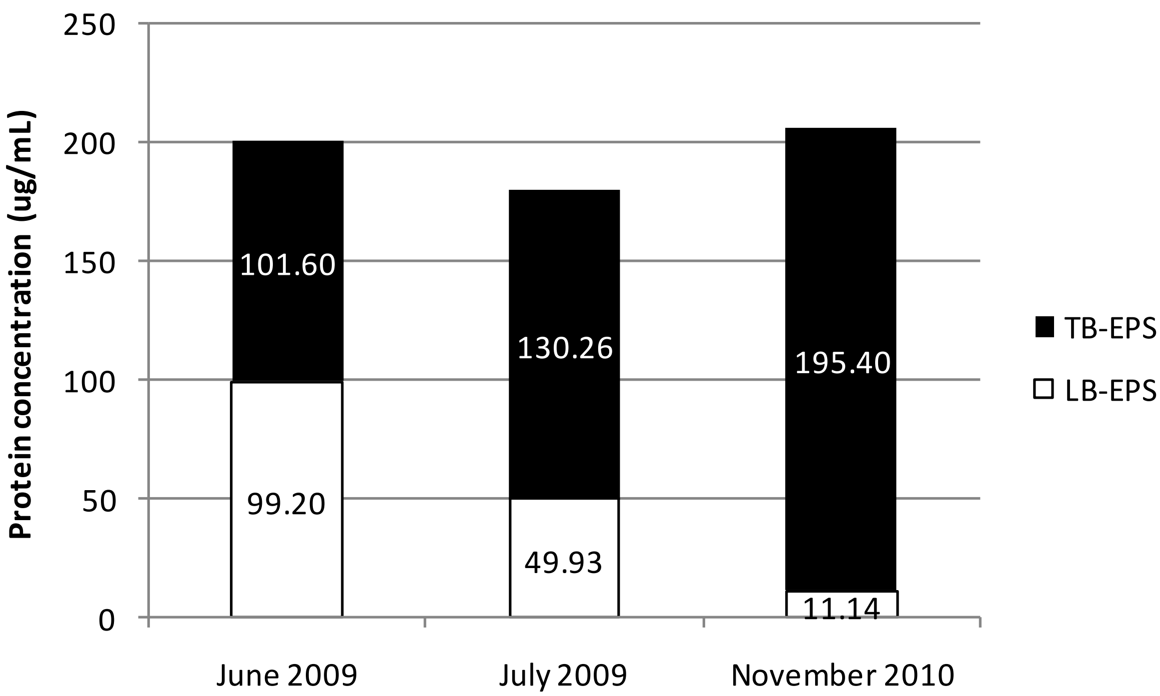

Figure 8. EPS protein composition changes in activated sludge. The wastewater temperature varied from approximately 24ºC in June to approximately 19 ºC in November.

GENOME BASED BACTERIA QUANTIFICATION IN HUMIC ACIDS LADEN SOILS

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Humic substances such as humic acids are naturally occurring organic substances in soils. Humic acids are the most commonly reported group of inhibitors in environmental samples. In order to overcome the adverse effects of humic acids in the typical gene quantifications such as real-time PCR, we have adopted our newly developed NanoGene assay to quantify the bacteria in soils that contain varying amounts of humic acids. The NanoGene assay is based on the combination of magnetic beads (MB), dual quantum dots labels (QD_{565} and QD_{655}), and sandwich DNA hybridization. As a result, the NanoGene assay was significantly resistant to the humic acids, when the real-time PCR assay was completely failed in the presence of humic acids. The two soils, which were inhibited by real-time PCR, contained 1.5% and 0.4% humic acids. However our assay resulted in the successful quantification of *eaeA* gene (functional gene of *E. coli* O157:H7) with the linear quantification range from 5×10^3 to 5×10^8 CFU/g soil (R^2=0.90). Interestingly, the real-time PCR assay was also failed even after the purifications. It is implicated that additional purifications did not completely remove the humic acids associated with gDNA. Our preliminary experiment demonstrated that the presented gene quantification method is suitable for the quantitative bacteria (or gene) monitoring in the soils that are rich in humic acids.

IMPACT OF SPATIAL AND TEMPORAL SCENARIOS RELATED TO URBANIZATION AND CLIMATE ON THE HYDROLOGY OF A RAPIDLY GROWING LATIN AMERICAN CITY

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Poorly planned urbanization in rapidly growing cities in the developing world has resulted in a lag in the provision of basic services such as piped water, sanitation, stormwater management, and waste collection. The loss of permeable surfaces due to urbanization creates a shift in the distribution of water from partially subsurface flow to predominantly surface runoff. Within the city of Santa Cruz (Bolivia), this increase in surface runoff causes yearly flooding as well as an increased use of impervious stormwater infrastructures. In this study, historical, current, and future impacts of spatial alterations (i.e., land use change) and temporal changes (i.e., climate change) on urban hydrology are estimated for Santa Cruz. A regional water balance model is used to conduct an initial assessment of the hydrological impacts of three development scenarios and three climate scenarios.

Results indicate a long-term shift in the regional hydroclimatology in Santa Cruz towards more arid conditions, which has the potential to trigger additional stresses on natural and engineered systems. Both temporal and spatial changes were found to impact urban hydrology, however, the most extensive land use changes produced the largest hydrological impacts – increased surface water runoff (30%), decreased groundwater recharge (115%), and decreased soil moisture (42%). Sustainable land use and integrated water management (e.g., decentralized stormwater management, designated aquifer recharge areas, green space preservation) are advocated to minimize negative impacts on urban water resources as well as provide adaptation strategies for future climate change.

IS SILVER ION A GOOD OPTION AS A DISINFECNTANT IN WATER SYSTEM?

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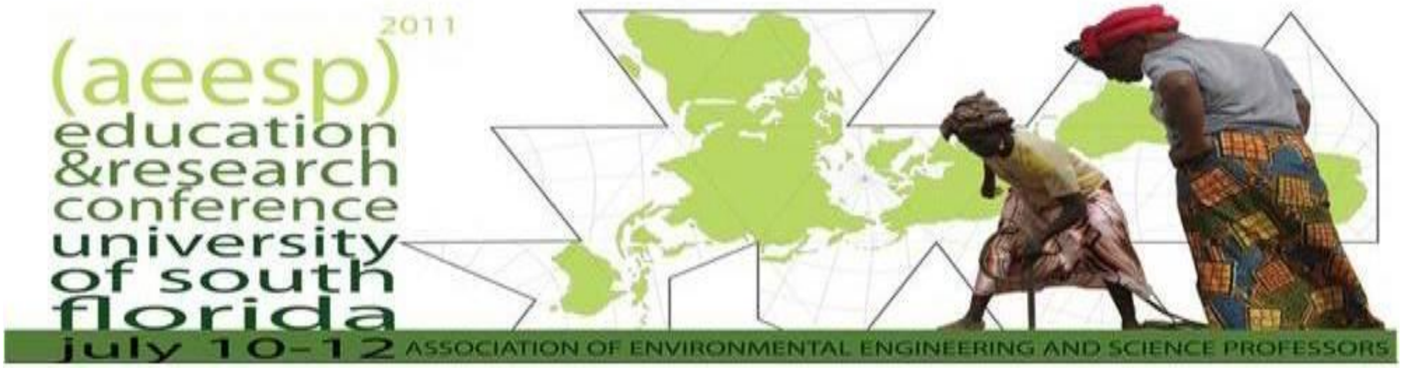
Recently, we have seen the increasing usages of silver ion (Ag^+), as a microbial disinfectant, such as an additive in everyday-consumer products and alterative disinfectant in water systems. However, the long-term Ag^+ efficiency hasn't been fully disclosed yet. Because silver-resistance mechanisms of microorganisms have been reported sharing similar genes of known copper-resistance mechanisms, microorganisms could adapt to Ag^+ toxicity over a long period of time, rendering Ag^+ useless as a bactericide. This study tested genetic responses of an opportunistic pathogen, *Pseudomonas aeruginosa*, in the sessile-biofilm condition (using annular reactor to simulate environmental condition in water distribution system) under the influences of Ag^+. The results suggested that *P. aeruginosa* in sessile biofilm not only used a copper-resistance gene, a P-type ATPase, to transport Ag^+ out of cell, but also used oxidant-defense-system genes to relieve the Ag^+ induced oxidative stress as well as accumulating Mg^{2+}inside the cytosol to reduce the entry of Ag^+. Most important, in our long-term test, we discovered that *P. aeruginosa* biofilm could adapt to Ag^+ toxicity and re-establish stable population after consistently exposing to 5 mg/L of Ag^+ over 51 days by using similar sets of genes. Because biofilm is the common phase that microorganisms exist in the environment, and the silver-adaptation-mechanism genes found in this study are common genes that widely exist in microorganisms. Therefore, if Ag^+ can't completely eradicate microorganisms, the resilient growth of microorganisms seems to be inevitable. We conclude that silver ion might not be a good choice as a disinfectant in water systems.



Research Category #6: ***Energy as a Cross-Cutting Theme***

Research Category # 6

ENERGY AS A CROSS-CUTTING THEME

A SCALABLE MICROBIAL ELECTROLYSIS CELL FOR RENEWABLE HYDROGEN PRODUCTION FROM WASTEWATER

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From food to fuel, hydrogen is a vital component of our society, yet clean and renewable methods for producing hydrogen are needed. One such method known as electrohydrogenesis combines the breakdown of organic matter by bacteria at an anode with a small input of electrical energy to generate hydrogen gas at a cathode at efficiencies much higher than those obtained using traditional water electrolysis. The reactors used to generate hydrogen in this manner are known as microbial electrolysis cells (MECs) and have thus far incorporated materials and designs that are not inherently scalable. Membrane separators, commonly included between the anode and cathode, contribute to both detrimental pH gradients and complex reactor designs. Platinum catalysts used to improve the hydrogen evolution reaction at the cathode are neither an affordable option for large scale reactors nor an environmentally sustainable material. In order to avoid these materials and move towards a scalable design, we developed a membrane-free MEC that used large surface area stainless steel brushes as cathodes. The utility of this design for scaling-up MECs was examined at the pilot level as we converted winery wastewater into electrical current in a 1,000 L membrane-free MEC using stainless steel cathodes. Alternatively, this new design was also scaled down to produce a high-throughput method of conducting bioelectrochemical research using small (5 mL) serum bottle based MECs. Further optimization of this scalable MEC design will likely make biological hydrogen production from waste streams a reality.

METHYLATION POTENTIAL OF MERCURY DERIVED FROM COAL ASH: FINDINGS FROM THE TVA KINGSTON DISASTER

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Coal combustion products (CCPs) represent the largest industrial waste stream in the U.S. Coal ash, in particular, contains elevated levels of toxic elements such as mercury (Hg), yet much of this waste is typically stored in unlined holding ponds and landfills that are not monitored for their discharge to adjacent waters and are susceptible to failures. In this study we investigated the impacts stemming from the largest coal ash spill in U.S. history that occurred on December 23, 2008 at the TVA Kingston Fossil Plant in Harriman, TN. The disaster was caused by a failure of a holding pond that resulted in the release of 4.1 million m^3 of coal ash into the adjacent Emory River. Here, we report our findings from an 18-month survey after the disaster that documented elevated levels of methylmercury (MeHg) in the river sediments near the spill site. Moreover, we used isotopes of Hg to differentiate between mercury originating from the coal ash and mercury originating from historical contamination sources to this ecosystem. We also observed other water and sediment parameters (e.g., organic carbon, sulfide, sulfate) that indicated conditions favorable for mercury methylation by anaerobic bacteria. Overall, our results suggested that the coal ash was stimulating biomethylation of Hg in the river sediments (either by providing Hg or other substrates for sediment bacteria). This study highlights the need to consider the bioavailability of the mercury to methylating bacteria and the potential for MeHg production when evaluating the hazards of CCPs with respect to mercury.

MADAGASCAR BIODIGESTER SYSTEM

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A low-cost anaerobic biodigester has been designed and constructed by a team of students and professionals for sustainable waste management and energy production in rural Madagascar. Currently in Madagascar, wood is used for cooking-fuel leading to deforestation that destroys the habitats of endemic species. Triple bottom line sustainability goals are achieved with this project through keeping the costs of the system low and accessible to rural communities, providing a clean biogas energy source to communities while preventing disease by treating sanitation waste, deforestation, and pollution. The constructed reactor system, with a volume of 13.5 gallons, is designed to operate in the mesophilic temperature range and produce enough cooking fuel to supply a single burner for one hour each day.

The system incorporates materials available in Madagascar in a design that incorporates three reactors in series. The first reactor, begins the hydrolysis process under slightly aerobic conditions. The second reactor, a plug flow reactor (PFR), is the main anaerobic reactor. The PFR stabilizes the process through allowing separation of acid- and methane-producing regimes along its length. The effluent from the second reactor is released into the third reactor that ensures pathogen removal. The contents of the last reactor will be used as nitrogen rich fertilizer in Madagascar. The reactor is currently being operated and is approaching a reliable steady-state with gas production. This summer, two teams will travel to Madagascar to implement prototype units and build relationships with communities with the goal of establishing a locally-run business distributing these systems.

INTEGRATION OF MICROBIAL FUEL CELL TECHNIQUES WITH CONVENTIONAL ACTIVATED SLUDGE TREATMENT PROCESSES

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Bio-assisted electrochemical systems have the potential to produce bio-energy (electricity) from the organic matter present in wastewaters. These systems channel away electrons through anode respiring organisms and the electrode which result in reduced biomass production. The presence of an anaerobic zone followed by an oxic/aerobic zone in activated sludge process coupled with recirculation/recycling is apt for nutrient removal. This research aims to integrate microbial fuel cell (MFC) technology with conventional activated sludge treatment processes. The experiment was conducted in two phases: Phase I involved an anaerobic/oxic (A/O) configuration coupled with an MFC and phase II involved a membrane bio-reactor (MBR) configuration coupled with an MFC. While phase I showed improved nitrate removal efficiency by 30%, phase-II showed an increase of 20% efficiency compared to their control counterparts, A/O and MBR respectively. Both phases showed a reduced biomass production, which also helped to reduce membrane fouling in the MBR-MFC system. The membrane module with the integrated MFC ran through the entire experiment period of 100 days without the need for physical cleaning while in the control MBR the membrane had to be cleaned twice. The electrons shuttled through an external circuit in the MFC integrated systems generated an average of 0.14 V across a 1000 Ω resistor throughout the study lasting more than 200 days. Therefore the benefits of integrating MFC technology with activated sludge processes including reduced sludge production with potential electricity generation, decreased nutrient concentrations and less membrane fouling should be further explored.

ASSESSING AND REDUCING ENERGY REQUIREMENTS FOR ALGAL BIOMASS HARVESTING USING MEMBRANE PROCESSES

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Much of the algal biofuel research currently ongoing is geared toward selecting and modifying strains to increase their lipid content and growth rates. However, algal harvesting is a key bottleneck in making algal biofuels sustainable, especially for the smallest microalgal strains (~3 µm) that tend to be the best biomass producers. This project seeks to determine which algal cell characteristics are most important for decreasing energy requirements. Five algal species (*Dunaliella tertiolecta*, *Nannochloropsis oculata*, *Spirulina* sp., *Skeletonema marinoi*, and *Synechocystis* sp.) are being cultured in the laboratory and membranes of various pore size (0.01 to 0.2 µm) are used in dead-end and crossflow membrane experiments to assess energy requirements. Cell morphology (size and shape), extracellular polymeric substance (EPS) production, and cell surface zeta potential are being compared to determine their effects on membrane fouling. Protein, polysaccharide, and lipid content of membrane foulant layers are also being evaluated. Initial results indicate that cell morphology is a major factor affecting filterability, with filamentous algae requiring lower energy for harvesting due to their porous foulant cake layers. However, even the smallest, near-spherical algae (*Synecchosystis* sp.) can be made significantly more filterable using osmotic shock. An expected result of this work will be an understanding of how tuning water chemistry parameters (e.g. osmolarity, ionic strength, and pH) along with membrane operating parameters (e.g. applied pressure and crossflow velocity) can achieve minimal energy requirements for membrane-based algal harvesting.

ENERGY AND RESIDENTIAL WATER HEATERS: THE WATER-ENERGY NEXUS AT HOME

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Residential water heating is linked to the primary source of waterborne disease outbreaks in the United States, and accounts for greater energy demand than the combined water/wastewater utility sector and represents an integral part of the water-energy nexus (Table 1). To date, there has been little practical research that can guide decision-making by consumers, public health officials and regulators with regards to water heater selection and operation to minimize energy costs and the likelihood of waterborne disease. While there are many sustainability claims of certain water heater types (i.e., hot water recirculation systems and instantaneous water heaters) these claims have not been substantiated in head-to-head testing the interplay between water temperature, energy, microbial growth, and scaling need to be better defined.

Table 1. Impacts of Residential Water Heating

	Total Energy Costs	% of US Energy Demand	Funded Research in Progress?
Residential Water Heating	$9 Billion*	3 – 5%	Very little
Commercial Water Heating	$2.08 Billion*	< 1%	Very little
Water and Waste Water Utility Sector	$4 Billion	3%	Numerous projects

*Electric Water Heating Only

This work is aimed at reducing that liability by conducting the first assessment of residential water heating infrastructure performance in terms of energy demands, public health and environmental impacts. Using electric water heaters as a "worst case scenario" from an energy and microbiological perspective, we have outlined three types of systems that currently dominate the marketplace: 1) a standard hot water tank with no hot water recirculation (STAND), 2) a hot water tank with hot water recirculation (RECIRC), and 3) an on-demand tankless hot water system with no hot water recirculation (DEMAND). The hot water tank with recirculation has been marketed as a water and energy saving technology, since hot water is circulated throughout the pipe network via a pump and no water should be theoretically "wasted" while waiting for hot water at the shower. These systems, however, have not been evaluated for energy consumption, microbial and chemical effects, or efficiency.

We have set up the three systems under various conditions (high use, low use, high temperature, and low temperature) to assess the aforementioned variables. We have found that not only is there added energy consumption for hot water recirculation from the pump (25% higher), but the tank itself requires nearly double the energy to heat water as compared to the standard hot water system due to heat loss during circulation through the pipe system and the loss of natural stratification within the tank. Although the RECIRC systems arguably save water at the tap, there will additional consumption at the energy production phase due to reduced energy efficiency and increased energy demand (Table 2).

Table 2. Energy Efficiency Data for Water Heater Systems

Water Heating System	Condition	Q (gpm)	Average Energy Efficiency
RECIRC	60 °C, High Use	1.5	55%
RECIRC	48 °C, High Use	1.5	60%
RECIRC	48 °C, Low Use	1.5	19%
RECIRC	60 °C, Low Use	1.5	TBD*
STAND	60 °C, High Use	1.5	86%
STAND	48 °C, High Use	1.5	88%
STAND	48 °C, Low Use	1.5	42%
STAND	60 °C, Low Use	1.5	TBD*
DEMAND	High Setting	1.5	100%
DEMAND	Low Setting	1.5	TBD*

*TBD: To be determined in next phase of study (January 2011 – April 2011)

Temperature and chemical profiles for these systems also vary. While DEMAND systems may show the most consistent temperature during a single shower or flushing event, the outflow temperature is highly dependent on the incoming temperature of the water and flow rate. For example, our results show that at the highest setting and lowest flow rate, the temperature rise is insufficient in the winter months. RECIRC systems without one way valves show highly variable temperature during flushing due to cold water mixing. Chemical profiles show similar favorability towards STAND systems given that disinfectant decays much faster in RECIRC systems and has repeatedly been found to be as much as 1 mg/L less in these sytems. This could potentially lead to increased microbial growth and amplification of pathogens such as Legionella. In fact, Pinellas County has documented increased Legionella growth within these systems. Hence, this particular green design does save a small amount of water, but with an enormous increase in energy costs and potentially significant adverse health consequences. Thus, the marketed "green" RECIRC system has lower energy efficiency, less temperature stability, lower disinfectant residual and possible higher incidence of *Legionella.* Our next phases of work will attempt to optimize the RECIRC system and re-evaluate these variables. It is possible that with optimization, RECIRC systems will perform more desirably.

LIFE CYCLE ASSESSMENT (LCA) OF ALGAE BIOFUEL AND/OR BIOGAS PRODUCTION USING WASTEWATER

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Due to increasing concerns about energy security, climate change and environmental degradation associated with excess nutrient releases to the environment, algal bioenergy production has attracted a great deal of attention because algae are productive utilizers of CO2 and can use waste-stream nutrients from municipal and agricultural wastewaters, while producing a wide range of fuels.

To understand the environmental impacts associated with algae energy systems, life cycle assessment (LCA) has been conducted. To date few existing LCA studies addressed the whole life cycle of bioenergy production from algae using wastewater as a nutrient stream. A recent study evaluated synergies between algae production with wastewater treatment and power production and quantified the benefits. However, only the biomass production phase was examined in the study and biomass harvesting and conversion were not considered.

The overall goal of this research is to evaluate the environmental impacts associated with different energy products via different routes across the whole life of algal bioenergy. The bioenergy production system under investigation uses domestic wastewater as a feed stream to provide water and nutrients required for algae growth in photo-bioreactor. Algal biomass is harvested and converted to liquid biofuels via thermochemcial process and biogas via anaerobic digestion. Nutrients remaining in liquid phase after biomass conversion are recycled back to algal photo-bioreactor. Co-products such as animal feeds and fertilizer from biomass conversion processes are also considered in the analysis. This LCA study will use the experimental data, simulation results from process modeling and data from several LCA databases.

POTENTIAL FOR FUEL AND CHEMICAL PRECURSORS – SELECTIVE OXIDATION OF METHANOL

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Methanol is seen as a viable option as a fuel in futuristic fuel cell vehicle applications and its selective oxidation to numerous high value chemicals such as dimethyl ether (DME), formaldehyde and hydroformylation products demonstrates it as a chemical platform. Both uses of methanol involved catalytic chemistry for efficient energy usage.

The focus of the current research is on the selective oxidation of methanol to various chemical products using catalytic chemistry. The catalysts were grouped into two categories, which include bulk catalysts (silica, ceria, silica-alumina, titania, copper, and aluminum phosphate) and supported metal catalysts (metals immobilized onto the various bulk catalysts). The acidic catalysts, which include silica-alumina and aluminum phosphate, demonstrated a tendency towards DME. Alternatively, ceria, silica, and the supported metal catalysts showed selectivity towards formaldehyde and combustion products. Currently, catalyst alterations to maximize selectivity for a single route are being investigated.

NUTRIENT MANAGEMENT USING AN ALGAL PHOTOBIOREACTOR PRODUCTION SYSTEM

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Continuous reliance on fossil fuel-based energy is unsustainable due to depletion of world fossil fuel reserves, global climate change and environmental degradation. Vigorous research initiatives are aimed at developing renewable and potentially carbon neutral biofuels as energy resources. Biofuels specifically derived from microalgae are a technically viable alternative energy resource that can also play a role in reducing nitrogen and phosphorus loading to eutrophic water resources. The overall goal of this research is to couple an algal photobioreactor production system with municipal wastewater treatment and biosequestration of CO_2 from combustion gases. Specific objectives are to investigate: 1) growth of algae on anaerobic sludge centrate under varying conditions, 2) the effect of gas transfer and mixing on algal growth and CO_2 uptake and 3) algae harvesting using coagulation and sedimentation. Centrate from anaerobic digestion of wastewater sludge is being used as a growth substrate for wild type *Chlorella* spp. in pilot-scale photobioreactors operated at varying mean cell residence times under natural light conditions. Inorganic carbon and mixing are provided by bubbling a synthetic combustion gas stream into the photobioreactors using coarse bubble diffusers. Abiotic CO_2 mass transfer tests are being conducted to establish optimal gas flow rates for photobioreactor operation. Algae harvesting is being investigated using jar tests with ferric chloride, alum, cationic polymers, polyaluminum chloride and anionic polymers.

A LATEX IMMOBILIZATION LAYER FOR ISOLATION OF EXOELECTROGENIC MICROBES

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Bioelectrochemical systems (BES) are reactors in which microbes transfer electrons either to or from a solid electrode. The current thus produced in these systems can be harvested as electricity in microbial fuel cells (MFC) or can be used to drive reactions such as hydrogen evolution in microbial electrolysis cells. MFCs can produce electricity sustainably because the organic matter oxidized by the microbes at the anode of the BES can come from waste streams such as domestic sewage or food processing. Isolation of microbes capable of generating current (exoelectrogens) in BES remains a challenge. The unique metabolic pathways involved in this type of electron transfer to a solid electrode surface are under investigation in the few known exoelectrogens, but identification of additional species with this capacity will facilitate our understanding of this metabolism, and allow further engineering in BES to generate electricity and other useful end-products. Isolation of iron-reducing bacteria on plates has failed to correlate directly to exoelectrogenic bacteria; isolation via dilution-to-extinction in BES has successfully identified novel exoelectrogens, but is costly and time-consuming. In this study, we investigate a latex coating that can immobilize microbes on an electrode without interference with exoelectrogenic activity. Fluorescent microspheres, as analogs for single cells, are deposited on an electrode surface. Following simulated operation as a BES, the microspheres are observed. Exoelectrogenic activity can be identified by observing, through the transparent latex layer, colony growth. This procedure can allow dozens or even hundreds of single cells to be tested for exoelectrogenic activity. Here we present the proof of concept for this latex immobilization layer.

CONVERGENT DEVELOPMENT OF BACTERIAL COMMUNITIES IN MICROBIAL FUEL CELLS

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Microbial fuel cells (MFCs) provide a simultaneous method of energy generation and wastewater treatment. The effect of the initial inoculum on community development or power production is not well characterized. We examined the temporal development of microbial communities using three inocula: wastewater from a plant with known performance (PSU), another wastewater source (UAJA), and an anaerobic bog sediment. The bog-inoculated MFCs initially produced higher power densities than the wastewater samples, but after 60 d all MFCs on average converged to similar voltages (0.466±0.026 V) and maximum power densities (590±170 mW/m^2). Voltages produced by bog-inoculated MFCs were not significantly different. One wastewater-inoculated MFC (UAJA3) produced substantially less voltage. DGGE profiling showed the development of a stable exoelectrogenic biofilm in all samples after 30 d, consistent with 16S rRNA clone library analysis. After 60 days, 58±10% of clones showed high similarity to *Geobacter sulfurreducens*. FISH analysis for *G. sulfurreducens* confirmed its predominance in the anode communities (63±6%). UAJA3 showed a lower percentage of 16S clones similar to *G. sulfurreducens* (36%), suggesting that a predominance of this microbe was needed for convergent power densities. This lower percentage in the UAJA3 MFC could not be verified by FISH analysis. These results suggest that replicate MFC anodic communities need not be individually sampled and analyzed when exhibiting similar performance, but sub-optimal performance can arise from a lack of specific microorganisms in the anode communities. Whether this finding can be generalized for MFCs needs to be further examined for other substrates, inocula, and reactor types.

A SYSTEM DYNAMICS SIMULATION MODEL FOR INTEGRATED WATER RESOURCES MANAGEMENT IN HILLSBOROUGH COUNTY

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Water and energy are essential commodities serving as the fundamental resources for the economic, social and cultural development in the progress of our civilization. Hillsborough County is located in the Tampa Bay Area, with the population of 1,195,317 in 2009. The increasing water demand due to the population growth, depletion of groundwater resources, deteriorating groundwater quality caused by the salt water intruding, and excessive water pollution resulting from agricultural and industrial development have caused intensive society concerns on water resources management.

This study developed an integrated water resources management model for Hillsborough County, *HillsboroughWater*, using system dynamics approach. System dynamics approach cross-fertilizes elements of traditional management, feedback control theory, and computer simulation (Mohapatra et al., 1994), which is capable of simulating interconnections among different components within the system, capturing the structure of the system, and explaining the behavior that the system produces (Sterman, 2000; Forrester, 2003). Due to the complex nature of water related problems, involving many ecological, human and social elements that depend on and affect water resources, the system dynamics approach is well suited for modeling and application to integrated water resources management. The *HillsboroughWater* model took into consideration the dynamic interactions between quantitative and qualitative characteristics of water supply and demand that were determined by population, economic development, land use change as well as the energy constraint. Water supply and demand were expressed as a matrix containing both water quantity and quality in order to investigate the benefits of meeting demands in term of quantity and quality. For example, the water quality required for drinking was different from cooling, which determined the water treatment level and energy consumption in turn. The *HillsboroughWater* model improved existing water system dynamics models by a) capturing the water behaviors by both water quantity and quality, b) incorporating energy as not only a main water user in the water demand side, but also a limiting factor determining water supply. Water supply included different water sources such as surface water, groundwater, reclaimed water, and desalinated water. Energy was presented as a constraint in determining the potential water supply since both treating water and wastewater to the required standard and delivering water to the end users or utilities require energy. Water demand was consisted of agricultural, industrial, municipal, and energy withdrawals, which was estimated using empirical equation or regression relationship based on historical data. Population and economic development were the autonomous elements that drove the overall system behaviors and population was formulated as the sum of tourism population and residents.

The *HillsboroughWater* model was a system dynamics simulation model that provided for investigation of different scenarios. Simulations would be run under the scenarios including population growth, water conservation, water and energy pricing. The modeling results are expected to describe the change in water supply, sectoral water demand, as well as water pollution under policy options in the area of water and energy pricing. It is expected to give supportive information for Southwest Florida Water Management District in future water management decision making.

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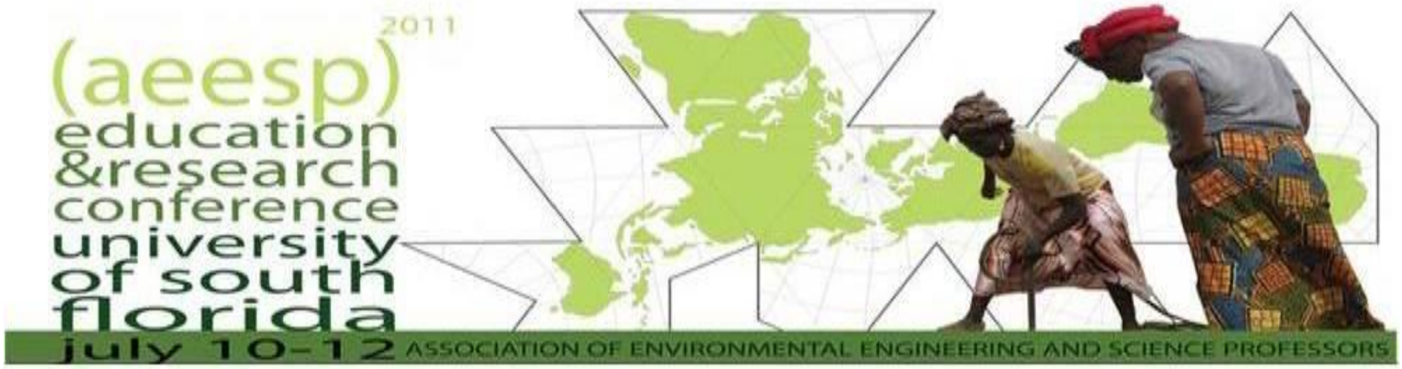

Research Category #7: ***Integration of Sustainability into Practice***

Research Category # 7

INTEGRATION OF SUSTAINABILITY INTO PRACTICE

A HISTORICAL PERSPECTIVE AND A LOOK TO THE FUTURE IN THE UF ENGINEERING SCHOOL OF SUSTAINABLE INFRASTRUCTURE AND ENVIRONMENT

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This poster will describe the evolution of the Sanitary Engineering and then the Environmental Engineering Sciences Program at the University of Florida. The program can be traced back to 1948 when Drs. A. Percy Black and Earle B. Phelps, both leaders in the fields of water chemistry and water treatment were prominent members of the Civil Engineering faculty. In 1966 their group of faculty broke off from Civil Engineer to establish a new Department of Bioenvironmental Engineering Sciences which soon after became the current Department of Environmental Engineering Sciences. The poster will illustrate the initial development of the graduate program followed by the formation of an undergraduate program in Environmental Engineering in 1972. The 16 faculty, consisting of both engineers and scientists were organized around federal major training and research grant programs in the following areas: air pollution, water and wastewater, environmental biology, water resources, radiological health, solid waste, and ecology. The poster will show how the department maintains this broad coverage of environmental media today. Enrollment and research funding history will be presented as well as the description of the formation of the online graduate courses and Master's degree programs that now have enrollment that outnumbers the on campus Master's degree enrollments. Finally, the poster will outline the organization of the new Engineering School of Sustainable Infrastructure and Environment, which will comprise the independent departments of Environmental Engineering Sciences and Civil and Coastal Engineering to increase research and academic potential through collaborative initiatives.

LIFE CYCLE COMPARISON OF ENVIRONMENTAL IMPACTS FROM ALTERNATIVE PHARMACEUTICAL DISPOSAL METHODS

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Household accumulation and disposal of unused pharmaceuticals pose many different risks to environmental and human health. Three disposal methods were examined and compared using life cycle assessment (LCA) methodology to quantify emissions and better understand these risks: Take-Back, compounds are driven to a pharmacy for incineration; Trash, compounds become municipal solid waste; Toilet, compounds become domestic wastewater. Destruction of pharmaceuticals by incineration for the Take-Back disposal method reduces concentrations of pharmaceuticals in the environment; however, it also results in greater global environmental impacts, compared to the Trash or Toilet disposal method, due to emissions from personal driving and incineration. Disposal using the Trash method results in some active pharmaceutical ingredient (API) emissions to the environment, which could decrease with improved leachate retention technology. The Toilet disposal method, compared to other options, results in the greatest amount of API emissions to the environment. Even though the contribution of wastewater API loadings from direct disposal compared to excretion is unknown, both loadings can be reduced by pharmaceutical development and dispensing pollution prevention techniques. Emission magnitudes are not necessarily proportional to damage caused and the result of uncontrolled API exposure by different organisms is still unknown for many compounds, so justification for increasing global environmental impacts will need to come from a better understanding of API contamination and effects on the environment. A comprehensive waste management recommendation must rely on balancing the benefits and disadvantages of the different emissions based on expected damage to human and environmental health.

WATERSHED MANAGEMENT BY AN INTEGRATED SUSTAINABLE APPROACH

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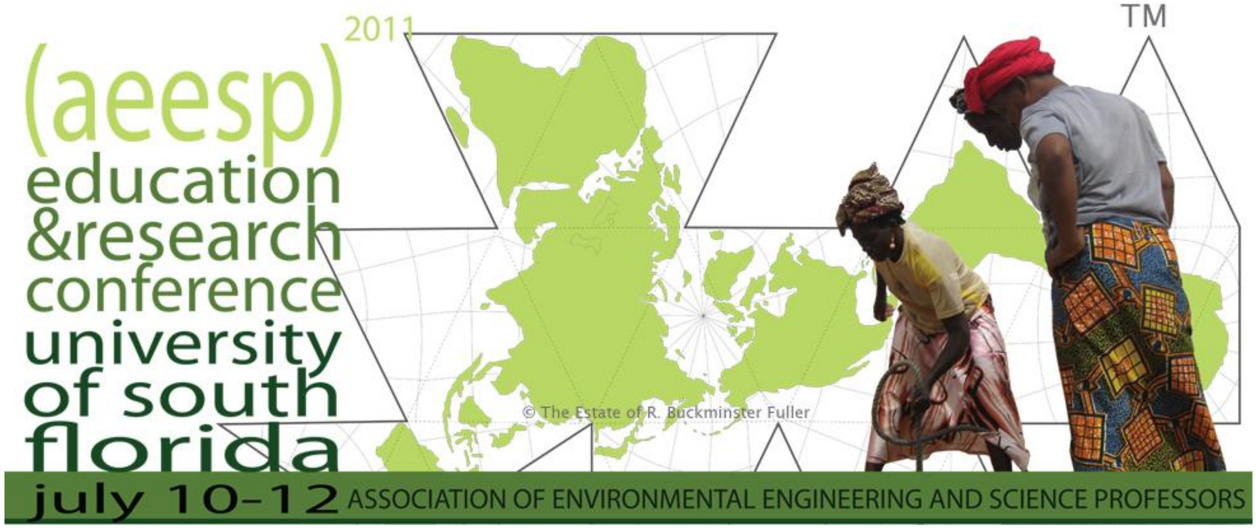
Metropolitan Sewer District of Greater Cincinnati (MSDGC) has a total of 210 combined sewer overflow (CSO) locations that discharge to 19 receiving waters including the Ohio River. During wet weather, combined sewers overflow into local water course after reaching pipe capacity. Consequently, large amounts of contaminants including metals, organic compounds, harmful bacteria and pathogens are also released into the rivers and are considered major sources of water body impairment.
In this study, an integrated sustainable approach targeting source control from both water quantity and water quality was explored in order to address CSO problems. A series of green solutions were compared to grey solutions in the Lick Run watershed in order to reduce 2 billion gallons per year of CSO. Comparing capital, operating and maintenance costs, the green solution has a much higher total social, economic and environmental benefit, which will better serve to revitalize the local community.

Regarding the water quality management, source control objective was accomplished by integrating novel molecular tools, GIS mapping technologies as well as physical, chemical, and biological analysis. The overall strategy is to identify the source of pollution loadings, such as household sewage treatment system (HSTS), CSO, sanitary sewer overflows (SSO) and contributing factors (agriculture/urban runoff, water temperature and available organic material). This is important in order to evaluate fecal microbial input both wet and dry weather and assess its potential impact on human health. It also provides a sensitive method to measure the efficacy of engineering projects designed to improve water quality.



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