Sixth International Conference on Sustainable Water Environment
Panel Discussion: Research Needs for Sustainable Water
July 30, 2010

Introduction

As part of the Sixth International Conference on Sustainable Water Environment, two panel discussions were held to address research needs for a sustainable water environment. Session A focused on the natural water environment and Session B addressed the built water environment. The discussions are summarized separately in this document. However, some topic overlap occurred because the division between "natural" and "built" water environments is not necessarily distinct.

Session A: Natural Water Environment

Panelists

In order to avoid redundancy, the panelists were given subtopics within the broad natural environment field. The panelists and subtopics in parentheses are as follows:

Jerry Schnoor, Allen S. Henry Chair and Professor of Civil & Environ. Engr., University of Iowa (climate impacts)

Craig Adams, Chair and Distinguished Professor, Civil, Environ. & Arch. Engr. Dept., University of Kansas (chemical contaminants)

Robert (Rob) Travers, Professor of Civil & Environ. Engr. Dept., Villanova University (stormwater management)

Bob Bastian, Senior Environ Scientist, USEPA, Office of Wastewater Management, located in Washington, DC (land-based treatment and reuse systems)

Elizabeth Fassman, Senior Lecturer, Civil & Environ. Engr., University of Auckland (NZ) (watershed protection, wetlands)

The panelist comments and audience responses have been organized around the five major topics assigned: climate impacts, chemical contaminants, stormwater, water reuse and conservation, and watershed management. Due to the breadth of the panel discussion scope, important identified issues and research needs that are beyond these specific categories have also been included.

Climate Change

The scale of human impacts on the earth has increased dramatically within one generation. The ocean pH has dropped from 8.2 to 8.08 in one lifetime. Many areas of the US are short of water, not just semi-arid regions. If you look at the whole world, in general, the wet areas are getting wetter and the dry areas are getting drier. Our water withdrawal practices are unsustainable. Climate change will complicate approaches to meeting future water needs.

Water resources need to be managed and studied in a more holistic fashion considering ground water and surface water together on a basin-wide scale. We're going to be doing more and more reuse even in water-rich areas, including practicing indirect potable reuse on a much larger scale than we are right now. Desalination will become more common. Other countries need to follow the examples of Australia and Israel when it comes to water use efficiency. And wherever you have water problems, you have energy problems and vice versa. And so this water-energy nexus is a major area for our future research.

Our field needs to become more of a predictive science. We have predictive capabilities in some areas. We can predict where a harmful algal bloom is going to occur. And we can predict where the gulf hypoxia is going to be. But predictions are based on incomplete information. Some basic information is lacking. For a predictive approach, we need to quantify how much water we have in ground water, and snow-packed reservoirs.

Chemical Contaminants

Because chemical contaminants involve adverse health impacts, more toxological data are needed to improve understanding of risk assessment and exposure to facilitate prioritization of these risks. There needs to be an enhanced ability to predict conditions when cyanotoxins will be produced in natural aquatic systems. Because some compounds have measurable impacts at nanogram per liter levels, improved methods are needed for concentration, extraction from environmental media, and analysis of these analytes. Improved monitoring technologies are also needed.

Emerging contaminants is an area of critical research need. More study is needed on aquatic species. Because of the number of contaminants of concern, they must be classified and investigated in groups. A key issue is the identification of surrogate or "target" analytes that can be studied as representative of a larger group compounds.

Stormwater Management

The concept of sustainability as it applies to stormwater management is not well defined. Current design drivers (peak flow and sediment capture efficiency) must be expanded to link the design to the end goal of surface or groundwater quality and hydrology. This would entail evolution of existing models. The role of evapotranspiration in stormwater management need to be more clearly understood.

An emerging area of research focuses on protecting existing developed areas in contrast to new construction sites. Biofiltration rain gardens, green roofs, and permeable pavement are methods for managing stormwater in urban areas. Research is needed to develop systems that will treat pollutants other than sediment as illustrated by bioretention cells installed in parking lots to remove nitrogen.

Water Reuse and Conservation

Since a major use of water is for irrigation, increasing irrigation water use efficiency (mass of dry matter produced per mass of water applied) is a research topic of great relevance. Deficit irrigation, where crops are intentionally exposed to water stress at pre-determined periods in the growth cycle, needs to be conducted in ways with minimal impact on crop yield or quality.

Augmenting water supplies with recycled wastewater by both indirect and direct means must become more widely practiced. There is a great public phobia over “toilet-to-tap” systems that will require a major educational effort to overcome. Indirect reuse is generally understood and accepted by the public. There are several successful long-term (>~50 yr) land-based systems where treated effluents are reused for irrigation and groundwater recharge.

Watershed Management

Watershed management needs to be integrated on a regional basis. And it needs to be integrated so that it includes not only water, but soil and vegetation. More intentional land use planning is needed. Watershed-scale experiments are needed to address some of the large and complex issues. Networks are required to monitor, model and forecast water behavior.

One important component of comprehensive watershed management is ecological conservation. Conflicts arise when decisions need to be made about how to allocate water to simultaneously maintain ecological health and address water demands of municipalities and industries. More research is requisite to defining and quantifying ecosystem needs in order to inform policy decisions. Other stakeholders, besides scientists, need to be engaged when management decisions are made.

Summary

Three issues needing investigative attention were mentioned by multiple speakers. First, the fate, transport, and health and ecological effects of emerging contaminants; second, the need to shift from a reactive to a predictive discipline; finally, adopting a holistic approach to managing natural water environments for sustainability. We need to shift the sustainability paradigm from treatment to prevention. An overriding need is educating the public of the global water scarcity issues that will dominate future geopolitical discussions. Good stewardship of natural water environments must be a widely held core value. To enhance the sustainability of natural aquatic systems, direct potable reuse of reclaimed water will involve changed attitudes and substantial political will.

Besides the technical challenges highlighted in the discussion, there are economic, institutional and social challenges that also must be addressed. The enormous global inequities in natural water resources and infrastructures must not be overlooked. Global poverty is linked to water resources and our research endeavors must not overlook simple technologies that often have a tremendous impact.

Session B: Built Water Environment

Panelists

In order to avoid redundancy, the panelists were given subtopics within the broad built environment field. The panelists and subtopics in parentheses are as follows:

William J. Cooper, Professor, Department of Civil and Environmental Engineering, University of California-Riverside (sustainable water use research needs)

David Reckhow, Professor, Department of Civil and Environmental Engineering, University of Massachusetts (water treatment, esp. chemical/ disinfection processes)

Nicholas Ashbolt, Senior Research Microbiologist, National Exposure Research Laboratory, U.S. EPA Cincinnati (research priorities based on risk)

Jeanne M. VanBriesen, Professor, Department of Civil and Environmental Engineering, Carnegie Mellon University (research priorities for biological treatment processes)

Presentations were also provided by Sayleong Ong, Professor, Department of Civil Engineering, National University of Singapore and Mike Templeton, Lecturer, Department of Civil and Environmental Engineering, Imperial College London.

The panelist comments and audience responses have been organized around the five major topics assigned: climate impacts, chemical contaminants, stormwater, water reuse and conservation, and watershed management. Due to the breadth of the panel discussion scope, important identified issues and research needs that are beyond these specific categories have also been included.

Sustainability: a Broad Perspective

The built water environment was seen as inextricably linked to other systems, both natural and built. For example, both water resources and the water supply infrastructure will be severely impacted by climate change, which is in turn driven by energy and industrial policies on a global scale. Population growth contributes to these trends, but the crucial population issue is human migration to the world's megacities. These population centers require greater amounts of water to be drawn from increasingly distant sources. They also need highly centralized infrastructures for water supply and wastewater treatment, but many lack the necessary resources. When these facilities do get constructed, they are often energy intensive, exacting both environmental and economic costs.

Linked as well are the infrastructures for transportation and agriculture. Transportation systems, planned appropriately, can decentralize population growth along corridors or hubs, which must be done in coordination with water supply planning. Advantages and disadvantages of decentralized water and wastewater systems must be weighed as an integral part of such planning; localized treatment may save energy because water or wastewater need not be transported over long distances, but larger facilities at population nodes may offer efficiencies of scale.

These types of issues are immense challenges due to their complexity and the need to plan decisively before all the requisite data are available. They also require expertise from many fields well beyond environmental science and engineering. The ability to link predictive capabilities based on political, economic, and sociological insights (for example) with those from engineering professions is essential to the development of a sustainable and resilient infrastructure.

Research priorities extend in other directions as well. Water and sanitation needs in much of the developing world are acute and ongoing and, although the needed improvements are often very basic, the appropriate technologies are not well understood. Examples are the intermittent biosand filters and ceramic filters being made and used in rural third world areas without complete understanding of scientific principles underlying their efficacy.

Agricultural use of water is in need of greater examination. Approximately 70% of water use in the U.S. is of this purpose rather than for potable consumption. Development of crops needing less water, and greater use of water conservation measures, could have great effects on the water budget in this country and elsewhere. Industrial use of water, particularly as cooling water in power plants, is another area where greater scrutiny could lead to reductions in water use.

Water Resources: Conservation Methods are Known

The densification of population centers, and the unpredictable effects of climate change, are leading to water needs that exceed steady-state supplies in significant areas of the globe. Many simple methods are available to increase water collection—such as rainwater harvesting from rooftops—and these are relatively simple, straightforward methods. They require little in the way of research investment, but rather await incentivization and education programs that will encourage wide-scale implementation. Alternatives to the use of potable water as a carrier for waste products are also available, such as composting or air-flush toilets. Reuse of grey water, and water purification by solar energy, are additional examples of established technologies that only require acceptance and demand. Appropriate pricing of water is an obvious means of encouraging water conservation although equity issues must obviously be dealt with.

Water Technologies: Membranes

Water conservation and reuse represent the "low hanging fruit" in addressing water shortages, due to the use of methods and technologies that are off-the-shelf at affordable rates. It is recognized, however, that more sophisticated processes will be needed in some contexts and, ultimately, when conservation and reuse are not enough. Membrane processes are identified as having significant potential for desalination, which could provide additional water in many areas of the world. These processes include membrane filtration, nanofiltration, reverse osmosis, forward osmosis, enhanced electrodialysis, and membrane distillation. The relevant applications include pretreatment, solute removal, and concentrate treatment. Although the processes are developed, cost and operational issues still limit their applicability. The key limitation continues to be membrane fouling, through concentration polarization, scaling, and biofouling. This is a key area in need of research. Other drawbacks of membrane desalination include high energy costs and the need to manage concentrate collected as the waste flow.

Water Technologies: Sensors and Control

Efficient collection of surface water and optimal treatment can be furthered by the use of real-time sensors that relay this information to a central monitoring and control site. Sensor research may be a priority due to homeland security concerns, but their applications might go well beyond immediate detection of toxins or pathogens, to the integrated, automatic control of unit processes to meet treatment and cost objectives. Beyond this are further possibilities: anticipation of water quality and quantity in plant intake based on upstream sensors and meteorological data, used for temporal adjustment of process parameters and even treatment flows over a network of treatment facilities. Monitoring systems could also be used to enhance preventive maintenance in water distribution and wastewater collection systems. Clearly, research on sensor and software for these purposes would provide significant long-term benefits.

Additional Water Technologies

Ultimately, the ability to manipulate biological processes at the genetic level, combined with new developments at the nanoscale, nay lead to water technologies unimaginable at present. It is not unlikely that membrane processes could use bio-membranes that regenerate if damaged, and use active transport mechanisms to remove specific water impurities in sequential fashion to allow their recycling. It should be noted that both nitrogen and phosphorus recovery and recycling from wastewaters is highly desirable due to anticipated shortfalls in their availability at a global scale. Likewise, direct electricity production from wastewater (e.g. by “microbial fuel cell”) could assist in decreasing the cost of wastewater treatment. Because the efficient production of energy from wastewater may interfere with the objective of water purification, application of this technology to the sludge, rather than the wastewater, may be advantageous.

Summary

This panel’s discussions were predicated on a broad definition of the “built environment.” As a result, major concerns were identified well outside of the boundaries of traditional environmental engineering and science. Many of these require a unified approach that includes “soft” sciences in interdisciplinary development. However, significant needs were also cited in process research toward the more efficient treatment of water and wastewater. These areas are underfunded at present and the research and development work has sifted overseas. This is an example of “green technology” that can provide jobs as well as a better environment.

January 23, 2015

Grand Challenge: Rethinking Urban Water, Wastewater, and Stormwater Systems

Ed Bouwer, Johns Hopkins University

Historically, urban water systems in the U.S. and most industrialized nations have developed around the concept of centralization (Sedlak, 2014). Water supplies are treated to produce drinking water in large centralized water treatment plants and distributed to the population. Wastewater is collected and treated in centralized facilities before discharge to receiving water bodies. Stormwater is collected in storm sewers to mitigate against flooding of streets and homes during precipitation events. These water systems make it possible for people to have enough water to drink without becoming sick and making sure they have adequate sanitation, but there are challenges. The increasing demand for water from population growth and uncertainties in water availability and quality associated with climate change are driving forces to rethink ways in which urban water systems evolve to provide adequate water for the future (NRC, 2012; Metcalf & Eddy/AECOM, 2014; Sedlak, 2014). The ongoing limits of funding that water systems face impose strong constraints on system maintenance. This has led much of the underground infrastructure that transports treated and untreated water to deteriorate to the point that there are major sewage leaks into urban streams and groundwater. Not only does this affect local streams, but these streams ultimately flow into receiving water bodies, adding to the deterioration of major economic and ecological resources. Meanwhile, energy-intensive treatment processes designed to mitigate worsening water quality further stretch already thin operating budgets and contribute to greenhouse gas emissions. Climate change has the potential to further exacerbate the challenges faced by urban water systems by affecting, for example, the frequency and intensity of storms and coastal flooding as well as source water quality.

Our current centralized systems have evolved over thousands of years, and we are not in a position to simply throw them all away and start over. This is not affordable or arguably desirable from a societal point of view. One overarching grand challenge is to integrate natural processes, human behavior, and advanced engineering technology to enable a transformation of the system from the ground up and to develop policy recommendations to help ease a transition from the current system to a more sustainable, human-natural system in the future.

Opportunities for research include:

1. Expand reliance on natural systems: Explore engineering enhancements, such as stormwater detention and treatment facilities, low-impact development, sanitary sewer rehabilitation, and reclaimed wastewater inputs to support base-flows to improve the water quality of urban streams and foster ecological restoration.

2. Input from social and behavioral science: Research is needed to promote widespread adoption of behavioral measures, including local water conservation and gray water reuse, best management practices for storm water management, and widespread acceptance of reclaimed wastewater for drinking water.

3. Integrated resource management and recovery: Research is needed so that wastewater and stormwater management focuses on minimizing energy use and on recovering and utilizing the resources that exist within the waste streams, including the water itself. Examples include heat and energy recovery, nutrient recovery, conversion under anaerobic conditions to yield biogas, and use of algae for photoautotrophic treatment coupled with conversion to biofuels.

References Cited

Metcalf & Eddy/AECOM. (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th Edition, McGraw-Hill.

National Research Council. (2012) Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater, National Academies Press, Washington, D.C.

Sedlak, David. (2014) Water 4.0 The Past, Present, and Future of the World's Most Vital Resource, Yale University Press, 352 pp.

Title: **Grand Challenges in Environmental Engineering and Science: An Arctic Perspective**

Name: Srijan Aggarwal (Assistant Professor, University of Alaska Fairbanks)

Overview: Alaska has the largest area (570,641 sq. mi.) and one of the smallest populations (735,132; U.S. Census Bureau 2013 estimate) of all the states in the union. The state's population density is only 1.2 persons per square mile as compared to California's 239 persons per square mile. Alaska's large geographic area encompasses some eight ecosystem types [1] and 32 unique ecoregions [2]. Climatic conditions range from a mid-latitude oceanic climate in the Southeast panhandle to an arctic climate in northern Alaska. In the interior of Alaska the climate is subarctic with temperatures reaching as low as -50˚C. It is known for its rainforests, glaciers, boreal forest, tundra, peatlands, and meadows. Alaska contains 75% of U.S. national parks and 90% of U.S. wildlife refuges, by area. Consequently, Alaska has been an attractive destination for explorers, adventurers and tourists in the quest for pristine nature and lands unknown. However, there are myriad environmental issues currently plaguing and/or threatening the environment, ecosystems, native as well as urban communities in the last frontier. Additionally, Alaska is facing a rapid climate change and the impacts are already visible. In this essay, I touch upon a few important Alaskan environmental issues.

1. Environmental Risks from Oil Exploration and Industrial activities

With climate change making the Arctic increasingly accessible there is an increased industrial interest in the region. According to USGS estimates the Arctic contains vast oil and natural gas reserves (amounting to 30% of world's undiscovered gas and 13% of oil). However, there are anticipated dangers and risks associated with Arctic energy development. Over the past 40 years, the world's oceans have received numerous impacts as a result of oil releases. The most notable and significant within the US, the Deepwater Horizon tragedy in April of 2010, released about 205 million gallons of oil [3]. This event, along with changes observed within the Arctic ice pack (due to warming climates) and a deeper understanding of the future commercial potential of the Arctic, has refocused interested parties in the planning and preparation for emergency response under different spill and climatic scenarios. In the wake of 2010 Deepwater Horizon incident, additional measures for emergency response and containment requirements are needed to address a possible oil release in the Arctic. In 2013 the United States Government outlined its direction for the Arctic in its National Strategy for the Arctic Region report to the President [4]. Strategic priorities were established, one of which is as follows: "Evolve Arctic Infrastructure and Strategic Capabilities –….we will develop, maintain, and exercise the capacity to execute Federal responsibilities in our Arctic waters, airspace, and coastal regions, including the capacity to respond to natural or man-made disasters." Given this National priority and direction, it is critical to fully understand and pre-plan for future potential oil spill incidents and the response capacity which would be needed to address these incidents in the remote and extreme conditions of the Arctic.

Many oil spill response technologies which are applicable in warm regions need to be re-assessed and re-designed for the Arctic application. There is also increased interest in the environmental fate and transport of oil spill response chemicals and any associated environmental impacts they may cause in Alaskan -off shore waters and marine wildlife – which are key to centuries old subsistence lifestyle followed by several rural Alaskan tribes and communities living on the north slope of Alaska. Apart from the threat of accidental oil release, there are additional environmental concerns associated with increased industrial activity which needs to be actively understood and addressed in order to preserve the Arctic.

2. Fresh Pristine Alaskan air: True or False

Winter temperature inversions, which trap colder, pollutant laden air near the ground, are a common phenomenon across the state especially in those regions with very low winter time temperatures, such as Fairbanks. Major air quality issues include home heating with wood or fuel oil, diesel electrical power generation, road dust from unpaved roads, and frequent summer wildfires. While these issues typically affect all Alaskan communities, there are issues unique to rural Alaskan communities that are detailed below.

An example of a major air quality issue affecting an urban area within the state is the $PM_{2.5}$ non-attainment status of the Fairbanks North Star Borough (FNSB). Portions of this borough, which encompasses the communities of Fairbanks and North Pole, were designated non-attainment for $PM_{2.5}$ in 2009 by the EPA. Challenges to achieving attainment include the extreme inversions experienced every winter in the Interior of Alaska, which can reach as low as 6 feet above the ground. These inversions trap emissions from home heating sources rather than larger stationary source emissions, thus requiring control strategies which reach into individual homes and small businesses. Many homes use wood heat as a secondary heating fuel to combat the extreme low winter temperatures and high cost of fossil fuels.

Air pollution in rural communities, while similar in source to urban areas, has far greater impacts on small isolated communities. Perennial frozen ground prevents burying waste in landfills forcing many communities to collectively burn trash in burn pits or to use individual burn barrels. Diesel generators, which provide the primary source of electricity to nearly all rural communities, produce $PM_{2.5}$ and other air pollutants. Many homes have older, inefficient wood or oil stoves that can be significant sources of $PM_{2.5}$ air pollution both indoors and outdoors. Unpaved village streets are the norm in most rural Alaskan communities and dust from unpaved roads is inhaled or deposited on subsistence food sources. Nearly all rural communities are geographically isolated from major population centers and lack road access to neighboring villages. Thus rural Alaskans rely on aircraft, boats, ATVs and snow machines in winter to travel between villages and are reliant on barges and airfreight for larger goods and services. These transport modes may be disrupted by winter storms, poor visibility, sea ice and host of additional variables that make living in Arctic and subarctic environments challenging. The vast distances between communities coupled with logistical complexity of transportation in inhospitable weather results in significantly higher costs for goods and services for rural Alaskans than for communities in the contiguous United States.

Monitoring air quality in a sparsely populated, spatially large and biogeographically diverse state is both expensive and logistically challenging. Monitoring sites are logistically and financially infeasible when it comes to remote areas with limited or no road access, limited or no facilities to accommodate staff site visits, limited instrument vendor support, uneven or unreliable commercial power, and limited infrastructure in general. In addition, extreme winter temperatures common in many areas of the state expose monitoring instruments to environmental conditions for which they are not rated.

The high cost of site installation and maintenance limits the extent of air monitoring by state agencies. Currently, Alaska's air monitoring program employs nine full time staff to oversee the only two delegated programs (Fairbanks North Star Borough and Municipality of Anchorage) as well as to develop, install, and maintain its own ambient air quality monitoring network. Data from this monitoring network are intended to demonstrate compliance with the National Ambient Air Quality standards throughout the entire state.

In addition some studies have also indicating long-range transport (e.g. from Russia and northen Europe) impacting air quality in Alaskan national parks. Compared to the size of the state, the air quality monitoring and research is highly insufficient. Overall there is an increased need for innovative and more efficient approaches for monitoring and remediating air quality in the state of Alaska.

3. Alaska Water and Sanitation Challenges [5, 6]

Despite significant advances in the water and wastewater industry in the last 50 years in the United States as well as internationally, rural Alaska continues to struggle with acute water and sanitation challenges. Rural Alaska is characterized by over 280 isolated villages scattered across an area more than twice the size of Texas. Populations in these communities are predominately Native and range between 25 and 6,000 residents, averaging about 300 residents per village. Nearly all villages are accessible by air and water only. Most residents practice a blended subsistence lifestyle and depend heavily on moose, caribou, walrus, whale, seal and fish for their food supply. Unemployment rates frequently exceed 50%. Many of these communities lack a safe source of drinking water or a safe means of sewage disposal. Many households in rural Alaska still use a toilet known as a "honey bucket": A plastic bag lined bucket collects urine and feces. Then, plastic bags of feces from honey buckets are disposed in a sewage lagoon. About 3,300 year-round occupied rural Alaskan homes lack running water and a flush toilet, and over 700 homes are served by operation-intensive haul systems. Additionally, keeping existing systems operations is a challenge for most villages, with about 4500 homes depend on aging and deteriorating piped and haul systems.

Lack of in-home water and sewer service in rural Alaska causes severe skin infections and respiratory illnesses. Residents of Southwest Alaska suffer rates of invasive pneumococcal disease (IPD) that are among the highest in the world. To correct this public health problem, federal and state agencies have funded conventional, community-wide piped and truck haul systems in the last couple of decades. Although these systems work, they are expensive to construct and many communities cannot afford their high operational costs. Funding to build systems has declined severely while costs have risen sharply. The deficit between available funds and needs is over $660 million. Given current fiscal realities, federal funding levels for rural Alaska sanitation projects are not likely to increase and state funding has been limited to the mandated matching requirement of 25% of federal appropriations. At best, funding for rural Alaska water and sewer projects can be expected to remain at current levels, with the gap between available sanitation funding and needs continuing to grow steadily. At worst, appropriations will continue to fall, and the gap will increase even faster. It has become increasingly clear that the current approach to rural Alaska sanitation is untenable and will result in rural residents facing increasing public health hazards associated with inadequate systems. A different approach to delivering these services is needed. To this end, Alaska Department of Environmental Conservation has also recently undertaken a broad competitive program to seek alternative solutions wherein the state agencies are exploring more economical and efficient decentralized approaches to deal with the water and sewer challenges of rural Alaska.

References

[1] http://www.adfg.alaska.gov/index.cfm?adfg=ecosystems.list

[2] Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgensen. (2001). Ecoregions of Alaska: 2001. USGS Open-File Report 02-297 (map).

[3] National Research Council. Responding to Oil Spills in the U.S. Arctic Marine Environment. Washington, DC: The National Academies Press, 2014.

[4] National Strategy for the Arctic Region. 2013. US White House.

[5] http://dec.alaska.gov/water/vsw/pdfs/vswbrief.pdf

[6] http://watersewerchallenge.alaska.gov/

Grand Challenge: *Rapid and accurate physicochemical property prediction of novel and exotic emerging contaminants based on first principles quantum chemical calculations including full three-dimensional conformational information*

William A. Alexander, Department of Chemistry, The University of Memphis

Submitted for consideration within the 'Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century' Workshop

Overview: In the 21st century and beyond, as the world population continues to rise, and the availability of global resources seems uncertain in light of climate change, a myriad of new "chemical solutions" will be developed to combat future problems (perceived or real). New and exotic compounds and engineering processes will be employed to solve needs related to clean water, food production, and first-world luxuries. All of these new and exotic compounds and processes have the potential to brew up new "chemical solutions" in the case of unintended (or intentional) releases into the water supply or environment. This will be especially true in developing nations, where industrial controls of these releases are likely to be relaxed in favor of production and development toward a first-world lifestyle. In these contamination events, the proper emergency response relies on the availability of accurate physicochemical property data to feed into existing models of fate, transport, and toxicity. If this data is not available, there is no time to obtain this data experimentally. As such, responders readily employ group additivity or other models to predict the needed properties. While these empirically-derived methods tend to be of acceptable accuracy for compounds that are well-covered in the method database, discrepancies of over a factor of two, or even an order of magnitude or more are not uncommon. When a compound is truly exotic, either in structure or atomic composition, there is little hope that additivity methods will perform well. Additionally, none of the existing established methods consider isomeric diversity or configurational complexity.

However, given enough time, modern computational chemistry methods are able to predict nearly any (and actually any, in theory) property of a molecule given nothing more than it's composition or primary structure. No experimental data is needed to garner this information, as the methodologies are based on first-principles quantum chemical theory (e.g. wavefunction-based or Density Functional Theory). Generally these methods are employed in investigations on an "academia time-scale" and in fact do require substantial computational time if not optimized to take full advantage of massively parallel computational schemes. However, this need not be the case – these computations can be executed immediately, and can quickly begin providing data in the event of a spill; no time-consuming sample collection and laboratory work would then be needed for these predictions of physicochemical data to inform fate, transport, and toxicity models.

The Grand Challenge for the 21st century will be to apply our knowledge and ability to calculate physicochemical properties of exacting accuracy using computational methods based on truly first-principles (non-empirical) models, in combination with high performance computing technology, to obtain properties for uncharacterized and exotic contaminant compounds in a rapid, on-demand way to inform spill response. We have the knowledge and the technology to meet this challenge. We need to tie together efforts from disparate fields to achieve these goals. Once we have methods established to produce rapid on-demand physicochemical property predictions of superior accuracy, we will be able to provide more accurate models of fate, transport, and toxicity in response to a contamination event involving poorly characterized or exotic species. This ability will help give the public confidence of the response efforts, and help responders make the correct, informed decisions in a timely manner, ultimately resulting in enhanced protection of the public well being.

Exploiting Interconnectivity of Complex Water Systems to Concurrently Address 7 Grand Challenges

Pedro J. Alvarez. Rice University

Environmental engineers and scientist are facing a growing responsibility (and opportunity) to serve society not only as environmental stewards, but also as leading integrators of solutions to complex challenges to sustainability. For example, many of us are directly or indirectly addressing challenges associated with the water-energy-food nexus. Consistent with this trend of holistic, policy-relevant research, there are many opportunities to *exploit the interconnectivity of complex water systems* and expand this triple-nexus consideration to address 7 interrelated water challenges that are critical to national security and global sustainability:

1. Safe water quality for a growing population
2. Water infrastructure (distribution, collection and drainage)
3. Water to produce enough food for all
4. Water to produce energy
5. Protection from water-induced disasters
6. Distribution of water between humans and ecosystems
7. Solutions for water conflicts and fair share of water for all

This broad topic serves as an inclusive umbrella for many fertile research areas, such as:

- Advanced materials and treatment technologies to enable water reuse and resource recovery (e.g., energy, nutrients, drinking water) from wastewater and storm water. For example, develop novel high-performance, modular, multifunctional treatment processes that minimize energy use (e.g., using nanophotonics for solar desalination) and decrease chemical use, waste residuals, and, in turn, environmental impact. Significant potential for disruptive technological innovation for decentralized mobile treatment units may occur at the convergence of nanotechnology with biotechnology.
- Integrated network topology analysis. For example, study the effects of integrated water, wastewater and storm water networks and treatment configurations on system performance by departing from traditional separate, centralized system topologies and focusing on decentralized, hybrid, and composite layouts. Alternative system topologies may significantly minimize the distance between consumer locations and supply sites (including unconventional water sources such as wastewater and storm water), and reduce the potential for contamination during transmission. In addition, hybrid, decentralized, and composite topologies would be less energy intensive than traditional centralized systems.
- Consider a life cycle systems perspective, and collaborate with policy experts to find transformative approaches to enable integrated water management.

Enhancing the functioning of degraded ecosystems through environmental engineering innovation and ecological research

Christine Angelini
Environmental Engineering Science, University of Florida, c.angelini@ufl.edu

As a result of climate change, invasive species, anthropogenic activities and a variety of other stressors, many of Earth's ecosystems are in an alarming state of decline. Given our ever-increasing demand for ecosystem services, improving the functioning of these degraded ecosystems is of paramount importance to human health and safety in the 21st Century[1]. Efforts to reverse ecosystem decline have been met with limited success, indicating our current understanding of and ability to recreate the complex relationships that control the assembly, behavior, and service provisioning of natural systems is insufficient[2]. To address this critical gap, engineers and ecologists must begin to collaborate in a more directed, consistent manner, as I argue that solutions for facilitating ecosystem recovery hinge upon both: 1) innovative technologies that reduce stress to levels that permit key species to re-establish and, 2) thorough understanding of how those species then interact to regulate ecosystem functioning.

In many cases, levels of nutrients, water flow, contaminants, and other abiotic factors are now so far from those present historically in our ecosystems that they pose insurmountable barriers to ecosystem recovery. For instance, nitrogen concentrations in many rivers and lakes are so high from chronic fertilizer use that efforts to restore submerged aquatic vegetation in these systems to enhance water filtration and carbon storage services have proven futile. Likewise, wave stress is so strong and persistent in many estuaries due to boating activity and climate change that programs aimed at transplanting vegetation to counteract wetland erosion show little to no sign of success. In order to create the conditions within which ecosystems have a chance to recover their structure and functioning, innovative engineering solutions to absorb, reduce, or attenuate abiotic stressors to levels amenable to the establishment and growth of key species are now needed. Environmental engineers are equipped with the training and expertise to tackle these complex technological problems.

In addition to developing techniques for relieving abiotic stressors that prevent ecosystems from recovering, there is also a need to advance our understanding of how biotic communities reassemble and ecosystems ultimately function in response to environmental engineering actions. As abiotic stressors diminish, studies of managed systems indicate that biota often do not recover to pre-disturbed states, but rather become dominated by weedy, early successional species that do not function as well as historically-dominant organisms. To overcome such obstacles, research that identifies how to best initiate the reassembly and persistence of desired communities is essential. Recent experiments, for example, reveal that restoring both shrubs and termites in drought-stricken savannas and grasses and bivalves in eutrophic marshes, rather than plants alone, jumpstart the recovery of diverse communities and the production of ecosystem services. Ecologists, through their understanding of the hierarchical nature of species interaction networks, can contribute much insight in restoration design, expertise that is essential to achieving desired management outcomes over the long term.

Given complementarity in their skill sets, environmental engineers and ecologists need to begin working together in a comprehensive, cohesive manner to coordinate and execute actions to restore degraded ecosystems and regain essential services. To further marry these fields, we must also begin considering ecology as a core component of undergraduate and graduate engineering program curricula as students with such interdisciplinary training will be central to mitigating the most pressing environmental problems that lie ahead. Facilitating the integration of these historically isolated fields thus stands as a grand challenge of our time.

1.IPCC. *Climate change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. *United Nations* 688 (Cambridge University Press, 2014). 2. Kareiva, P. et al. *Science* **316,** 1866–1869 (2007).

Grand Challenges for Environmental Engineers in the 21st Century:

Effectively Reclaim Wastes

Laura H. Arias Chavez

Achieving sustainability requires resolving inefficiencies and dead-ends in our current production and use of critical resources. Byproducts, residues, and wastes must be effectively reclaimed to fully close the loop on water, food, and energy management. While progress has been made in transitioning to closed loops, much remains to be done, particularly in the following areas:

1. New strategies and technologies to **capture non-point sources** of wastes must be developed to the point of economic viability. Failure to reclaim non-point sources, such as agricultural run-off, creates two problems: (i) valuable resources are wasted, some of which may not be renewable, and (ii) allowing these materials to mix with natural resources can negatively impact the environment and human health.

2. Use of captured wastes must **be as direct as possible** to minimize the losses associated with (i) converting resources from one form to another and (ii) transporting resources over long distances. For example, using wastewater to directly cultivate food crops, biofuel feedstocks, or other marketable plant products avoids the energy costs of separating out nutrients from water (or manufacturing fertilizer) and of transporting freshwater for crop irrigation.

3. Similarly, resource reclamation efforts must **be integrated across sectors and within local geographic areas** to make better use of waste products in replacing prime resources whenever possible. Waste heat or gray water from one industry can be used by another to reduce overall costs to the companies and to society. However, a stronger framework for exchanging information, identifying technologically feasible partnerships in light of supporting science, and forming collaborations must be built first to foster this integration.

4. Wastes should be reclaimed **as close to the origination point** as possible, using a distributed network of specialized, relatively small scale recovery facilities. Combining waste streams from a variety of diverse sources with diverse compositions makes it more difficult to effectively separate out specific components for re-use. The mixed stream entering a municipal wastewater treatment plant, where we might ultimately seek to reclaim some resources, is complex and dilute with respect to most components. Its potential resources therefore are mostly inaccessible, and the focus becomes removing these materials (to a landfill or an incinerator) to prevent them from harming the environment or the public rather than reclaiming them. Decentralizing waste reclamation

through the placement of tailored technology at the source of particular wastes will make water treatment and resource recovery more efficient and effective.

Proactive and Innovative Water Solutions

William Arnold, University of Minnesota

Water is already an essential focus of environmental engineering and will continue to be so throughout the 21st century. The field of environmental engineering has been reactive for much of its history. Reactive responses to problems have led to innovations in drinking water treatment, wastewater treatment, and development of remediation technologies. We are reaching the limits in terms of what we can do in terms of traditional environmental engineering practice. The field needs to move to a proactive and innovative model to tackle challenges that combine environmental quality, water availability, food production, energy use/production, and resource recovery. All of these challenges involve a combination of both water quality and water quantity and must balance the needs of humans, human activities, and ecosystem functions.

We need to break with 'tradition' in several ways. We need to look at problems with new perspectives. Our goal can no longer be treatment of wastes to obtain a water stream of the highest quality without considerations of cost, energy use, carbon footprint, or generation of other waste streams. Any time product generation/recovery, be it energy, mineral, or feedstock, can be coupled with waste treatment, this needs to be explored. Developing such technologies is non-trivial. We need environmental engineers that have experience in not only chemistry, microbiology, and fluid mechanics, but also, for example, materials science, synthetic biology, life cycle assessment, and computational methods. We need the opportunities and training for faculty and students to move across disciplinary boundaries.

We also require innovation in how we use, distribute, and reuse water. The infrastructure we built a century ago is not adequate for our current population (both in terms of number and distribution) , not sufficient for our industrial/agricultural needs, and not adaptable (enough) in a changing climate. Environmental engineers have a huge opportunity to lead the discussions of how to optimize infrastructure for treatment, distribution, and reuse of water in urban and agricultural environments from a technical and policy standpoint. Engagement of scientists and engineers with planners, stakeholders, and policy makers is going to part of our mandate.

My own research focuses on the fate/reactions of contaminants in aquatic systems. By looking more broadly at the knowledge gained from such studies, information is gathered that could assist with development of green chemicals (i.e., those that degrade quickly to non-toxic products or are unlikely to have adverse environmental effects) or inform those that use/prescribe chemicals as to which have the least potential environmental impact/persistence. For example, I am currently starting a collaboration with someone in our pharmacy school with the goal of educating medical practitioners about the environmental fate/persistence of chemicals used in medicine. Having such information would lead to more informed choices that help the patient and minimize environmental impact. These challenges require communication among disciplines.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINNERING AND SCIENCE IN THE 21ST CENTURY

AEESP 2015 CONFERENCE

Grand Challenge: Integrating the Impact of Natural Disasters on Water Supply Infrastructure Management

Marcelo Aybar, PhD student, Civil and Environmental Engineering and Earth Sciences, University of Notre Dame

An average of 60 volcano eruptions and 15 big earthquakes (7+ of magnitude) happen every year around the world (sometimes both events are related), carrying immense localized (and occasionally global) losses in human lives, infrastructure and biodiversity. Volcanic eruptions and earthquakes can be extremely damaging to aqueous environments. For example, Sulphur dioxide gas from volcanic pyroclastic material is converted to sulfuric acid in the stratosphere, the main cause of acid rain. According to EPA, in the U.S. 75% of acidic lakes and 50% of acidic streams are the results of acid rain. Furthermore, pyroclastic material (e.g. ash) can cause short term physical and chemical changes in water quality (increase of turbidity and metal and salts concentrations), increased wear on water-delivery and treatment systems, and high demand for water during cleanup operations. Water from water supplies may become undrinkable and infrastructure such as tanks and pipes may be corroded, stained and clogged by scale deposits.

Earthquakes can also have detrimental effects on water supplies. Besides the direct damage on infrastructure due to seismic waves, water wells may become turbid or dry. Surface water quality can become degraded as a result of earthquakes, with responses including changes in chemistry, wave oscillations in lakes and other open water bodies, increase in stream, spring and seep discharge, and some instances of springs going dry. Urban water supply systems can be damaged, for example, house service connections, power supplies, control systems, trunk mains, service reservoirs and pumps and treatments plants.

Population growth and increasing urbanization in earthquake-prone areas suggest that earthquake impacts on human population will increase in the coming decades. People living in these areas (urban or rural) are exposed not only to short time life threatening events, but also to long term health related issues and economic complications, in particular, when high water demanding activities such as agriculture and livestock farming represent the main source of family income. New or replacing water supply infrastructure in these areas should be prepared and consciously designed to be resilient faced to natural disasters, and protocols and appropriate measures should be implemented to mitigate their effects.

Future research, should explore some of the following topics:

- Protection of new or replacing water supply infrastructure from air particle deposition (such as ash from volcanic eruptions) for short term impacts
- Engineered isolation of surface natural water supplies such as rivers, reservoirs and lakes from mud and land slides
- Implementation of monitoring strategies to control short and long term contamination of water supplies (e.g. groundwater)

- Studies to predict the long term effect on water quality from volcano eruptions and earthquakes
- Long term investment decisions considering resilient infrastructure, for example, routing water transmission mains and distribution networks
- Identifying areas in which water supplies have high risk of been disrupted or contaminated by catastrophic events and implementation of mitigation strategies

Tarek N. Aziz
NC State University

Engineering Microbial Ecosystems −A Need for Multiscale, Multiphysics, and Agent-Based Models

Tarek N. Aziz and Daniel R. Obenour

The modeling of microbial systems is not new. Engineers and scientists frequently use biokinetic models both in engineered systems (e.g. wastewater process design with implementations of the Activated Sludge Model) and in studying natural systems (e.g. water quality modeling with WASP or AQUATOX). These models are used to optimize engineering design, forecast potential problems, and as decision support tools in the planning of new infrastructure. Despite their prevalence, however, there is increasing evidence that many of the commonly used models will lack the sophistication to sufficiently predict the complex nature of some important environmental modeling challenges moving forward. Our ability to utilize biological models for prediction and exploration of emerging challenges in microbial ecosystems hinges on the development and adoption of new modeling approaches. I believe the modeling of these approaches will require simulation on multiple scales, involve the coupling of multiple physical models, and necessitate the use of agent-based approaches to better replicate microbial community dynamics.

The efficacy of most current models to predict the behavior of a microbial system hinges upon the appropriateness of a population-based modeling (PBM) approach. In PBM microorganisms and the parameters describing the various aspects of their life are grouped and averaged across control volumes. The result is a set of population-level differential equations (1). While this approach works for many scenarios, it specifically breaks down in the presence of microbial diversity. An alternative approach is known as agent based (or individual based) modeling (ABM). ABM would simulate individual microorganisms (or small clusters of microorganisms) each with potentially distinct characteristics and life histories. While these models have been used for decades for larger organisms, developments in biochemistry and microbial ecology have more recently made ABM of microbial systems a reality (2). Thus far, these approaches have shown the capacity to express more microbial system complexity, diverging from conventional population-based models in complex cases. There is still work needed to further enhance these tools and link them to the array of advances in microbial ecology. In addition, there are still a number of environmental systems in which ABM approaches should be able to provide more insight than conventional PBM.

One system that requires the application of ABM is the formation of harmful algal blooms in surface source waters. Harmful algal blooms are a major concern for human and ecosystem health. As recent as 2014, these blooms resulted in a drinking water ban in Toledo, Ohio. Two major factors commonly attributed to the formation of these blooms are increased nutrient loadings from non-point sources (resulting from urbanization and agriculture) and increased temperature and hydrologic shifts resulting from climate change (3). The cyanobacteria credited with the adverse health effects in the Lake Erie bloom is *Microcystis*. *Microcystis* is a fascinating organism that self-regulates its buoyancy, thereby developing a competitive advantage over other phytoplankton in the water column, despite its relatively slow growth rate. A model able to sufficiently describe phytoplankton dynamics under a range of scenarios would be an enormous aid to engineers and scientists. The model should sufficiently couple multiple physical models (light, hydrodynamics, thermodynamics, and chemical kinetics) with a microbial model featuring phytoplankton life-history, motility, and biokinetics. It will be computationally challenging to model the multitude of physical system and microbial features necessary to replicate the linkage of phytoplankton populations to each other and their environment. As a result, this model will serve as a critical piece of the larger-scale analyses required to develop mechanistically valid prediction tools for water quality. By combining these scales the critical linkage between climate change, water-shed management, and water quality can be established.

(1) Hellweger, F. L.; Kianirad, E. Accounting for intrapopulation variability in biogeochemical models using agent-based methods. *Environ. Sci. Technol.* **2007**, *41* (8), 2855–2860.
(2) Hellweger, F. L.; Bucci, V. A bunch of tiny individuals-Individual-based modeling for microbes. *Ecol. Modell.* **2009**, *220* (1), 8–22.
(3) Paerl, H. W., & Huisman, J. (2008). Climate. Blooms like it hot. *Science (New York, N.Y.)*, *320*(5872), 57–58. http://doi.org/10.1126/science.1155398

Groundwater Salinity: a Worldwide Problem

Ryan Bailey
Dept. of Civil and Environmental Engineering
Colorado State University

High groundwater salinity is a major water quality issue in many regions worldwide. Specific problems associated with high groundwater salinity include decrease in crop yield and associated profits, destruction of fertile agricultural land, unusable groundwater supplies for drinking water, increased water treatment costs, and damage to eco-systems. Water and land management strategies, engineering techniques, and long-term monitoring are required to remediate saline aquifer systems and to prevent future salinization.

The causes of high groundwater salinity vary depending on regional geography and climate. In semi-arid environments, the long-term practice of irrigation has led to salinization of soil and groundwater systems. Continual irrigation for crop production results in increasing concentrations of salinity in the soil and root zone, often leading to reduction in crop yield. Irrigation-induced shallow water tables bring salt to the upper layers of the soil profile, where the salts are evapo-concentrated[1,2]. The primary causes of high water tables include inadequate drainage of agricultural land, excessive water application, and leakage from poorly lined canals and reservoirs[3]. Worldwide, approximately 20-25% of the 230 million ha of land under irrigation experiences severe salinity problems[4,5], with the salt-affected area increasing by about 1 to 1.5 million ha each year. In addition to crop production losses, damages to the environment also can occur as highly saline groundwater discharges to streams and is transported to downstream areas. The increase in salinity-affected areas will continue unless water and land management schemes are implemented at the basin scale.

For coastal regions and islands, high groundwater salinity can occur due to seawater intrusion in the aquifer, rising sea levels, and storm-surge overwash events[6-7]. Excessive pumping within high-permeable coastal aquifer systems causes saline water to move landward into freshwater aquifers, leading to contamination of drinking water. Rising sea levels result in shoreline recession (i.e. coastal erosion), with freshwater volumes pushed landward and upward in the coastal aquifers. In addition to the long-term effects of sea-level rise, groundwater along coastal areas and within island aquifers can become salinized due to storm-surge overwash events during hurricanes or typhoons. For small oceanic islands, these overwash events can be especially devastating, with seawater often completely salinizing the soil and aquifer system[8]. Such events have occurred recently on Kayangel Island, Palau (November 2013, Super Typhoon Haiyan) and Ulithi Atoll, Federated States of Micronesia (April 2015, Typhoon Maysak).

References

[1] Abernethy, C.L., Kijne, J.W. (1993), Managing the interactions of irrigation systems with their environments. In: Parey, P. (Ed.), Ecologically Sound Resources Management in Irrigation: German Association for Water Resources and Land Improvement. Verlag, Hamburg, Germany.

[2] Kijne, J.W., Prathapar, S.A., Wopereis, M.C.S., and K.L. Sahrawat (1998), How to manage salinity in irrigated lands: a selective review with particular reference to irrigation in developing countries. System-Wide Initiative for Water Management, International Irrigation Management Institute, P.C. Box 2075, Colombo, Sri Lanka.

[3] Wichelns, D. (1999), An economic model of waterlogging and salinization in arid regions. Ecological Economics 30, 475-491.

[4] Ghassemi, F., Jakeman, A., and Nix, H. (1995), Salinization of land and water resources: Human causes, extent, management, and case studies. Univ. of New South Wales Press, Sydney, Australia.

[5] Tanji, K. K., ed. (1990), Agricultural salinity assessment and management. ASCE Manuals and Reports on Engineering Practice No. 71, ASCE, New York.

[6] Werner, A.D., Bakker, M., Post, V.E.A., Vandenbohede, A., Lu, C., Ataie-Ashtiani, B., Simmons, C.T., and D.A. Barry (2013), Seawater intrusion processes, investigation and management: Recent advances and future challenges. Advances in Water Resources 51, 3-26.

[7] Barlow, P.M. and E.G. Reichard (2010), Saltwater intrusion in coastal regions of North America. Hydrogeology Journal 18, 247-260.

[8] Terry, J.P. and A.C. Falkland (2010), Responses of atoll freshwater lenses to storm-surge overwash in the Northern Cook Islands. Hydrogeology Journal 18, 227-246.

<u>Grand Challenge</u>: Maintaining Estuarine and Coastal Water Quality in the Face of Population Growth and Continuing Human Development

<u>Author</u>: William P. Ball
Professor of Environmental Engineering, Johns Hopkins University, Baltimore, MD
Executive Director, Chesapeake Research Consortium, Edgewater, MD

<u>Description</u>:

Many scientists agree that Earth is now well into a human-dominated geological epoch, the Anthropocene Epoch, reflecting the fact that global-scale changes to Earth's status have been driven by recognizable human causes (Lewis and Maslin, 2015). Within this context, Earth's coastal waters and estuaries are key indicators of change that are showing some of the most profound and clearly defined impacts. Such indicators include not only the effects of human-induced climate change, sea level rise, and atmospheric CO_2 (which are already affecting shore lines, and oceanic pH), but also impacts related to growing fluxes of sediments and nutrients, including deleterious effects on living resources within our estuaries and coastal waters. Coastal hypoxia in particular is one well-documented dramatic and important impact of the current combination of still increasing human populations and dramatic current increases in per capita productivity and consumption, especially in coastal regions (Diaz and Rosenburg, 2008).

Within the above context, a grand challenge for environmental engineering and science is to develop and provide the integrated understanding needed to predict and manage the environmental impacts of continuing human development. At the heart of the challenge is the need to better understand and manage (*i.e.,* engineer) the interconnected global cycling of water, nitrogen, phosphorus, and carbon. Within this broad goal, a more immediate and well defined need is to better understand and manage the impacts on estuarine and coastal water quality that result from increasing food production, increasing fossil fuel combustion, and other aspects of human developments in watersheds. Increased understanding will require both depth and breadth of contribution in all disciplines, ranging from microbiology and geochemistry through hydrology, estuarine ecology and fishery sciences to sociology and international relations, and with ample application of computer and information science toward better application of computer models. But foremost, it will require a new breed of environmental engineer who is capable of integrating these disparate disciplines within the context of environmental fluid mechanics, water chemistry, water quality modeling, microbial ecology, ecosystem management, environmental systems engineering, environmental economics, and environmental policy. In short, this is a global problem, requiring major investments and contributions from scientists and engineers of every discipline, but under the leadership and guidance of environmental engineers and scientists.

<u>References</u>:

Diaz, R.J. and R. Rosenburg, 2008. "Spreading Dead Zones and Consequences for Marine Ecosystems," *Science* **321:** 926-929 (15 August 2008); DOI: 10.1126/science.1156401.

Lewis, S.L. and M.A. Maslin, 2015. "Defining the Anthropocene," *Nature* **519**:171–180 (12 March 2015) doi:10.1038/nature14258.

Investigating the effect of chemical pollution on biodiversity loss: Towards a functional relationship between pollution by contaminants of emerging concern and biodiversity loss

By Daniel K. Bampoh, Dr. Swheta Singh

Agricultural and Biological Engineering, Purdue University

Biodiversity is essential for ecosystem function, provisioning and regulation. A healthy ecosystem is one that has a diversity of species in relative richness and abundance represented at the different levels and nodes of food trophic networks that act as functional substitutes, to absorb shocks and preserve the stability and integrity of life-sustaining relationships across various organismal food web pathways. Biodiversity is absolutely essential for the sustainability of earth ecosystems goods and services that form the basis of the natural capital required for sustaining humans as part of the earth's ecological systems. The contribution of chemical pollution from human activities and development to global biodiversity loss is a problem that remains substantially challenging to investigate and address. There is an incredibly vast number of anthropic-chemical species and associated transformations, with relatively insignificant data on the eco-toxicological effects across a plethora of environmental conditions and space-time coordinates. The United States Environmental Protection Agency's inventory of chemicals mandated by the Toxic Substances Control Act (TSCA) reported 73,757 chemicals in commercial use by manufactures by February 2001 (GAO 1994b). Among these, approximately 7% of the estimated 2,800 high production volume (HPV) chemicals at 1,000,000 units per year have adequately assessed for basic-screening environmental toxicity, transport and fate data (EPA 1998) after being approved through the EPAs Pre- Manufacture Notification (PMN) process (Decarlo et al., EPA 1997) Including unreported (unknown) chemicals, there are anywhere between 7 million and 50 million chemicals made, found and used by humans. The eco-toxicological risks that over 99% of these chemical species pose as environmental stressors and their impact on earth natural earth systems biodiversity remain largely unknown and incalculable, yet in many ways palpable.

"Planetary Boundaries: Exploring the Safe Operating Space for Humanity" by Rockstrom et al. (2009), explores biodiversity loss as a part of system of global tipping of points and approximate limits of some of the earth's most fundamental natural resources for the successful continuance of human life within the Bruntland Commission's definition of the sustainability paradigm. Humans have accelerated species extinction rates by 100 – 1000 times the typical historical background rates of the planet since the advent of the Anthropocene (Mace et al. 2005) and the current and projected rates of biodiversity loss constitute the sixth major extinction event in the history of life of earth (Chapin et al. 2000). Pereira et al 2010 provides a comprehensive literature review of quantitative scenarios for global biodiversity loss based on socioeconomic development pathways in "Scenarios for Global Biodiversity in the 21st Century." This study accounts for the impact direct drivers like climate change, land-use change, water extraction and fish harvesting on biodiversity change metrics such as species abundance, extinctions and community structure, as well as habitat loss and degradation resulting in shifts in biome distribution. Other works of notable mention like Alkemade et al (2009) and (2011) investigate the global terrestrial biodiversity loss through the Netherlands Environmental Assessment Agency and United Nations Environmental Program Conservation Monitoring Center GLOBIO3 model framework. The American Fisheries Society asserts that of the 1200 fish species in North American, 300 icthyofauna populations are considered severely troubled, endangered or imperiled due to human impacted drivers of ecological change, with overfishing, habitat alteration and degradation, and chemical pollution contributing the most to this condition.

While Allan et al. (1993) elucidates on declining biodiversity and the need for conservation in running waters, the research, data and literature remain acutely sparse when it comes to investigating the regional and global impact of anthropic chemical species, some of which have become contaminants of emerging concern in aquatic ecosystems. Hydrophilic agro-industrial chemicals are widely commercialized and used in US and are notable contaminants of emerging concern in freshwater systems which are complex ecosystems. The contribution to biodiversity decline by cascading toxico-dynamic and toxico-kinetic effects of the presence of these chemicals in aquatic ecosystems is an area that is intricate and largely unexplored. This study is aimed at providing a preliminary assessment of the direct and indirect toxicity effects of the presence of miscellaneous pesticides as contaminants of emerging concern on the fish biodiversity decline in two North East US Urban streams; the Charles River above Watertown dam and Aberjona River at Winchester in Massachusetts. Given that both are sufficiently urban streams with 77% and 79% urbanization levels in their respective catchment areas of the same hydrologic unit code (HUC-01090001), this study examines the validity of using regression-based models derived for the larger catchment area (Charles River) to explain variations in toxicity effects on fish biodiversity observed in the smaller catchment area (Aberjona River). This is based on the hydro- dynamic premise that hydrophilic compounds translocate along a hydrologic gradient and are mobile in the direction of flow in aquatic environments. The larger aim is to derive a predictor toxico-dynamic and toxico-kinetic mechanism for estimating the stress effects and pressures of the presence of toxic chemicals on freshwater biodiversity in aquatic ecosystems, with consideration for other systemic attributes such as dissolved organic matter content, temperature, nutrient concentration and oxygen concentration in these environments. The evaluated validity of a successful model will be its ability to serve as viable predictor tool of these effects in a smaller catchment area based on regression model extrapolation-testing from a containing or linked catchment area. Based on concentration addition Pesticide Toxicity Index (PTI) model (Nowell et al. 2014), initial results show that there was a 23.57% reduction in fish biodiversity between 1998 and 2007, with a predicted 69.13% reduction in biodiversity through 2014 with respect to toxicity trends and developed probabilistic models.

Building Ecosystem Resiliency and Watershed Sustainability in the Era of Aging Infrastructure and Climatic Shifts

David J. Bandrowski

Over the last century, our global watersheds and broader freshwater ecosystems including rivers, streams, and wetlands have been so severely compromised and neglected that their ability to sustain and meet the demands of our population in the future is in peril (Richter et al. 2003). During the 20th century, the global human population increased fourfold to more than six billion and water withdrawn from natural freshwater ecosystems increased eightfold during the same period (Gleick 1998). Facing an ominous specter of increasingly severe water-supply shortages in many areas of the world, social planners and government leaders are exploring strategies for managing water resources sustainably (IUCN 2000). Across the world, intense growing of human populations are rapidly depleting available freshwater supplies to the point that the United Nations, World Health Organization performed a Millennium Ecosystem Assessment in 2000. This assessment has helped establish the scientific basis for actions needed to enhance the conservation and sustainable use of our water resources to supply the services that underpin all aspects of human life (*Ecosystems and human well-being* 2005*).*

In addition, across the U.S. there is widespread decay of critical infrastructure. The 20th century saw rapid growth in population, the economy, and infrastructure (Doyle et al. 2008). Many structures have been in place for more than 50 years, and an increasing portion of national infrastructure is now approaching or exceeding its originally intended design life and will require over $1.6 trillion to reach acceptable levels of safety and function (ASCE 2005). Scientific evidence has proven that dam removal is vital next step in restoration of our aquatic ecosystems (Peoff et al. 2002) and the benefit to remove this critical infrastructure often times will outweigh the cost of retrofits or new construction (Babbitt 2002). The truth in finally being told, that dams once intended to tame the earths rivers are destroying our ecosystem, and that these structures provide only a false sense of security as we approach an era of erratic climate shifts (Beard 2015).

Recently, paleo-climatologists have been piecing together ancient clues in the natural archives of trees, sediment, and the landscape. Through this multi-disciplinary research in geology, chemistry, biology, hydrology, and archeology of past environments we can better understand what type of climate could be around the corner for us tomorrow (Ingram and Malamud-Roam 2013). There is clear evidence of cataclysmic megafloods that have struck the region in the past centuries. What the historical evidence and emerging research is now predicting is that places like the arid American West will be punctuated by larger and more frequent floods (Ingram and Malamud-Roam 2013). The U.S. Geological Survey has recently published a new emergency preparedness scenario called ARkStorm – Atmospheric River 1000 Storm (Porter et al. 2011). This ARkStorm scenario assesses the impact and damage that would result if a hypothetical series of atmospheric river storms, analogous to those of 1861-62 slammed the West Coast today.

We need to stop ignoring this call for action before it is impossible to reverse the degradation that we have inflicted on our global freshwater ecosystem. The time to take act is now, waiting is no longer an option. Future generations depend on our fortitude to fight this battle and protect our resources at all costs. "*If future generations are to remember us with gratitude rather than contempt, we must leave them a glimpse of the world as it was in the beginning, not just after we go through with it.*" (President Lyndon B. Johnson – said while signing the Wilderness Act, 1964)

Citations American Society of Civil Engineers (ASCE), Report Card for America’s Infrastructure (ASCE, New York, 2005).

Babbitt, Bruce. "What Goes Up, May Come Down, Learning from our experiences with dam construction in the past can guide and improve dam removal in the future." *BioScience* 52, no. 8 (2002): 656-658.

Daniel P. Beard. *Deadbeat Dams: Why We Should Abolish the U.S. Bureau of Reclamation & Tear Down Glen Canyon Dam*. Johnson Books, 2015.
Ecosystems and human well-being. Vol. 5. Washington, DC: Island Press, 2005.

Gleick, Peter H. "A look at twenty-first century water resources development. “*Water International* 25, no. 1 (2000): 127-138.

Ingram, B. Lynn, and Frances Malamud-Roam. *The West Without Water: What Past Floods, Droughts, and Other Climatic Clues Tell Us about Tomorrow*. Univ of California Press, 2013.

Martin W. Doyle, Emily H. Stanley, David G. Havlick, Mark J. Kaiser, George Steinbach, William L. Graf, Gerald E. Galloway, J. Adam Riggsbee POLICYFORUM Targeted decommissioning of deteriorated and obsolete infrastructure can provide opportunities for restoring degraded ecosystems. Aging Infrastructure and Ecosystem Restoration, 2008

Poff, N. Leroy, and David D. Hart. "How Dams Vary and Why It Matters for the Emerging Science of Dam Removal An ecological classification of dams is needed to characterize how the tremendous variation in the size, operational mode, age, and number of dams in a river basin influences the potential for restoring regulated rivers via dam removal." *BioScience* 52, no. 8 (2002): 659-668.

Porter K., A. Wein, C. Alpers, M. Hughes, P. J. Neiman, F. M. Ralph, et al. (January 2011): Overview of the ARkStorm Scenario. MONOGRAPH - Other. USGS Open File Report 2010-1312. -- monograph

Richter, Brian D., Ruth Mathews, David L. Harrison, and Robert Wigington. "Ecologically sustainable water management: managing river flows for ecological integrity." *Ecological applications* 13, no. 1 (2003): 206-224.

The World Conservation Union (IUCN) - Species Survival Commission (SSC) *red list of threatened species*. Gland, Switzerland: IUCN, 2000.

AEESP Grand Challenges: Investigating the Human Microbiome, Environmental Exposure, and Disease Transmission

Kyle Bibby, PhD
Assistant Professor, Civil and Environmental Engineering, University of Pittsburgh
BibbyKJ@Pitt.edu; 412-624-9207

Over the past decade, research has identified that our commensal microorganisms, referred to collectively as the 'human microbiome', play a profound role in regulating our health. All humans are colonized by a diverse array of microorganisms that outnumber human cells in our body 10:1. A role for the microbiome has been suggested in obesity, mood, autoimmune diseases, such as allergies, and susceptibility to infectious disease. However, the role of the human microbiome in modulating environmental exposures, and the role of environmental exposures in modulating the microbiome (and thus human health) have been largely unexplored. These recent findings, and current gap in knowledge regarding the role(s) of environmental exposures in this field, open the possibility for contributions by the environmental engineering field. Environmental engineers have the potential to contribute through analysis of microbiome (microbial ecology) data, exposure science, risk assessment, and toxicology. Additionally, this line of inquiry may open funding for the environmental engineering field. Some potential questions are noted below.

- What role does our microbiome play in transforming chemicals after environmental exposure, and mitigating or enhancing their toxicity? Does the microbiome play a role in removing harmful chemicals from our body? Microorganisms in our gut may transform toxic compounds prior to their adsorption into the body, understanding these transformations is essential for assessing risk and inferring the human health impacts of hazardous chemical and compound releases.

- What role does the microbiome play in modulating immune status and susceptibility infectious diseases in the environment? Recent findings have shown that the microbiome modulates immune response, and may alter susceptibility to infection by disease causing agents. Understanding the role of immune response in disease transmission may prove to be a crucial component in understanding the spread of epidemic and chronic diseases through environmental exposure.

- How does access to improved drinking water or sanitation influence the microbiome? Water access or poor sanitation may have implications for human microbiome composition, suggesting another mechanism for human health impacts, for example through altering host immune status.

- What role does early microbial exposure play in the development of autoimmune diseases, such as allergies, and can we engineer conditions for desirable exposures? Recent studies have shown a correlation between allergenic disease and the diversity of microbes young children are exposed to, but our ability to engineer 'desirable' microbial exposures is currently untested. The ability to control these exposures may prove to be an effective method to address autoimmune diseases, such as allergies.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY

Title: Antimicrobial resistance: Examining the need for source control and determining the contribution of wastewater effluent to resistance in clinical pathogens

Name: Lee Blaney, Assistant Professor, Department of Chemical, Biochemical and Environmental Engineering, University of Maryland Baltimore County

Overview

The World Health Organization (WHO) has deemed antimicrobial resistance a global health challenge. In fact, the overview to the WHO's 2014 *Antimicrobial Resistance: Global Report on Surveillance* report stated, "A post-antibiotic era – in which common infections and minor injuries can kill – far from being an apocalyptic fantasy, is instead a very real possibility for the 21st Century." This strong language suggests that research is needed in regard to the development of new antibiotics, restructuring of medical practices (*i.e.*, personalized dosing), and planning other strategies to combat increasing levels of antimicrobial resistance. While a number of factors contribute to the spread and development of antimicrobial resistance, several key questions still need to be addressed in the environmental engineering and science community. In fact, much of the discussion of antibiotic stewardship has altogether neglected to address the environmental fate and transport of trace concentrations of antibiotics in water/wastewater.

Here we propose three topics for consideration:

Hospital effluent. Even though the overall load of antibiotics, among other pharmaceuticals, in hospital wastewater is generally less than the corresponding load from residential sources, these streams may have important consequences with regard to the introduction of select antibiotics, antimicrobial resistant bacteria (ARB), and antimicrobial resistance genes (ARGs) into municipal wastewater treatment plants. In particular, antimicrobial resistant pathogens and last-ditch antibiotics are expected to be present at higher levels in hospital wastewater. For this reason, source control of select wastewater streams, such as hospitals and other healthcare facilities, should be more rigorously considered to prevent increased spread of resistance to our most powerful antibiotics.

Contribution of wastewater effluent to antimicrobial resistance in clinical pathogens. While a good amount of work in the last decade has focused on the detection of antibiotics, ARB, and ARGs in a variety of environmental compartments, more work is needed to identify how these residues contribute to the development of antimicrobial resistance in human pathogens. The increasing identification of superbugs is a major public health concern, but the contribution of the ubiquitous presence of antibiotics in water/wastewater to multidrug resistant superbugs needs to be determined. Identifying the importance of this contribution, and comparing it to the other mechanisms for development of resistance, is critical for slowing the spread of antimicrobial resistance in clinical pathogens and ensuring public health.

Impact of disinfection/oxidation processes on antibiotics and resistance. Disinfection and oxidation processes have been shown to result in transformation of antibiotics; however, there is a growing body of literature suggesting that some transformation products are also antibiotics. Furthermore, disinfection processes may selectively inactivate non-resistant organisms over resistant organisms. For these reasons, a better understanding of how disinfection/oxidation processes affect not only antibiotic molecules, but also resistant organisms is critical. Both of these aspects, as well as possible sub-inhibitory effects of antibiotics, should be considered as treatment metrics rather than relying on traditional methods that only consider the parent compound concentration.

Grand Challenge Submission - Water Resources, Policy, Technology and Uncertainty

Ronald J. Breitmeyer[1]

The UN World Water Development Report for 2015 indicates the very real possibility of severe global water shortages by 2030. Currently, the American Southwest is enduring a years-long drought due to year-over-year below average winter precipitation and snow pack development. These drought conditions have been recognized as an emergency situation in California with California Governor Jerry Brown recently mandating a 25% reduction in residential water use. Other western states such as Nevada are facing requests by utilities to reduce water consumption by 10% or more and industries such as agriculture and mining are increasingly competing for water resources.

Water usage reductions and conservation efforts, while important, fail to address issues associated with socio-economic realities and food supply. For instance, a good portion of California's economy is driven by agriculture and many livelihoods and communities throughout the state are dependent on agricultural water use. Likewise, in Nevada, mining comprises the primary share of high-paying employment and supports local infrastructure such as schools in many communities that would likely be otherwise impoverished. Additionally, food supplies for the entire United States, and to an extent, the world are dependent on the agricultural production in California, particularly fruits and nuts. Therefore, policies that demand blanket restrictions on water use often exempt agricultural or other industrial use, or risk substantial economic and social harm. While seemingly a reasonable approach in the short-term failing to address water supply and conservation in agriculture just pushes a potentially crippling problem into the future.

This is a grand challenge due to the sheer scale of the problem of water supply. According to the US EPA, every American uses 100 gallons of water per day meaning a family of four uses about 146,000 gallons per year. To meet this challenge, an "all options" approach needs to be taken which combines water conservation and improved efficiency, as well as engineering solutions enabling utilization or even identification of non-traditional water sources (e.g., waste-water treatment for re-use, water vapor extraction, desalinated sea water) and better prediction and forecasting of future water supplies which will enable longer-term policy and infrastructure development for water utilization. Water transference strategies and methods could also be considered along with investigation of the energy requirements for such systems. This requires investment in uncertainty measurement and communication as policy decisions can often be governed by the crisis of the moment. Engineering or infrastructure projects at substantial cost only to have those projects appear to be obsolete once the current drought cycle abates leads to a "cry-wolf" mentality and ultimately damages long-term preparation. This highly interdisciplinary research that explores radical new ideas and options for addressing the impending water crisis could produce "disruptive" new technologies that change the face of how we manage and plan water use in the arid west. These ideas are sorely needed in the face of a changing climate in order to protect the global economy and continue to provide the agricultural supplies required to support a growing population.

[1] Assistant Professor Geological Engineering, University of Nevada-Reno, Reno, NV 89557; rbreitmeyer@unr.edu

Grand Challenges:

Gail Brion.

Educating Engineers to Innovate: The Need for Investment in Undergraduate Laboratories

There are multiple challenges that face our institutions that educate the engineers that will have to find new and innovative solutions to the Grand Challenges. The ever increasing demands of multiple accrediting agencies, shrinking state and federal funding, larger fraction of students that are unready to succeed in the foundational base science and math courses, and soaring tuition costs have forced institutions to try and pack what used to be a 150+ credit hour program, with multiple lab experiences that tie theory into applications, into a scant 120 hours, many of these spent in large lecture halls with students trying to teach each other. Traditional laboratories are too expensive to support, and are being dropped from required curricula with virtual computing labs substituting. The American University has lost what made it so valuable, the quality education that spawned many generations of thinkers and innovators. Without funding to support quality undergraduate education, at a reasonable cost, our future engineers will not have the cross-disciplinary foundation upon which to stand to face the Grand Challenges. Our future engineers will be technologists, using other people's innovations, not the innovators we need them to be to solve these challenges.

While I have outlined multiple issues that we face, if there was but one target, I would select finding support for undergraduate students to "tinker" with science, math, and engineering in well-equipped and staffed laboratories designed to support their curiosity and innovation. I find that what sets students up to innovate, is being offered the opportunity to do so in hands-on experimentation. In the core laboratory that I direct, it is clear when students come from another country, or a disadvantaged part of America. They come into the lab and put their hands in their pockets. It is what I was told to do in the small college I attended when we obtained our first electron microscope. We filed in, hands in our pockets, and gazed at a hunk of instrumentation that was doing nothing. The result, we learned nothing. Only the competent doctoral level faculty were allowed to actually touch the instrument. It was only later, when I obtained entrance into an industrial laboratory, was I allowed to touch my first graphite furnace, and test its limitations, 5 years after graduation. The lab was at a nuclear power plant, and if I broke it, there were funds to fix or replace the unit. My small college did not have those options.

Undergraduate education looking at open-ended questions needs support. It takes dedicated staff and facilities to support this type of education. While there are multiple funding opportunities for infrastructure to support graduate/post-doctoral level research laboratories, especially with NIH-based funding, there is scant support for the types of programs and laboratories that first stimulate a young engineer into research, which is tinkering with ideas and equipment and is an educational experience that cannot be duplicated virtually. Faculty and universities cannot continue to support these activities out of pocket. We must find a way to support all of our universities, especially the smaller state institutions, to enhance undergraduate's exposure to research and experimentation, which will in-turn enhance their ability to think creatively, across disciplinary boundaries, and design new solutions. I do not want the next generation of American-educated engineers to stand aside, with their hands in pockets, while others tackle the Grand Challenges.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY, AEESP Research and Education Conference, Yale University, 13 June 2015

Robust Fate and Transport Models in Urban Systems under Climate Variability

Bryan W. Brooks, Department of Environmental Science, Baylor University. bryan_brooks@baylor.edu

I recently reviewed some lessons learned during our studies to understand fate and effects of contaminants in urban waters [1]. More people live in cities now than ever before - by 2050 70% of the world population will reside in urban areas. In these rapidly urbanizing regions, instream flows are influenced by or even dependent on municipal effluent discharge from water reclamation plants, particularly in semi-arid and arid regions [2]. In these effluent-dominated and dependent systems, it is necessary to reconsider contaminant persistence designation and advance chemical fate modeling. Effective exposure duration increases when chemical introduction rates from effluent discharges exceed a chemical's rate of degradation [3]. Instream flows of the Trinity River in Texas, for example, are currently ~98% reclaimed waters [2]. Travel time in the Trinity River over hundreds of miles downstream from the Dallas/Ft. Worth region is ~2 weeks [4] before it is impounded by Lake Livingston, which provides an important water supply for Houston. The Trinity River thus provides an "unplanned" water reuse project. In these systems, chemicals not historically considered to be persistent (e.g., $t_{½}$ in water < 60-180 d) present exposure to aquatic life more closely resembling persistent organic pollutants because continuous exposure occurs. Revisiting the current persistence paradigm is needed to account for exposure scenarios in urban waters. Developing more robust fate and transport models for chemical persistence and exposure in urban waters under climate variability is necessary.

Bioaccumulation of contaminants in these urban waters also requires attention [1]. Computational models for organics bioaccumulation were historically derived for nonionizable chemicals (e.g., PCBs), and often depend on log Kow to predict chemical uptake and thus bioconcentration factors (BCF). Regulatory agencies subsequently identify BCF cut-off values (e.g., 1000-5000) to guide chemical safety assessments. Initially important bioaccumulation efforts were developed to predict BCF [e.g., 5,6], and advanced by fugacity [e.g., 7], equilibrium partitioning [e.g., 8] and food chain [e.g., 9] modeling for nonionic organic contaminants. However, a large proportion of the industrial chemicals presently in commerce, and over 70% of pharmaceuticals, include molecules that ionize at environmental relevant pH [10]. This is important for risk assessment and management because pH varies spatial-temporally, and when it is particularly responsive to climate variability and landscape modifications, the bioavailability and toxicity profiles of many ionizable chemicals are altered [11]. Unfortunately, appropriate fate and transport models are not available for these ionizable contaminants [1].

Our recent studies identified the importance of gill uptake [12], biotransformation [13] and trophic transfer [14] to initially understand bioaccumulation behaviors of weak bases, including pharmaceuticals, in urban waters. Collectively these studies indicate that ionizable contaminant uptake by fish is driven by inhalation uptake rather than diet. Partitioning and bioaccumulation of a model weak base was explored using a comparative pharmacology approach rather than relying on partition modeling driven by log Kow and lipid normalization. Volume of distribution (Vd), a pharmacokinetic parameter that describes chemical disposition, appears more appropriate, particularly when coupled with clearance kinetics, than traditional log Kow approaches to define chemical attributes resulting in bioaccumulation. For example, we identified an apparent Vd of a model weak base to be identical in fish and in humans [12], yet intrinsic clearance of this molecule was not observed. Such observations appear particularly relevant because our group (Scott et al, in review) and others [15] have observed fish in urban waters to accumulate human medicines in plasma at levels approaching, and in some cases exceeding, human therapeutic doses. Due to evolutionary conservations of many drug targets in vertebrates [16,17], adverse outcomes are expected to occur with such observations [18,19] and have been recently observed for two substances [20,21]. Though this comparative pharmacology approach appears promising for advanced model development, it has only examined a few compounds. A more robust understanding of partitioning behaviors of more diverse ionizable substances is necessary before broadly applicable bioaccumulation models can be developed.

References

1. Brooks BW. 2014. Fish on Prozac (and Zoloft): Ten years later. *Aquatic Toxicology* 151: 61-67.
2. Brooks BW, Riley TM, Taylor RD. 2006. Water quality of effluent-dominated stream ecosystems: ecotoxicological, hydrological, and management considerations. *Hydrobiologia* 556: 365-379.
3. Ankley GT, Brooks BW, Huggett DB, Sumpter JP. 2007. Repeating history: pharmaceuticals in the environment. *Environ Sci Technol* 41: 8211-8217.
4. Fono LJ, Kolodziej EP, Sedlak DL. 2006. Attenuation of wastewater-derived contaminants in an effluent-dominated river. *Environ Sci Technol* 40: 7257-7262.
5. Veith GD, DeFoe DL, Bergstedt BV. 1979. Measuring and estimating the bioconcentration factor of chemicals in fish. *J Fish Res Bd Canada* 36:1040-1048
6. McKim JM, Schnieder PK, Veith G. 1985. Absorption dynamics of organic chemical transport across trout gills as related to octanol-water partition coefficient. *Toxicol Appl Pharmacol* 77: 1-10.
7. Mackay D. 2001. *Multimedia Environmental Models: The Fugacity Approach*, 2^{nd} Ed. CRC Press. 261 p.
8. Di Toro DM, Zarba CS, Hansen DJ, Berry WJ, Swartz RC, Cowan CE, Pavlou SP, Allen HE, Thomas NA, Paquin PR. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. *Environ Toxicol Chem* 10: 1541-1583.
9. Gobas FAPC. 1993. A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: application to Lake Ontario. *Ecol Model* 69: 1-17.
10. Franco A, Ferranti A, Davidsen C, Trapp S. 2010. An unexpected challenge: ionizable compounds in the REACH chemical space. *Int J Life Cycle Assess* 15:321–325.
11. Valenti TW, Taylor JM, Back JA, King RS, Brooks BW. 2011. Influence of drought and total phosphorus on diel pH in wadeable streams: Implications for ecological risk assessment of ionizable contaminants. *Integr Environ Assess Manage* 7: 636-647.
12. Nichols JW, Du B, Berninger JP, Connors KA, Chambliss CK, Erickson R, Hoffman A, Brooks BW. 2015, In press. Observed and modeled effects of pH on bioconcentration of diphenhydramine, a weakly basic pharmaceutical, in fathead minnows. *Environ Toxicol Chem* DOI:10.1002/etc.2948
13. Connors KA, Du B, Fitzsimmons PN, Hoffman AD, Chambliss CK, Nichols JW, Brooks BW. 2013. Comparative pharmaceutical metabolism by rainbow trout (*Oncorhynchus mykiss*) liver S9 fractions. *Environ Toxicol Chem* 32: 1810-1818.
14. Du B, Haddad SP, Luek A, Scott WC, Saari GN, Kristofco LA, Connors KA, Rash C, Rasmussen JB, Chambliss CK, Brooks BW. 2014. Bioaccumulation and trophic dilution of human pharmaceuticals across trophic levels of an effluent-dependent wadeable stream. *Phil Trans R Soc B* 1656: 20140058.
15. Fick J, Lindberg RH, Parkkonen J, Arvidsson B, Tysklind M, Larsson DGJ. 2010. Therapeutic levels of levonorgestrel detected in blood plasma of fish: Results from screening rainbow trout exposed to treated sewage effluents. *Environ Sci Technol* 44: 2661-2666.
16. Gunnarsson L, Jauhiainen A, Kristiansson E, Nerman O, Larsson DJ. 2008. Evolutionary conservation of human drug targets in organisms used for environmental risk assessments. *Environ Sci Technol* 42:5807-5813.
17. McRobb FM, Sahagún V, Kufareva I, Abagyan R. 2014. In silico analysis of the conservation of human toxicity and endocrine disruption targets in aquatic species. *Environ Sci Technol* 48:1964-1972.
18. Huggett D, Cook J, Ericson J, Williams R. 2003. A theoretical model for utilizing mammalian pharmacology and safety data to prioritize potential impacts of human pharmaceuticals to fish. *Human Ecol Risk Assess* 9:1789-1799.
19. LaLone CA, Berninger JP, Villeneuve DL, Ankley GT. 2014. Leveraging existing data for prioritization of the ecological risks of human and veterinary pharmaceuticals to aquatic organisms. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369:10.1098.
20. Valenti TV, Gould GG, Berninger JP, Connors KA, Keele NB, Prosser KN, Brooks BW. 2012. Human therapeutic plasma levels of the selective serotonin reuptake inhibitor (SSRI) sertraline decrease serotonin reuptake transporter binding and shelter seeking behavior in adult male fathead minnows. *Environmental Science & Technology* 46: 2427-2435.
21. Margiotta-Casaluci L, Owen SF, Cumming RI, de Polo A, Winter MJ, Panter GH, Rand-Weaver M, Sumpter JP. 2014. Quantitative cross-species extrapolation between humans and fish: The case of the anti-depressant fluoxetine. *PloS one* 9:e110467.

Sanitation for the Next Billion: Re-Imagining Infrastructure for Tomorrow's Megacities

Joe Brown, School of Civil and Environmental Engineering, Georgia Institute of Technology

Sanitation-related enteric infections result in diarrheal diseases, killing 842,000 children per year, and may contribute to chronic inflammation of the gut[1] leading to reduced absorption of nutrients and malnutrition[2], environmental enteric dysfunction[3], growth faltering and stunting, and death. Taken together, these health effects represent a massive drain on the world's human potential and are frustratingly persistent despite increasing global wealth.

Urbanization is a global trend that is likely to accelerate in the 21st century. By 2050, Africa is projected to be 56% urban[4]. Because urban infrastructure may not expand to serve the needs of poor migrant populations emigrating from rural areas, informal, unplanned settlements – slums – are likely to persist and proliferate in the coming decades[5]. Slums are characterized in part by a lack of basic services, overcrowding and high population density, substandard housing, unhealthy living conditions, insecure property tenure, lack of security, and poverty[6,7].

Despite progress in overall urban sanitation access coverage and equity[8], residents of urban slums experience persistently elevated disease risks associated with poor sanitation[9]. Although the proportion of the population without adequate sanitation is lower in urban areas than in rural areas, the public health risks of unsafe excreta disposal may be much greater within a dense urban population compared to a low-density rural population. In terms of volume of excreta produced and probability of exposure, dense urban environments represent critical settings for sanitation infrastructure development.

Our current model for collecting and handling sewage from these types of dense, urban settings is expensive and potentially unworkable for many of the cities that will face this challenge. We need new technologies, infrastructure, services, and financing models that can provide sanitation – from collection to treatment and disposal – safely in the world's densest megacities. Otherwise, we will face waves of epidemics associated with diseases we have known how to control for 150 years.

---

[1] Humphrey, J.H. 2009. Child undernutrition, tropical enteropathy, toilets, and handwashing. *The Lancet*, Volume 374, Issue 9694, Pages 1032 - 1035, 19 September 2009 doi:10.1016/S0140-6736(09)60950-8

[2] Water, sanitation, and hygiene (WASH), environmental enteropathy, nutrition, and early child development: making the links. Ngure FM, Reid BM, Humphrey JH, Mbuya MN, Pelto G, Stoltzfus RJ.Ann N Y Acad Sci. 2014 Jan;1308:118-28.

[3] McKay, S., Gaudier, E., Campell, D.I., Prentice, A.M., & Albers, R. (2010). Environmental enteropathy: new targets for nutritional interventions. *International Health*, 2(3), 172-180.

[4] UN-HABITAT. (2014). The State of African Cities: Re-imagining sustainable urban transitions. [http://unhabitat.org/the-state-of-african-cities-2014/].

[5] Lüthi, C., McConville, J., and Kvarnström, E. 2009. Community-based approaches for addressing the urban sanitation challenges. International Journal of Urban Sustainable Development 1(1-2): 49-63.

[6] UN-HABITAT. (2003). The challenge of slums. . *retrieved from http://www.unhabitat.org.jo/pdf/GRHS.2003.pdf.*

[7] Ravaillon, M., Chen, S., and Sangraula, P. 2007. New evidence on the urbanization of global poverty. World Bank Policy Research Working Paper No. 4199. World Bank, Washington DC.

[8] Approximately 2.5 billion people lack access to basic "improved" sanitation, with an estimated 756 million in urban areas (JMP 2014). This is likely to be an underestimate, as slums are not always included in surveys.

[9] Blackett, I., Hawkins, P., and Heymans, C. 2014. The Missing Link in Sanitation Service Delivery: A Review of Fecal Sludge Management in 12 Cities. Washington, DC: WSP-World Bank Research Brief.

Sustainability in Mega Cities - A Grand Challenge in 21st Century

Hua Cai

Today, over half of the world's population lives in urban areas. While the trend of urbanization is expected to continue, improving urban sustainability and especially sustainability in mega cities becomes increasingly important in the 21st century. However, it is a challenging task to sustainably support mega cities which need to provide clean water, food, clean air, green space, mobility to millions of population and process the wastes generated in gaseous, liquid, and solid phases. What makes it more challenging is the lock-in effect due to existing built infrastructures. But what makes it a grand challenge is the intertwined relationship among different components.

In recent years, the water-energy nexus and food-water-energy nexus have received increasing attentions, However, there are additional interrelationships need to be further studied to better understand the complex system of mega cities, especially those considering human involvement. For example, how would different land uses and urban planning for different urban functions cause human flow and transportation needs? In addition, how to stimulate sustainable consumer behavior and make urban life style more sustainable? Furthermore, with the unprecedented connectedness brought by the wide adoption of smartphones, what are the opportunities can be captured in terms of sustainability? Traditional environmental engineering or environmental assessments often focus on the physical properties and ignore/simplify the impact from individual human beings. While human involvement makes the system more complex, better understanding of it also present potential significant opportunity for intervention to improve sustainability in mega cities.

Grand Challenge: Maximizing Wastewater Reuse

Douglas F. Call
Assistant Professor, Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Raleigh, NC

The challenge is to maximize the beneficial reuse of wastewater and its resources without compromising treatment or public health; to determine which technologies and at what scale resource recovery is economical and safe; and to understand from a systems perspective the role that wastewater reuse and recovery can play in developing sustainable, closed-loop urban water networks.

There is a critical imperative to find renewable and reliable sources of water, energy, and nutrients. Water resources are limited in arid regions and increasingly in wet regions. Energy alternatives to fossil-based sources are essential in the context of current and projected climate instability. Nutrients (nitrogen and phosphorous) are vital to sustain our systems of food production. Although all of these resources are available in domestic and industrial wastewaters, conventional methods of handling these wastes focus first on treatment and then discharge into the environment. In this case, these resources are lost. Considering the fact that wastewater is renewable and widely available across urban and rural settings, beneficial reuse can play a role in meeting our growing demand for water/food/energy resources across multiple scales.

Converting existing wastewater infrastructure in developed countries and creating new infrastructure in developing ones to maximize resource recovery are challenges that will require a deeper understanding of the interactions between technology, humans, and the environment. Many technological treatment and recovery options are emerging, but further refinements, primarily cost reductions, are required. The scale at which resource recovery is both economical and safe is a critical question. Centralized facilities collect and process wastes under controlled conditions, minimizing exposure to humans. However, resource demand may be located distant from the facilities. Distributed recovery systems may provide localized benefits, but little is known how technologies targeted for centralized facilities can function at smaller-scales. Human interactions with decentralized systems may be a requirement for successful implementation and operation, yet this may lead to potentially harmful exposure routes. Finally, cultural barriers to successful integration of resource recovery technologies, in particular for developing countries, may be a challenge for which no engineering solutions are available. A better understanding of these barriers and the knowledge needed to overcome them will be essential for maximizing and realizing the full potential of resource recovery from wastewater.

Addressing Environmental Engineering Challenges by Taking Guidance from Nature

Bin CAO (bincao@ntu.edu.sg), School of Civil and Environmental Engineering and Singapore Centre on Environmental Life Sciences Engineering, Nanyang Technological University, Singapore

While we engineers are scratching our head to find engineering solutions to address water and energy challenges, the nature may already have developed clever solutions. So, one less explored but very promising research area in environmental engineering is to explore fundamental mechanisms in natural ecosystems and to harness such mechanisms to help engineer innovative solutions to grand challenges in energy and water. Here are some examples: (1) understanding on how natural microbial communities assemble into a highly resilient and functional unit under specific physicochemical conditions may help us design more efficient bioprocesses for wastewater treatment based on physicochemical characteristics of the wastewater; (2) understanding on how microbes interact with each other in natural biofilm communities established on plant biomass would help us develop novel bioprocesses for waste-to-energy conversions; (3) biomimetic membranes for more energy-efficient water purification and seawater desalination; and (4) can we use what we have learnt from natural biological systems to engineer our wastewater infrastructure so that the cracks and leakages can be self-fixed?

Grand Challenge: Climate Change Adaptation for Infrastructure

David Dzombak, Constantine Samaras
Peter Adams, Iris Grossman, Paulina Jaramillo, Athanasios Karamalidis, Kelly Klima, Greg Lowry, Scott Matthews, Mitchell Small, Jeanne VanBriesen

Carnegie Mellon University
March 2015

The Challenge: The climate is changing globally and across the U.S., with different types and extent of change in different regions (Melillo et al, 2014). Observed changes include sustained deviation from long-term trends in atmospheric temperatures, water temperatures, precipitation amounts, drought duration, storm frequency, wind velocities, snow melt timing, flood frequency and characteristics, permafrost melting, and other phenomena. These changes are affecting civil and environmental infrastructure and leading to demand for infrastructure modification. The capacity for existing infrastructure to accommodate expected climate change is not well understood. Also not well understood are the types of alterations needed in current design guidelines and codes for new infrastructure to account for climate change impacts.

Societal Needs: Communities experiencing the leading edge of climate change effects, especially in arid, coastal and cold regions, are adapting and rebuilding infrastructure for climate change in an ad hoc manner to address clearly changing local conditions. Examples include hardening of coastal infrastructure; levee construction and infrastructure elevation to protect newly-flood-prone neighborhoods; modification of building designs to address higher wind loads and less-stable permafrost; and modification of drinking water treatment plant operations to address more frequent and extensive algal blooms in warmer reservoirs. Effective and cost-efficient adaptation of infrastructure design and operation to accommodate current and future climate change requires new approaches in civil and environmental engineering. Existing approaches rely on the assumption of a “stationary” environment. However, it is now clear that the stationary environment assumption is not valid, and that engineering design and operation practices must account for a changing environment, and be more adaptive in nature.

Research Needs: Climate change affects operation and performance of a wide range of infrastructure, and leads to demand for new or modified designs, adaptation in management strategies, and other changes. Much climate change adaptation research has focused on response to sea-level rise. Sea-level rise has been in progress for decades and has led to immediate needs for adaptation in coastal and island communities. There are many other kinds of climate change impacts on infrastructure and communities that have received little attention and that merit analysis. These include effects on transportation systems, materials, energy system supplies and demands, building heating and cooling systems, water supply systems, infrastructure in permafrost regions, and others. There are integrated questions that need to be addressed with respect to engineering to accommodate climate change impacts, including:

- How can regional climate change projection uncertainty be best incorporated into infrastructure planning?
- What is most important with respect to adaptation for particular kinds of infrastructure: climate change trends, extreme event frequency, extreme event peaks, or other issues?
- What are the infrastructure adaptation needs of greatest interest for particular communities and regions?
- What are the limits in current designs for extreme wind and snow loadings, temperature, rainfall?
- How should climate change risk be valued with respect to current and future infrastructure?

Investigating these questions will enable communities, cities, and states planning resiliency efforts to maximize the performance and life-cycle cost-effectiveness of their climate-ready infrastructure investments.

Need for CEE Leadership: Climate change adaptation for infrastructure is critical for civil and environmental engineering, and communities, in the 21st Century. Climate change adaptation is an area of significant focus in the earth science and climate science academic communities. However, there has been limited engagement by engineers in climate change adaptation, mostly in relation to coastal issues. Much more engagement and leadership of civil and environmental engineers is needed across the broad spectrum of relevant infrastructure issues. Civil and environmental engineers need to be prepared to lead in answering questions about risks of and responses to climate change. New research and changes in curricula are needed for engineers to be able to provide leadership and solutions.

References

Melillo, J.M., Richmond, T.C., and Yohe, G.W., Editors (2014), "Climate Change Impacts in the United States: The Third National Climate Assessment," U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. Available at: http://nca2014.globalchange.gov/report

Grand Challenge: Remediation of Contaminated Sites from Metal Mining Legacy in Semi-Arid Regions

José M. Cerrato (University of New Mexico, UNM)

Mining of metals extracted for energy generation and weapons manufacturing has left a legacy of abandoned mine wastes in semi-arid regions of the US. Metal contamination of vital resources such as food and water in these abandoned mine waste sites substantiates the need for identifying potential human exposure pathways and cost-effective remediation solutions. This is a critical issue in semi-arid regions given existing challenges related to water scarcity caused by the effects of climate change. Decreased winter precipitation has caused substantial water limitation stress in Western states such as California, Arizona, New Mexico, Utah, Wyoming, and Colorado. Thus, negative effects on water quality can be accentuated in these regions due to the limited sources for potable use.

The adequate management and remediation of abandoned mine waste sites is an overwhelming challenge for local and federal agencies such as EPA, the Abandoned Mine Lands (AML) program of the Bureau of Land Management, the US Nuclear Regulatory Commision (NRC), DOE, and others. For instance, due to their physical and social isolation, limited scientific studies have been performed to assess the human health risks resulting from metal exposure by those living in Native American communities that are co-located at these abandoned mine waste sites. More than 1,100 abandoned mine sites remain in Navajo Nation; at least 500 of these sites contain mixtures of uranium, arsenic, and other metals (USEPA 2008a, 2013). Native American communities in the Southwest rely on surface and groundwater sources containing elevated metal concentrations for agriculture and livestock; these sources are especially relevant during arid seasons.

Innovative scientific approaches and solutions are necessary to understand the mechanisms controlling the fate of metals in abandoned mine waste sites and to develop cost-effective remediation technologies to address this challenge.

References

USEPA (2008a) Technical Report on Technologically Enhanced Naturally Occurring Radioactive Materials from Uranium Mining Volume 1: Mining and Reclamation Background, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, EPA 402-R-08-005.

USEPA (2013) Federal Actions to Address Impacts of Uranium Contamination in the Navajo Nation: Five-Year Plan Summary Report. Agency, U.S.E.P. (ed), Region 9.

Increasing the Role of Economics in Environmental Engineering Research (or moving beyond the mindset that Economics = Accounting)[1]

Gregory W. Characklis, University of North Carolina at Chapel Hill

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 ubiquitous in environmental policy debates, with discussions over climate change mitigation revolving around "discount rates" and "cap-and-trade", while concerns over "equity" are part of any discussion of sustainability. With respect to more traditional regulatory themes (e.g., drinking water standards), benefit-cost analysis has emerged as a common, often mandatory, part of policymaking. Meanwhile, regulatory schemes employing market- or incentive-based approaches are receiving greater attention (e.g. nutrient trading), financial theory is being used to devise strategies for addressing environmental risks (e.g., drought), as well as developing world challenges (e.g., microfinance), and "green" technology" has become one of the fastest growing sectors of investment. Together these trends reveal tremendous opportunities for environmental engineers and scientists to expand into new areas involving the integration of technical and economic expertise. At present, however, much of this potential remains unrealized, raising questions as to why our community has failed to pursue these opportunities more aggressively, as well as how we can better position ourselves to do so in the future.

In 2011, the National Science Foundation sponsored a workshop (organized in cooperation with AEESP) to explore these questions, as well as to identify promising areas of interdisciplinary environmental research involving engineers, scientists and economists. The discussion revolved around several general collaborative themes, including:

Innovation in Environmental Regulatory Institutions: Scientists and engineers can play an important role in overcoming regulatory challenges associated with identifying, monitoring and enforcing performance standards, a major hurdle in the drive to develop more effective and efficient regulatory institutions.

Informing Design of Environmental Engineering Solutions using Benefit-Cost Analysis: Benefit-cost analysis has become a common part of many environmental decisions, but a major shortcoming is often incomplete knowledge in areas involving science and engineering.

Using Economic and Financial Concepts to Improve Environmental Risk Management: Risk management innovations from the fields of economics and finance can be combined with scientific and engineering knowledge to significantly improve the characterization and mitigation of environmental risks.

Assessing Actions and Investments that Promote Sustainability: While scientific information is critical to the formulation of sustainable strategies, behavioral, economic and financial principles are often decisive in identifying successful implementation paths.

Environmental Engineering in the Developing World: Technical knowledge is an important factor in improving conditions in the developing world, but it is critical that this knowledge be applied with an understanding of the social, economic and institutional context.

So what stands in the way of the environmental engineering and science community accelerating its movement into these (and related) areas? When considering this question, two primary issues emerged, (i) the paucity of environmental engineers and scientists who are conversant in economics and related social sciences, and (ii) the limited (albeit growing) level of funding available for this type of interdisciplinary research.

There is an increasing call for environmental solutions that involve elements of engineering, science and economics. This demand offers tremendous opportunities to expand into intellectually stimulating and socially relevant areas of research, but changes will be required if environmental engineers and scientists are to play a more significant role in meeting that demand.

---

[1] The title and the text are derived from a 2011 article in ES&T (dx.doi.org/10.1021/es202128s), co-authored by Gregory W. Characklis, Peter Adriaens, John B. Braden, Jennifer Davis, Bruce Hamilton, Joseph B. Hughes, Mitchell J. Small, John Wolfe

“Low-pressure” membrane filtration for water treatment and reuse

Shankar Chellam

Broad Context. The United Nations estimates that one-fifth of the world’s population currently lives in areas of physical water scarcity, a number which is only estimated to increase in the near future. Coupled to the deteriorating quality of our “fresh” water sources, uncertainties associated with climate change, and unsustainable usage, advanced treatment technologies are necessary to quench the thirst of our growing population.

Technical Background. Membrane technologies are capable of removing a wide range of contaminants ranging from the molecular scale (e.g. salts) to large difficult-to-inactivate parasites (e.g. *Cryptosporidium*). This document targets microfiltration, ultrafiltration, and nanofiltration membranes for water purification and reuse (including hybrid systems such as membrane bioreactors). Although desalination by reverse osmosis is technically feasible, the abovementioned membranes operate at significantly lower pressures; i.e. they consume significantly lower energy thereby increasing their feasibility. Even though membranes are implemented based on their excellent contaminant control ability, every installation is prone to fouling, which refers to the loss of specific productivity (i.e. water flux per unit driving pressure). One seemingly obvious method to increase contaminant removal is to use membranes with smaller pores. However, this is inefficient since lowering pore sizes simultaneously increases pressure (energy) requirements and the rate of fouling.

Research Questions. The overarching goal of this research thrust is to simultaneously maximize water productivity and contaminant removal by “low-pressure” membranes. A myriad of specific questions pertaining to this overall goal can be formulated. For example, although micro- and ultrafilters efficiently remove parasites and bacteria, they allow substantial passage of viruses and macromolecular constituents including natural organic matter, disinfection byproduct precursors, organic micropollutants, and inorganic contaminants such as arsenic. A few yet unresolved questions include (note that associated with each technological point several mechanistic engineering-science hypotheses can be formulated):

- Can pretreatment with chemical/electrochemical coagulation or flotation increase trace contaminant removal and concurrently control fouling?
- Are viruses capable of being simultaneously coagulated and inactivated during (electro)coagulation pretreatment?
- How can backwashing hollow-fiber membranes minimize energy and chemical consumption?
- Can the performance of polymeric membranes be improved by modifying their surfaces?
- Under what circumstances can nanofiltration successfully desalinate brackish waters?
- Why do nanofiltration membranes foul rapidly when operating on surface waters and what can be done to mitigate fouling under these conditions?
- How do polymeric membranes respond to changing feed water conditions (both composition and temperature)?
- What is the role of ceramic membranes to purify highly contaminated waters?

Third Generation Renewable Energy Production

Dr. Yongsheng Chen, Associate Professor
School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332
Phone: 404-894-3089; Fax: 404-894-2278; Email:yongsheng.chen@ce.gatech.edu

In recent years, renewable energy has played a critical role in addressing issues of energy security and mitigation of greenhouse gas (GHG) emissions. First-generation liquid biofuels, such as corn-based ethanol in the U.S. and sugarcane ethanol in Brazil[1], have already been widely produced. However, the mass production of first-generation liquid biofuels has resulted in a series of problems related to elevated food prices, diminished land availability for agriculture, and high water and fertilizer requirements[1-3]. Second-generation biofuels derived from lignocellulosic agriculture and forest residues and from non-food crop feedstocks address some of these problems; however there is still concern over competition with land use directed toward other activities, or required changes to land usage. Thus, the Energy Independence and Security Act (EISA) of 2007 limits the production of corn-based ethanol and promotes instead the production of environmentally benign biofuels[3].

Third-generation biofuels specifically derived from microalgae are considered a technically viable alternative energy resource that is devoid of the major drawbacks associated with first- and second-generation biofuels. Microalgae-based biofuels have the following appealing attributes[4]: 1) microalgae have a rapid growth rate (cell doubling time of 1–10 days) and can grow all year round with high lipid content (20–50% dry weight of biomass)[5], meaning oil production is 15–300 times more than conventional crops on a per-area basis[6]; 2) microalgae can be cultivated in seawater, brackish water, and wastewater on non-arable land, which is useful for wastewater treatment and significantly reduces the usage of fresh water and exogenous nutrients (e.g., N and P) [7]; and 3) microalgae have high carbon dioxide (CO_2) absorption and uptake rates (1 kg of dry algal biomass utilizes about 1.83 kg of CO_2)[8], which will help mitigate GHG emissions associated with traditional carbon-based fuels. Given these advantages, microalgae-based biofuels have been recognized as the “third-generation biofuels”, and the “only current renewable source of oil that could meet the global demand for transport fuels”.

Although microalgae represent enormous potential for biofuel production, bio-treatment of wastewater, and CO_2 sequestration, major challenges to commercial viability exist: 1) no reported engineering coupling processes exist that integrate microalgae production with wastewater treatment to achieve a positive energy return and make the process economically viable[9-11]; 2) lack of cost-effective harvesting and water recycling technologies which preclude coagulant addition and its detrimental effects on downstream processing (e.g., biofuel refining); 3) lack of field data to evaluate the economic feasibility of coupling algal cultivation and wastewater treatment. Thus, although wastewater presents a promising way to produce economically viable algal biomass for conversion to biofuels with minimum or reduced environmental impacts, both fundamental and field-scale research are greatly needed to address the challenges cited above, as well as to achieve a better understanding of the economic viability and large-scale implementation of algal-based biofuel production systems.

References:

1. Sims, R. E. H., Mabee, W., Saddler, J.N., Taylor, M. 2010. An overview of second generation biofuel technologies. *Bioresource Technol*. 101, 1570–1580.

2. International Energy Agency, 2007. World energy outlook; Paris:

3. Energy Independence and Security Act of 2007. http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf

4. Zhang, X. Z.; Hu, Q.; Sommerfeld, M.; Puruhito, E.; Chen, Y. S. 2010. Harvesting algal biomass for biofuels using ultrafiltration membranes. *Bioresource Technol.* 101 (14), 5297-5304.

5. Hu, Q.; Sommerfeld, M.; Jarvis, E.; Ghirardi, M.; Posewitz, M.; Seibert, M.; Darzins, A. 2008. Microalgal triacylglycerols as feedstocks for biofuel production: perspectives and advances. *Plant J* 54 (4), 621-639.

6. Schenk, P. M.; Thomas-Hall, S. R.; Stephens, E.; Marx, U. C.; Mussgnug, J. H.; Posten, C.; Kruse, O.; Hankamer, B. 2008.Second Generation Biofuels: High-Efficiency Microalgae for Biodiesel Production. *Bioenerg Res*. 1 (1), 20-43.

7. Hu, Q.; Westerhoff, P.; Vermaas, W. 2000. Removal of nitrate from groundwater by cyanobacteria: Quantitative assessment of factors influencing nitrate uptake. *Appl. Environ. Microbiol.* 66 (1), 133-139.

8. Jorquera, O.; Kiperstok, A.; Sales, E. A.; Embirucu, M.; Ghirardi, M. L. 2010. Comparative energy life-cycle analyses of microalgal biomass production in open ponds and photobioreactors. *Bioresource Technol.* 101 (4), 1406-1413; (b) Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnol. Adv.* 25 (3), 294-306.

9. Pittman, J. K.; Dean, A. P.; Osundeko, O. 2011. The potential of sustainable algal biofuel production using wastewater resources. *Bioresource Technol.* 102 (1), 17-25.

10. Yang, J.; Xu, M.; Zhang, X.; Hu, Q.; Sommerfeld, M.; Chen, Y. 2011. Life-cycle analysis on biodiesel production from microalgae: Water footprint and nutrients balance. *Bioresource Technol.* 102, 159–165.

11. Van Ginkel, S.W. and Chen, Y. 2014. Water footprint of algal biofuels. In: Algal fuels: an assessment of opportunities and challenges. Future Science Ltd, London, UK.

Grand Challenges for the 21st Century in Environmental Engineering Science

Yu-Ping (Yo) Chin and Bill Arnold

Legacy Contaminants:

While much research in our field over the past decade has focused on endocrine disrupting compounds and emerging contaminants e.g., pharmaceuticals and personal care products, research on understanding the fate of older legacy contaminants such as TCE and BTEX and technologies to remediate sites contaminated with these substances fell out of favor. The relatively recent 2013 NRC study entitled *Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites* was a wake up call with respect to reintroducing our field to the magnitude of the legacy contaminant problem. As stated in the executive summary, there are 126,000 sites in the country that have residual legacy contamination that prevents their closure. Roughly 10% (~ 12,000) are very complex from a hydrogeological perspective and are *likely to never reach closure*. Further, the report noted that the pace of remediation related research "has slowed considerably" since the last study was issued by the NRC 10 years ago and that the development of "effective treatment technologies is likely to occur at a much reduced pace". The scope of this problem actually dwarfs issues associated with the release of emerging contaminants and nanoparticles to the environment and should be revisited with a renewed effort to develop technologies that can effectively remediate many of these contaminated sites.

Pesticides:

When it comes to organic contaminants harming waterways, pesticides associated with non-point source runoff are detected more frequently than any emergent contaminant. In a follow-up to the Kolpin et al., 2002 EST paper a 2007 report by Gilliom in EST found that pesticides were detected in 97% of stream waters in urban and agriculturally impacted watersheds and even 65% in undisturbed streams. Further, while direct threats to human health were relatively low (< 10% in all cases) threats to ecosystem function at the levels detected were considerably greater (up to 57 and 83% in agriculture and urban areas respectively). In contrast the Kolpin et al., 2002 study found that some common pharmaceuticals were detected in a bit more than 10% of stream water samples, which is in contrast to the detection frequency of pesticides. Thus, while emerging contaminants should continue to be studied more studies are needed to assess the environmental impact of pesticides and clever strategies to limit their release to receiving waters. The recent reports in *Nature* linking neonicotinoid pesticides to bee colony collapse are good examples of ecological consequences of their widespread use and occurrence.

Geological and Climate Associated Hazards:

From the engineering perspective how well equipped is this country in dealing with 1) geological hazards e.g., earthquakes, volcanic eruptions, etc. and 2) climate related events e.g., super storms, drought, flooding? While point 1 is significantly difficult to predict several regions of the country are at high risk for at least earthquakes including areas considered tectonically stable e.g., St. Louis due to its proximity to the New Madrid fault. Further, aside from California other large metro centers are in tectonically active areas e.g., Salt Lake City, which is in area of rifting and the Pacific Northwest, which is on a continental volcanic arc (volcanism also occurs there as well). Are the water and wastewater facilities sufficiently "hardened" to take such a hit? What are the contingency plans? How about distribution systems?

With respect to climate change related events challenges fall into two categories: 1) episodic and 2) protracted. Both require different approaches. With respect to the former many of the water supply and distribution issues facing communities with known geologic hazards are similar i.e., are facilities hardened? What about distribution systems? What are the contingency plans? With respect to the later some hard choices will need to be made with respect to water reuse, rationing, etc. For example the RENUWIT STC at Stanford and Berkeley are already addressing many of these later issues, but more needs to be done.

Pesticide Persistence, Effects on Ecosystems, and Possible Threats to Food Supply:
Yu-Ping (Yo) Chin

When it comes to organic contaminants harming waterways, pesticides associated with non-point source runoff are *detected more frequently than any emergent contaminant*. In a follow-up to the Kolpin et al., 2002 EST paper a 2007 report by Gilliom in EST found that pesticides were detected in 97% of stream waters in urban and agriculturally impacted watersheds and even 65% in undisturbed streams. Further, while direct threats to human health were relatively low (< 10% in all cases) threats to ecosystem function at the levels detected were considerably greater (up to 57 and 83% in agriculture and urban areas respectively). In contrast the Kolpin et al., 2002 study found that some common pharmaceuticals were detected in a bit more than 10% of stream water samples, which is in contrast to the detection frequency of pesticides. Thus, while emerging contaminants should continue to be studied more studies are needed to assess the environmental impact of pesticides and clever strategies to limit their release to receiving waters.

One complication that has developed since the beginning of the millennium is the use of new classes of pesticides that are being brought onto market. These include triketones e.g., mesotrione, which are 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors, second-generation pyrethroids, and neonicotinoids. Some of these pesticides have been around since the mid twentieth century, but have gained popularity due to their resemblance to similar compounds found naturally in plants, which makes them appealing as a less harmful pesticide to humans. Many of these insecticides, however, exhibit toxicity to beneficial insects e.g., bees, mayflies, etc. Recent reports in *Nature* (Kessler et al., (2015) "Bees prefer foods containing neonicotinoid pesticides", 521, 74-76 and Rundlof et al., (2015) "Seed coating with a neonicotinoid insecticide negatively affects wild bees", 521, 77-80) have linked neonicotinoid pesticides to bee disorders, and are good examples of ecological consequences of their widespread use and occurrence. Further, even though these substances are relatively labile once released to the environment it is unclear whether their transformation products possess residual toxicity or can even possibly revert back to the parent compound as have been observed for trenbolone (Qu et al., "Product-to-parent reversion of trenbolone: unrecognized risks for endocrine disruption." *Science* (2013) 347-351.). Because so much is at stake with respect to the possible deleterious effects of these substances on critical ecosystem services e.g., pollination of food crops by bees, disruption of the aquatic foodweb due to losses of beneficial benthic organisms such as mayflies and caddis flies more research needs to be conducted that will help us better understand the long term effects and possible consequences of their continued use.

Climate Adaptive Urban Water Infrastructure: Applications of Advanced Materials

Indranil Chowdhury
National Research Council Associate
National Exposure Research Laboratory, US EPA, Athens, GA.
Email: Chowdhury.Indranil@epa.gov

Climate change will create tremendous pressure in our water systems including availability and quality. Several places in U.S. including California are already facing water shortages due to drought. Our urban water infrastructure system needs to be designed to withstand and adapt with climate change. Advanced materials can play significant roles in designing energy efficient and climate resilient urban water infrastructure. For climate adaptive infrastructure, sensing and monitoring are essential and advanced materials can play major roles in developing sensor technology for urban water infrastructure. Potential applications of advanced materials are in water distribution systems, sensor technology for water quality monitoring and control, water treatment, water reuse, desalination, decentralized treatment (greywater reuse). Besides engineered systems, advanced materials can be applicable to naturally managed systems for efficiency and monitoring including stormwater management, wetland and groundwater monitoring. Furthermore, advanced materials may be useful for designing biomimetic environmental systems, which can adapt with climate change.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century
Workshop at the AEESP 2015 Meeting

Title of Grand Challenge:
Carbon Management

Andres Clarens
http://cee.virginia.edu/andresclarens/

Over the past several years, wind and solar generation capacity have grown at a pace that suggests efforts to decarbonize our electric power sector are possible in the long term. In the short to medium term, however, these sources will only make up a small fraction of our total generation while we continue to rely heavily on fossil fuels, primarily coal and natural gas. Burning these will result in significant carbon emissions to the atmosphere and these emissions are the principal contributors to anthropogenic climate change. The United Nations and most governments agree that in order to avoid the most dramatic effects of climate change, we have to limit warming to 2 ºC. This target cannot be achieved under any scenario without interim strategies to manage the carbon emissions associated with fossil fuel use. Active carbon management is going to be a critical piece of any realistic strategy to mitigate the impacts of climate change. Environmental engineers have many skills that could contribute to innovative strategies to address this critical problem.

There are at least three reasons that active carbon management should be considered a grand challenge and opportunity in environmental engineering. First, as a discipline, we have a great deal of domain-specific knowledge to bring to bear on this problem. Environmental engineers are experts in a variety of subjects that are relevant for identifying mitigation strategies. Pollutant transport in the atmosphere, separations, water chemistry, groundwater hydrology, and other related fields that could all be part of a one or more strategies for managing these emissions. Second, environmental engineers have a long history of practicing engineering at large scales. Efforts to manage carbon emissions are hindered by the enormous quantity that we emit into the atmosphere ($\sim 1.5^{10}$ kg/day). In a year, this is equivalent to a mass of CO_2 six times greater than the mass of rock in Mount Everest into an atmosphere that is only a few miles thick. In the past, efforts to clean up entire rivers, airsheds over cities, or the water underneath a region, environmental engineers have the experience deploying large-scale technological strategies to clean up pollution. Third, climate change touches on all other areas of environmental engineering. If climate change continues unabated, the impacts to water quality, water quantity, food systems, regional air quality, and many other problems that we focus on will be impacted. For this reason, most of the world's relevant scientific bodies including the National Academies of Engineering have identified carbon management as one of their top scientific priorities. Environmental engineers have an opportunity to be leaders on this critical problem.

There are already a large number of examples of projects that the AEESP community works on that could be classified under this grand challenge. A large number of researchers are looking at biological sequestration using algae. Others are exploring carbon sequestration and the transport of CO_2 and other gases in the deep subsurface. Some have focused on the biochar and other techniques to reverse the loss of carbon from our soils. The green engineering community is focused on using CO_2 for beneficial uses that will keep the emissions out of the atmosphere. Other projects would harness aqueous geochemistry to precipitate carbon on the back end of power plants. Exploring these efforts in the context of this broader challenge could help improve the impact of the work and move us closer to developing deployable technologies that could advance critically important emissions reductions goals.

Grand Challenge - Food-Energy-Water Nexus and Wastewater Resource Recovery

Erik R. Coats, P.E., Ph.D. – University of Idaho

May 2015 – Prepared for AEESP Workshop

As we look to achieve sustainable water resource systems within an increasingly developed world, wastewater resource recovery must become intrinsically linked to the food-energy-water (FEW) nexus. Within a broad resource-recovery context, the goal is to advance sustainable technologies for recovering value from what is otherwise considered a waste that is "thrown away." The "disposal-first" concept has historically applied to most waste streams generated in developed societies and has a legacy embedded in environmental regulations. However, in recent years the potential value of waste streams has become apparent [1, 2]. Commensurately, technologies have been developed to capture more of the intrinsic value in wastewater. For example, technologies have been proposed and/or advanced to produce/recover the following from wastewater: (i) a slow-release fertilizer ([3, 4]), (ii) a biomass-based fertilizer as Class A/B biosolids [5], (iii) electricity via combustion of biogas [5], (iv) biodegradable plastics [6, 7], and (v) methanol from biogas [8].

The concept of resource recovery is being advocated by WEF, even going so far as to rename wastewater treatment plants to water resource recovery facilities (WRRFs). Conceptually, WRRFs play a central role in the FEW nexus, with the concept of resource recovery from waste streams [2] aligning well with sustaining FEW resources for urban and rural needs [2, 9]. However, progress toward actualizing the intention of the new nomenclature has been slow. For example:

THE NEXUS OF FOOD-ENERGY-WATER: WASTEWATER RESOURCE RECOVERY

- Municipal WRRFs produce approximately 32 billion gallons of reclaimed water daily [10]; however, less than 3% is utilized for non-potable water needs [11].
- An estimated 8 million dry tons/yr of sludge is produced at municipal WRRFs in the U.S. [11]; however, only ~54% of the sludge is converted to useful biosolids [11], the remainder being landfilled.
- Energy demand to treat wastewater at municipal WRRFs is ~30.2 billion kWh/yr[10]. Use of biogas to produce electricity could offset ~40% of WRRF energy demand [12]. However, less than 10% of WRRFs employ such technologies [13], and the majority of biogas produced is ultimately flared vs. being converted to electricity [14].

In 2013, the EPA reported the investment needs of America's publicly-owned treatment works were $188 billion [15]. Continued investment in traditional wastewater treatment configurations is not sustainable [2, 16]. New strategies must maximize nutrient removal efficiency and reduce energy usage, all within the context of resource recovery and the FEW nexus.

I see our **<u>Grand Challenge</u>** as truly actualizing the broad-scale concept of WRRFs. We need to: i) continue to develop technologies that can sustainably achieve maximal resource recovery from wastewater; ii) conduct research to demonstrate new technologies at an appropriate pilot-scale; iii) ensure that new technologies integrate effectively within current WRRF infrastructure; iv) test technologies at a pilot scale; and v) understand and address the sociological/political barriers that are currently limiting use of available technologies for resource recovery (to a certain degree the challenge is sociological and institutional in nature [2, 17]). More specifically, I see items (ii-v) as most critical. However, WRRFs are required to produce effluent to remain in compliance with a federally issued permit; excursions from this permit lead to expensive fines. Thus, the focus is on the avoidance of permit violations and adverse publicity by embracing the traditional approach to wastewater management (i.e., *status quo*). We need to help facilitate the transition to WRRFs that achieve permit compliance while maximizing resource recovery.

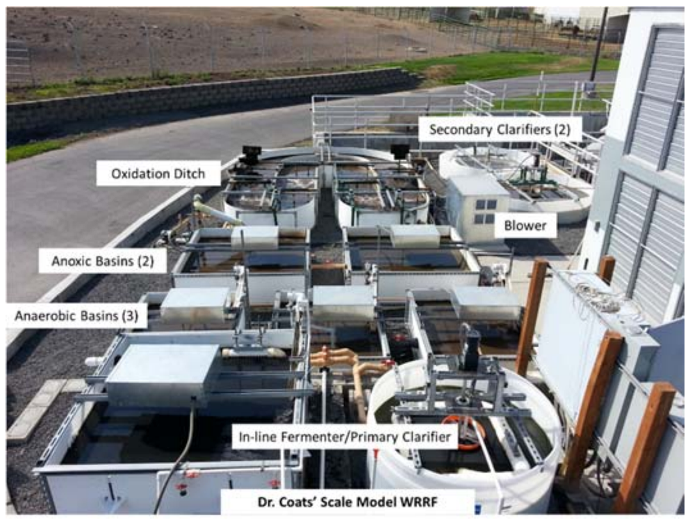
References.

1. Rittmann, B.E., *Microbial ecology to manage processes in environmental biotechnology.* Trends Biotechnol, 2006. **24**(6): p. 261-266.
2. Guest, J.S., S.J. Skerlos, J.L. Barnard, M.B. Beck, G.T. Daigger, H. Hilger, S.J. Jackson, K. Karvazy, L. Kelly, L. Macpherson, J.R. Mihelcic, A. Pramanik, L. Raskin, M.C.M. Van Loosdrecht, D. Yeh, and N.G. Love, *A new planning and design paradigm to achieve sustainable resource recovery from wastewater.* Environ. Sci. Technol., 2009. **43**(16): p. 6126-6130.
3. Doyle, J.D. and S.A. Parsons, *Struvite formation, control and recovery.* Water Res., 2002. **36**(16): p. 3925-3940.
4. Baur, R., R. Prasad, and A. Britton, *Reducing Ammonia and Phosphorus Recycle Loads by Struvite Harvesting.* Proceedings of the Water Environment Federation, 2008. **2008**(9): p. 6262-6270.
5. Tchobanoglous, G., H.D. Stensel, R. Tsuchihashi, and F. Burton, *Wastewater engineering: Treatment and resource recovery*. 5th ed. 2014, New York, NY: Metcalf & Eddy/AECOM. 2018.
6. Coats, E.R., K.E. VandeVoort, J.L. Darby, and F.J. Loge, *Toward polyhydroxyalkonate production concurrent with municipal wastewater treatment in a sequencing batch reactor system.* ASCE J. Environ. Engr., 2011. **137**(1): p. 46-54.
7. Coats, E.R., F.J. Loge, M.P. Wolcott, K. Englund, and A.G. McDonald, *Synthesis of polyhydroxyalkanoates in municipal wastewater treatment.* Water Environ. Res., 2007. **79**(12): p. 2396-2403.
8. Taher, E. and K. Chandran, *High-Rate, High-Yield Production of Methanol by Ammonia-Oxidizing Bacteria.* Environ. Sci. Technol., 2013. **47**(7): p. 3167-3173.
9. Daigger, G.T. *The IWA Cities of the Future Approach to Achieving a Resilient Water Supply System-Pursuing Safety, Sustainability and Environmental Friendliness*. in *ASWIN International Symposium*. 2012. Yokohama, Japan: ASWIN.
10. Pabi, S., A. Armarnath, R. Goldstein, and L. Reekie, *Electricity use and management in the municipal water supply and wastewater industries*, 2013, EPRI, 194 p.
11. Center for Sustainable Systems, University of Michigan, 2013, "U.S. Wastewater Treatment Factsheet", Pub. No. CSS04-14.
12. Wiser, J.R., J.W. Schettler, and J.L. Willis, *Evaluation of combined heat and power technologies for wastewater treatment facilities*, 2010, EPA/WERF, EPA 832-R-10-006, 213 p.
13. CHP, *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field*, 2011, EPA/CHP, 50 p.
14. Daigger, G.T., *Evolving Urban Water and Residuals Management Paradigms: Water Reclamation and Reuse, Decentralization, and Resource Recovery.* Water Environment Research, 2009. **81**(8): p. 809-823.
15. ASCE. *Report Card for America's Infrastructure-Wastewater*. 2013; Available from: http://www.infrastructurereportcard.org/fact-sheet/wastewater.
16. Foley, J., D. de Haas, K. Hartley, and P. Lant, *Comprehensive life cycle inventories of alternative wastewater treatment systems.* Water Res., 2010. **44**: p. 1654-1666.
17. Daigger, G.T., *Changing Paradigms: From Wastewater Treatment to Resource Recovery.* Proceedings of the Water Environment Federation, 2011. **2011**(6): p. 942-957.

Grand Challenge – From the Laboratory to Full-scale Deployment
Erik R. Coats, P.E., Ph.D. – University of Idaho
May 2015 – prepared for AEESP Workshop

As environmental engineering and science professors, we excel at teaching, researching, and developing new wastewater processes/technologies. However, be it teaching or research, it can be a challenge to transfer our new knowledge (be it a specific process or technology, or new operating criteria) from the micro-scale in the lab (e.g., 1L beakers operated as sequencing batch reactors) to full-scale operations (treating millions of gallons of wastewater daily, in a continuous flow mode of operations). A further challenge can be transferring a process that has been developed based on the use of synthetic wastewater to full-scale that receives a more complex real wastewater.

Scale model operations can be an effective bridge between the lab and full-scale. Scale models can be used to generate critical data and overall process validation related to ultimate full-scale application, as well as identify important gaps between lab- and full-scale operations. Further, scale models provide important pedagogical opportunities. For example, I own and operate a pilot-scale water resource recovery facility (WRRF) that has the ability to process 1-3 gpm of real wastewater. The pilot system is a 1:1,000 scale model of the Moscow, Idaho WRRF, and is located on the Moscow WRRF site (see adjacent image). Graduate and undergraduate civil/environmental engineering students operate the system, and are responsible for process operations and control (students also designed and constructed the system). The value of this system to my research program has been quite tangible. We are currently leveraging the system to extend the study of two lab-based investigations to a larger, continuous flow scale. Moreover, students report that the experience gained applying principles learned in class has been invaluable in helping cement their understanding of wastewater treatment processes. In addition, with the scale model being located at a full-scale WRRF, students regularly engage with operations staff. Such interactions provide them the opportunity to learn more about the operations side of wastewater treatment, and also to gain experience on interpersonal professional relationships/interactions that will be necessary as they enter the workforce (most as consulting engineers). Finally, scale model systems provide opportunities to conduct training for WRRF operators.



What I see as a **Grand Challenge** is the need to expand the number of WRRF scale models available to university faculty, with such facilities owned and operated by university faculty. Let me clarify – this is not me trying to "sell" use of my scale model. I constructed my scale model as a means to help connect my research and my students (principally MSc, but some PhD) to the real world. I see, and have realized, real value in my scale models (I have three in total), and I believe that our profession as a collective would benefit similarly. In expanding the availability of scale models, perhaps a network can be developed through which faculty can test and evaluate lab-scale research at a larger scale.

AEESP Grand Challenges Workshop

Title: Setting sustainability criteria for the development of new technologies & implementation of existing technologies

Name: Sherri Cook (sherri.cook@colorado.edu)

Overview:

The sustainable implementation of existing technology and development of new technology requires the use of life cycle and systems thinking in order to support targeted and effective research efforts and the advancement of sustainable environmental engineering practices. Life cycle thinking can identify the environmental impacts and costs over a system's lifetime. It allows the holistic comparison of engineered systems and improves our understanding of multiple human and environmental health issues, life cycle costs, and tradeoffs. Systems-thinking shows the influence each system component has on the entire system, and it allows for the informed multi-objective optimization of a system as well as for an improved understanding of the interaction between multiple engineered systems. This modeling approach provides the information needed to improve technology development and to optimize system design, operation, and implementation. At present, however, the process of designing new technologies or of implementing existing technologies often lacks a consistent systems-thinking and life cycle approach to developing sustainable solutions.

As we face many different grand challenges in environmental engineering– water scarcity and reuse, global population increase, the need for accessible and effective sanitation—the field can support more effective and sustainable designs and implementations by developing and applying consistent life cycle and systems thinking approaches. As challenges become more complex, our approach for developing solutions needs to be similarly comprehensive in order to support sustainable solutions. While a life cycle and systems approach provide effective and efficient tools for tackling grand challenges, the approach can only be effective if it's systematically applied and understood. This approach lets us understand how a system interacts with the environment and other engineered systems, it can highlight the most important aspect of a system's function in order to focus future research efforts, and it helps to identify any important tradeoffs of a systems implementation so that we can have a more informed decision making process. Overall, this approach helps environmental engineers understand how a system functions and interacts with other systems. With this information, we can set "sustainability criteria" for the design and implementation of new and existing technologies to assure that our solutions specifically and holistically address the environmental and human health challenges in our field.

Possible Discussion Points:

- To better navigate tradeoffs, how can environmental engineers better inform the decision making process and the weighting process for the various types of environmental impacts/emission?
- How can the mostly environmentally focused LCA approaches be used to better understand the tradeoffs between environmental impacts the human health risks?
- How can we support the use of systems and life cycle thinking to understand and improve a technology and overcome the perception that LCA can "doom" the development of otherwise promising technologies?

AEESP Grand Challenges Workshop

Title: Setting sustainability criteria for the development of new technologies & implementation of existing technologies

Name: Sherri Cook (sherri.cook@colorado.edu)

Overview:

The sustainable implementation of existing technology and development of new technology requires the use of life cycle and systems thinking in order to support targeted and effective research efforts and the advancement of sustainable environmental engineering practices. Life cycle thinking can identify the environmental impacts and costs over a system's lifetime. It allows the holistic comparison of engineered systems and improves our understanding of multiple human and environmental health issues, life cycle costs, and tradeoffs. Systems-thinking shows the influence each system component has on the entire system, and it allows for the informed multi-objective optimization of a system as well as for an improved understanding of the interaction between multiple engineered systems. This modeling approach provides the information needed to improve technology development and to optimize system design, operation, and implementation. At present, however, the process of designing new technologies or of implementing existing technologies often lacks a consistent systems-thinking and life cycle approach to developing sustainable solutions.

As we face many different grand challenges in environmental engineering– water scarcity and reuse, global population increase, the need for accessible and effective sanitation—the field can support more effective and sustainable designs and implementations by developing and applying consistent life cycle and systems thinking approaches. As challenges become more complex, our approach for developing solutions needs to be similarly comprehensive in order to support sustainable solutions. While a life cycle and systems approach provide effective and efficient tools for tackling grand challenges, the approach can only be effective if it's systematically applied and understood. This approach lets us understand how a system interacts with the environment and other engineered systems, it can highlight the most important aspect of a system's function in order to focus future research efforts, and it helps to identify any important tradeoffs of a systems implementation so that we can have a more informed decision making process. Overall, this approach helps environmental engineers understand how a system functions and interacts with other systems. With this information, we can set "sustainability criteria" for the design and implementation of new and existing technologies to assure that our solutions specifically and holistically address the environmental and human health challenges in our field.

Possible Discussion Points:

- To better navigate tradeoffs, how can environmental engineers better inform the decision making process and the weighting process for the various types of environmental impacts/emission?
- How can the mostly environmentally focused LCA approaches be used to better understand the tradeoffs between environmental impacts the human health risks?
- How can we support the use of systems and life cycle thinking to understand and improve a technology and overcome the perception that LCA can "doom" the development of otherwise promising technologies?

Workshop: Re-Thinking Wastewater Treatment at the Nexus of Energy, Climate Change, and Resource Recovery

Motivation: Historically, the principal goal of centralized municipal wastewater treatment has been to treat the wastewater to an appropriate standard such that the quality of the receiving water is not unacceptably impaired, thereby protecting the health of both humans and ecosystems. We recognize now that we can meet such standards while revisiting the traditional infrastructural paradigm of large, built centralized facilities. The inclusion of decentralization, natural treatment systems, and non-traditional metrics to elucidate fundamental understanding and technical decision-making is currently re-shaping research and practice, and will be central to this proposed workshop. In addition to considering how we can best treat wastewater to protect human and ecosystem health, we are now faced with several additional important questions: How much and what form of energy is used to treat wastewater and to reclaim water and nutrients? How does wastewater treatment contribute to climate change? How can we recover resources such as water, nutrients, and energy from wastewater during the treatment process – and is it economically and environmentally beneficial to do so? How do the answers to these preceding questions affect the way(s) in which wastewater treatment in the 21st century should differ from treatment in the 20th century? What are the key knowledge gaps that should be addressed by members of AEESP?

Description of Workshop: Objectives of the workshop will be: (1) to enhance collaborative interaction within the community of scholars working on wastewater treatment in the context of decentralized systems, water-energy, climate change, and resource recovery; (2) to collaboratively prepare a concise summary of the most important ways that wastewater treatment affects, and is affected by, related systems, with emphasis on energy, climate change, and resource recovery; and (3) to collaboratively develop (and, perhaps, to prioritize) a list of knowledge gaps and major research questions that confront us as we re-think wastewater treatment for the remainder of the 21st century. Questions might relate to issues such as source separation, de-centralized treatment, energy-neutral or energy-positive wastewater treatment, recovery of N and P from centralized treatment, novel biological processes, load management strategies, emission of greenhouse gases from wastewater treatment facilities, potable re-use of treated effluent, etc.

Intended Audience: The workshop is aimed at participants (faculty, scientists, post-doctoral researchers, graduate students, industrial practitioners) who are actively engaged in research on wastewater treatment at the nexus of one or more other systems/topics, principally energy, climate change, and resource recovery.

Workshop Organizers:
Jeff Cunningham, University of South Florida, cunning@usf.edu
Jeremy Guest, University of Illinois at Urbana-Champaign, jsguest@illinois.edu
Diego Rosso, University of California, Irvine, bidui@uci.edu

Sustainable Carbon Sequestration

Ning Dai

Carbon sequestration, the capture and storage of CO_2, is a key player in mitigating global climate change. Compared to renewable energy deployment, carbon sequestration has the potential to significantly curb CO_2 emission within the century while fossil fuels remain dominant in the energy supply. The National Academy of Engineering lists the development of carbon sequestration methods as one of the grand challenges for engineering.

Despite the recognition on the importance of carbon sequestration, the concept of sustainable carbon sequestration has not well developed. Currently, the impediment to implementing carbon sequestration arises from the lack of sustainability, and can be attributed to two factors: 1) the concern on the effectiveness and the unintended consequences of carbon capture and storage; 2) the high cost associated with carbon sequestration and the lack of economic incentives. The long-term stability of deep subsurface formation in sequestering CO_2 is often questioned. For carbon capture, amine scrubbing, considered a mature technology by the chemical engineering community, was recently found to produce carcinogenic byproducts. Moreover, CO_2 capture on average imposes a 40% increase in electricity cost.[1] These challenges call for creative and interdisciplinary solutions:

1) Innovative CO_2 capture technologies. The energy penalty of current CO_2 capture technologies can be reduced by improving system configuration and employing new chemicals. The environmental impacts of CO_2 capture systems through waste and exhaust gas should be incorporated into the initial design, rather than an after-thought. These tasks will require collaborative efforts in chemical engineering, environmental engineering, and material science.

2) Beneficial use of CO_2. Local solutions can collectively contribute to solving global problems. In areas where geologic CO_2 storage is not an optimal option, beneficial use of CO_2 in chemical production can provide incentives to carbon sequestration. For example, the benefit of using captured CO_2 for enhanced oil recovery is shown able to offset the cost of CO_2 capture.

3) Participation from the public, power industry, and regulation agencies. In addition to the technology advancement, policy incentives are needed to overcome the inertia in the power industry. Scientific evidence of the safety and effectiveness of carbon sequestration will increase public awareness and provide sustainable support to the low carbon policies.

---

[1] U.S. Energy Information Administration (2014). "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014."

Short-Circuiting Urban Water Cycle:
Wastewater Recycling and Stormwater Management

Ning Dai

Water scarcity is an imminent challenge to the sustainable development of the nation and the globe. Our water supply is continually stressed by the changing climate. The Intergovernmental Panel on Climate Change has concluded that there is strong evidence to show that the changing precipitation is altering the hydrological systems and the climate-related extremes are rendering many societies vulnerable.

The growing water demand of cities is a result of the increasing urban population. In California and Arizona, two of the driest states in the U.S., a quarter of the water supply is consumed by urban use. Accompanied with the high water demand is the generation of large quantity of wastewater from urban environment. In addition, increasing percentage of precipitation is occurring as intense single-day events in recent years, resulting in the spike in stormwater runoff from the impervious surfaces in urban areas. Promoting wastewater recycling and stormwater management will provide alternative water sources to tackle water scarcity, minimize environmental impacts of urban activities, and ensure the sustainability of urban ecosystems.

Although wastewater recycling and stormwater management has been embraced by some cities that are stressed by draught or flooding, these practices have not been widely adopted across the nation. The following issues remain:

1) Health and ecosystem impacts of trace contaminants in wastewater and stormwater runoff remain unclear.
2) Treatment technologies are expensive.
3) System-level understanding of the value of urban water resource is lacking.
4) Regulation framework for urban water management is not mature.

An interdisciplinary task force is needed to address these issues. Analytical chemistry, toxicology, and public health research is needed to understand the health implications of trace contaminants to human and ecosystems upon prolonged exposure. This will inform the development of treatment technologies and appropriate usage of particular water resource. Novel treatment systems and materials for producing high quality water in an energy- and cost-effective fashion are needed. System-level models for evaluating the value of urban water resource and benefits need to be developed. The utilities, governmental agencies, and the public should be engaged.

Lastly, it is worth noting that the development of wastewater recycling and stormwater management technologies and practices has international impacts. The growth of urban population in developing countries is 3-5 times faster than in the U.S. These new cities provide opportunities for new model of sustainable development.

EES Grand Challenge

Transitions in Socio-Economic-Political Systems

Glen T. Daigger, Ph.D., P.E., BCEE, NAE
Professor of Engineering Practice, Department of Civil and Environmental Engineering, Un iversity of Michigan

It is abundantly clear that we must transition to a much more resource-efficient society if the projected population of planet earth (10 billion people) is to enjoy a reasonable standard of living. We are already exceeding planetary limits in three out of nice critical planetary systems[1], which in fact is likely degrading the capacity of these systems to provide the ecological services that humanity depends on. Fortunately solutions exist which can not only mitigate the environmental degradation occurring but which can provide needed resources for human life while restoring the planet.[2] The fundamental constraint is not the availability of solutions but the pace at which solutions are evaluated and translated into practice. This occurs for several reasons, but perhaps the most important one is that existing socio-economic-political systems have evolved to effectively implement and sustain the solutions of the past, not those of the future. Thus, while environmental engineering and science (EES) has much to offer to solve current and future problems facing humanity and the planet, the benefits of these solutions will not be realized unless associated socio-economic-political systems are changed.

While EES is well grounded in the physical, chemical, and biological sciences, it has not traditionally embraced the social sciences where social, economic, and political systems are studied. But, a much greater facility with the relevant social sciences is needed if the full benefits of the knowledge developed by EES is to be translated into actions which actually produce benefits. Since the fundamental purpose of EES is to produce solutions which solve the environmental problems of humanity and the planet, incorporating social sciences into EES research, education, and practice, is essential. Moreover, EES researchers and practitioners must become much more engaged in actually helping social, economic, and political systems to make the necessary changes. The profession is certainly positioned to play a leading role in such transitions as EES professionals are in key leadership positions throughout the regulatory agencies and utilities which require, oversee, and implement environmental solutions. What is needed is greater knowledge and skill in how to make the necessary transitions in social, economic, and political systems to occur, and the organized will to make this happen.

This a key challenge for EES is to build research, education, and practice capacity in the relevant social sciences and to convert this knowledge into an organized and routinely used professional practice that accelerates the needed changes that allow environmental solutions to be implemented much more quicly.

---

[1] Rockstrőm, J., *et al*., "A Safe Operating Space for Humanity," *Nature*, **461**(24), 472-475, September, 2009.

[22] Daigger, G. T., S. Murthy, N. G. Love, J. Sandino, "Transforming Environment Engineering and Science Research, Education, and Practice," Invited Paper, *Environmental Engineering and Science*, In Preparation.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY

Daniel Gomez Gutierrez, Bogota, Columbia

Many of the environmental problems worldwide are driven by other disciplines that sometimes have only the small picture and 1" of deepness in the matter. This is how we see that politician, businesspersons, architects, economists, lawyers and other professionals figure as environmental experts while environmental engineers and scientists continue working on finding the solutions to environmental problems and trying to predict what our future will be.

In the case of environmental engineering, it is considered a "soft" engineering and this may explain why people address environmental issues like talking about the trending TV shows or pop stars. As an environmental engineering professor, I strive to show my students how the numbers and the applied science show the path for solving contemporary problems. Undoubtedly we require the help of the other professionals mentioned above as for they are part of the problem and can be part of the solution, and as an example we see what people like Al Gore, William McDonough are doing, while becoming part of the solution.

Another challenge that environmental engineers have is the way environmental education is handed to people and how we compromise them to transform their bad life habits (consumption, nutrition, way of living, etc.) into good practices that even help support the lost environmental resilience; this is one of the only engineering professionals that deals with people and their behavior, and although we are not psychologists or sociologists, we have to train similar abilities and work more in the transformation of societies. For example, we need to address social phenomena like collaborative consumption and social media where we may find a natural place to educate with the right language and best possible actions. Finally yet importantly, environmental issues need being addressed in the framework of sustainability. Which means we need to find a way where there is social support for environmental issues and the money to generate the solutions.

Education in Sustainability Science and Engineering

Cliff Davidson

June 13, 2015 AEESP Grand Challenge Workshop

Over the past fifty years, the breadth of knowledge in environmental science and engineering has grown by leaps and bounds. We have made great progress in understanding our environment, and we have applied this understanding in attempts to reduce environmental impact while improving standards of living for millions of people. While there is a lot to celebrate, there is also great uncertainty in the future: the human species is apparently unable to behave in such a way as to reduce environmental impact enough to ensure high standards of living in the future.

This is more than studying CO_2 emissions or changes in the hydrologic cycle or changes in land use. This is about understanding the relationships among myriad systems, some natural and some anthropogenic, that determine our day-to-day existence and quality of life. We realize that our lives are greatly affected by political, economic, and legal systems, and there are countless experts who have in-depth knowledge of politics, economics, and law. We also know that psychologists, sociologists, and anthropologists can tell us how people will behave under certain circumstances and with a particular probability. But it becomes much more difficult to bring diverse experts together to discuss how our knowledge in different disciplines fits together to help us chart a course for the coming decades. Yet this is what we must do if we hope to make real progress in moving toward a sustainable future.

The Grand Challenge of moving toward sustainability will require experts from numerous disciplines working together, and engineers must be among these experts. The effort will require systems engineers who understand different types of complex systems and how they function. It will require engineers who can work at interfaces between engineering and the social sciences. It will require engineers who understand big data, the limits of technology, and how to create resiliency. And it will require engineers who can communicate with non-engineers.

Despite the critical importance of engineers in helping the world move toward sustainability, we have made only small increments of progress in transitioning our engineering education programs. Furthermore, it is clear that that practicing engineers have little knowledge and little incentive to include sustainability constraints in their projects. A survey conducted last year by the author and others, funded by NSF and hosted by the ASEE, showed that we are not yet including sustainability issues in most engineering curricula in accredited U.S. engineering programs.

Engineers of the 21st century must understand how new technologies as well as changes in human behavior can mitigate environmental disasters. They must understand what can be done so that people more rapidly accept new technologies, become willing to accommodate changes in lifestyle, and spend their time in ways that minimize environmental impact as the population continues to grow. All of this requires changes in education of engineers. How can the AEESP provide leadership in this endeavor?

GRAND CHALLENGES AND OPPORTUNITIES FOR ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY

SANITATION IN THE DEVELOPING WORLD

Proposer: Francis L. de los Reyes III, North Carolina State University

The latest (2012) United Nations data show that a staggering 2.5 billion people across the globe do not have access to adequate sanitation, and 1 billion still practice open defecation[1]. About 748 million people do not have access to safe drinking water, and about 1.8 billion people use a source of drinking water that is contaminated with fecal matter[1]. The number of children dying from diarrheal diseases, which are strongly associated with poor water and lack of sanitation, was 1.5 million annually in 1990[2]. While the number has decreased, diarrhea and related diseases such as cholera and typhus still accounted for 10% of all childhood deaths on a global basis in 2010, which was nearly the same as malaria, HIV/AIDS, and measles combined[3]. Clearly, there is a global water and sanitation crisis.

In response to this crisis, the UN set as one of the Millenium Development Goal (MDG) targets to halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation, with 1990 as the base year. The verdict is now in: the drinking water target was met in 2010, but the sanitation target will not be met. Even with significant progress, billions of people in the poorest regions of the world are still without safe drinking water and adequate sanitation. The international focus is now on adopting the post-2015 Sustainable Development Goals (SDGs) related to Water, Sanitation, and Hygiene (WaSH). The failure to meet the water and sanitation needs of billions, despite the efforts of governments, non-government organizations (NGOs), and donor agencies, shows the complexity of the WaSH problem. The challenge is not simply scientific and technical: *the interwoven impacts of culture, economics, and human behavior on science and policy have made water and sanitation among the most complex problems of our society, requiring the focus of an interdisciplinary team of researchers.* I propose making GLOBAL SANITATION a defined Grand Challenge for the AEESP community.

Several factors combine to make GLOBAL SANITATION a promising and rich area of teaching, research, and service excellence for the Environmental Engineering and Science community. ***First*****,** this ‘wicked’ problem encompasses and requires expertise in several disciplines, foremost of which is environmental engineering and science. ***Second***, the realization of the scale, magnitude, and complexity of the sanitation problem has drawn international agencies and national governments to increase their resolve to face the challenge. Opportunities for funding from international donor agencies and foundations are increasing, **but there are very few US universities** that have faculty working on this problem. ***Third,*** the students of today and tomorrow are increasingly aware of, and drawn to, human health, environmental and social justice issues. Students have a strong sense of purpose, and see themselves as positive agents of change in the global community. AEESP’s focus on this important issue will allow us to train students in interdisciplinary area with skills that are much needed around the globe.

Addressing sanitation requires multiple advances in several disciplines. First, the technologies need to be context-sensitive and practical, and yet take advantage of leading edge developments in energy, environmental processes, materials science, data technologies, design, and ecology. Second, advances in public health and environmental research are required in an interconnected world with increasing population and environmental pressures. Third, an enabling environment that includes local and national regulatory frameworks requires new, evidence-based approaches to policy-making. Fourth, scalable solutions require novel business models that are entrepreneurial, socially sensitive, and profitable while protecting the environment and public health. Finally, behavioral change would require research on education and culture. All of these are within the realm of environmental engineering and science.

---

[1] WHO/UNICEF (2014) Progress on drinking-water and sanitation – 2014 update. World Health Organization. Geneva.
[2] WHO (2014) Preventing diarrhoea through better water, sanitation and hygiene. World Health Organization, Geneva.
[3] Liu, L et al., WHO; Unicef, Global, regional, and national causes of child mortality: An updated systematic analysis for 2010 with time trends since 2000. Lancet 2012, 379 (9832), 2151−2161.

1-pager on

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

Baolin Deng, University of Missouri

There are many challenges related to Environmental Engineering that we need to address in modern society:

- Air pollution (e.g., smog) and pollution control
- Climate change and CO_2 sequestration
- Renewable energy and sustainable energy supplies
- Environmental quality and sustainable food production
- Water pollutions by pesticides, pharmaceuticals, and endocrine disruptors
- Emerging contaminants (e.g., nanomaterials)
- Disinfection by products
- Environmental health: risk assessment, monitoring and control
- Ground water and surface water contamination
- Soil contamination (e.g., toxic metals)
- Nuclear waste management and disposal
- Waste site remediation (including superfund sites)
- Nutrient management (P, N) and eutrophication control
- ……

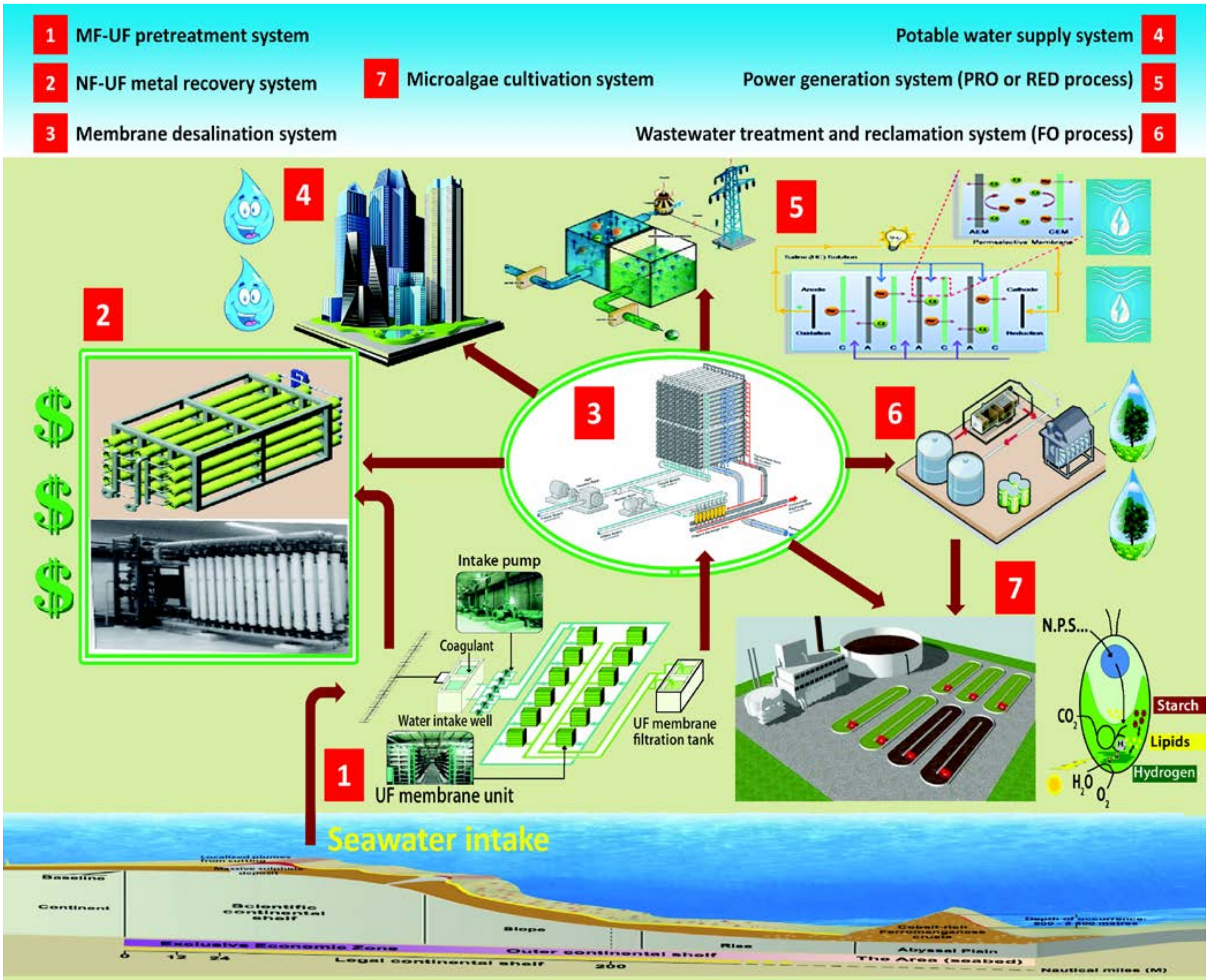
However, there is ONE grand challenge in Environmental Engineering, which is:

Water Treatment and Water Reuse

Rationales:

1. Some areas are grand challenges to society (e.g., sustainable energy supplies and climate change). While environmental engineering plays an important role, it is the only one of many important disciplines important to topics. Policy is often be more important than engineering there.
2. Some topics (disinfection by products, heavy metals in soil) are relatively narrow in scope, while those are absolutely important, they may not be considered grant challenges.
3. Water Treatment and Water Reuse is the grand challenge for environmental engineering because:
    a. Suitable water supply is essential to society
    b. The water challenge is exacerbated by population growth, urbanization and industrialization, and climate change in the 21st century
    c. Environmental engineering is the most important, if not the only discipline in charge of providing quality water for various uses.
    d. Many other challenges could be addressed under this umbrella (e.g., phosphorus and nitrogen management, control of emerging contaminants).

Figure 1. A model seawater factory of the future: Integration of water production with energy generation from salinity gradients, resource recovery (e.g. metal mining) and agriculture. The figure is taken from Diallo et al. (*Environ. Sci. Technol.*, **Just Accepted Manuscript** • DOI: 10.1021/acs.est.5b00463 • Publication Date (Web): **20 Apr 2015.**



Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

Kyle Doudrick, Assistant Professor, Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame

AEESP Grand Challenges Workshop (July 13, 2015)

Grand Challenge: Advanced Water Treatment Technologies for Emerging Contaminants

For most freshwater sources today, providing conventional treatment with disinfection is appropriate for delivering potable water to the public. However, the population will soon outgrow its freshwater capacity, and this growth will also bring an increased mass of contaminants such as nitrate, which is needed to meet food demand. As these sources are depleted or further contaminated, we must begin to consider implementing more advanced technologies that can treat water sustainably. With advances in materials science and a better understanding of new contaminants, environmental engineers are poised to lead this issue.

Nitrate is a great example of such a contaminant. It currently pollutes 20% of rural drinking water sources (above EPA MCL of 10 mg-N/L),[1] and these populations are most susceptible to contaminated drinking water because they draw from private, untreated well water. While nitrate is regulated by the EPA for infants, it is also a suspected carcinogen and endocrine disruptor.[2-4] Even though it is not currently regulated as a hazard to adults, history has shown that the EPA has about a twenty year lag period from toxicity evidence to regulation (e.g., the case of hexavalent chromium, which just received SWDA regulation last year), and thus we cannot rely on regulators to make decisions before beginning to develop new technologies.

One issue with new treatment technologies is cost. Traditional methods such as coagulation/flocculation and granular filtration are cheap and thus it is difficult to justify replacing them. However, these technologies will be ineffective for treating water sources containing emerging recalcitrant contaminants. Having cost effective technologies available and ready to go will be important to maintaining quality drinking water. The current accepted method for removing nitrate at the tap is ion exchange. While effective, ion exchange is an unsustainable process that generates highly concentrated brine waste containing nitrate and other anions, and it requires a salt solution for regeneration. A better technology choice would be one that uses little energy to reduce nitrate to nitrogen gas, thus treating water and completing the nitrogen cycle in a sustainable manner. Technologies that can accomplish this (e.g., biological,[5] photocatalysis,[6] catalysis[7]) are already available at the pilot scale. However, more effort and funding is needed to reduce current limitations and bring these to the market at a competitive cost.

I see two broad solutions to start meeting this challenge. (1) Collaboration between environmental engineers, chemists, material scientists, and chemical engineers. Developing new materials such as catalysts that are sourced from abundant materials, economic, efficient, are selective toward non-toxic by-products is a task that will require an interdisciplinary effort. Beyond material functionality, new materials or technologies will require reactor engineering (e.g., delivering light to photocatalysts) and implementation into existing infrastructure. (2) Preparation of tomorrow's environmental engineers to work with new technologies. Typical environmental engineering curriculums today have little room for additional chemistry or materials courses, and introductory water treatment courses provide only a brief glimpse into advanced technologies. If future environmental engineers are to develop new technologies or communicate with those developing new solutions for water treatment, then improving their education by adding more chemistry/materials/advanced treatment based courses is imperative.

References

1. K. R. Burow, B. T. Nolan, M. G. Rupert and N. M. Dubrovsky, *Environmental Science & Technology*, 2010, **44**, 4988-4997.
2. J. W. H. Adam, *Water SA*, 1980, **6**, 79-84.
3. A. A. Avery, *Environ. Health Perspect.*, 1999, **107**, 583-586.
4. J. Pelley, *Environmental Science & Technology*, 2003, **37**, 162A-162A.
5. R. Nerenberg and B. E. Rittmann, *Water Science and Technology*, 2004, **49**, 223.
6. K. Doudrick, O. Monzon, A. Mangonon, K. Hristovski and P. Westerhoff, *Journal of Environmental Engineering-ASCE*, 2012, **138**, 852-861.
7. B. P. Chaplin, M. Reinhard, W. F. Schneider, C. Schuth, J. R. Shapley, T. J. Strathmann and C. J. Werth, *Environmental Science & Technology*, 2012, **46**, 3655-3670.

Maintaining High Ethical Standards for Environmental Research in the 21st Century: Hypercompetitive Funding Environments and Perverse Reward Structures

Marc Edwards and Siddhartha Roy, Virginia Tech

Over the last 50 years, incentives for scientists have become increasingly perverse in both academia and government in terms of competition for research funding, metrics used to gauge performance, and changing business models. Decreased discretionary budgets at the federal and state level in the present and near future, will create an increasingly hypercompetitive funding environment between federal agencies themselves (e.g., EPA, NIH versus other agencies), for scientists working within these agencies, and for academics seeking funding from these agencies. The risk aversion of funding agencies and limits on funding will impact the types of research that can be done, make or break academic careers, and affect the scope and quality of science that is being produced. It is also apparent that many exemplary scientists at agencies associated with environmental work, have been closeted in non-productive positions, are quitting, or in some cases have been terminated for simply doing their jobs. It is doubtful that these agencies can be trusted to support work "holding paramount the safety, health and welfare of the public," if that work is in opposition to protecting their own growing financial interests-- if so, accepting funding to work with such agencies is no longer a decision that is obviously ethical.

The perverse incentives of academic institutions are arguably growing in scope and impact. For example, it has been noted that "The rubric for today's faculty has gone from publish or perish to 'funding or famine'[(1)]," the current climate has triggered a new genre of academic writing termed "quit lit" by the Chronicle of Higher Education [(2)] in which altruistic and public minded professors give rational explanations for leaving the profession. Moreover, these individuals are easily replaced with new hires more comfortable with perverse incentives that are in place. The performance metrics that have evolved to gauge the performance of scientists have become increasingly quantitative, and are subject to manipulation as would be expected based on Goodhardt's Law (i.e., "When a measure becomes a target, it ceases to be a good measure"). The results are as would be expected: scientists are increasingly pressured to emphasize quantity versus quality, over-sell the potential of their research and gloss over an honest accounting of limitations. *The Economist* has noted the high tendency for shoddy and non-reproducible modern scientific research, its high financial cost to society, posed an open question as to whether science was worthy of the public trust and demanded that science reform itself. [(3)] If we do not do so, and openly acknowledge the problems we face and take steps to counter the powerful effects of perverse incentives, we risk eventually becoming a corrupt profession akin to those recently revealed in professional cycling or in the Atlanta school system cheating scandal.

Assuming that we can openly admit that we have a potential problem on our hands, what could we do about it, as a profession, especially considering that we are self-policing? We suggest that the National Science Foundation could commission a panel of economists and social scientists with expertise in perverse incentives, to solicit input from all levels of academia from graduate students to retired National Academy members, and conduct the first assessment of the nature and scope of the problem. The panel could also develop a list of "best and worst practices" to guide evaluation of candidates for hiring and promotion, from a long-term perspective of promoting science in the public interest and for the public good.

References:

(1) Quake, S. (2009) "Letting Scientists Off the Leash." *The New York Times Blog,* February 10.
(2) Chronicle Vitae (2013-14) "Quit Lit." *Vitae (from the Chronicle of Higher Education).*
(3) The Economist (2013, October 19th) *How Science Goes Wrong.*

Additional Reading:

(1) Godin, K. and Moriarty, A. (2014) *Research Misconduct on the Rise: Combating Institutional Risk.* Available here: http://ncuraregioni.org/uploads/3/3/6/2/3362892/radg_presentation_final.pdf
(2) Stephan, P. (2012) *How Economics Shapes Science.* Boston, MA: Harvard University Press.

Title: Wastewater Management in the 21st Century

Author: Mark Elliott, Asst. Prof., University of Alabama

Description:
The Millennium Development Goals (MDGs) measure progress in sanitation by basically "counting toilets" and the MDG sanitation target is based on halving the population without access to an "improved" sanitation facility. In parallel to this, the Western norm of the flush toilet has become more and more widely accepted worldwide and, as global populations have become wealthier, the corresponding use of large volumes of water as a carrier of human excreta has become more widely practiced. An increasingly large proportion of the world's population wants to "flush and forget."

Water can be used as a medium to carry human excreta without deleterious impacts on the environment and public health, if toilets flush to a comprehensive collection and treatment systems. However, the majority of global households with sewerage connections are flushing to sewers without any treatment (Baum et al., 2013; Malik et al., 2015); and if any treatment is provided, it is likely to be primary treatment only. Additionally, emerging evidence from a UNC/Univ. of Alabama research project funded by the Gates Foundation reveals rapid growth in the number of urban and rural flush toilets that are not connected to sewerage. Many of these toilets are ostensibly connected to "septic tanks" but in developing countries a functioning drain field is exceedingly rare, and many of these are simply a tank for solids settling with surface discharge.

The 2016-2040 Sustainable Development Goals (SDGs) may yet incorporate a sanitation target that goes beyond counting toilets and incorporates some aspects of protection of environment and health. The focus of the Gates Foundation project cited above is to evaluate the feasibility of this more comprehensive approach to monitoring progress in sanitation.

As the global standard of living and demand for flush toilets continue to increase rapidly in the 21st century, safely and sustainably managing wastewater becomes increasingly challenging.

References:
Baum, R., Luh, J., & Bartram, J. (2013). Sanitation: a global estimate of sewerage connections without treatment and the resulting impact on MDG progress. *Environmental science & technology*, *47*(4), 1994-2000.

Malik, O. A., Hsu, A., Johnson, L. A., & de Sherbinin, A. (2015). A global indicator of wastewater treatment to inform the Sustainable Development Goals (SDGs). *Environmental Science & Policy*, *48*, 172-185.

Carbon-Negative Municipal Water Management

James D. Englehardt, Ph.D., P.E.

Challenge:

A grand challenge for environmental engineering is the development of the net-zero water building, i.e. economical buildings that are off the water and sewer grids, to achieve new levels of energy savings, hydrologic restoration, water conservation, and environmental protection.

Background:

While treatment of water and wastewater represents only 0.3% of total primary US energy consumption, conveyance of water and wastewater consumes 1.3%, more than four times that amount (ICF Consulting 2002; U.S. Department of Energy 2014). More important, an additional 2.9% was consumed for residential hot water in 2012, more than twice the conveyance energy.

The development of net zero water buildings raises the prospect of saving substantial:

- Conveyance energy representing 1.3% of total US energy consumption; and
- Hot water energy representing 2.9% of total US energy consumption.

When compared with the average 0.3% energy demand of current treatment, potential energy savings are several times higher, making *carbon-negative* municipal water management a short-term possibility, even assuming higher energy demand for a higher level of treatment.

An example of net-zero water technology would be biological treatment followed by membrane filtration and reverse osmosis. In that case, continual disposal of a concentrate stream potentially containing endocrine-disrupting compounds would be required. An alternative would be to replace reverse osmosis with advanced oxidation, to produce a mineral water with organics mineralized to below detection in terms of chemical oxygen demand. In that case the only continually-disposed residual would be a minor stream of potable irrigation water (Englehardt et al. 2013).

Research issues:

- Data generation and dissemination to support regulatory permitting; and
- Technological developments to support economies of scale for onsite treatment.

References

Englehardt, J., T. Wu and G. Tchobanoglous (2013) "Urban Net-Zero Water Treatment and Mineralization: System Modeling and Design," *Water Research*, 47(13), pp. 4680-4691.

ICF Consulting (2014) Water and Sustainability: U.S. Electricity Consumption for Water Supply & Treatment – the Next Half Century. Report No.: 1006787. EPRI, Palo Alto.

U.S. Department of Energy (2014) Annual Energy Outlook 2014 with Projections to 2040, Wash, DC.

Habitat-Sustainable Development

James D. Englehardt, Ph.D., P.E.

Challenge:

A grand challenge for environmental engineering, architecture, and landscape architecture is the development of principles for habitat-sustainable development, including approaches to sustainable regional landscaping addressing loss of native wildlife habitat, the need for high-energy maintenance activities, routine landscape watering, pesticides, and fertilizer.

Background:

Land recently comprising wildlife habitat is being rapidly converted to urban development in many areas. For example, in 1997, 52% of the State of Florida was urban or cropland. At a typical land use rate of 1.4 acres/person (residential, commercial, agricultural), and a growth rate of 2.11%, the entire surface area of Florida would have been developed by May 2005. In fact this has happened substantially, critically impacting wildlife habitat.

Principally as a result of habitat loss, species are now lost at a rate of 1000 annually, 1000 times the historical rate. Loss is multiplied through current landscaping practice involving replacement of natural mulch with artificial mulch, often consisting of dyed wood chips, continual maintenance with high-energy, high sound-pressure equipment, excessive irrigation, and unnecessary clearing of underbrush and other habitat, resulting in rapid decline of native species.

Ecologists note that "Even as we are losing species and wild places … the worldwide number of protected areas has risen dramatically," in what is termed the Anthropocene (Kareiva et al. 2012). They note that "Nature could be a garden -- not a carefully manicured and rigid one, but a tangle of species and wildness amidst lands used for food production, mineral extraction, and urban life. Protecting nature that is dynamic and resilient, that is in our midst rather than far away, and that sustains human communities -- these are the ways forward now."

Ecologists, however, are not generally involved in development -- engineers and architects are, and we offer little guidance in terms of developing land while maintaining habitat functions, including communication among habitat patches. Current practice can and must be reversed, analogous to the rapid restoration of the Kissimmee River, planning of which began a mere ten years after straightening was complete.

Research issues:

- Development of habitat-sustainable development principles; and
- Development and implementation of pedagogical and curriculum material.

References

Kareiva, P., M. Marvier, & R. Lalasz (2012) Conservation in the Anthropocene: Beyond Solitude and Fragility, The Breakthrough Institute, Oakland, CA, http://thebreakthrough.org.

Fostering the environment for creative environmental engineering design

N. Fahrenfeld

It is easy to teach the design lessons of the past – the challenge is educating our engineering students to build infrastructure that meets our society's future demands and needs in a regional and global network. Our design space is limited by the need to negotiate increasing demands on limited resources at regional and global scales. Thus, the constraints of current engineering design problems are greater than before. Yet, as a leader the tech industry suggested "Creativity thrives best when constrained." (Mayer, 2006) Therefore, a grand challenge in environmental engineering is fostering the environment for creativity in education so it can be applied in the field.

Creativity involves making new connections between ideas and feeling empowered to take risks. Engineering students surveyed were found to experience almost none of ten identified tenants of creativity during their academic experience (Kazerounian and Foley, 2007). Further, a recent study of why students leave engineering included student responses that indicated the curriculum did not allow them to perform creative work or prepare them for a career where they felt they could help people (Marra et al. 2012). The later is one part of the leaky pipeline in engineering education reducing the diversity of the pool of engineers. A diverse and creative field of engineers is needed to achieve the environmental justice inherent in providing regional and global environmental solutions.

Given that we are not fully meeting this goal in our current educational framework, how will we address this issue and what will this entail as our educational environment and platforms evolve? What will it take to improve opportunities for creative thinkers and their solutions?

Kazerounian, K. and S. Foley (2007). "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions." Journal of Mechanical Design **129**(7): 761-768.

Marra, R. M., K. Rodgers, D. Shen and B. Bogue (2012). "Leaving engineering: A multi-year single institution study." Journal of Engineering Education **101**(1): 1-22.

Mayer, M.A. Creativity Loves Constraints. February 12, 2006. Business Week Magazine.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

Linda Figueroa

1. Blind enforcement of regulatory limits has led to poor allocation of limited resources to maximize human wellbeing and health benefits.

   The protection of drinking water quality by regulating wastewater treatment plant discharges transformed human health and wellbeing in the 20th Century. In the 21st Century, our ability to measure contaminants to even lower concentration has led to increased pressure to provide incrementally improved removal efficiencies at disproportionate resource expenditures. A more holistic approach to the beneficial expenditure of limited resources to maximize global human health and wellbeing is needed. Environmental Engineers have a duty to lead the effort rebalance water quality and potential health concerns with realistic socioeconomic limitations.

Examples include

- Trend toward requirements for domestic WWTPs to meet all primary and secondary drinking water standards for discharge to surface water
- Requirement of greater efficiency from WWTPs because non-point sources are not controlled.
- Requirements for mine water treatment at legacy sites to meet drinking water and aquatic stream standards for discharge to surface water.
- Application of factors of safety to regulatory limits that are several orders of magnitude because effects not known.
- Requirements below the practical quantitation limits.
- Linear dose response assumptions.

Submitted by: David Gattie, University of Georgia

The Grand Challenge
Develop Strategies for Diversifying the U.S. Energy Economy Under Realistic Economic, Environmental and Geographic Constraints

Overview of Idea
Energy, sustainability, and climate change are inexorably linked, and are ubiquitous issues that dominate scientific, political and diplomatic discussions at the highest levels and broadest scales. Consequently, this triad has become a polarizing composite that is politically charged and oftentimes pits environmental advocates against industry leaders. At the core, the environmental concerns are GHG emissions and the impact of these emissions on global climate while economic concerns revolve around the practical issues associated with transitioning a fossil fuel based industrial economy to one that is significantly, if not entirely, based on intermittent energy resources [1, 2]. While technological development continues to be critical in brokering this debate, perhaps the more problematic issue is identifying the limits to which such a transition should extend and developing robust and pragmatic strategies for making a transition. As such, we need to get beyond the academic cliché of sustainability and move forward with demonstration projects that will help identify problem areas associated with such transitions.

Issues of Particular Concern

1. There is a paucity of efficacy studies demonstrating the practical constraints and realities of energy diversification that cut across geographically disparate energy resource bases (e.g., city, county, state)
   a. Issue a national call to establish study sites within the U.S. to implement manageable energy diversification transitions in order to provide insight into problematic issues, challenges, constraints, unintended consequences, etc.
   b. Studies should be geographically diverse with respect to renewable and non-renewable energy resource endowments (e.g., energy-rich Texas vs. energy-poor Georgia)
2. Energy storage is critical
   a. This is probably the understatement of the day, but this issue has not been fully vetted
3. Energy and economics are not core elements of the U.S. education system, yet they are fundamental to this global scale debate and the public is being asked to take positions on these issues; this is even more true with respect to energy economics, which is a field in and of itself
   a. Academic programs (minor, major, certificate level) that prepare students with core competency in energy economics should be established
   b. Economics within engineering needs to be reoriented
4. The political polarization of energy, sustainability and climate change has created an environment that potentially stigmatizes collaborations between academia and industry as being biased or non-scholarly
   a. Industry must be engaged in ways that are realistic, pragmatic and transparent—they're the ones who will be implementing the concepts

References
[1] Jacobson M.Z. and Delucchi M.A. 2011. *Energy Policy, 39:1154-1169*.
[2] Delucchi M.A. and Jacobson M.Z. 2011. *Energy Policy, 39:1170-1190*.

Novel measurement methods and devices to propel coming generations of environmental research

Prof. Drew R. Gentner
Yale University

The trajectories of progress in our fields rely on the development of novel analytical techniques, methods, and devices to better measure and understand pollutants (known, emerging, and unknown), and evaluate the fundamental chemical processes driving the behavior of these pollutants, human exposure, and environmental impacts. This requires:

– New techniques to expand the measurement capabilities for emerging and unknown pollutants. This can be accomplished through better connectivity of analytical chemistry and environmental engineering/science fields.

– Cost-effective measurements of existing pollutants, with tools that empower robust science (and monitoring) at the individual and community level, and more importantly in the developing world where environmental pollution problems go undiagnosed due to limited resources for research. This requires durable, portable devices that can be implemented by users with a range of training and abilities. Such devices will also promote better spatiotemporal coverage and projects everywhere. A critical aspect of these devices that requires attention is having the necessary accuracy and precision to provide viable data that translates to actionable results.

Understanding Global Anthropogenic Impacts on Freshwater Ecosystem Services

Gordon J. Getzinger

Ecosystem services embody the human benefits derived from the functioning of natural ecosystem processes. Of the numerous renewable ecosystem services, water supply and regulation and waste treatment are the most intimately related to freshwater ecosystems. Ecosystem services can be valued based on the cost required to replicate the service in a technologically produced artificial biosphere. Terrestrial freshwater ecosystems (i.e., wetlands, lakes and rivers) are valued at approximately $\$6.6 \times 10^{12}$ yr^{-1} worldwide, with >69% of that value arising from water regulation, water supply and waste treatment services.(1) Freshwater ecosystems are directly threatened by human activities and stand to be further affected by global climate change and human development (e.g., population growth, urbanization).

The productivity of freshwater ecosystem services are closely linked to the biodiversity of those systems. While the effect of conventional pollutants (e.g, nutrients, thermal pollution) on biodiversity and ecosystem services have been extensively studied, a comprehensive understanding of the impacts associated with domestic and industrial wastewaters, urban water runoff, changes in land-use associated with population growth and urbanization and emerging energy extraction technologies (e.g., shale gas and bituminous sand extraction) are comparatively less well understood. In particular, the impact on biodiversity and ecosystem services of the thousands of organic chemicals in commerce that are purposely or inadvertently dispersed into surface waters remain largely unknown. Furthermore, the sensitivity of freshwater ecosystems to anthropogenic perturbations may be dramatically altered by changes in climate, intensified freshwater withdraw and wastewater discharge associated with growing and increasingly urbanized populations. Current valuation systems may underestimate the cost associated with the occurrence of pollutants, including both legacy and emerging pollutants, by focusing on human health outcomes and failing to consider the impacts incurred through losses in biodiversity and subsequently ecosystem services. A convergent valuation of ecosystem services critically requires a comprehensive and unified model of the impact of *all* pollutants on freshwater ecosystems. Such a model would facilitate interventions aimed at restoring and preserving essential ecosystem services through engineering, technology and design, ensuring the continued security of our precious natural water resources.

References

1. R. Costanza et al., The value of the world's ecosystem services and natural capital. Nature (London) 387, 253 (//, 1997).

A need to work/research on a collaborative platform of environmental process engineering, environmental health and environmental policy

Ramesh Goel, Associate Professor
Civil & Environmental Engineering
University of Utah

Several pressing issues related to the presence of nutrients in waste and surface waters, micropollutants in our water, greenhouse gas emissions, as well as the increasing demands on energy and water reserves caused by rapid population growth, climate change, and the aging water infrastructure are now at the forefront of scientific and Environmental Engineering research. Also of concern is the prevalence of poverty and the increasing unavailability of fresh water across the globe. Poverty and the availability of clean water directly affect the quality and longevity of life for an enormous segment of the global population, particularly in under-developed countries. These problems are larger than any one country or society, and thus require collaboration across local and international boundaries in order to seek and implement solutions.

Now that the importance of source separation and the recovery of nutrients is realized and in fact being practiced in some parts of the world, the priority should be to make these practices easily implementable and sustainable. Alternative sources of energy (e.g. solar energy and bioenergy) are being sought now, but the processes to implement them have yet to be made economical and efficient. This calls for more research and thus more funding for that research. Creating a common platform where researchers across the globe come together with multiple funding agencies (federal and non-federal alike) in order to examine similar issues as a way to maximize funding, seek common solutions, and increase cross-discipline collaboration has the potential to be an efficient and effective direction.

While the advent of some excellent programs like NSF's PIRE program have encouraged US researchers to think beyond boundaries, there is still a need to expand the network of researchers and enhance connectivity between these researchers if we want to address these global problems. It is necessary for international researchers to visit each other, share their data, and disseminate it more widely so that duplicate research efforts can be avoided and successes can be built upon. In addition, since these crucial issues in environmental engineering are closely tied to the dynamics of the society utilizing the environment around them, it is increasingly important to incorporate social issues and engineering ethics into environmental engineering research and curricula, as well as utilize cross-cultural collaboration in order to broaden our problem-solving abilities. In my opinion, it is of paramount importance to conduct transformative, collaborative research such that the results obtained through fundamental research can be applied to solve these pressing environmental and social problems.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY

Social support for environmental issues and the money to generate the solutions

Daniel Gomez-Gutierrez

Many of the environmental problems worldwide are driven by other disciplines that sometimes have only the small picture and 1" of deepness in the matter. This is how we see that politician, businesspersons, architects, economists, lawyers and other professionals figure as environmental experts while environmental engineers and scientists continue working on finding the solutions to environmental problems and trying to predict what our future will be.

In the case of environmental engineering, it is considered a "soft" engineering and this may explain why people address environmental issues like talking about the trending TV shows or pop stars. As an environmental engineering professor, I strive to show my students how the numbers and the applied science show the path for solving contemporary problems. Undoubtedly we require the help of the other professionals mentioned above as for they are part of the problem and can be part of the solution, and as an example we see what people like Al Gore, William McDonough are doing, while becoming part of the solution.

Another challenge that environmental engineers have is the way environmental education is handed to people and how we compromise them to transform their bad life habits (consumption, nutrition, way of living, etc.) into good practices that even help support the lost environmental resilience; this is one of the only engineering professionals that deals with people and their behavior, and although we are not psychologists or sociologists, we have to train similar abilities and work more in the transformation of societies. For example, we need to address social phenomena like collaborative consumption and social media where we may find a natural place to educate with the right language and best possible actions.

Finally yet importantly, environmental issues need being addressed in the framework of sustainability. Which means we need to find a way where there is social support for environmental issues and the money to generate the solutions.

Grand Challenge: Phosphorus: Trash or Treasure?

Submitted by Brooke Mayer, Assistant Professor in Environmental Engineering, Marquette University

Phosphorus (P) is an essential nutrient for all biologic activity. Yet, unlike other critical bionutrients such as nitrogen and carbon, P has no stable atmospheric gas phase, leaving ecosystems entirely dependent on aqueous P transfer. Moreover, natural global cycling redistributes P on geologic timescales, meaning that renewal of mineral P resources occurs over thousands to millions of years, effectively rendering it a nonrenewable resource. As P is critically important to biological, chemical, and geological systems, two increasingly significant and interlinked water/wastewater treatment grand challenges are removal of P to alleviate eutrophication and recovery of "waste" P to support global food production.

The US Environmental Protection Agency (USEPA) regards eutrophication as the "biggest overall source of impairment of the nation's rivers and streams, lakes and reservoirs, and estuaries"[1]. Yearly economic damages associated with cultural eutrophication of freshwaters are estimated at $2.2 billion in the US alone[2]. In an effort to limit eutrophication, USEPA guidelines establish maximum total P concentrations of 50 – 100 μg-P/L in streams and 25 μg-P/L in lakes and reservoirs[3]. However, in some P-sensitive environments, concentrations as low as 20 μg-P/L may stimulate algal production, thereby necessitating much lower limits than typical regulations or guidelines, and driving efforts to improve approaches to reduce P to even lower levels.

At the same time, depleting reserves of bioavailable P give rise to potential concerns for global food security. Modern human society is "effectively addicted to phosphate rock"[4] in order to sustain the global food supply. This heavy reliance compels increasing recognition and analysis of the geochemical realities of P as a limited resource, reserves of which could become scarce or exhausted during the next century[4]. Unprecedented economic, social, and political challenges will likely emerge as mineral P reserves are depleted. Declining supply in the face of increasing demand creates a threat multiplier: P scarcity causes price increases to farmers, P pollution causes environmental costs to society, P scarcity and pollution exacerbate public health problems, and the concentrated geospatial distribution of P reserves introduces sociopolitical tension[5]. The myriad of implications of global P scarcity are significant, ranking it as one of the greatest challenges of the 21st century.

Declining P reserves dictate that P recovery and reuse will play central roles in closing the human P cycle. It is essential to implement strategies such as P recovery and reuse from water and wastewater to close the human P cycle and avert the simultaneous concerns of too much P in surface waters and too little P for agriculture. Economical technologies that capture waste P and recover it in a usable form would turn the costs of pollution abatement into an economic benefit[6].

References

1. USEPA. *National strategy for the development of regional nutrient criteria*. Washington, D.C.; 1998.

2. Dodds WK, Bouska WW, Eitzmann JL, et al. Eutrophication of U.S. freshwaters: Analysis of potential economic damages. *Environ Sci Technol*. 2009;43(1):12–19. doi:10.1021/es801217q.

3. USEPA. *Quality criteria for water: 1986 (Gold Book)*. Washington, D.C.; 1986. Available at: http://www.epa.gov/waterscience/criteria/library/goldbook.pdf.

4. Cordell D, Drangert J-O, White S. The story of phosphorus: Global food security and food for thought. *Glob Environ Chang*. 2009;19(2):292–305. doi:10.1016/j.gloenvcha.2008.10.009.

5. Childers DL, Corman J, Edwards M, Elser JJ. Sustainability challenges of phosphorus and food: Solutions from closing the human phosphorus cycle. *Bioscience*. 2011;61(2):117–124. doi:10.1525/bio.2011.61.2.6.

6. Rittmann BE, Mayer B, Westerhoff P, Edwards M. Capturing the lost phosphorus. *Chemosphere*. 2011;84(6):846–853. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21377188.

IMPACTS OF BAKKEN OIL PRODUCTION ON WATER-ENERGY-FOOD NEXUS

GADHAMSHETTY, SD SCHOOL OF MINES & TECHNOLOGY, RAPID CITY, SD

Background: A common concern in the recent body of growing peer-reviewed journal articles on the renewable energy is related to depleting fossil fuels- "The current rates of fossil fuel (e.g. petroleum products) will have a serious implications on energy security?". Will this concern require a closer introspection? Are we really running out of oil in 21st century, especially in the light of increasing sources of oil reserves in North America? After decades of decline in the crude oil production, the recent unconventional oil production techniques (i.e. horizontal drilling and multistage hydraulic fracturing) has promoted the extraction of oil and gas from previously inaccessible tight shales, and have transformed the U.S as a net exporter of petroleum products. The recent EIA reports indicate that the U.S.shale and tight oil production has increased from 0.4 million bbl/day to nearly 3200 Mbbl/day. The largest shale and tight oil production is concentrated in the Eagle Ford, Permian, and Bakken shales. The Bakken formation has emerged as the second largest oil-producing state in the US, with majority of the drilling and production occurring in the state of ND. As a result of increased production in the Bakken, and long-term production decline in Alaska and California, the state of ND has emerged as the second largest oil-producing state. We have witness an exponential rise in the oil production at Bakken during last five years; the Bakken production is now rated at record level of 1 million barrels per day. This beneficial growth in our crude production comes with a growing pain, especially in the form of out-stripped pipeline capacity, increasing stress on fresh water sources, increasing oil spills in the vicinity of food crops and wetlands, and risks for air, water, and land pollution. The recent USGS report[1] indicate the lack of information on environmental, human, health, and safety impacts of fracturing operations. More importantly, we may not even have proper analytical techniques to confirm the absence of environmental impacts, especially the proprietary chemicals.

Broader Impacts: Several unanswered questions on the environmental impacts of oil exploration and production will require closer attention from academia, government, and industries, with an ultimate objective of mitigating the ever-distorting nexus between energy, water, and food. **Some of the eminent questions include:** "***First***, Can we continue to flare the natural gas in open atmosphere and ignore the risks for air pollution? Nearly 28% of the Natural gas is being flared, and the justification is that we do not have adequate infrastructure to transport and store the natural gas[2]". "***Second***, the total dissolved solids in the produced water from the Bakken fields is as high as 300,000 mg/L[3]; there are several undisclosed and unquantified contaminants of environmental concern. Each oil well generates nearly 4 million gallons of produced water during initial phases of production, and several million gallons throughout the life of well. All the produced water is currently being injected in Type II injection wells. Do we have adequate federal regulations overseeing the discharge of produced water? Are we equipped to quantify the extent of environmental contamination due to the unanticipated leakage of produced water? Do we have infrastructure to treat the produced water". "***Third***, there is a growing concern on the unreported oil spills and its impacts on agricultural fields. What are the possible measures to monitor and prevent the oil spills?" Clearly, there is a need to identify and address the long, and yet non-exhaustive list of relevant environmental concerns associated with oil production.

1.*Retrieved from http://www.usgs.gov/budget/2015/docs/fy15_hydraulic_fracturing.pdf , 02/01/2015*
2.*Retrieved from http*://www.rigzone.com/news/oil_gas/a/135603/Natural_Gas_Flaring_In_Bakken_Reduced_Following_New_Regulations , *02/01/2015*
3. Retrieved from http://www.halliburton.com/public/multichem/contents/Papers_and_Articles/web/Feb-2014-Oil-Gas-Facilities-Article.pdf, 02/01/2015

Concept Note for AEESP Workshop – June 13, 2015

Grand Challenges in Environmental Engineering and Science for the 21st Century

Title: Universal energy access to meet basic human needs: What can society and the environment sustain?

Name: Andrew Grieshop, NC State University

Access to energy to meet basic needs for heating, cooking and lighting are fundamental requirements for human development. In many areas, limited access to 'modern' forms of energy means that these requirements are often met incompletely and/or via the use of primitive combustion devices and solid fuels. The former leads to limited access to opportunities for human thriving and development (e.g. security, medical care, water and sanitation, education); the latter is accompanied by impacts both on the users and the broader population due to emissions of air pollutants with strong health and climate effects and varied environmental/ecosystem impacts. There is clearly a need to expand energy access to the point where it is not a critical bottleneck for human development while provide energy sources that avoid the health and environmental damages associated with current solid-fuel use practices. On the other hand, we are running up against the limits of our resources in many spheres (e.g. atmospheric CO_2 levels).

Current efforts to provide for basic household needs in less developed countries (LDC) often emphasize that 'sustainable' or 'green' energy sources be used for these purposes. However, it is (or should be) recognized that a tiny fraction of industrialized nations' fossil fuel use could provide for all global household fuel use (Smith 2002), meet a universal energy requirement and massively reduce disease burden, with negligible impact on carbon emissions. Analysis suggests that universal electrification would have a relatively minor impact on carbon emissions in industrializing India (Pachauri 2014). Instead, it is clear that the consumption patterns of the affluent are the main driver for carbon emissions (thus climate change and many other environmental challenges), though human development need not be accompanied by excessive environmental damages (Rao, Riahi, and Grubler 2014) .

The question here, and this is perhaps as much one of philosophy or political economy, is: **How can universal energy access be developed in a way that addresses the acute needs of the world's poor without placing undue pressure on resources (e.g. the atmosphere)?** The corollary to this is whether/how the energy use of the affluent and/or associated environmental impacts can be curtailed, either through reduced demand or through more benign (e.g. renewable) technologies.

References:

Pachauri, Shonali. 2014. "Household Electricity Access a Trivial Contributor to CO2 Emissions Growth in India." *Nature Climate Change* 4 (12): 1073–76. doi:10.1038/nclimate2414.

Rao, Narasimha D., Keywan Riahi, and Arnulf Grubler. 2014. "Climate Impacts of Poverty Eradication." *Nature Climate Change* 4 (9): 749–51. doi:10.1038/nclimate2340.

Smith, K.R. 2002. "In Praise of Petroleum?" *Science* 298 (5600): 1847. doi:10.1126/science.298.5600.1847.

Unambiguous Demonstration of the Critical Structure and Reaction of Molecularly-Uncharacterized Organic Matter (MUOM) in Natural and Engineered System:

Last Chapter of Never-Ending Story

Baohua Gu, Environmental Sciences Division, Oak Ridge National Laboratory

David A. Reckhow, Department of Civil and Environmental Engineering, University of Massachusetts, Amherst

Fernando L. Rosario-Ortiz, Department of Civil, Department of Architectural and Environmental Engineering, University of Colorado, Boulder

Donald L. Sparks, Department of Plant and Soil Science, University of Delaware

Baoshan Xing, Stockbridge School of Agriculture, University of Massachusetts, Amherst

Yu (Frank) Yang, Department of Civil and Environmental Engineering, University of Nevada, Reno

(*Authors are listed alphabetically and contribute equally to this abstract*)

Organic matter (OM) is ubiquitous in natural environments and plays an important role in affecting the environmental fate and transport of toxic compounds. The engineered water treatment system is also influenced greatly by the presence of OM. For instance, OM is important precursor for disinfection byproducts, contributes to the membrane fouling, and influences the efficiency of filtration system and lifetime of engineered infrastructure. However, we still do not have a clear idea about the molecular structure and composition of OM because it is a natural product and consists of thousands of highly complex and heterogeneous compounds. A grand challenge is to *unambiguously demonstrate the critical structure and reaction of molecularly-uncharacterized organic matter (MUOM), with broad implications on determining the environmental fate of pollutants and improving the treatment process*. Along this line, many important progresses have been made recently: 1) advancement in the state-of-the-art analytical technologies, including advanced nuclear magnetic resonance (NMR) and synchrotron-based X-ray absorption spectroscopy and high-resolution mass spectrometry, have provided novel insights into the chemical composition and structure of OM; 2) active roles of OM in important reactions, such as sorption, reduction, transformation and degradation, for pollutants have been uncovered; 3) relationships between the chemical properties of OM and its influences on the engineering treatment processes (disinfection byproducts formation and membrane filtration) have been determined. In the future, further investigations are warranted to advance our understanding toward the chemical nature of MUOM and its effects on the reactions and removal of contaminants: 1) advanced fractionation, purification and characterizations of OM to shed light on its chemical structure; 2) studies on the OM-mediated reactions, including redox and photochemical reactions with radicals involved, OM-mineral-bacteria interfacial reactions and important reactions for emergent contaminants (nanomaterial, antibiotics and others); 3) comparative analysis about the chemical nature and properties of OM in natural and engineered systems, i.e. natural waters, waste waters, and recycled water; and 4) ecotoxicology-based evaluation for determining OM influences on water treatment.

Paradigm Shift in Water Quality Monitoring, Regulation and Technology

One of the grand engineering challenges for the 21st century is access to clean water and mankind prosperity dependents on the availability of fresh, potable water for health and economic activity. Therefore, providing sustainable solutions to ensure safe water supply for public health protection is our primary mission. In order to meet the growing needs of cleaner water due both to continued population growth and increased standards of living, it is crucial that we must make paradigm shifts and reforms in vision of water quality monitoring, regulation and treatment technology development.

Water-pollution monitoring traditionally focuses only on limited number of priority chemicals that are considered responsible for the most significant human and environmental risks and for which regulatory benchmarks exist. Since the mid-1990s, there has been an increasing concern raised from the recognition that a large and ever-increasing number of unregulated yet widely used chemicals pose risk to our aquatic ecosystem and water supplies; such chemicals are referred to as “contaminants of emerging concern” (CECs). One main challenge that remains is the lack of feasible and accepted methods for assessing and quantifying the toxicity exerted by these pollutants in water. This lack greatly hampers the development and implementation of effective regulations, strategies, and technologies to control and eliminate the harmful effects from these CECs.

There is an urgent need to have a paradigm shift in the approach and strategy of water treatment technology effectiveness assessment and water quality monitoring from the current that suffer from “biased and limited” chemical information to more reliable ones that identify realistic endpoints better reflecting the actual risks to receptors. This shift could result in the changes in the remediation strategy development, remediation technology design, optimization, monitoring and, consequently impact risk management and environmental and human health protection. Despite considerable progress in clean up of contaminated water over the past decades, water quality deterioration is still a major problem in the U.S. and worldwide. It is estimated that the cost for remediation over the next 30 years will be more than hundreds of billions. Strategies to achieve maximal risks reduction within the resource limits are demanded. Current regulations and accepted standard remediation effectiveness assessment procedures are based on concentration measurements of only targeted contaminants in reference to the regulation limit. This approach is insufficient because it neither discerns the differences in exposure and effects nor considers the complex and broader risks that specific or mixtures of contaminants pose to the environment and human health. All these issues point to the pressing need for more sophisticated and informative, yet feasible and reliable assessment methods to detect and evaluate the toxicity effects of water pollutants mixture so that their risk to the public and environment can be understood and eliminated.

Traditional chemical regulation-driven and local cost-benefit analysis based approach for water infrastructures establishment and treatment technology implementation can no longer ensure long-term water sustainability and human prosperity. Sustainable development requires the management of the throughput of all materials including water and energy to be within the biosphere’s capacity for regeneration and waste assimilation. More advanced water treatment technologies and levels have been pushed to meet progressively stringent effluent discharges permits, but at expenses of exponentially increasing ecological footprint with more energy and material input. Risk-based approach that understands the benefits and trade-offs of advanced treatment technologies with consideration of both local water quality benefits and systems-level impacts or co-cost on the environment and human health is demanded. Various stakeholders need to work together to adapt to changing circumstances to ensure the widest possible access to potable water in the least damaging way possible across the globe. This will require that engineers work closely with social, ecological, legal, and financial experts and with all levels of government.

Water Systems in an age of Decentralization

Charles N Haas — Drexel University

Potable water systems in the US, especially in older cities are reaching the end of their useful life. Old distribution systems in Boston, New York, Philadelphia, etc. have pipe sections older than 125 years. Except for upgrading for increasingly stringent drinking water standards, treatment plants in 2015 bear striking resemblance to those of 1915.

If we look at other municipal networked services, notably the electric grid, we see these utilities coping with dramatic changes such as residential power generation (solar and other), negative metering, and use of the grid as a "common carrier" for transmission of power from a portfolio of sources.

Can we envision a water system of the future in which there is extreme decentralization of supply, such as by stormwater capture, building and neighborhood reuse and recycling, and perhaps transmission of multiple qualities of water (e.g., for potable, non-consumptive human contact, and other uses)? What physical systems need to be devised and implemented to facilitate this. Are there ways to transmit waters of multiple qualities in the same "pipe"? What are the economies of scale? What are the institutional (legal, business) barriers. What is the overall impact of such a reconception of the water system with respect to energy consumption and other sustainability metrics. Do we thereby see the role of a utility shifting more towards circuit riding operations? What is the net effect on reliability, risk (both quality and quantity) and resilience?

Water Quality Anywhere Anytime (Pathogens)

Charles N Haas — Drexel University

Environmental engineering evolved from public health engineering. Even in the US there are estimates of tens of millions of cases from waterborne (drinking, recreational, etc.) disease per year.

Despite the large investment in water and wastewater infrastructure that has occurred, particularly since 1970, we are unable to provide high fidelity predictions of the degree to which our treatment processes remove pathogens. Unlike many toxic pollutants, pathogen exposure may occur from a single event, and therefore it is important to predict the dynamic variability of pathogen exposure.

Part of this inability stems from lack of detailed modeling for fate and transport thru common treatment elements. In this regard, the water industry can look towards the well developed field of predictive microbiology in the field of food safety for tools and approaches.

However there are key fundamental knowledge gaps (that even occur in food safety) which need to be closed.

For example, virtually all of our knowledge on disinfection kinetics has been obtained in steady state or quasi steady state conditions. Yet in practice, pathogens face water quality and disinfection challenges that may be variable, and it is simply unknown whether the steady state approaches predict performance under dynamic conditions. Similarly, in the natural environment, we have data on survival (e.g., t_{90}) perhaps as a function of temperature, insolation, etc. However we do not know whether variability of these antagonistic conditions produces a response that is directly predictable from quasi steady state information.

If we had data enabling us to predict water quality (for pathogens) anywhere anytime, this could lead towards the optimal design of our water protection strategies (especially important in systems such as potable reuse) and thereby reduce cost and excess resource consumption needed to implement a safety factor based approach. We might even be able to update the predictive techniques using sensors (including *omics based techniques) with bayesian updating or other statistical learning algorithms.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

"Hydrologic Forecasting"

Amir Hajiali
(Ph.D. of Engineering in Earth Science)

The challenge is to develop an improved understanding of and ability to predict changes in freshwater resources and the environment caused by floods, droughts, sedimentation, and contamination. Important research areas include improving understanding of hydrologic responses to precipitation, surface water generation and transport, environmental stresses on aquatic ecosystems, the relationships between landscape changes and sediment fluxes, and subsurface transport, as well as mapping groundwater recharge and discharge vulnerability.

Practical Importance
Water is an essential natural resource that shapes regional landscapes and is vital for ecosystem functioning and human well-being. Human use and contamination of freshwater are stressing the resource, and alterations in the hydrologic regime have serious consequences for people and the environment. This grand challenge addresses the need to forecast both the hydrologic regime and the environmental consequences of changing that regime.

Scientific Importance
Currently, our understanding and predictive ability with regard to hydrologic forecasting are limited by theory, method, and the scope of available models, as well as by data. Recent and evolving developments in remote sensing of parameters such as precipitation, soil moisture, snowpack, river discharge, vegetation cover, and surface topography are beginning to yield spatial and temporal data that are driving a revolution in hydrologic science, making it possible to measure hydrologic phenomena never before seen and thus poorly understood.

Scientific Readiness
The primary obstacles to advances in hydrologic research have been limited, sparse, spatially distributed data and broad disconnects between the scales of data generated. Recent and projected technological advances in remote data collection, coupled with field experiments, can supply abundant information about vast regions of the Earth at increasingly finer spatial and temporal scales. These data—including high-resolution visual, radar, and infrared satellite-based maps of the land, water, and atmosphere; precise surface topographic maps; new geophysical images of the shallow subsurface; and real-time, integrative environmental information—have never before been available. When linked with data on human consumptive use of water, contaminant emissions, and land-use patterns, this new information will provide the basis for greatly improved understanding and prediction of hydrologic and related environmental processes.

Important Areas
1. *Improve understanding of hydrologic and geomorphic responses to pre-cipitation.* New biophysical theories and models needed to utilize the new high-resolution radar data are not yet in place. Comprehensive theories of flooding and new methods of flood forecasting would soon

become possible if scientific advances enabled hydrologists and geomorphologists to take advantage of satellite images of the atmosphere and the earth 's surface.

2. Improve understanding of surface water generation and transport. Research is required to extract critical environmental-sensitivity information from satellite imagery and field instrumentation. New methods are needed to develop standard environmental indicators for surface water that can take advantage of the high resolution of precipitation forecasts. Such indicators could be used to inform and constrain process-based models of river flow and lake circulation. For example, satellite data could be used to detect contamination events and changes in water temperature, and to develop quantitative descriptions of hydrologic transport processes in rivers and lakes. Forecasting based on hydrologic and geomorphic simulations and real-time data analysis could also provide an early warning of waterborne disease outbreaks, of impending fish kills (as high water temperature indicates low dissolved oxygen content), and environmental disasters resulting from hot-water or contaminant discharges.

3. Examine environmental stresses on aquatic ecosystems. Future remote sensing capability will enable ecologists to quantify the effects of altered hydrologic regimes (for instance, from irrigation and dams) and of environmental stresses (such as pollution, erosion, and salination) on the fundamental ecological properties of aquatic systems such as biodiversity, community dynamics, primary and secondary productivity, elemental cycling, and resistance/resilience to disturbance. Such increased understanding would allow the development of creative strategies for assessing the tradeoffs between preservation and restoration of aquatic resources and demand for water.

4. Explain the relationships between landscape change and sediment fluxes. Future hydrologic research should be aimed at developing new concepts and quantitative physical models of sediment transport, erosion, and deposition that are based on precise topographic data of entire watersheds and high-resolution radar imagery. With improved theories of landscape evolution over a range of time scales, quantitative hydrologic and mass-transport models could become tools for anticipating environmental hazards that are the consequence of active surficial processes. Such research could help provide improved real-time warnings of land-slides and mudslides; estimates of the long-term impacts of sedimentation and erosion on river morphology and consequently on navigability and flooding potential; and, when combined with analysis of land-use dynamics estimates of the cumulative impacts of forest clearcutting, urban development, and other land-cover changes on water quality and on habitat as a result of changes in flooding patterns and frequencies.

5. Improve understanding of subsurface transport. New high-resolution geophysical techniques will enable scientists to “see through” the Earth and develop a clearer understanding of the structure and behavior of subsurface water-bearing and -transmitting reservoirs. This understanding is beyond the reach of traditional invasive measurement methods involving well drilling and trenching. Subsurface reservoirs supply much of the nation's public water supplies, and yet many are threatened by overuse and by contamination with industrial solvents, metals, fertilizers, pesticides, and herbicides. Zones of contamination are of undetermined extent, and the migration path is often unknown. The rapidly advancing field of geophysical tomography could, for the first time, make it possible for geological scientists to observe the shallow subsurface. This type of data, combined with hydraulic information, could yield a new understanding of subsurface properties and the distribution of relative flow paths and flow barriers. The resulting hydrogeological theories and models could be used to assess declining water levels, locate subsurface contaminants, track contaminant migration, and improve the knowledge base for decisions on managing aquifers.

6. Map groundwater recharge and discharge vulnerability. New remote mapping capability using radar and infrared satellite data could be coupled with field measurements and new theories in hydrologic science to understand the signature of recharge areas and estimate evapotranspiration rates over vast regions. There are two critical environmental problems to be addressed. First, maintaining groundwater supplies depends on identifying groundwater recharge areas and assessing which of these areas are threatened by depletion or contamination resulting from human activities. Second, identifying regions experiencing environmental stress due to a lack of soil moisture is key to managing agricultural production potential and assessing vulnerable aquatic habitats. New hydrologic models would make it possible to interpret high-resolution radar and infrared satellite imagery collected over time to identify and quantitatively assess impacts to recharge and discharge areas.

References

- *"Grand Challenges in the Environmental Sciences", Committee on Grand Challenges in Environmental Sciences, Oversight Commission for the Committee on Grand Challenges in Environmental Sciences, National Research Council, P. 31-36.*

Engineering solutions to sense climate changes in dryland ecosystems to reverse land degradation

Marta C. Hatzell

Drylands and deserts encompass 41% of the land on the globe, are home to nearly ~30% of the global population and support 44% of the earth's agriculture and livestock (1). Therefore, it is important to gain a deeper understanding of climate trends and changes within these regions through rigorous data collection and modeling. Most drylands have grown at alarming rates over the last century, but historical data has been hard to rely on when forming predictions. The Gobi Desert for instance once estimated to be expanding by 1390 square miles per year, recently has shown an overall compression trend. The leading reasons for changing conditions in drylands are typically linked to deforestation, livestock overgrazing, expansion of cropped areas, poor large scale irrigation practices, and to a range of climatology factors(2). However, evaluating each individual cause cannot truly be evaluated at this time without more resolved data.

The United Nations sustainability development conference (Rio+20) outlined the urgent need to reverse land degradation in order to achieve zero net land degradation (ZNLD)(3, 4). While many sources find this goal not likely attainable, engineering efforts to mitigate the rate of degradation can be obtained through improving sensor technologies for monitoring changes in key global environmental indicators such as: 1.) dryland boundaries 2.) ground water levels, 3.) soil erosion, and 4.) rain use efficiency, and 5.) surface run off to name a few. Documenting temporal and spatial changes with fine resolutions in these climates will most likely improve the decision making capabilities of governmental agencies through the development of models with larger parameterization. Understanding these fluctuations will not only be critical to maintain ecosystems, but will play a large role in guaranteeing food and water security in the coming decades.

Current climate monitoring systems utilize earth observed data sets which track the normalized difference vegetation index (NDVI). The NDVI is able to discern regions of heavy vegetation based on tracking the spectral reflectance's changes between the visible (red) and near infrared wavelengths. If there is more reflected radiation in the near-IR than the visible, it is assumed the region has significant vegetation. While NDVI has been appropriate for obtaining qualitative data of particular regions, this approach is not sufficient for garnering quantitative data. Most NDVI measurements are made using a sensor (AVHRR radiometer) developed originally for meteorology purposes and therefore the sensors do not have the capability to discern when local atmospheric conditions (e.g. clouds and water vapor) may be influencing the measurements. This sensor also only has a resolution of 5-8 km(5). Newer sensors with built in atmospheric corrections have been developed, but spatial agreement of multiple NDVI measurements are rarely observed, which is necessary for quality assurance. Further developments will not only be needed in the sensor capacities, but in the development of new assessment measures to enable broader more reliable data sets.

Additionally, sensor development can also be used to monitor local human-based indicators which may affect dryland regions such as: 1.) water consumption 2.) water reuse 3.) livestock/land management practices, and 4) carbon footprints. Readily available GPS-enabled mobile devices have allowed individuals to gain access to low cost accelerometers, altimeters, barometers, and gyroscopes with already established algorithms capable of tracking everything from steps taken to calories burned. This ability to track ones daily health behaviors has led to an augmented sense of accountability, which has been shown to increase individuals motivation toward living healthier lives (6). Growing these efforts and aiming them toward monitoring carbon, water, and land practices may also lead to a more sustainable human practices. In the coming decades redefining human interactions with the environment will likely be just as important as developing technologies to reverse land degradations.

References:

1. Safriel U, Adeel Z. Dryland Systems. In Ecosystems and Human Well-being: Current State and Trends. Vol. 1, edited by R. Hassan, R. Scholes, & N. Ash, 623–662. Washington, DC: Island Press; 2005.
2. Sternberg T, Rueff H, Middleton N. Contraction of the Gobi Desert, 2000–2012. Remote Sensing. 2015;7(2):1346-58.
3. Chasek P, Safriel U, Shikongo S, Fuhrman VF. Operationalizing Zero Net Land Degradation: The next stage in international efforts to combat desertification? Journal of Arid Environments. 2015;112:5-13.
4. The Future We Want- Outcome Document. United Nations: 2012.
5. Higginbottom TP, Symeonakis E. Assessing Land Degradation and Desertification Using Vegetation Index Data: Current Frameworks and Future Directions. Remote Sensing. 2014;6(10):9552-75.
6. Ba S, Wang L. Digital health communities: The effect of their motivation mechanisms. Decision Support Systems. 2013;55(4):941-7.

Grand Challenge: Converting intermittent renewables to a constant energy generation process through the development of sustainable energy storage.

Kelsey Hatzell

The percentage of energy produced through modern renewables which operate intermittently (wind and solar) has risen steadily over the last decade. As markets have extended and manufacturing improved, the cost associated with the development of renewables has made integration available to a wide range of countries and economies. In the United States, European Union, and China between 140-230 and 4.3-75 TW-h of energy are produced each year at wind and solar plants. The use of variable renewables has cut CO_2 emissions by over 300 million metric tons per year, incentivizing further growth(1). Expansion of renewables has also enabled once off grid locations gain access to electricity, which has aided in improving these regions overall quality of life. However this renewables maturing process has also produced new challenges with respect to storing and integrating the electricity generated within our current infrastructures(2).

When the electricity supply produced by renewables cannot meet the grid base load demand, alternative energy supplies or sinks must be created to maintain the resiliency of the grid. Typically when there are deficits, fossil based generators are utilized which diminishes the emission free advantages associated with renewables. If the electricity production exceeds the grid demand, resource curtailment takes place decreasing the renewables efficiencies. This leads to the following grand challenge: **How can energy storage be implemented within the electrical grid infrastructure so energy can be 'continuously' drawn from renewables.**

Emerging methods for energy storage currently cost 5 to 10 times more than the current cost of a fossil based generation plant, thus cost is the most significant limiting factor for energy storage. Additionally there are large concerns regarding the round trip energy efficiency of renewables when combined with energy storage systems (3-5). Comprehensive analyses on renewables have highlighted that significant energy losses (primarily with solar technologies) occur when the manufacturing and deployment energy consumption is considered. To date, the electricity required to manufacture and deploy most photovoltaics has exceeded the energy capacity of the photovoltaics themselves. By adding energy storage, the energy deficit would only increase. Thus round trip energy balances on renewables and storage systems need to maintain a net positive energy gain for emissions to truly be lessened.

In terms of choosing an energy storage pathway, or technology, engineers and scientist primarily consider the cost (~100$ kWh^{-1}), system energy efficiency, flexibility, and energy density. Yet an entire energy and carbon balance of various technologies and processes are rarely considered. Currently, the materials and manufacturing required for most electrochemical based energy storage systems consumes energy on the order of 0.153 kWH per each Wh of storage capacity. For comparison, geologic energy storage system (pumped hydro and compressed air) only consume 0.026 kWH per each Wh of storage, making electrochemical energy storage devices nearly 10 times less energy efficient. Geologic based energy storage systems today comprise nearly 99% of all energy storage, but are geographically limited. Therefore developing new electrochemical based energy storage systems is essential, but emphasis on materials and manufacturing processes which mitigate energy consumption will be crucial.

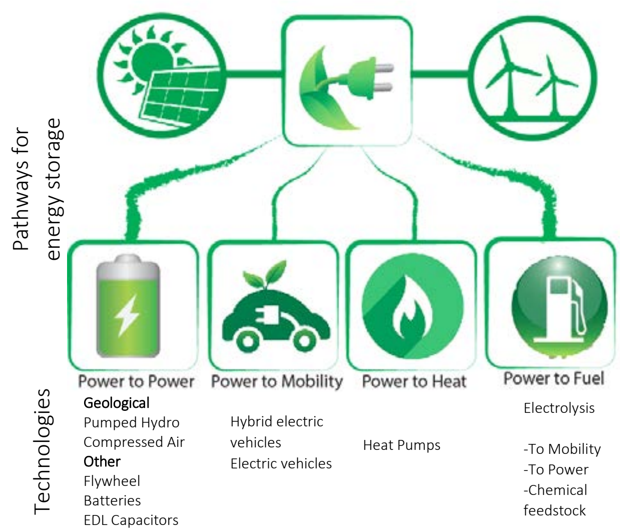


Figure 1: Various pathways and technologies must be considered for grid energy storage to mitigate CO_2 emissions and maximize energy.

Surplus electrical energy from renewables can also be harvested and stored in a variety of ways besides power to power conversion technologies. Alternatively electricity could be transferred to support an electrified transportation infrastructure, converted to heat for HVAC applications, or used to produce fuels (hydrogen and methanol)(6) (Figure 1). Currently the annual mobility demand within the US approaches 300-450 TW h, the annual space heating demand approaches 250-575 TW h and the global demand for hydrogen and methanol approaches 3200-5400 TW h and 575-959 TW h. Considering the alternative approaches for mobility, heating and cooling and hydrogen production (combustion engines, electric boilers, methane reformation), significant gains in reducing CO_2 emissions would result in each sector if the surplus renewable electricity demand was potentially converted rather than stored directly.

Over the coming decades many infrastructural changes related to renewables and the electric grid will undoubtable take place. Care in discerning the potential energy and environmental challenges associated with the various routes will need to be thoroughly evaluated to insure a sustainable solution is developed.

References

1. eGRID, U.S. annual non-baseload CO2 output emission rate 2010.
2. Renwables 2014 Global Status Report. Paris, France: REN21, 2014.
3. Carbajales-Dale M, Barnhart CJ, Benson SM. Can we afford storage? A dynamic net energy analysis of renewable electricity generation supported by energy storage. Energy & Environmental Science. 2014;7(5):1538-44.
4. Barnhart CJ, Dale M, Brandt AR, Benson SM. The energetic implications of curtailing versus storing solar-and wind-generated electricity. Energy & Environmental Science. 2013;6(10):2804-10.
5. Barnhart CJ, Benson SM. On the importance of reducing the energetic and material demands of electrical energy storage. Energy & Environmental Science. 2013;6(4):1083-92.
6. Sternberg A, Bardow A. Power-to-What?–Environmental assessment of energy storage systems. Energy & Environmental Science. 2015.

Name
Jon M. Hathaway - Assistant Professor, University of Tennessee

Title
Informing Urban Stormwater Management through Science

Abstract / Description
As increasingly stringent U.S. EPA regulations push stormwater controls throughout the United States, the need for scientifically sound approaches to urban watershed management has become critical. Billions of dollars are being spent to maintain and/or improve surface waters by mitigating the water quality and hydrologic impacts of stormwater runoff. This topic is at the forefront of watershed restoration efforts from Chesapeake Bay to Lake Tahoe. However, the science behind many facets of stormwater management is still relatively undeveloped. Better understanding and modeling urban watersheds will allow more cost effective and targeted solutions. There is a critical need to understand the fate and transport of water and pollutants in the urban environment from the watershed, through green infrastructure systems, and into surface waters, and to use this information to improve modeling techniques and better understand impacts to ecological and public health. In a review of model performance for predicting pollutant transport, Dotto et al. (2010) tested three currently used watershed models and concluded that the models poorly represented watershed processes over multiple experimental sites. For example, Nash-Sutcliffe coefficients for observed vs. modeled total nitrogen concentrations for the four watersheds ranged from -0.38 to 0.36 between the three models, showing both poor performance and a high level of variability. This is indicative of the substantial challenge in urban watersheds where land use is patchy, pollution is episodic, and systems are highly responsive to rainfall. Added to this complexity is a range of societal issues influencing management decisions such as citizen desires, land acquisition requirements, and aesthetic concerns.

An improved understanding of urban systems will ultimately lead to scientifically informed decisions regarding stormwater control placement and the expected outcomes of restoration. Essentially, practitioners can better develop restoration scenarios, understand the outcomes, and determine the cost of restoration before implementation occurs. Such a process would revolutionize how stormwater is managed in the United States and globally.

Note
This topic crosses over with multiple Grand Challenges of the NAE including: (1) Restore and Improve Urban Infrastructure, (2) Manage the Nitrogen Cycle, and (3) Provide Access to Clean Water

References
Fletcher, T.D., Andrieu, H., and Hamel, P. (2013). Understanding, management and modeling of urban hydrology and its consequences for receiving waters: A state of the art. Advances in Water Resources, 51: 261-279

Dotto, C.B.S., Kleidorfer, M., Deletic, A., Fletcher, T.D., McCarthy, D.T., and Rauch, W. (2010). Stormwater quality models: performance and sensitivity analysis. Water Science and Technology, 62(4): 837-843

Photosynthetic Organisms at the Food:Energy:Water Nexus

Berat Z. Haznedaroglu (Bogazici University, Istanbul, Turkey)

Access to safe and secure food, energy, and water resources will be a top priority for engineers and scientists of the 21st century. The impetus forced by global climate change increases the difficulty of addressing these grand challenges. One plausible strategy to go forward would be to utilize microorganisms bearing the capability of making multi-products targeted to resolve not only individual challenges but also implicate them at their nexus. Based on expertise and knowledge in our group, we believe photosynthetic organisms, particularly microalgae and cyanobacteria species, have the capability to undertake these challenges if designed in a biorefinery type setting.

What can we achieve?

- *In food domain:* Certain cyanobacteria are capable of nitrogen fixation, which can be useful for fertilizing agricultural land. Certain microalgae can produce essential amino and fatty acids that cannot be synthesized by humans and animals and must be acquired by diet.
- *In water domain:* Advanced nitrogen and phosphorus removal capacity as well as phytoremediation of heavy metals
- *In energy domain:* Having higher efficiency in photosynthesis (i.e. better carbon capture), microalgae and cyanobacteria possess the ability to make energy rich hydrocarbons to produce liquid fuels including but not limited to biodiesel, biojetfuel, bioethanol, and biohydrogen

What needs to be done?

- Bioprospect new & novel species and investigate their molecular and cellular capacity for value-added product synthesis
- Choose geo-smart locations (with close proximity between flue gas emitting industries and wastewater treatment plants in moderate climates).
- Develop less-energy intensive technologies for downstream applications (biomass harvesting and product extraction)

Grand Challenge:
Reinvent "Old" Technologies

Qiang He

Department of Civil and Environmental Engineering
The University of Tennessee, Knoxville
E-mail: qianghe@utk.edu

The field of environmental engineering is full of excitement with the ongoing development of a wide range of new technologies such as MxCs and AnMBR with applications in wastewater treatment for energy and resource recovery. These new technologies are very promising; however, traditional "old" technologies such as activated sludge and anaerobic digestion appear to remain as the workhorse in the foreseeable future. The grand challenge is how to improve these "old" technologies at reasonably low cost.

Anaerobic digestion is a relevant example as a technology with a long history of application. Despite of its advantages in sustainability including the capability for energy and nutrient recovery, the adoption of anaerobic digestion has been hindered by the perception of its sensitivity to process perturbation. While new technology alternatives such as MxCs and AnMBR are shown to be promising, considerations of the economics and scale of implementation seem to tilt the balance to anaerobic digestion at the current stage. Thus, one practical strategy to improve the sustainability of waste treatment is to improve the efficiency and reliability of anaerobic digestion processes.

The challenge is, despite the broad application of anaerobic digestion, much remains to be learned on the underlying complex anaerobic microbial communities in order to guide the development of strategies to improve process efficiency and reliability. The application of metagenomics provides opportunities to gain new insight into the drivers of anaerobic microbial community assembly and determinants of methanogenic process performance. Subsequently, potential integration of new developments in membrane technology and microbial electrochemical processes also provides opportunity to develop enhanced reactor systems to overcome the grand challenge of reinventing the "old" technology of anaerobic digestion and beyond.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

Title: Thinking and Behaving as a System
Name: Lesley M. Herstein, Yves R. Filion, Barry J. Adams

Overview:
There are many environmental engineering and science challenges that must be addressed in this century, such as those associated with water, climate, energy, land, food, health, and air. Each challenge is often addressed individually with its own solution or set of solutions. As solutions to individual challenges are implemented, unforeseen consequences may materialize in other realms, some of which may be more threatening and irreversible than the initial issues they were meant to address. Without an understanding or appreciation of systemic linkages (e.g., ecological, cultural, economic, technological, governance), the risk, uncertainty, ambiguity, and ignorance associated with solution implementation and outcomes can be amplified.

The uncertainty and complexity associated with the integrality of challenges in this century leads to two additional grand challenges. The first is to develop a collective appreciation for and understanding of the systemic linkages between challenges. The second additional challenge, following from the first, is to use this understanding to intentionally move forward within this system into the future. In short, environmental engineers and environmental scientist must begin to think as a system and behave as a system.

Thinking and behaving as a system translates into greater collaboration between environmental engineering and science disciplines and with disciplines outside this realm. This requires greater exploration of alternative means with which to work with other disciplines to understand and share insights and develop new insights. Collaborating in this manner requires the development of common language for discussing and describing system issues, which can allow for a more appropriate redefinition of challenges along broader system lines. Such systems thinking can help identify levers for change, opportunities, and immediate issues, thereby allowing for the development of short-, medium-, and long-term strategies that can address challenges and create and take advantage of opportunities over time.

GRAND CHALLENGE IDEA
Environmental Engineering
Submitted by Britt A. Holmén, University of Vermont
May 1, 2015

The Challenge: **Improving Spatiotemporal Resolution of Air Pollution Exposure for Advanced Understanding of Public Health Risk in Urban and Rural Communities**

Overview:
A broad range of human health effects have been associated with exposure to air pollutants: chronic and acute respiratory disease, asthma, cardiovascular diseases (stroke, ischemic heart disease), cardiopulmonary morbidity, and, recently, cancer. In March 2014, the World Health Organization (WHO) *doubled* its estimate of air pollution's effect on human health at the global scale: one of eight premature deaths in 2012 (in total 7 million) was attributed to air pollution exposure [1]. These global estimates were based on ground-based measurements for urban areas, chemical transport models, and satellite data for more remote regions without monitoring infrastructure. The reliability of these estimates is unknown. A difference in the burden of air pollution-related disease was found by region, with higher incidence in low- and middle -income countries where "household air pollution" (i.e., dirty biomass combustion [2]) commonly leads to extreme fine particulate matter ($PM_{2.5}$) exposure. In developed countries, $PM_{2.5}$, ozone and air toxics continue to pose significant health risks and risk is similarly spatially variable. Additionally, the degree to which climate change will exacerbate air pollution risk remains unknown. **The Challenge is to fill the gap in data needed to quantify the relationships between air pollutant concentration, daily activity and personal exposure to air pollution, the "world's largest single environmental health risk".** [1]

Large differences in air pollution occur at the "local" or "micro" spatial scales— at the street, facility or neighborhood resolution or smaller—but there is a lack of long-term, air pollutant data at this scale. Further, higher temporal resolution data is important to enable interdisciplinary research teams to quantify the relationships between ambient air pollutant concentrations, personal exposure and public health outcomes. Part of the problem stems from the fact that most ambient air pollutant concentration data is only routinely available at low spatial and temporal resolution from sparsely distributed Federal Reference Monitors (FRMs). The FRMs may be located at just one or two locations across an entire urban area and are often completely absent from less developed areas. This sparse ground-based data, combined with low-resolution models of emission sources, and chemical reaction/ transport are typically at large spatial scales that are not useful to determine an individual's daily air pollution exposure. High spatial and temporal resolution data are needed on $PM_{2.5}$, ozone and air toxics concentrations, personal exposure duration, and associated health effects. New measurement technology will require new modeling techniques for improved public health forecasts.

Environmental scientists and engineers are ideally suited to develop robust and reliable personal monitoring technology, validate the data, design robust data aggregation, analysis/modeling techniques and communicate the results across disciplines. Recognizing recent advances in personal mobile technology and air pollutant sensors, the data gap can be filled by development of a new "widely distributed" and "mobile" air pollution data monitoring program that will improve the spatial and temporal resolution of ground-based air pollutant concentration data. This data can then be combined with data on the numerous factors beyond air pollutant concentration (nutrition, socioeconomic status, maternal exposure, stress, physical activity, etc.) to improve quantitative understanding of the resulting health effects associated with air pollution exposure, both chronic and acute.

---

1 World Health Organization (2014) 7 million premature deaths annually linked to air pollution. News release, March 25, 2014. Accessed April 30, 2015, http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

2 Smith, K.R. et al. (2014) Millions Dead: How Do We Know and What Does It Mean? Methods Used in the Comparative Risk Assessment of Household Air Pollution. *Annu. Rev. Public Health* 2014. 35:185–206.

GRAND CHALLENGE IDEA 2
Environmental Engineering

Submitted by Britt A. Holmén, School of Engineering, University of Vermont
May 1, 2015

The Challenge: **Triple Benefits in Biofuels for Electricity and Transportation: Global Climate Effects, Environment and Public Health**

Biomass represents a source of renewable, domestic low carbon fuel that can be used to generate electricity, power our transportation vehicles and make use of our agricultural waste products. Future distributed energy scenarios to meet U.S. demand include electricity and transportation fuels from biomass. Biomass sources range from combustion of solid agricultural residues and animal manure to manufacturing liquid transportation fuels from oil-rich plant "fuel crops" and animal fats (i.e., biodiesel) or crop residue (cellulosic ethanol). Distributed biomass-to-energy electricity is viewed as an essential part of a diverse comprehensive energy plan to combat climate change. The Energy Information Administration anticipates a growth in biomass for energy of 3.1% per year through 2040, chiefly for bioelectricity.[1]

Recent modeling studies on the net effects associated with future use of alternative transportation fuels demonstrate that the air quality-related health risks of light-duty vehicles, including biomass-powered electric vehicles, can *exceed* climate change damages[2]. Thus, development of comprehensive understanding of the full environmental effects of biofuels use must move beyond greenhouse gas emissions to include effects on public health. This is especially important given the need to incorporate accurate, up-to-date information on biofuels use in our energy, air quality and climate models.

While overall energy consumption in the transportation sector is anticipated to decline as passenger vehicles become more fuel efficient, freight transportation (diesel trucks) is projected to grow 0.8%/year [1]. The transportation sector generates at least 30% of airborne particulate matter (PM), and biodiesel use ranges from 5-20%. Increased use of biodiesel will have significant greenhouse gas emission benefits. However, the toxicity of emissions from biofuel combustion is relatively understudied; data from different studies often gives conflicting results on PM and air toxic emissions, including carbonyls and PAHs. Further, the data that do exist for diesel engine emissions are chiefly from older technology engines, outdated high-sulfur petroleum diesel blends and for steady-state engine operation that is not realistic of real-world vehicle operation. More detailed studies are needed to quantify the relationships between biofuel feedstock, exhaust composition and human health effects. These data are especially needed for advanced clean diesel modern fleet vehicles.

The challenge is to identify the biofuel resources that are best suited to maximize the "triple-benefits" for sustainable transportation and bioelectricity applications: (1) high energy efficiency and low greenhouse gas emissions (climate); (2) reduce soil and water consumption (environment); and at the same time (3) minimize emissions of criteria and air toxic pollutants (public health).

---

[1] U.S. Energy Information Administration (2015) Annual Energy Outlook 2015, April 14, 2015. Available on-line: http://www.eia.gov/forecasts/aeo/index.cfms

[2] Tessum, C.W. et al. (2014) Life cycle air quality impacts of conventional and alternative light-duty transportation in the United States. PNAS 111 (52) 18490-5.

Title: Holistic Perspective on the Appropriateness of Water Treatment Technologies

By: Kerry Howe
Director, Center for Water and the Environment
University of New Mexico

For water treatment technologies of the future, factors related to relative health benefits, energy consumption, waste production, use of toxic materials, and other aspects of sustainability will be as important as the technology's effectiveness for contaminant removal. Early water treatment technologies, such as granular media filtration and chlorination, achieved dramatic public health benefits by eliminating waterborne diseases like cholera and typhus. Because of these relatively straightforward technologies, widespread waterborne disease outbreaks in developed countries have been largely eradicated.

Today's water quality challenges in developed countries are more sophisticated: endocrine disrupting compounds, pharmaceuticals and personal care products, contaminants of emerging concern. The concern over trace contaminants and long-term health effects will increase as water sources become more impaired with wastewater discharges, analytical instruments become more sensitive, and the water industry contemplates direct potable reuse. Increasingly, we are tempted to provide treatment to address health risks we cannot measure and do not understand. In response to the Precautionary Principle, the tendency is to require more advanced treatment. In 2013, the California Department of Public Health introduced full advanced treatment (consisting of microfiltration, reverse osmosis, and advanced oxidation) as the appropriate treatment train for some wastewater reuse applications.

A common trait of advanced water treatment processes is that they often have greater negative environmental consequences than traditional processes. Reverse osmosis is a perfect example. Reverse osmosis is often touted as an essential technology for potable reuse because of its effectiveness at removing contaminants. However, it is one of the most energy intensive treatment processes. It also recovers less fresh water (therefore wasting precious resources) and produces more waste than other treatment technologies. It is possible that, in some instances, the negative consequences outweigh the health benefits. A challenge for the future is to develop a comprehensive way to assess the health benefits of achieving a particular level of water quality and to quantify the negative consequences of achieving that quality, such that society can make informed decisions about what levels of treatment and technologies are appropriate. With that framework, technologies could be developed more rationally from the perspective of minimizing the overall impact on environmental and human health.

Reference: Howe, Hand, Crittenden, Trussell, and Tchobanoglous (2012). *Principles of Water Treatment*, Chapters 1 to 3. John Wiley and Sons, NY.

A novel process in the N cycle: From discovery to implementation

Peter R Jaffé, Civil and Environmental Engineering, Princeton University

A novel ammonium (NH_4^+) oxidation process, coupled to iron (Fe) reduction in the absence of oxygen and nitrate/nitrite (NO_3^-/NO_2^-) was observed in a forested riparian wetland in New Jersey (Clement *et al*., 2005; Shrestha *et al*., 2009, Huang and Jaffé, 2013, 2014, 2015), in a bioreactor (Sawayama, 2006), in tropical rainforest soils in Puerto Rico (Yang *et al*., 2012), and in paddy soils in South China (Ding *et al.*, 2014). This process was coined Feammox, as opposed to anammox, the only other known biological NH_4^+ oxidation process under anoxic conditions, which requires NO_2^- as electron acceptor. Feammox consists of the anaerobic NH_4^+ oxidation using ferric iron as electron acceptor to produce NO_2^- (Huang and Jaffé, 2014, 2015) or N_2 (Yang *et al*., 2012).

We have shown that an *Acidimicrobiaceae* bacterium A6 (referred to as A6 from here on), previously unknown, belonging to the *Acidimicrobiaceae* family, is likely to be responsible for this Feammox process (Huang *et al*., 2013, 2014, 2015). We have enriched and isolated the pure A6 strain, and operated a Feammox membrane reactor to which ferrihydrite was added regularly as the Fe(III) source. Sequencing of A6 did not show any known gene for the N cycle, but we identified a novel enzyme related to monooxygenases that seems to be key in the Feammox reaction. Incubations showed strong A6 activity over the 15 ^{o}C to 30 ^{o}C range. Primers developed for A6 have shown its presence in various sediment samples in New Jersey, South Carolina, and South China, always in soils with high Fe(III) and acidic conditions. This, plus the reports from other investigators on Feammox in different geographical locations, indicates that Feammox might play an important role in the global N cycle, which needs to be further elucidated so it can be accounted for in N cycling and exploited in natural and engineered settings (i.e. wetlands).

A Feammox reactor has the potential to work as an energy efficient treatment of wastewater for NH_4^+ removal, requiring neither aeration nor heating, and the Fe may be reused after re-oxidizing it. Much research is still needed, especially iron handling, to make such reactors practical for field-scale implementation. The stoichiometric molar ratio of Fe(III):NH_4^+ = 6:1 which may be non-practical for reactor operation. Initial experiments have shown that A6 is capable of growing in microbial electrolysis cells, bypassing the need for Fe(III) addition.

Other applications of Feammox for industrial wastewater treatment and/or contaminated groundwater are being investigated. Like many organisms that produce oxygenases, A6 seems to be able to co-metabolically break down chlorinated ethenes and oxidize aromatics while oxidizing ammonium, and like heterotrophic iron reducers A6 can reduce other metals/radionuclides.

This work shows that building on existing knowledge, new discoveries of natural processes can be exploited by Environmental Engineers for many novel environmental applications.

References

Abbassi, R., A.K. Yadav, S. Huang, and P.R. Jaffé (2014). Laboratory Study of Nitrification, Denitrification and Anammox Processes in Membrane Bioreactors Considering Periodic Aeration. *J. of* Environ. Management. **142**:53-9

Clement, J.C., J. Shrestha, J.G. Ehrenfeld and P.R. Jaffé (2005). Ammonium oxidation coupled to dissimilatory reduction of iron under anaerobic conditions in wetland soils. *Soil Biol Biochem* **37**:2323–2328.

Ding, L., An, X, Li, S., Zhang, G., Zhu, Y. (2014). Nitrogen Loss through Anaerobic Ammonium Oxidation Coupled to Iron Reduction from Paddy Soils in a Chronosequence. *Environ Sci Technol*. **48(18):**10641-7.

Huang, S., and P.R. Jaffe (2013). A newly identified microorganism affecting the N cycle: Ammonium oxidation in iron reducing soils. 23nd V.M. Goldschmidt Conference, August 2013, Florence, Italy. *Mineralogical Magazine*, **77(5)** 1339.

Huang, S., and P.R. Jaffé (2014). Identification of an *Actinobacteria* species capable to oxidize ammonium under iron reducing conditions. *Biogeosciences Discuss.* **11,** 12295-12321.

Huang, S. and P.R. Jaffé (2015). Characterization of incubation experiments and development of an enrichment culture capable of ammonium oxidation under iron-reducing conditions. *Biogeosciences*, 12, 769-779, doi:10.5194/bg-12-769-2015, 2015.

Li, C., Salas, W., Deangelo, and Rose, S., (2006). Assessing Alternatives for Mitigating Net Greenhouse Gas Emissions and Increasing Yields from Rice Production in China Over the Next Twenty Years. *J. of Environ quality*. **35:** 1554-1565

Sawayama, S. (2006). Possibility of anoxic ferric ammonium oxidation. *J Biosci Bioeng* **101**:70–72.

Shrestha, J., J. Rich, J. Ehrenfeld, P.R. Jaffé (2009). Oxidation of ammonium to nitrite under iron-reducing conditions in wetland soils: Laboratory, field demonstrations, and push-pull rate determination. *Soil Sci* **174**:156–164.

Yang W.H., K.A. Weber, W. Silver (2012) Nitrogen loss from soil through anaerobic ammonium oxidation coupled to iron reduction. *Nat Geosc* **5**: 538–541.

Global solid waste management: A growing, moving target in need of a paradigm shift

Jenna Jambeck, University of Georgia

In 2010, we estimated that globally, 2.5 billion metric tons of solid waste was produced worldwide (1). We are not predicted to reach peak waste this century, unless major changes take place (2). Solid waste has specific challenges to management, and the scope and change in our waste stream in the past 40 years (e.g., an increase of more than 600% in plastic resin production has then impacted our waste characterization) has been a game changer. In addition, per capita solid waste generation is coupled with economic growth. Therefore, as economies develop (and some currently very rapidly), waste generation grows, but more organized waste management, including collection and disposal, is not economical until it reaches a large enough scale. However, before that point, large quantities of solid waste can go unmanaged. For example, 8 million metric tons of plastic waste was estimated to enter our oceans in 2010 (1). And this mismanaged waste is a snapshot in time, changing as countries continue to develop, i.e., it is a moving target and not one solution fits all. A paradigm shift in solid waste is needed, more circular economies and resource recovery need to be a focus. While in some ways, globalization has contributed to factors exacerbating this problem, it can also be a major part of the solution. With growing populations and developing economies, the solid waste management problem cannot be addressed with the lag we have seen in the past. More holistic and integrated solutions are needed - and solutions will need to be culturally appropriate and should incorporate multi-disciplines such as social, cultural and economical issues (sciences) as well as environmental engineering and science.

1. J.R. Jambeck et al., (2015) “Plastic Waste Entering the Ocean from Land,” Science, vol. 347, issue no. 6223, 2015, pp. 768–771.
2. Hoornweg, D. et al. “Environment: Waste production must peak this century,” Nature Comment, Oct. 30, 2013.

Wastewater Treatment Plants as Energy Producers and Next-generation Contaminant Scrubbers

Scott C. James, Baylor University

Currently, about 21,600 wastewater treatment plants (WWTPs) treat the wastewater of 226.4 million US residents. This treatment consumes 2% of all electricity produced by the United States, totaling 81.2 million kWh per year [1]. In the process, WWTPs add up to 45 million tons of greenhouse gases to the atmosphere annually. However, the potential energy content in wastewater and its biosolids/biogases is an order of magnitude greater than the energy used to treat it, and, if harvested, WWTPs could potentially meet 10% of the national electricity demand [2]. Interestingly, 41% of available fresh water in the US is used by thermoelectric power plants [3]. This intersection is a prime example of a growing disquiet about the stability of the water-energy nexus: increasing power production places greater strains on water supplies and wastewater treatment from the growing populace consumes more energy. WWTPs could not only provide most of the cooling-water requirements for these thermoelectric power plants, but they could actually be energy producers by converting the energy potential in wastewater into fuels.

On another topic, unregulated organic compounds known as “contaminants of emerging concern” (CECs) are becoming a major issue for water-treatment engineers. These contaminants, including pharmaceuticals, cosmetics, hormones, nanomaterials, and others, may have adverse effects on aquatic life and may pose a potential risk to humans (e.g., they may be endocrine disruptors). Many of these chemicals are not currently removed by WWTPs. However, the potential exists for CECs to be biologically removed using the same algae grown to produce fuels and gases to operate the WWTP.

Most WWTPs are owned by municipal governments and are typically their largest energy consumers (30-40% of total energy consumed). Local governments are also keen to explore clean-energy options. Growing algae at a WWTP can simultaneously resolve several major issues: (1) algae can take advantage of free and abundant water, nutrients, and CO_2, shortages of which may otherwise be showstoppers to cost-effective algae growth, (2) algae may sequester and fix CECs to increase capabilities to meet effluent standards, (3) algae can clarify wastewater that can be used for cooling water at a nearby thermoelectric power plant, (4) algae may provide livestock feed and neutraceuticals, (5) algae may yield biogases to power WWTP operations like heating and drying of biosolids thereby decreasing energy use, (6) they may increase treatment capacity, (7) algae can reduce greenhouse gas emissions as a solar-to-chemical energy conversion for transportation and process fuels.

The Grand Challenge will be to develop the technology to transition WWTPs into net energy producers that can supply cooling water to thermoelectric power plants while removing with high efficiency known and emerging CECs. A major component to this technology can be the growth of algae and cyanobacteria that produce transportation fuels, fuel gases (like methane and hydrogen), neutraceutical, and livestock feed. In this capacity, the algae will also conduct the essential service rendered by WWTPs – specifically removing nutrient, biosolids, and CECs from wastewater. The algae will also consume CO_2 emissions that would otherwise be released from WWTPs as greenhouse gases. Moreover, burning the produced algal biofuels will provide the process heat and electricity required for plant operation and those flue gases will be recycled into the algae growth media as a nutrient source.

References

1. EPRI, *Water and Sustainability: U.S. Electricity Consumption for Water Supply & Treatment - The Next Half Century*, ICF Consulting, Editor. 2000, Electric Power Research Institute: Palo Alto, CA. p. 93.

2. Water Environment Research Foundation, *Energy production and energy efficiency - The roadmap to net-zero energy*. 2011, WERF: Alexandria, VA. p. 8.

3. Averyt, K., et al., *Freshwater use by U.S. power plants: Electricity's thirst for a precious resource*. 2011, Energy and Water in a Warming World Initiative: Cambridge, MA. p. 62.

Scott C. James, PE
Baylor University
Departments of Geology and Mechanical Engineering
Center for Reservoir and Aquatic System Research
One Bear Place #97354
Waco, TX 76706-7354
(254)710-2534
SC_James@baylor.edu

Grand Challenges in Environmental Engineering and Science: Is it Time for Environmental Engineering Departments to Cut the Cord?

David Jassby

The vast majority of Environmental Engineering faculty are part of Civil and Environmental Engineering Departments. This is largely due to historical reasons, since the discipline of Environmental Engineering emerged from Sanitation Engineering, which was an offshoot of Civil Engineering. However, the discipline of Environmental Engineering has grown far beyond its original scope. A partial list of topics that now fall under the domain of Environmental Engineers includes (by no means a comprehensive list):

- Water and wastewater treatment
- Remediation of environmental matrices (soil, groundwater, sediments, etc.)
- Fate, transport and transformations of contaminants (chemical and biological) in the environment
- Risk assessment and life cycle analysis
- Air quality and atmospheric studies
- Environmental health and safety
- Hydrology
- Hydraulics

In many departments, Environmental Engineering faculty are the most productive in terms of research funding, scientific publications, and patent filings. Yet, there are barely any purely Environmental Engineering departments. Why is this? Is it time for independent Environmental Engineering departments? Some advantages to independence include:

- A clearer vision of the field of Environmental Engineering that is disentwined from its historical roots
- An ability to steer the direction of the department towards areas that are of importance to Environmental Engineers (such as international development, sustainability)
- Ability to determine an undergraduate curriculum that meets the demands of employers specifically interested in hiring Environmental Engineers
- Hire new faculty that meet the emerging needs of the field
- Determine graduate student curriculum and prerequisite skills
- Advertise the unique set of skills possessed by Environmental Engineers

So, is it time to cut the cord and declare our independence? Are there significant disadvantages to this move? Is this move warranted or is it merely hand waving, and ultimately, labels do not matter?

Grand Challenges in Environmental Engineering and Science: Treatment and Reuse of Impaired Waters Under the Watch of an Informed Public

David Jassby

The recent drought experienced by many parts of the Southwestern USA has pushed utilities to seriously consider the treatment and reuse of water resources previously considered too contaminated and unappealing. Examples of such impaired waters include:

- Domestic wastewater that is treated and directly (in Texas) or indirectly reused (in California) as potable water
- Produced water from oil and gas fields used for agricultural irrigation in California
- Seawater desalination in California and Texas

The treatment of such impaired water sources carries significant costs and risks. Known risks include (a partial list) the exposure of consumers to pathogens and contaminants from recycled wastewater, soil salinization resulting from irrigation with brackish water, and the environmental costs associated with certain water treatment activities such as brine management during desalination. An important factor that influences treatment decisions by utilities is public opinion. Since information on water quality and treatment is widely and freely available, an increasing number of consumers, advocates and other interested parties are weighing-in on the debate. These groups and individuals carry significant weight, and can sway the direction of water resource development through political or legal action.

As professionals in the field of water quality and treatment, Environmental Engineers are uniquely positioned to inform and participate in the debate on the future of water resources under constrained supply conditions. In particular, it is critical to evaluate the impact of various treatment methods on the removal of emerging contaminants such as pharmaceuticals and endocrine disrupting chemicals as well as establish technologies that reduce the environmental impacts of the different treatment processes and lower their energy demands. Additionally, it is important that we actively engage with the public on these water treatment methods. This could be done through forums that bring together scientists and engineers with members of the public, participation in public debates, and outreach activities facilitated through mass media. The large number of mass media outlets, driven by the ever increasing numbers of people actively engaged in environmental issues, offer an excellent platform to interact and educate the public. By joining the conversation, scientists and engineers can help separate fact from fiction, educate the public and influence policy.

Securing Clean Water Production and Supply in a Climate-Constrained Future

Yi Jiang

Department of Energy, Environmental, and Chemical Engineering

Washington University in St. Louis

Water quantity and quality underpin major, yet interwoven global development and sustainability challenges spanning from human health to the techno-economics of energy production. Clean water production and supply face unprecedented risks as a consequence of climate-related impacts, including water resources redistribution (local availability), increased intensity and frequency of extreme weather events (e.g., extreme floods and storms putting stress on current water/wastewater treatment systems), increases in sea level (e.g., utilization seawater through desalination), changes in agriculture due to climate adaptation (nonpoint pollution source) etc. As the most recent report from the Intergovernmental Panel on Climate Change makes clear, our changing climate has already begun to reshape our world, and we need to take decisive actions to secure our future water production and supply in a climate-constrained world. With that particular regard, there are two outstanding aspects needing urgent technological advancement:

(1) *Adaptation of current water treatment systems to changes of local availability of water resources.* Climate change has brought in reallocation of water resources locally as seen in many parts of the world, namely increasing quantity in forms of more floods and storms, or decreasing availability through severe droughts (likely now happening in California). Current water treatment systems may not be able to cope with such rapid changes.

(2) *Energy consumption associated with water production and supply.* Climate mitigation (carbon emission reduction) will likely exert significant stress on conventional way of energy production and consumption in a future where renewables are still not economically competitive at large scale. This requires new technological solutions to drastically reduce the energy used for producing and transporting more water to meet the demand of 9 billion people.

Grand Challenge:
Integrating Knowledge Across Scales: From Nanoparticles to Systems

Carol Johnson
Postdoctoral Associate, Civil & Environmental Engineering, Duke University

The difference in scale between a nanoparticle and the Earth is 10^{16}. Even though nanoparticles are a minority in terms of mass or volume in the Earth's critical zone, they are major players in chemical and biological reactions. For example, iron oxide nanoparticles in the ocean provide an energy source for phytoplankton that take up CO_2 from the atmosphere. This complex process has even led to the (perhaps unrealistic) idea of "seeding the oceans" with iron oxide nanoparticles to partially counteract global warming. Other great advances in nanobiogeocience include using bacteria and minerals to naturally remediate contaminated sites, analyzing the atomic-level structure and composition of minerals, and detecting and imaging nanoscale reactions in real time. At the same time, large advances have been made in systems-level thinking and analysis such as geographic information systems (GIS) mapping, remote sensing, and life cycle assessment. Systems can be both natural (e.g. watersheds, airsheds) and engineered (e.g. water treatment utilities).

In my opinion, one of the Grand Challenges for environmental engineers and scientists is to bridge this gap between nanoscale and systems scale thinking. Current research does not often take into account the most reactive parts of the system, the nanoparticles, because there is currently no way to quantify and probe them on a large scale. However, by applying a "black box" approach and ignoring nanoscale interactions, a potentially critical piece of the predictive model is missing. In order to start filling in the models, it is necessary know nanoparticle fluxes between Earth components on a global scale; initial estimates have been made for natural nanoparticles[1] and engineered nanoparticles[2]. Future research could focus on the following areas:

- mapping nanoparticle transport within systems;
- quantifying the *in situ* kinetics of nanoparticle reactions so that they can be applied to predictive models; and
- quantifying the relative percentages of nanoparticles in different Earth components.

In order to continue to make strong advances in these areas, we need to improve nanoparticle detection methods, apply statistics to electron microscopy, and learn how to integrate knowledge across boundaries of both size and discipline.

References:
1) Hochella Jr, M. F., Aruguete, D., & Kim, B. (2012). Naturally occurring inorganic nanoparticles: General assessment and a global budget for one of Earth's last unexplored major geochemical components. In A. S. Barnard & H. Guo (Eds.), *Nature's Nanostructures* (pp. 1–31). Pan Stanford Pte Ltd.
2) Keller, A. a.; McFerran, S.; Lazareva, A.; Suh, S. Global life cycle releases of engineered nanomaterials. *J. Nanoparticle Res.* **2013**, *15*.

2015 AEESP research and education conference, June 13-16, 2015

Grand challenges and opportunities in environmental engineering and science in the 21st century

Title: Challenge of energy access for clean water in remote areas

Name: Sung Hee Joo, University of Miami

Overview of the challenge:

Water scarcity is a significant global issue to be faced in the future, especially considering climatic and hydrological change combined with increasing population. Countries suffering from extreme poverty and hunger often lack water supplies as well as resources and facilities to meet clean water standards. As a result, at least 1.8 million children die every year from water-related disease, or one every 20 seconds (UNEP, 2010). We have collaborated in the design of water filtration packages that have been successfully installed and operated in developing countries, supplying clean drinking water to communities in Ghana (100 m^3/d), and in Cambodia (20 m^3/d), for example. These water treatment packages, which apply solar energy to a filtration system, have operated since 2011, helping to prevent and ameliorate diseases caused by poor water quality. However, the lack of access to energy is one of the biggest challenges to be faced in providing clean water. Energy demand has constantly risen and is expected to continue rising over the next 15 years. Indeed, water and energy are very closely linked, in that energy is required for treating, cleaning, and transporting water, while in turn water is used to produce energy. Various avenues can be explored to achieve energy savings and improve access through increased investment in and new research on renewables. These could include solar energy, revolution of desalination with less energy-intensive water cleansing techniques, and extraction of materials that can be turned into solar panels to generate renewable energy, especially in remote areas where facilities and resources are most severely limited.

Quantifying Composition Complexity, Formation Controls, and Environmental Impacts of Waste Waters Produced from Shale-Oil Formations

Kenneth C. Carroll, kccarr@nmsu.edu, Plant & Environmental Science at NMSU

Grand Challenge Overview:

Energy, water, and food sustainability are innately coupled, and they support and compete with each other, especially in water-scarce regions. Waste-water reuse is becoming required to enable sustainability, but the complex-mixture chemistry and environmental implications still need to be assessed. One ***grand challenge*** needing to be addressed is to advance our understanding of complex, aqueous chemistry by examining produced water (PW) from the Permian Basin, which could be the ***most chemically complex waste water***. PW is any water brought to the surface during hydrocarbon production. It includes water from the reservoir, fracturing flow-back water, water injected into the formation, and any chemicals added during the drilling/production processes. PW contains many petroleum hydrocarbons (>1300) and salts (300 - 10 g/L), the composition is extremely variable, and it is generally reinjected for waste disposal. In fact, the complete composition of these complex mixtures, compositional variability, and processes controlling the formation of these mixtures are still generally unknown.

Due to drought, demand, and climate change, there is a dire need for preservation & restoration of water for agricultural, domestic, industrial, and other beneficial uses, especially in regions where water is scarce such, as the region where Permian Basin oil production occurs. Developing efficient and cost-effective treatment technologies and beneficial use options for PW should be a ***grand challenge***. If PW can be treated and reused, treatment and reuse of essentially all other unconventional waters should be feasible. Despite availability of PW, vast quantities of potable groundwater are purchased from farmers by the oil industry for use in hydraulic fracturing, which converts this potable water into PW that is reinjected for disposal. Our preliminary work suggests that unconventional, shale-oil PW is very different from conventional PW. We identified ~1300 organic compounds, but confidence in structures was achieved for only 1/3. We also observed increasing TDS and TOC with depth, which is not supported by salting-out impacts on organic solubility. The unconventional, shale-oil boom is likely creating an extreme perturbation in the Basin's brine geochemical system through fracturing flow-back and PW reinjection.

A primary **objective** of this ***challenge*** is to advance our understanding of produced-water chemistry to evaluate feasible and environmentally-sound strategies for beneficial uses of PW. ***Hypothesis:*** *Despite compositional complexity and variability of PWs, geochemical evaluation can be used to develop compositional predictive methods that support treatment-option and beneficial-use evaluation*. An additional **objective** includes assessment of PW transport, as well as attenuation processes and rates acting in plants and soils to evaluate groundwater-contamination potential of PW. ***Hypothesis:*** *PW contaminant attenuation can be quantified and used to determine the level of partial treatment required to protect groundwater*.

Intellectual Merit:

This work will advance our fundamental understanding of the potential environmental impacts of chemicals in complex mixtures and unconventional water sources such as PW, and it will develop our understanding of the potential opportunities for using waste-water reclamation for food-water-energy sustainability. We aim to quantify the >1300 organic structures in produced-water samples, compare the source oil/rock organic composition to evaluate source controls, and examine mixture nonideality impacts on solubility and *in situ* compositions. We will evaluate the impact of changes in formation temperature and salt content in this hyper-saline water to investigate the nonideal impacts on the inorganic and organic aqueous interactions. Isotopic signatures will also support elucidation of compositional evolution. Fracture flow-back reinjection and PW reinjection have implications for alteration of formation geochemistry evolution.

We will develop the fundamental transport, biochemical interactions (e.g., transformation, bioaccumulation, toxicity), and fate processes that occur within soils and plants when PW is used for irrigation and other beneficial uses. We will use metabolomics and proteomics to examine microbial and plant transformation processes. We will use ultra-high resolution mass spectrometry to quantify complex, organic-mixture composition and to identify transformation pathways and products. Specifically, fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS) and high-resolution gas and liquid chromatography with time-of-flight mass spectrometry (GC-TOF-MS and LC-TOF-MS) will be developed to evaluate PW composition variability and to evaluate solubility and source (rock/oil) controls over the mixture composition. This will create an invaluable tool for complex-mixture analysis as it will provide the highest resolution and mass-measurement accuracy available to any system of mass spectrometers. Tens of thousands of individual molecular formulae may be elucidated, simultaneously, from a single sample. This coupling of FT-ICR-MS analysis with LC-TOF-MS and GC-TOF-MS will support quantitative mixture analysis for thousands of organic compounds. This will also be the ideal analytical platform for both proteomic and metabolomic analysis of transformation processes in plants and microbes, as well as evaluation of toxicity and transformation processes for fracturing additives.

Broader Impacts:

Many regions where hydrocarbon production occurs lack sufficient water supply for municipal, agricultural, or industrial uses. The baseline for both domestic and agricultural water-supply quantity and quality is shifting, and unconventional-water sources such as PW, previously not considered viable, will soon be required. The data and innovations developed herein will be leveraged to advance public awareness, policy, and application of technologies for treatment and reuse of unconventional waters (e.g., PW), which will be used to sustain food, water, and energy security around the world.

Title: Challenges in Water use and Access

Name: Shamitha Keerthi, Doctoral Student, School of Natural Resources and Environment, University of Michigan

Water and in particular, freshwater, is intimately connected to human existence and access to freshwater ultimately determines civilization's survival. The challenge is to understand how population growth and climate change[1] will impact the availability of freshwater resources globally and map the road towards equitable access to all in the future.

There are three main parts to this challenge:

(i) Determining how population growth will impact water consumption

The world's population is expected to grow from 7.2 billion to 9.6 billion by 2050[2]. Most of that increase will come from developing countries[3]. Analyzing existing data of water consumption by countries, it is apparent that in general, countries with higher GDPs also tend to use more water[4,5] as well as more energy (that needs more water for its production). Therefore we can expect consumption in developing countries to rise due to both population *and* economic growth. The challenge is develop accurate measures of water consumption at a high resolution for all countries as a function of both these factors. Measuring consumption accurately will be the first step in managing water use in the future.

(ii) Determining the impact of climate change on water availability

The challenge will be to predict with a lower degree of uncertainty the occurrence of extreme events as well as water availability through the year at a high resolution. This will help agriculturists and urban planners prepare for both floods and droughts which are likely to increase under most future climate scenarios[6]. This will require both the development of models and hydrologic monitoring in countries that are data scarce to calibrate and validate them.

(iii) Equitable Access to water

Having determined both water availability and consumption, analyzed under the lens of climate change and population growth, it will be a challenge to provide equitable access to water to all

---

[1] Vörösmarty, Charles J., Pamela Green, Joseph Salisbury, and Richard B. Lammers. "Global water resources: vulnerability from climate change and population growth." *science* 289, no. 5477 (2000): 284-288.
[2] United Nations. "World Population Prospects: The 2012 Revision." *Highlights and Advance Tables (Working Paper No. ESA/P/WP. 228) New York: United Nations Publications* (2013).
[3] Gerland, Patrick, Adrian E. Raftery, Hana Ševčíková, Nan Li, Danan Gu, Thomas Spoorenberg, Leontine Alkema et al. "World population stabilization unlikely this century." *Science* 346, no. 6206 (2014): 234-237.
[4] Hoekstra, Arjen Y., and Ashok K. Chapagain. "Water footprints of nations: water use by people as a function of their consumption pattern." *Water resources management* 21, no. 1 (2007): 35-48.
[5] Shen, J. "Average Water Use Per Person Per Day". Data360.org. 15 Apr 2010. Web. Accessed 21 Apr 2015. http://hdr.undp.org/en/media/HDR06-complete.pdf
[6] Hirabayashi, Yukiko, Shinjiro Kanae, Seita Emori, Taikan Oki, and Masahide Kimoto. "Global projections of changing risks of floods and droughts in a changing climate." *Hydrological Sciences Journal* 53, no. 4 (2008): 754-772.

at the local, national as well as global levels. This is especially important as different countries are bound to have different water stress levels, as they currently do, and as we consider economic mechanisms such as water pricing[7] to reduce consumption. The challenge will be to also reform institutions such as water right laws and alter them to benefit all citizens.

[7] Rogers, Peter, Radhika De Silva, and Ramesh Bhatia. "Water is an economic good: How to use prices to promote equity, efficiency, and sustainability."*Water policy* 4, no. 1 (2002): 1-17.

April 28, 2015
Bvk

"GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY"

Title:
How to get environmentally sustainable bioremediation approaches out of the laboratory and into the field?

Name:
Birthe Veno Kjellerup, Ph.D.
Assistant Professor in Environmental Microbiology & The Pedro E. Wasmer Professor in Engineering
University of Maryland at College Park, Department of Civil and Environmental Engineering
1147 Glenn L. Martin Hall, College Park MD, 20742; Email: bvk@umd.edu

Overview of the idea:
This idea is based on the gab there currently exists between the bioremediation approaches that can be developed and tested in the laboratory in micro/mesocosm scale and the success that is observed in the field. Many great and novel bioremediation approaches are developed and published, but they do necessarily make it to the field. A significant barrier exists for the bioremediation applications to reach the level of field application, where many parameters cannot be controlled as easily as in the lab. One example is the application of activated carbon and other sorbent materials that are being deployed in contaminated sediment for adsorption of for instance organic contaminants (PCBs, PAHs). When these sorbents are applied in the laboratory, robust bioaugmentation approaches can be developed that can increase the dechlorination rate of PCBs and reduce the amount present in the sediment (1). However, it is a challenge to get the sorbents deployed, since they are often hydrophobic, have a low density so they float. In addition, the microorganisms applied simultaneously might not survive the traditional treatment that would be applied for abiotic solutions such as exposure to oxygen (for anaerobic microbes), presence in the water column (turbulence, predation).

<u>Question 1</u>: How can this "bench to field" challenge be approached in the future, so more of the bench scale bioremediation approaches will be developed with consideration to realistic field applications, so they can reach their full potential?

<u>Question 2</u>: How can we ensure that the bioremediation approaches that reach the field are environmentally <u>sustainable</u> and are not causing other environmental problems (such as more toxic break down products, excessive energy consumption for production/deployment, impacting macro organisms etc.), while solving the original problem? Would it be possible to include an "assessment guide" in proposals/papers, so the technical solutions must be evaluated with regards to a set of sustainability parameters to ensure that all environmental perspectives are included prior to field application? This could be based on the principles of Life Cycle Assessment (2).

A reference or two if appropriate.
1. "Effects of activated carbon on reductive dechlorination of PCBs by organohalide respiring bacteria indigenous to sediments". Kjellerup BV, Naff C, Edwards SJ, Ghosh U, Baker JE, Sowers KR. *Water Res. 2014 Apr 1;52:1-10.*
2. "Environmental impacts of remediation of a trichloroethene-contaminated site: life cycle assessment of remediation alternatives". Lemming G1, Hauschild MZ, Chambon J, Binning PJ, Bulle C, Margni M, Bjerg PL. *Environ Sci Technol. 2010; 44(23):9163-9.*

Grand Challenge

Mark Krzmarzick
Assistant Professor
Oklahoma State University

I can easily think up of many worldwide grand challenges between a changing climate and a modernizing world, but I think a grand challenge people have not talked enough about is dealing with the problems of our own successes as environmental engineers in the US and western world.

In the 1960s through the 1990s, environmental catastratophes were common enough that the importance of national regulation and new environmental technology were obvious to the American public. Between the burning of the Cuyahoga River, a permanent smog over Los Angeles, and even disease outbreaks like the Crypto outbreak in Milwaukee, the public got very real and easy-to-see examples of why we need environmental protections and new technologies to deal with pollution. But in 2015, many young people today in the United State (myself included), have not experienced the same level of acute disastors nor chronic exposure to visible pollution problems. We may all still have some asthma from living near the freeway, but we no longer see the smog so easy. We may have feminization of frogs from pharmaceuticals in the water, but unless we are catching them it is nothing more than an abstract story in the news (if you even care to seek it out online). Our problems are still real today, but they are no less much less visible to the every day non-engaged public.

There are calls by many people, even political leaders, to disband and defund the EPA, to roll back CERCLA regulations, and other things and these calls have gained traction with a part of the public. Has the success of our environmental programs created a new problem of losing the public’s support of having them? Is it possible to get to a point where the lack of environmental disaster in the US results in the roll back of the very programs that saved us from disaster just a couple of generations ago? Will this ultimately lead us into a future where we will again have to learn what the ‘tragedy of the commons’ truly looks like when we let the commons become an unregulated dumping ground again? Is there a limit to how far human beings will care for the environment and are we approaching that limit?

Thus, my grand challenge in the 21st century. How do we as a field not become a victim of our own success?

Open Public Communication/Education

one important grand challenge
submitted by David Ladner, Clemson University
to the workshop
GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY

The grand challenge I would like to focus on lies in a serious lack of understanding and miscommunication at the heart of so many environmental (as well as social and political) problems in our world. We can think about climate change, oil spills, water scarcity, and a host of other topics. With any of these we find a great deal of disagreement about how to overcome them. For some challenges, the technical solutions are fairly simple, but those solutions cannot be implemented because we cannot agree as a society about how to implement the solution. Note that this is not merely a problem of the public not understanding what the scientists and engineers are telling them, but also that the scientists and engineers often do not understand what the public feels and experiences. It is a two-way communication/education problem; engineers and scientists need to learn from as well as teach the public and political leadership.

One of the ways this problem is manifest is in the "black or white" approach toward issues. The use of dispersants in the BP Gulf of Mexico spill is an illustrative case. Much of the rhetoric revolves around whether the dispersants "are safe" or "are harmful." The truth is that they are somewhere in between; some organisms are severely affected by the dispersants, while others are not. Using dispersants probably prevented some shoreline species from being exposed, while it probably caused increased exposure for species in the water column. In order to come to a consensus about whether or not dispersants should be used in the future, we need to look at as much data as possible, and think through the pros and cons. That requires good research, but also good communication and education. Scientists and engineers need to know how the public feels about dispersant use, and need to think through the social and economic impacts that the public will likely experience. The public (all of us!) needs to learn about the gray areas of research, realizing that nobody has all the answers, but that we need to use whatever data are available to make an educated decision.

One underlying requirement to enable constructive debate is to have a basic understanding of scientific principles and language. Often communication is hampered because one party simply does not understand what the other is saying; this breeds mistrust and polarization. Education (both formal and informal) are needed to raise the level of discourse to a point where we can think through the issues together, explore the caveats, and come up with solutions that everyone can agree upon.

Merging innovative, flexible, sustainable engineering with human nature
Rebecca H. Lahr

Recent water engineering failures include the shutoff of drinking water to more than 17,000 Detroit households in 2014 despite water abundance,[1] $1.5 billion total direct losses in California Agriculture in 2014 due to drought alongside a 5.1 million acre-feet increase in groundwater pumping,[2] cyanotoxin contamination of Toledo drinking water in 2014, increases in gastrointestinal illness when drinking water supplies are contaminated by combined sewer overflows,[3] and increases in coastal economic losses globally due to catastrophe over the past decades.[4] Meanwhile, in 2012 approximately 19% of the global population didn't have access to clean drinking water and 36% didn't have access to sanitation.[5] ***In the 21st century we will continue to be challenged to engineer reliable water systems that service rich and poor individuals through drought, flood, and increasingly rigorous water quality standards***.

Unfortunately, ***silver bullet solutions are rarely available***. Even key historical accomplishments such as drinking water chlorination, penicillin, and the Haber-Bosch process are tarnished by side effects including disinfection byproducts, antibiotic resistance genes, and eutrophication. The benefits of these technologies far outweighed the costs, but the costs remain. Communicating the pros and cons to the public can cause headlines that inspire panic in the masses and distrust of science. Therefore, ***we are challenged to design diverse and flexible systems; to value interdisciplinary collaborations that create usable solutions; to be persistent about communicating implications of scientific findings directly to users and regulators; and to design for our neighbors' needs as well as our own.***

Flexible solutions. To accommodate climate change, resource limitations, and population increases, we must implement flexible, diverse, and innovative solutions. For example, water treatment plants that can tailor the effluent quality to various desires of the end user, waterless toilets that separate waste streams for recycling in water stressed regions,[6] or water infrastructure with sensors to modify water flow based on volumes or concentrations.[7] Flexible solutions will likely require updated regulation and modifications to human habits, topics which are often beyond the areas of expertise of environmental engineers. Therefore, we must collaborate beyond our discipline.

Interdisciplinary collaboration. Technology is useless if people will not use it, if it is not culturally acceptable, if it cannot be maintained, or if regulation does not permit implementation. Creating interdisciplinary teams early will save time and resources.

Communication. It is not enough to present scientific results and expect the public to know what to do with them. If we who know the most about our work cannot take the next step to explain which technologies may be useful for what situations, how do we expect users to sift through the masses of results to decide? Subjectivity in analysis is of the utmost importance, but it should not undermine our role of serving the public by communicating our work in an accessible format.

Literature cited: **(1)** Wahowiak, L. *The Nation's Health* 2014, 44 (8):1-20. **(2)** Howitt, R. E.; Medellin-Azuara, J.; MacEwan, D.; Lund, J. R.; Sumner, D. A. Economic analysis of the 2014 drought for California agriculture; Center for Watershed Sciences, University of California, Davis, California: 2014. **(3)** Jagai, J. S.; Li, Q.; Wang, S.; Messier, K. P.; Wade, T. J.; Hilborn, E. D. *Environmental Health Perspectives* 2015. **(4)** Kron, W. *Nat Hazards* 2013, 66 (3):1363-1382. **(5)** WHO; UNICEF. Progress on drinking water and sanitation - 2014 report. **(6)** Fewless, K. L.; Sharvelle, S.; Roesner, L. A. Source separation and treatment of anthropogenic urine, IWA Publishing: London, 2011. **(7)** Hill, D., Kerkez, B., Rasekh, A., Ostfeld, A., Minsker, B., and Banks, M. *Journal of Water Resources Planning and Management* 2014, 140 (7):01814002.

Sustainable nitrogen removal in wastewater reclamation

Ellen Lauchnor, Montana State University

Maximum effluent limits for nitrogen and phosphorus from municipal wastewater treatment plants (WWTP) are decreasing in the United States to the point where current biological nutrient removal technologies may reach the limits of removal capability[i]. Additional concerns regarding the need for reuse of treated wastewater in urban areas and application of reclaimed wastewater for aquifer recharge further support the goal of achieving high efficiencies of nutrient removal. There is a growing need for alternative and innovative wastewater treatment strategies that can increase the capacity of reclamation facilities to reach low effluent nutrient limits.

The precise process control essential for biological nutrient removal can be easily upset by fluctuations in raw wastewater quality, incoming pollutants and changes in environmental conditions. Highly efficient and sustainable treatment of nitrogen in municipal wastewaters is needed due to:

- Low effluent requirements and increasing regulations for nitrogen in reclaimed water discharged to surface waters.
- Energy requirements for aeration and amendments to maintain nitrogen removal are becoming major costs in wastewater treatment.
- Generation of the greenhouse gas N_2O from incomplete processes of nitrification and denitrification can contribute to climate change.

Nutrient recovery and removal efforts in municipal wastewater treatment currently require energy intensive operations to remove nitrogen, in addition to highly specific process control. Close to half of the energy required in a tertiary wastewater treatment plant can be due to aeration requirements for nitrification[ii]. New technologies using partial nitrification followed by anammox processes can achieve nitrogen removal in side streams at WWTP while requiring a fraction of the energy for aeration as compared to conventional nitrification and denitrification[iii]. Additionally, biofilm based treatment strategies, such as membrane bioreactors and biocarrier based treatment systems, have been developed[iv], although more studies and monitoring are needed to evaluate performance of these processes. New research on algal based tertiary treatment indicates the possibility of integrating nitrogen removal and algal lipid-based biofuel production, showing promise towards facilitating more sustainable wastewater reclamation. Nevertheless, such strategies will still be challenged to meet the effluent requirements in some states and require more pilot scale and optimization studies. Additional research towards optimizing these new strategies and technologies is necessary for widespread application of sustainable nitrogen removal.

A potential concern with maintaining nitrogen removal reliability is the susceptibility of nitrifying bacteria to contaminants and environmental stresses in WWTP. In cold regions the ability to meet low effluent requirements will depend upon maintaining activity of the temperature sensitive nitrifying organisms. Additionally, the increasing occurrence of emerging household contaminants such as pharmaceuticals and personal care products can stress or inhibit nitrification[v]. Increasing sustainability is also important, such as mitigating N_2O emissions from incomplete N removal and eliminating chemical additions, such as methanol for denitrification.

A Grand Challenge for Environmental Engineers today is to improve upon existing and recent advances in biological nutrient removal to implement and design operations that both limit energy and chemical input and provide reliable nitrogen removal capability. In addition to investigating new and innovative approaches to achieving lower effluent requirements for nitrogen removal in WWTP, a more watershed-based or holistic approach may include reducing non-point sources of nutrients as part of the overall plan for mitigating environmental impacts of nitrogen in surface waters.

---

[i] Bott, C. B., D. S. Parker, J. Jiminez, M. W. Miller and J. B. Neethling. (2012) WEF/WERF study of BNR plants achieving very low N and P limits: evaluation of technology performance and process reliability. *Water Sci & Technol* 65.5 808-815. DOI: 10.2166/wst.2012.949.

[ii]Tchobanoglous, G., F. L. Burton, H. D. Stensel. (2003) *Wastewater Engineering, treatment and reuse*. 4th ed. Metcalf & Eddy, Inc. McGraw-Hill, New York, NY.

[iii]Van Hulle, S. W. H., H. J. P. Vandeweyer, B. D. Meesschaert, P. A Vanrolleghem, P. Dejans, A. Dumoulin. (2010) Engineering aspects and practical application of autotrophic nitrogen removal from nitrogen rich streams. *Chem Engin J* 162, 1-20.

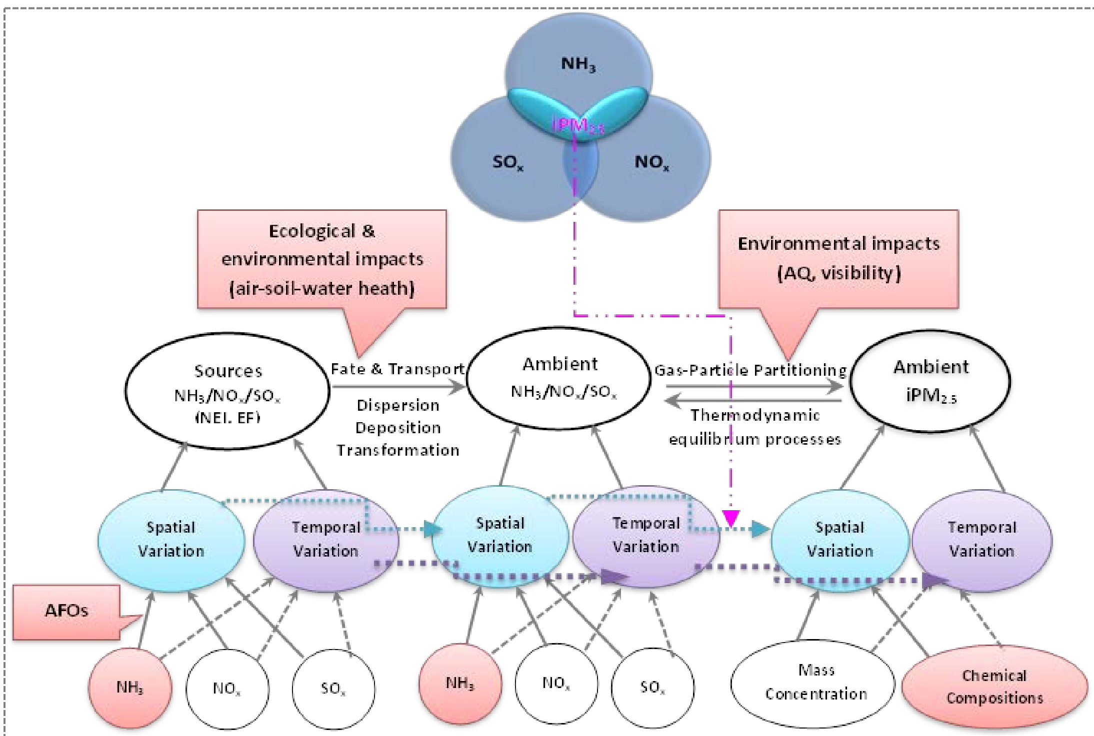
[iv]Martin, K. J., R. Nerenberg. (2012) The membrane biofilm reactor (MBfR) for water and wastewater treatment: Principles, applications, and recent developments. *Bioresource Technol* 122, 83-94.

[v]Schmidt, S., J. Winter, C. Gallert. (2012) Long-term effects of antibiotics on the elimination of chemical oxygen demand, nitrification, and viable bacteria in laboratory-scale wastewater treatment plants. *Arch Environ Contam Toxicol* 63, 354-364. DOI 10.1007/s00244-012-9773-4.

Ecological and Environmental Impacts of Fate, Transport and Transformation of Atmospheric Nitrogen

Lingjuan Wang Li, Associate Professor
Department of Biological & Agricultural Engineering, North Carolina State University

While providing meat, milk and egg to meet increasing demand for food, animal feeding operations (AFOs) contribute about 85% of national NH_3 emissions in the United States. A considerable amount of nitrogen ("N") is lost to the environment from AFOs. Although the scientific community has fundamental understanding of the "N" cycle, the reduced "N" form is the least known part of the cycle. As a reduced N species, ammonia (NH_3) is essential in ecology and in the environment. Ammonia emissions contribute to the formation of secondary inorganic fine particulate matter ($iPM_{2.5}$), and NH_3 depositions (dry & wet) contribute to the eutrophication of surface water and acidification of the ecosystem. The scientific understanding of the reduced "N" in the environment needs to be strengthened to develop decision support tools to assess ecosystem services and to quantify the dynamic exchange of "N" species (e.g., from NH_3 gas to ammonium NH_4^+ particulate) across air-soil-water interfaces. As shown in Figure 1, to develop a holistic understanding of the ecological and environmental impacts of atmospheric "N" fate, transport, and transformation, research should go beyond isolated single media studies on NH_3 emissions, deposition, and their impact on air, or soil, or water. Emissions, depositions and transformations of NH_3, acidic gases (e.g., NO_x, SO_x), and $iPM_{2.5}$ ions, responses of the soil & water properties should be investigated simultaneously through a multi-disciplines, multi-media approach.



Note: **$iPM_{2.5}$**: inorganic $PM_{2.5}$; **NEI**: national emission inventory; **EF**: emission factor; **AQ**: air quality; AFOs: animal feeding operations

Figure 1. Holistic pathway to the formation of secondary $iPM_{2.5}$ and its ecological and environmental impacts

The holistic research on emission, fate, transport, and transformation of atmospheric "N" will lead to new knowledge about (1) how atmospheric oxidized and reduced "N" concentrations change and how secondary $iPM_{2.5}$ are formed in response to agricultural NH_3 emissions; (2) depositions of gases and particulate "N" species and their impacts on soil and water properties. The new knowledge will allow ecologists, land managers, air quality modelers, and regulators to (1) assess agricultural NH_3 emission impact on ecosystem health; (2) validate atmospheric transport models; (3) estimate contributions of agricultural NH_3 emissions to ambient air quality and haze problem; (4) support development of decision-support tools for assessment of ecosystem services.

Treating water and wastewater utilizing sunlight

Qilin Li
Department of Civil and Environmental Engineering
Rice University

The sun is an enormous source of energy that is being actively exploited for electricity generation to power a myriad of applications. However, its use in water and wastewater treatment has been very limited compared to other fields.

In water and wastewater treatment, although electricity is necessary for pumping, many processes are driven by chemical reactions (e.g., advanced oxidation), photon (e.g., UV disinfection), thermal (e.g., distillation) or mechanical (e.g., membrane filtration) energy. Given the low conversion efficiency of commercial solar cells (14 – 19%) and the inevitable energy loss in generating heat and pressure using electricity, it seems that sunlight derived energy forms other than electricity from photovoltaic devices, e.g., light, photo-thermal, photo-chemical, may be utilized at higher efficiency when it comes to water and wastewater treatment. Utilization of these energy forms is aided by photocatalysts and photothermal materials that exhibit near unity quantum yield or photothermal conversion efficiency. Therefore, treatment schemes based on photocatalytic and photothermal processes can potentially have very high energy efficiency.

Kinetics of most (bio)chemical reactions used in water and wastewater treatment increases with increasing temperature. Unfortunately, heating water is highly energy intensive due to the large heat capacity of water. As a result, temperature, an important control parameter used in chemical engineering systems, has not been used in water and wastewater treatment. Advances in nanophotonics now allow us to generate highly localized and intense photothermal effects that can potentially be utilized to degrade recalcitrant contaminants.

Scientific research to more efficiently harvest sunlight through photochemical and photothermal conversion has great potential to realize high efficiency solar water treatment.

Control of Microbiologically Influenced Corrosion in Engineered Systems

Mengyan "Ian" Li

Postdoctoral Research Associate, Department of Civil and Environmental Engineering, Rice University

Corrosion of metal materials in engineered systems causes tremendous economic impairment to human society and severe unforeseeable contamination to the global environment. Despite the technical advancement of anti-corrosion (e.g., coating and alloying) for centuries, corrosion still presently costs approximately 3 % of gross domestic product (GDP) even in developed countries. A profound portion of the erosive damage is due to microbiologically influenced corrosion (MIC), particularly in anoxic environment with a neutral or basic pH value[1]. Sulfidogenic bacteria, a group of prokaryotic microorganisms that generate corrosive hydrogen sulfide by reducing sulfate and other formats of sulfur compounds, are typically recognized as the major culprits in the internal deterioration of pipelines or other important infrastructure for transportation and energy production. By coupling with other fermentative organisms, sulfidongenic bacteria tend to form biofilms that can accelerate the overall corrosion activity and enhance the resistance to excellular interference. The proliferation of sulfidongenic bacteria may also lead to other negative impacts causing severe water and safety issues, such as reservoir souring, pipeline plugging, and reduced product quality.

Increasing concerns on MIC and biosouring involving sulfidongenic bacteria have recently emerged during unconventional oil and gas production. Several previous studies using culture-independent tools have demonstrated that sulfidogenic bacteria belonging to the genus of *Halanaerobium* were found in a number of hydraulic fracturing fluids and produced water samples from shale gas extraction[2]. The ubiquity and dominance of the *Halanaerobium* bacteria suggests long-term unintentional *in situ* selection at the sites, since these thiosulfate-reducing organisms are known to utilize a large variety of carbon sources as electron donors and are able to grow and multiply in extreme conditions with high salinity, temperature, pressure, and presence of biocides. However, knowledge remains very limited regarding shale reservoir microbiology, which underscores the need for research to understand the metabolic mechanisms and communication schemes not only within archetype sulfidogenic bacterial strains, but also among complex microbial assemblages collected from representative environments. This research will provide substantial value for developing feasible and economical approaches to mitigate and minimize these undesirable microbial processes in engineered systems, especially in the areas of shale gas exploration and production.

1. Enning, D.; Garrelfs, J., Corrosion of Iron by Sulfate-Reducing Bacteria: New Views of an Old Problem. *Appl Environ Microb* **2014,** *80*, (4), 1226-1236.
2. Gaspar, J.; Mathieu, J.; Yang, Y.; Tomson, R.; Leyris, J. D.; Gregory, K. B.; Alvarez, P. J. J., Microbial Dynamics and Control in Shale Gas Production. *Environ Sci Tech Let* **2014,** *1*, (12), 465-473.

Sustainability at the Water-Energy-Environment Nexus

Shihong Lin, Civil and Environmental Engineering, Vanderbilt University

Our society has witnessed a population explosion and an unprecedented rise in living standard in the 20th century with concerning aftermaths that we carried on to the 21st century. We are now facing grand challenges that, if not addressed appropriately and timely, will profoundly compromise our and the future generations. Several of these grand challenges are of particular significance as they are essential to the functional operation of our society. These challenges include providing sufficient drinking water (which is also one of the 14 grand challenges proposed by the National Academy of Engineering), securing and managing our energy resources and exploring sustainable alternatives, and last but not least, protecting the environment. Addressing these challenges are not independent tasks as these problems are highly interrelated to each other. Therefore, it is necessary to take a systematic and holistic approach to address these problems not only within themselves but also at their interfaces. I propose an interdisciplinary grand challenge of securing our sustainability at the water-energy-environment nexus. This challenge include the following specific goals to achieve at the interfaces between three of our most valuable resources—water, energy, and the environment:

- Securing sufficient fresh water with minimal reliance on fossil fuels. This includes water treatment and desalination technologies that are either more energy efficient or powered by different forms of sustainable energy.
- Reducing the potential detrimental impacts of energy production on water resource and environmental quality. For example, develop effective management strategy (including treatment) to minimize the negative impacts of shale oil/gas production, of coal mining, on fresh water resource and air quality.
- Understanding the global and long-term impact of existing water and energy supply portfolio on our environment and resource sustainability. Exploring alternative portfolios from a system level to enhance the environmental sustainability of water and energy supply.

Achieving these specific goals can contribute to addressing the proposed grand challenge and ensuring that our society is steered towards a sustainable way of securing the most essential resources for future development.

Development of Highly Efficient and Cost-effective Advanced Oxidative Treatment for Potable Water Reuse

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINNERING AND SCIENCE IN THE 21ST CENTURY

Haizhou Liu

Department of Chemical and Environmental Engineering

University of California, Riverside

Water shortage has become a global crisis. This situation is exacerbated - and will continue to be so - by the global shrinkage of surface water sources, notably sharp decreases caused by extreme climate condition. We can here refer to the unprecedented and unrelenting drought that is currently taking places in the Southwest United States including California. Meanwhile, large populations have migrated to and grown in warm and arid regions. This shift in population and associated water demand make it extremely challenging and expensive to find high-quality fresh water sources from elsewhere.

Municipal wastewater reuse offers the potential to significantly increase the nation's total available water resources. Approximately 12 billion gallons of municipal wastewater effluent is discharged each day in U.S., which is equivalent to 27% of total public water supply. Reclamation of these effluent discharges would directly augment available drinking water resources. However, only about 10% of the effluent is actively reused nationwide. The major challenge to reclamation is the development of efficient and cost-effective purification process. Wastewater effluent is widely compromised by wastes produced from growing populations, industries and agriculture. In particular, our existing water treatment systems are poorly equipped to deal with contamination from trace organic chemicals including antibiotics, personal care products, algal toxins, petroleum hydrocarbon and solvent.

Advanced oxidative treatment provides a viable option to remove trace organic contaminants for water reuse. Prior studies were mainly focused on hydroxyl radical ($HO^{\bullet}$) based oxidation. $HO^{\bullet}$ is produced by UV activation of hydrogen peroxide (H_2O_2). However, $HO^{\bullet}$ based treatment may not be the best answer to the increasing demand on potable water reuse. First, the inherent low quantum yield makes the UV photolysis of H_2O_2 an energy intensive process. Second, $HO^{\bullet}$ is a non-selective oxidant that is often scavenged by effluent chemical matrices. Third, little is known about the degradation pathways of trace organic contaminants. It is very likely that $HO^{\bullet}$ oxidation can produce more toxic transformation products.

Other alternative radical based treatment may be better options, for example, using sulfate radical ($SO_4^{\bullet-}$) or chlorine radical ($Cl^{\bullet}$) based oxidation. However, these alternative treatment systems are still not widely adapted and facing many challenges. Anticipated key challenges include: (1) to optimize oxidant dosage and reduce transformation by-product formation; (2) to achieve high removal efficiency of organic contaminants in a variety of water chemical matrices; (3) to prevent the formation of potentially toxic transformation products; (4) to achieve lower energy consumption compared to other conventional treatment processes.

Grand Challenge in the 21st Century for Environmental Engineering Research

Jinyong Liu

Education and research for next-generation environmental technologies

Since new environmental challenges are emerging in a very fast pace, technical innovations are imperative. However, the fact we have to face (although many people might not want to admit) is that the current curriculum settings for civil engineering cannot equip undergraduate students with sufficient science knowledge to work on research frontiers in graduate school. It is sad to see that students with little or no chemistry/biology background will work in the environmental chemistry/microbiology field. They have to start with acid/base equilibrium and citric acid cycle or A-T C-G pairing at graduate school class while immediately starting their frontier research work! A common situation for environmental engineering students is that, they really need to increase their knowledge and skills while the heavy research load does not allow them to take adequate time to learn the advanced knowledge and flexibly apply the knowledge (versus following a protocol of established methods) for technology innovation. However, many countries outside US have the environmental engineering/science major for undergraduates. Will there be a change in US?

When it comes to graduation, it is difficult to find a relevant R&D job although the graduate research is under those categories. According to my own communication with a BASF chemists in “environmental catalysis” division, they do not hire an environmental engineering PhD doing catalysis work because “what they do at school is generally not what we want”. Are we really working on something at the cutting-edge so that the industry cannot catch up? No. We are taking what has been well developed by chemical engineering and chemistry, and conducting meticulous tests on trivial aspects. When new generation of environmental catalyst have been under development, we stay and carefully studies the mechanisms of some aspects of the old catalyst that can be overcome by the new generation catalyst. We fall behind. Why we have a slower action? Why environmental engineering research choose these directions that some graduate students feel frustrated about both its application potential and scientific attraction? What can be done to change this situation?

On the other hand, the pressure on high-end publication has shown some negative influence on research topics. When a promising technology is identified, the information cannot be immediately shared to the research community, partly because a high end journal requires “deep” mechanistic study. The publication has been automatically delayed because the researchers have to spend extra time to generate the elegant but possibly unnecessary data to fulfill this requirement. Some graduate students told me that when they want to get information on how to build a system, they search low-impact engineering journals for the direct help. Then they read the high-end journals just to learn what kind of “mechanistic studies” are conducted so that they can follow to publish a similar paper in the same high-end journal. Should we continue this mode? How much “elegant data” must be produced for a high-end journal for environmental engineering? When people have such a publication pressure, how many of them would like to focus on technology innovation rather than the “deep” studies on established system which are not that effective? Should such publication rule be adjusted to encourage real innovation?

I think these issues might be even more important than pointing out an environmental problem, because how environmental engineering scholars conduct research is the determining factor on how the real problems can be solved.

Food, Energy and Water Nexus

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINNERING AND SCIENCE IN THE 21ST CENTURY

Haizhou Liu

Department of Chemical and Environmental Engineering

University of California, Riverside

Water is the one of the most essential requirements for human survival, while we need food to assure our survival in the long run. The growth of food including vegetables and meat products consumes a large amount of water and generates a large quantity of water that needs to be treated. Typically, agriculture-impacted wastewater contains many chemicals of concerns. These chemicals include nutrients and emerging organic compounds. The most common nutrient is nitrate that is leached from irrigated water (NO_3^-). Elevated levels of nitrate have been observed in agricultural run-off and groundwater that is impacted by the run-off. A variety of pesticides have also been detected in these agriculture-impacted waters. In addition, in animal agriculture, the application of antibiotics (*e.g.*, from cow farms) resulted in the release of recalcitrant antibiotic organic compounds to the environment. What's more, as an important water resource for agriculture, the presence of trace organic contaminants (*e.g.*, hormones, antibiotics) in groundwater can impact the food quality if the contaminated water is used for irrigation.

Treatment of these contaminants in agriculture-impacted water is challenging. It calls for a cost-effective and efficient treatment technology that can be applied in a holistic approach. Examples of challenging issues include: (1) the capture and recovery of nitrogen from agricultural runoff; (2) new catalyst materials that can be synthesized and tailored to remove contaminants from waste stream with minimal energy foot print; (3) fundamental understanding of the input of water and energy during food production and during waste stream treament, thus to achieve energy-neutral treatment process.

Grand Challenge in the 21st Century for Environmental Engineering Research

Jinyong Liu

Soil Contamination

Soil contamination with heavy metals and toxic organics have been a serious problem worldwide. First, contaminated soils in large areas are used for agricultural production, and the contamination has not been mitigated. This is a global issue with billions of people under impact. Second, the detection and control measures are still rudimentary. Extraction of the target compounds from the soil matrix is very difficult, making the evaluation of contamination levels and remediation measures not highly reliable. The main practical remediation approach is soil replacement, however this method cannot be applied in a large scale, for example agricultural lands. Third, the information of soil contamination in certain countries is confidential, making it impossible to implement effective management, regulation and control.

Surface Chemistry in Drinking Water Distribution Systems and Water Quality

Haizhou Liu

Water distribution infrastructure – the pipes and pumps between the drinking water treatment plant and people's homes – is often considered to be a simple means of transmitting water to the public. However, it is often under-appreciated that the distribution system is a very complex system with many interactions among reactive components, including pipeline materials, residual disinfectants, trace organic chemicals and biofilms. These surface chemical processes impact water quality in ways that pose potential health risks and compromise the aesthetics of water. Much of our existing water distribution infrastructure has reached the end of its design life. Over the next several decades, there will be tremendous economic and societal pressure to manage water distribution systems more effectively to avoid adverse impacts on water quality caused by aging infrastructure.

The fundamental issue on drinking water distribution systems is related to the role of aquatic chemistry on water quality and the way in which this knowledge can be used to manage water infrastructure. Examples include the redox behavior of metals and adsorbed elements, interactions of these elements with residual disinfectants and the associated contaminant release. For example, metal release phenomena including chromium, arsenic, copper, lead and iron from many public water systems are still unresolved issues. Monitoring data from distribution system frequently showed changes of contaminant concentration between point of entry and maximal residence time in distribution system.

In the new era of water reuse, drinking water distribution systems are facing a host of new challenges. For example, more cities are exploiting new water sources with pronounced differences in composition relative to the water currently being sent through distribution systems. One example is the application of seawater desalination. Different levels of chloride, sulfate, and natural organic matter content between traditional and new water sources can cause disruption of chemical equilibrium at the water-solid interface of corrosion scales. Inadequate understanding of the microscopic surface chemistry can cause deterioration of water quality and compromise the efforts of producing high-quality drinking water in upstream treatment. These unanswered questions highlight the importance of developing new management strategies for water systems in response to changes of water chemistry attributable to alternative water sources.

A Case for Computational Modeling

Nancy Love

In the US we are not as proficient in training our students at computational modeling of the systems we are experimentally evaluating. At the simplest level, I see clearly that US graduates are not competent in general on wastewater process modeling. In Europe and to some degree in Asia, it is the opposite - they are highly proficient because the faculty are proficient on average. In the US, students aren't very proficient because, on average, the faculty are not proficient on average. Take it beyond wastewater process modeling and we are typically not training our students in modeling best practices. This is important because as we see the increasing complexities of the systems we are trying to evaluate or redesign or discover, computational models are a critical tool to help break down the complexity so that we can determine where to focus our research effort (what is important? where will the biggest impact be?). This is especially important for our non-computational, laboratory or field experimental efforts because they are much more expensive to execute. From my own experience, by not taking time up front to complete a computational assessment of the system we are considering, we often pick off an experimental piece that is not contextualized for us and may not be the most impactful (but may be the most intellectually interesting). In this way, we keep plucking off low hanging fruit or getting side tracked, and I fear that we do not come to the best solution or make the kind of progress as a profession that we should make to address these complex environmental issues. As more people want to incorporate mass/material balance-like models (like LCA, etc) into their analysis, they really shouldn't do that without coupling it with both uncertainty analysis, consideration of dynamic factors (temporal or spatial) and in-depth models of the components that are being assessed for the LCA. This requires a more sophisticated understanding of models and model integration which is, in itself, a bit of an art.

These comments are in the context that is not a modeler. But, increasingly, I am seeing the beauty of models and how they help us focus our work; so, I am working to improve my skill set and I see how much computational work (especially non-deterministic) has both been advanced in many disciplines and how helpful it is to framing problems so that a focused assessment toward solutions can be done.

In short, I think we need to beef up our core competency as a profession at computational tools to enhance our experiential space in our research activities. We are very science oriented and really very good at the deep scientific tools, as a discipline. We fall down (more so in the US) when it comes to integrating our experimental work with computational work, especially of the more complex systems that we increasingly want to evaluate.

Exploration, optimization and sustainability assessment of unconventional resource recovery from wastewater

Huijie Lu, Assistant Professor, University of Vermont

Municipal and industrial wastewater is increasingly recognized as valuable materials rather than wastes to be treated. High-value commodities, including carbon products (e.g., methane, biopolymers, biofuels and alginate), fertilizers, rare earth elements (REE) and plasmids can be recovered from either centralized or decentralized wastewater treatment utilities. Attempts so far to recover some unconventional but economically more attractive products, such as biopolymers, plasmids and REE are largely hampered by the lack of effective recovery technologies, inefficient quality management, and low marketability of the products. Some fundamental challenges associated with recovering these unconventional resources from wastewater, from a research perspective, include:

1. *Understanding microbial processes resulting in the production of unconventional microbial products from wastewater streams*

Recently, the recovery of various biopolymers, for example, alginate (a quick moisture absorber) and polyhydroalkanoates (PHAs, a precursor of bioplastics and materials used as 3D printing filaments) from wastewater biomass has been technologically proven. Microbial species, metabolic routes, and optimal growth conditions leading to the production of these microbial products have been widely investigated using pure microbes with commercially available compounds as substrates. However, a lot of the findings are not transferrable to resource recovery from complex wastewater streams and microbial communities. It is therefore important to better understand the microbial ecology of unconventional resource recovery processes by using traditional and high-throughput system biology approaches.

2. *Designing, engineering, and manipulating biological treatment processes toward enhanced pollutant removal and resource recovery*

Full-scale applications of many unconventional resource recovery technologies are at the embryonic stage, due to the low quality, productivity, and challenges associated with the separation of products (e.g. alginate, PHAs and plasmids) from bacterial biomass. Appropriate resource recovery approaches need to be developed and evaluated at pilot- or full-scale to find if unconventional resource recovery is a viable treatment alternative for facilities. In the meantime, these resource recovery units should not adversely affect the quality, or prohibit a designated use of treated water. Integrating biomass-based resource recovery into biological wastewater treatment process modeling is also critical to the design and upgrade of facilities.

3. *Assessing the sustainability of various resource recovery strategies to find the most sustainable solutions in a given geographic and cultural context*

Besides the technological and market penetration barriers, the lack of sustainability assessment and decision-making tools remains a challenge to identifying the most sustainable resource recovery solutions, especially for unconventional product recovery. Decisions need to be made for resource recovery facilities on a case-by-case basis by considering a number of economic, environmental and social-cultural criteria in a given geographic and cultural context.

Allison MacKay

AEESP Grand Challenges Statement

As we look to the future, the infrastructure to support societal activities will differ fundamentally from the conventional designs of today as a result of resource limitations, urbanizing growth patterns, and the need for resilience to both natural and man-made events of large impact. One example is the supply of municipal water with the emergent need to integrate water 'reuse' plans in many locations. Environmental engineers already have savvy technical solutions to supply product water for municipal needs; however, the challenge of social acceptability is still to be overcome. This situation highlights a **Grand Challenge in Environmental Engineering – appropriate contextual training for engineers** to integrate technical elements into larger trans-disciplinary solution strategies.

The training of engineers is often biased by a very solution-centric approach – here is a problem, design a solution – that belies the interwoven set of economic, policy and social factors[1] influencing technology implementation. While these other factors are recognized through the ABET accreditation process, they are usually addressed in program curricula through one-off offerings (e.g., guest lecturer) or general education lists of courses in other departments where concepts are presented in the framework of educating majors in those disciplines. Transferring and imbedding those concepts into engineering design decisions is beyond the skill set and experience of most young adults pursuing engineering degrees. Thus, the 'global, economic and environmental factors' assessment of senior design projects, for example, almost becomes an add-on at the end.

There is a need to create opportunities for deeper engagement with our social science colleagues to develop meaningful experiences to train engineers in economic, policy and social concepts within the context of engineering practice. This is particularly true in the case of environmental engineers who practice at the interface of people and societal institutions.

[1] Only 1 of the 14 NAE Grand Challenge descriptions explicitly recognizes these linkages, that is 'Access to Clean Water' which notes "technological solutions … must be implemented within [emphasis added] systems that recognize and address these inequities [power structures and access of high- vs low-income users]."

Novel analytical techniques to investigate ever-changing air quality

Dr. Aurelie Marcotte, Postdoctoral Researcher, Yale University

Outdoor air pollution is responsible for 3.7 million deaths annually. It is imperative to manage and regulate air quality to prevent aerosol related health issues, especially for people in urban areas and high risk populations. Particulate matter smaller than 2.5µm ($PM_{2.5}$) and ozone are the two major components of this air pollution; also known as photochemical smog. However, policy is inhibited by significant uncertainties in future climate models and energy use. These uncertainties are largely due to limitations in analytical instrumentation as well as changing energy needs. The largest impact on air quality appears to be changes in emissions (i.e. energy-related); therefore, it is vital that potential precursors to $PM_{2.5}$ and ozone are investigated. Yet, to study these precursors, developments in analytical characterization and measurements are necessary, especially for compounds that have been historically difficult to measure. There are two “grand challenges” embedded in this research topic. The first is continually increasing the capability of analytical instrumentation to better characterize emerging contaminants and by-products in the environment. The second is investigating emissions profiles (using enhanced analytical instrumentation) from current and future energy sources to better model future air quality and climate, and inform policy decisions.

References

Avise, J. et al. Attribution of projected changes in summertime US ozone and PM 2.5 concentrations to global changes. Atmos. Chem. Phys. 2009, 9, 1111–1124.

The importance of topic specific environmental engineering classes in undergraduate education

Dr. Aurelie Marcotte, Postdoctoral Researcher, Yale University

Topic specific environmental engineering courses are usually reserved for graduate studies, but I think undergraduate students would benefit greatly from these classes as well. The field of environmental engineering suffers from being grouped in with other engineering fields such as chemical and civil, which causes students to have course requirements that don't have a direct application to their field of study. Environmental engineering classes with a more specific focus on topics such as air quality, wastewater, soils, and contaminant fate and transport, would better prepare senior-level undergraduates for careers in industry, consulting, government, and graduate school. These classes would provide undergraduates with an in-depth understanding of the environmental systems they will be working on, preventing the "black box" mentality that seems to plague many engineers. One specific area that is lacking in environmental engineering education is a more in-depth understanding of chemical processes occurring in environmental systems. General and organic chemistry are part of the general requirements for engineering majors, but chemical education seems to stop there for undergraduate environmental engineers at a lot of universities. Topic specific environmental engineering classes would bridge knowledge gaps left unanswered in lower division chemistry courses, teaching classic engineering topics such as treatment and remediation in environmental systems from a chemical viewpoint. Topic specific classes provide more opportunities for undergraduate students to pursue personal interests and breaks down chemistry into applied sub topics. Topic specific undergraduate classes should especially focus on current environmental engineering problems and "hot" topics such as the increased use of nanomaterials and climate change.

Grand Challenges in Sustainable Environmental Management in the 21st Century

Valorization of Wastes

Alex Mathews

The 21st century will witness the largest human population on the earth competing for and consuming material and energy resources at an unprecedented rate. This increased consumption will result in an unprecedented amount of waste byproducts that must be managed properly. If we continue on our present path, large amount of energy and material resources will be required to meet the oxygen demands for the oxidation of carbonaceous wastes and ammonia, and material and energy resources for the removal of nitrate and phosphorous compounds from organic wastes from industrial and municipal wastewaters. At present, energy is expended to oxidize ammonia to nitrate and to denitrify nitrate to nitrogen gas. Then we turn around and take nitrogen from the air, and compress it with hydrogen at pressures ranging from 200 to 400 atmospheres to produce ammonia for use in anthropogenic activities. The Grand Challenge for environmental management in the 21st century will be to find processes that can be used for synthesis rather than decomposition of the complex compounds that are present in waste byproducts. Valorization of waste material should be a key theme for environmental management in the 21st century. At present, one of the biggest components of the operating budgets of municipal governments is the energy required to operate waste treatment facilities. Waste processing facilities must change from energy hogs to net zero energy consumers.

There are many avenues that need to be explored to achieve these goals. The currently available and new tools of molecular biology must be studied to identify consortia of bacteria or archaea that can be tailored to specific organic wastes to produce useful products such as biodegradable plastics (polylactate), biodegradable road deiciers, acetic anhydride, PVC, etc. Pyrosequencing and Q-PCR tools are available to identify and isolate specific organisms that can be used to optimize the synthesis of chemicals. Bioconversion processes that are robust (tolerate pH variations), have high productivity, high conversion rates (less waste), and produce product at a high concentration must be developed. Basic building block chemicals such as acetic and propionic acids can be produced at high concentrations using selective biocatalysts. Metabolic processes, pathways, and alteration of these pathways will need to be investigated to produce chemicals economically from wastes. Also, biocatalysts and processes that can generate biodegradable polymers such as pullulan, polyhydroxyalkanoate, polylactate, etc., must be investigated in addition to basic building block chemicals such as acetic acid.

One of the challenges in the valorization of chemical products from wastes is the low concentration of chemicals in the product streams. Advances in separations processes are needed to concentrate the waste stream and to concentrate the product stream. If the waste stream is concentrated to some extent, reactors can be operated more efficiently at lower costs. The use of robust ceramic and polymeric membranes, the development of charge selective membranes, and new advances in this area can lead to fruitful results. Nanotechnology tools can be used to increase chemical reaction rates and separation efficiencies. Interfacing nanotechnology with bioconversion processes in both increasing reaction rates and separation efficiencies must be studied.

One of the grand challenges of the 21st century will be to minimize the consumption of resources and to minimize the production of additional wastes such as greenhouse gases in the management of an unprecedented amount of wastes. Valorization wastes and net zero energy consumption should be one of the research, development, and implementation goals of the 21st century.

Two Grand Challenges Related to Sustainably Meeting Water Demand in an Energy Constrained World

How do we practically leverage the resource efficiency gains associated with utility-scale integration?

Meagan S. Mauter
Assistant Professor
Carnegie Mellon University

Meeting world demand for water and energy at manageable costs, while curbing greenhouse gas emissions, will require engineers and policy makers to prioritize resource efficiency. To date, the question has been how? Upstream efficiency gains in water and energy production have been modest and are often constrained by alternative objectives, such as improving water quality or reducing end costs to the consumer. Downstream interventions that promote resource efficiency at the individual consumer level have successfully reduced consumption but achieve significantly lower returns as demands harden.

One promising path forward is to cultivate municipal-scale efficiency gains through utilities integration. Utilities integration, defined here as the reclamation of rejected process effluent for another process input, offers an opportunity to cost-effectively improve efficiency without requiring significant changes in consumer behavior. Combined heat and power,[2] municipal solid waste to power,[3] biogas collection from wastewater treatment facilities,[4] and wastewater treatment and reuse as drinking water[5] each demonstrate the efficiency opportunities presented by material exchanges among drinking and wastewater treatment, municipal solid waste management, and power generation.

For instance, a great deal of recent research has focused on reducing the energy consumption of water desalination or wastewater treatment by using waste heat from the cooling water of electric power plants as the primary energy input.[6, 7] Rather than decoupling water and energy, however, these technologies introduce new modes of interaction and new constraints. The deployment of fully integrated water treatment and electricity generation systems will depend both on the efficiency, economic, and environmental benefits they offer, as well as on the urban infrastructure, regulatory, and sociopolitical interactions that facilitate their implementation.

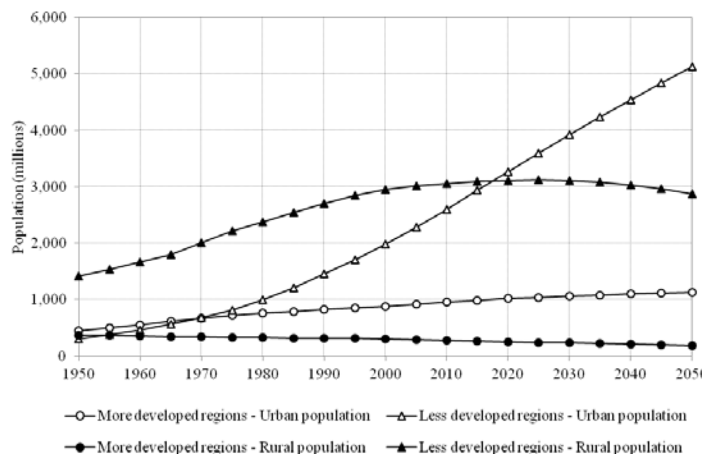
Indeed, cross-sectoral barriers, including siting constraints, incongruent scales of service, regulatory barriers, conflicting organizational objectives, and a desire for system simplicity have hindered the widespread implementation of integrated water and energy infrastructure in the United States. Lessons from failures of central planning in other domains would also suggest that a robust integrated network must prove itself resilient, open to innovation, tailored to unique regional needs, and adaptive in the face of risk. The magnitude of these barriers will remain powerful justification for the stand-alone design of complex engineered processes until holistic system assessment on the regional scale is feasible.

Two Grand Challenges Related to Sustainably Meeting Water Demand in an Energy Constrained World

How does the world sustainably meet the needs of a rapidly urbanizing population?

Meagan S. Mauter
Assistant Professor
Carnegie Mellon University

Supplying rapidly urbanizing developing regions with basic infrastructure services is a pressing challenge for the next 50 years. Figuring out how to design these systems so that they are adaptable, resilient, and sustainable is even more difficult. To tackle this challenge, we need to employ both bottom up observational tools and top-down decision support tools to help engineers and governments meet basic human services.



Our community needs to invest in "bottom-up" observational tools integral to understanding the context for these infrastructure services: the cultural, economic, and political preferences that need to inform the design process, as well as the innovation and adaptation tools that these urbanizing communities are already deploying. Doing so will require investment in collaboration with social scientists so that we have the tools to describe and design in a culturally appropriate manner.

We also need to develop "top-down" multi-objective decision support tools for designing hybrid formal and informal infrastructure networks that balance efficiency, adaptability, resiliency, cost, and sustainability. Doing so will require skills in acquiring (sensing), managing, and processing data; leveraging that data for infrastructure design and management; and applying these models as interactive communication tools.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century:
Identification and Quantification of Anthropogenic Sources as Regulations Evolve
Andrew May, Ohio State University

The middle portion of the 20th century was a critical time for environmental engineering and science in the United States (US) with legislation being passed to protect air, water, and land resources, ultimately resulting in the formation of the US Environmental Protection Agency (EPA). The EPA established National Ambient Air Quality Standards (NAAQS) to govern "criteria" pollutants (such as carbon monoxide CO, ozone O_3, and particulate matter PM) for the protection of human health and the environment; NAAQS are met, in part, due to emission standards, which regulate the quantity of pollutants emitted by given sources, and thus, can control primary emissions (e.g., CO and primary PM) and limit secondary pollutant formation (e.g., O_3 and secondary PM). These regulations were the impetus for the development of new vehicle technologies such as the catalytic converter and also resulted in reformulated gasoline, largely since there was an understanding that vehicular emissions contribute to the production of photochemical smog in urban areas.

Recent EPA regulations include the regulation of greenhouse gases (GHG) in collaboration with the National Highway Traffic Safety Administration which limits emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and is coupled to increasing corporate-average fuel economy (CAFE) standards. To address these regulations, the automotive industry and academic researchers are again investigating new vehicle technologies and alternative vehicle fuels. While these technologies and fuels successfully reduce CO_2 emissions, there are many uncertainties associated with other regulated emissions. For example, there is conflicting evidence in the literature related to the direction of change in emissions of hydrocarbons (HCs) and nitrogen oxides (NO_x) from compressed natural gas (CNG) light-duty vehicles (1–4). Furthermore, the general consensus is that PM emissions from gasoline-direct-injection (GDI) engines emit greater amounts of PM compared to conventional port-fuel-injection engines (5–8).

These uncertainties are even greater for "unintended consequences". For example, an increase in CNG use in Rio de Janeiro, Brazil, between 1998 and 2002 is thought to have caused ambient formaldehyde concentrations to increase by 20% yr^{-1} (9), which has implications for both human health and O_3 production. Furthermore, GDI vehicles have been demonstrated to emit larger numbers of particles, by up to an order of magnitude, compared to conventional gasoline vehicles (8, 10); particle number emissions are currently regulated in Europe due to their suspected greater impacts on human health. GDI vehicles also appear to emit greater quantities of polycyclic aromatic hydrocarbons (PAH) than conventional gasoline vehicles (10, 11). Finally, there have been no published efforts of which I am aware that considers the formation of secondary pollutants (e.g., O_3, PM) from these alternative fuel or emerging technology vehicles.

While this narrative describes one specific emission source, its main purpose is to frame the thought process, as the underlying principles can be likely be extrapolated to other sources (as well as other media such as soil or water) when a change in a process (e.g., fuel, technology, chemical) is utilized to mitigate an environmental concern. Vehicle emissions are, and should continue to be, of significant interest in scientific research due to their near-ubiquitous nature in the US and due to their continual evolution as fuels and technologies change. However, I recently read a review article entitled "Photochemical and Microbial Transformation of Emerging Flame Retardants: Cause for Concern?" (12). The authors of this article write that degradation products may be even more hazardous than the parent compounds, but there is a lack of existing evidence to draw strong conclusions on this statement, so there is a clear extension of this narrative to additional sources. Thus, the grand challenge question becomes "*Do the expected environmental quality benefits of a proposed (or already implemented) change exceed potential human health or climate risks?*" Hence, before we begin to promote "The Next Big Thing", we need to fully understand all consequences, no matter how insignificant they may appear to be. After all, carbonaceous PM is on the order of 0.01% of all carbon emitted from light-duty vehicles, yet these PM emissions are of growing concern.

References

1. Aslam M et al. (2006) An experimental investigation of CNG as an alternative fuel for a retrofitted gasoline vehicle. *Fuel* 85:717–724.

2. Jahirul MI et al. (2010) Comparative engine performance and emission analysis of CNG and gasoline in a retrofitted car engine. *Appl Therm Eng* 30:2219–2226.

3. Bielaczyc P, Woodburn J, Szczotka A (2014) An assessment of regulated emissions and CO2 emissions from a European light-duty CNG-fueled vehicle in the context of Euro 6 emissions regulations. *Appl Energy* 117:134–141.

4. Yao Z et al. (2014) On-road emission characteristics of CNG-fueled bi-fuel taxis. *Atmos Environ* 94:198–204.

5. Khalek IA, Bougher T, Jetter JJ (2010) Particle Emissions from a 2009 Gasoline Direct Injection Engine Using Different Commercially Available Fuels. *SAE Int J Fuels Lubr* 3:623–637.

6. Zhang S, McMahon W (2012) Particulate Emissions for LEV II Light-Duty Gasoline Direct Injection Vehicles. *SAE Int J Fuels Lubr* 5:637–646.

7. Maricq MM, Szente JJ, Adams J, Tennison P, Rumpsa T (2013) Influence of mileage accumulation on the particle mass and number emissions of two gasoline direct injection vehicles. *Environ Sci Technol* 47:11890–6.

8. Karavalakis G et al. (2014) Regulated Emissions, Air Toxics, and Particle Emissions from SI-DI Light-Duty Vehicles Operating on Different Iso-Butanol and Ethanol Blends. *SAE Int J Fuels Lubr* 7.

9. Corrêa SM, Arbilla G (2005) Formaldehyde and acetaldehyde associated with the use of natural gas as a fuel for light vehicles. *Atmos Environ* 39:4513–4518.

10. Samaras Z et al. (2005) *Characterisation of Exhaust Particulate Emissions from Road Vehicles* Available at: http://lat.eng.auth.gr/particulates/.

11. Matthias N et al. (2011) Particulate Matter Sampling and Volatile Organic Compound Removal for Characterization of Spark Ignited Direct Injection Engine Emissions. *SAE Int J Fuels Lubr* 5:399–409.

12. Chen D, Hale RC, Letcher RJ (2015) Photochemical and microbial transformation of emerging flame retardants: Cause for concern? *Environ Toxicol Chem* 34:687–699.

13. Bond TC et al. (2013) Bounding the role of black carbon in the climate system: A scientific assessment. *J Geophys Res Atmos* 118:5380–5552.

14. Guenther A et al. (2006) Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature). *Atmos Chem Phys* 6:3181–3210. Available at: http://www.atmos-chem-phys.net/6/3181/2006/ [Accessed December 19, 2013].

15. Saleh R et al. (2014) Brownness of organics in aerosols from biomass burning linked to their black carbon content. *Nat Geosci* 7:647–650.

16. Petters MD et al. (2009) Cloud condensation nucleation activity of biomass burning aerosol. *J Geophys Res* 114:D22205.

17. DeCarlo PF et al. (2010) Investigation of the sources and processing of organic aerosol over the Central Mexican Plateau from aircraft measurements during MILAGRO. *Atmos Chem Phys* 10:5257–5280.

18. Hennigan CJ et al. (2011) Chemical and physical transformations of organic aerosol from the photo-oxidation of open biomass burning emissions in an environmental chamber. *Atmos Chem Phys* 11:7669–7686.

19. Pfister GG, Wiedinmyer C, Emmons LK (2008) Impacts of the fall 2007 California wildfires on surface ozone: Integrating local observations with global model simulations. *Geophys Res Lett* 35:L19814.

20. Yokelson RJ et al. (2009) Emissions from biomass burning in the Yucatan. *Atmos Chem Phys* 9:5785–5812.

21. Akagi SK et al. (2013) Measurements of reactive trace gases and variable O3 formation rates in some South Carolina biomass burning plumes. *Atmos Chem Phys* 13:1141–1165.

AEESP Grand Challenges Workshop

Quantifying and Mitigating the Impacts of Environmental Antibiotic Resistance

Patrick McNamara, Assistant Professor, Marquette University

Antibiotic resistance is a serious health threat worldwide, and is defined as the ability of bacteria to survive (or not be inhibited by) a concentration of antibiotics which inhibits the majority of other cells. Antibiotics are extensively used in medicine to treat or prevent bacterial infections in humans and animals. Each year in the United States, over 2 million people are infected by antibiotic resistant bacteria, resulting in greater than 25,000 deaths. The cost of managing antibiotic resistance in this country is estimated to be higher than $50 billion annually. The associated financial cost has increased because bacteria are perpetually acquiring mechanisms to fight against antibiotics. Bacteria acquire antibiotic resistance genes (ARGs) on transferred genetic material that originates from other bacteria. Hospitals, wastewater treatment plants, animal farms, and effluent streams from each of these sources are all hotspots for dissemination of antibiotic resistant bacteria into the environment.

While antibiotic resistance is known to arise in pathogenic strains of bacteria, the relationship between antibiotic resistance in the environment and human health is not well defined. The scientific community has been able to demonstrate where antibiotic resistant genes are present in the environment. Now, it is imperative to understand how environmental conditions impact the spread of environmental antibiotic resistance. What are the sub-inhibitory levels of antibiotics and antimicrobials that select for resistance? Furthermore, are there environmental conditions that can assuage the spread of environmental antibiotic resistance? By understanding more about the conditions that select for resistance we can determine where to target efforts to control the spread of resistance, i.e. hospital effluents, wastewater treatment plants, animal farms. Moving forward it is crucial to quantify how environmental antibiotic resistance directly impacts bacteria to which humans are exposed. Quantitative risk assessment models, similar to those used in quantitative microbial risk assessment, are required to help determine how the spread of environmental antibiotic resistance is linked to antibiotic resistance that directly harms human health. We know that the environment contains a stronger resistance profile in human-impacted areas, but to protect public health we need to quantify the risk of environmental resistance on human health. With these data policy can be made to assuage the spread of antibiotic resistance and prolong the use of antibiotics.

References

CDC, US Department of Health and Human Services (2013) “Antibiotic Resistance Threats in the United States.”

Berendonk et al. (2015) “Tackling antibiotic resistance: the environmental framework” *Nature*, 13, 310-317.

Global N-cycle: challenges and opportunities for environmental engineers and scientists

Yujie Men

Eawag, Swiss Federal Institute of Aquatic Water Science and Technology, 8600 Dübendorf, Switzerland

The increasing anthropogenic activity leads to global changes in many aspects. One of them is the global nitrogen cycle (N-cycle). The use of nitrogen fertilizers in agriculture, organic nitrogen from meat processing, and nitrogen oxides (NOx) from combustion and vehicle emissions are among the major anthropogenic nitrogen sources in soil, water and air. The different forms of nitrogen generated from human activities, together with the naturally present ones can be converted from one to another through both abiotic and biological processes. The biological processes include nitrogen fixation, ammonification, nitrification, denitrification, and so forth that largely carried out by environmental microorganisms. During the past two decades, our understanding of N-cycle and the involved microorganisms has been advanced dramatically. The discoveries of ammonia oxidizing Archaea, anaerobic ammonia oxidizing (anammox) bacteria had altered the previous understanding, and brought in more complex networks in the current N-cycle. Each of the breakthrough findings in the N-cycle inspires biotechnology innovation in environmental engineering applications, such as wastewater treatment. Nitrification/denitrification or anammox have been successfully applied to remove nitrogen nutrient in both domestic and industrial wastewater. The potential formation of NO and N_2O from denitrification made us to reevaluate and redesign our current wastewater treatment technologies. Nowadays, the mysteries of microorganisms involved in N-cycle are even being further unraveled by the more recent discovery of Bacteria/Archaea responsible for anaerobic methane oxidation coupled with nitrite/nitrate reduction (denitrifying anaerobic methane oxidation, DAMO), linking the global N- and C- cycles. Undoubtedly, these findings will bring great opportunities for not only new recognition of global cycles on earth, but also the development of sustainable environmental biotechnologies. In the meanwhile, we are also facing challenges: 1) the enzymatic pathways and intermediates during anammox and DAMO processes are still not fully understood, hence lack of fundamental guidance for engineering application; 2) there are also technical hurdles of implementing the concept into environmental engineering practice; 3) the unprecedented increase of global change requires more research on microbial response in the N-cycle and the interactions between N- and C- cycles. There might be even more unknowns on the way.

Time for reinventing environmental engineering research and education under more interdisciplinary circumstance?

Yujie Men

Eawag, Swiss Federal Institute of Aquatic Water Science and Technology, 8600 Dübendorf, Switzerland

One consequence of the global change in the natural and built environments is an increased interdisciplinary nature of the research and education in the field of environment engineering and science (EES). The boundary between EES and the other primary disciplines such as biology, chemistry, physics, social science, becomes more and more blurry. This is reflected by 1) increasing demand of expertise from other primary disciplines to carry out in-depth research in EES; 2) more and more researchers from other primary disciplines are conducting projects related to EES individually (or cooperatively). I would like to bring up the following challenges caused by the more interdisciplinary feature of EES for discussion:

1. For scientific research: what roles should environmental engineers/scientists play in the interdisciplinary work to solve more complex or global environmental problems (e.g. global cycles, climate change, renewable energy, etc.)? How to collaborate with colleagues inside and outside environmental engineering, in order to maximize the outcome? What expertise should they bring in and what expertise should they borrow from the outsiders? How much of knowledge from primary disciplines should they master, in order to fulfil their roles?

2. For undergraduate and graduate education: does the current curriculum for EES students meet with the need for interdisciplinary research sufficiently? If not, how should we improve or even reform the EES curriculum accordingly, in order to arm EES students with the expertise required by the future interdisciplinary tasks in both academia and industry?

Selective Removal of Trace Contaminants in Wastewater Reuse

Baoxia Mi

Assistant Professor, Civil and Environmental Engineering Department

University of Maryland, College Park, MD 20742

One of the grand challenges in Environmental Engineering and Science in the 21st century is to ensure water safety in wastewater or storm water reuse by selectively removing trace water contaminants. Dwindling water resources and increasing water demands have forced us to consider treating water from non-traditional sources (e.g., wastewater, storm water) that may contain contaminants typically overlooked in conventional water treatment. Besides, new water contaminants (e.g., metals, pharmaceuticals, endocrine disrupting compounds or EDCs) are constantly emerging with the rapid advancement in various fields such as pharmaceutical and agricultural industries. Many of these emerging contaminants have potential adverse health effects and thereby have raised severe public concerns over water safety. However, they are often small in size and thereby cannot be successfully removed by traditional water treatment technologies.

Advanced treatment technologies (e.g., adsorption, advanced oxidation, membrane filtration) are potential strategies to remove the emerging contaminants from water, among which membrane processes are one of the most effective technologies to achieve almost complete removal for most contaminants. For example, unlike adsorption and advanced oxidation that are capable of removing only certain groups of contaminants, the nanofiltration and reverse osmosis membrane can achieve high removal of both emerging contaminants and almost all existing contaminants. However, a dilemma exists for today's membrane-based water separation: reliance mainly on size exclusion may attain a stable, high rejection rate but the energy requirement can be enormous.

Therefore, it is very desirable to enable new contaminant removal mechanisms (e.g., optimized selectivity, photodegradation) in membrane processes so that contaminants can be adequately removed without unduly decreasing membrane pore sizes (hence increasing energy demand). Resolving these difficulties calls for synthesis of new membranes or surface modification of existing membranes that (1) use facile, easier to scale-up procedures involving low-cost, environmentally benign raw materials and (2) enable multiple mechanisms for significantly improved removal of water contaminants.

White Paper

Impacts of Climate-induced and Anthropogenic Changes in Dissolved Organic Matter in Water to Engineered Water Infrastructure Systems and Socioeconomic Environments

Daisuke Minakata
Department of Civil and Environmental Engineering
Michigan Technological University

Within the planetary boundaries for global freshwater use (< 4,000 km^3/year of consumptive use of runoff resources [Rockström et al., 2009]), water footprint of humanity per capita and total water consumption will have to be significantly decreased. For example, in order for the water footprint of humanity as a whole not to grow under the United Nation's medium population scenario, the average water footprint will have to be decreased from 1385 m^3 in 2000 to 835 m^3 in 2100 [Hoekstra and Wiedmann, 2014]. In addition to quantitative measures, climate change and associated consequences, urbanization, population increase, and changes in landuse patterns would affect the water quality significantly. Dissolved organic matter (DOM) is one of the important water quality measures because it contains natural organic matter from natural environments, soluble microbial product from human engineered systems, and anthropogenic organic chemicals from human activities. The uncertainty about degree of changes in DOM presents tremendous challenges to next generation water infrastructures dealing with water reuse at different scales. Furthermore, impacts to socioeconomic environments are not well understood and have to be quantitatively measured.

To quantify the overarching impacts of DOM, the natural environmental system should be coupled with both the engineered water infrastructure and the socio economic environment. First, the changes in DOM in natural environments should be quantified at various scales and regions and need to be predicted under the various future climate change scenarios. This includes consequences from temperature rise, atmospheric carbon and nitrogen deposition, drought, and increased precipitation. Second, the impacts of DOM to water infrastructure systems should be understood and predicted (treatability of DOM and fate of chemicals in water treatment processes). Third, impacts of social behaviors and economic activities need to be understood and associated consequences have to be predicted. This includes public acceptance of risk, cost, toxicity, and public preference, as well as economic impacts, energy, and policy. Then, three components should be combined to understand the interactions among them at different scales. The scales include watersheds, states, nationals, hemispheres, and global. Once we quantify the impacts from each system and those interactions, we should be able to identify how to address the global and local water scarcity issues (e.g., water conservation, technological solutions to maintain the quality of DOM, human consumption and production behavior).

Rockström, J.; Steffen, W.; Noone, K. et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society*, 2009, *14*(2), 32.
Hoekstra, A.Y.; Wiedmann, T.O. Humanity's unsustainable environmental footprint. *Science*, 2014, *344*, 1114.

Coupling Ab initio Calculations and Experiments in Environmental Engineering

Daisuke Minakata
Department of Civil and Environmental Engineering
Michigan Technological University

Environmental engineering research and applications have helped us understand many phenomena in engineered human systems and natural environment based on the traditional laboratory-scale experiments to full-/field-scale observations. Mathematical and mechanistic models have been developed to investigate, understand, design, and predict the processes based on fundamental principles and theories combined with experimental observations. While this approach has been successfully applied to discover numerous unknown phenomena, environmental engineers are always aware of the limitations of analytical capabilities, data scarcity, and difficulties in finding consistent outcomes. Complexity in the systems presents further challenges in understanding numerous interactions.

Ab initio calculations have been emerging to play important roles in environmental engineering applications. Advancement of high performance computational initiatives and development of many sophisticated computational suites make it feasible to examine chemical physical reactions at molecular levels in various phases. For example, ab initio nano reactor showed new molecules and mechanisms without preordained reaction coordinates or elementary steps (Wang et al., 2014). First-principles computer-based kinetic model attempted to predict toxic byproducts from oxidation of chemicals of emerging concern in advanced oxidation processes (Guo et al., 2014). Ab initio computational chemistry calculations provide high-throughput screening of materials to select functional materials for water treatment and energy harvesting technologies. All of these ab initio studies highlight the emergence of theoretical and computational chemistry as a tool for discovery and provide new mechanistic insights into what is happening at molecular levels. Outcomes from ab initio calculations will help us identify what to be investigated in the future experiments and provide critical information about the experimental design. Priori assessment will save a number of time-consuming experiments and hazardous chemicals in the experiments. There will be numerous potential areas that can be applied (e.g., complex atmospheric, aqueous, solid, and interfacial chemical physical chemical phenomena), where traditional experiments are not able to touch. It is important to know the limitations about the state-of-art approaches and the outcomes must be validated with the experiments.

Wang, L-P.; Titov, A.; McGibbon, R.; Liu, F.; Pande, V.S.; Martínez, T.J. Discovering chemistry with an ab initio nanoreactor. Nature Chemistry. 2014, DOI: 10.1038/NCHEM.2099.

Guo, X.; Minakata, D.; Junfeng, N.; Crittenden, J.C. Computer-based first-principles kinetic modeling of degradation pathways and byproduct fates in aqueous phase advanced oxidation processes. Environ. Sci. & Technol. 2014, 48(10), 5718-5725.

Impacts of Climate-induced and Anthropogenic Changes in Dissolved Organic Matter in Water to Engineered Water Infrastructure Systems and Socioeconomic Environments

Daisuke Minakata
Department of Civil and Environmental Engineering
Michigan Technological University

Within the planetary boundaries for global freshwater use (< 4,000 km3/year of consumptive use of runoff resources [Rockström et al., 2009]), water footprint of humanity per capita and total water consumption will have to be significantly decreased. For example, in order for the water footprint of humanity as a whole not to grow under the United Nation's medium population scenario, the average water footprint will have to be decreased from 1385 m3 in 2000 to 835 m3 in 2100 [Hoekstra and Wiedmann, 2014]. In addition to quantitative measures, climate change and associated consequences, urbanization, population increase, and changes in landuse patterns would affect the water quality significantly. Dissolved organic matter (DOM) is one of the important water quality measures because it contains natural organic matter from natural environments, soluble microbial product from human engineered systems, and anthropogenic organic chemicals from human activities. The uncertainty about degree of changes in DOM presents tremendous challenges to next generation water infrastructures dealing with water reuse at different scales. Furthermore, impacts to socioeconomic environments are not well understood and have to be quantitatively measured.

To quantify the overarching impacts of DOM, the natural environmental system should be coupled with both the engineered water infrastructure and the socio economic environment. First, the changes in DOM in natural environments should be quantified at various scales and regions and need to be predicted under the various future climate change scenarios. This includes consequences from temperature rise, atmospheric carbon and nitrogen deposition, drought, and increased precipitation. Second, the impacts of DOM to water infrastructure systems should be understood and predicted (treatability of DOM and fate of chemicals in water treatment processes). Third, impacts of social behaviors and economic activities need to be understood and associated consequences have to be predicted. This includes public acceptance of risk, cost, toxicity, and public preference, as well as economic impacts, energy, and policy. Then, three components should be combined to understand the interactions among them at different scales. The scales include watersheds, states, nationals, hemispheres, and global. Once we quantify the impacts from each system and those interactions, we should be able to identify how to address the global and local water scarcity issues (e.g., water conservation, technological solutions to maintain the quality of DOM, human consumption and production behavior).

Rockström, J.; Steffen, W.; Noone, K. et al. Planetary boundaries: Exploring the safe operating space for humanity. Ecology and Society, 2009, 14(2), 32.
Hoekstra, A.Y.; Wiedmann, T.O. Humanity's unsustainable environmental footprint. Science, 2014, 344, 1114.

Landfills Fire Detection, Monitoring and Management

Rouzbeh Nazari
Department of Civil and Environmental Engineering
Rowan University, Nazari@Rowan.edu

Problem Statement

Landfills are the most common and oldest method of organized waste disposal. During past decades, the amount of waste collected and processed in the United States was gradually increasing. At the same time the nature of the waste disposed in landfills has changed towards more hazardous material arising safety concerns all around the country. One of particular important landfill issues is fires that may occur both at active and closed landfills. Large amounts of toxic and harmful chemicals released as a result of a fire contaminate air, soil and water and hence present a considerable risk to the public health. About 8,400 landfill fires occur yearly in the United States. The US Federal Emergency Management Agency (FEMA) reports millions of dollars in yearly damages to the properties (vehicles, structures, etc.) caused by landfill fires. In case of Bridgeton, Missouri landfill fire, over quarter billion dollar has been spent without any progress in controlling the fire. Landfill fires attract significant public attention and present a challenge for the fire services to extinguish. Damage to the leachate collection system (if present) or to the geo-membrane liner of the landfill due to a fire may result in the release of toxic elements into the surrounding soil and groundwater. Landfill fires and associated environmental pollutions are particularly important issues in human and socioeconomic health of the region. In most cases these fires go unnoticed for many years since they are can initiate internally through pyrolysis. Timely landfill fire identification, warnings and management leading to the prevention of the fire or its extinguishing at early stage is critical for the public wellbeing and for minimizing environmental pollution and other associated damages related to these fires.

REFERENCES

[1] P. Foss-Smith. *Understanding landfill fire* [Online]. Available: http://www.waste- management-world.com/articles/print/volume-11/issue-4/Features/understanding-landfill- ires.html

[2]"Towards Improved Fire Management in Landfill Sites," Fire Services Commissioner Victoria, Victoria, Canada, Rep. July 2012.

[3] "Landfill Fires, Their Magnitude, Characteristics, and Mitigation," Federal Emergency Management Agency, 2012

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY
AEESP 2015 Conference

Grand Challenge: Adapting Urban Infrastructure to Enhance Sustainability and Resilience

Rob Nerenberg, Associate Professor, Civil and Environmental Engineering and Earth Sciences, University of Notre Dame

The global population has increased dramatically over the past fifty years, with major urbanization: over half of the world's 7 billion people now live in cities. While the effects of population growth on sustainability are well known, the increased urbanization presents additional challenges and opportunities.

Cities are major consumers of food, water, energy, materials, and products. In turn, they produce of solid, liquid, and gaseous wastes. The management of inputs and wastes requires energy and sophisticated networks of power, transportation, water supply, storm water management, and waste management. Most of these networks were designed when resources (e.g., water, energy) were abundant, with little concern for sustainability. They also were designed for past climate conditions. Key infrastructure, including sanitary and storm water infrastructure, should be modified to improve sustainability as well as resiliency against climate change.

The need for adapting infrastructure comes at an interesting time. ASCE reports that the civil and sanitary infrastructure in the US needs a major overhaul, due to age and lack of upkeep. This provides an opportunity to re-think and reconfigure urban infrastructure to enhance sustainability and resilience. This may be true for other industrialized countries, while developing countries may benefit from new paradigms for urban infrastructure.

Future research should explore how adapt infrastructure to meet human needs (food, water, shelter, energy, transportation, education, work) with increased sustainability. Researchers need to think "outside the box," bringing together the social sciences (e.g., sociology, psychology, urban planning, architecture, education, business) with science and engineering. Together, these groups should explore technical options and identify research needs for improving urban wellbeing, sustainability, and resilience.

Environmental engineers can contribute with measures such as

- Decentralized treatment and reuse of wastewater
- Resource recycle within the city (e.g., nutrient recovery, industrial recycle)
- Urban agriculture and aquaculture
- Urban energy production (e.g., waste to energy, wind, solar, biomass)
- Advanced network management with sensing (e.g., smart valves on storm water systems, real-time monitoring of water demands, incentives not to consumption during peak hours)
- Advanced technologies to minimize water contaminants and gaseous emissions (e.g., urine recovery and treatment, anaerobic wastewater treatment)

Harmful Algal Blooms and the Challenge of Managing Complex Ecological Systems

Daniel R. Obenour and Tarek N. Aziz, North Carolina State University

A harmful algal bloom (HAB) occurs when algal growth reaches levels that produce negative consequences for ecosystems and society. These negative consequences can be direct or indirect, acute or long-term. Some HABs, such as the 2014 *Microcystis* bloom leading to a drinking water ban in Toledo, Ohio, produce toxins that can sicken humans and other animals. While toxins are a particularly salient problem, even non-toxic blooms can have severe consequences. HABs typically reduce the aesthetic and recreational value of water bodies, and they exacerbate the accumulation of organic matter, known as eutrophication. Eutrophication degrades ecosystems through an intensification of dissolved oxygen depletion, often leading to hypoxia; and it degrades public water supplies through increased treatment costs, taste and odor issues, and the formation of carcinogenic disinfection byproducts.

Water quality in the United States has generally improved since the passage of the Clean Water Act in 1972, largely through improved treatment of municipal and industrial waste discharges. However, diffuse (nonpoint) sources of nutrients are proving more difficult to control, especially with increases in population and agricultural production. Further, the synergistic impacts of nonpoint source pollution and climate change are conspiring to increase the prevalence the prevalence of HABs throughout much of the world (Taranu et al., 2015).

Civil and environmental engineers have long been tasked with the protection of water resources, and thus have a large role to play in HABs prevention and mitigation. Lakes, rivers, and estuaries can be thought of as the 'next' series of reactors, processing pollutants downstream of our cities, farms, and wastewater treatment facilities. In the anthropocene, we control these natural reactors based on how we manage flows and nutrient loads, and how we alter the internal chemical and hydrodynamic properties of these systems, through algaecides or artificial mixing, for example. However, ecological systems are notoriously difficult to manage and predict, due to the non-linearites associates with system feedbacks and ecological regime shifts (Duarte et al., 2009). As such, our environmental models must be enhanced to capture more of the relevant biophysical processes acting on these systems. Engineers can work with ecologists to learn more about, for example, how different algal species compete based on variable growth rates, light sensitivities, and motilities. These factors can then be included within mathematical models to better predict how these systems will respond to various engineering options. At the same time, it must be recognized that ecological systems are subject to numerous inherent uncertainties that are unlikely to be resolved in the near future (Robson, 2014). As such, the decidedly deterministic modeling framework that is used in most engineering applications (including traditional water quality modeling) should be over-hauled to reflect a more probabilistic reality. And, uncertainty quantification needs to move beyond just the variability in natural forcings, to also include the uncertainty in observational data, parameter estimation, and even model formulation. It appears unrealistic and undesirable to engineer ecological systems to completely eliminate HABs. However, it seems quite possible to engineer systems to have a lower probability of HABs, and thus produce a better outcome for society and the environment.

References:

Robson, B. J. (2014). When do aquatic systems models provide useful predictions, what is changing, and what is next? Environmental Modelling & Software, 61, 287-296.

Taranu, Z. E.,et al. (2015). Acceleration of cyanobacterial dominance in north temperate-subarctic lakes during the Anthropocene. Ecology letters, 18(4), 375-384.

Duarte, C. M., et al. (2009). Return to Neverland: shifting baselines affect eutrophication restoration targets. Estuaries and Coasts, 32(1), 29-36.

Transforming environmental engineering via breakthroughs in environmental molecular science

Environmental molecular science is making revolutionary progress in understanding pollutant interactions with environmental interfaces and in studies of environmentally relevant reactions. Recent advances, enabled by new synchrotron radiation sources at the DOE National Labs, such as NSLS-2 at the Brookhaven National Lab (BNL), can deliver unprecedented levels of special and temporal resolution for many traditional and new spectroscopic techniques. Moreover, the recent push by DOE to develop *in-situ* microscopy and spectroscopy techniques can now enable studies of environmental processes and remediation technologies under conditions close to environmentally relevant ones. For example, our group is now using the latest generation of Transmission Electron Microscopy (TEM) capable of studying samples under different gaseous and even liquid environments. This is a truly groundbreaking development as in the past we could only image samples under vacuum, which was irrelevant to environmental conditions. Another example of transformative capability of synchrotron radiation sources is our work on X-ray synchrotron tomography of biochar, which is an inexpensive soil additive produced by heating agricultural waste in the absence of oxygen. This work, highlighted this month on the cover of the ACS Energy and Fuels Journal, helps to clarify the impacts of biochar porosity on water retention/transport, pesticide adsorption and soil remediation. Whereas the BNL NSLS-1 facility had impressively small (1 µm) resolution for the X-ray tomography measurements, the newly opened NSLS-2 has finally sub-µm resolution. Incorporation of atmospheric and high pressure cells with new capabilities of heating and cooling samples, while utilizing both synchrotron and other modulated or pulsed light sources, can now clarify mechanisms of fast reactions with a detection limit of down to one molecule. Some of the new microscopy techniques are now operating at atomic resolution, with capabilities of imaging bond formation of a single molecule. These are incredibly exciting developments, which have been already utilized to solve industrially relevant problems, such as design of better catalysts for chemical and energy industries Although most of the techniques mentioned above are not routinely used in environmental labs, there is no doubts they will be making a tremendous impact on both fundamental and practical aspects of environmental engineering. These new instruments, open to university community via user proposals, will revolutionize many aspects remediation technologies, design of novel membranes and adsorbents, and many other environmental areas.

References:

Jones, K., Ramakrishnan, G., Uchimiya, S., Orlov, A. "New Applications of X-ray Tomography in Pyrolysis of Biomass: Biochar Imaging*", Energy and Fuels*, 2015, 29, 1628.

Developing a Resource Budget for the Water Energy-Food-Nexus

Authors: Juan Fausto Ortiz Medina and Jonathan Julian Moreno Barbosa
North Carolina State University

Population growth and rising living standards will increase global demands for water, food and energy, which are already used beyond the point of sustainability (UNC Water Institute, 2014). Each of these resources is inextricably interconnected in what is called the Water-Energy-Food Nexus (Hoff, 2011). Although the Nexus has been well described, its inherent complexity makes finding a solution a difficult task.

The challenge is large: food demand will increase 70% by 2050, primary energy needs will increase by 50% by 2035, and in 2030 demand for water will exceed global availability by 40% (UNC Water Institute, 2014). Even though these needs are interconnected, institutions handling them are compartmentalized (World Commission on Environment and Development, 1987). For example, it is quite common for a ministry of food and ministry of energy to exist, yet they rarely communicate and cooperate even less. As a result, externalities are not considered and problems are shifted rather than solved, as in the cases of water desalination energy demand (Tsiourtis, 2001) or the high water demand for beef production (Gerbens-Leenes et al., 2013).

Although significant work has quantified current and future resource demands, sustainable use rates have yet to be described. While there are many efforts to produce more efficient processes, there are no well-developed quantifiable efficiency targets. This is analogous to someone knowing that they are spending more than they earn, but only resolving to vaguely ‘spend less’. In that situation, a budget is needed. The same holds for managing the Nexus; we do not have widely accepted estimates of how much of each resource we can sustainably ‘spend’, making it difficult to rationally develop solutions. Thus, we propose this grand challenge: To establish a ‘water ceiling’ budget which quantifies sustainable use at regional and global levels and which uses a common unit unifying water, energy, and food demands.

Such a water ceiling would allow a context in which to evaluate resource challenges. For example, instead of vaguely targeting ”increased efficiency” for thermoelectric cooling, which accounts for 39% of US fresh water withdrawals (Feely et al., 2008), it would be possible to set a specific goal requiring that thermoelectric cooling must be made more efficient by *X*, otherwise the water ceiling will be violated. A person with a concrete budget knows exactly how much they can spend before entering a grocery store; without a spending limit, they may feel they are doing fine by spending 20% less, but still surprisingly (to them) end up in debt. In much the same way, we can move on from ‘being more efficient’ to knowing exactly how efficient with Nexus resources we must be.

The integrated nature of the budget will also prevent problem shifting – either between resources or regions. By incorporating global and regional water ceilings, such inequitable situations can be more easily avoided. Indeed, a well-developed system may not only prevent exploitive practices, but encourage efficient resource transfers.

Finally, a well-developed water budget complements research to determine the most effective social programs encouraging efficiency. Although in the absence of a budget it is still possible to determine if, say, tax credits on water heaters result in better resource efficiency than tiered water rates, incorporating a budget would allow us to determine if either program is sufficient and, if not, how much more efficient it must be.

References

Feeley, Thomas J., et al. 2008. Water: A critical resource in the thermoelectric power industry. *Energy* 33(1): 1-11.

Hoff, H. 2011. Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm.

Gerbens-Leenes, P., Mekonnen, M., Hoesktra, A. 2013. The water footprint of poultry, pork and beef: a comparative study in different countries and production systems. *Water Resources and Industry* 1(2): 25-36.

Tsiourtis, Nicos X. 2001. Desalination and the environment. *Desalination* 141(3): 223-236.

World Commision on Environment and Development. 1987. *Our Common Future*. Oxford: Oxford University Press

Sustainability of critical elements: Challenges and opportunities in e-waste recycling

Paramjeet Pati, email: param@vt.edu

Precious metals and rare earth elements (REEs) wield great influence over societal prosperity and environmental sustainability. A nation's prosperity depends on successfully developing, adopting and implementing next-generation technologies. These technologies in turn are intimately tied to the reliable supply of several precious metals and REEs. These critical elements are also integral to the development of green energy technologies such as photovoltaics, fuel cells, and permanent magnets used in wind energy generation. However, our planet's endowment of these critical elements is finite. Uncertainties about their availability loom large as our desire for sustainable growth and development clashes with the realities of our limited resources and their unsustainable consumption.

In the past, humanity's efforts for mining and extracting critical elements have been embroiled in environmental catastrophes and social conflicts. Today, with much of our planet's critical material endowment residing above the ground - in the electronic gadgets in our cars, on our desks and in our pockets - access to such concentrated amounts of precious metals and REEs has never been easier. At the same time, recovering these critical elements from electronic waste (e-waste) is quite difficult.

The sustainability challenges we face today with regard to e-waste are multi-level, complex and systemic. Environmental challenges are intimately intertwined with socio-economic issues; the two cannot be addressed in isolation. For example, consumer electronics from *developed* nations are unsafely dismantled (often by underage workers in ill-equipped recycling facilities) in *developing* nations. Global e-waste traffic and trade creates both environmental challenges and societal inequities. Social impacts of e-waste cannot be captured in analyses that focus solely on environmental indicators, thus requiring the development of more sophisticated metrics and models.

To effectively tackle sustainability challenges for critical elements, environmental and societal metrics need to be complemented with market strategies, economic incentives and novel entrepreneurial initiatives. **The grand challenge for sustainability of critical elements and e-waste management is to tackle the intertwined environmental, societal and economic issues simultaneously.** It is therefore necessary to address these issues through an interdisciplinary framework, global stewardship efforts and a collective vision.

The Grand Challenges Workshop is an ideal platform to discuss and brainstorm ideas for tackling some of the key issues related to this global challenge, as outlined below:

Technical challenges	▪ Prioritize which metals should be recovered based on their criticality ▪ Identify sources of high value e-waste streams ▪ Design for easy dismantling of electronics goods in their end-of-life phase ▪ Thermodynamic analyses for assessing recyclability of critical elements from e-waste ▪ Anticipatory life cycle assessment of recycling approaches
Societal challenges	▪ Equitable distribution of the costs and benefits associated with critical elements trade ▪ Social life cycle assessments (S-LCAs) of transboundary e-waste traffic and trade
Market-based approaches	▪ Environmental rating systems and positive recognition for products using recycled critical elements ▪ Setting up material flow cycles that keep critical elements in circulation within specific industries/economies (e.g., platinum leasing programs for fuel cells) ▪ Economic incentives to guide e-waste recycling behavior of consumers and to encourage corporate take-back policies
Policy innovations	▪ Allocate critical elements to meet critical needs, and for uses that are most amenable for recycling ▪ Identify latent demands for products and services to safeguard against potential macroeconomic rebound effects that may undermine the sustainability of critical elements despite increases in material use efficiency ▪ International policies and intergovernmental collaborations for global stewardship of critical materials and e-waste management.

Key references:

1. Alonso, E. et al. Evaluating Rare Earth Element Availability: A Case with Revolutionary Demand from Clean Technologies. Environ. Sci. Technol. 46, 3406–3414 (2012).
2. Stone, R. Confronting a Toxic Blowback From the Electronics Trade. Science 325, 1055–1055 (2009).
3. Dahmus, J. B. & Gutowski, T. G. What Gets Recycled: An Information Theory Based Model for Product Recycling. Environ. Sci. Technol. 41, 7543–7550 (2007).

Sustainable Buildings

Jordan Peccia, Associate Professor, Yale University, jordan.peccia@yale.edu

The impact of buildings on environmental and human health is profound. Residential and commercial buildings account for 40% of U.S. energy consumption, which produces at least 35% of green house gas emissions. The majority of domestic wastewater and treated drinking water is produced and consumed in residential buildings. The indoor environment is central to human contaminant exposure. Adults and children spend more than 90% of their time indoors where the majority of a human's inhalation, contact, and ingestion exposures occur. Although a traditional and narrow interpretation of the environment has meant outdoors, any serious effort toward improving human and environmental health must consider the built environment. **The sustainable design and operation of buildings is a grand challenge for environmental engineers and scientists in the 21st century.**

Improving building sustainability will allow environmental engineering research to evolve in two important ways. **First**, building design involves choices in water and energy use. Thus buildings are the sources of many subsequent air and water quality problems that environmental engineers have traditionally addressed. Focusing on sources, rather than emissions monitoring and cleanup, will force environmental engineers to become more heavily involved in prevention and green design. **Second**, the private nature of residential and commercial buildings requires environmental engineers to work on solving problems that are not mandated by regulations, but rather by economic and health-based drivers of sustainability.

Some specific building sustainability challenges include the following:

- Preventing the deterioration of drinking water quality in premise plumbing;
- Designing building materials that inhibit microbial growth and do not off-gas hazardous chemicals;
- Determining how building design, operation, and occupancy influences childhood exposure to beneficial microbes and prevents the development of immune-system disorders;
- Designing and operating buildings to reduce the more than 1 billion yearly cases of respiratory infections and to alleviate symptoms ascribed to allergenic disease and asthma;
- Designing buildings to reduce water and energy consumption, and greenhouse gas and wastewater production;
- Developing ways to better ventilate buildings while reducing energy consumption;
- Understanding the impacts of climate change on indoor air quality and human health.

Grand Challenge: Empowering Sustainable Design Choices Through Policy

William Pennock

May 1, 2015

As constraints on water supplies, power grids, and government funds are growing, it is important that designs for water and wastewater treatment plants become optimized to efficiently use available resources. Research is continually being conducted to ensure that the capabilities of treatment technology grow with the increasing demands on it. In a time where great innovations and even disruptions are needed in treatment technology, there is reason to be concerned that dated legislation may hinder adoption of new technologies. Older standards, some based on an empirical understanding of treatment processes, may be limited in their allowance of new approaches to treatment. There is a need, then, for policy to be responsive to new ideas. Rather than blocking progress, legislation can promote the dissemination of new technologies through responsible advocacy of them. A more proactive approach to regulating treatment technologies will be required for meeting the future water and wastewater needs of our communities.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY AEESP 2015 Conference

Grand challenge: Innovative Processes for Waste Water Treatment Adapted to Different Scenarios

Patricia Pérez, PhD student, Civil and Environmental Engineering and Earth Sciences, University of Notre Dame

Both, the shortage of water and the standards of water quality, imply an important technological challenge to overcome. This opens an opportunity for innovation in the field of treatment and reuse of wastewaters. Nowadays, waste-water treatment (WWT) processes have to face common problems as for example the increase in energy consumption derived from more strict requirements in water quality, the excess sludge production and the potential environmental risks and impacts. In addition, we need to consider some specific problems derived from different scenarios such as: massive displacements of people, limitation of hydric resources, agricultural waste water etc.

The new challenges regarding the sustainable use and reuse of the hydric resources, substantially condition the conception, design and operation of new WWT plants. It is necessary to develop and implement new technologies to conceive flexible WWT plant adapted to different scenarios, depending on its location, size of the plant, destination of the final effluent etc, and taking into account the priority for recovering valuable products and water reuse. Therefore, many objectives should be considered by designers at the same time (e.g. economic, environmental, technical, legal) to select treatment alternatives.

Many WWT plants do not fully exploit their potentials, reaching low treatment efficacies and assuming high operational costs, especially regarding energy consumption. The main reasons for this are the inappropriate design of the plant, which normally follows a general scheme without being adapted to each particulate situation, the lack of appropriate operational and control strategies and the inadequate training of the plant operators.

Effective and adequate wastewater treatment is specially complex for small communities and decentralized treatment, where the limitation of economical status of the receiving media, social perception, seasonal effects and tourist interest are among the specific criteria that will affect the decision to select the most appropriate technology. It is also necessary to reach an optimal balance between the simplification of the process management and the level of instrumentation to guarantee the flexibility, automation, and reliability of the treatment systems.

Submission to:
"GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY"

TITLE:
Geoenvironmental engineering and emerging challenges in the energy sector

May 1, 2015

Contributors:
Catherine Peters, Princeton University
Andres Clarens, University of Virginia
Young-Shin Jun, Washington University of St. Louis
Brian Ellis, University of Michigan
Lauren Beckingham, Lawrence Berkeley National Lab
Ian Bourg, Princeton University

Environmental engineers are needed to play a leadership role in the emerging areas of energy and environment of the subsurface. The subsurface environment is critical in the transition to a sustainable energy future, as in hydraulic fracturing of shales, enhanced geothermal energy production, and geologic carbon sequestration. These technologies present opportunities to mitigate climate change, but they have created new environmental challenges. They require vast quantities of water, they can lead to contamination of groundwater resources, and they may inadvertently release potent greenhouse gases like methane. In all cases, there is a critical need to understand the environmental implications of developing these resources, minimize risks, and ensure the resilience of our energy systems. Increasingly, these activities are being characterized by the new name "geoenvironmental engineering."

Examples of emerging subsurface energy technologies that present new environmental challenges and place demands on scarce water resources include:

- hydraulic fracturing of shales
- geologic carbon sequestration
- production of oil/tar sands
- nuclear waste disposal
- deep injection of hazardous wastes
- intermittent energy storage in the subsurface

New scientific research questions derive from our need to understand, measure, characterize, and predict geo-environmental processes and their roles in controlling reactivity, mass transfer and flows, and geophysical properties of subsurface environments. Examples include interactions between hydraulic fracturing fluids and shales that enable gas extraction but may also mobilize hazardous substances; clay mineral migration that can serve to trap waste streams or impede resource extraction; mineral dissolution and precipitation that alters and adaptively manipulates permeability and wettability of subsurface fluids; and mineralization reactions that lead to long-term sequestration of CO_2 and other substances.

Grand Challenges in Environmental Engineering: Optimal Strategy for Ameliorating the Consequences of Climate Change

George Pinder

If, for the sake of argument, **we assume that global warming is inevitable**, then, at best, we will be able to forestall, prepare for, and manage its consequences. In this case, **the intellectual and practical challenge shifts from prevention to one of forecasting, evaluating and mitigating impact**. The grand challenge thus has three components; 1) to simulate the hydrological consequences of global warming at a scale that is meaningful from the perspective of human behavior (forecast), 2) to translate the forecasted hydrological behavior into plausible risk to human health, man-made structures and the environment and to quantify this risk (evaluation) and 3) to take the action required to reduce risk to a level deemed acceptable from a societal perspective (mitigation).

Forecasting the hydrologic impact of warming at the global scale is achieved via comprehensive monitoring networks combined with global climate models which currently have a horizontal resolution on the order of only 100km (grid block size). Behavior modeled below this scale requires downscaling which is very difficult but very important to forecasting. Thus it is the first element of this grand challenge.

Evaluation of the risk of hydrological behavior on human health, man-made structures and the environment not only requires forecasting of forces and plausible consequences, but also the probability of these consequences occurring. This is the area of risk assessment, and although well known in many areas of engineering, application of this methodology to climate-related impacts on human health, man-made structures and the environment is very limited. Adaptation of risk-based methods to address these potential impacts is a second element of this grand challenge.

A third and very important element of this grand challenge, is identification of the intervention that can take place today to avoid catastrophic consequences in later years. Decision analysis addresses this issue and has many components. Two of these involve optimization and are especially germane. One optimization methodology addresses the creation of optimal designs for projects and facilities to accommodate the impacts of climate change. Involved is the creation of engineering and activity based designs that achieve specified goals given a series of physical or management constraints. The other optimization methodology optimally controls a series of ongoing events or activities as they occur.

The insight provided by the decision analysis methodology outlined above yields the best strategy to build, retrofit, or otherwise respond, so as to protect human health, man-made structures and the environment under the impact of global warming. However, to utilize this quantitative approach requires mathematical tools, such as numerical modeling and linear, non-linear and multiobjective optimization along with an enormous amount of both objective and subjective data. To obtain this data requires 1) a degree of communication between various data collectors that does not currently exist and 2) a common data repository that is generally accessible to researchers and decision-makers. This is the final element of this grand challenge.

On a Strategy for Integration of Analyses of Food, Water and Energy

George Pinder, University of Vermont

While food, water and energy can be investigated separately, the open question is how to study all three as a system. One approach is to use a multiple-objective optimization approach.

In the simplest case, optimization involves minimizing (or maximizing) an objective function by changing the values of decision variables constrained within a predefined range (constraints). Success is achieved when the decision variable values that optimize the objective function are realized.

In the case of problems wherein water, food and energy are interdependent, there would be three-objective functions and sets of constraints, one for food, another for water and yet another for energy. However, the values of these objective functions and constraints could be interdependent if the decision variables in energy, for example, were to appear in models describing water and food.

Let us consider a simple example. Assume we wish to use groundwater to irrigate an apple orchard. Assume there are three optimization problems involved: 1) how to provide the maximum amount of pumped water for irrigation while maintaining minimum groundwater elevations (water), 2) how to maximize the quality of the apples constrained by the amount of water available (food) and 3) how to minimize the amount of energy needed to pump the groundwater constrained by pump efficiency (energy).

Each of the above problems has an objective function and a set of constraints. Each can be solved alone provided each is independent. However, they are not independent, the quality of the apples depends upon the available water and the amount of energy used depends upon the pumping strategy. Thus we have three problems that are interdependent and we want an overall optimal strategy.

To achieve this goal there must be compromise. Each solution must give a little for the benefit of all three taken together. There are several ways to do this. One way to do this is to combine the objective functions into one using a weighted sum. The weights are established by a human decision maker.

The multi-objective optimization has provided the mechanism to address the seemingly intractable problem of selecting optimal strategies for three completely different but interdependent objective functions. However, this approach is predicated on the availability of models that will forecast the behavior of these variables in systems of concern. In other words, we need not only the optimization methods, but models that will describe how the objective function of one problem will respond to changes in the decision variables in another. For example how much more water can be obtained using an additional unit of energy.

In summary, the multi-objective optimization approach provides the intellectual glue needed to solve seemingly disparate problems when the overall problem involves them all.

Grand Challenge

Valentina Prigiobbe
Stevens Institute of Technology, Department of Civil, Environmental, and Ocean Engineering, Castle Point on Hudson, Hoboken, NJ, U.S.A.

Two are the grand challenges in environmental engineering and science I would like to highlight, one in education and one in research.

The first challenge is in the background of environmental engineers. As it is now I think the education does not always allow to approach problems in a classical/rigorous way, i.e., similarly to other engineering disciplines. In many environmental engineering problems, solutions are drawn from simplified theories. This simplification does not help understanding and more importantly does not help interdisciplinary collaborations. Environmental issues where physics and/or mathematics is necessary for finding a solution might be investigated by a team of experts, but also by an environmental engineer or scientist, who sees the problem, urges to solve it, and can understand it possibly also through interdisciplinary collaborations. However, often fundamental concepts in environmental engineering are simplified to the point that it is difficult to understand the original theory and therefore open an interdisciplinary dialog.

The second challenge is in environmental engineering and science research. It concerns the prediction of the transport of emerging contaminants (ECs) in the subsurface. Particularly, in urban areas, where subsurface water might need to be exploited in the near future. However, due to past and current anthropogenic stress because of industrialization and urbanization, this water has been significantly contaminated. ECs are materials or chemicals that might threat the human health and/or the environment, lack health standards, or their paths to humans have only been observed, recently. They includes organic molecules, metals, and nanomaterials and their chemical and physical behavior during transport is not well understood. The study of fundamental chemical and physical mechanisms occurring during the migration of ECs in the subsurface is strongly affected by interfacial processes such as adsorption and desorption and dissolution and growth. This processes evolve throughout a multiscale domain and depend on the crystal structure of the rock and its mineralology, the solution composition, the flow conditions, and the heterogeneity of the porous medium. Combination of computational tools for flow and chemistry, mathematical modeling of flow and transport coupled with experiments might allow to build a solid framework. The necessary tools and methods might be already even partially be developed in physics, material science, and chemistry as well as in geosystems and process engineering, but they should be rediscovered, integrated, and further developed to study the behavior of a large range of ECs in the subsurface environment.

Grand Challenge

Valentina Prigiobbe
Stevens Institute of Technology, Department of Civil, Environmental, and Ocean Engineering, Castle Point on Hudson, Hoboken, NJ, U.S.A.

Two are the grand challenges in environmental engineering and science I would like to highlight, one in education and one in research.

The first challenge is in the background of environmental engineers. As it is now I think the education does not always allow to approach problems in a classical/rigorous way, i.e., similarly to other engineering disciplines. In many environmental engineering problems, solutions are drawn from simplified theories. This simplification does not help understanding and more importantly does not help interdisciplinary collaborations. Environmental issues where physics and/or mathematics is necessary for finding a solution might be investigated by a team of experts, but also by an environmental engineer or scientist, who sees the problem, urges to solve it, and can understand it possibly also through interdisciplinary collaborations. However, often fundamental concepts in environmental engineering are simplified to the point that it is difficult to understand the original theory and therefore open an interdisciplinary dialog.

The second challenge is in environmental engineering and science research. It concerns the prediction of the transport of emerging contaminants (ECs) in the subsurface. Particularly, in urban areas, where subsurface water might need to be exploited in the near future. However, due to past and current anthropogenic stress because of industrialization and urbanization, this water has been significantly contaminated. ECs are materials or chemicals that might threat the human health and/or the environment, lack health standards, or their paths to humans have only been observed, recently. They includes organic molecules, metals, and nanomaterials and their chemical and physical behavior during transport is not well understood. The study of fundamental chemical and physical mechanisms occurring during the migration of ECs in the subsurface is strongly affected by interfacial processes such as adsorption and desorption and dissolution and growth. This processes evolve throughout a multiscale domain and depend on the crystal structure of the rock and its mineralology, the solution composition, the flow conditions, and the heterogeneity of the porous medium. Combination of computational tools for flow and chemistry, mathematical modeling of flow and transport coupled with experiments might allow to build a solid framework. The necessary tools and methods might be already even partially be developed in physics, material science, and chemistry as well as in geosystems and process engineering, but they should be rediscovered, integrated, and further developed to study the behavior of a large range of ECs in the subsurface environment.

Advancing Environmental Engineering Paradigms to Address the Problem of Antibiotic Resistance. Amy Pruden, Professor, Virginia Tech, Blacksburg, VA

Antibiotic resistance is poised to be one of the greatest public health challenges of the 21st Century. For over fifty years, quality of life and overall life expectancy has made a quantum leap, in large part because of the advent of antibiotics. However, we now stand at a cross roads, where antibiotic resistance has been steadily spreading, making more and more infections essentially untreatable. The U.S. Centers for Disease Control recently made a conservative estimate that 2 million Americans suffer, and 20 million die per year as a result of antibiotic resistance (CDC, 2013). Notably, it was pointed out that the majority of these infections now arise in the community, not in hospitals. Notably, The White House recently issued an executive order to develop a national action plan for comprehensively combatting antibiotic resistance (The White House, 2015), making the present moment particularly opportune to address antibiotic resistance as a Grand Challenge in environmental engineering.

Environmental engineers are uniquely poised to help address the problem of antibiotic resistance. Over the past decade, research conducted around the globe has built a consensus, making it clear that there is an environmental dimension to the spread of antibiotic resistance. In particular, it is now well-documented that wastewater treatment plants and livestock facilities are key reservoirs of antibiotic resistant bacteria and antibiotic resistance genes (ARGs). Likewise, it is apparent that ARGs become elevated in soil and water bodies influenced by wastewater treatment plant and livestock inputs.

The grand challenge, however, is that antibiotic resistance does not fit within the current environmental engineering paradigm for understanding pathogen fate and control. Firstly, antibiotic resistance is imparted by ARGs (i.e., segments of DNA), which can be shared among bacteria via horizontal gene transfer. Thus, the fate of the DNA may be as important as the fate of the host organism. Likewise, treatment technologies aimed at inactivating pathogens may not be sufficient for controlling antibiotic resistance, rather, destruction or removal of the DNA may be the optimal approach. Further, there is evidence that traditional disinfection strategies, such as chlorination, could make antibiotic resistance worse under some circumstances by selecting for antibiotic resistant organisms. Antibiotic resistance also poses a challenge for microbial risk assessment models. This is because non-pathogenic bacteria, and even extracellular DNA can be important because of the potential to transfer ARGs to pathogenic bacteria, which does not fit the standard dose-response framework. Finally, detection and monitoring technologies are needed, ranging from accessibly pipelines for analyzing complex metagenomics data sets to simple and economical sensor-based technologies to enable rapid monitoring of key targets.

These are but a few of the challenges environmental engineers will face in addressing antibiotic resistance. However, the need for environmental engineers to take on these challenges will only intensify as antibiotic resistance continues to worsen and as we take on the need to re-build and re-tool our water infrastructure for sustainability. Combatting antibiotic resistance should be considered as a critical part of the design of water treatment and distribution efforts.

References:

The U.S. Centers for Disease Control. 2013. Antibiotic Resistance Threats in the United States, 2013. http://www.cdc.gov/drugresistance/pdf/ar-threats-2013-508.pdf

The White House. 2015. National Action Plan for Combatting Antibiotic Resistant Bacteria. March, 2015 https://www.whitehouse.gov/sites/default/files/docs/national_action_plan_for_combating_antibotic-resistant_bacteria.pdf.

Harmonizing Green Engineering with Emerging Public Health Concerns

Amy Pruden, Marc Edwards, Peter Vikesland, Linsey Marr, Virginia Tech, Blacksburg, VA

Engineering for sustainability is most certainly THE overarching grand challenge in environmental engineering for the 21st Century. The water-energy nexus is a core feature of sustainability, calling for water conservation and reuse. Accordingly, a boom in both intellectual and capital investment in green engineering is currently underway and accelerating. It is predicted that within 10 years the annual global market for energy efficient building products will reach $623 billion and that green material use for U.S. construction alone will exceed $256 billion, with about half of new non-residential construction classified as green. **While such investments are admirable and important, we urge that public health concerns be considered as an integral component of green engineering. Further, it is equally critical that claims of water and energy savings be confirmed and validated.**

While environmental engineering has traditionally served as a pillar of public health, since the time of typhoid, new challenges are emerging that must be addressed as we undertake major investments to retool our infrastructure. We are beginning to recognize that certain aspects of the built environment may unintentionally enhance exposure to toxic chemicals and pathogens. In particular, the U.S. Centers for Disease Control, the National Research Council, and others now acknowledge that opportunistic pathogens, such as *Legionella pneumophila*, *Mycobacterium avium*, and *Pseudomonas aeruginosa*, have become the leading cause of waterborne disease and death in developed countries. Opportunistic pathogens pose a major challenge because they are established as part of the microbial ecology native to the environment of potable water distribution systems. As such, traditional disinfection strategies intended to control fecal pathogens are ineffective. Antibiotic resistance also represents an emerging and cross-cutting challenge for pathogen control in water distribution systems. There is a growing body of evidence that the water environment is likely a key factor in the spread of antimicrobial resistance, and that treatment of wastewater, drinking water, and water intended for reuse may serve as critical control points. Research is needed to advance the science of water treatment and distribution to proactively alleviate concerns regarding the potential to contribute to the spread of antimicrobial resistance. Finally, in an era of alarm over the prospect of emerging infectious disease, such as the recent Ebola outbreak, water systems need to stand ready to respond to new information on disease control. For example, current research led by Marr and co-funded by NSF and WERF seeks to fill a critical knowledge gap regarding the potential for Ebola to be spread via toilets, sewage conveyance, and sewage treatment.

As we forge new territory in advancing green infrastructure, it is absolutely critical that public health research keep pace with emerging public health concerns. For example, while water and energy conservation are essential goals, it must be recognized that longer residence times of water and air in their respective systems will present opportunities for microbial growth, exposure, and associated public health risks. Likewise, recent research on devices intended for water conservation, such as hands-free faucets, has indicated a tendency to harbor *L. pneumophila* and *P. aeruginosa*. Given the stakes that are at play, recycled water systems should be challenged to go beyond meeting traditional criteria for establishing microbial water quality, but also strive to address concerns such as antibiotic resistance. Perhaps the most alarming of all is recent research, led by Edwards, revealing that some “green” water systems now required by code actually waste more energy and water than their conventional counterparts. Thus, the urgency is clear that public health research must keep pace with advances in green engineering in order to avoid unintended public health consequences.

Crop Yield Gap Minimization with Integrated Water and Energy Sustainability

Chittaranjan Ray, University of Nebraska

Overview and Objectives

A growing population, coupled with higher calorie intake and energy use per capita, is increasing worldwide demand for food. Researchers and international agencies are currently working to delineate areas with large gaps between current yields of major crops and potential maximum yields, which are called "yield gaps." The yield gap atlas is a tool for (1) identifying the areas with the greatest potential to increase current production, and (2) targeting research and investment more efficiently. Solutions for closing the yield gap are site-specific and may include use of better crop cultivars; appropriate management of nutrients and irrigation water; and adequate control of weeds, diseases, and insect pests. Intensely cropped areas draw a significant amount of power during summer irrigation, which conflicts with urban and industrial demand. The current yield gap estimates do not consider the effect of nutrient loss and crop protection chemicals on surface and groundwater or other ecological issues such as stream depletion. This leads to ***the goal for this project***, which is to develop an integrated optimization framework for maximum food production within the context of groundwater availability for irrigation, minimization of groundwater level changes, stream flow depletion, and energy conservation. Toward that end, ***four objectives*** will be pursued: (1) develop and revise a crop model that can be applied to a large area to predict potential yield of a cereal crop and to examine water nutrient balance on a daily basis; (2) develop a hydrologic model to predict groundwater level changes due to irrigation pumpage and associated stream flow depletions, and to estimate nitrate loading and nitrate fate in the aquifer on a long-term basis; (3) develop a model to predict energy consumption and costs for irrigation pumpage; and (4) develop a stochastic optimization framework to maximize food production within the constraints of water, energy, and environmental sustainability addressed by the three models.

Intellectual Merit

The ongoing quest for increased food production calls for the long-term sustainability of production systems to be addressed using models, big data, and sensor technology. This includes estimating crop nitrogen requirements and maximum yield for irrigated and non-irrigated land, addressing the impact of intensive production on the quality of surface and groundwaters, assessing the ability of local aquifers to supply the needed water and the associated depletion in stream flows, optimizing alternative power input to the grid to balance demand amongst residential, industrial, and irrigation users, and addressing the impact of droughts and climate variability on reducing the yield gap. This work will be first to contribute a series of validated models optimized for solving real-world problems. Uncertainty bands in each of the modeling systems are used to develop robust solutions to the linked set of problems.

Broader Impacts

The research results will have worldwide implications, as an increase in field crop productivity will reduce world hunger and increase the nutrition and health of all people. Policymakers at local, state, and federal levels can use these findings to implement targeted incentives aimed at improving the quality of life for human beings, while balancing long-term agricultural productivity and economic growth objectives with environmental concerns. The work is truly interdisciplinary and will involve students and STEM professionals from engineering, natural sciences, and agriculture.

Grand Challenges - Management of Municipal Solid Waste

Debbie Reinhart* and Stephanie Bolyard, University of Central Florida
Nicole Berge, University of South Carolina

According to the USEPA (2014), the U.S. produced 251 million tons of municipal solid waste (MSW) in 2012, although some sources suggest that the amount may be much greater. Globally, it is estimated that 1.3 billion tonnes of MSW were generated in 2010 and that value is projected to increase to 2.5 billion tonnes per year by 2025 (Hoornweg and Bhada-Tata, 2012). The collection, processing, and disposal of MSW potentially leads to adverse environmental impacts, undesirable land uses, and reduced housing values. Increasing urbanization magnifies these impacts as the population densifies and local disposal options (i.e., landfills) become limited.

On the other hand, MSW can be considered to be a commodity that, if managed properly, can provide positive environmental and economic benefits to a community. Examples of waste-derived resources include the following:

- Energy recovered during waste combustion or other thermal conversion,
- Methane produced during anaerobic biological degradation of organic wastes which can serve as a fuel or as a precursor for high-value chemicals,
- Biochar/hydrochar that can serve as a fuel, carbon storage, or sorbent,
- Stable, biodegraded material that can serve as a soil amendment,
- Pyrolitic oils or syngas,
- Nitrogen and other nutrients,
- Rare earth and heavy metals recovered from post-consumer products, mining waste, or coal ash, and
- Gypsum from air pollution treatment or phosphate wastes.

Because of the complex, heterogeneous, and disperse nature of MSW, recovery of resources presents many challenges including the following:

- Long-term management of landfills dictated by the continued presence of ammonia-nitrogen, dissolved metals, recalcitrant organic matter, and gas potential,
- Co-treatment of wastewater and leachate due to the presence of recalcitrant organic matter that passes through conventional treatment processes,
- Emerging contaminants that have yet to be identified in landfill leachates and may be present due to the vast number of complex consumer products being manufactured and ending up at a landfill at the end of their useful life,
- Cost and inefficiency of collecting multiple streams of source separated MSW and the greenhouse gas emissions and fuel consumption associated with collection,
- Co-contaminants in waste materials, e.g., radon in phosphate mining wastes, that limit resource recovery,
- Inefficient capture of methane from landfills, estimated to be approximately 50% of the total methane potential,
- Littering and other sources of uncontrolled waste that end up polluting marine environments,
- Transport of wastes to developing countries for resource recovery under unregulated conditions,
- Loss of materials to waste along the manufacturing and supply chains,

- Excess packaging required for consumer product protection and loss avoidance,
- Multiple cycles of recycling that lead to toxic concentrations of recalcitrant organic matter and metals, and
- The consumable society making poor purchasing decisions.

These challenges, however, can be dealt with, or minimized, through research and development of engineered solutions which include the following:

- Assessment tools to evaluate sustainable solutions (e.g., life cycle analysis and water/carbon footprint analyses),
- Development of advanced analytical techniques to identify and characterize emerging containment (e.g., nanoparticles, pharmaceuticals, personal care products, and fluorinated compounds) in complex environmental matrices,
- Appropriate and sustainable treatment processes for leachate treatment,
- Heat management in landfills,
- Improved process emissions monitoring,
- Public education and engagement as citizen scientists,
- Regulation of organic waste landfilling,
- Design of products and packaging for maximum resource recovery and safe residual management,
- Volume reduction of unrecoverable waste,
- More efficient waste collection (e.g.,improved design of vehicles, greater use of natural gas and green fuels, underground vacuum waste collection systems),
- More sustainable management of process residuals, particularly ash and inert material, and
- Reduced or less toxic chemicals for extraction of resources from waste.

References

Hoornweg, D.; Bhada-Tat, P., What a Waste: A Global Review of Solid Waste Management, The World Bank, March 2012, No. 15.

U.S. Environmental Protection Agency, 2014. Municipal Solid Waste (MSW) in the United States: 2012 Facts and Figures, EPA-530-F-14-001, February, 2013.

* Reinhart@ucf.edu

University of Colorado Boulder

Department of Civil, Environmental, and Architectural Engineering
UCB 428, ECES 136
Boulder, Colorado 80309

For AEESP GRAND CHALLENGES Workshop

"Wastes are Resources out of Place" – How to Maximize Energy & Resource Recovery from Wastewater

Zhiyong "Jason" Ren, Associate Professor, Environmental Engineering, Jason.Ren@colorado.edu

While people are working on many different aspects of the grand challenge to transform traditional wastewater treatment from energy-intensive, treatment-focused processes into integrated systems that recover energy, nutrient, water, and other value-added products, there has been lack of coordinated efforts to understand the technological and economic potential of the newly named "water resource recovery facilities" (WRRFs). Most R&D activities have been focusing on technology development to recover one specific resource (water, energy, nutrient, etc.), yet from a municipality or industry perspective, one needs to understand what the integrated potentials are for a specific facility with specific wastewater condition. The table below lists what energy and resources that have been recovered or being considered recoverable.

Organic Chemicals	Inorganic Chemicals	Energy and Others
• Value-added organics (esters, acid, alcohol, long chain organics, etc.) • PHB and other bioplastic precursors • Designer biosolids (N-P-K ratio) • Biochar • Others	• Clean water • N and P (gas or solid phase) • Disinfectants (peroxide and caustic) • Reduced metals • Nanoparticles • Others	• Biogas • H_2 • Electricity • Liquid Fuel • Others

In order to maximize the energy and resource recovery potential from wastewater, I hope propose more studies for establishing a platform or benchmark to test, assess, and predict the potential of energy & recovery from different typical facilities or conditions, and when and where such practice will be considered feasible. This may need a coordinated effort from a consortium of groups, and the entry point may focus on specific wastewater streams from industries, which are generally early adopters of new technologies than municipalities. The goal can be either product oriented (eg. P recovery from sludge centrate) or technology oriented (eg. bioelectrochemical systems), or both. System models maybe developed based on experimental and operation data, and the technology potentials, barriers, and challenges can be identified in a coordinated way to better serve the industry and scientific community. With such information, further R&D work will be more relevant to the reality, and team work can achieve goals faster.

My research has been focusing on using microbial and electrochemical approaches to recover energy and value-added products from wastewater during the treatment process, and I developed a new course called "Energy and Resource Recovery" at CU Boulder. I would be glad to discuss my experience in the field of water reuse, energy recovery, and CO_2 capture during wastewater treatment, as well as share class experience on this popular topic.

Donghyun Rim, Ph.D.
Assistant Professor
Department of Architectural Engineering
The Pennsylvania State University
104 Engineering Unit A., University Park, PA 16802, USA

Global Challenges and Opportunities in Environmental Engineering & Science in the 21th Century: **Balancing population increase, building energy use, and human health**

- Rapid population increase and urbanization lead to increased energy consumption, transportation/motorization, and economic growth.
- Unfortunately, quality of life is not assured by industrialization and energy consumption[1].
- The main challenge is how to sustain and improve environmental quality while transforming populated cities sustainable and energy-efficient.
- Human activity pattern studies reveal that people spend almost 90% in buildings[2].
- This reflects that human beings are indoor creature, and 90% of air we are breathing is indoor air.
- Undoubtedly, deleterious cardiovascular and respiratory symptoms among premature infants and adults have been found to be attributed to indoor exposure to aerosol, chemicals from consumer products, and allergens in homes, schools, and workplaces[3].
- At the same time, buildings account for 41% of primary energy use in the U.S. followed by transportation (30%) and industry sector (29%)[4].
- Therefore, building is a critical domain of human health and energy consumption.
- Nonetheless, fate and transport of nanoparticles and reactive gases around a human body remain under-investigated.
- As modern buildings are being built airtight for saving heating/cooling energy, indoor abundance of reactive chemicals (e.g., OH- radical), organic compounds and aerosol will have important consequences for human health impacts[5].
- It is a critical task to elucidate fate and transport of toxic organic gases and particles around human body, and come up with strategies to control exposure to such air toxins while saving energy in buildings.

References

[1]Chen, B., & Kan, H. (2008). Air pollution and population health: a global challenge. *Environmental health and preventive medicine*, 13(2), 94-101.
[2]Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., ... &Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. Journal of exposure analysis and environmental epidemiology, 11(3), 231-252.
[3] Bruce, N., Perez-Padilla, R., & Albalak, R. (2000). Indoor air pollution in developing countries: a major environmental and public health challenge. *Bulletin of the World Health Organization*, *78*(9), 1078-1092.
[4]Energy Information Administration (2014). International Energy Outlook, U.S. Department of Energy.
[4] Mitchell, C. S., Zhang, J., Sigsgaard, T., Jantunen, M., Lioy, P. J., Samson, R., & Karol, M. H. (2007). Current state of the science: health effects and indoor environmental quality. Environmental Health Perspectives, 958-964.

What can molecular simulation contribute to membrane science?

Santiago Romero-Vargas Castrillón
Department of Civil, Environmental, and Geo- Engineering
University of Minnesota

Although significant advances in membrane materials have occurred in the past few decades, membrane fouling and low rejection of solutes such as boron and small organic molecules continue to affect the efficiency and economics of membrane processes. These problems stem from the unsystematic, haphazard approach to low-fouling membrane development, and from the lack of a fundamental understanding of small solute rejection and transport in membrane materials. Molecular simulation (i.e., Monte Carlo, molecular dynamics (MD), and dissipative particle dynamics (DPD)), can be brought to bear on these problems, with the potential to yield significant insights into the rational development of novel membrane materials.

Given the availability of intermolecular potentials for a wide variety of chemistries, and ever increasing computing power, molecular simulation can probe molecular-level properties of membrane systems (and more generally, aqueous interfaces of environmental relevance) that are difficult, if not impossible, to access experimentally. Two main classes of molecular simulation methods are of interest to membrane scientists: molecular dynamics (MD) and Monte Carlo (MC). Non-equilibrium MD (NEMD) can be used to simulate hydraulic pressure (p)-, osmotic pressure (π)-, and temperature (T)-driven membrane processes (RO/NF, forward osmosis, and membrane distillation, respectively). Dissipative particle dynamics (DPD) is a coarse-grained MD simulation technique that can be applied to systems with larger characteristic length scales, such as ultrafiltration, and membrane distillation. Further, molecular simulations in conjunction with free energy calculation methods (e.g., umbrella sampling, and thermodynamic integration) could enable the computation of the free energy profile of foulant adsorption on the membrane, and the free energy of transfer of a solute into the membrane matrix. The computed free energies can guide the rational design of fouling-resistance membrane materials, as well as membranes with targeted selectivity.

Some areas in membrane science where molecular simulation can prove useful include:

- A systematic investigation of structure-fouling propensity relations in anti-fouling coatings. Such a study could provide design rules for antifouling chemistries in terms of the desirable polymer functional groups (e.g., zwitterions, hydrogen bond donors and acceptors), molecular weight, degree of branching (e.g., dendrimeric coatings), and grafting density.
- Molecular simulations of solute transport across membrane materials can expose the solute rejection mechanisms at play (e.g., size exclusion, solubility or free energy of transfer, hydrogen bonding). The ability to prove these phenomena with molecular resolution could aid in the formulation of novel membranes for targeted removal of small solutes such as boric and arsenious acid, and small organic molecules.

In conjunction with experimental research, these studies could result in the development and fabrication of novel, low-fouling, chemically selective membranes for water separations.

"GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY"

Grand Challenge: Promotion of Innovative and Optimized Sanitation Technology Strategies for Protection of the Biohealth of the Planet

Emerging and evolving pathogens effecting animals, plants and humans have now been recognized in sewage impacting all types of waters throughout the world. This along with global, societal change, population growth and urbanization resulting in land use change along with climate change (extreme events, flooding, disasters) have exerted tremendous pressures on infrastructure needs for sanitation in both the developing and developed regions of the world. All water systems in the world are impacted to one extent or another by fecal contamination from either point or non-point sources. Both human and animal wastes carry a pathogen load with considerable risk. Waterborne disease as well as water pollution in general and the blue economy are incompatible and to address the future global economic challenges and promote global health key research at the interface between microbiology and engineering are imperative. To address the continued assurance of water quality protection and water reuse pollution science/engineering research should include investment in four main programs.

EXPLORATION OF THE WATER MICROBIOME: Use of the next-generation sequencing instrumentation and further development of the bioinformatics to characterize the water microbiome and in particular the virome in wastewater is woefully lacking as we enter the genomics era of science. This work is essential and will provide insight into emerging risks, biological stability and biological treatment.

IMPROVEMENT OF QUANTITATIVE MICROBIAL RISK ASSESSMENT FOR SANITATION: Quantitative Microbial Risk Assessment (QMRA) has been seen as a significant framework for pulling scientific and engineering data together and has led to innovative work in decision science but has yet to be used for wastewater treatment outside of the reuse arena.

ADVANCEMENT OF MICROBIAL MEASUREMENTS IN WASTEWATER SYSTEMS: There is no doubt that untreated sewage remains an important source of contaminants in water including nutrients and emerging pollutants such as pharmaceuticals and waterborne disease causing bacteria, viruses and parasites (pathogens). The pathogens in particular have been a target for control as the health effects are immediate (days to weeks), acute and a single exposure through drinking and recreational waters has been known to cause large outbreaks, leading to chronic illnesses. Characterization of pathogens and removal by various new engineered systems including resource recovery technology of key groups that are persistent, potent, and excreted in high numbers (viruses and protozoa) are needed.

CREATION OF ENGINEERING INNOVATIONS FOR MICROBIAL WATER SAFETY: Prevention and control of waterborne pathogens requires an understanding of the removal of pathogenic bacteria, viruses and parasites by various types of wastewater treatment. Optimization methods which balance all goals (cost, compliance, efficacy, human resource needs etc) are crucial. Innovative technology for water reuse and discharge to surface/ground waters of the world must be shown to achieve public health safety.

Joan B. Rose
Michigan State University
rosejo@msu.edu

A Grand Challenge:
Development of An Integrated Wastewater Treatment - Agricultural System

Andrew Schuler
University of New Mexico
May 1, 2015

Submitted to the “Grand Challenges And Opportunities In Environmental Engineering And Science In The 21st Century” Workshop, part of the 2015 AEESP Research and Education Conference

Grant et al., 2012 provided a thoughtful and comprehensive summary of contemporary strategies and opportunities for wastewater reuse and reduced freshwater consumption to meet human needs. With increasing interest in resource recovery from wastewater, coupled with water scarcity in many agriculture regions, there are striking potential synergies between the goals and needs of the wastewater treatment and agricultural industries. Wastewater treatment is commonly performed with the primary goals of protecting human and ecosystem health, with increasingly stringent requirements. Agricultural runoff is a major source of freshwater pollution from fertilizer nutrients, resulting in severe environmental damage such as the immense hypoxic zone in the Gulf of Mexico. How would treatment systems be designed if their primary purpose was to provide water and nutrients for agriculture, and the outputs of the combined wastewater/agricultural systems were regulated to protect human and ecosystem health?

Leaving nutrients in the wastewater stream can reduce costs and energy usage for treatment, while providing additional (and possibly even greater) benefits by reducing or eliminating needs for fertilizer application, with energy savings by reducing the need for synthetic nitrogen fixation (the Haber process). Some agricultural systems, such as agricultural fields linked to the Rio Grande, are actually nutrient sinks; they effectively provide for treatment of nutrient laden water. A better understanding of such systems may yield opportunities for improving water quality simultaneous with wastewater reuse for agriculture. Wastewater reuse for agriculture is common in many parts of the world, such as Israel (Grant et al., 2012), but increased use in other countries such as the U.S. will require a better understanding of several key issues. Critical research questions include:

1. What are the economic, energy, and water usage tradeoffs with respect to implementing large scale agricultural wastewater reuse, including selection of various treatment technologies? How can low energy technologies, such as mainstream anaerobic or low DO treatment, be utilized?
2. What is the fate of potentially dangerous contaminants, such as trace organics, metals, and pathogens, under various irrigation designs?
3. How can irrigation systems be designed and operated to reduce contamination of freshwater resources relative to conventional fertilizer application in terms of nutrients, trace organics, and other compounds? Are there novel designs that can be developed? Which crops are best matched with different effluents, in term of nutrient needs and treatment provided?
4. What are the legal, regulatory, public perception, economic, and infrastructure barriers to greater implementation of wastewater reuse for agriculture? How can these be overcome? What local conditions, such as proximity, infrastructure, and water scarcity, are necessary for economically viable implementation?

Reference:

Grant, S.B., Saphores, J.D., Feldman, D.L., Hamilton, A.J., Fletcher, T.D., Cook, P.L.M., Stewardson, M., Sanders, B.F., Levin, L.A., Ambrose, R.F., Deletic, A., Brown, R., Jiang, S.C., Rosso, D., Cooper, W.J. and Marusic, I., 2012. Taking the "Waste" Out of "Wastewater" for Human Water Security and Ecosystem Sustainability. Science 337(6095), 681-686.

Grand Challenges and Opportunities in Environmental Engineering & Science

Topic: **Influence of Aged Water Infrastructure on Water Quality Control**

Youngwoo (Young) Seo

University of Toledo

Challenges & Opportunities

After the collapse of the I-35 W Mississippi River Bridge, which killed 13 people and injured 145, aged transportation infrastructure receives the most attention. Recently, there also has been great concerns over our aged transportation systems, due to the associated high national price tag necessitating approximately $302 billion dollars just over next four years (Beech 2014). While significant attention is given to our aged transportation systems, our aged water infrastructures are relatively neglected, as they are not as visible as highway systems. However, they have great potentials to create public health threats (Engineers 2013). The American Society of Civil Engineers rated America's drinking water infrastructure 'D+' in 2013. The main reasons for the grade are frequent water main breaks in aged water distribution systems (over 240,000 water main breaks happen per year in the US alone). To address the future water infrastructure issues, the investment in pipe replacements will double from "roughly $13 billion a year today to almost $30 billion annually by the 2040s. Even a medium-sized water utility can have thousands of miles of pipes composed of various types of materials. In large cities, replacing or rehabilitating small segment of ruptured/deteriorated water distribution system can require a significant cost, related to both construction and the impact on city's commerce. Considering the huge number of aged water pipes, of which 26% are unlined cast iron pipes, there have been increasing concerns about the reliability of aged water distribution systems. Aged distribution systems with corroded pipes can cause several problems such as deteriorated water quality, total pipe mass loss, hydraulic head loss, etc. Among them, water quality deterioration has been a great issue not only due to aesthetic problems (red water), but because of potential health risks related to a system failure. Previous studies have reported that corroded iron pipes can be a common source of pathogen dissemination and have very high potential for the catastrophic spread of epidemic diseases. **However, due to the significant replacement cost of aged infrastructure, the potential public health risk associated aged water distribution system remains unresolved and compromised. To better safeguard public health from biological and chemical hazards in distribution systems, integrated understanding in biological, chemical and hydraulic dynamics of the water distribution system is necessary for engineers who design and maintain our water distribution systems. In addition, there are great needs for engineers to find sustainable solutions to manage our aged water infrastructure.**

References

1. http://www.dot.gov/sites/dot.gov/files/docs/GROW-AMERICA-Overall-Fact-Sheet.pdf
2. Engineers, A. S. o. C. (2013). "2013 Report Card for America's Infrastructure."

Grand Challenge

Integration of Natural Water Infrastructure Systems for the Triple Bottom Line

Jonathan (Josh) Sharp, Associate Professor, Colorado School of Mines and NSF Engineering Research Center Reinventing the Nation's Urban Water Infrastructure (ReNUWIt)

Background: Water infrastructure in most first world countries was developed during a time of inexpensive energy, smaller urban populations, and less consideration for environmental impacts. Water resource implications of climate change and variability, coupled to population grown in arid regions with finite pristine water supplies, have further challenged "business as usual" and collectively present a challenge to develop and implement alternative approaches. The ideal implementation of future infrastructure should have societal, environmental, and economic advantages and in doing so better address triple bottom line full spectrum accounting: people, planet, *and* profit.

The integration of managed natural treatment systems can help to ameliorate some of these current limitations by offering a potentially cost, energy, waste-neutral, and aesthetically effective tool for remediation when compared to existing tertiary treatment technologies. Managed natural treatment systems mimic or capitalize on natural biogeochemical processes for implementation and include engineered wetlands, riverbank filtration, aquifer recharge and recovery. These alternatives to more traditional engineered technologies hold particular promise for emerging / trace organic pollutant and nutrient attenuation in various impaired waters (i.e. municipal wastewater and stormwater). However at present, the mechanisms of attenuation are poorly understood and not universally reliable. Of particular uncertainty is the role of microorganisms (i.e. bacteria and fungi) in these systems. A better understanding of microbial processes could lead to system design developments that would enhance treatment and reliability metrics so crucial to displacing current technologies.

Key Points for Discussion:

- Limitations and adaptations of environmental molecular microbiology tools for designing and monitoring natural treatment and other analogous systems
- Promise and limitations of current managed nature treatment technologies as part of a larger process treatment approach as well as legal and institutional barriers
- Opportunities to interface natural treatment technologies into agricultural systems for upstream and downstream treatment as well as managing the nutrient cycle
- Advantages and disadvantages of natural treatment systems during increasing climatic variability and change and implementation in different regions
- Application to natural treatment technologies to other impaired water supplies (i.e. produced and flowback water from hydraulic fracking activities)

References:

- Jasper JT, Jones ZL, Sharp JO, Sedlak DL. (2014) Nitrate removal in shallow, open-water treatment wetlands. Environ. Sci. Technol 48(19): 11512-20
- Li D, Alidina M, Ouf M, Sharp JO, Saikaly P, Drewes J (2013). Microbial community evolution during managed aquifer recharge in response to different biodegradable dissolved organic carbon (BDOC) concentrations. Water Research 47: 2421-2430
- Regnery J, Lee J, Kitandidis P, Illangasekare T, Sharp JO, Drewes J. (2013) Integration of managed aquifer recharge systems in urban water infrastructure – overcoming current limitations and engineering challenges. Environ Eng Science. 30(8): 421-436

Water Sustainability and Social Awareness

Heather Shipley and Drew Johnson - University of Texas at San Antonio

Water sustainability is commonly recognized as among the most formidable environmental challenges in the twenty-first century. The safety and availability of water are a National Academy of Engineering Grand Challenge inextricably linked to global health, energy production, and economic development. But not only is water sustainability a challenge but the societal awareness and acceptance of these challenges.

The water problems can be grouped into three types: acute, chronic and predicted. Acute water problems require an immediate response, chronic water problems consist of recurring or prolonged conditions whose adverse impact has accumulated over time, and predicted water problems are just becoming understood by the scientific community and may pose the greatest knowledge dissemination challenge. An example of an acute problem is the excessive growth of cyanobacteria, in hypereutrophic water bodies causes harmful algal blooms (CyanoHAB). CyanoHAB pose severe health risks to the users of drinking and recreation waters, due to the cyanotoxins produced (1, 2) causing severe environmental and economic damage (3). Examples of a chronic problem are water conservation and water recycling. Urbanization and population growth threaten the sustainability of water systems because of the imbalance between rising water demands and limited water supplies. This problem is even more pronounced in semi-arid and drought-prone regions such as the Southwestern US (4), creating great pressure on water supplies. Highly treated wastewater (reclaimed water) will be a major component of municipal water supplies in the near future. Public opposition is currently considered the greatest obstacle to successful potable reuse projects (5). A lack of faith in water managers' abilities to ensure water quality has been identified as a central factor in determining public acceptance of using reclaimed water as drinking water (6). Examples of predicted problems include emerging contaminants and effects related to climate change. As society continues to generate new technologies and chemicals, these developments have led to an increase in the release of contaminants into natural waters. Many of these contaminants are introduced continuously into the environment and wastewater because they are used in our daily lives. Conventional water and wastewater treatment processes can remove some of these substances but improved and advanced treatment technologies are needed to ensure these contaminants do not end up in reusable water or the environment (7). Effects of global warming are particularly evident in extreme environments such as the polar, arid, and mountainous regions of the Earth, causing observable changes in environments and ecosystems (8). These regional problems themselves have global significance through changes induced from sea level rise due to melting glaciers and ice sheets and new extremes (drought or flooding) throughout arid and semi-arid regions.

In order to meet these challenges an interdisciplinary approach is needed to address the distinct aspects of water literacy and sustainability. The next generation of researchers will be faced with the dual tasks of solving the grand technical challenges of water supply and treatment and communicating their assessments of various technical solutions to the broader public.

References:

1. Foflonker, F., *Biological methods to control common algal bloom-forming species*. 2009. 2009.
2. Lürling, M. and E.J. Faassen, *Dog Poisonings Associated with a Microcystis aeruginosa Bloom in the Netherlands.* Toxins, 2013. **5**(3): p. 556-567.
3. Paerl, H.W. and J. Huisman, *Blooms Like It Hot.* Science, 2008. **320**(5872): p. 57-58.
4. TWDB, *Water for Texas 2012 State Water Plan*. 2012, Texas Water Development Board: Austin, TX.

5. Dolničar, S. and C. Saunders, *Recycled water for consumer markets — a marketing research review and agenda*. Desalination, 2006. **187**(1–3): p. 203-214.
6. Ormerod, K.J. and C.A. Scott, *Drinking Wastewater: Public Trust in Potable Reuse.* Science, Technology & Human Values, 2012.
7. Klamerth, N., et al., *Degradation of fifteen emerging contaminants at μg/L initial concentrations by mild solar photo-Fenton in MWTP effluents.* Water Research, 2010. **44**: p. 545-554.
8. IPCC, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]*. IPCC. 2013, Cambridge, UK and New York, NY, USA: Cambridge University Press. 1535.

Title: Providing environmentally sustainable wastewater treatment to the global south
Author: Deborah Sills , Bucknell University

Description
Approximately 80% of the wastewater produced worldwide is not treated and, instead, is discharged into waterways, resulting in polluted aquatic ecosystems (Tauseef et al., 2013). Even though conventional aerobic wastewater treatment is effectively used throughout the developed world, its high cost and dependence on reliable electricity has prevented its implementation in the developing world. Additionally, aerobic treatment results in large amounts of carbon dioxide emissions. In the United States alone, 45 million tons of greenhouse gases (GHGs) per year come from wastewater treatment (US EPA, 2013).

Anaerobic wastewater treatment, on the other hand, consumes less energy than aerobic treatment, emits less carbon dioxide, and is a net producer of energy in the form of gaseous methane, which can be used to generate renewable electricity (McCarty et al., 2011). Although anaerobic treatment has the potential to provide a sustainable alternative to aerobic treatment, it may not be as environmentally friendly previously thought, because of high levels of dissolved methane present in treated effluent (Liu et al., 2014). The presence of dissolved methane, not easily captured in the gaseous form, reduces energy production from anaerobic systems and results in discharge of methane into waterways. Discharged methane— a potent GHG with a global warming potential (GWP) that is approximately 25 times greater than carbon dioxide—is eventually released to the atmosphere, which may offset reductions in GWP compared to aerobic treatment (Cakir and Stenstrom, 2005). Processes that remove or reduce levels of dissolved methane in treated effluents are needed for anaerobic treatment to be a sustainable technology. Furthermore, analyses that quantify life cycle environmental impacts of wastewater treatment technologies (including the effects of dissolved methane in anaerobic systems) will elucidate the pros and cons of anaerobic and aerobic treatment technologies.

In addition to the question of aerobic versus anaerobic centralized treatment, I'm interested in comparing environmental, economic, and social implications of centralized versus decentralized technologies for treatment of human waste. Clearly there are situations where decentralized treatment (e.g., Eco-sanitation toilets) has advantages over centralized treatment (e.g., in arid locations). And I'm interested in developing a framework that quantifies tradeoffs for these two classes of technologies for wastewater treatment.

References
Cakir, F.Y., Stenstrom, M.K., 2005. Greenhouse gas production: A comparison between aerobic and anaerobic wastewater treatment technology. Water Res. 39, 4197–4203.
McCarty, P.L., Bae, J., Kim, J., 2011. Domestic wastewater treatment as a net energy producer–Can this be achieved? Environ. Sci. Technol. 45, 7100–7106.
Tauseef, S. M., Abbasi, T., & Abbasi, S. A., 2013. Energy recovery from wastewaters with high-rate anaerobic digesters. Renew. Sust. Energ. Rev., *19*, 704-741.
US EPA, 2013. Energy Efficiency in Water and Wastewater Facilities: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs - wastewater-guide.pdf. URL: http://epa.gov/statelocalclimate/documents/pdf/wastewater-guide.pdf

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century: Linking Microbial Community Analyses with Functional Stability

Dr. Adam L. Smith, University of Southern California

A grand challenge and opportunity for environmental engineers is to establish a better link between microbial community structure and biological system performance/configuration. We now have advanced molecular biology methods (e.g., high-throughput sequencing, DNA/RNA-SIP, bioinformatics) at our disposal to study microbial communities yet we still struggle to use feedback from this research to improve system performance via changes in process control or configuration. Apart from the work more than a decade ago linking bulking in activated sludge to filamentous bacteria (de los Reyes et al. 1997), few molecular biology studies on water treatment systems have made a meaningful impact in how we design or operate them.

One example that has received some debate in recent years is temporal microbial community stability. Some studies suggest that a community that is stable over time is more resilient and has better overall performance. However, other studies propose the exact opposite. If we conclude that a less stable community performs better, we could consider operational changes such as periodic re-inoculation or spiking the system with certain substrates (e.g., acetate or propionate to an anaerobic digester) to drive less microbial stability (De Vrieze et al. 2013). If the opposite were true, we may design systems with more equalization prior to biological reactors. We need to devise and conduct systematic studies of systems at bench-, pilot-, and full-scale to elucidate the impact of temporal microbial community stability on system performance.

Several hurdles exist to making meaningful strides in this area. The majority of molecular biology methods including high-throughput sequencing are cost prohibitive for many academics and the majority of utilities. Part of the limitation is convincing utilities and other stakeholders that this work is truly valuable. It remains difficult to justify the high costs. Another challenge is the time-scales over which we do these analyses. Nearly all molecular biology methods are far from real-time making it difficult to use them to prevent a reactor upset or decline in performance. If we had tools to monitor microbial communities in real-time, we may be able to inform reactor operation to improve or at least maintain performance.

de los Reyes, F.L., Ritter, W. and Raskin, L. (1997) Group-specific small-subunit rRNA hybridization probes to characterize filamentous foaming in activated sludge systems. Applied and environmental microbiology 63(3), 1107-1117.

De Vrieze, J., Verstraete, W. and Boon, N. (2013) Repeated pulse feeding induces functional stability in anaerobic digestion. Microbial biotechnology 6(4), 414-424.

Antimicrobially Resistant Bacteria

Mark Sobsey and Amy Pruden

A cross-cutting topic that seems worthy of consideration for this "Grand Challenges" workshop is that of antimicrobial resistant bacteria in the environment. This is an environmental and public health issue. The World Health Organization has elevated this topic to a high priority for global action and a new Global Action Plan will be presented to the World Health Assembly in May. Many countries and regions are mounting new initiatives to address this cross-cutting issue, including the European Union and the USA. The President this month issued a National Action Plan for Combating Antibiotic-Resistant Bacteria in which the role of the environment is acknowledged but for which an environmental approach is not yet articulated.

We lack an understanding of the extent to which antimicrobially resistant bacteria that are the greatest threats to human and animal health have significant environmental reservoirs and sinks and and understanding of the extent to which engineering treatment processes and systems for wastewater, biosolids, animal manures and drinking water can either reduce or increase the risks of human and animal exposure to these bacteria. Currently, there is no systematic environmental surveillance for these bacteria and a call for action to develop such a surveillance system has been proposed by the WHO. But, what would be monitored in such a global environmental surveillance system, what would the indicators for effective management be to minimize occurrence, horizontal transfer of the most risky resistance traits and other measures to protect and environment and human health and who would do the surveillance and monitoring? It is not likely to be done by the healthcare sector or the agricultural sector some maybe those of us in environmental sciences and engineering need to do it.

I attach two documents that may be of interest. A brief description of a workshop on this issue held last October at the UNC Water and Health Conference and a Briefing Note to the WHO and the World Health Assembly that I led the writing of last May. This is a topic that deserves the further attention and action of people in our field.

Sustainable replacement of non-renewable resources

Lindsay Soh

In order to keep pace with global development demands, sustainable means for producing and/or replacing limiting resources are needed. In the general sense, these limitations relate to materials that would be consumed at a higher rate than production and includes water and energy. Other specific issues pertain to rare elements and products created from non-renewable feedstocks such as petroleum-derived materials. Thus, the engineering challenge is the sustainable design and production of alternatives for these commodities. Additionally, the life cycle impacts of processing these materials must be considered for reduced or marginal energy usage as well as marginalization of waste streams.

Regarding the replacement of petroleum-derived materials, the concept of a biorefinery potentially serves as an opportunity to create a variety of products from biomass.[1] Akin to a petroleum refinery where efficient use of basically every fraction of feedstock is utilized and allocated, a biorefinery would utilize the entirety of a renewable feedstock to supplant current products from non-renewable sources. The process of oil refining is over 150 years old and has been optimized to the point where the economics of altering feedstocks seems cost prohibitive. Refining of biomass has a lot of catching up to do, but improvements in the manufacturing and utilizing a holistic perspective to avoid future impacts will hopefully allow the development of materials and products to keep up with our growing needs. In the current early stages of development, biorefineries offer great opportunity to design and implement processes for sustainable product creation.

There are a significant number of processing steps necessary to achieve high-quality products. These processing steps include extractions, chemical reactions, and separations, many of which are energy intensive and/or waste-producing. While improvements to current processing practices are continuously needed, the application of green chemistry and green engineering principles towards renewable feedstocks would provide a forward thinking platform. Such improvements could be make in terms of increased efficiencies as well as utilization of green solvents.[2] Solvents are the major contributor to mass utilization in fine chemical processing and also require significant resources to produce and recycle. Development of greener solvent alternatives as well as the chemistries by which to use them in alternative syntheses for a variety of applications would be an effective pathway to decrease energy requirements and reduce waste production from processing with large-scale impact.

1. Bozell, J.J. and G.R. Petersen, *Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy's "top 10" revisited.* Green Chemistry, 2010. **12**(4): p. 539-554.
2. Jessop, P.G., *Searching for green solvents.* Green Chemistry, 2011. **13**(6): p. 1391-1398.

Grand challenge is biofouling formation in water treatment membranes and marine devices.

Adel Soroush

Adel.soroush@gmail.com

Biofouling formation on the surface of water treatment membranes and the wall of any devices and instruments in the sea or ocean is a big challenge because can reduce productivity and decrease lifetime of membranes and devices. Although biofouling mitigation methods have been increasingly studied, the nature of biofilm and the mechanism of its formation is still in the shadow of uncertainty.

Lauren Stadler
PhD Candidate, University of Michigan

Rethinking scale and flexibility to advance resiliency and sustainability in the water sector

The challenge is to rethink the design of water infrastructure such that it is scalable and flexible. Much of the country's water treatment and distribution systems are nearing the end of their design life. Substantial replacements and renovations will be required to upgrade old infrastructure, as well as put into place new infrastructure as the population grows and urbanizes. The challenge (and opportunity) we face is how to reimagine our water systems. Will we continue to retrofit existing centralized treatment systems? Or can we imagine a different system that might be more varied in scale, specific to locality, and designed with flexibility such that water may be produced at multiple different qualities based on its end use? The water infrastructure of the future needs to be reimagined to address new challenges in the 21st century and this will require greater flexibility than our current system affords.

Conventional water treatment schemes are centralized: wastewater is transported over considerable distances to central treatment facilities, and similarly drinking water is distributed over considerable distances from a central treatment facility to households and businesses. The energy consumed by the wastewater treatment industry amounts to approximately 30 terawatt-hours per year, which represents a 74% increase since 2006. This is largely due to growing water demands and the higher levels of treatment required (specifically with respect to nutrient removal). Over 50 percent of the electricity demand associated with treatment is due to aeration. As our water infrastructure reaches the end of its design-life, it is paving the way for the design and implementation of next-generation technologies. This represents a great opportunity to implement resource recovery (energy, water, nutrients) and more energy efficient technologies. Which resources to recover and how best to do so, depends to a significant degree on the scale of implementation and local needs. As direct and indirect water reuse becomes more commonplace, decentralized treatment strategies provide opportunities for generating reclaimed water that can be used locally and reduce the need to pump water over long distances. Further, decentralized approaches that recover both energy and water via the use of novel treatment technologies, such as anaerobic membrane bioreactors and microbial fuel cells, may be much more efficient at smaller scales because of more concentrated waste streams.

In addition to rethinking the scale of treatment facilities, we are challenged with how to design and implement more flexible treatment systems that can adapt to changing water quantity and quality needs. Water reclamation facilities that can produce multiple different quality waters have the potential to make water reuse more economically viable and resilient. Creative, real-time stormwater capture and treatment systems that can be serve as another important source of reclaimed water and prevent pollution from entering natural water bodies. Advancements water quality sensors have resulted in more robust sensors that can withstand harsh reactor environments, run autonomously for long periods without significant maintenance, and that are relatively inexpensive. These advancements are making real-time sensing and sensor-mediated control strategies a reality and decentralized and flexible treatment systems more technically feasible.

Future research should focus on evaluating where efficiencies and resource recovery can be implemented and at what scale those efficiency gains are maximized. Systems approaches can be used to comprehensively evaluate and compare next-generation centralized and decentralized treatment approaches for water treatment and resource recovery. Modeling, incorporating extensive uncertainty analyses, can be used to understand the relationship between resiliency and process scale. And finally, research that demonstrates real-time sensing and control of treatment systems at small-scale treatment facilities will help to advance decentralized and flexible water reclamation treatment systems.

Grand Challenge: New Technologies for Valorizing Waste Streams

Author: Timothy Strathmann, Professor, Colorado School of Mines and the National Renewable Energy Laboratory (NREL)

Background and Statement of Need

Population growth and economic development are spurring increases in demand for new sources of energy and chemical precursors while simultaneously producing growing quantities of liquid and solid wastes. At this same time, we are undergoing a fundamental shift in our view of waste treatment processes from energy-consuming end-of-pipe operations to energy- and product-generating "biorefinery" operations. Current wastewater treatment operations are energy intensive, and ~3% of electrical energy in the U.S. is used for wastewater treatment despite the fact that wastewater contains (1) organic materials possessing several times the energy needed for treatment,[1] and (2) valuable nutrients that can be recovered for economic value or used to produce even larger amounts of organic materials (e.g., through photo-autotrophic processes). Exploiting these resources represents an important opportunity, but new technologies and systems are necessary to advance the wastewater biorefinery towards reality.

New Technologies and Hybrid Technologies

Environmental engineers area uniquely positioned to play a central role in valorizing waste streams, developing new technologies that meet environmental quality goals while simultaneously producing energy and economically valuable chemicals. Anaerobic digestion is the most mature technology for energy recovery at wastewater treatment facilities, but the process is carbon inefficient and methane has low value in comparison to liquid fuels and higher-value industrial chemical feedstocks that can be produced from the same waste streams using alternative processes.[2] For example, the carbon-normalized commodity price of gasoline is 3.8 times the price of natural gas on 04/03/15. In a biorefinery strategy, the value of individual process streams is maximized by application of a variety of biological, thermochemical, and catalytic processes.[3] Moving forward, it is critical for researchers in the field to embrace a variety of technological pathways from within and beyond the traditional domains of our field. This includes thermochemical, hydrothermal/supercritical, liquid and gas-phase catalytic, (bio)electrochemical, and separations technologies in addition to innovative biological processing (e.g., photo-autotrophic, targeted fermentation, PHA accumulation, genetically engineered bioreactors, enzyme treatments).

Key Points for Discussion

Some key points for discussion could include the following:

- Unique challenges of recovering products economically from waste streams that are (1) heterogeneous, (2) dilute, and (3) highly variable in nature.
- Synergistic outcomes from integrating biological and chemo-catalytic processes.
- Challenges of scaling up and piloting innovative technologies.
- How to feed products into industrial/commercial pipelines.
- Applying techno-economic analysis and life cycle assessment approaches to identify critical technology barriers and paths forward for sustainable technology development.

References Cited

(1) McCarty, P. L.; Bae, J.; Kim, J. Domestic Wastewater Treatment as a Net Energy Producer–Can This be Achieved? *Environ. Sci. Technol.* **2011**, *45* (17), 7100–7106.
(2) Bozell, J. J.; Petersen, G. R. Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy's "Top 10" revisited. *Green Chem.* **2010**, *12* (4), 539.
(3) Ryan, D.; Gadd, A.; Kavanagh, J.; Barton, G. W. Integrated biorefinery wastewater design. *Chem. Eng. Res. Des.* **2009**, *87* (9), 1261–1268.

"Resource Recovery Technology Development is Not Enough – We Must Train Engineers to Engage Municipalities and Overcome Socioeconomic Adoption Barriers"

Dr. Belinda Sturm, Associate Professor, University of Kansas

Sustainability is difficult to achieve due to fast-growing urban populations and diminishing natural resources, particularly usable freshwater, accessible nutrients, and fuel feedstocks. By 2015, 45% of the world's population will live in regions under water stress[1]. For food production, global phosphorus scarcity is expected to be one of the greatest challenges of the 21st century as phosphorus mining from non-renewable phosphate rock is expected to peak around 2035[2]. Finally, oil fields that once yielded abundant petroleum are currently being produced using tertiary oil recovery methods to access the remaining reserves. While residential and industrial activities deplete natural resources, they also produce wastewater. Historically, wastewater dischargers conduct treatment to meet regulatory requirements. As resource limitations spur development of reuse technologies and identification of renewable commodities, wastewater can be viewed as a *renewable resource* that contains valuable raw materials.

The Water Environment Federation refers to wastewater facilities as "Water and Resource Reclamation Facilities (WRRFs)." This naming convention represents a paradigm shift within the water sector, and today examples of resource recovery systems (RRS) exist around the globe. Water reclamation and reuse provides both non-potable and potable water resources in water stressed areas. Singapore's NEWater initiative produces 60 million gallons of water per day from wastewater for non-potable industrial reuse and indirect potable reuse[3]. Energy recovery from wastewater is widespread for anaerobic digestion systems that produce methane-containing biogas[4], which can be used to produce heat and power. New photosynthetic systems, including algal open ponds and photobioreactors, have the potential to recover nutrients and other value-added solid products, while producing biogas or biofuel feedstocks[5-7]. Finally, nutrient recovery from municipal and industrial wastewater is common for fertilizers in the form of Class A and B biosolids, and commercial technology is available to recover fertilizers in the form of struvite precipitation[8].

Despite these examples of resource recovery from wastewater, RRS are not common throughout the United States. Increases in technology efficiencies and reduction in capital and operational costs clearly help to promote adoption. As important, leading academics and professional engineers[9] assert, "The primary problem we face is not the availability of technology for resource recovery, but the lack of a socio-technological planning and design methodology to identify and deploy the most sustainable solution in a given geographic and cultural context." The decision to adopt an RRS is made by various decision-makers (i.e., utility managers, local government officials, regulators) in a complex environment, requiring financial, political, and social capital aligning to support the improved technology. Overall, an individual company's or local government's willingness to adopt an RRS represents a decision to innovate[10], which can be a function of <u>the innovation itself</u> (e.g., land requirements), <u>the innovator</u> (e.g., work experience, education), and <u>the innovation context</u> (e.g., local community)[11].

In recent years, a growing number of cities have pursued initiatives to improve the environment and enhance overall sustainability. While these progressive actions signal a commitment to environmental management, research suggests that cities can do significantly more to advance sustainability[12]. Limited technical, managerial, and financial capacity, combined with insufficient political will, often result in decisions that constrain technological innovation and environmental protection[13]. As important, cities have entered an era where fiscal stress is expected to remain "the new normal"[14]. This stress may make cities less willing to make large investments in sustainability technologies, while making them more receptive to cost saving and revenue-generating initiatives. The closed-loop technologies associated with RRS may yield a dual sustainability benefit for the adopting city, enhancing both its environmental and economic dimensions. Research conducted by social science peers helps to elucidate adoption barriers.

As educators, we must provide graduating students (future professionals and civic leaders) the ability to help cities loosen the technical, financial, and human capacity constraints of RRS adoption. Widespread adoption of RRS requires the training of interdisciplinary professionals and researchers who understand the emerging technologies (the innovation), the environmental and socio-economic factors important in the decision-making process (the innovation context), and the socio-economic factors of the decision-maker (the innovator).

References

1. Daigger, G. T., Wastewater management in the 21st century. *Journal of Environmental Engineering* **2007,** *133*, (7), 671-680.
2. Cordell, D.; Rosemarin, A.; Schröder, J.; Smit, A., Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. *Chemosphere* **2011,** *84*, (6), 747-758.
3. PUB NEWater Homepage. http://www.pub.gov.sg/water/newater/Pages/default.aspx
4. Eastern Research Group, I. E. a. R. D. C. R. *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field*; U.S. Environmental Protection Agency, Combined Heat and Power Partnership: October 2011.
5. Sturm, B. S.; Lamer, S. L., An energy evaluation of coupling nutrient removal from wastewater with algal biomass production. *Applied Energy* **2011,** *88*, (10), 3499-3506.
6. Lu, T.; Kim, J.; Lee, J.-Y.; Dunlap, P.; Shaw, A.; Barnard, J.; George, B.; Parrott, J.; Metz, D. In *Investigation of Synergistic Relationship between Nutrient Removal and Algae Growth in Municipal Wastewater Treatment Plants*, Water Environment Federation Nutrients and Energy, Toronto, Canada, 2013; Toronto, Canada, 2013.
7. Shoener, B.; Bradley, I.; Cusick, R.; Guest, J., Energy positive domestic wastewater treatment: the roles of anaerobic and phototrophic technologies. *Environmental Science: Processes & Impacts* **2014,** *16*, (6), 1204-1222.
8. Hao, X.; Wang, C.; van Loosdrecht, M. C.; Hu, Y., Looking beyond struvite for P-recovery. *Environmental science & technology* **2013,** *47*, (10), 4965-4966.
9. Guest, J. S.; Skerlos, S. J.; Barnard, J. L.; Beck, M. B.; Daigger, G. T.; Hilger, H.; Jackson, S. J.; Karvazy, K.; Kelly, L.; Macpherson, L., A New Planning and Design Paradigm to Achieve Sustainable Resource Recovery from Wastewater. *Environmental science & technology* **2009,** *43*, (16), 6126-6130.
10. Rogers, E. M., *Diffusion of Innovations, 5th Edition*. Free Press: 2003.
11. Wejnert, B., Integrating Models of Diffusion of Innovations: A Conceptual Framework. *Annual Review of Sociology* **2002,** *28*, (1), 297-326.
12. Ramaswami, A., Social Actors and Key Policy Levers for Mitigating the Greenhouse Gas Footprint of US Cities. *Cityscape* **2013**, 209-232.
13. Copeland, C., *Water infrastructure needs and investment: Review and analysis of key issues*. DIANE Publishing: 2010.
14. Scorsone, E. A.; Plerhoples, C., Fiscal Stress and Cutback Management Amongst State and Local Governments What Have We Learned and What Remains to Be Learned? *State and Local Government Review* **2010,** *42*, (2), 176-187.

Grand Challenge: Facilitating Transformation of Environmental Research Results to Practical Applications

Mei Sun, North Carolina State University, Raleigh, NC

Statement of Problem

For centuries, scientific research has driven the development of human society and advances of technologies, including the ones used to solve environmental problems. Nowadays, a worldwide scientific community larger than ever is diligently conducting research in various environmentally related fields, and the results are disseminated every day in form of numerous publications. The Web of Science™ search results show the number of publications within the categories of "Environmental Engineering", "Environmental Sciences", "Environmental Studies", and "Public, Environmental & Occupational Health" combined together is 18,379 in 1984, 46,571 in 2004, and 90,594 in 2014. However, with such rapid increase of the number of research publications, how many of them actually provide useful information to solve environmental problems is questionable. Some publications only circulate inside the scientific community and never get the chance to be tested in the real world, while even more fail to draw interest from other researchers, not to mention people outside the ivory tower.

Efforts needed

It is a huge waste of resources if the majority of research results stay on paper instead of helping people constructing a better environment in the real world. Therefore, efforts are needed to facilitate research transformation to practical applications. Multiple sectors of society can affect knowledge transformation, and **academic researchers, industry, and government agencies** are in my view the three key players with the most social responsibilities.

Academic researchers are expected to focus on solving current environmental problems. Although fundamental research with simplified assumptions and ideal conditions is essential for the advance of scientific knowledge, research activities more closely connected with long-term practical issues and urgent environmental problems should receive higher priority. Taking considerations of environmentally relevant conditions into research design and resource intensity into solution evaluation should be always emphasized when conducting research.

Industry should actively communicate with researchers to stay abreast of new environmental challenges and solutions, disclose potential contamination information, and be open to adopt new technologies. Collaboration with researchers to develop scale-up procedures for incorporating scientific research results into industrial systems is also desirable for knowledge transformation.

Government agencies are responsible for developing policies that promote the growth of new environmental-friendly technologies, through both research support and industrial incentivization. Also, they can make positive contributions through public education and reward researchers who are dedicated to developing solutions to real-world problems.

Overcoming the Legacy of Pollution from the 20th Century

Sarang D. Supekar, Ph.D.

Department of Mechanical Engineering, University of Michigan, Ann Arbor, Michigan, USA

The Challenge. Climate change and the threat it poses to ecosystems, food and water supplies, human health, and political and economic stability at large is unequivocally one of the biggest problems facing our generation. Although the twenty first century has witnessed a rapid growth in innovation and development of new technologies to curb greenhouse gas (GHG) emissions, we are still faced with the issue of managing old carbon-intensive technologies from the previous century such as coal-fired power plants, fuel oil-fired industrial boilers, and internal combustion engines in motor vehicles that are still in operation. With high capital costs and service lives spanning 30 – 60 years, these energy service technologies (which collectively account for about 70% of the world's annual GHG emissions) are poised to emit several gigatons of carbon dioxide over the next few decades. Keeping these so called "locked-in" emissions born from the legacy of the twentieth century technologies out of our atmosphere through strategic development and implementation of technological solutions in an ever shrinking window of opportunity for climate action, all while minimizing costs and meeting the meeting the world's growing demand for energy services is a grand challenge facing engineers and scientists in the twenty first century.

Photo: Ken Stewart, Zuma Press

Photo: Reed Saxon, AP

The Opportunity. The complex nature of this challenge creates several opportunities for cross-disciplinary research that connects carbon mitigation technology development to industrial ecology as well as economics and public policy. Life cycle environmental and economic assessments of commercially developed as well as developing carbon mitigation technologies can inform R&D and catalyze innovation of technologies to meet specific climate and cost targets. Incorporating macro- and/or micro-economic effects of these new and developing technologies, and quantifying as best as possible the social externalities created by them can help policy-makers, researchers, and innovators alike in the design, planning and management of carbon mitigation strategies that minimize societal cost or maximize social welfare. Such an integrated approach to developing carbon mitigation technologies and policies for managing the pollution legacy of the twentieth century has the potential to achieve the triple bottom line of sustainability (environmental, economic, and social). This integrated sustainability framework has applications beyond management of carbon pollution from old power plants and vehicles. It can also be used by environmental scientists, engineers, and policy-makers working on solving problems related to legacy technologies in municipal water and wastewater systems, energy and resource inefficient homes, food and agricultural systems, mineral commodities extraction and disposal supply chains, consumer electronic goods, and several other domains where sustainable pollution control or resource management are made challenging due to system complexities.

Cost-Effective Resource Recovery from Wastewater

Youneng Tang (ytang2@fsu.edu), Gang Chen (gchen2@fsu.edu)

(Florida State University)

Wastewater is now recognized as a valued source of renewable resources, which include renewable energy (i.e., electricity, methane and nitrous oxide, etc.), nutrients such as phosphorus and nitrogen, reclaimed water that can be reused for a variety of purposes, and chemicals that can be used as industrial raw materials such as hydrogen gas, metals, metalloids, and polymers. Water resource recovery thus should be one of the focuses of environmental engineering research. While recovery of some resources (e.g., methane, phosphorus, and clean water) have been widely practiced, the recovery of many other resources such as nitrous oxide and polymers has been limited to bench-scale tests, pilot-scale tests, or limited field-scale applications. A key obstacle to their wide application is the high cost associated with current technologies. The high cost is due to factors such as 1) slow reaction kinetics or low conversion efficiency to produce the chemicals, 2) low concentration of chemicals produced (i.e., some precious metals), 3) high input to produce the chemicals (i.e., expensive membrane for water reuse), 4) high cost to separate the chemicals from the treated water or solids, and 5) high cost to retrofit existing wastewater treatment plants.

With the advance of science and technology, some of the above challenges now can be addressed. Especially, interdisciplinary research plays the key role in this process. One example is the successful application of material science and engineering in environmental engineering: new cost-effective and multi-functional polymers are now one potential solution to the high cost of water reuse through membrane technologies. With new science and technology, we anticipate that turning wastewater treatment plants into resource recovery plants will occur in the near future.

AEESP 2015 GRAND CHALLENGES WORKSHOP.

Title: Chemicals in the commons-Designs for estimating ecosystem exposure.

Name: Louis J. Thibodeaux, LSU.

"The dose makes the poison."[M. Alice Ottoboni. 1984. Vincente Books. Berkeley, CA.] The nexus of: chemical specie and particle sources in the media, their pathways, the concentration-time product persistence of each, the organisms present and being in contact and finally the mass uptake/intake by each organism yields its dose. Based on the dose the toxicology folks do the impact/effects bit to determine hazard degree/level. But we, AEESP-types instruct our students on how to perform state-of-the-art designs [aka predictive models] for estimating source-to-dose ecosystem exposure. I am talking about all the media [The Commons.] and all exposure scenarios. The known, continuous point and area sources design protocols we teach for estimating exposures are old-school; here I mean the Gaussian plume in air and contaminants ground water modeling, for example. At this juncture I am talking about the hard, theoretically tough and complex ones for future uses: outdoor, indoor, accidental, acts of terrorism, purposeful, ignorant acts, random events, odd puffs and pulses, explosions, dormant then active, nature activated and driven, etc., exposures and their associated design systems and procedures. That is the grand challenge, real engineering designs for exposure in the natural environment. The following are examples of these sources and designs, as humble as some may be.

<u>Purposeful.</u> Poor design-Incineration or economic shortcut? A supply capsule went into uncontrollable spin and was declared lost, it was expected to burn up harmlessly in the atmosphere as is the case of all Progress (NASA and Russian Space Station) carriers, once they have delivered their shipments and all are filled with trash. [The Advocate, 30 April 2015. Baton Rouge, LA. Page 12A]. What? Outer space incineration; did I miss that EES issue that contained the design algorithms for estimating exposure?

<u>Accident.</u> Absolutely clueless; no oil spill exposure design made for the Macondo 252 oil-chemical release incident in the GOM. No pre-spill design forecast made as to where the oil and gas from a deep-water blowout would go (Thibodeaux, et al., 2011). Did BP have risk probability for this type of failure occurring? Likely they did. Only NOAA had an oil fate model and a multimedia exposure design but it was flawed.

A chemical engineering colleague offered the exposure design protocol: use the ratio of oil spilled to the total volume of Gulf water. And presumably to compare the concentration to oil dose-response curve for baby oysters. The outcome was, "see, there is no problem dude". That is a true story. Was this instantaneous, completely mixed GOM waters exposure model the one BP's used? Maybe.

<u>Process Safety.</u> Flaring gas, was it a manufacturing upset or the incineration of waste or just a convenient way to dispose some off-specification product? Like a continuous 200 foot high, 4 th of July Roman candle it lit up the night sky for a week. What a carbon dioxide foot print signal that must have been! In happened, I enjoyed it from my home a few miles upriver. When I called on a previous flaring event, there are several each year, I was told that a compressor went down. If so, clearly the need for a flare was either due to a poor chemical engineering process design or poor process control design. If not, just how many human errors can result in the same event occurring over and over and over year after year?

Exposure comes at you from all sides when you live in the commons. We need the best source-to-dose exposure designs to address all types of releases. Who besides us EESs types can produce these?

Thibodeaux, LT, KT Valsaraj, V John, K Papadopoulos, L Pratt and N Pesika. 2011. Marine oil fate: knowledge gap, basic research development needs: a perspective. Env. Eng. Science. Vol. 28, No. 2, p. 87-93.

WHAT DOES IT MEAN TO BE ME?

Disruptive technologies and development engineering **are not peripheral to the profession today.**

The Boiler and Pressure Vessel Code, first published in 1915, was for many years an emblem of ASME and representative of the discipline of mechanical engineering. Our role was clear: Mechanical engineers worried about welding, gears, sprockets, pistons, and valves. Big things that move stuff.

Today, our discipline is changing and the role of a mechanical engineer is no longer so easily defined. There are external pulls—the advent of highly capable, low-cost microcontrollers, hobbyist 3-D printers, and drone kits that turn kids into pilots and programmers. These disruptive innovations are reducing the entry barrier for individuals to engage in engineering innovation and invention.

There are internal pulls within our profession. Students in engineering colleges around the world are no longer satisfied with discipline-specific, technical information cramming, while employers are demanding graduates who are better prepared to be well rounded professionals and are willing to compensate for any technical deficiencies with on-the-job training.

ASME's own *Vision 2030*, published in 2012, highlights some discrepancies between student and industry expectations and the reality of many ME curriculums today. "Mechanical engineering education programs should be configured somewhat more flexibly in ways that allow students to pursue their passion," the report says. "Systems-level and big-picture thinking is highly valued by industry. A more flexible, holistic undergraduate curriculum with a strong professional skills component integrated across the curriculum is envisioned. ... We suggest that undergraduate programs be designed with the expectation that most technical specialization and depth will come later."

Some leading universities are responding. At the Massachusetts Institute of Technology, the ME department mission considers giving "students the broad skills set they need to pursue their goals—whether that means working as an engineer, founding a company, continuing on to graduate study and research, or going to a professional school to study medicine, business, or law."

THE MOTIVES STUDENTS TODAY GIVE FOR STUDYING ENGINEERING ARE BOTH TECHNICALLY GROUNDED AND DEEPLY PERSONAL.

But others resist these changes. A faculty discussion in my department a few years ago circled around how we could best evaluate our effectiveness as educators. The criterion was simple: Are our alumni employed in positions with "mechanical engineer" in the title? If so, we've succeeded. If not, we've failed.

We discussed that many people with mechanical engineering degrees go on to medicine, law, and business, and within a few years are running companies, labs, and influential public sector organizations.

No one called any of these outcomes failures, but some held firm that our mission was to teach pure, traditional mechanical engineering.

I recently surveyed 66 Portland State University juniors on why they chose to enroll in mechanical engineering. They spoke not only in terms grounded in technical vocabulary, such as "systematic problem solving," but also of personal motives—impact, society, and making life better.

How does this affect professional practice? One example is the decade-long trend in students and young professionals attracted to humanitarian applications of their skills. Since 2002, when Engineers Without Borders-USA was founded (and I joined the first chapter), nearly 15,000 professional and student engineers have engaged in poverty-reduction efforts.

Indeed, the Boiler and Pressure Vessel Code may soon have to share room on the bookshelf (or favorites bar) with the Engineering for Change Solutions Library, a guide ASME is developing along with Engineers Without Borders-USA, IEEE, and members, including myself, of the academic, design, and implementation communities working to apply technology in developing countries.

These are not 'nice to have' extracurricular activities. These are purpose-driven career paths. **ME**

EVAN THOMAS is an assistant professor of mechanical engineering at Portland State University, COO of DelAgua Health, and CEO of SweetSense Inc.

MAINTENANCE MATTERS

Funders of global development programs **continue to incentivize construction.** But the most cost-effective interventions often involve **helping communities maintain what they already have.**

Driving along rural dirt roads in many developing countries, you see frequent evidence of the generous intent of global humanitarian aid agencies. Most tangible are hand-driven water pumps that dot the landscape.

These pumps are the concrete and steel outputs of a global intent to provide more clean water to more people. Thousands, funded and implemented by organizations large and small, are installed every year in developing countries.

But, sadly, you can never predict whether the next water pump you pass will be surrounded by people, often women and children, filling their jerry cans, or will stand as a decrepit artifact of wasted resources.

Studies show that between 30 and 80 percent of water pumps fail within a year of their installation. While the proximate failures may be a leaky seal, a broken riser, or a missing handle, these are only symptoms of the ultimate failure in how we fund, incentivize, and monitor these efforts.

Some experts suggest that for the cost of installing a new hand pump, operation and maintenance could be funded on its neighbor pump for a century. Or, put another way, an implementer with 500 installed pumps, could choose either to install 100 new hand pumps in a year or to maintain the original 500 for 20 years.

But the choice is possible only if funders can be persuaded to consider maintenance as interesting as new construction.

Instead, funders continue to focus on construction, and sustainability is usually addressed through "participatory community development," where local communities are, in theory, empowered to manage their own water supplies. In reality, this approach has often not resulted in cost effective interventions.

And these challenges exist not just for hand pumps, but for a myriad of health and environmental interventions both in developing and developed countries.

Some organizations are now testing alternatives that focus on outcomes rather than intent. Instead of pushing money toward projects based on promises, some implementers are showing how funders could support programs that demonstrate successful results and not just good intentions.

HOW CAN FUNDERS SUPPORT PROGRAMS THAT DEMONSTRATE SUCCESSFUL RESULTS, NOT JUST GOOD INTENTIONS?

Technology can also play a role. Our team at Portland State University has designed sensors that are connected to cell phone networks to automatically report to the world how things are going with interventions like water pumps.

With support from the U.K. Department for International Development and the GSM Association and in partnership with Living Water International and the Rwanda Ministry of Natural Resources, our team is testing new approaches.

This summer we're installing over 200 sensors and running a study of three different models for maintenance of hand pumps. We're going to compare the current model of operation and maintenance against two others. One experiment is a "call us" model that requires communities to report pump outages, and the other is an "ambulance service" model in which the sensors directly notify technicians that maintenance is required. Data will be collected by sensors in all three models, but only in the ambulance service case are the technicians going to see what the sensors are saying.

With over half of water pumps failing in some countries, if we reduce that failure rate even by a quarter through better maintenance and accountability, these fancy sensors will pay for themselves.

These and other approaches can start to align intent with impact, and start to ensure that pictures of kids drinking clean water match the reality on the ground. ME

EVAN THOMAS is an assistant professor of mechanical engineering at Portland State University, COO of DelAgua Health, and CEO of SweetSense Inc.

MAKING GAINS IN RWANDA

It will take new business models, not small donations, **to provide meaningful development.**

Nearly a billion people in the world drink dirty water. Two billion don't have a sanitary toilet. Three billion use campfires every day. Governments and charities spend billions of dollars every year to address these problems. And there are big successes in some places, but more innovation is needed.

In Rwanda, most rural villagers drink untreated water and burn firewood on open stoves. For the past ten years, our team has been learning how to address these challenges. In 2014, we reached nearly half a million people with water filters, improved cookstoves, and extensive health education. In 2015, we are on track to reach another two million people.

In the last three months, we've had a staff of nearly 1,000 working across the western province of Rwanda, a 6,000 square kilometer area, distributing filters and stoves at 400 community meetings and visiting nearly 110,000 homes. Working with the Rwanda National Police and the Ministry of Health, we moved 220,000 products across muddy roads and into homes.

So why Rwanda? Almost 20 years ago Rwanda suffered a genocide that killed nearly a million people. Some may still think of Rwanda as failed state.

In fact, Rwanda today is considered among the least corrupt countries in Africa. It has one of the fastest GDP growth rates in the region, and has the fastest annual decline in child deaths globally. But still, pneumonia and diarrhea remain the leading causes of illness and death among children in Rwanda.

Our company, DelAgua, is a for-profit social enterprise using an innovative funding mechanism to distribute the filters and cookstoves free of charge to the poorest 25 percent of households across the country. Our business model involves United Nations carbon credits—generated from the projects themselves and sold to international buyers. This creates pay-for-performance system where we are incentivized to have an impact because that's how we get paid.

The United Nations carbon credit market is a $120 billion a year industry. More than 90 percent of credits come from just five countries, and less than 2 percent from all of Africa. My team was the first in the world to commandeer this system and apply it to household drinking water.

This approach stands in contrast to a typical approach in poverty reduction programs globally. Typical funders, from church and community groups, universities, all the way up to the U.K. Department for International Development, the U.S. Agency for International Development, and the World Bank, provide funding for projects that are intended to improve the health and livelihood of people in developing communities. These include things like water pumps and water filters, cookstoves, latrines, and solar lighting systems.

This funding usually lasts a couple of years, and during that time the implementers will try to evaluate their impact. If you can afford it, you might run a randomized controlled trial to see if the projects are improving health or other outcomes. But, usually sooner rather than later, the funding runs out, and everyone moves on.

This has resulted in sad statistics. Some estimates suggest that at least half the water programs in some African countries are broken a few years after they're installed.

Our intention is to instead lay the foundations for a long-term presence in Rwanda, making substantial contributions to public health and economic development.

The program, called Tubeho Neza (meaning "let us live well") is a partnership between DelAgua and the Rwandan Ministry of Health. We recruited more than 850 community health workers to manage the distribution and help households with installation and maintenance. This year, we'll be back in nearly every household reinforcing healthy behaviors.

Independent researchers from the London School of Hygiene and Tropical Medicine and Emory University are running a randomized controlled trial and using cellular sensors, household surveys, and other techniques to measure uptake, correct usage, and water and air quality improvements.

Many of us have heard of the idea that a donation of something like $25 will bring water to someone for his or her entire life in a developing country. But $25 donations haven't solved this problem yet.

We need new and better business models, to engage businesses in these challenges, in a way that can help pay for ongoing services. We need payments to be based on performance, and not pictures and promises. ME

EVAN THOMAS is an assistant professor of mechanical engineering at Portland State University, COO of DelAgua Health, and CEO of SweetSense Inc.

AEESP Grand Challenge Workshop June 13, 2015.
Some input from John E. Tobiason, PhD, PE, BCEE

"Developed" World Challenge:

I think that within the Environmental Engineering and Science (EES) community, and in society, we may have a looming problem of a disconnection between the research topics being pursued in academia and the continuing need for education and training of designers and operators of facilities for changing the quality of routine water flows that humans interact with, i.e., what we have traditionally referred to as drinking water, wastewater, and stormwater treatment systems. I sense that the majority of research funding from NSF and other agencies is not now in the area of treatment process research (here I include highly engineered as well as what some would call "natural" processes), or is perhaps is in areas that have either a very long or perhaps infinite time to resulting application. The root of the problem may well be the very low value of water in terms of willingness to pay by users, resulting in under-educated and under-trained staff being tasked with operation of sophisticated chemical/physical/biological process facilities, often without the appropriate monitoring equipment to assess performance. There needs to be sufficient research or training funding for faculty to support students to lead to the outcomes which traditionally lead to successful academic careers. Within this challenge is the need for academia and research institutions to whole-heartedly embrace the reality of "one water" when addressing assessment and control of water quality. I think that our education and research need to emphasize the broad and universal applicability of fundamental understanding of physical/chemical/biological processes to all aspects of the water cycle (especially with respect to water quality); too often I think graduate students are very narrowly educated on a specific topic (that may have no applicability in their lifetime) and may have trouble providing appropriate education to EES students should they become faculty members.

"Developing" World Challenge – so maybe not relevant to US NSF/NRC??

Simple common challenge: providing appropriate sanitation and potable water supply to everyone. The challenge is to do this at lower cost than the traditional developed world approach, and perhaps this is mostly a political, social and economic challenge, not a technical one for the EES community. However, I think that rational and careful assessment of the impacts of specific approaches on water quality and human health may lead to lower cost approaches that are widely adopted. Perhaps the US EES community can have a significant impact. I know many in AEESP already work in this area, but there are not a lot of available resources.

AEESP Grand Challenge Workshop June 13, 2015.
Some input from John E. Tobiason, PhD, PE, BCEE

"Developed" World Challenge:

I think that within the Environmental Engineering and Science (EES) community, and in society, we may have a looming problem of a disconnection between the research topics being pursued in academia and the continuing need for education and training of designers and operators of facilities for changing the quality of routine water flows that humans interact with, i.e., what we have traditionally referred to as drinking water, wastewater, and stormwater treatment systems. I sense that the majority of research funding from NSF and other agencies is not now in the area of treatment process research (here I include highly engineered as well as what some would call "natural" processes), or is perhaps is in areas that have either a very long or perhaps infinite time to resulting application. The root of the problem may well be the very low value of water in terms of willingness to pay by users, resulting in under-educated and under-trained staff being tasked with operation of sophisticated chemical/physical/biological process facilities, often without the appropriate monitoring equipment to assess performance. There needs to be sufficient research or training funding for faculty to support students to lead to the outcomes which traditionally lead to successful academic careers. Within this challenge is the need for academia and research institutions to whole-heartedly embrace the reality of "one water" when addressing assessment and control of water quality. I think that our education and research need to emphasize the broad and universal applicability of fundamental understanding of physical/chemical/biological processes to all aspects of the water cycle (especially with respect to water quality); too often I think graduate students are very narrowly educated on a specific topic (that may have no applicability in their lifetime) and may have trouble providing appropriate education to EES students should they become faculty members.

"Developing" World Challenge – so maybe not relevant to US NSF/NRC??

Simple common challenge: providing appropriate sanitation and potable water supply to everyone. The challenge is to do this at lower cost than the traditional developed world approach, and perhaps this is mostly a political, social and economic challenge, not a technical one for the EES community. However, I think that rational and careful assessment of the impacts of specific approaches on water quality and human health may lead to lower cost approaches that are widely adopted. Perhaps the US EES community can have a significant impact. I know many in AEESP already work in this area, but there are not a lot of available resources.

Education, Engagement, Sustainability, and Environmental Engineering

Maya A. Trotz, Associate Professor, University of South Florida

Forty-five states, four territories and the District of Columbia, recently adopted the Common Core State Standards, the first national standards for mathematics and English language competency in the US. Designed to be robust, relevant to the real world, and reflective of the knowledge and skills needed for success in college and careers, these standards overlap with 50% of the Next Generation Science Standards (NGSS) that are currently under evaluation by 26 states. Sponsored by the National Research Council and supported by many professional science organizations, the NGSS present four disciplinary core ideas (Physical Sciences, Life Sciences, Earth and Space Sciences, and Engineering, Technology and Applications of Science) with many subthemes that intersect with engineering and design challenges facing sustainable urban infrastructure. The time is ripe for a concerted transdiciplinary effort to develop, test, evaluate and improve K-12 education policies and practices to align with and increase resilience and sustainability of urban systems. This would require a new approach to university K-12 relations and a commitment of faculty to aligning their research, education, and outreach, with local schools.

While K-12 engagement of environmental engineers will help to develop a next generation of more holistic global citizens in the US, more must be done to meaningfully engage with others now. Our field is too important to be associated with US infrastructure that receives D grades today, with its inability to provide potable water to 750,000 people in the world, and with its inability to reduce by 50% the number of people without access to safe sanitation since 1990. A concerted effort at public relations and marketing is needed along with a commitment to change our discipline so that our courses and research provide meaningful opportunities to move out of our disciplinary comfort zones and engage, through social media even, with diverse populations in the public domain.

Connections Between Measurement Science and Environmental Engineering – How low can we go in terms of contaminant detection and what does it mean?

Peter Vikesland, Virginia Tech, Blacksburg, VA

Many techniques used for the detection of environmental contaminants have been in use for decades. Continual advancements in these existing techniques and the development of new techniques over time have led to an ever-improving capacity to detect analytes at trace levels. These improvements now enable detection of analytes as diverse as fluorochemicals, cyanotoxins, pesticides, and disinfection by-products (THMs, NDMA, chloropicrin) as well as a diverse array of different organisms. Not only can we now detect these analytes at ever-decreasing concentrations, but we can look for them in an ever expanding set of environments. With the advent of new techniques (nanotechnology enabled; next generation sequencing approaches; protein nanopores; etc.) and the continual improvements obtained with existing methods the environmental monitoring community is now at the cusp of single molecule or single organism detection. The implications of being able to detect analytes at such low levels raises many questions that the environmental engineering and science community should begin to consider:

1) How low is too low? Just because we can detect an analyte in a particular environment does not necessarily mean that it is important from an ecological or public health perspective. The nature of the analyte and its potential toxicity within that environment should be considered.
2) At what levels should we require an analyte to be reported? The general public is most comfortable thinking that an environment is uncontaminated. However, as we push detection levels lower and lower it is becoming clear that there are potential contaminants of concern in many ‘pristine’ environments. (For example, the recent reports of plague in the NYC subway).

A proactive approach to consider these questions (and many others) would be of great utility to the environmental engineering and science communities as the world further increases water reuse and other approaches in response to the need for global sustainability.

Contribution for Grand Challenges Workshop at AEESP 2015

Title: Incorporating Human Dimensions in Environmental Sustainability Planning

Contributor: Dr. Kristina Wagstrom, University of Connecticut

Problem Statement

It has become abundantly clear that when developing environmental management plans, it is important to consider the cultural, social and behavioral aspects of the problem alongside the environmental data and research findings from physical scientists and engineers. Traditionally, environmental management has focused on decisions made by scientific experts with less focus put on the input from non-specialist community members. Recent research has shown that the impacted community is more likely to support environmental policies developed with consideration for the larger scale cultural and organizational influences through involved partnerships[1,2]. Decisions must also consider perceived equity, both in terms of available resources and pollution burden. As part of this, it is necessary to consider the relative vulnerability of different populations to potential environmental changes[3].

Needs

Multidisciplinary teams are needed to address these challenges. The community needs programs that actively encourage and facilitate the formation of interdisciplinary teams of physical scientists, social scientists, economists, and engineers. Over time these partnerships will add to the analyses tools already being developed and provide more policy relevant research[4].

Well defined steps towards addressing environmental equity in policy development will also lend guidance to these multidisciplinary teams in developing more robust approaches to account for population inequities in environmental sustainability decisions.

Policy development would benefit from community involvement from two types of programs: (1) those to educate stakeholders and impacted communities on potential new policy decisions and (2) those to arrange significant involvement of the community in the planning phases.

Major Obstacles

There are several challenges associated with bringing the human dimension more fully into the development of environmental sustainability decisions: (1) there is a significant learning curve is likely as researchers from different sectors develop new collaborations, (2) it is important that policy makers are trained in working with the public, and (3) agencies will need defined methods for approaching situations with large numbers of stakeholders with potentially competing interests.

References

[1]Blount, B.G., Pitchon, A. (2007). *Human Organization*. 66, 2.
[2]Charnley, S., Engelbert, B. (2005). *J. of Environmental Management*. 77.
[3]Jäger et al. (2007). *Vulnerability of People and the Environment*. UNEP GEO4 Report.
[4]Charnley, S., Durham, W. (2010). *American Anthropologist*. 112, 3.

GRAND CHALLENGES IN WASTEWATER MANAGEMENT IN DEVELOPING COUNTRIES

Hongtao WANG*, Fengting LI
UNEP-TONGJI Institute of Environment for Sustainable Development,
College of Environmental Sciences and Engineering, Tongji University,
Shanghai, P. R. China, 200092 E-mail: hongtao@tongji.edu.cn

Most developing countries are facing severe challenges in wastewater management. According to the “Wastewater Management- A UN-Water Analytical Brief” released in February 2015, on average only 20% of globally generated wastewater has been treated properly, with 70% in developed countries and 8% in developing countries. Nearly 70% of industrial effluent is untreated in developing countries. The rapid population growth, urbanization, economic growth and land use change are making the challenges of wastewater management in developing countries more serious.

In past decades, great achievements have been realized in safe drinking water and basic sanitation in developing countries within the framework of Millennium Development Goals (MDGs). However, one major problem of MDGs is that the wastewater management has been overlooked. As the MDGs come to its deadline in the year of 2015, it is recognized that a Post-2015 Development Agenda is needed to improve the wastewater management in developing countries.

In recent years, with the coordination of the United Nations Environment Programme (UNEP), we investigated tens of wastewater treatment plants in China, Vietnam, Cambodia, and African countries. It was found that current practices for wastewater management in these countries are insufficient and need improvement. Typical challenges include weak governance, insufficient infrastructure, lack of monitoring and analyzing instruments as well as standards, poor operation and maintenance, and lack of professional engineers and managers. To address these challenges, joint efforts are needed, including improving governance and management, transforming to green economy, innovating technologies, improving operation and maintenance, harvesting energy from wastewater, promoting public participation, establishing water quality standards, and strengthening capacity building.

Reference:

Wastewater Management- A UN-Water Analytical Brief.
http://www.unwater.org/publications/publications-detail/en/c/275896/

Grand Challenge: Maintaining ecosystem services in agriculturally rich watersheds under pressure from increased food production requires a solutions-oriented, science-based, adaptive management research program.

Linda Weavers and Dion Dionysiou

NATURE OF THE PROBLEM. Despite the progress made in dealing with point sources of contamination in the 1970s-80s, it is now clear that impaired water quality in the US (and around the world) is attributable to a range of causes, including non-point source pollution, climate change, municipal water treatment, and invasive species. In particular, the demand of producing food for a growing population is causing local and regional tradeoffs in water quality in the form of direct contamination by solubilized nutrients, antibiotics, pharmaceuticals, and other compounds of poorly understood toxicity and in the form of emergingphenomena such as harmful algal blooms (HABs), hypoxic "dead zones" and drug-resistant microbes. Moreover, deterioration of quality of water in aquatic systems affects ecosystem health, recreational activities, fishing and tourist industries, as well as agricultural practices when such aquatic systems serve as sources of water for irrigation.

The limited success of well-known, decades-long efforts to solve downstream contamination issues (e.g., Chesapeake Bay, Gulf of Mexico, Lake Erie) demonstrates the scientific, technological, and social complexity of managing these impaired systems. The sources of contamination are spatially distributed, the response time between mitigating actions and results can be decades or longer, and results can only be measured cumulatively in space and through time. Further, the social and economic incentives between stakeholders at source, tributary, lake and treatment locations in the watershed are often decoupled and in opposition, pitting the urban core against the rural agricultural communities. Policy makers are still ill-equipped to deal in a systematic fashion with the causes of the degraded water or its public health effects. Predictive models and real-time field sensors are in their infancy; science-based protocols for treating emerging contaminants at plants are lacking; and multi-scale science-based adaptive management has yet to be fully embraced despite the inevitability of societal and ecosystem changes. It is for these and other reasons that the National Academy of Engineering and the National Research Council have identified access to clean water, managing the nitrogen cycle, and engineering the tools required for science discovery as Grand Challenges.

Science related to solving water quality issues are aligned with these challenges, but this systems issue from end to end (field to faucet) needs a multi-system solution approach that involves better agricultural practices, improvements in weather forecasting, efficient water quality management, and low cost engineered processes through deeper understanding of the science and transformative approaches of the interrelated food-water-energy-climate nexus challenges.

Design for resilience and for maximum resource efficiency

Monroe Weber-Shirk
Cornell University

The core technologies for treating drinking water that were developed in the early 1900's have failed to providing safe drinking water to about 25% of the global population. The available technologies (prior to the Cornell AguaClara inventions) were too expensive, required too much energy, and have too short a life. The challenge and the opportunity is to continue to reduce the resource demand for drinking water treatment and to extend this research/invent/design/engage approach to other grand challenges including sanitation and energy.

We have an opportunity to develop the fundamental science of water treatment so that we can for the first time begin to optimize the design for both capital and operating costs. We will select treatment processes that are cost effective and energy efficient. As an increasingly large number of organizations have begun working to devise new methods for providing safe drinking water there has been a tendency to develop increasingly expensive and energy intensive water treatment processes. For example, the National Academy of Engineers suggests using distillation as a means to provide safe drinking water in rural communities. The failure to evaluate the entire system and take energy and cost into consideration reveals a grand challenge as we educate the next generation of engineers.

The rapidly decreasing life of water treatment infrastructure is the result of a focus on "high tech" that made it possible to control a water treatment plant using a smartphone, but had the unintended consequence of significantly reducing the mean-time between failures. The high failure rates are particularly challenging in the Global South. According to the World Bank official responsible for water infrastructure in Africa the average life of package water treatment plants is now less than 3 years. The challenge is to reverse the tendency to design infrastructure with shorter and shorter useful life.

The solution for the short lived high tech infrastructure is to redesign infrastructure for resilience by reducing the complexity and replacing high tech electronics and mechanical controls with high tech hydraulics. This will require more sophisticated designs that are simpler to maintain.

The energy and resource costs of infrastructure need to be part of the system design. Students need to learn that distilling water is not energy or resource efficient and they need to know that a water treatment plant that has a 3 hr residence time will require too much land and concrete to be a viable design. The focus on resilience, resource efficiency, and design for the operator will become increasingly important as economies contract and it becomes necessary to further reduce CO_2 emissions.

Transform Universities into Innovation Systems

Monroe Weber-Shirk
Cornell University

A grand challenge is to reintegrate Research, Invention, Design and Engagement (RIDE) as a core part of our undergraduate and graduate curriculum. The challenges that we face require all the creativity we can muster, high performing teams, collaborative open-source idea sex, and a long term commitment to develop the knowledge necessary to methodically move toward the goal. The RIDE model integrates undergraduate research, project based learning, and a global network of partner organizations. The RIDE innovation system has been implemented and refined at Cornell University since 2005.

The RIDE curriculum was crafted to facilitate peer-based learning and a project-based course sequence for knowledge generation, a theory course for knowledge synthesis and multiple modes of knowledge exchange between the university team and implementation partners. The innovation system is designed to maximize distributed intelligence and to reduce dependency on the leadership team. The ability of a 50 member team that includes undergraduates, M. Eng., and M.S./Ph.D. students to continue to invent new treatment processes, reduce costs, and enhance performance suggests that this innovation system approach could be adapted to solve other global challenges.

GRAND CHALLENGES AND OPPORTUNITIES:

Development of Microbial Cell Factories for Waste-Based Biorefinery

Na Wei
Department of Civil and Environmental Engineering, University of Pittsburgh

Modern society is generating vast amounts of wastes (e.g. industrial, agricultural and municipal wastewater and solid residues), placing considerable strain on the environment and ecological resources. Meanwhile, there is growing concern about meeting the ever-increasing demands of energy and commodity products with limited, non-renewable resources. An on-going paradigm shift in environmental engineering and science is to view wastes as valuable renewable resources rather than pollution sources or economic burdens. With the heightened awareness of environmental concerns and economic challenges associated with fossil fuels and conventional chemical refinery, waste-based biorefinery is of increasing interest and presents an opportunity to provide new sources of fuels and chemicals while meeting environmental quality goals.

Under the biorefinery concept where the value of each stream is maximized, the focus of waste treatment will be no longer "how to remove" but instead "how to valorize". Namely, it is desirable that waste treatment generates fuels and/or commodity chemicals while recycling water and nutrients. However, critical challenges exist in developing effective, efficient and inexpensive technologies to convert organic compounds in waste feedstocks to desirable value-added products that are economically competitive. Biological conversion can be a promising alternative as it proceeds under mild conditions, has relatively high efficiency and no byproducts, requires less energy input and low cost compared to (thermo)chemical conversion processes. Particularly, there has been a substantial biotechnology push over the past decade in transforming microorganisms into the "cell factory" for sustainable production of a wide range of fuels/chemicals [1]. Microorganisms play essential roles in chemical transformation in nature and possess extraordinarily diverse metabolisms. It is envisioned that the emerging biotechnologies to construct robust and efficient microbial cell factories will allow us to harness the diverse genetic reservoir of microorganisms and their functional capacity to make the waste-based biorefinery concept come into fruition (**Figure 1**).

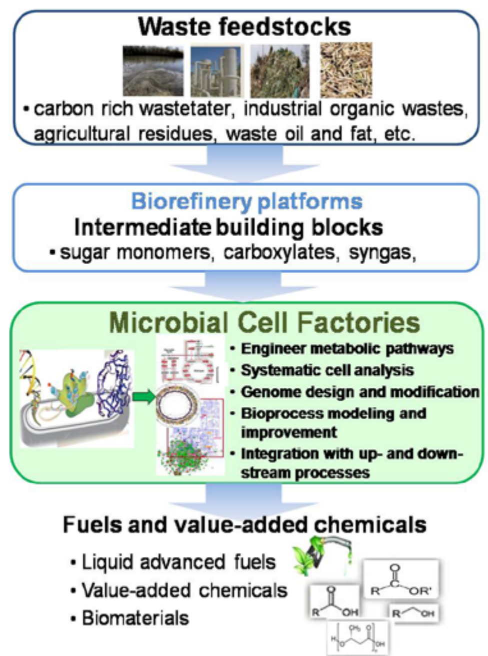


Figure 1. Microbial cell factories for waste-based biorefinery (key scientific challenges listed in green box).

The microbial cell factory has to meet the requirements for high conversion rate, product yield, and titer, so that the bioconversion process can be economically viable. To this end, metabolic engineering is a powerful platform technology to transform microbes to super cell factories through designing and modifying microbial metabolism genetically. The key methodology here is applying synthetic biology and systems biology techniques as well as metabolic modeling tools to implement new bioconversion capacity unachievable by native microbial metabolism. Advancements in molecular biotechnology and genetic toolkits provide unprecedented opportunities to explore microbial biocatalytic potential and engineer desirable cell factories for waste-based biorefinery, though tremendous scientific challenges await us (with some highlighted in **Figure 1**).

1.Peralta-Yahya, P. P.; Zhang, F.; del Cardayre, S. B.; Keasling, J. D., Microbial engineering for the production of advanced biofuels. *Nature* **2012,** *488*, (7411), 320-328.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

Weile Yan, Texas Tech

The challenges faced by EES are manifold. On one hand, social-economic developments have led to global-scale changes such as population growth, increase in personal income (particularly in developing countries), urbanization, and globalization. These changes will likely impose more stress on the environment. For example, the demand for higher life quality will inevitably increase energy consumption, which is tied to increased resource exploitation, water consumption, and environment pollution. Will EES be able to help countries to formulate solutions to reach a good balance between development and environment conservation?

On the other hand, the rapid expansion of knowledge domains in different fields has led to an explosive increase in science breakthroughs and technological innovations. While S&T advancements are the primary driving force for societal development, there are always unpredicted risks. How can environmental scientists and engineers be able to stay informed of the progress at the frontier of S&T? How can we proactively safeguard the environment in the face of the next big innovations? What are the limitations of LCA and other models in predicting the environment burdens of new products/processes? What will be the roles of future EES education – will a branch of EES evolve into a super-discipline, taking inputs from and feeding knowledge to all other science and engineering disciplines on sustainability and env. risk management?

Here are some other major challenges as well as opportunities:

Technology. The latest developments in computational analysis and data management will provide opportunities to develop quantitative, system-level understanding of pollutant-environment interactions. Nonetheless, there are many technical challenges ahead before one can effectively harness the new found power. For example, our understanding of local (e.g. molecular, cellular) processes is still quite limited. Even with better fundamental insights, it may be very difficult (if not infeasible) to capture their complex interactions in a macroscopic system.

Technology has also created a new set of challenges for EES educators. Will on-line education replace classrooms to become the mainstream learning mode? What skills do students need to acquire if all engineering computations can be delegated to software tools? What is the value of conventional text-book-learning when internet provides access to a richer and more updated set of information at no (or lower) costs?

Globalization. Globalization has accelerated the rate of knowledge exchange. To a great extent, this has increased the efficiency of R&D and makes the job market of any technical profession much more competitive. What is the mission of undergraduate and graduate education in EES in this context? What leverage can educational institutes in the developed countries, with more mature education infrastructure and more advanced R&D status, take to gain an edge? Along a different line, how can international collaboration creates new opportunities for EES educators and practitioners in both the developing and developed regions?

Grand Challenge: Critical Thinking Skills of Future Engineers and Scientists
Mark Weir, Temple

Engineers and scientists are most productive due to their problem solving abilities and critical thinkingskills. Problem solving abilities allow engineers and scientists to market and apply themselves not only in the engineering and science fields, but disparate fields as well. The skills and capabilities to distill a problem to its minimum solvable segments and address these systematically is a learned skill and art. This skill allows engineers and scientists to experience success in a wide array of fields and continue to have an impact throughout the nation and world. As important is the ability to think critically. Critical thinking allows for the solution of problems that have not been addressed yet, therefore, allowing us proactive solutions rather than simple reactionary solutions. With the impacts of climate change becoming apparent and set to intensify this skill is vital. From the water-engineering front, variable water quantity and quality is becoming the norm. Problem solving skills will allow for our adaptation, however, the ability to think critically allows us to stay ahead of additional complications from adapting current treatment paradigms.

Critical thinking can be instructed over time, however, a baseline before entering higher education allows us as professors more time to expand this skill. A worrying prospect that can be seen from current student pools is a decrease in critical thinking skills. As students have been in the No-Child-Left-Behind (NCLB) system for years it can be noted the decrease in these students' critical thinking skills when entering higher education. Since this skill cannot be measured with a standardized metric, this is difficult to track, additionally complicated in the light of socioeconomic differences. It has been noted at institutions of higher education that typically draw from more benefited socioeconomic levels (*i.e.* students from private academies and schools) their critical thinking skills have not altered as much. However, at higher education institutions that serve students from less benefited socioeconomic statuses (*i.e.* students from typically impoverished urban public schools) this decrease is more marked. There is a possible trend here in NTLB leaving students ill-prepared for the rigors of an engineering education or to be forward thinking engineers and scientists we need for future challenges. With the institution of common core standards this challenge to engineering and science educators may be exacerbated.

In this brief narrative, there are essentially two grand challenges. First, how do we as engineering and science educators overcome a potential decrease in baseline critical thinking skills of our pupils? Second, how do we address the continuing disparity of engineering and science higher education preparation based on socioeconomic status? Innovation crosses socioeconomic, racial, gender and sexual orientation. We have done fairly well in expanding racial and gender demographics of our fields and pupils. However, innovation and care of the environment should and cannot become something that is financially blocked to a segment of the population based on socioeconomic status. Students have increased financial stresses in achieving a higher education degree but also are potentially limited from poorer preparation outside of the basic STEM knowledge. How do we address those students with the drive and passion, but perhaps not this crucial layer of preparation? This must go beyond remedial classes given the ever-increasing costs of higher education, we as educators must find a new path.

Trigger for systems microbiology in environmental engineering

David Gregory Weissbrodt[1] and Mari-Karoliina Winkler[2]
[1]Delft University of Technology and Aalborg University, [2]University of Washington

Why are microbes an opportunity for engineering sustainability?

When closely looking at microbial architectures in wastewater treatment systems (floc-, granule-, biofilm-based) under the microscope one can get strongly fascinated by the extent of organization and functionalization of their underlying microbiomes (4, 13, 15). These confined ecosystems comprise a degree of phylogenetic and genetic functionality that can extensively be harnessed in innovative environmental biotechnology systems (10). Novel open mixed-microbial cultures technologies are continuously re-invented based on key novel features identified at microbiology level in the vision of achieving technological sustainability (8). In this perspective, novel approaches on microbial community engineering allow for an enhanced management of the microbial resource (2, 11). Microbes are forming the essence of environmental biotechnologies that contribute to shaping a bio-based and sustainable society.

Why engineers might care about microbial ecology?

The field of environmental process engineering has continuously evolved from different approaches of sanitary engineering, civil engineering, chemical engineering, environmental engineering, and more recently life technologies (5). Environmental bioprocess design therefore relies on a close connection of these different fields and are linked to the unique biochemistry and physiology of the microorganisms that make a complex system (7). Whereas this concept is not new, the recent fundamental breakthrough of the molecular bioscience has dramatically stimulated the reappraisal of the field. Depending on the disciplines, open mixed microbial processes are considered in black-box or white-box approaches. Independently of any disciplines, the success of any environmental bioprocess relies on the health state of the microbial ecosystem, which is impacted by the periodical variations in environmental and operational variables. The main duty of all disciplines is therefore to generate optimized living conditions for the microbial unit.

New-generation methods for next-generation environmental engineering processes

The microbial ecology science has strongly evolved over the last century from black-box to high-resolution understanding of microbial communities by means of major developments in the field of molecular biology methods (6). The advent of high-throughput sequencing and bioinformatics workflows is a key milestone for gaining system level insights into the phylogenetic and metabolic features of microbial communities, a discipline also referred to as "ecogenomics" (1, 9). New-generation bioanalytical technologies are thoroughly evaluated with higher degree of standardization, as pre-requisite for robust implementation in the applied perspective. In the engineering branch, latest research efforts target the potential for integration of the high-resolution information gained at microbial community level as base for process understanding and design (12, 14).

Challenge: Toward a fusion of systems microbiology and environmental engineering

The Grand Challenge for shaping sustainable microbial communities therefore consists in unifying the two disciplines of environmental engineering and systems microbiology that display at first glance significant disconnection in terms, concepts, and proficiency. In this context, the following three key applied questions arise. *First*, can genetic signatures of microbial communities, coding for lineages and metabolic functions, be harnessed to better anticipate process behavior under specific environmental and operational conditions? *Second*, how can new-generation methods be considered for direct and rational implementation on process site? *Third* – in an extended vision – can such methods potentially be integrated at line? This fascinating latter objective might specifically link with recent approaches of process engineering that include big-data mining and data-driven modelling in order to decipher the dynamic behaviors of biological wastewater treatment processes as basis for an enhanced real-time process control (3). Efforts can alternatively concentrate on the development and use of rapid biomarkers for determining how well microbes are doing and predicting process failures. The fields of granular sludge, aerobic-anaerobic ammonium oxidation, membrane bioreactors, and anaerobic digestion are four illustrations of the effervescence launched at the nexus of ecogenomics and environmental engineering in order to make a difference.

References

1. Albertsen, M., Hugenholtz, P., *et al.* (2013) *Nature Biotechnology* 31(6): 533-538.
2. Angenent L. T. and Kleerebezem, R. (2011) *Microbial Biotechnology* 4(2): 109-110.
3. Dürrenmatt, D.J. and Gujer, W. (2012) *Environmental Modelling and Software* 30: 47-56.
4. Flemming, H.-C. and Wingender, J. (2010) *Nature Reviews Microbiology* 8(9): 623-633.
5. Morgenroth, E., Daigger, G.T., *et al.* (2004) *Water Science and Technology* 49(8): 11-18.
6. Nielsen, P.H., Saunders, A.M., *et al.* (2012) *Current Opinion in Biotechnology* 23(3): 452-459.
7. Rittmann, B.E., Hausner, M., *et al.* (2006) *Environmental Science and Technology* 40(4):1096-1103.
8. Strous, M., Kuenen, J.G., *et al.* (2002) *Antonie van Leeuwenhoek* 81(1-4): 693-702.
9. Vanwonterghem, I., Jensen, P.D., *et al.* (2014) *Current Opinion in Biotechnology* 27: 55-64.
10. van Loosdrecht, M.C.M. and Brdjanovic, D. (2014) *Science* 344(6191): 1452-1453.
11. Verstraete, W., Wittebolle, L., *et al.* (2007) *Engineering in Life Sciences* 7(2): 117-126.
12. Vuono, D. C., Benecke, J., *et al.* (2014) *ISME Journal* 9: 425-435.
13. Weissbrodt, D.G., Neu T.R., *et al.* (2013) *Frontiers in Microbiology* 4:175.
14. Weissbrodt, D.G., Wells, G.F., *et al.* (2015) *Proceedings of IWA NRR 2015*. Gdansk, Poland.
15. Winkler, M.-K.H., Kleerebezem, R., *et al.* (2013) *Applied Microbiology and Biotechnology* 97(16): 7447-7458.

Sustainable urban communities: Transition of urban food, water, and energy supply by integrating decentralized systems into existing centralized networks

Weiwei Mo, Assistant Professor, University of New Hampshire

Ensuring sufficient quality and quantity of water, energy, and food supplies is critical to the continuous prosperity of our communities. In the US, development over the past century has created a dominance of large-scale centralized water, energy, and food supply networks. While centralized systems benefit from economies of scale, they have drawbacks pertaining to significant delivery/transmission costs, greater vulnerability in face of system failure and terrorism, and high dependency on non-renewable water and energy resources. These centralized systems have also created substantial interdependency among food, water, and energy resources: providing one resource requires or competes with other uses of the other two resources. This interrelationship is commonly referred to as the “food-energy-water nexus”. The food-energy-water nexus as well as the uncertain future global changes, such as climate change, population growth, economic development, land use change, and urbanization have imposed great challenges to the sustainable management of water, energy, and food supplies.

Integration of household or community-scale decentralized water and energy systems and urban agriculture systems into existing centralized supply networks could be a potentially viable strategy in delaying the need to renovate, expand, or construct new centralized systems as well as providing redundancies, resilience, and independence in face of a changing future. Decentralized systems refers to smaller-scale dispersed facilities that are located near or at the point of use. They can serve individual homes or communities and function independently or remain connected to a centralized system. Decentralized water supply systems usually utilizes alternative water sources, such as stormwater, graywater, or to a lesser extent, black water or separated urine (yellow water), while decentralized energy supply systems could potentially utilize a variety of renewable energy resources, including solar, wind, geothermal, biogas, biomass, and low-impact hydro to generate electricity or heat. Urban agriculture systems refer to small-scaled food production using household landscape, roof tops, and community gardens which is intended to fully or partially satisfy the food demand of each household. Given that around half of the domestic water use goes to residential irrigation, household landscape agriculture allows this amount of water to be beneficially used for food production and thus minimizes agricultural freshwater water withdrawal. Conversion of constructed surfaces (roof tops, asphalt) to vegetated food production would also increase albedo reducing urban heat island effects. Additionally, localized and self-maintained food production minimizes food waste and the need of food transportation. Such decentralized systems are much less financially restricted and more resilient to natural and physical security threats.

On the other hand, implementation of decentralized systems has barriers including the intermittent nature of the renewable resources as well as the low public acceptance on certain decentralized technologies. Economic, environmental, and social costs and benefits also vary across technologies and geographical locations, yet our understanding on such environmental and socioeconomic synergies and tradeoffs is still very limited. Water, energy, and food are usually considered as separate resources. Decision making and planning of these resources are usually conducted separately without considering the interactions and feedbacks among these resources. Hence, systematic and robust decision support tools need to be developed to inform the planning of integrating decentralized systems under heterogeneous settings.

E-waste and its management: the emerging global problem of our time

Paweł Weroński

E-waste, or waste electrical and electronic equipment, is a complex and fast-growing waste stream. It covers a large variety of products of different composition, posing a serious hazard to the environment, which makes e-waste very difficult to manage. Many electronic scrap components contain and release lead, cadmium, beryllium, or brominated flame retardants. Rapid innovation of information and communication technology products, their miniaturization and replacement, as well as falling prices are fuelling the increase of e-waste. More and more products contain a power supplier or battery. These are smart tools and toys, intelligent clothes, tooth brushes, medical equipment, and dispensers - to mention just a few examples. The collection and environmentally-sound treatment of e-waste is limited. Most nations still have no such e-waste management systems or the systems do not work efficiently. Consequently, a large part of e-waste ends up in non-separately collected household waste. A lot of the world's e-waste is shipped to developing countries. Then, crude techniques are often used to recycle materials and components, posing dangers to poorly protected workers and to the natural environment. This procedure has already led to environmental catastrophes in a number of places.

A precise determination of the amount of e-waste generated and collected in various countries across the globe is impossible. However, we can estimate the total amount of e-waste generated in 2014 to be 41.8 million metric tonnes (Mt)[1]. This e-waste is comprised of 12.8 Mt of small equipment (toasters, vacuum cleaners, electric shavers, microwaves, video cameras, etc.), 11.8 Mt of large equipment (clothes dryers, washing machines, dishwashers, photovoltaic panels, electric stoves, etc.), 7.0 Mt of cooling and freezing equipment, 6.3 Mt of screens, 3.0 Mt of small IT (pocket calculators, mobile phones, printers, personal computers, etc.), and 1.0 Mt of lamps. The annual supply of toxins from e-waste in 2014 is comprised of, among other substances, 2.2 Mt of lead glass, 0.3 Mt of batteries, and 4 kilo tonnes of ozone-depleting substances. Only 6.5 Mt of the 41.8 Mt of e-waste are documented and recycled with the highest standards. It is worthy to note that the intrinsic material value of global e-waste in 2014, dominated by gold, copper, and plastic contents, is estimated to be 48 billion euro. We can also predict that the total amount of e-waste is going to grow rapidly in the future. In 2018, this number will increase to 50 Mt[1]. Thus, there is an urgent need to protect our natural environment and to fully explore the potential of e-waste collection and treatment. We must successfully develop and enforce e-waste related legislation. We have to work out efficient ways to segregate and document e-waste collected. We also need to plan and create the necessary recycling infrastructure.

References

1. Baldé, C.P., Wang, F., Kuehr, R., Huisman, J. (2015), The global e-waste monitor – 2014, United Nations University, IAS – SCYCLE, Bonn, Germany.

Grand Challenges & Opportunities in Environmental Engineering and Science in the 21st Century

Title: **Be an agent of change rather than a reactionary agent**

Paul Westerhoff

Environmental engineering often deals with problems after they have been recognized (e.g., nutrient pollution, PPCPs, DBPs, PCBs, etc.). Consequently we have been viewed as the clean up people. Two approaches could be taken to change the trajectory of how we approach pollution.

First, environmental engineers need to develop rapid, scientifically sound, screening models (computational and physical/chemical/biological) that are capable of predicting known outcomes. Today we rely too heavily on Kow, for example, which is most valid for lower molecular weight hydrophobic pollutants – we lack tools to predict potential problems associated with acids and larger molecules, for example. New paradigms to screen existing chemicals must be developed. While many chemicals have known outcomes (e.g., cancer), we are currently not equipped to understand impacts of chemicals of behavior or sub-lethal or reproductive impacts nearly as well.

Second, to be an agent of change we have to appreciate that consumers will demand new products (or be sold them by industries that are forced to grow to succeed in the world). Environmental engineers should be at the forefront of helping leading polluters to develop new alternatives, and better define what green products really are. We should not be afraid to embrace new technology, and be part of investigating and demonstrating its safety (not trying to demonstrate its problems). A prime example is nanotechnology. The Environmental community started off thinking that nano would be dangerous. For the most part this helped slow the commercialization of nano-products. Today, with exception of nanomaterials of known toxicity (e.g., those made of heavy metals), we have not come close to finding any nanomaterials worse than what nature already developed; it takes less than 10 virus particles to infect a human (virus are nature-engineered nanomaterials). We should be willing to use nanomaterials to displace organic chemicals (e.g., nanosilver instead of triclosan perhaps). This means more environmental engineers need to be part of the product development process and interact with chemical companies and industry.

Grand Challenges & Opportunities in Environmental Engineering and Science in the 21st Century

Title: **Big Data for Environmental Benefit**

Paul Westerhoff

Most other commercial sectors have embraced big data for either financial benefit or social-networking benefit. Environmental engineering has been slow to identify the opportunities and needs related to accessibility, privacy issues and uses of data analytics.

Environmental engineers were not afraid to embrace advanced biological concepts during the biotech revolution. We were not afraid to dive deep into material science during the nanotechnology revolution. However, we have been slow in broaching the big data / data analytics domain.

Data analytics offer a wealth of possibilities ranging from accessibility to the reams of existing environmental databases held and maintained by federal agencies, states, municipalities, etc. ranging from NASA to private industries. Data ranging from space-mounted satellites to deep ocean probes are available. We have been slow in adopting citizen scientists to image and document environmental problems. Accessing the wealth of data may better prioritize environmental challenges perceived by the public or which may be buried under mountains of what seemed unrelated data. The public pays a financial burden for environmental compliance monitoring – they deserve the data they paid to collect to be put to maximum usage.

Advances in privacy, accessibility, visualization and processing of data has advanced tremendously over the past decade. Environmental engineers must find a way to tap into and utilize this information for the public good.

Grand Challenges & Opportunities in Environmental Engineering and Science in the 21st Century

Title: **Reconceptualizing Clean Water Through Water-Elimination Devices and Systems**

Paul Westerhoff

Urban civilizations and most industry grew up around waterways (rivers, lakes, oceans, freshwater springs). Water was plentiful and cheap, so society embraced a wide range of uses including access to safe drinking water, expansion of bathing, dish, floor and textile washing, fountains and decorative uses, building and other washing services, fire fighting, recreational/sporting irrigation, agricultural irrigation, industrial and commercial cooling, industrial processing, conveyance of sewage for sanitation and many others. These uses are now integrated in the fabric and regulations, culture, and engineering practice. Getting to this point has required tremendous built infrastructure at a present value in the trillions of dollars. We are on a path of self destruction, and causing water crisis when water and technology are the underlying issue, as much as policy and social acceptance.

We are on the cusp of an infrastructure tipping point, much like the Ma-Bell generation faced with telecommunications. Older means of communication – wires for telephone signals have been replaced by fiber optics, satellites and cellular coverage. Technology was the solution and society paid the trillions of infrastructure investment. Telecommunications moves digital bits with near zero mass, whereas water has significant mass. Is this difference insurmountable? The answer could be "yes" if we envision the services water provides today, as those necessary for the future – such that even with conservation demands on water will grow at a rate unequal to natures ability to replenish supplies or engineering know-how to reuse water more than possible today.

Can alternative technologies for providing current water-related services be developed? These may include new sanitation devices, new ways of bathing or showing, new ways of cleaning surfaces, new ways of washing clothes and dishes, new ways of cooling. Current approaches have been incremental (e.g., low water consuming washing machines), but we need a fundamental shift in technologies and systems of technologies. Should we deliver natural gas to houses, from renewable sources of course, that can be used in fuel cells for energy with water vapor collected for drinking? This has been done already, but because of the legacy benefits of the built water infrastructure we fail the vision and momentum to try new systems approaches. **It would be bold and creative to develop living buildings or communities where new technologies and systems could be deployed and tested in ways that go beyond "reducing water consumption" to "eliminating water consumption". Such technologies would be transformative, create new jobs and businesses and allow society to live within its means of water resources.**

Grand Challenges & Opportunities in Environmental Engineering and Science in the 21st Century

Title: **Total Resource Recovery Inspired by Biomimicry is Required for the Anthoprocene To Outlast Jurassic Period**

Paul Westerhoff

Society utilizes nearly everything on Earth, just not where nature has originally put it. We spend tremendous resources in procuring, purifying and moving resources across the globe, and from beneath and above the Earths surface. This is true for mineral resources ranging from carbon (oil) to iron to helium. We also harvest embedded energy of water that arises because of phase changes, ranging from evaporation in vegetable to power plants to kinetic energy of water being pulled by gravity. Therefore, it is clear that life on earth depends upon three critical fluxes: elements, water and energy (solar, geothermal).

The age of the Anthoprocene means that humans now dominate all three of the critical fluxes. We know much about these fluxes based upon economic and supply chain models, and some natural models developed at multiple scales for a world once viewed as pristine where these resources are often used just once. Global warming concerns have driven us to understand the interconnectivess of people across the earth in a way akin to the realization that the Earth was a sphere instead of a flat plate. Consequently, we now need to develop science, technologies, and models that are integrated together and allow us to map and track critical fluxes at a global scale. These efforts must move beyond carbon, and begin to understand the implications of mass fluxes of other elements. Understanding water footprints and scarcity has helped advance technologies for sustainable futures, yet our ability remains naisent to understand impacts of a warming climate on local availability of water resources. New paradigms of thinking and engineering are needed to move beyond single cause-effect relationships, and this is the cusp of where environmental engineering is today – we know the single cause-effect of most pollutants, actions and we attempt to regulate accordingly, but we fail to understand the second and third order effects of our actions.

Environmental scientists and engineers should become inspired by the concepts of biomimicry to understand from the atomic to global scale how societies, and to understand second and third order effects – and potentially develop technologies inspired by biomimicry to benefit from the critical fluxes that are all, simultaneously, being dominated by humans. The Websters dictionary defines biomimicry as “the design and production of materials, structures, and systems that are modeled on biological entities and processes”. Just as living organisms have various organs, viens and interfaces – the entirety of the Earth should be viewed as a single entity. Just as biological processes and organs purify, encapsulate and store elements using bio-physical chemical processes – environmental engineers should identify points in society to capture critical elements, and then move, store and utilize them when and where they are needed. This moves environmental engineering from a reactive mode, much of which emerged from the concepts of waste treatment by sanitary engineers, to on of resource managers. Just as most bodily fluids flows through the liver or kidney to be detoxified or captured, urban communities and should be viewed as places to capture and reuse critical resources. This needs to be done in a way to minimizes net energy for procuring these resources.

GRAND CHALLENGE PROPOSAL: Strengthen Community Disaster Resilience

Andrew Whelton, Ph.D., Purdue University, awhelton@purdue.edu

A series of major chemical disasters have struck and in some cases devastated communities across our nation. These events have exposed critical deficiencies in science and engineering methods and our ability to protect public welfare, safety, and the environment. Recent chemical disasters have caused illness, harmed environmental health, undercut social structures, and exposed the fragility of our economic security. These events have also degraded public confidence in governmental systems, and, in some cases, populations have migrated away from disaster areas to other parts of the nation. Our nation requires a new generation of engineers and scientists expressly equipped to confront this pressing issue facing society. New scientific and engineering methods and technologies are needed to better prevent, respond to and recover from chemical disasters.

In 2014, more than 10,000 gallons of a poorly characterized liquid was discharged from a corroded above ground storage tank into the water supply serving 15% of West Virginia's population. Residents in nine counties were then distributed toxic drinking water and warned not to use it by the Governor. Investigations revealed that utility, state, and federal officials did not understand chemical fate, transformation, and chemical exposure risks associated with the large-scale contamination incident. More than 2100 miles, 100 storage tanks, and tens of thousands of plumbing systems were affected shutting down businesses, schools, and critical community facilities for up to 10 days. Residents became ill when they flushed their plumbing systems at the direction of the responders because responders failed to estimate chemical toxicity, chemical fate, and exposure pathways. The damage to West Virginia's economy was estimated at $61 million during the first month of the six month recovery. This is one of the largest chemical spill caused water contamination incidents in US history.

In 2014, 27 million gallons of coal ash contaminated water was discharged from a failed containment structure and contaminated 70 miles of waterways in North Carolina and Virginia. Today, residents are still unable to return to the river for nutrition and recreation because of residual gross contamination. In some places, heavy metal laden coal ash remains multiple feet thick on river bottoms. Nearby groundwater has been found to be extensively contaminated and hazardous sludge has been accumulating in downstream drinking water treatment facilities. The extent of environmental damage is still being investigated, but estimates are that dredging of waste coal ash and residual contaminants continues today. One estimate is that the cost of the spill will eclipse $300 million. This is the 3rd largest coal ash environmental release in US history.

In 2010, a failed oil drilling structure resulted in the discharge of more than 205 million gallons of crude oil into the fishery rich Gulf of Mexico. This is the largest oil spill disaster in US history. In response, millions of gallons of chemical dispersant (with little known toxicity and persistence) was discharged into the waters. Nine months after the spill ingredients of the dispersant were still present in the Gulf. The environmental damage has been catastrophic to certain aquatic populations and economic vitality of several Gulf coast states.

The increasing number of chemicals in commerce, aging infrastructure, and the frequency and magnitude of disasters that have affected both the environment and public health, underscores the urgency of this GRAND CHALLENGE. Failure to train a new cadre of scientists and engineers will not simply maintain status quo, but result in greater devastating consequences from chemical disasters as the frequency and scale of chemical spills will continue to increase.

Name: Mari-Karoliina Winkler
Affiliation: University of Washington
Grand challenge: Minimize waste and recovery of fertilizer and energy
Suggested solution: bio-drying technology

During wastewater treatment circa 40% of the biologically removed organic carbon is converted to biomass (sludge). This **excess sludge is an unwanted by-product and presents rising challenges since it accounts for about half of the total cost of a wastewater treatment plant** (*1*). Technologies such as landfilling, incineration, oxidization and digestion with hydrolysis are used to reduce sludge after (*2*) or before sludge thickening (*3*). A commonly used technology to handle organic waste is biological composting, which stabilizes organic matter to an almost odour and pathogen free humus, which can be beneficially applied to land (*4*). Composting aims for the maximal biological conversion of organic material. Therefore, water is added to the process when the organic matrix reaches certain dryness in order to preserve moisture for optimal microbial activity and hence maximal organic conversion. As a consequence, **long residence times of circa 50 days are required for compositing, which is less practical for large quantities of sludge**. Composting has significant uncertainties since it is increasing the dry solid content due the water evaporation by biologically produced heat, while decreasing the caloric value of mixed sludge to values, which are critical for an economically attractive combustion (*5*). For incineration a dry solid content of 45% [w/w] or more is needed to gain energy from the combustion, which is typically not attained by sludge composting (*6*). **Other techniques such as thermal drying or direct combustion do not rely on microbial produced heat. Instead external energy needs to be supplied to evaporate water leading to high costs. A new technology, which is based on a similar process as composting, is the biodrying concept (*7, 8*).** In this process the **metabolic heat is used to remove water** from the waste matrix at the **lowest possible residence time and minimal biodegradation hence preserving most of the gross calorific value of the waste matrix**. During this process the organic matrix is both: substrate for microorganisms (which produce heat for drying) and the end product. The end product (fuel / granules) **contains a high energy value and can be used as a replacement of coal and for thermal energy generation**. Bio-drying of sludge can (in contrast to landfilling) **reduce fossil fuel requirements and greenhouse gas emissions if combusted to produce steam and or power henceforth positively contributing to prevent climate change** (*9, 10*). Within the biodrying concept waste is reduced and recycled making this technology not only renewable but also sustainable. **A full-scale biodrying installation is operated in the Netherlands treating 150 kton** (wet weight) of dewatered waste activated sludge per year (*8*). The waste is treated at thermophilic conditions (65-75°C) in a 2-step forced aeration process **reducing the total wet sludge weight by 73%**. The final product has a high caloric value (7,700-10,400 [kJ/kg]), **allowing a combustion for energy generation in external facilities**. The resulting product meets the European microbial and heavy metal quality standards needed for an **application as organic fertilizer**. The facility uses <0.5 MW of **electricity and recovers 9.3 MW from biologically produced heat**, which is internally used for the heating of office buildings. **Produced ammonia, originating from the microbial conversion of organic matter, is recovered** from the ventilated air in an acid gas scrubber **as an ammonium sulphate solution 40% (w/w) (7.3 kton/year)** and is sold as substitute for artificial fertilizers. Combustion of biologically **dried sludge has a negative (-153 kgCO_2/ton) CO_2 emission balance** if compared to other sludge treatment processes (*11*). Burning of biologically dried sludge is decreasing fossil fuel demands (e.g. coal) thus **preventing additional atmospheric input of CO_2**, whereas burning of coal jeopardizes fossil fuels resources and pollutes our atmosphere with surplus CO_2 emissions. This process creates a **mindset that sludge can be seen as resource rather than waste.**

References

1. R. D. Davis, J. E. Hall, *European Water Pollution Control* **7**, 9 (1997).
2. Y. Wei, R. T. Van Houten, A. R. Borger, D. H. Eikelboom, Y. Fan, *Water Research* **37**, 4453 (2003).
3. J. A. Müller. (Intational Water Association, Athens, Greece, 2000), pp. v. 42, 167-174, ISBN 02731223
4. C. R. Mote, C. L. Griffis, *Agricultural Waste* **4**, 65 (1982).
5. L. Cai *et al.*, *Water Research,* (2013).
6. T. Kudra, Z. Gawrzynski, R. Glaser, J. Stanislawski, M. Poirier, *Drying Technology* **20**, 917 (2002).
7. M. K. H. Winkler, *TEDx talk, https://www.youtube.com/watch?v=YTpZL-r5yDk*, (2014).
8. M. K. H. Winkler, M. H. Bennenbroek, F. H. Horstink, M. C. M. van Loosdrecht, G. J. van de Pol, *Bioresource Technology* **147**, 124 (2013).
9. S. Navaee-Ardeh, F. Bertrand, P. R. Stuart, *Drying Technology* **24**, 863 (2006).
10. E. C. Rada, M. Ragazzi, V. Panaitescu, *UPB Scientific Bulletin, Series D: Mechanical Engineering* **71**, 113 (2009).
11. STOWA, *ISBN 90577733145* (2010).

Broadly Interdisciplinary Education: Seeing "Soft" Skills as Integral, not Peripheral

Alison Wood

As environmental engineers and scientists are forced to face novel and increasingly complex environmental challenges, our set of tools for tackling these challenges must expand. While excellent analytical skills will always be critical to successful science and engineering, skills in such areas as communications, cross-cultural cooperation, and transdisciplinary synthesis will be increasingly crucial if the "fundamental connections between human activities and global ecosystems" are to be understood and managed. This implies challenges for educating young engineers and scientists throughout their schooling as well as for ongoing education and training of practicing professionals, including teachers. The challenges also extend to the policy level in establishing appropriate curricula at every level of education.

The complexity and interconnectedness of the problems we face must be reflected in the strategies and skills applied in devising solutions. Development and identification of sustainable technologies will require not only the technical capacity for design, but also understanding of the economic, social/psychological, and political aspects of implementing the new technologies at large scales. Successful communication with the public about both the solutions and the problems will be necessary to instigate changes in policies and adoption of products or processes. Regional and global problems that span languages and cultures will only further complicate these challenges.

Clearly, environmental scientists and engineers will need at the very least to work closely with practitioners who have these varied skills, and ideally incorporate some of these skills in their own knowledge base. As the U.S. pushes for increased STEM education at younger and younger ages, crowding out learning opportunities in the humanities and arts in favor of more math and science, children's capabilities in creative problem solving, critical thinking, and other crucial competencies are suffering. We must reprioritize so-called "soft" skills as integral parts of engineering and science work, so that our practitioners will be equipped to handle the complex challenges we'll be increasingly facing over the coming decades.

One example of this issue under discussion: http://www.washingtonpost.com/opinions/why-stem-wont-make-us-successful/2015/03/26/5f4604f2-d2a5-11e4-ab77-9646eea6a4c7_story.html

Grand Challenge of Chemical Contaminants in Water/Wastewater Treatment and Reuse

Tingting Wu (tingting.wu@uah.edu), Department of Civil and Environmental Engineering
The University of Alabama in Huntsville, 5000 Technology Drive, Huntsville, AL, 35899

Chemical contamination of aquatic systems is a well- recognized problem and has drawn researchers' attention all over the world. Although thousands of papers have been published, discrepancies even exist in the department of terminology: micro-pollutants vs. emerging contaminants vs. contaminants of emerging concern. The diversity, ubiquitousness, low concentration, and toxicological concerns (largely unknown) represent the unique challenge of these insidious contaminants, especially when fresh water availability is becoming a problem in many areas of the world and more and more communities may be forced to rely on low-quality water sources. For example:

1. Long-term effects on human health and ecosystem. Most of these contaminants are present at very low levels and before we simply didn't know they were there due to the limitation of analytical technology. With the advancement of instrumentation, we may be able to detect more contaminants at even lower concentrations. So, which and at what level should we care?
2. Cost-effective treatment technologies. Specifically, simple removal of the parent compounds may be inadequate as certain intermediate products can be even more toxic and/or synergistic effect may occur.
3. Detection and monitoring of these contaminants are resource-intensive. Is it possible to obtain some guidelines (e.g. prediction of the formation and/or transformation of the contaminants of concern) using computational methods/simulation before we have a well-trained technician/student grab samples and run numerous time-consuming tests with an expensive and sophisticated machine?

AEESP Grand Challenges Workshop

Title: The Virus-Human-Environment Nexus

Name: Chang-Yu Wu, University of Florida

Overview: Outbreaks of epidemics such as avian flu that caused slaughter of millions of birds in the Midwest and Severe Acute Respiratory Syndrome (SARS) that caused thousands of deaths around the world manifest the vulnerability of humans and animals when exposed to infectious viruses. As powerful as they may seem, viruses are strongly influenced by environmental conditions such as light, humidity, temperature and pollution level. On the other hand, recent studies[1] demonstrating the ability of viruses to initiate water vapor condensation better than well-known cloud condensation nuclei materials imply their unrecognized role in cloud formation and therefore unknown impact on climate change. All these examples point out the intriguing interactions among viruses, humans and the environment. Nevertheless, truly we are only at the dawn of understanding the important role of viruses. To develop a better strategy to protect the health of humans, agriculture or the ecosystem, the knowledge of how viruses behave, distribute, transport and evolve in the environment is indispensable and indeed lacking. Several challenges exist that require grand and enduring efforts to enable our society to be knowledgeable about the virus-environment -human interactions.

The first challenge is ***"the ability to effectively and accurately detect viruses in the environment"***. While the scientific community has advanced greatly in detecting inorganic and organic pollutants at low level in the environment, our ability to detect viruses fall way behind. Their ultrafine size, low concentration in the environment plus the complexity of the environmental conditions, coupled with the limit in current analytical capability, make it extremely challenging to effectively sample them[2] and accurately detect their presence. It is even more challenging when knowledge of their viability is needed. The second challenge is ***"the ability to profile their spatial and temporal distribution"***. Such knowledge is critically important in understanding their dynamic evolution and transformation in the environment, the information of which is minimally existing. The tools we develop to address the first challenge form the basis for solving the second challenge, but it has additional constraints to meet such as affordability and portability of the tools. Furthermore, large monitoring networks will be indispensable to avail distribution information. The historical approach of establishing supersites will not satisfy our needs in the 21st century; rather, widespread citizen participation in collecting the data will create a superior database unimaginable and unmatched by data collected by professionals alone. Such a humongous database poses another challenge that will require big data expertise to extract the useful information. The abilities to respond to these two challenges will enable us to take measures to mitigate adverse impact of viruses instead of learning their presence only after the fact. They will also enable beneficial use of viruses for the betterment of human society and the environment.

1. Junge, K.; Swanson, B. D., High-resolution ice nucleation spectra of sea-ice bacteria: implications for cloud formation and life in frozen environments. *Biogeosciences* **2008,** *5* (3), 865-873.
2. Oh, S.; Anwar, D.; Theodore, A.; Lee, J. H.; Wu, C. Y.; Wander, J., Development and Evaluation of a Novel Bioaerosol Amplification Unit (BAU) for Improved Viral Aerosol Collection. *J. Aerosol Sci.* **2010,** *41* (9), 889-894.

Title: Understanding Hindered Adsorption on Porous Carbonaceous Materials

Author: Feng XIAO, Department of Environmental Sciences, Connecticut Agricultural Experiment Station (current) & Department of Civil Engineering, University of North Dakota (after August 2015)

Description: Biochar (BC) and activated carbon (AC) are porous carbonaceous materials of great interest in environmental engineering due to their diverse applications in water purification, catalysis, gas storage, capacitance, carbon sequestration and *in situ* soil/sediment remediation. All these applications involve the adsorption on the carbons and diffusion of target compounds into their pore networks. Therefore a deep understanding of fundamental adsorptive processes is a prerequisite to technological control. The driving forces for adsorption on BC/AC consist of hydrophobic, dispersion, electrostatic, dipolar and (for some compounds) π–π and H-bonding interactions, which have been studied extensively on both a theoretical and an experimental level. Little attention, however, has been paid to steric effects that can suppress the adsorption. BC and AC possess all three varieties of pores (macropores, mesopores and micropores) simultaneously, but are typically nanoporous having apertures within the range of solute molecular diameters. Molecules of environmental concern are ordinarily < 10 Å in their longest dimension. Therefore, it is conventionally believed that adsorption mainly takes place in micropores (< 20 Å), and that mesopores are merely a means of passage for adsorption from solution to permit access to micropores. However, the role of pore size distribution in adsorption may have been previously misinterpreted due to the limitations in both the conventional N_2 porosimetry and in the classical approaches (e.g., the BET and Dubinin–Radushkevich methods) for interpreting N_2 adsorption isotherms. More importantly, the diffusion in micropores is dominated by collisions between a diffusing molecule and the pore wall, which is an activated process; that is the diffusing molecule must overcome a significant activation energy barrier, leading to a slowed uptake rate and restricted adsorption. Diffusivities in water-filled pores of AC are 10^{-10}–10^{-11} cm^2/s that are several orders of magnitude smaller than the expected aqueous diffusivities computed by the Hayduk−Laudie equation and too small to be due to mesopore diffusion. The steric/diffusion hindrance may cause the adsorption processes reach equilibrium only slowly and incomplete removal and remediation at polluted sites. Since the costs of treatment and remediation rise exponentially with both the degree and rate of adsorption, **it is a major challenge of us to understand the steric hindrance and to find ways to overcome it**. Specially, the author believes that systematic research is needed to *1) study the influence of steric hindrance on the adsorption of typical organic compounds, including their adsorption rate behavior, quantified as a diffusion rate parameter; 2) identify specific pore regions of either mesopore-rich or mesopore-depleted carbons where effective adsorption takes place; 3) determine the changes in carbon pore geometry during activation and the relationships with the adsorbency of AC; and 4) develop protocols for parameterization of steric effects that can be useful in establishing poly-parameter quantitative structure–property relationships*. Such research will reveal insight into the mechanisms hindering adsorption on BC/AC that have been frequently overlooked or misinterpreted in the scientific literature. An added benefit will be the acquisition of underlying knowledge towards the goal of optimizing the pore size distribution of BC/AC and improving their performance. It is also socially relevant and will result in concrete benefits to everyday citizens with respect to the cleanup of contaminated sites and the removal of synthetic organic contaminants from drinking water.

An Energy-neutral, Direct Nutrient Removal Process using Anammox Bacteria and Biochar

Wenqing Xu and Metin Duran
Department of Civil and Environmental Engineering, Villanova University

Introduction. One of the greatest challenges we are facing in this century in environmental engineering is to provide sufficient water for our skyrocketing population. However, eutrophication from excess nutrient input through anthropogenic activities can result in algal blooms with subsequent oxygen depletion, which not only disrupts aquatic life, but also threatens the already scarce drinking water sources[1]. Excess nutrient can be introduced to the water environment from both non-point discharges (e.g., agriculture runoff) and point source discharges, where municipal and industrial wastewaters are the biggest contributors[2]. The conventional nutrient removal in wastewater treatment involves sequential nitrification and denitrification processes, which requires enormous energy to aerate water and oxidize ammonia (NH_4^+) to nitrate (NO_3^-) and then reduce it back to nitrogen gas (N_2). As an alternative, the recent discovered anammox process oxidizes ammonia to nitrogen in one step under limited oxygen, which avoids costly aeration and offers a more economical and sustainable technology for removal of nitrogen in wastewaters, including up to 75% reduction in energy use and 90% reduction in greenhouse gas emissions[3, 4]. However, the long doubling time of anammox bacteria (i.e., 7 to 11 days) hinders its engineering applications[4].

Recent research suggests that biochar, a charcoal-like organic carbon-rich solid residue from biomass pyrolysis under oxygen-limited conditions, can mediate certain abiotic reactions[5] and enhance microbial activity[6]. The conductivity[5], electron accepting and donating capacities[7] of biochar seem to contribute to its redox reactivity. Here, we hypothesize that the adsorptive and redox properties of biochar can enable direct nutrient removal by ammonox bacteria via, 1) serve as an attachment surface for anammox bacteria and promote their growth, and 2) facilitate electron transfers between nitrogen species and accelerate the reaction kinetics.

References

1. Manuel, J., *Nutrient Pollution: A Persistent Threat to Waterways.* Environmental Health Perspectives, 2014. **122**(11): p. A304-A309.
2. *TMDL Reports. United States Environmental Protection Agency;*. April 28, 2015]; Available from: http://iaspub.epa.gov/waters10/state_rept.control?p_state=PA&p_cycle=2004.
3. Hu, Z.Y., et al., *Nitrogen Removal by a Nitritation-Anammox Bioreactor at Low Temperature.* Applied and Environmental Microbiology, 2013. **79**(8): p. 2807-2812.
4. Kartal, B., J.G. Kuenen, and M.C.M. van Loosdrecht, *Sewage Treatment with Anammox.* Science, 2010. **328**(5979): p. 702-703.
5. Xu, W.Q., J.J. Pignatello, and W.A. Mitch, *Role of Black Carbon Electrical Conductivity in Mediating Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) Transformation on Carbon Surfaces by Sulfides.* Environmental Science & Technology, 2013. **47**(13): p. 7129-7136.
6. Chen, S.S., et al., *Promoting Interspecies Electron Transfer with Biochar.* Scientific Reports, 2014. **4**.
7. Kluepfel, L., et al., *Redox Properties of Plant Biomass-Derived Black Carbon (Biochar).* Environmental Science & Technology, 2014. **48**(10): p. 5601-5611.

Title: Expand the role of wastewater infrastructure in public health protection
Name: Tao Yan

Overview.

The wastewater infrastructure, including the collection and treatment systems, plays a critical role in removing human pathogens from the communities and reducing pathogen loading to the environment. This role is becoming increasingly more important as urbanization continues to expand and new diseases continue to emerge on the global scale. Expanding the role of wastewater infrastructure in public health protection could add powerful tools to the toolbox for fighting against infectious diseases. This can also improve the recognition of the importance of wastewater infrastructure by the public and policy makers, which can facilitate additional investment in this critical infrastructure, and expand the discipline of environmental engineering by adding important health-related functions.

The wastewater infrastructure offers unparalleled advantages as one-stop locations for collecting accurate and real-time information about community enteric diseases. First of all, the enteric pathogens and disease information carried by municipal wastewater is free from reporting biases that are inherent in traditional clinic-based approaches. Secondly, municipal wastewater contains near real-time disease information of the community, because typically wastewater only needs several hours to travel to a centralized location where pathogen quantification can be completed within several hours using today's molecular tools. In contrast, the clinic disease data usually take weeks, sometime even months, to produce. Thirdly, individual MWSs can be organized into national and even international enteric disease monitoring networks, and such networks would provide a game-changing capability in protecting the public from enteric disease outbreaks and in understanding the origin, transmission, and evolution of enteric diseases around the world. These advantages can be explored for various purposes, such as monitoring real-time occurrence of infectious disease in communities, studying human pathogen diversity in a community, studying how human activities affect pathogen evolution, etc.

Grand Challenges and Opportunities in Environmental Engineering and Science in the 21st Century

Ngai Yin Yip

Department of Earth and Environmental Engineering, Columbia University, New York, NY 10027, USA

Email: nyy2002@columbia.edu

The world population is facing an increasingly challenging energy landscape and declining water quality and availability, further compounded by a rapidly expanding global population against the backdrop of climate change. Addressing our water and energy problems are pressing priorities for the 21st century. This urgency is echoed by the National Academy of Engineering's Grand Challenges, with water- and energy-related issues polling in at four out of the top five spots.

In developed countries, implementation of new innovations to address water and energy challenges has been encumbered by the existing infrastructure. In the US, drinking water facilities and distribution networks, wastewater and stormwater systems, electrical grids, and fossil fuel-based transportation system mostly originated over a century ago. Upgrades and improvements made over the years have, by and large, worked around and complemented the existing infrastructure rather than displace them, chiefly due to a large capital requirement amplified by risks and uncertainties.

On the other hand, developing countries face a lack of public works and infrastructure for water and energy services. The blank slate of infrastructure presents opportunities that can be mutually beneficial for both developing and developed countries. New water and energy technologies can be more readily implemented in places not burdened with existing infrastructure, to service the local population. The lessons learnt and experience gleaned from actual operation will be invaluable for instructing how these innovations can be adapted to developed countries.

In the last century, the diffusion of ideas and innovations from developed countries has enabled developing countries to catch up with the rest of the world. Moving into the next hundred years, a reversal in the direction of information flow might just be the paradigm shift needed to catalyze the reinvention of our infrastructure, while providing equitable water and energy services for the population of developing countries.

Title of Grand Challenge

Engineered nanomaterials for sustainable water treatment systems in membrane filtration and photocatalytic reactors

Author (that is you and colleagues if you desire)

Wen Zhang, Ph.D., P.E.
Assistant Professor
John A. Reif, Jr. Department of Civil and Environmental Engineering
New Jersey Institute of Technology
Email: wzhang81@njit.edu

Description

How to build robust, durable, and antifouling systems for water/wastewater treatment remain the most difficult challenges for environmental engineers. Nanotechnology enables many potential routes to improve the efficiency and cost effectiveness of water treatment processes in membrane filtration or photocatalysis. The knowledge gaps are the explicit understandings of interconnections between nanomaterials properties and their performances and engineering applications as well as the search and use of naturally abundant elements that elicit low or no toxicity to the environment at low carbon footprint during production.

References if you choose

None

Title of Grand Challenge

Microalgae: A Renewable Energy Source and a Sustainable Solution for the Environment

Author (that is you and colleagues if you desire)

Wen Zhang, Ph.D., P.E.
Assistant Professor
John A. Reif, Jr. Department of Civil and Environmental Engineering
New Jersey Institute of Technology
Email: wzhang81@njit.edu

Description

Microalgae are not only the promising feedstock for biodiesel production, but also a water contaminant that negatively affects water quality with uncontrolled growth (harmful algal bloom). Properly managing the interactions between environmental engineers and microalgae would largely warrant the path to the positive sides of microalgae toward renewable energy harvesting and wastewater decontamination with algal biomass. Microalgal biomass can be engineered to be promising feedstock for fertilizers, animal food sources, and other valuable substances such as antioxidants, antibiotics and polyunsaturated fatty acids (PUFAs). Recently, microalgae are considered as good candidates for biofuel production and have gained enormous research interests. Microalgae can also be used for the removal of nutrients (e.g., nitrate (NO_3^-), nitrite (NO_2^-) and phosphate (PO_4^{3-}) from impaired water and the sequestration of CO_2, a greenhouse gas resulting in global climate change. However, critical challenges to address include microalgae cultivation, separation from growth media, post-treatment, and biofuel production, where interdisciplinary research activities should merge. These integrated and intriguing research activities will likely catalyze new and meaningful knowledge, mentor highly capable workforce, and increase opportunities and sustainability of our society.

References if you choose

1. Zhang, Wen, etc, Recovering Magnetic Fe_3O_4-ZnO Nanocomposites from Algal Biomass Based on Hydrophobicity Shift under UV Irradiation. ***ACS applied materials & interfaces*** **2015,** DOI: 10.1021/acsami.5b03472
2. Ge, S.; Agbakpe, M.; Zhang, W.; Kuang, L., Heteroaggregation between PEI-Coated Magnetic Nanoparticles and Algae: Effect of Particle Size on Algal Harvesting Efficiency. *ACS applied materials & interfaces* **2015,** *7*, 6102-6108.
3. Ge, S.; Agbakpe, M.; Wu, Z.; Kuang, L.; Zhang, W.; Wang, X., Influences of Surface Coating, UV Irradiation and Magnetic Field on the Algae Removal Using Magnetite Nanoparticles. ***Environmental Science & Technology*** **2014**.
4. Agbakpe, M.; Ge, S.; Zhang, W.; Zhang, X.; Kobylarz, P., Algae harvesting for biofuel production: Influences of UV irradiation and polyethylenimine (PEI) coating on bacterial biocoagulation. *Bioresource technology* **2014,** *166*, 266-272.

GRAND CHALLENGES AND OPPORTUNITIES IN ENVIRONMENTAL ENGINEERING AND SCIENCE IN THE 21st CENTURY

Title:

Interdisciplinary Research on the Earth system- linking atmosphere-biosphere-hydrosphere-lithosphere-anthrosphere

Author:

Yang Zhang, Dept. of Marine, Earth, and Atmospheric Sciences, NCSU, yzhang9@ncsu.edu

Description:

We live in an era with rapid global changes and numerous environmental concerns caused by human activities and associated consequences accumulated more than one century. Among them, the most pressing issues include energy shortage, global warming, air and water pollution, ocean acidification, ecosystem eutrophication, natural resource damages/diminishing, as well as associated adverse human health and eco-environmental effects. Despite their intimate linkages and highly interdisciplinary natures, these pressing issues have been studied traditionally within receptive sub-disciplines in environmental engineering and science. Understanding these issues and sustainable solutions pose unprecedented grand challenges to every aspect of our life and society. Tackling these challenges requires not only the advanced technologies and clean energy sources but also a new generation of STEM workforce with multi and inter-disciplinary knowledge and skills.

The proposed discussion will focus on the demands of STEM workfore for the Earth system research that crosses the boundaries of traditional disciplines and that requires linking atmosphere-biosphere-hydrosphere-lithosphere-anthrosphere as a holistic system. Major topics will include but are not limited to:

- What are the emerging research areas and industries that have crossed the boundaries of traditional disciplines and require integrated multi- and interdisciplinary knowledge and workfore?

- What are the major road blocks towards a successful interdisciplinary research and workfore training in the existing research and education programs?

- How can we develop new and enhance existing curriculums for interdisciplinary research and education program that will meet the real-world demands?

- How can we effectively cultivate future generation of leaders in the Earth system research, education, service, enterprise, and policy?

Managing the Nexus – a Grand Challenge
Qiong Zhang, Assistant Professor,
Civil and Environmental Engineering, University of South Florida

Central Question. It is a grand challenge to manage finite resources (e.g., water, energy, nutrients) in a dynamic world for long term development while protecting the environment. It has been recognized that resource systems are complex, nonlinear, and interconnected (referred to nexus) (DOE, 2014). Thus, without systems thinking, solutions to one system might cause unintended consequences to another. The central question in the area of nexus is, "What are technical and nontechnical solutions that can achieve more sustainable utilization of multiple resources instead of sub-optimum of an individual resource?"

Knowledge Gaps. To answer this question and achieve sustainable resource management, system level evaluation metrics and multi-resource system models have to be developed based on improved understandings and quantification of the nexuses. With the increasing awareness of the nexuses (e.g., water-energy nexus), the number of studies investigating their interdependency has grown significantly. However, those studies are limited to a static quantification of the connections, such as the amount of water used in energy generation, or the energy requirement for water cycle. Several major knowledge gaps exist in the area of nexuses including: 1) consistent and comprehensive data, 2) cause-effect relationships at different scales, 3) robust multi-resource modeling framework, 4) synergistic technologies at different scales, and 5) integrated policy and management strategies.

Barriers and Approaches in Research. The barriers to fill each of the knowledge gaps can be identified in the workshop and the approaches to address the identified barriers can be discussed. For example, one barrier to creating a multi-resource modeling framework is the *mismatch* between resource systems that is caused by different spatial and temporal scales and the classification of end users of resources (e.g., water at a watershed scale while energy at political boundaries). The combination of different approaches, such as node-link network structure, system dynamics modeling, scaling up/down and disaggregation/aggregation, might be needed to address this barrier.

Barriers and Approaches in Education. In general, systems thinking and approaches are needed to fill those knowledge gaps. Traditional engineering focuses on analysis of isolated parts of the system through a reductionist approach. Environmental engineers need to understand critical linkages among components within resource systems so they can develop sustainable solutions to increasingly complex problems. However, systems thinking and systemic approach are largely lacking in engineering education (Murphy et al., 2009). The barriers to introduce systems thinking and approaches and the strategies to address those barriers in environmental engineering education can be discussed in the workshop.

Reference
U.S. Department of Energy. 2014. The Water-Energy Nexus: Challenges and Opportunities
Murphy, C.F., D. Allen, B. Allenby, J.C. Crittenden, et al. 2009. Sustainability in engineering education and research at US universities. *Environ. Sci. Technol.*, 43(15): 5558–5564.

Promoting Computational Fluid Dynamics Applications in Environmental Engineering

Jie Zhang

Department of Civil and Environmental Engineering, University of South Florida, Tampa, FL

Fluid mechanics is important in environmental engineering. It has a significant impact on residence time distribution, mixing efficiency, and mass transfer efficiency etc. However, it has been often overly simplified in modeling the physical and chemical processes in environmental engineering flows, such as the reactive flows in water and wastewater treatment, for decades. The CMFR (completely mixed flow reactor) and PFR (plug flow reactor) were the commonly used ideal models for modeling flow. The former assumes the mixing is so strong that fluids mix in no time and the latter assumes no mixing. Therefore the CMFR can only represent dispersion (or diffusion)-dominated flow and the PFR can only represent convection-dominated flow. The derivative models of CMFR and PFR, like the TIS (tank in series), DFM (dispersed flow model), and SFM (segregated flow model) incorporated both dispersion and convection in a certain way; however, experimental data is needed to determine the ratio of dispersion intensity to convection intensity, which varies for different situations.

Computational Fluid Dynamics (CFD), which has been prevalent in aerospace engineering and mechanical engineering flow applications, can provide comprehensive fluids flow information without any case-specific calibrations on the CFD model. CFD has been demonstrated to be able to simulate water flow and passive tracer transport accurately. Besides, it is able to simulate chemical reactions and inactivation in flows as well. People working across the areas of CFD and environmental engineering have successfully applied CFD to various environmental engineering problems in recent years. However, due to the legacy of traditional methods and the lack of CFD experts in the environmental engineering community, most of the environmental engineers are not aware of the usefulness of CFD. Some environmental engineers may know CFD but hesitate to adopt it since CFD tools require extensive knowledge of mathematics and computer technologies. So they would prefer using traditional models, which are usually inaccurate, or experiments, which are cost, energy and time-intensive, in solving environmental engineering flow problems such as evaluating performance of water and wastewater systems and improving future designs. Therefore promoting CFD applications in the environmental engineering community would benefit environmental engineers significantly.

However, promoting CFD applications in the environmental engineering community and changing the situation is a grand challenge. Potential solutions could be: 1) Introduce CFD in the courses, such as *Physical and Chemical Processes,* for environmental engineering students at the undergraduate level; 2) Develop a manual of practice for CFD applications in environmental engineering. This can be conducted by a task committee in a professional organization or a research group at a university; 3) Organize workshops and webinars on CFD applications in environmental engineering; 4) Persuade funding agencies to put a high value on the researches in this area; 5) Report a transformative success of CFD application in environmental engineering by public media.

Biological Drinking Water Treatment and Water Quality Guarantee

Liang Zhu (Zhejiang University &Rice University)

Water environmental issues are serious in the world, especially in developing countries. Seeking the high-efficiency and environmental-friendly drinking water treatment technology is important for safety of drinking water and sustainability of water resource. For example, high-level pollution of nitrogen and phosphorus has frequently appeared in natural waters due to wastewater discharge and non-point source of runoff, and emerging contaminants such as endocrine disrupting compound (EDC) and antibiotics are becoming the key priority in water quality control in recent years. There are at least 3 important challenges needed to address in the future:

1. Microbial in-situ remediation for polluted natural waters
2. Enhanced biological nitrogen and emerging contaminants removals for water treatment plants
3. Water quality guarantee and energy saving in water treatment plants

This topic includes many valuable research areas, such as:

- Biological technologies to improve the attenuation of polluted natural waters and treatment of raw water. The ecological engineering has been applied in the remediation of polluted natural waters, and the novel carrier addition and biofilm enrichment favor the removal of nitrogen and emerging contaminants synchronously. At the same time, The interaction of plant, carrier, and biofilm should be focused for the attenuation of polluted natural waters. Furthermore, the environmental factors (Oxygen, organics, turbidity, etc.) and operation mode (Aeration, recycle, etc.) influence the performance and energy consumption of biological drinking water treatment process, highly effective and low consumptive biological techniques should be developed for water treatment plants.
- Novel materials and treatment technologies for water quality guarantee and energy saving. For example, developing novel adsorbing material for the biofilter and multifunctional RO/FO membrane are important for enhanced removal of emerging contaminants. Furthermore, the combination of photochemical catalysis and membrane technology with biological drinking water treatment process favors the biology stability and quality safety of drinking water production and distribution.

Grand Challenge: Economical Desalination using Renewable Energy

Katherine R. Zodrow

Civil and Environmental Engineering, Rice University

We are faced by several difficult, interlinked challenges, often referred to collectively as the "Nexus". When considering the nexus, we often encounter positive feedback loops that result in negative consequences. For example, society requires water suitable for drinking, agriculture, and industry. In a growing number of instances, clean water is produced using desalination, an energy intensive, and therefore expensive, process. Desalination is often a last resort, resulting from insufficient reliable fresh water supply. Although desalination increases water supply by allowing utilization of unconventional water sources (e.g. wastewater, seawater, and impaired/brackish groundwater), it releases greenhouse gases into the atmosphere, contributing to climate change, when fossil fuels are used as an energy source. The effects of climate change include changes in weather patterns, such as drought, decreased snowpack due to increased temperatures, and decreased snowfall. Thus, changes in climate increase the need for energy-intensive desalination, thereby completing the loop.

One solution that would allow us to exit this positive feedback loop (with negative consequences) is desalination that does not require the use of fossil fuels. Several alternative energy sources exist, including solar, wind, hydropower, biofuels, and nuclear. Because of growing concerns of the environmental and social impacts of hydropower (in the form of dams), further development of this resource may not be in line with current goals of sustainability, social equality, and ecological preservation. Nuclear, although a proven alternative energy technology, requires a huge capital investment and produces hazardous waste. Biofuel production requires large amounts of land and water and often competes with food supplies. Wind and solar are two renewable technologies that can produce energy on small scale in decentralized locations, making them interesting energy sources for decentralized water treatment facilities that would not require large amounts of energy for water transport to end users (as centralized treatment facilities do).

Economical desalination using renewable energy would:

1. Provide *high purity water from highly contaminated sources* (including wastewater, brackish groundwater, and seawater). It could also be used to remove contaminants that are currently deemed "uneconomical" to remove. This could potentially improve quality of life in both developing and developed countries.
2. Allow individuals or small communities to treat impaired water sources. This *decentralized water treatment* scheme would decrease the cost of pumping water and opportunities for contaminants/pathogens to enter the water.
3. Enable advanced water treatment *without increasing greenhouse gas* emissions.

This challenge is attainable. Reverse osmosis is currently the state-of-the-art desalination technology, but its efficiency is approaching the theoretical limit (Elimelech & Phillip, 2011). It also requires large capital investments and extensive pretreatment. Other promising technologies are under development that would allow the use of low-grade heat sources, including waste heat or heat generated with renewable energy, especially solar. Promising technologies include, but are by no means limited to, forward osmosis and membrane distillation. Forward osmosis uses the osmotic pressure of a concentrated draw solution to pull water across a semipermeable membrane. The draw solution is the critical element – its subsequent separation from water must be efficient. Alternatively, the draw solution could require no removal, depending on the application. Membrane distillation uses a temperature difference and resulting partial pressure difference across a hydrophobic membrane to drive water vapor from a hot feed stream to a cold distillate stream. Because the technology depends upon a vapor pressure difference, it may operate at below-boiling temperatures, enabling utilization of low-grade heat sources.

Attainment of economical desalination with renewable energy necessitates a multidisciplinary effort. This effort will include communication and collaboration between experts in several disciplines, including environmental engineering, materials science, biology, economics, systems engineering, and public policy (to name a few). The principles of desalination and renewable energy rest in fundamental science. Development of materials that will work in a complex system will require materials scientists, water chemists, system engineers, and biologists. Implementation and distribution of economical desalination technologies demands experts in business, public health, and social sciences. Success will be measured by good data – data concerning energy use and efficiency of individual systems, data detailing use of different types of systems by individuals, communities, and perhaps even municipalities, and reliable data demonstrating long-term feasibility of these systems to accurately determine the return on investment. Acceptable standard methods and accessible data repositories preclude quality data production and comparison. Water and its neighbors in the Nexus present a problem of huge proportions, but sound, collaborative work will provide solutions, like economical desalination with renewables, that result in higher quality of life without great environmental impact.

Reference:

Elimelech, M., & Phillip, W. A. (2011). The Future of Seawater Desalination: Energy, Technology, and the Environment. *Science*, *333*(6043), 712–717. doi:DOI 10.1126/science.1200488