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FEW Workshop: Food, Energy, and Water Nexus in Sustainable Cities in Beijing, China, October 20-21, 2015

Organized by
NEW YORK INSTITUTE OF TECHNOLOGY

In Collaboration with
PEKING UNIVERSITY

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SYNTHESIS REPORT

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TABLE OF CONTENTS

Appendices

Figure and Tables

Note: All figures are from PowerPoint presentations given by the workshop speakers. They signed release forms authorizing the use of their presentations for the purpose of disseminating materials about the workshop *Food, Energy, and Water Nexus in Sustainable Cities***,** held in Beijing, China on October 20-21, 2015.

ACKNOWLEDGMENTS

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This workshop benefited from significant contributions of 30 active participants including our U.S. – China EcoPartners, Peking University (PKU); Wuhan University; the International Society for Water Solutions (ISWS) of the American Institute of Chemical Engineers (AIChE), and HDR Inc. Special thanks go to the staff of the Center for Water Research (CWR) at PKU, including Chunmiao Zheng, Ph.D., Professor and Chair, Water Resources and CWR's Director and Jie Liu, Ph.D., Associate Professor, PKU, for their assistance in making this a successful event and for hosting the workshop at PKU.

NYIT would like to take this opportunity to thank the workshop's programming team that was led by New York Institute of Technology (NYIT) and Peking University (PKU), who initiated their U.S.-China EcoPartnership collaboration in 2013 and held a conference in April 2014 on the Energy-Water Nexus. Several academic, government and private entities were engaged in planning the workshop, including from the United States: NYIT (Drs. Nada Marie Assaf-Anid and Marta Panero), and the American Institute of Chemical Engineers and its Institute for Sustainability (AIChE-IfS, Dr. Darlene Schuster), and from China: Peking University (Drs. Jie Liu and Chunmiao Zheng) and Wuhan University (WHU) (Dr. Xiahui Cui), along with representatives from the government agencies, in particular the National Science Foundation.

We would also like to recognize the participation of Dr. Bernard Engel, Professor and Head of the Agricultural and Biological Engineering Program at Purdue University; Dr. Zhongming Lu, Post Doc at Georgia Institute of Technology; Keith Schneider, Senior Editor for Circle of Blue and NY Times contributor; Dr. Joshua Sperling, Research Fellow, Urban Futures Program at NCAR; Dr. Jimmy Tran, Program Manager II, Lawrence Berkeley National Laboratory, Xia Zhao, Associate Professor, Qinghai Normal University; Lijin Zhong, Senior Associate and China Water Lead for the Water Program at the World Resources Institute; Dr. Guangwei Zhu, Deputy Director of the Chinese Academy of Sciences' Lake Tai Eco-Research and the Department of Hydrology and Hydrodynamics at the Nanjing Institute of Geography and Limnology. Our thanks also go to all workshop participants, including the U.S.-China Eco-Partners, such as Merrit Cooke, Founder and Chairman, China Partnership of Greater Philadelphia; Linghao He, Brookhaven National Lab; Dr. Devinder Mahajan, Professor and Co-Director, Chemical and Molecular Engineering, Stony Brook University, as well as Jennifer Turner, Director, China Environment Forum and Manager of the Global Choke Point Initiative at the Woodrow Wilson Center for International Scholars. Without their generous contribution of time and expertise, as well as their suggestions for future research directions, this synthesis report would not have been possible. While this report has benefited greatly from the participants' guidance, the views presented by the report's authors may not necessarily reflect those of the workshop sponsors and participants.

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EXECUTIVE SUMMARY

The overarching goal of the "*Food, Energy, and Water Nexus in Sustainable Cities*" workshop was to stimulate basic research on the interdependence of systems involving agriculture, water and energy. It also identified barriers to sustainability in food production, transport, distribution, use and access in urban environments. Participants discussed how best to study FEW couplings and stressors, with attention to systems-based approaches that help identify fundamental principles underlying various socio-economic, physical, and natural processes operating in built environments.

The workshop was structured around four topical areas: 1) FEW Nexus – Sustainability Challenges; 2) Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources; 3) Research Advances on Systems-Based Analysis for Complex FEW Systems, and 4) Sensors and Information Systems for Real-time Monitoring and Analysis and Modeling of FEW Systems. It also included a synthesis session. A summary of these sessions and recommendations is provided below.

Session 1: FEW Nexus – Sustainability Challenges

This session was designed to advance the understanding of the interactions among FEW resources, recognizing their inter-related nature and feedback mechanisms. Speakers presented on sustainability challenges, responses to stressors and coupling affecting FEW resources as part of dynamic and interrelated structural systems. Their recommendations included:

1.a. Given current and future stresses on FEW resources, and their nexus, decision makers need to have good inventories of resources use, including choke points, in order to improve sustainable planning and management. There is a great need for good data and to "map" local, regional and global FEW resources linkages, in particular water for energy and energy for water.

1.b. A holistic assessment was recommended as the best way to understand specific FEW nexus relationships, such as efforts to "map" water resources for energy and for holistic water footprinting analyses that consider the high evaporation rate from larger reservoir areas (e.g., hydropower).

1.c. Support technologies that promote water and energy efficiency, "harvest" waste, and/or close the material loop and/or those that can reduce the pressure of finding new resources, while also minimizing environmental impacts, (e.g., GHG emissions contributing to climate change). These include harvesting flared and fugitive CH_4.. A number of discoveries are enabling harvesting technologies of CH_4 and clean water and the extraction of nutrients from wastewater; including new membrane materials, novel microbial pathways, and advanced catalysts. Wastewater sludge can be converted to compressed natural gas; recovered water can be used for irrigation. Anaerobic digestion facilities (co-located at WWTPs) should be considered to create compressed natural gas from sludge.

1.d. Reduce waste during food production and distribution. The food waste alone, from "farm to fork," represents close to one-third of the total food produced at the global level. The concomitant losses in "embedded" water and the energy to carry food to consumers are also considerable.

1.e. Other recommendations during the group discussion included:

- FEW analyses need to note the significant differences in the energy-water nexus profiles at various levels, within nations, regions within a country, and different unit processes.
- Increased coordination is needed among agencies managing any infrastructure that has an impact on FEW resources. The water-energy nexus is poorly understood by decision-makers, in great part because water and energy infrastructure systems, although often interlinked, are currently managed separately. Such infrastructure management arrangements need to be revised. Urban planners and developers also need to be part of the dialogue.
- Top down approaches that result in fast and efficient implementation of measures to conserve FEW resources may be needed. In Dubai, centralized decision-making is used to implement best practices in a fast and efficient way when faced with rapid developments affecting FEW resources.

Session 2: Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources

This session focused on both increased disruptions to, and competition for, resources that sustain life and significantly impact the livelihoods of large populations and the environment. Potential solutions were also addressed, highlighting technological breakthroughs to ecological deterioration of water bodies that are vital for fisheries and other activities, as a result of growing urbanization and agricultural development. A summary of main findings and participants' recommendations follows.

2.a. Urbanization is a major phenomenon affecting FEW resources across the world today. In China, rapid growth, rising electricity and water demands, and an explosion in the number of vehicles are the main causes of poor air and water quality, and higher public health and climate change risks.

2.b. Competing demands for FEW resources are being felt across the globe and allocation regimes to supply FEW resources to cities often fail to consider constraints. For example, China, Yemen and several other countries, resort to transferring water to their cities in order to avoid extreme water shortages but the water transferred to cities is diverted from agricultural uses.

2.c. Water quality impairments are also a problem, as illustrated by the case of Lake Taihu where excessive nutrient enrichment (e.g. agriculture, industry) as well as warming trends, result in extended algae bloom. Long-term management must therefore consider both the human and climatic factors controlling these impacts on the water supply and food (fish) in this and other large lakes.

2.d. Harmonized methods and international data standards are needed to operationalize the FEW framework, in order to analyze the carbon footprints of cities, water vulnerabilities, or the social actors that shape urban infrastructures and consumption patterns toward sustainability. To implement concrete interventions it is important to improve the resolution of FEW flows' analyses, become more adept at identifying the possible uses of the information, and work to apply it in practical settings.

During the moderated discussion, participants recommended that:

- To address the growing stresses and seek solutions, the growth of cities may be understood at two levels: a) the "Sustainable city," which focuses on how it secures its resources and maximizes its efficiencies; and, b) the "Sustainable Organization," which analyses how much of a country's resource the city is going to consume.
- The value of information lies entirely within our ability to compartmentalize interventions that

can be undertaken by specific stakeholders to either use resources more efficiently (by doing the same things in a better way) or more effectively (by doing better things). Big opportunity areas to affect change, which can improve the lives of large population tracks are:

- Improve residential infrastructure planning, to promote sustainable life /development. Research to map out the specific behaviors that have an impact on water, food and carbon, identify those that may be influenced to have the biggest impact on the environment.
- Increase the food supply chain efficiency, evaluating efficiency losses taking place in each segment of the food chain.

Session 3: Research Advances on Systems-Based Analysis for Complex FEW Systems

This session focused on research advances for FEW systems protection, in particular the integration of heterogeneous data and uncertainties for systems-based modeling and analysis of FEW systems. Participants proposed frameworks for systems' modeling and for supporting decision-making associated with food, energy and water systems, such as:

3.a. Models were recommended to provide insight and decision support tools for FEW systems. One modeling framework includes FEW databases, GIS, optimization techniques, other information technology based approaches, real-time sensing data, and web interfaces to allow stakeholders to conduct site-specific assessments. Web-enabled decision support tools can assist decision makers and local stakeholders understand the complexity of the overall system and nexus interrelations.

3.b. The "Infrastructure Ecology" systems-based analytical framework seeks to characterize energy-water-transportation-food linkages and assist in the development of sustainable nexus relationships. The current paradigm of urban infrastructure development is fragmented in approach and lacking a systems perspective. This emerging trans-discipline fundamentally changes the questions asked by focusing on the interdependences of urban infrastructure systems, which are seen as analogous to ecological systems. A critical aspect for cities to become more sustainable is to focus on the infrastructure systems (e.g., energy, water, transportation) on which they rely, and on how to make them more productive, efficient and resilient. These infrastructure systems include: a) physical infrastructure systems and their interactions (e.g., water-transportation−energy nexus), b) ecological infrastructure, c) information and communications technology (ICT) infrastructure, d) socio-economic infrastructure (e.g., banking, finance) and e) social network infrastructure."

3.c. A "participatory" model for urban systems (MUST) may be used to characterize the symbiosis of complex urban infrastructure systems, as well as for optimizing their relationships. The key research elements of this model are:

- Systems dynamics modeling of complex urban infrastructure systems (i.e., the Metamodel).
- Quantifying the resilience of urban infrastructure systems.
- Social, Behavioral, and Economic decision making
- Optimizing resilience and sustainability

3.d. An integrated and analytical model called Markal may provide simple solutions for cities. Markal's optimization model for New York City minimizes the total system cost and maximizes customer benefits. In a city where close to 80% of GHG and other air pollutants comes from buildings, the model has helped identify alternatives for cooling buildings and minimize the heat island effect, shaving energy demand during peak hours, and reducing emissions of GHG and other pollutants. Thus, the Markal model is a powerful tool to support sustainability plans.

Session 4: Sensors and Information Systems for Real-time Monitoring and Analysis and Modeling of FEW Systems

This session focused on advances in the integration of IT and cyber-physical systems for real-time water quality monitoring and analysis. Participants' discussion and recommendations included:

4.a. Advances in sensors and other information systems for real-time monitoring can enhance the management of FEW resources by supporting analyses of FEW system interactions.

4.b. Wireless Sensor Networks (WSNs) are becoming prolific because they are inexpensive and easily deployable means to collect environmental data. WSNs enable the measurement and monitoring of various physical phenomena across disciplines. WSNs can monitor physical and environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and can cooperatively pass their data through the network to a central location. Monitoring data may be used to improve the management of water and energy intensive systems (power plants, desalination plants, residential use, water treatment).

4.c. Research is needed to support a unified and comprehensive reference model for WSNs to cover limitless and diverse applications of WSNs. Moreover, a reusable and flexible framework is needed to allow code reuse and rapid reconfiguration of a WSN for evolving needs and requirements.

4.d. Further research is also needed to support the development of cell-based biosensors capable of detecting water toxicity through perfusion and monitoring of living cells on a microfluidic chip. They are an improvement over current methods of monitoring toxicity, which are time-consuming, as they require moving water samples from the field to the lab for testing.

4.e. The emerging internet-of-things (IoT) is creating a world of digital and mechanical devices connected through an information network both wired and wirelessly.

Summary Session 5: Future Research and Implementation Directions

During this session the moderators for each session summarized the main knowledge gaps and data needs along with future research. They presented on shared concerns and common issues highlighted at all four sessions are summarized below, by categories.

5.a. Further Research is needed to:

- Improve the understanding of FEW trade-offs. Sustainable urbanization does not necessarily equate to sustainable cities.
- understand the applications on the effective fragment potential (EFP) to understand the energy components that may be harvested from wastewater treatment plants
- Assess the cumulative anthropogenic impacts at the river basin or lake scale in relation to land use, and identify social and economic solutions.

5.b. Further data and modeling tools to understand the FEW nexus and footprint, such as:

- Model validation and precise data collection efforts; better optimization techniques, visualization tools for the presentation of alternative scenarios and new tools to translate knowledge to stakeholders.
- Scaling - how to scale from one population to another.
- create modeling tools for Decision Support Systems – promote dialogue between data scientists and design professionals (complex) and policymakers (simple)
    - Simple Tools: such as models to provide stakeholders information about consequences of alternative development projects.
    - Complex Tools: MARKAL model emphasizes complex interactions
- Cross-cutting approaches to consider energy and water infrastructure as well as agricultural systems, in a holistic manner.
- Improve FEW resources' data collection and harmonization efforts, so that it is easier to synchronize data from various sources. Coordination before the data collection starts.

5.c. Further technology development and cost-effectiveness analysis are needed to mitigate the footprint of FEW nexus

- Technological advances to harness fuels from waste streams (flared gas, exhaust heat, wastewater treatment plants, sludge)
- Water monitoring technologies to improve ecological management that supports feedback loops from water and energy intensive systems (powerplants, desalination plants, water treatment)
- Various technologies should be explored to help reduce anthropogenic impacts, such as artificially constructed wetlands (ACW). Rather than a central treatment plant, the ACWs may be small, low cost, distributed plants that can treat the water in a sustainable manner.

5.d. Governance of energy-water such as top down vs. democratic, best practice vs. participatory.

- Interagency coordination is needed. Water management agencies need to incorporate energy requirements for wastewater treatment. Likewise, energy management agencies need to consider water requirements and impacts of their operation (e.g., water footprint hydropower expansion, including evaporation rates).
- Cross-cutting consideration for governance, which for FEW is multifold (e.g. demands for water from many stakeholders).

5.e. Best Practice and Exchanges for implementation

- Recommended best practices include identifying specific risks and opportunities for decision making and supply chain management, and bring increased understanding of human behavior.
- Participatory approaches and civic engagement and education are key to improve the management of FEW resources. Regions vary dramatically in terms of water security – one solution does not fit all, and regional assessments are recommended.
- Infrastructure-type "fixes" are not that difficult to implement, provided the funding is available. However, changing unsustainable human behavior is more challenging and requires more education and coordinated action.

BACKGROUND AND GOALS FOR THE WORKSHOP

The FEW workshop "*Food, Energy, and Water Nexus in Sustainable Cities"*, by NYIT was organized in association with PKU, builds upon previous collaborations, in particular *"The Water-Energy Nexus: Sustainability and Global Challenges"* conference, held on April 17, 2014 in Beijing, China as well as the workshop *"Clean Water Matters: Challenges and Research Perspectives,"* held at the Center for Water Research, PKU, Beijing, China on April 18, 2014.

The interdisciplinary nature of the workshop allowed for a broad-based perspective drawing from the federal government, industry, research scientists, academia, NGOs and entities focusing on the advancement of science and technology, including national agencies, foundations and private corporations in both countries. It called attention to the pressing crises in the provision of food, energy and water - all vital global resources that support cities.

Increased disruption to, and competition for, resources that sustain life have a significant impact on the livelihoods of large populations and the environment. These impacts are likely to be exacerbated by expected population growth and continued migration to urbanized areas in the coming decades, which account for 82% of the population in the United States[1] and 54% of the world population (projected to grow to 66% by 2050).[2] Therefore, particular attention will be paid to the role that urban centers play in consuming global resources, and how they may do so sustainably.

This workshop was sponsored by three entities: New York Institute of Technology, Peking University, and the Institute for Sustainability (IfS) of the American Institute of Chemical Engineers (AIChE). By engaging multi-disciplinary experts working on food, energy and water management and security, the workshop sought to provide a platform for informed exchange about the best approach to research and management of the global resource base.

Workshop Structure and Topics

Advancing the understanding of the interactions among FEW resources requires a systems-based approach that recognizes their inter-related nature and feedback mechanisms. For example, 71% of

[1] The World Bank IBRD.IDA; population data, by country
http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

[2] World Health Organization, Population Growth statistics for 2014
http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

global freshwater resources[3] and 30% of total energy consumed globally[4] are used for agriculture and food production. However, in 2010, close to one third of the food produced in the United States was not available for human consumption and this waste represents concomitant losses of land, water and energy resources.[5] Moreover, changing dietary patterns are also seen as having an impact on the water footprint of food production.[6] Similarly, alternative sources of energy such as biofuels are increasingly competing for land and water resources previously allocated to food production.[7] Therefore, participants were asked to consider *sustainability challenges faced by cities*, when addressing competing supply and demand for global resources. They were also asked to discuss *systems-based responses to stressors and coupling affecting FEW resources* as part of a dynamic and inter-related structural system.

The systems-based framework, emphasizing a "nexus" approach[8] to inform resource allocation and management decisions can help balance different resource user goals and interests, while maintaining the integrity of ecosystems and support sustainable cities. A key analytical aspect of this approach is to integrate information about the *life cycle of FEW resources* into current management practices and policy regimes that affect their supply and demand (generation, transport, use and ultimate disposal/ recycling and/or reuse). This approach is strengthened by *scientific advances in cyber-infrastructure to facilitate the integration of heterogeneous data uncertainties for systems-based analysis of FEW systems*. Challenges in the *protection of cyber-infrastructure* must also be addressed.

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[3] World Economic Forum, 2011; Water Security – The Water-Food-Energy-Climate Nexus; Island Press; Washington, Covelo, London.

[4] Food and Agriculture Organization of the United Nations; *The Water-Energy-Food Nexus: A new approach in support of food security and sustainable agriculture*; FAO, Rome, 2014.

[5] USDA's Economic Research Service (ERS), *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States*; Economic Information Bulletin # 121, February 2014; prepared by Jean C. Buzby, Hodan F. Wells, and Jeffrey Hyman. This publication reports on the amount and value of food loss in the United States, estimating that in 2010, approximately 31 percent of the 430 billion pounds of food produced was not available for human consumption at the retail and consumer levels. http://www.endhunger.org/PDFs/2014/USDA-FoodLoss-2014.pdf

[6] Several articles indicate that reducing animal products in the human diet offer the potential to save water resources, up to the amount currently required to feed 1.8 billion additional people globally; see for example: Diet change—a solution to reduce water use? M Jalava et al 2014 Environ. Res. Lett. 9 074016; http://iopscience.iop.org/1748-9326/9/7/074016/article

[7] UNEP, UNCCD; GEO 5; Global Environmental Outlook; Managing Increasing Pressures on Land http://www.unep.org/geo/pdfs/geo5/GEO-5_LAND-small.pdf

[8] FAO, Rome, 2014. Op. Cit.,

Participants also considered synergetic activities to optimize resource use. For example, the agricultural sector, including urban agriculture projects, may benefit from the integration of wastewater streams. As the sector begins to reuse wastewater for irrigation, water quality parameters will need to be correlated to potential negative health impacts. Public agencies, farmers and consumers will require food safety real-time information, in particular in view of recent episodes of bacterial contamination and health effects.[9] *Advances in sensors and other information systems for real-time monitoring* can address these concerns by supporting analyses of FEW system interactions.

Additionally, workshop participants provided insights on other *technological breakthroughs to reduce the ecological footprint of cities and propose pathways to sustainable, smart urban centers*. By using technological innovations and engaging residents, smart cities can play a critical role in reducing their material throughput and waste in key sectors such as energy, water, food and transport. This new vision of urban development recognizes the different demands placed on vital resources, the linkages, trade-offs and potential synergies among resources to optimize management and policy decisions about food safety and security. Technology innovations and infrastructure upgrades (e.g. new wastewater treatment approaches for enhanced water reuse) WERE considered emphasizing a systems-based approach, as well as metrics that evaluate the life-cycle impacts of investments on social and environmental resources.

The workshop began with an introductory session to highlight government agencies' broad perspective on sustainability challenges facing megacities and the complexities of the FEW nexus. The morning session on October 20 featured representatives from the US National Science Foundation, the National Natural Science Foundation of China, the U.S. Trade and Development Agency, the Chinese State Environmental Protection Agency (CS-EPA), the US Embassy in Beijing, the US-China EcoPartnership Program, and others.

A series of four 100-minute topical moderated discussion sessions were held over the remainder of the workshop, along with a final wrap up session. The four discussion sessions focused on the topics listed below and were followed by a synthesis session.

1. Sustainability and life-cycle assessment challenges in addressing complex systems-based indicators and responses to stressors and coupling those responses to FEW systems;
2. Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources.

[9] See, for example, episodes of spinach contamination in California.
http://www.foodsafetynews.com/2015/03/wa-firm-recalls-four-brands-of-frozen-spinach-sourced-from-ca/

3. Research Advances on Systems-Based Analysis for Complex FEW Systems, and

4. Sensors and information systems for real-time monitoring and predictive analysis and modeling of FEW systems.

The Food-Energy-Water Nexus

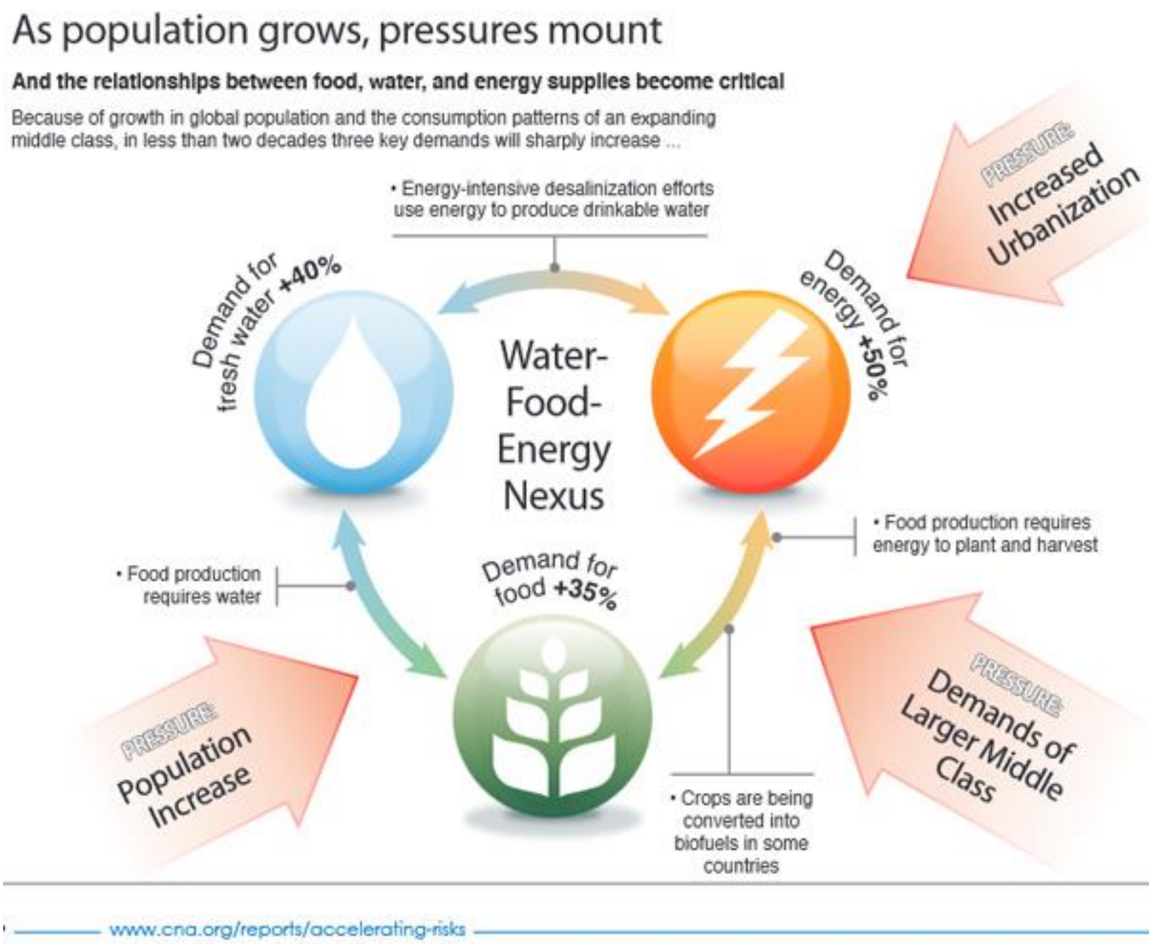

Figure 1 Food-Energy-Water Nexus

PROGRAM HIGHLIGHTS

Workshop Session 1: FEW Nexus – Sustainability Challenges

This session was designed to advance the understanding of the interactions among FEW resources, recognizing their inter-related nature and feedback mechanisms. Speakers presented on sustainability challenges, responses to stressors and coupling affecting FEW resources as part of dynamic and interrelated structural systems.

Chaired by Dr. Jimmy H. Tran, of the China Energy Group at Lawrence Berkeley National Laboratory, the session featured presentations by:[10]

- Junguo Liu, Ph.D., Professor from Beijing Forestry University;
- Devinder Mahajan, Ph.D., Professor and Co-Director of Chemical and Molecular Engineering at Stony Brook University;
- Lijin Zhong, Senior Associate and China Water Lead of the Water Program at the World Resources Institute; and,
- Paul Anid, Ph.D., Vice President of Water Quality Management Services at HDR, Inc.

This session provided insights for future energy-water nexus management decisions in China and abroad. Panelists presented on the main energy-water nexus challenges that will drive future technology development and suggested best management practices, and energy development pathways to maximize water/energy efficiency and greenhouse gas (GHG) reduction.

Junguo LIU, Ph.D., *Professor of Hydrology and Water Resources, Beijing Forestry University.*

Dr. Lui's presentation, "China's rising hydropower demand challenges for the water sector" highlighted the significance of the global water scarcity challenge. He noted that the World Economic Forum annual report, which evaluates 13 factors that can affect the world economy, recognized in 2014 that the water crisis has become one of the biggest challenges of the global economy. One third of the world population already lives in countries with moderate to high water stress and by 2030 nearly half of the global population could be facing water scarcity, and in the worst case scenario, about two thirds of the population will suffer from water scarcity.[11]

[10] Vincent TIDWELL, Ph.D., Distinguished Member of the Technical Staff Sandia National Laboratories, was detained and could not participate in person but he also contributed to this session, by sending comments to Jimmy Tran.

[11] Oki and Kanae, 2006. *Science;* Vörösmarty et al., 2000. *Science;* Vörösmarty et al., 2010. *Nature.*

In China, the water scarcity problem is of particular concern because about one third of the population is now living in areas with "absolute water scarcity" and about three-fourths live in areas with some level of water scarcity.

Dr. Liu then discussed food-energy-water nexus research,[12] in particular quantifying China's food-induced (and land-induced) water footprint and using this data to assess water scarcity from different activities in various regions. He focused on hydropower and its rising demand in China, which from 1949 to 2010 has increased from 1.2 billion to 1.7 billion, or about 600 times more hydropower production. Since 2013 China became the largest country in terms of gross installed hydropower capacity as well as hydropower generation. By 2020, China will top its own production of hydropower compared to 2007. This is due to China's 12th five-year plan (2011-2015), which set a goal for non-fossil fuel energy to account for 15% of the total energy consumption by 2020, with more than half from hydropower (or an increase of hydropower use by 50%).

Yet there are many concerns about hydropower sustainability, in particular concerns about the water footprint (WFs) of reservoirs and hydropower, and their contributions to water scarcity, which are poorly understood. For instance, dams can reduce sediments flux and change temporal patterns of river discharge to downstream and the ocean, and also affect biodiversity (e.g., Yangtze finless porpoises, which used to live in the river, and are now extinct). There are also GHG effects and more significantly, regional water supply issues.

Dr. Liu argued that it is important to quantify the water footprint of hydropower production in a holistic manner. To that effect, he and his team have calculated reservoirs' water footprint (WF) (freshwater that evaporates from reservoirs) and hydropower WFs (the WF of hydroelectricity) in China based on data from 875 representative reservoirs (209 with power plants). In 2010, the reservoir WF totaled 27.9 Ã— 109 m3 (Gm3), or 22% of China's total water consumption. Ignoring the reservoir WF seriously underestimates human water appropriation related to hydropower production.

Since hydropower is a water intensive energy carrier, comparing the hydropower water footprint with many other energy carriers, Dr. Liu's team found that the hydropower WF is relatively much higher.[13] This signifies that from a water consumption perspective, hydropower is not an efficient solution to energy supply. To exacerbate the situation, and as a response to the global climate change challenge, the Chinese government is promoting further increase in hydropower energy by 70% by 2020 compared to 2012. This energy policy imposes pressure on available freshwater resources and increases water scarcity. The water-energy nexus requires strategic and coordinated implementations of hydropower

[12] Being conducted by Dr. Liu and his team at Beijing Forestry University.

[13] His team also worked on quantifying the water footprint of biofuels and found that producing biofuels requires 1000 times more than the biofuel in volume.

development among geographical regions, as well as trade-off analysis between rising energy demand and water use sustainability.

Dr. Liu also called attention to food waste and the embedded water that is lost when agricultural products don't make it to the table. His Team quantified the amount of lost grains "from field to fork" in China and found that 19% of the grains are lost in the supply chain and this represents 26 million hectares of cropland used in vain. While in China the volume of "wasted" grains is large, it is much smaller than in other developed countries where from 40% to 60% of the food produced is wasted. Dr. Liu's team also quantified the embedded water in "wasted" grains in China and estimated that 135 billion cubic meters of water is used to produce food that is never eaten (equivalent to the WF of all of Canada).

Figure 2: Food losses and food waste in China.

Devinder MAHAJAN, Ph.D., *SBU/BNL Joint Appointment, Professor and Co-Director, Chemical & Molecular Engineering, Stony Brook University, SUNY*

Dr. Mahajan continued the discussion of specific challenges and potential solutions faced by cities, but focusing on energy. He started his presentation by acknowledging partners and mentioned the ongoing work to develop advanced energy technologies at "Low-Carbon Energy Management" (L-CEM) laboratories at the Advanced Energy Research & Technology Center (AERTC), a $45 million New York State funded research facility. Dr. Devinder also referenced the "Eco Partnership" between Stony Brook and Tongji University.

His presentation, *"Smart Cities: Challenges and Solutions to the Development of Low-Carbon Technologies"* called attention to the impacts ensuing from a dramatic expected increase in the global population. It is projected to rise from over 7 billion today to 9 billion in 2040, with most people residing at urban centers. In terms of climate change, atmospheric concentrations of CO_2 keep increasing, with the projected number for 2035 at around 450ppm. To compound the problem, energy demand is increasing across the globe, in particular in China; therefore, he argued that the key question is whether carbon dioxide emissions can be contained, since impacts are already being felt today with concentrations already over 400ppm.

These changes in both population and climate change will further strain the planet's vital resources. As population grows, it is critical to consider the relationship between food, water and energy supplies. Given three key drivers – projected growth in the global population, rising consumption patterns of an expanding middle class, and increased urbanization patterns – he highlighted how these will affect FEW resources in the coming two decades, with increased demands for:

1. Food, projected to increase by 35% (increased food production requires more water as well as energy during planting and harvesting)
2. Fresh water, expected to grow by 40% (e.g., due to energy intensive desalination to produce drinkable water)
3. Energy, demand estimated to growth by 50% (some countries are converting crops into biofuels).

Dr. Devinder then discussed potential solutions to address the increased energy demand. He said that one option is recoverable gas,[14] which has been estimated at over 550 trillion cubic meters (tcm); however as demand will be increasing over the next two decades, fossil fuels' supply *share* will drop from 81% to 74%. The other option is to recover fugitive methane. Figure 3 below shows global anthropogenic emissions of methane by source, and illustrates potential opportunities to "harvest" methane (CH_4),[15] which can be used to supply the expected increased demand.

Dr. Devinder noted that although advanced technologies that pair seismic surveys to methane hydrate systems continue to help locate new resources such as oil & gas, and fertilizers have increased food yield per hectare, the increased use of hydrocarbons must be weighed against continued rise of atmospheric CO_2 and other negative impact of increased use of fertilizers. He argued that focusing on making cities "smart," is a timely endeavor in order to address challenges and find potential solutions.

[14] The amount of resources identified in a reserve that is technologically or economically feasible to extract, as defined at: http://www.investopedia.com/terms/r/recoverabel-reserve.asp#ixzz41aGOSJM7

[15] In terms of GHG effect each CH_4 unit is equivalent to 21 CO_2 units. As per the U.S. EPA, methane (CH4) is the second most prevalent GHG emitted in the United States from human activities. In 2013, CH4 accounted for about 10% of all U.S. GHG emissions from human activities. Methane's lifetime in the atmosphere is much shorter than carbon dioxide (CO2), but CH4 is more efficient at trapping radiation than CO2. Pound for pound, the comparative impact of CH4 on climate change is more than 25 times greater than CO2 over a 100-year period. In formation available at: http://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html.

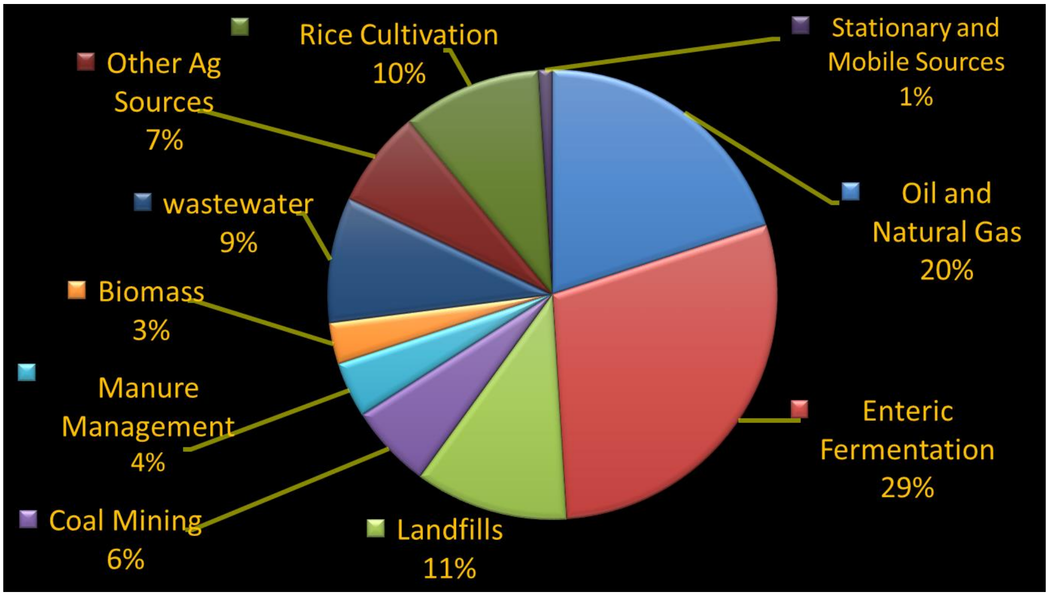

Figure 3: Global anthropogenic emissions of methane gas, by source.
Based on data from U.S. EPA (2006) EPA 430-R-06-003, revised 2012.

Smart cities could utilize what is produced within city boundaries in an integrated systems approach. Waste utilization is a low-hanging fruit that can meet the projected higher energy demand from increased population, standard of living while addressing Climate Change. With respect to FEW resources, he discussed various solutions, including:

Energy:

- Harvesting flared and fugitive CH_4 to mitigate GHGs, which has the potential to replace 3 thousand barrels of oil equivalent (mb-oe) per day.
  - Capturing methane from landfills and wastewater, and from manure management, which represent 11%, 9%, and 4%, respectively, are good opportunities to reduce almost one quarter of the global emissions and generate renewable energy (e.g., compressed natural gas).
  - Flared natural gas is estimated at 134 billion cubic meters (bcm) gas annually, which approximates 5% of the total global gas usage, or 400 mb or 2% of total global CO_2 emissions. This has the potential to displace oil (1.4 mb per day).[16]
- Producing biogas from:
  - Recovered waste materials from landfills, such as municipal solid waste (MSW), construction and demolition (C&D), and yard waste. Currently, landfill managers are paying to dispose of any materials at incinerators or transported to other facilities, besides materials recovered for recycling.
  - Wastewater treatment plants: Sewage sludge (see below)
  - Agricultural residues: plant waste and animal manure
- Low-temperature waste heat from industry mediated by low temperature reversible reaction could be a key to avoided new resources.

[16] The Global Gas Flaring Reduction (GGFR) Initiative supports efforts to capture flared methane.

- S& T will play a major role in addressing the challenge that certain known pathways of waste utilization are too energy intensive to be economical. Processes that are economical at small scale, such as skid-mounted units that can be applied in cities, are desired.

Water:

- Wastewater sludge can be converted to compressed natural gas; recovered water can be used for irrigation. Anaerobic digestion facilities (possibly co-located at WWTPs) should be considered to create compressed natural gas from sludge.
- New technologies are needed in order to more fully realize wastewater as a resource. Wastewater has the potential to be a source of renewable energy, water, and nutrients. A number of discoveries are enabling advances in technology to recover energy, water and nutrients from wastewater, such as new membrane materials, novel microbial pathways, advanced catalysis, and others.

Food:

Dr. Devinder and his team are working on the "Farm-to-Plate" concept, which addresses waste that is currently generated during food production, distribution, and consumption. The waste amounts to more than one-third of all three FEW resources:

- Food waste that could be recycled to produce renewable fuels,
- Low-temperature heat waste (below 100^{o} C) from industrial processes that could be used for residential buildings and
- Wastewater (embedded and recycled), ripe for harnessing CH_4 in the process.

Dr. Devinder concluded his presentation by stating that we need to address the nexus of all three FEW resources. As an example, he envisions that the harnessed energy from waste, once recycled, is more than sufficient to accommodate the projected population increase while also stalling the growth of GHG in the atmosphere and maintaining the 2-degree scenario (2DS) to stabilize atmospheric CO_2 and prevent the worsening of climate change effects.

Lijin ZHONG, Ph.D., *Senior Associate, China Water Lead, Water Program, World Resources Institute (WRI).*

Dr. Zhong began her presentation titled "Water-Energy Nexus in Cities," stating that the agenda of the WRI focuses on the connection between the human population and the environment. She discussed the water and energy challenges faced by Chinese cities. There are several problems, including air pollution and traffic congestion. She noted that in 2013 there were 189 days of high pollution in Beijing, in part because of coal combustion with China's consumption representing 50% of the global total. Moreover, 32% of the particulate matter 2.5PM emissions are associated with transport, and since vehicle ownership is increasing the transport share of these emissions is likely to go up.

Given higher requirements on water quality and reclaimed water reuse, the energy consumption of urban wastewater system increased 80% compared with 2007 and the energy intensity per unit wastewater treated increased 11%. With the higher demand on water resources and water quality, urban water systems become more energy intensive, and GHG emissions have been rising as well, thus directly contributing to climate change.

These trends are likely to be exacerbated with economic growth. Water shortages are another challenge. Over 30% of the population, in particular in northeast China, has been experiencing extreme water stress episodes. The water supply is not sustainable, she argued, because available water is either in short supply or not sufficiently clean to be consumed by humans, which only aggravates the water shortages in some regions. At the same time, heavy rains cause floods in other regions.

The rapid urbanization patterns are a key factor. Dr. Zhong noted a WRI research project looking at the speed of urbanization and the increase in water demand over the past decade in different provinces in China. The WRI has catalogued different cities into different groups, according to water resources per capita. Interestingly, if a city has a faster rate of urbanization, it will also have a faster increase in the rate of water demand per capita. On the one hand, economic development is the goal, but at the same time the increase of water demand becomes a challenge. A key issue in China is to also think about the water energy nexus, in particular energy intensive water systems (e.g., filtration, desalination).

Dr. Zhong highlighted the water-energy nexus as another challenge in China, which is poorly understood by decision-makers. She mentioned that the water and energy infrastructure systems, although often interlinked, are currently managed separately, she argued that this infrastructure arrangement needs to be revised, in particular because urbanization is seen to increase the demand for water.

Next, she discussed the water-energy nexus by focusing on the urban water supply, highlighting three case studies being advanced as part of the World Resources Institute's "Sustainable and Livable Cities" Project, which started five years ago. These projects include a wastewater treatment facility in Chengdu in Sichuan Province, a "Sludge to Energy" project in Xiangyang in Hubei Province, and a water supply project in Qindao, Shangdong Province, where the available water resources per capita is 15% of the national average.[17] Since the local supply, in particular surface water, is not sufficient to support the development of the city, a water-transfer project will bring freshwater from the Yangtze River to Qindao.

The WRI conducted research comparing traditional and nontraditional alternative ways to supply water, focusing on their energy consumption per unit of water production. They found that, compared to treating surface water or ground water, the energy intensity increased dramatically – 10 times more for desalination, and 2.7 for long distance transfer of water to Qingdao. Therefore, she recommended that desalination should be considered more carefully, as part of an energy-water nexus assessment that evaluates total impacts on the environment.

The Chengdu case study illustrates potential energy efficiency improvements for wastewater treatment plants (WWTPs). This study benchmarked 2800 plants in China and found that over half of these

[17] She mentioned that the average water resources of China are just 1/3 of the global average.

facilities are below the average energy efficiency per unit of wastewater treated. The study estimates that if all WWTPs are upgraded to meet the standards used by the most energy plants, then over 6 billion kilowatt-hours can be potentially saved.

Similarly, the Xiangyang case study reveals opportunities for energy efficiency measures, with applicability to the 4000 WWTPs in China. While most managers focus their attention on the water treatment aspects, most treat sludge (a bi-product of the wastewater treatment process) as a disposal problem instead of an opportunity. Typically, a WWTP has to pay to dispose of the sludge at landfills, composting sites, or incineration facilities. This is not only costly but also energy inefficient. A better approach is to divert the sludge to an anaerobic digestion facility, which can result in profitable outputs, such as compressed natural gas that may be used to generate electricity, as well as bio-char (a charcoal used as soil amendment that can be used to plant trees that capture CO_2).

In closing, Dr. Zhong summarized the main challenges that need to be overcome in order to make decisions that consider the nexus between water, energy and climate change:

- Lacking consideration of energy as a factor in water resource selection and wastewater treatment
- Insufficiency in R&D and infrastructure investment (e.g. pipes, construction)
- Ignorance of the impacts of urban water systems on climate change
- Lacking data and statistics on the energy consumption of water supply and wastewater treatment

Paul J. ANID, *Dr. Sc., Vice-President, HDR Inc., New Jersey, USA*

Dr. Paul Anid discussed the case of Dubai – one of the seven United Arab Emirates. While the city has only 2.4 million permanent inhabitants, he argued that Dubai behaves as a "mega" city. More than the concrete and glass with their different shapes, dimensions and forms, it is the surroundings, ambiance, services and people that make some of the Gulf States unique, including their skyscrapers, regardless of their quantity or height. However, this development comes along with ineluctable environmental concerns.

Water consumption in Dubai is one of the highest resources used, with 60 percent of the water being consumed by residential users, followed by commercial and industrial users. Land reclamation has had its toll on the marine coastal resources. In 2015, its coastal line has increased from 80km to 300km compared to 2000, by adding "palm" islands. Natural currents and long-shore sediment transport have been altered, resulting in new deposition and re-suspension patterns. The quality of coastal waters has dramatically degraded in particular in the islands and near the points of discharge. The effect has been a rise in the water table, which is affecting infrastructure and foundations.

Dubai's air quality, which is already subject to natural sand storms, is worsened by rising emissions from stationary (power plants and industry) and mobile sources (transport sector). Food security is still largely dependent on imports or on energy and water intensive techniques. The industries built were far away from the city when they were constructed. Now Power Plants and desalination units are adjacent to urban communities. Cooling water and effluents from desalination plants are discharged along the 80km coastline.

The elevated energy consumption per capita is another concern, in addition to air quality deterioration exacerbated by naturally occurring sand storms. Energy consumption was about 35,000 GWH in year 2014. This is the largest per capita consumption of 30 KWh per person, per day (versus a world average of ~ 15 KWh per capita). Yet this represents a drop of 4.2% compared to per capita consumption per day in 2010. The elevated energy consumption is related to desalination. The UAE is the second largest producer of desalinated water in the world and they have the largest desalination unit in the world. Yet, he added, a large deficit is expected in the next 15 years, as current desalination capacity will not suffice if the same consumption patterns persist. Dubai has become today the fourth tourist destination in the world with 12,000 million tourists in 2014 and an expected 20 million tourists visiting in 2020.

In the near future, Dubai is planning to construct another tallest building in the world, and they are also planning to expand the port. This means that more resources will be demanded in the future and the usage of water, energy, food will grow massively.

In Dubai, the water from desalination plants provides water for residential and commercial uses. As to wastewater, in the past it used to be discharged. Now the wastewater released from residential usages is sent to treatment plants where nitrogen, phosphorus and other substances in the water are treated. The treated water is now used for citywide landscape irrigation projects, which is a great innovation in Dubai. Imagine most of the landscapes in the city being irrigated by wastewater. The Dubai canal, a 20km canal linking Dubai Creek to the Arabian Gulf, will create a north-south and east-west connection and an "*Island*" inside Dubai. The rising water table is a spreading phenomenon affecting the infrastructure in some areas.

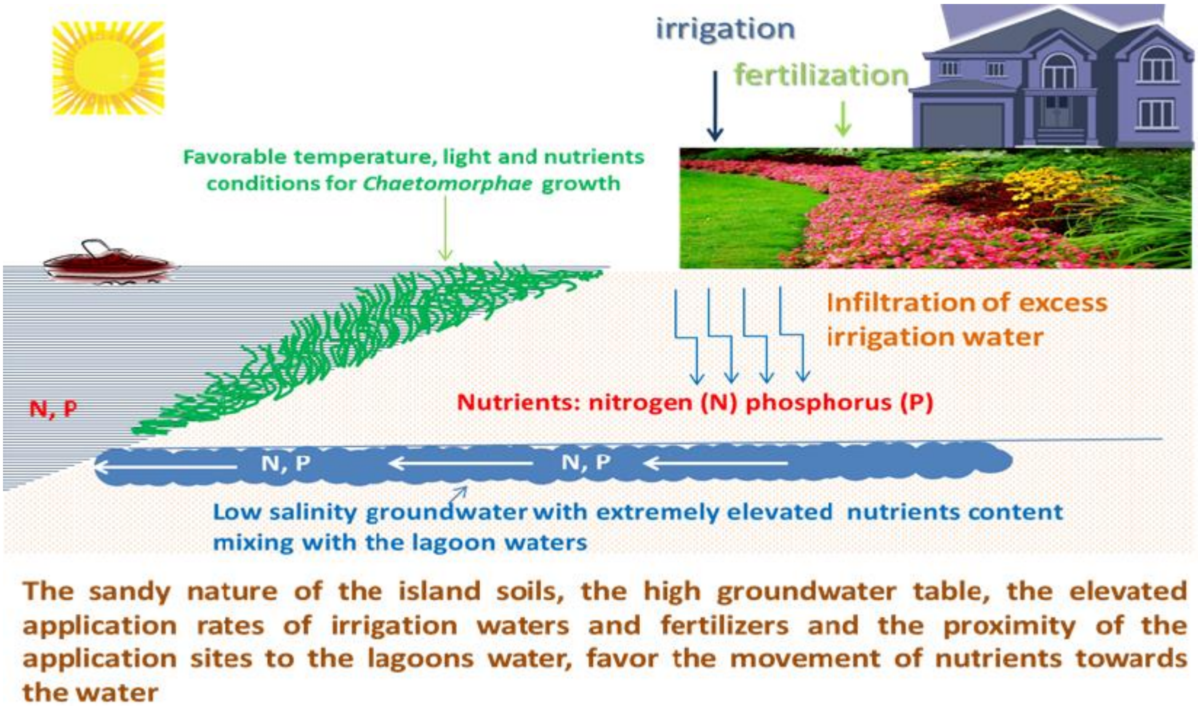

Figure 4: Factors affecting the water quality in Dubai and contributing to the proliferation of microalgae.

Dubai faces many challenges. Urban sprawl and development cannot go unfettered especially when waterfront and access to water scenes is the backbone of a city. The coastal marine resources are probably among the resources that suffered the most given the magnitude of past and current land reclamation projects along the coast.

A major challenge is that development in the city is happening too fast and too soon, and citywide planning is not able to keep up. The government has instituted a few policy or regulations such as environmental impact assessment studies, which are being enforced on government projects. Dubai has instituted management approaches to sustainability. They have locally derived and empowered environmental standards, as well as monitoring programs by both government and project proponents. They also have plans (e.g., the 2021 and 2030 plans) that include environmental protection as the main components with numerical, achievable targets. To illustrate, they plan cutting the air emissions by 90% by 2021 and to generate 30% of energy from renewable energy sources by 2030, to reach 100 percent water recycling, and reduce in per-capita water and energy use.

Moreover, the government has food sustainability and security plans, which include replicating U.S. designs to produce millions and millions of fingerling fish that will be put back into the sea for replenishment. Dr. Anid concluded stating that the challenges Dubai faces are great but they are attempting to overcome them with increased planning for tangible outcomes over the next 5 years.

Workshop Session 2: Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources.

This session focused on both increased disruptions to, and competition for, resources that sustain life and have a significant impact on the livelihoods of large populations and the environment, as well as potential solutions, highlighting technological breakthroughs to ecological deterioration of water bodies that are vital for fisheries and other activities, as a result of growing urbanization and agricultural development.

Chaired by Sarah Meyland, J.D., Associate Professor of Environmental Technology and Sustainability at NYIT's School of Engineering and Computing Sciences, the session featured presentations by her along with:

- Joshua Sperling, Ph.D., Research Fellow at the Urban Futures Program of the National Center for Atmospheric Research;
- Josh Weinberg, Program Manager for Water, Energy and Food at the Stockholm International Water Institute;
- Shenglong Zhang, Ph.D. Assistant Professor of Life Sciences, College of Arts and Sciences, NYIT; and
- Guangwei Zhu, Deputy Director of the Chinese Academy of Sciences' Lake Tai Eo-Research and the Department of Hydrology and Hydrodynamics at the Nanjing Institute of Geography and Limnology.

After their presentations, participants engaged in a moderated discussion to advance the understanding of the interactions among FEW resources, and the need for a systems-based approach to recognize their inter-related nature and feedback mechanisms.

Sarah J. MEYLAND; *Associate Professor; NYIT*

Prof. Meyland presented on a "Water Treatment Technology that Works for Megacities" in need of efficient wastewater treatment, recycling, soil remediation and as a food production resource. The project being developed at NYIT's Long Island campus involves the use of Constructive Treatment Wetlands (CTWs). Wetlands have often been referred to as the kidneys of the planet, as their unusual combination of bacteria and plants provide clean water. They have cleaned and recycled water on Earth for over two billions years, as part of a natural process.

The idea of using wetlands to clean polluted water has resulted in various applications and technologies all over the world. Prof. Meyland highlighted a CTW project in a small city in California, north of San Francisco, on Humboldt Bay. About 30 years ago, this small city of about 17,000 people started developing the native wetlands on Humboldt Bay, which is right next to their city. Over the years they have enhanced and perfected the wetland treatment process. So now they treat all of the city's sewage, approximately 2.3million gallons a day (MGD). This wetland system covers about 160 acres and includes primary, secondary and tertiary treatment and then disinfection prior to the discharging the wetland effluent into Humboldt Bay.

She mentioned that the idea of using artificially created wetlands to mimic the natural treatment process is getting much more popular and one of the people leading this research is Dr. John Todd. His research has led to many different approaches to using wetlands for treatment, including a technology called "living machine." The U.S. EPA and USGS very much like this approach and have been funding and promoting it.

Engineered mechanical systems in use today treat water but at a much higher price than the process nature performs for free. CTWs systems that mimic nature can reach higher levels of performance for wastewater treatment and contaminated site remediation with fewer disposal by-products, and thus are making significant gains.

Meyland discussed how CTWs are being employed in large urban areas to clean polluted water, to treat municipal and industrial wastewater, and to reclaim contaminated soils. CTWs are ideal for large cities where collection infrastructure and treatment are expensive, and where space may be limited and disposal of wastewater can be complicated. They can be deployed in small modules or scaled to meet large treatment needs (> 1 MGD flows). In megacities, growing local food can be a challenge, especially when the soil itself is no longer safe for food production.

CTWs can help reclaim sites damaged by industrial waste and can be located strategically in decentralized treatment hubs. Water from the systems can be recycled to support creative farming practices such as vertical farms. Most significantly, these new biological systems are highly sustainable, using less energy, no chemicals and requiring little maintenance. Because they are plant-based, to the casual observer the treatment systems look like planted areas or native gardens.

A demonstration CTW system for NYIT's Long Island New York campus is in the planning stage. The system at NYIT is called the enhanced Subsurface Flow Constructive Treatment Wetland (SSF CTWs). The SSF CTW has an aeration component making it the best choice among existing systems. It not only has the ability to treat waste water but it also takes the organic materials and nutrients of the water and its specific application includes removal of pollutants like metals, toxic chemicals, suspended and colloidal materials. It also kills pathogens and serves as a disinfectant. It is an extremely green technology, has very low power needs, and no chemicals are required.

The CTW system is also self-sustaining, as it is very low maintenance and fits into a small space. Ultimately this technology can fit into existing systems in cities. It can help reduce storm water overflows, treat contaminated surface and groundwater, and also treat soil and water that comes out of the system and can be recycled for variety of uses such as urban (vertical or roof) farming. She concluded, stating that this is an approach that has lot of applications and could definitely work to ensure the sustainability of megacities.

Joshua SPERLING, *Research Fellow and Adjunct Professor; National Center for Atmospheric Research | University of Colorado.*

In his presentation, "FEW-Related Risks, Inter-dependencies, and Priorities: Exploring a Parallel Nexus of Infrastructures, Environmental Change, and Health in Urbanizing Cities," Dr. Sperling shared insights from interdisciplinary research activities at the NCAR Urban Futures and Climate Science and Applications Program. This research aims at understanding the impacts and addressing some of the critical risks of urbanization and anthropogenic disruptions on vital FEW resources, in the context of a parallel nexus of urban infrastructures, environment, and health in cities of the US, India and China.

He referred to four published papers[18] on urbanization and understanding of the common issues that are relevant to the FEW nexus, reporting key challenges such as rising infrastructure resource demands. In the case of China, rapid growth and increasing electricity and water demands, as well as an explosion in the number of vehicles have translated to increased pollutant and GHG emissions, which may be are associated with thousands of premature deaths and climate change risks. He suggested that public private partnerships can help to address the challenge of managing increased and competing demand on FEW resources. The papers ensue from two recent projects, including:

1) The Partnership for International Research and Education (PIRE): Developing Low-Carbon, Healthy and Resilient Cities in the US, China, and India through integration across Engineering, Environmental Sciences, Social Sciences, and Public Health. The PIRE award supports a five-year project that brings researchers and students from six U.S. institutions together with five partner institutions in India and three in China (Tongji University, Tsinghua University, the Chinese Academy of Sciences Institute for the Urban Environment) to conduct transformative research that will contribute to the development of low-carbon, sustainable cities in the U.S., India, and China. This research effort is two-pronged, focusing on reducing greenhouse gas emissions in selected cities and also addressing broader sustainability goals such as economic development, resource scarcity, environmental pollution, climate change, and public health.

2) The award Research Coordination Network (RCN) on "Sustainable Cities: People and Infrastructure at the Energy-Water-Climate Nexus," is funded under NSF's Science, Engineering, and Education for Sustainability (SEES) program. It aims to address the challenges of creating a sustainable world.[19] The

[18] Building on efforts by Dr. Joshua Sperling with Dr. Patricia Romero Lankao, Dr. Anu Ramaswami and other international collaborators, which discuss FEW-relevant results and proceedings evolving out of two recent US NSF awards focused on urban sustainability.

[19] The RCN provides science based systems analysis tools which is needed by more than 1000 cities worldwide that are developing sustainability plans addressing energy, water and climate change. A unique aspect of this RCN is broad-based integration across urban ecology, industrial ecology, atmospheric sciences, infrastructure engineering, architecture, urban planning, behavioral sciences, public affairs and public health toward the goal of sustainable cities. Cross-discipline integration, coordination of data across scales, and cross-city comparisons are expected to advance the science of sustainable cities. The RCN has potential to impact more than 1200 students

project seeks to develop a research collaboration network (RCN) across 20+ US universities and two national labs to coordinate work on the overarching theme of sustainable cities, with focus on reducing energy use, carbon emissions and mitigating climate-risks to water supply and public health in cities. The US network will collaborate with international sustainability research networks (in Australia, EU, Asia) and with a network of practitioners and policymakers in US and global cities. RCN activities will lead to the development of:

a) inter-disciplinary systems framework(s) to represent linkages between people, infrastructures and the natural system, from the city-scale to the global scale that shape sustainability outcomes in cities.

b) harmonized methods and international data standards to operationalize the framework, to report, for example, the carbon footprints of cities, water vulnerability of cities, or to analyze social actors who shape urban infrastructures and consumption patterns toward sustainability.

c) a network of 12 global cities for testing the framework and its component theories and models/methods in cities with different natural, infrastructural, socioeconomic and cultural characteristics,

d) a virtual collaborative forum to share research methods, experiences and teaching tools across more than 20+ US universities on the common thematic area of sustainable cities.

In his concluding remarks, Dr. Sperling envisioned the future development of a cross-national network focusing on the FEW nexus in Sustainable Cities, which will serve as a common platform to share experiences on interdisciplinary and international research, education, and sustainable community development programs.

Joshua WEINBERG, *Program Manager, Knowledge Services, FEW, Stockholm International Water Institute*

Mr. Weinberg started his presentation “Making Operational Nexus Approaches to support Sustainable Urbanization” by introducing the work of the Stockholm International Water Institute (SIWI). He stated that this water policy and management institute does not deal with infrastructure projects but rather with guiding decision makers on such projects. The SIWI organizes the “World Water Week” in Stockholm,” which is really important within the water developing communities and engages 3500 participants every year from 350 participating organizations.

SIWI has a new program, the Urban Water Security program, which in China attempts to map and

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in participating US universities and 65 million people in the network of cities where fieldwork will be coordinated. Dissemination potential is high through network links with policy groups such as ICLEI-USA and the World Bank who work with cities worldwide.

access the water energy linkages in the Taihu basin, as this is one of the most heavily urbanized water basins in the world. The project seeks to understand water, energy and security impacts.

Weinberg noted that urbanization is a major phenomenon happening around the world today – urbanization. The growth of cities may be understood at two levels – the "Sustainable city," which focuses the analysis at the city level, and how it secures its resources and maximizes its efficiencies. There is also the "Sustainable Organization" level, which analyses how much of a country's resource the city is going to consume.

Analyses of the water-energy-food nexus can take many forms, and can add anywhere between marginal to significant value depending upon how well targeted the research design is from its onset. The value of the information and insights produced lies entirely within our ability to compartmentalize interventions that can be taken by specific stakeholders to either use resources more efficiently (doing the same things in a better way) or more effectively (doing better things).

SIWI has improved its ability to navigate the FEW nexus significantly by leveraging several applied tools and methodologies. SIWI is cataloguing approximately 50 of current FEW nexus tools and trying to understand data requirements, key users and what they produce. These can be matched against the context of the Taihu basin. SIWI is working on three connected issues that will enhance the understanding of nexus tools, such as:

- Understanding the nexus: working on basic assessments, such as what are the amounts of water used for energy, energy used for food, etc.
- Governing the nexus: guiding specific institutional interventions, ranging from policy responses to the FEW crisis, or changing government structures at the city level and help those attempting to achieve better governance.
- Implementing the nexus: technical intervention to improve efficiencies and the process of implementing technologies, including scaling up.

He also noted that there are big opportunity areas to affect change, which can improve the lives of large population groups. These include:

- *Residential Infrastructure Planning*, to promote sustainable life. SIWI conducted a simpler exercise where they mapped out the specific behaviors that have an impact on water, food and carbon and identified the ones that may be influenced to have the biggest impact on the environment.
- *Food Supply Chain Efficiency*. There is lot of work being done in this field, including some SIWI studies in China, evaluating efficiency losses taking place in each segment of the food chain.
- *Rapid organization*. China is working to transfer water to its cities in order to avoid water shortages, as is the case of Yemen or other cities that have grave water shortages. China will allocate the water to cities from agricultural uses. The Chinese government seeks to emphasize water

efficiency improvements in agriculture (e.g., more water going to the crop). However, the impacts that water reallocation measures have on entire watersheds are poorly understood.

These are largely untapped opportunities and to make concrete interventions he argued it is important to improve the analysis of FEW flows, and becoming more adept at identifying the range of possible uses of that information, and applying the information in practical settings. SIWI is also supporting various initiatives to advance the state of the art for understanding FEW nexus relationships with respect to climate change, such as IAEA's CLEWS Framework.

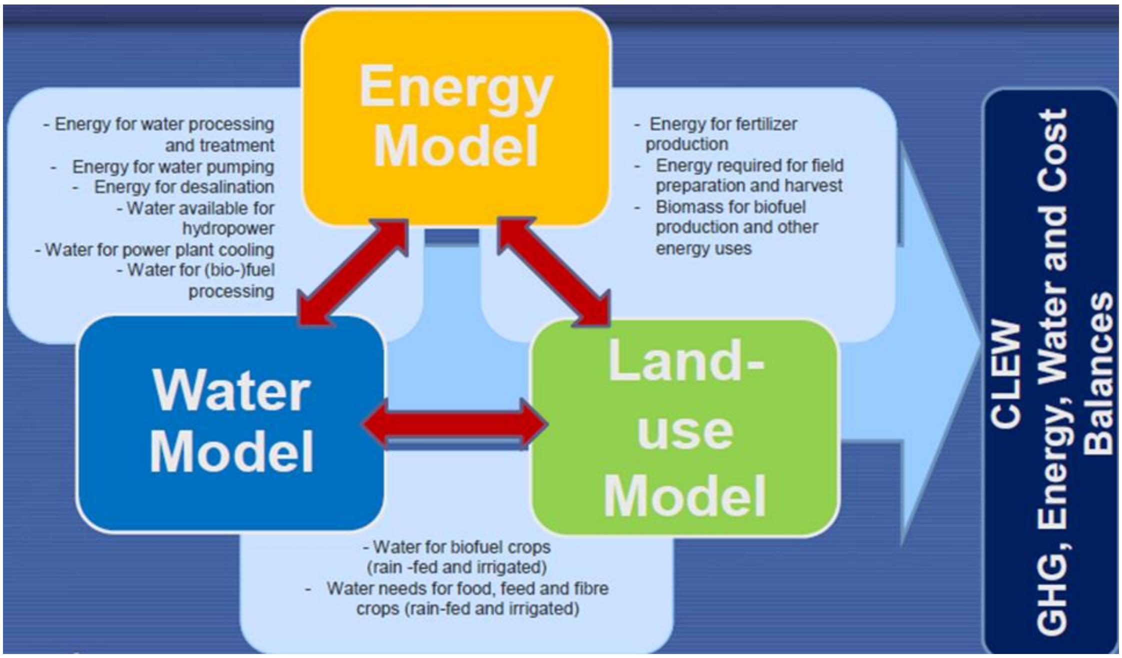

Figure 5: CLEWS Framework for integrated analysis of climate change, land-use, energy and water strategies.

Shenglong ZHANG; *Assistant Professor; New York Institute of Technology*

In his presentation "Finding the Environmental Footprints of Growing Megacities on DNA/RNA," Dr. Zhang discussed a recently developed technology in his lab, which can help to answer questions of how genetic material, such as DNA or RNA, may change or be modified chemically in response to changes in FEW resources during the course of the building and maintenance of megacities. Given that growing megacities bring a lot of changes to the environment, our life and ecosystems, he said that it makes us ask whether DNA/RNA genetic material is sufficiently stable to survive these changes.

A systematic evaluation of how megacities impact our ecosystems requires new technologies that can accurately detect and monitor their footprint on organisms at the molecular level. Dr. Zhang's lab is developing new technologies to detect genetic variations of different organisms in response to changes in food, energy, and water from megacities.

Taking DNA methylation as an example, it has been associated with a broad range of diseases including cancer, asthma, metabolic disorders and various reproductive conditions. Environmental exposures such as malnutrition, tobacco smoke, air pollutants, metals, organic chemicals, other sources of oxidative stress, and the micro-biome, represent an important pathway to induce the epigenetic change, which is inheritable through generations.

Environmental changes such as nutrient deprivation and heat shock can induce other ribonucleotide modifications like pseudo-uridine. It is one of the very common RNA modifications and has been found in all the species. Studies of these ribonucleotide modifications are very important because people grow up and live in very different environments, and changes of these modifications can serve as biomarkers, which could be very unique and very personal. The information in this direction could be very helpful to develop personalized medicine for different environmentally induced diseases.

A more specific question he discussed is how the higher temperature from urban heat islands in megacities is going to affect the DNA/RNA of organisms in our ecosystems. His new technology can help answer this question, which is largely unknown currently due to lack of efficient technologies to detect RNA modifications. The research his lab is pursuing will provide scientific evidence in this field so that we can understand better the environmental impact on gene expression. Ultimately, the resulting data will provide policy makers and the Nexus Community of Water, Energy, Food Security with scientific evidence to better manage the impact of megacities on our ecosystems.

Guangwei ZHU, Ph.D., *Research Professor; Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences*

Dr. Zhu's presentation focused on the Water Crisis of Lake Taihu –China's third largest freshwater lake. He briefly introduced the work of the Taihu Laboratory for Lake Ecosystem Research (TLLER) research center, located 110 kms west of Shanghai. Lake Taihu's water surface is 2,338 km^2 (smaller than Lake Superior), with an average depth of 2 meters and maximum depth of 3 meters; its catchment area (Changjiang Delta) is 36,500 km^2.

The Taihu Lake is the main water source for the cities of Wuxi, Suzhou and Shanghai. According to data collected by the lab, in 2009 there were 2,693 lakes in China that occupied less than one square kilometer. He also mentioned that according to a report from the same year, 243 lakes have disappeared over the past 40 years and 13% of lakes have shrunk in size.

Dr. Zhu mentioned that in late May 2007, a drinking water crisis was experienced in Wuxi, Jiangsu Province, following a massive cyanobacteria bloom, with the toxin producing microcystis species being a major factor and the anabaena species a supporting factor. Taihu Lake was Wuxi city's sole water supply, leaving approximately two million people without drinking water for at least a week (May 29-

June 3, 2007). The cyanobacteria Microcystis[20] started spreading in Taihu River in the year 1970, affecting only a small part of the lake but by the year 2006, it was covering more than 50 percent of the lake's surface.

In 2007, the cyanobacterial bloom event began two months earlier than previously documented. Three key factors have been identified as exacerbating this massive bloom. First, 2007 was an unusually warm spring. Notably, the spring air temperature has been increasing since 1951, as reflected in changes in daily mean surface water temperatures. Another factor was the prevailing wind direction during this period, which caused the bloom to accumulate at the shoreline near the intake of the drinking water plant. A simulated spatial distribution of chlorophyll under the influence of different wind regimes showed that the bloom intensifies with easterly winds. Thirdly, a patch of an extremely serious bloom (black patch) started on April 8 (a month earlier than expected) and blocked the water plant intake at Gonghu.

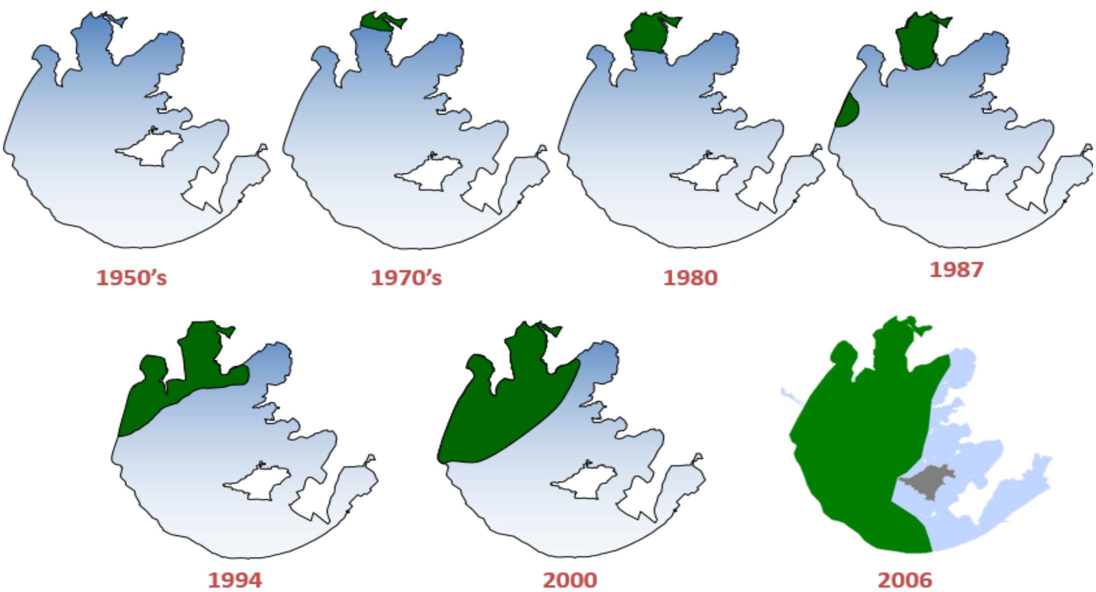

Figure 6: History of blooms in Taihu Lake.

In an effort to flush the lake of the bloom, water was diverted from the nearby Yangtze River. However, this management action was counterproductive because it produced a current, which transported the bloom into the water plant intake, exacerbating the drinking water contamination problem. The

[20] Boqiang Qin, Guangwei Zhu, et al; A Drinking Water Crisis in Lake Taihu, China: Linkage to Climatic Variability and Lake Management. November 2009; Springer Science+Business Media, LLC 2009. ww.academia.edu/17950531/

government has taken a number of actions after the water crisis in 2007 and invested 100 billion RMB[21] in several activities. At the catchment level, it has worked to identify sources of nitrogen and phosphorous and to control fertilizers to cut down the influx of these chemicals that "feed" the algae. It is also monitoring effluents from factories, and has forced hundreds of chemical and manufacturing plants to relocate.

Several wastewater and sewage treatment plants have been built on the tributaries of the Taihu Lake. Authorities have also invested in ecological restoration projects. At the lake level, the government has been dredging to remove nutrient-rich sediments, including at the mouths of the lake's tributaries. Other initiatives include ecological engineering projects.

The TLLER lab has been collecting bloom samples and has been monitoring the bloom growth using remote sensing technology. They installed high frequency sensors on buoy systems to monitor and forecast the growth of the bloom. They collect data (chlorophyll, temperature, suspended solids and transparency) and use information from various datasets (HJ – CCD, MODIS, MERIS, GOCI) to help team interpret trends in the algae bloom. They have developed a hydro dynamical bloom simulation model that uses a 3-D model and is calibrated with field data.

As a summary, Dr. Zhu mentioned that the severity of the 2007 microcystin toxin containing bloom and the ensuing drinking water crisis was attributable to excessive nutrient enrichment as well as a multi-annual warming trend, which extended the bloom period and amplified its severity. This situation was made worse by unanticipated negative impacts of water management. Long-term management must therefore consider both the human and climatic factors controlling these blooms and their impacts on the water supply in this and other large lakes threatened by accelerating eutrophication.

Finally, he stated that Taihu, which is located in the delta region of Changjiang, a megacity, is seriously over-burdened to supply the cities around it, a situation that will largely affect the sustainable development of these cities. The use of environmental sensors and information technology, including high-frequency buoy and models, has prevented another drinking water pollution event in Taihu. However, Dr. Zhu warned that the ability of environmental technology to address this issue is limited, as this is a social and economic issue, too and for a holistic solution of the problem, a large number of social and economic considerations are needed.

[21] The report "On Lake Taihu, China Moves To Battle Massive Algae Blooms" by Yale Environment 360 estimated in 2011 that $155 million would be invested over 5 years to restore Lake Taihu's ecological balance. http://e360.yale.edu/feature/on_lake_taihu_china_moves_to_battle_massive_algae_blooms/2429/

Workshop Session 3: Research Advances on Systems-Based Analysis of Complex FEW Systems

This session focused on research advances for FEW systems protection, in particular the integration of heterogeneous data and uncertainties for systems-based modeling and analysis of FEW systems. Dr. Xiaohui (Sean) Cui, Dean and Professor at the International School of Software of Wuhan University, chaired the session and moderated discussion also addressed challenges in the analysis and protection of FEW resources utilizing mathematical modeling and GIS techniques.

- Dr. Cui moderated and presented
- Bernie Engel, Ph.D., Professor and Head of Agricultural and Biological Engineering, Purdue University;
- Linghao He, Sustainable Energy Technologies, Brookhaven National Laboratory;
- Zhongming Lu, Ph.D., Brook Byers Institute for Sustainable Systems, School of Civil and Engineering at Georgia Institute of Technology; and,
- Yi Zheng, Ph.D., Associate Professor at the Department of Energy and Resource Engineering, College of Engineering of Peking University.

Xiaohui CUI, *Dean of the International School of Software; Wuhan University*

Dr. Cui's presentation focused on a computational simulation model for understanding the impact of electric vehicles on the power grid. He said that the power grid has been traditionally used to provide the energy supply to address the energy demand by homes and/or buildings, and or industries. When a new energy requirement is introduced, for example via added demand from plug-in hybrid electrical vehicles (PHEV), then the power grid will be affected and new capabilities may be needed. To understand the impact on the power grid, Dr. Cui proposed running a model that can highlight the distribution and pockets of high PHEV ownership at the local level.

Identifying high PHEV ownership areas within a city or province can better demonstrate where additional power grid capabilities (e.g. adding a micro-grid powered by solar and/or wind) might be needed. He added that this is an improvement over most other high level models and research efforts that focus on that average level of energy consumption of a region, like how many PHEVs are in the Hubei province. A model with finer grain resolution capable of distinguishing the demand profiles of each small zone better helps policymakers understand the impacts on the power grid at the local level.

The model may be designed to simulate various scenarios; e.g., what would happen if PHEV ownership increases dramatically and thus help determine if the increased demand may overpower the local power grid. The model can pay particular attention to peak demand, or times when the demand from other usages (e.g., air conditioning) cannot be shaved. Dr. Cui and his research team are looking at how this is exactly going to impact the grid, based on simulation results. The model considers how many are going to buy PHEVs, at what locations, and when they are going to charge their electric vehicles.

One reason he has been focusing on this issue is that in the future we might not use traditional power supplies to provide the energy to the local communities. Each house is going to have their solar panels on the roof. But those panels can provide only limited energy supply and might not enough to charge PHEVs. He argued that if the number of PHEV ownership increases very fast, then additional power plants or additional power panels at the local level may be needed.

The model uses an agent-based framework to model the distribution of PHEVs to evaluate their impact on a particular zone. Dr. Cui discussed a model he runs with collaborators from Oakridge National Lab, based on data collected in the Knoxville area, which is located in Tennessee County. The agent model is a basic model, based on each individual agent behaving and making decisions driven by the surrounding environment, and the market and social context.

The model was designed to provide the total power demand distribution for a particular area. It includes high fidelity household demographic data for 190,000 households. For each household, the model fed on information about each individual person's age, income, work destinations, and other likely travel behaviors, and the distance they are going to travel for work or shopping. Data extracted from land scans developed by Oakridge National Lab, add geolocation information, and travel distance categories (10, 20, 40 miles) showing travel patterns, which may vary according to type of vehicle, e.g., distance without using gasoline, electric charge, and if more distance is traveled via electric cars, that means more expensive cars because they rely more on batteries. So, based on this simple model, families likely to purchase electric vehicles can be tracked. Running simulations into the year 2025 could help in planning for a resilient power supply.

A key issue to make accurate predictions is to validate the data used for these simulation models. In addition, the model itself, as any consumer-decision model, needs to be validated. The key is to interpret human behavior correctly and input it into the agent-based model. Representative surveys can help correct the data. Finally, the output (final results) of the model need to be validated. The simulation model results will help decide where to allocate additional resources on the power grid, thus the importance of a high accuracy model. Similar models may be used to understand choke points and tradeoffs between FEW resources.

Bernard ENGEL; *Professor, Agricultural and Biological Engineering, Purdue University; and, Head Member of the U.S.-China Eco Partnership for Environmental Sustainability (USCEES).*

Dr. Engel presented on modeling and decision support tools for food, energy, and water (FEW) systems. Due to the complexity of these systems and their interactions, innovative models and tools are needed to assist a range of stakeholders in understanding these systems and the likely impacts of the decisions they make. Dr. Engel and his colleagues have developed a systems modeling framework that utilize models, databases, geographic information systems (GIS), optimization, other information technology based approaches, and real-time sensing data, which can assist decision makers and local groups in the development of sustainable FEW systems.

Most of the models and decisions support systems focus primarily on water, but there are also some that integrate food and energy systems into the analysis. Models of hydrological water quality systems, pull data from a variety of databases that are typically web enabled, and combine various data sets (including GIS and recently also including sensing data and real-time monitoring data). The data can be retrieved and models can provide a whole set of outputs, including tabular graphical data. Some of the most popular of these tools are accessed thousands of times per year and use web interfaces to allow stakeholders to readily retrieve data and conduct site-specific analyses.

In Indiana, these tools have been typically used for analyzing water quality, based on the total maximum daily load approach. The analysis can help determine if a source of contamination is from industry, from agriculture, or from stream bank erosion. It also helps stakeholders and/or decision-makers in their decisions. In another model, it was possible to go back and pre-populate the model with some of the local information, then run an optimization to find out which practice should be prioritized to optimally address the water quality issue.

Another model case is in the northeast of the State, where there were substantial issues caused by algae-blooms over several years, probably due to climate change. Data were pulled together to run a hydrological impact assessment model, showing what happens when different measures are taken. The results helped stakeholders understand what happens to the water system when changing land use practices or measures to control run off.

Dr. Engel added that these models have been around for about the last 15 years in various versions. He described one model, which is based on a simple web interface, collecting data from a web GIS kind of application. People can do queries about local communities or larger towns in which they live, to understand the impacts of land of changes on such communities, including their water quality and amount of water that might be running off various land uses. To illustrate, a community in the central part of Indiana was facing development decisions and wanted to determine what run-off impacts would ensue form developing a particular area, in particular impacts on local streams and river. Interestingly, they used the model, and people could compare the amount of runoff prior to the development against the expected runoff due to the planned development scenario.

These types of models can also help plan for countermeasures. If the expected run off will double, people will be unhappy with that outcome, but maybe they can develop a number of low impact development practices. The model could help decide what combination of countermeasures will be more effective in solving the runoff problem at the local level.

Also, interestingly, some studies with more progressive approaches to development integrate real population trends. Populations may be growing but urbanization may change very little, therefore decreasing the per capita impact of runoff. Another effort to carry this model a step further is adding optimization and the ability to represent a variety of low impact development practices, like rain gardens, green roofs and other practices that may be integrated in an optimized framework. He mentioned that communities or planners can ask questions such as, "if I have a million dollars to spend on improving the water quality, how much benefit does that get us?"

Such optimization simulation models can help to identify the best options as well as where these need to be implemented. One project in a 5000-hectare watershed used the model to identify the best combination practices and where they would be applied to attain an optimum level, given a set amount of dollars to spend. By using this simulation model the decision makers can see what measures can achieve a 20% reduction in run off entering the watershed, instead of just 10% or 15% reduction for random placement of these measures. Therefore, just by running out the simulation model, a community improves its decision making process, while also attaining larger environmental benefits.

In closing, Dr. Engel mentioned that he and his team have consistently engaged stakeholders, by working with people on the ground to help them make decision using these models. He added that his approach is driven by science, engineering, and technology. Additionally, it provides experiential learning opportunities to students to develop these tools over the years. Students are now working on expanding this framework, to go beyond water models by integrating food and energy.

Linghao HE, *Sustainable Energy Technologies, Brookhaven National Laboratory*

In his presentation, Linghao He discussed a case study run at BNL with Dr. Vatsal Bhatt. The study focuses on New York City (NYC) and illustrates the energy and water nexus in an urban setting. He first offered some background on New York City and introduced the MARKAL model, and then provided a detailed analysis of energy and water systems in the context of climate change impact. Mr. He argued that NYC is one of the biggest megacities in the world, in terms of both its population and economy.

NYC is also facing many challenges, such as continuous population growth and rising water and energy demand. To address these challenges and strengthen the resiliency of the city, in 2007, Mayor *Bloomberg* released a long-term sustainability plan, now called NYC plan. The data shows that New York city has the lowest greenhouse emissions per capita in the United States, thus making NYC the greenest city in the country. This is in part because of NYC's extensive use of public transport. However, given NYC's aggregate population,[22] the total GHG emissions are considerable and the city's vital infrastructure resources are vulnerable. This was evident in 2003 when a massive power outage swept through the northeast of North America including Toronto and NYC.[23] Certain areas of the city also lost power and water for a week due to Super storm Sandy in 2012.

[22] New York City Population Closes In On 8.5 Million, more than what 39 of the 50 U.S. States have individually. http://newyorkyimby.com/2015/03/new-york-city-population-closes-in-on-8-5-million.html

[23] It is estimated that 50 million people were affected and economic losses were between 7 to 10 billion dollars.

Mr. He mentioned that NYC has asked for the assistance of the U.S. Department of Energy to find preventative solutions for such infrastructure challenges (e.g., power and water shortages). His work at Brookhaven National Lab has been to run an integrated and analytical model called MARKAL, which may provide simple solutions for cities. He stated that over the past few years, he and Dr. Bhatt have been working with approximately 200 indicators, of which the greenhouse effect is a key indicator. The MAKRAL model focuses on long-term integrated energy, environmental, and economic analyses, at either the global, national or regional levels. The U.S. MARKAL model provides a comprehensive and integrated energy-water analysis, with the goal of identifying alternatives for cooling the city to minimize the heat island effect, shaving energy demand during peak hours, and reducing emissions of GHG and other pollutants.

He has run different scenarios for NYC, comparing various alternative energy and water policy and technology solutions that may be implemented in cities. Given that 78% of GHGs in NYC are associated with buildings, the solutions range from reducing peak electricity demand, to green roofs and planting trees, to increased energy efficiency measures, He noted that the base case scenario considers the installed electricity production capacity and whether the productive life of existing power plants can be extended to 2050 (via retrofits or new technologies).

It also takes into account certain constrains, such as land-use laws, expensive real estate, mandates for producing 80% of needed electricity demands within the geographic boundaries of the city (without using nuclear), as well as sustainability goals, which imply clean and increasingly efficient technologies. Given these constrains, one can run a MARKAL optimization model, where the main objective is to minimize the total system cost and maximize customer benefits. It can be applied with different user-defined time horizons, for short or long term planning, as well as for smaller, community level analyses. It can also be scaled up to the city level.

He then turned to the analysis of NYC water systems and their relationship to energy. The main drinking water source is a system of 19 surface water reservoirs north of the city.[24] The energy challenges in NYC relate to the water transmission, supply of clean water, and wastewater treatment. He developed a model to analyze and evaluate energy required, and associated emissions, from wastewater treatment plans in NYC, which treat 1.3 billion gallons of wastewater per day.

The simulation model shows that there are several strategies that can be implemented to reduce the energy demand of power, such as installing fuel cells at wastewater treatment plants that may provide >30MW by 2050. Other energy efficiency measures focus on reducing the amount of sewage and storm water that enters the system and then needs to be treated (e.g. by minimizing leaks, installing efficient appliances and toilets and creating rain catchment areas or gardens). He added that when talking about the energy-water nexus it is important to consider climate change, because of its impacts on energy and

[24] Some reservoirs are more than 125 miles from NYC (e.g., Catskill / Delaware Watershed). http://www.nyc.gov/html/nycwater/html/drinking/reservoir.shtml

water systems. The temperature of NYC has been warming up and there are more energy requirements for cooling; however, providing more energy for the increasing cooling demand is very difficult. The MARKAL model, which identifies various technologies and the most effective and simple solutions, is an important planning and forecasting tool.

He concluded by emphasizing that the MARKAL model has shown it is a powerful tool to support sustainability plans and to provide strategies for the city, with robust and secured energy and water infrastructure systems for NYC. However, more work is needed to strengthen the resiliency of the city in the case of future super storms, or other impacts of climate change.

Zhongming LU; *Post Doc; Georgia Institute of Technology*

Dr. Lu presented on the new concept of "Infrastructure Ecology" that proposes a systems-based approach for characterizing energy-water-transportation-food linkages and developing a sustainable nexus relationship. He mentioned that the increased rate of urbanization places cities at the forefront of achieving global sustainability. A critical aspect for cities to become more sustainable is to focus on the infrastructure (e.g., energy, water, transportation) on which they rely, and this infrastructure must become more productive, efficient and resilient.[25]

He presented on a "participatory" model for urban systems (MUST) for complex urban infrastructure systems. The key research elements of this model are:

1. Systems dynamics modeling of complex urban infrastructure systems (i.e., the Metamodel).
2. Quantifying the resilience of urban infrastructure systems.
3. Social, Behavioral, and Economic decision making
4. Optimizing resilience and sustainability

Dr. Lu argued that the current paradigm of urban infrastructure development is a fragmented approach and a lacking systems perspective. A new paradigm is "Infrastructure Ecology" – an emerging trans-discipline[26] that fundamentally changes the questions that are asked. It focuses on the interdependence of urban infrastructure systems, which are seen as analogous to ecological systems. These infrastructure systems include: a) physical infrastructure systems and their interactions (e.g., water-transportation–energy nexus), b) ecological infrastructure, c) information and communications technology (ICT) infrastructure, d) socio-economic infrastructure (e.g., banking, finance) and e) social network infrastructure."

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[25] Before starting the discussion Dr. Lu mentioned an international conference on Sustainable Infrastructure, which will take place in September 2016 in China. This conference is lead by Dr. John Crittenden from Georgia Tech and the leading sponsors are the Chinese and the US Academy of Engineering in the city of Shenzhen, China.
[26] Infrastructure Ecology seeks to create a body of knowledge distinct from its antecedents (engineering, ecology).

Such systems are interconnected, complex, and adaptive components that exchange material, information and energy among themselves and to and from the environment. Analyzing them together as a whole, as one would do for an ecological system, provides a better understanding about their dynamics and interactions, and enables system-level optimization. Indeed, Infrastructure Ecology seeks to alter and reorganize energy and resource flows and to consider the potential synergistic effects arising from infrastructure symbiosis.[27]

There are two essential components of the methods in infrastructure ecology: 1) systems thinking of infrastructural symbiosis and 2) managing the complexity of urban infrastructures. Systems-thinking of infrastructural symbiosis refers to the application of flow analysis in closing the loops of water, energy, carbon, materials and nutrients.

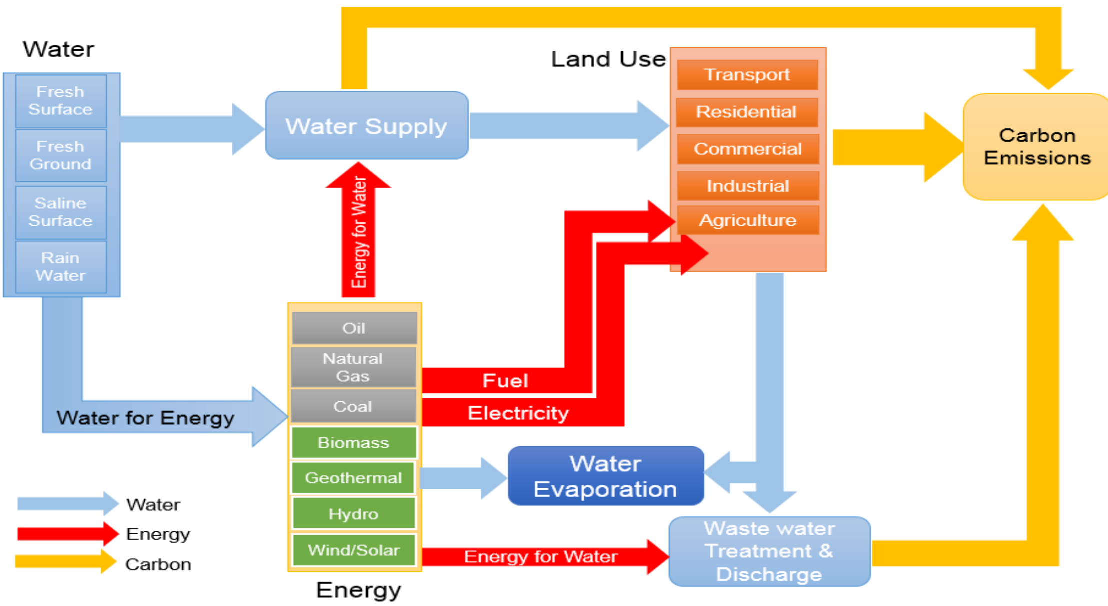

Figure 7: Interdependences of Urban Infrastructure Systems.

In terms of "Infrastructure Symbiosis," Dr. Lu then presented on a set of integrated examples using decentralized water and energy solutions that created synergistic benefits for developing more sustainable energy-water-transportation-food nexus.[28] He discussed three examples to address cities' increasing demand for clean water. The first one is decentralized energy systems that effectively reduce

[27] IE analyses may facilitate the adoption of new urban (re) development that requires lower investment of both financial and natural resources (to either build or maintain), is more sustainable and resilient (e.g. uses less materials and energy and generates less waste), and enables greater and more equitable opportunities for the creation of wealth and comfort.

[28] He mentioned that Georgia Tech is running a master project involving eleven PIs to understand the inter-dependence between water, energy, food and transportation network. The PI's carrying the computer science infrastructure as asset management, environment engineering, urban planning most importantly ecologist.

water used in energy production. Another one is grey water reclamation system in homes, which could save 50% of the water supply in a control case. The water saved may be used for irrigation for urban farming, thus making urban food systems more resilient.

Grey-water systems are also effective in reducing the volume of wastewater effluents, and therefore could decrease the energy required at wastewater treatment plants. This means cities could save money by being able to operate smaller wastewater treatment plants; and also have more concentrated wastewater sludge for energy and initial recovery. He also discussed other solutions for decentralized energy production, such as upgrading current infrastructure by adding thermo storage, micro-grid systems, and/or cogeneration turbines, which could increase the range of renewable resources to include in urban infrastructure systems.

A key aspect of infrastructure ecology practitioners is how to incorporate human behavior and provide the analytical results to citizens. Many decisions on how and where we live, how we go work etc. underlay the inter dependencies between infrastructure and social ecologies in environment. Considering cities as complex adaptive systems, the Georgia Tech team has developed a meta-model approach to predict the emergent patterns of cities and their citizens.

This approach involves big data science, which informs the development of a decision-making model, and an agent-based model that can be used to explore policy incentives for the adoption of more sustainable infrastructure designs. Coupled with the feedback from life-cycle assessment and various sustainability metrics, the approach enables the emergence of a more sustainable future by providing more desirable amenities that can drive the adoption and adaptive management of the system.

He added that it is important to have the right cyber infrastructure to allow cities to integrate these tools and specify connections and communications and then run these tools on high performing computers. The analysis informs decisions and right choices that impact various strategies and how they can affect real scenarios for infrastructure systems management in the future. To validate the model, one can use the “impacts” data to project the electricity and water savings from use of distributed water energy technologies, as well as the emission and cost reduction of NOx.

In closing, Dr. Lu emphasized the importance of using system-based approaches to recognize the inter dependencies that can be leveraged to support synergetic effects. These synergies can help cities create sustainability plans that support reduced water and energy consumption, and lower dependency on central infrastructure systems.

Yi Zheng; *Associate Professor, and Associate Director of the Center for Water Research, Peking University*

Dr. Zheng presented on PAHs contamination on topsoil – as a buried evidence of the evolving environmental quality and energy consumption in megacities. He said that New York City and Beijing are both megacities facing very complex issues with respect to FEW resources and their nexus relationships are difficult to understand solely from field data. So he is proposing a systems approach to tackle these megacities FEW problems.

He noted that PAHs contamination in topsoil is closely related to air pollution from combustion sources, and essentially linked with energy consumption. In Beijing there has been a change in the approach to battle air pollution. Before the 2008 Olympic Games, a big motivation was to have good quality air and several policy measures were implemented to achieve this goal. For example, in downtown Beijing, an initiative started in 2003, dealt with heating sources, such as producing heat from coal. Another major measure was the relocation or shutdown of major emission sources, such as Capital Iron and Steel Co., a Beijing Coking plant and a Beijing chemical plant.

After the games, one challenge the government has faced was to simulate significant public awareness to improve air quality. This led to more public policy measures, which include controls to decrease the volume of regular traffic, starting from the year 2008, and restrictions on car purchases staring on 2010 and as recently as 2013, the substitution of natural gas for coke (coal). He added that when it comes to air quality, two critical questions must be asked: first, has the environmental quality in Beijing really improved through all these years? Second, are the existing policy measures appropriate? Also even if appropriate they may not be cost effective.

To address these questions, Dr. Zheng led a study of PAH content in topsoil, which can be considered as an indicator of the energy consumption-related pollution in megacities. PAHs stands for polycyclic aromatic hydrocarbons. There are 16 USEPA priority PAHs. They are persistent organic compounds that result from incomplete combustion via car emissions, coal combustion, cooking and biomass burning and other activities. PAHs have a high toxicity and pose potential harm to humans making PAH contamination in megacities not only a health issue but also an energy issue. The most important compound is Benzo(a)Pyrene (BAP), with regard to toxicity.

PAHs can be released from many different sources and be transported through the atmosphere for eventual deposition, where they go into soil and road dust. The main point is that soil is a major PAH sink. Most of the PAH particles are black carbon, interestingly many of the particles are below 2.5 ppm, so the PAH problem is also related to health problems associated with particular matter (PM 2.5).

Regarding the methodology used, Dr. Zheng stated that he and his team tried to take a snapshot of the soil contamination, for both 2004 and 2013. This research is mainly concentrated on six downtown districts and four sub-urban districts of Beijing. The contents of 16 priority-PAH compounds were measured using a source apportionment analysis that relied on a Principal Component Analysis (PCA), which is one type of Positive Matrix Factorization (PMF) method to evaluate risks using the content carcinogenic equivalent concentration of PAHs.

Dr. Zheng's team did not observer a change in the overall PAH content but in the composition profile of the soil samples. For high ring compounds (those with more toxicity), they saw a clear decreasing percentage trend. He added that with this source apportionment method, people are now debating about whether traffic emissions are more important than coal burning or the other way around. He provided some indirect evidence on this issue. Clearly with regards to soil contamination, there is evidence that vehicle emissions outplay coal burning.

These are preliminary results to be further refined because an important technical issue is that the data does not allow for the successful separation of coal and vehicle emissions for 2004. Ten years ago the lumped contributions of coal and vehicles were about 67.5% of the total; however, today these two sectors' combined contributions has increased up to 90%. But when one looks at energy consumption data in Beijing today, the coal consumption has remained relatively stable and even decreased slightly while the number of vehicles have tripled, and the transportation's contributions has clearly increased.

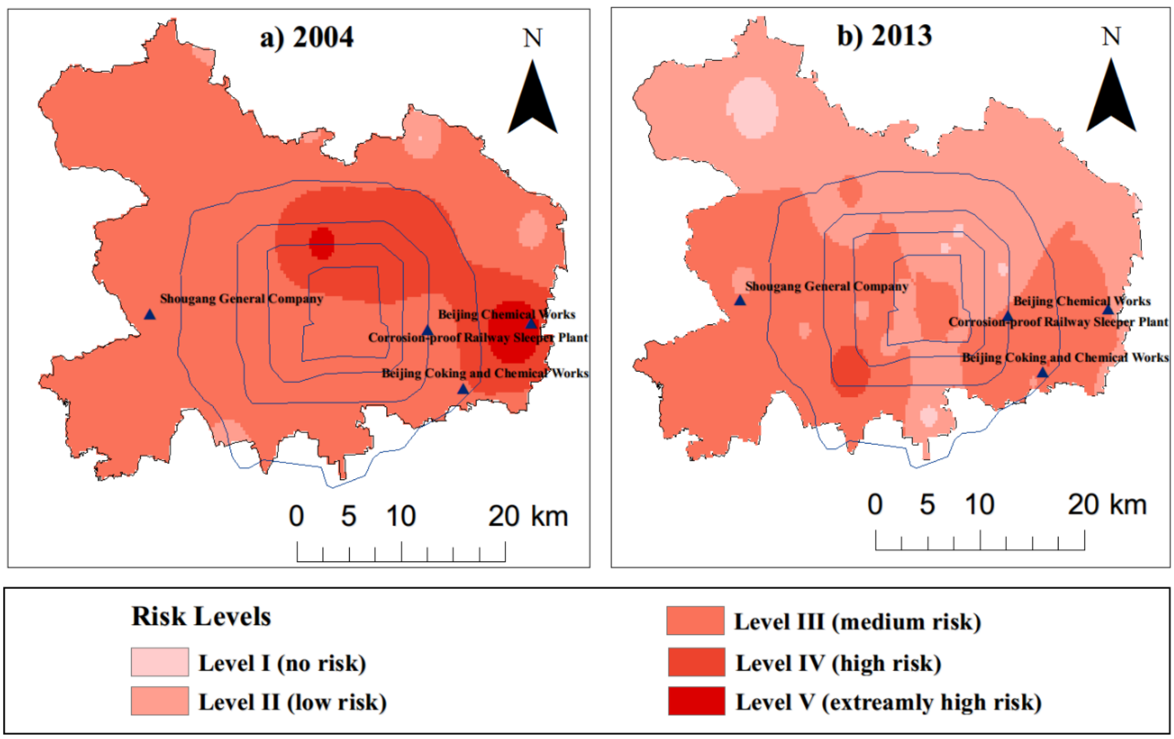

Figure 8: Changing risk in soil contamination of PAHs.

The table above shows that the average BaP_{eq} values of all samples were 139.48 ng/g and 310.42 ng/g for 2013 and 2004, respectively, indicating a significant reduction of the risk associated with the soil contamination by PAHs. This represents a significant improvement of the soil environment quality, reflecting the impact of the policy measures.

Dr. Zheng stated that their study showed that at present:

- The composition of soil PAHs had changed over time as well, which implies a notable increase of the contribution of vehicle emission. *At present, vehicle emission appears to be a more important combustion source than coal burning and coking plants, which were relocated out of the city*

- The PAHs content in soil and its associated human health risks have been significantly reduced from 2004 to 2013, since the PAHs presently found on soil are lower rings compounds. *This reflects Beijing's tremendous efforts of pollution prevention in the past decade.*
- PAHs contamination in topsoil is *a good indicator* of a megacity's environmental quality and energy consumption status, and *deserves continuous investigation*.

Workshop Session 4: Sensors and Information Systems for Real-time Monitoring and Analysis and Modeling of FEW Systems

This session focused on advances in the integration of IT and cyber-physical systems for real-time water quality monitoring and analysis. The effective management of FEW Resources requires increased coordination among public agencies, city officials, farmers, and consumer, as well as synergistic activities to optimize resource use. Advances in sensors and other information systems for real-tie monitoring can enhance the management of FEW resources by supporting analyses of FEW system interactions.

The session was chaired by Dr. Jie Liu, Associate Professor, College of Engineering, Center for Water Research, Peking University. She also moderated the discussion after presentations by:

- Babak D. Beheshti, Ph.D., Associate Dean and Professor, School of Engineering and Computing Sciences (SoECS), NYIT;
- Fang Li, Ph.D., Assistant Professor, SoECS, NYIT;
- Ziqian Dong, Ph.D., Assistant Professor, SoECS, NYIT;
- Xiaoliang Meng, Ph.D., Associate Professor and Director, Joint International Centr for Resource, Environment Management and Digital Technologies, International School of Software, Wuhan University, and
- Alan Mickelson, Ph.D, Associate Professor of Electrical Engineering, Dept. of Electrical and Computer and Energy Engineering, University of Colorado at Boulder.
- Jonathan Voris, Ph.D., Assistant Professor, Computer Science, SoECS, NYIT

Babak BEHESHTI; *Professor and Assistant Dean; New York Institute of Technology*

Dr. Beheshti presented on a framework for Wireless Sensor Networks (WSNs) security. He noted that WSNs have proliferated in the past few years because they are inexpensive and easily deployable means to collect environmental data. WSNs enable the measurement and monitoring of various physical phenomena across disciplines, and may be applied to best manage FEW resources.

He argued that research on WSNs is very important to advance the understanding of FEW Systems Nexus and Sustainability. WSNs consist of spatially distributed autonomous sensors that can monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and can cooperatively pass their data through the network to a main location. WSNs are also integral to automation systems for infrastructure and/or intelligent buildings (or bridges), and help optimize their management. For example, sensors may measure room occupancy, temperature, airflow, which can help reduce energy wastage by providing proper humidity, ventilation and air-conditioning. They can also help monitor mechanical stress on bridges and overpasses, or monitor stress and torsion on buildings after earthquakes. Therefore, he added that further research is needed to provide a unified and comprehensive reference model for WSNs to cover their limitless and diverse applications. Moreover, he added that a reusable and flexible framework is needed to allow code reuse and rapid reconfiguration of a WSN for evolving needs and requirements.

A key aspect when deploying WSNs is selecting low power consumption sensors that could operate in the field on their own battery power for more than a year. Energy-efficient networking protocols provide guidance ranging from the optimal use of multi-hop routes, resolving conflicts between different optimizations, to taking into account the available battery capacity of the various devices. Other protocols and standards have been developed for wireless sensors networks, ranging from routing aspects to wireless network transmission aspects as well as some data collection standards.

Unfortunately there is no single unified reference model that puts sensors together. Therefore, he added, it is of upmost significance to conduct further research to settle on a reference model that creates a framework for a self-aware network that can achieve self-configuration, reconfiguration and self-healing etc.

Dr. Beheshti said that with the increased scope of applications of WSNs it is imperative to assure the security of the network against attacks, as well as to assure privacy and integrity of the data that is being collected and transmitted through the network. The I-TRM (Integrated Technical Reference Model) of a WSN has been proposed to standardize network models in a three faced pyramid, where the three faces are Control, Information and Behavior protocol stacks. The I-TRM achieves a number of significant tasks. It defines a layered architecture with a high-level goal definition to task execution. It manages how and where the data is collected. The I-TRM combines:

a) a Control Technical Reference Model (C-TRM), which addresses the field of control architecture, authentication of the semantic correctness, control of the data flows,
b) an Information-Centric Technical Reference Model (IC-TRM), which defines a layered architecture for data collection, how the information is aggregated and presented.
c) a Behavioral (intelligence-based) Technical Reference Model (B-TRM) which provides a complete system technical reference model. Behavior is mapped from sensory inputs and then “mapped” to a pattern of motor/ component actions, which then are used to perform a task, as defined within rule-clusters.

He then presented an additional Security Technical Reference Model (S-TRM) to be added to the integrated reference model. He argued that there is a need for special security models in WSNs that are power and resource efficient. Important security issues may include: key establishment, secrecy, authentication, privacy, denial-of-service attacks, secure routing, and node capture, among other key features. The S-TRM includes several layers (e.g., physical, link, network, transport, trust management, and application layer), as illustrated in figure 9, below.

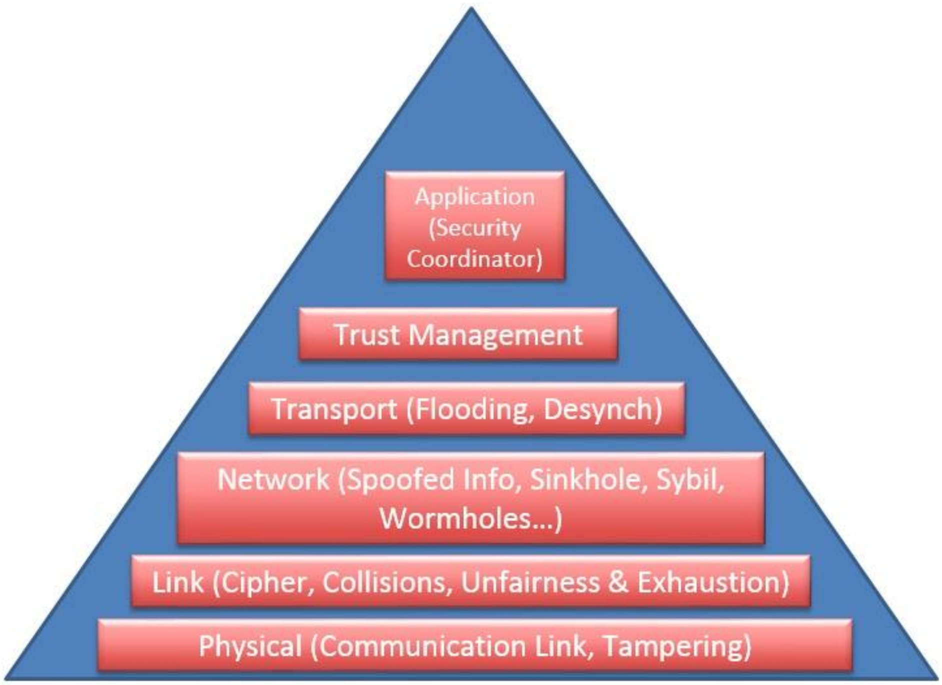

Figure 9: Security Technical Reference Model (S-TRM)

Dr. Beheshti concluded his presentation by delineating future research that is required to advance the field, including:

- Development of an API and meta-data for all S-TRM layers
- Addressing the mobility of sensor nodes which influence sensor network topology and thus raise many issues in secure routing protocols
- In addition, current work on security in sensor networks which focuses on discrete events such as temperature and humidity, addressing continuous stream events such as video and images.

Fang LI; *Assistant Professor; New York Institute of Technology*

Dr. Li presented on water toxicity detection through perfusion and monitoring of living cells on a microfluidic chip. She mentioned that climate change, urbanization, increased population and extensive agriculture are becoming threats to the global supply of freshwater. In this context, she argued that it is very important to check frequently on the quality of water, including toxicity. But current methods of

monitoring are time-consuming, as it requires moving water samples from the field to the lab for testing. In addition, this type of testing requires expensive instrumentation and experts.
One problem is that some chemicals are only detected with delays, sometimes at the detriment to the public's health. In short, Dr. Li said that there is an urgent need to develop a highly sensitive cost effective and faster method to test a broad range of toxicants in water. Her proposed solution is cell-based bio-sensors (CBB) that use a microfluidic device integrated on Electric Cell-substrate Impedance Sensing (ECIS), which are able to detect a broad range of analytes in a single assay. CBBs are fast and low-cost and relate the measurement data to cell pathology and physiology. Dr. Li discussed a study focusing on how to improve sensor performance in terms of sensitivity and response time of cell-based biosensors. The study compared water toxicity testing capabilities for two different cell lines: bovine aortic endothelial cells (BAEC) and rat fat pad endothelial cells (RFPEC).

The study found that BAECs were optimal for water toxicity testing, due to better intercellular junction and shorter times to form cell monolayers than RFPEC. To further improve sensor performance, a lab-on-a-chip was used to perfuse the cell culture medium and toxicant solution into the cell culture chamber during water toxicity analysis. Both finite element simulations and experimental results showed that the ECIS sensors combined with the perfusion chamber have better performance than ECIS sensors with open cell culture wells.

The lab-on-a-chip device allows uniform perfusion of toxicants, decreasing the adverse influence of shear stress on the sensing cell monolayer. Better integrity and morphology were also observed in the cell monolayer formed inside the lab-on-a-chip. The integrated ECIS sensor with the perfusion chamber also significantly shortens the response time of the cells due to toxicants compared with experiments conducted in open cell culture wells.

The ECIS sensor integrated with open and enclosed culture wells was tested with water containing toxicants such as: nicotine, phenol, ammonia and aldicarb. Experimental results demonstrated that ECIS biosensors seeded with BAECs inside enclosed cell culture chambers successfully detect the effect of toxicants on the cells in real time. Dr. Li mentioned ongoing work to improve sensor sensitivity, such as:

- Development of a mathematical model to describe the relation between the measured impedance spectrum and cell electrical properties and morphology, including: a) extracting cellular parameters: cell membrane capacitance, cell-cell junction, cell-substrate distance, etc., b) improving sensor sensitivity to a broad range of toxic chemicals, and, c) correlating cellular parameters to toxicant level and type
- Combining multiple sensing techniques: impendence and acoustic wave sensors
- Applying nano-materials on top of the sensors surface to improve their sensitivity

In her concluding remarks, she said that CBB toxicity sensors used for monitoring FEW, are able to provide water safety data every 3 to 4 hours. They can be integrated to the water quality WSNs and provide information on water safety and toxicity in drinking water infrastructure. CBBs serve as an early warning system for FEW management. They help evaluate and optimize sensor network design, as well as evaluate the effectiveness of FEW management in terms of drinking water safety.

Ziqian DONG; *Assistant Professor; New York Institute of Technology*

Dr. Dong presented on the importance of effective timing and synchronization in the context of Smart Cities. She said that the emerging internet-of-things (IoT) is creating a world of digital and mechanical devices connected through an information network both wired and wirelessly. Communication among these devices requires precision timing especially for critical infrastructures such as the smart grid, smart cars, and telemedicine systems.

She added that the impact of synchronization and multiple internet of things (IoT) deployed devices in sensor networks is an issue that is not well understood and needs to be further studied. Time synchronization is important in networks, wired or wireless. It is the fundamental requirement for communication between nodes on the network. Synchronization nodes can be utilized over a multi-hop wireless network. Typical synchronization applications are location and speed determination, relative proximity determination among nodes, and energy saving.

One challenge is that hardware clocks have variations in oscillators, so the clocks may drift and result in added time intervals of events among nodes. In this case the information is sent through the network optical cable and propagation delay is significant. The delay affects access time, set time, receive time, and intermediate nodes add to queuing delays. Potential network censorship in certain countries means that all communications are being buffered somewhere and certain information is being sanitized before it makes it to the receiver. She said that this brings up another issue –delay effects on the whole network, when there are large numbers of sensors, and a lot of information being transmitted. Understanding traffic patterns and how to synchronize large data, for IoT devices that will handle this kind of information is very important.

Dr. Dong presented on a case that illustrates the importance of precision timing in fixed wireless networks such as Wi-Fi network, which are used to support communication in a large number of IoT devices. The study focused on detecting and locating Man-in-the-Middle (MITM) attacks in fixed wireless networks. An MITM attack is considered an active eavesdropping attack, often carried out on the media access control (MAC) layer through address resolution protocol (ARP) cache poisoning.[29] The purpose of a MITM attack is to intercept a connection between two legitimate hosts in the network pretending to be the intended sender or receiver between two legitimate nodes, in order to carry out different kinds of attacks between the two nodes. So the MITM attacker will take information from the

[29] Different protocols are available to meet the different synchronization needs, among them are the: a) reference broadcast synchronization (RBS) protocol, b) timing-sync protocol for sensor networks (TPSN), and c) flooding time synchronization protocol (FTSP).

server and collect multi agent system (MAS) data and send it to another intended client and then change the information to their own MAC address.

She discussed preliminary results of using measured timing information (round trip time) and signal strength to identify a MITM attack in fixed wireless networks and locating the source of the attacker using three machine learning approaches. Experiments were conducted in both rural and densely populated urban environments and results demonstrated the importance of precision timing and synchronization in smart cities. They further shows that the proposed method can effectively detect and locate a MITM attack and achieve a mean location estimation error of 0.8 meters in an indoor environment.

In closing, she mentioned that the experiment may be used to address the question of real time sensing for FEW systems, in particular when the data is very sparse or is measured with large gaps. The key is to understand the dynamics of the FEW systems. These are the challenges she is trying to solve, what kind of time range is needed to use in WSNs by providing more density of data, which can improve models that predict FEW systems dynamics.

Xiaoliang MENG; *Associate Professor and Director; International School of Software*, *Wuhan University*

Dr. Meng presented on an ontology-underpinned emergency response system for water pollution accidents. He noted that on April 23, 2014, two major water supply plants (Baihezui and Yushidun) in Wuhan city halted production at around 4 p.m. and 7 p.m.. As a result it became evident that the water in Wuhan's section of the Han River contained excessive amounts of ammonia and nitrogen, exceeding national standards. The ensuing suspension of water supply caused a water shortage that affected 300,000 people.[30] The production of the Yushidun Water plant was restored at 8 a.m. on the 24th, but it was suspended at 9:40 a.m. again. When it got back to normal around 4 p.m. on 24th, the citizens worried about the safety of the water and another suspension of services. This serious accident alerted the government that it was necessary to have an emergency response system for polluter identification and tracking, early warning and decision-support, and public awareness for water pollution accidents.

[30] http://news.xinhuanet.com/english/china/2014-04/24/c_126426298.htm.

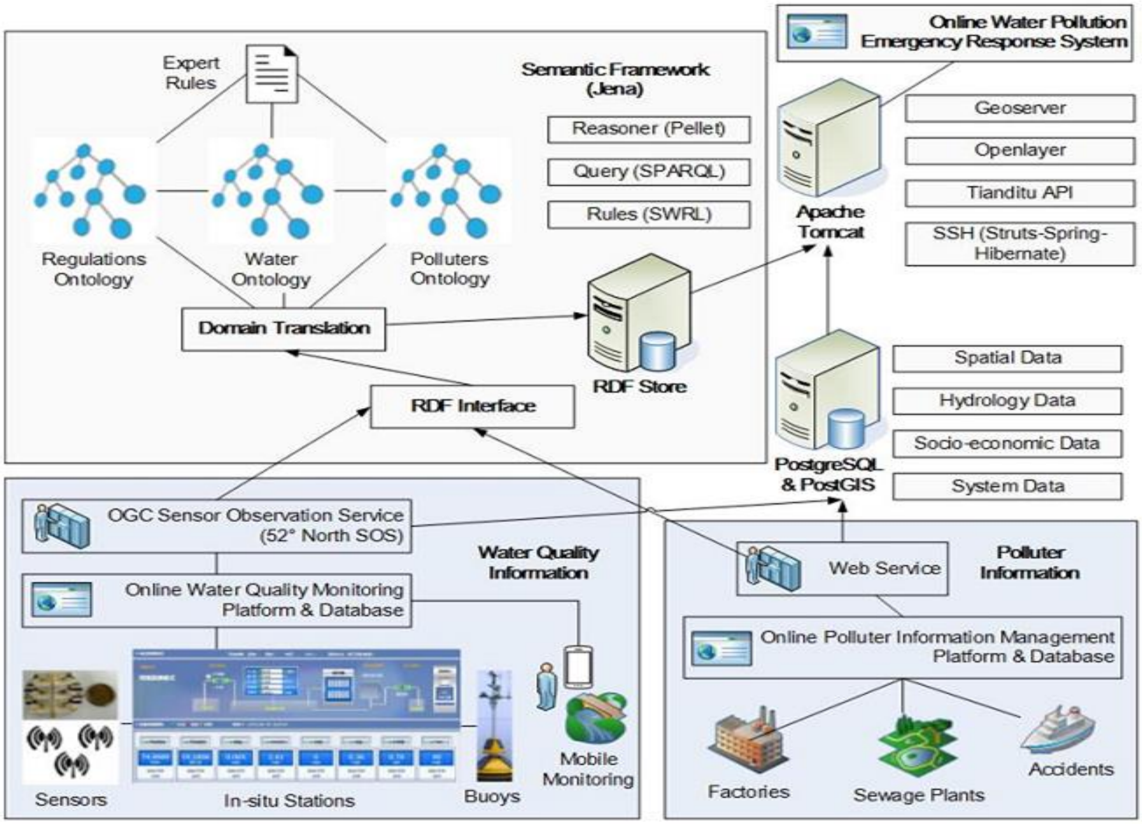

Figure 10: Structure of the emergency response system for water pollution.

He said that he was agreeing with Dr. Fang Li, that the old-fashioned approach of monitoring water quality – collecting water samples manually and transporting them to a laboratory for analyses – is expensive and time-consuming. It is also prone to errors, fluctuations of pollutant concentrations such as periodic release of toxins, may be limited by weather conditions, and does not allow for continuous data collection.

On the other side, he argued, the technological improvements on sensor and network capabilities for long range data distribution and storage provide a platform capable of utilizing low cost, high performance and real-time monitoring WNSs for water quality management. He then discussed a case study focusing on the Han River – the largest tributary of the Yangtze River, which was funded by the Hubei Environmental Protection Bureau. There are 19 boundary stations along the Han River in Hubei Province, providing hydrology and water quality data. Real-time data can be read through the existing Online Water Quality Monitoring Platform maintained by Hubei Environmental Monitoring Central Station.

He then described the case study, which required three sets of data, including water quality data, hazards data and pollution data. Sensor data processing encapsulates processing historical data stored on permanent databases, as well as real-time stream data. Various sensors were deployed in the water monitoring stations to gather hydrological data and detect the water quality and pollution, which can be gathered automatically through web services. In order to share the observational data from heterogeneous sensor nodes, the Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE), which is a standards-based framework was utilized as the solution. SWE is a Service Oriented Architecture (SOA) approach, and the Sensor Observation Service (SOS) is used as the standard web service interface for requesting, filtering, and retrieving observations and sensor system information from in-situ stations and mobile monitoring devices. There is an intermediary stage, between the emergency response system and the online water quality-monitoring platform, which provides the observation repository or near real-time sensor channel.

Each data source in the system uses an RDF interface. Each component performs an ontological translation required to get the data into the knowledge models, including water quality, pollution and regulation ontology models. Once the data is in RDF and described according to the appropriate ontology, it is stored in the RDF storage, which is a knowledge base, and is accessible to the system interface. Thus, a flexible knowledge management system is required to represent the water domain knowledge. The ontological capability of knowledge reuse and sharing is the main reason why the ontologies are best suited for modeling water quality monitoring domains. His vision, he added, is to build a pure Semantic Web framework for effective management of water quality and sustainable development. In line with this, his group has built SSN (Semantic Sensor Networks)-based ontology for water quality management to support emergency response for water pollution accidents.

Alan MICKELSON; *Associate Professor; University of Colorado*

Dr. Mickelson presented on autonomous sensors for FEW systems, and how they can be modified to use water quality as an indicator of stressors in food and energy in an urban environment. He pointed out that cities allow for economies of scale through localizing the distribution of goods and services, energy and food requirements of a dense population, and all these place constraints on the water supply. The most important interactions between food production and water involve the release of nitrogen (nitrate) and phosphorous (phosphates) into the water system that subsequently can lead to eutrophication, while those between energy and water systems are releases of exhaust-heat and/or pollutants that may foul the water appearance. A water management plan must place limits on food and energy production in order to preserve sufficient water for all uses.

Figure 11: Water Quality sensors at Lake Muttamuskeet, NC

Dr. Mickelson added that real time management decisions necessitate accurate real-time data from a mesh of spatial locations, in particular for water quality monitors, which alone may be used to indicate the state of energy and food production systems. Autonomous sensing systems can help assess water conditions including nitrogen and phosphorous content, dissolved oxygen, temperature and turbidity.[31] Fine-grained spatial distribution of sensors require low-cost and autonomy of operation, so that the sensors are able to function without an external power source and to store data until it is recalled..

Building on his experience in working on sensor networks in the Amazon, Dr. Mickelson is now working on a pilot project at Boulder Colorado. He is planning to deploy sensing systems to monitor water quality at the university campus (e.g., water holding tanks, groundwater). Dr. Mickelson expects that there are going to be variations in water quality after precipitation events, when runoff from surrounding agricultural fields will bring pesticides, fertilizer and animal waste. The system he is working on is an easy to build one, with off the shelve components (microprocessor packs), capable of fitting a sensor on a chip in the network, using Bluetooth, which is the cheapest interface. One challenge to be aware of is energy consumption, which can be solved via small solar photovoltaic cells. He concluded by highlighting that in order for the sensing system to be deployed broadly and provide real-time monitoring data to policymakers, it is important that it can be built easily and deployed and operated in a cost efficient manner.

[31] There are other methods to measure heavy metals or oils spills.

Jonathan Voris, Ph.D., *Assistant Professor of Computer Sciences, School of Engineering & Computing Sciences, NYIT.*

Dr. Voris presented on his data modeling research and how it relates to enabling smart cities applications, including megacities such as New York and Beijing. He mentioned that several massive data collections efforts are underway at cities, which facilitate the development of smart applications, including technologies and wireless sensors networks that enable more efficient management of transportation networks. Likewise, micro-sensors installed in New York City are being used to detect the movement of bicycles and vehicles, and when they are attached to traffic lights, the system can be synchronized to improve the flow of traffic. Other smart applications use sensors to detect open parking spaces on city streets, or give alerts when a parked car starts moving, which can be used both for payment-based and free parking.

Insurance companies are developing smart applications that may be installed by drivers, which directly connect to the network and can collect a variety of data based on drivers' activities (whether they are driving safely or unsafely). Insurance companies may use this information to determine insurance fees according to each driver's behavior. Similar systems could be applied by the buildings sector to stimulate more energy efficiency measures, and support sustainable efforts consistent with infrastructure ecology. Personal devices such as cell phones already have some sensors installed and these could be used to monitor a lot of different variables, such as air quality, road conditions, and even help track earthquakes. In New York City, an advantage is that agencies have recently released different datasets to the public via an open data platform.

A big problem is data tampering, spoofing, and overall cybersecurity, which can affect the data collected by the sensors, therefore jeopardizing the effectiveness of using such applications to run smart city networks. This of course could interfere with building applications by causing service type attacks and thus dangerous conditions. So the common problem is lack of trust in the data generated by the sensors. In many cases it is desirable to verify the source of the data but it is often impossible to link it to a particular user. He added that the core of his work is in the domain of security and in one current project he is applying the same idea to transportation security and a couple of applications that are useful for smart cities.

The smart phones that we carry can be thought as a sensor networks. Just observing the history of past sensor measurements, one may construct a sophisticated model, with different variables and machine-learning techniques that may be applied to detect deviations. He has run an experiment using the model to profile how users work their phones and integrate the information with time and geo-location data.. Using machine-learning algorithms, the model was able to positively identify the true owner of the device within 10-minute time detection window. So the experiment has yielded positive results from an operational perspective and he will continue this research focusing on how to secure smart infrastructure with applications in cities.

Wrap Up Session and Workshop Recommendations

Towards the end of the workshop the moderators for each session summarized the main knowledge gaps and data needs along with future research. All participants then contributed to the discussion, and the main issues and recommendations for future research are summarized below.

FEW Nexus – Sustainability Challenges:

1. **Further data and modeling tools** are required to understand the FEW nexus and footprint, in particular:

    a. Water For Energy**:** mapping hydropower's water footprint (WFP)[32]

    b. Energy for Water: further research and applications on the Effective Fragment Potential (EFP) method that decomposes the interaction energy as a sum of the five fundamental forces—electrostatic, exchange-repulsion, polarization, dispersion, and charge transfer.[33]

    c. Create modeling tools for Decision Support Systems – promote dialogue between data scientists and design professionals (complex) and policymakers (simple)

    - Simple Tools: such as models to provide stakeholders information about consequences of alternative development projects.[34]
    - Complex Tools: MARKAL model emphasizes complex interactions[35]

2. **Further technology development** and cost-effectiveness analysis are needed to mitigate the footprint of FEW nexus

    a. Technological advances are needed to harness fuels from waste streams (flared gas, exhaust heat, wastewater treatment plants, sludge)[36]

    b. Use water monitoring technologies to improve ecological management that support feedback loops from water and energy intensive systems (powerplants, desalination plants, residential use, water treatment)[37]

    c. Use cross-cutting approaches and consider energy and water infrastructure as well as agricultural systems, in a holistic manner.

3. **Governance** of energy-water – various approaches were discussed (e.g. top down vs. democratic, best practice vs. participatory).

    a. Interagency coordination is needed. Water management agencies need to incorporate energy requirements for wastewater treatment.[38] Likewise, energy management agencies

[32] As mentioned by Junguo LIU, Beijing Forestry University

[33] Lijin ZHONG

[34] Bernie ENGEL, Purdue University

[35] Presented by Linghao HE, Brookhaven National Lab

[36] Devinder MAHAJAN, Stony Brook University

[37] Paul Anid, HDR, Inc.

[38] Lijin ZHONG, World Resources Institute - China

need to consider water requirements and impacts of their operation (e.g., water footprint hydropower expansion, including evaporation rates).[39]

b. Cross-cutting consideration for governance, which for FEW is multifold (e.g. demands for water from many stakeholders).[40]

4. **Best Practice and Exchanges** for implementation
    a. Recommended best practices include identifying specific risks and opportunities for decision making and supply chain management, and bring increased understanding of human behavior.
    b. Participatory approaches and civic engagement and education are key to improve the management of FEW resources.[41]
    c. Different cases such as top-down urban planning approach in Dubai demonstrates what a well-financed approach can achieve.[42]
    d. Asia pacific regions vary dramatically in terms of water security – one solution does not fit all, and regional assessments are recommended.[43]

Session 2: Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources.

- Water impacts from human activities need to be further characterized and addressed. Several related issues were noted, such as:
    1. Further understanding of trade-offs is needed. Sustainable urbanization does not necessarily equate to sustainable cities.
    2. Infrastructure-type "fixes" are not that difficult to implement, provided the funding is available. However, changing unsustainable human behavior is more challenging and requires more education and coordinated action
    3. Issues of scale are important to consider – how to scale from one population to another.

- Further research is needed to assess the cumulative impacts of anthropogenic impacts at the river basin or lake scale in relation to land use.
    a. Water quality monitoring of entire river basins is recommended. For example, in the Huangshui River basi of Qinghai Province the Water Quality Monitoring Center conducted

[39] Junguo LIU, Beijing Forestry University. He argued that from a water conservation perspective, eastern China should not further expand its capacity in hydropower where water resources are scarce

[40] Josh WEINBERG, Stockholm International Water Institute, has expertise in governance of water systems

[41] Josh Sperling, NCAR

[42] Paul Anid, HDR, Inc.

[43] Vincent Tidwell, Sandia National Lab, sent his remarks.

a zoning (by level) assessment and determined that improving sewage treatment could dramatically reduce eutrophication impacts.

b. Similar approaches are needed to reduce algal blooms in lakes, such as that being applied in Taihu Lake in China, which includes monitoring sensors in the buoy system and remote sensing. Nutrient sources (agriculture, sewage, industry) have been identified but social and economic solutions must be added.

- Various technologies should be explored to help reduce anthropogenic impacts, such as artificially constructed wetlands (ACW). Rather than a central treatment plant, the ACWs may be small, low cost, distributed plants that can treat the water in a sustainable manner.

Session 3: Research Advances on Systems-Based Analysis for Complex FEW Systems

The importance of modeling was highlighted along with efforts to collect data. Models can serve as comprehensive tools to understand complex and large data sets related to FEW systems and their nexus relationships.

Participants reviewed various models, which may be used to optimize the power grid, the MARKAL model applied to New York City, and a model to assess pollution in soils that serves to evaluate the success of past policy measures, as well as a "classical" model that helps managers and decision makers understand the outcomes from alternative land development paths. A different modeling approach is "Infrastructure Ecology" which can help understand the symbiosis between various infrastructure systems within cities and thus optimize the "metabolism" of urban centers.

In terms of future research directions, all participants agreed that more research is needed on:

- Alternative scenarios
- Model validation and precise data collection efforts
- New tools to translate the knowledge to stakeholders
- Optimization
- Visualization tools

Session 4: Sensors and Information Systems for Real-time Monitoring and Analysis and Modeling of FEW Systems

Three major aspects were noted with respect to future research needed and applications related to sensors and information systems.

1. Improving the performance of the sensors themselves, whether they are biological or autonomous sensors. Key features for improvement are the sensors' sensitivity, reliability and robustness.

2. Applying sensors for emergency response, in particular applications for monitoring FEW resources, such as sensors capable of sending alerts about water pollution episodes.

3. Improving data collection efforts for FEW resources, so that it is easier to synchronize data from different sources. This may require coordination before the data collection starts.

Additional group discussion and action items:

Dr. Nada Anid then led the group discussion, stating that all participants must leverage existing networks and/or form new partnerships to work together to continue to identify the main challenges and gaps related to FEW resources and their nexus.

Participants agreed that several questions as outlined above must be addressed, along with advancing the state of the art of technologies and applying them in order to close the energy, water and material cycle and optimize infrastructure operations. Capacity building for stakeholders' involvement and public education and training was noted as a significant component to effect change that is often not taken into account.

Participants recommended that research should be conducted in any city, not just megacities, which may not be the proper scale to conduct research on FEW resources. The FEW nexus relationships may be more clearly delineated in smaller urban centers. Once we have studies with a range of urban centers' sizes, it would be important to understand how the size of cities may affect the management of FEW resources and their nexus relationships. Another recommendation was to keep rural communities vibrant as a way to mitigate population migration to urban centers.

Participants then focused on concrete actions that they can carry out together, such as seminars, regular webinars, publications, public private partnerships, sharing networks, instrumentation, models and resources. Dr. Nada Anid is leading a special FEW issue of the Journal of Environmental Progress and invited everyone to contribute articles. Participants also discussed joint proposals to funding agencies, such as the NSF solicitation on FEW projects due on March 22nd, 2016. Other opportunities were also noted, including for young investigators and students, such as NSF' IGER for research traineeship and education, NRT, or the RNC for early career opportunities.

CONCLUSION

The FEW Workshop: Food, Energy, and Water Nexus in Sustainable Cities convened participants with a broad base of experiences and representing various perspectives from the China and the United States, as well as Dubai and Sweden.

The workshop was successful in identifying opportunities for joint research projects, including a couple between researchers in both nations. This synthesis report summarizes the scientific, technology, engineering and information systems challenges identified by more than 30 active participants.

The commitment of the participants was evident by their active engagement and discussions, which helped identify the most important data and modeling challenges as well as priorities for further research in four key areas: a) *FEW Nexus – Sustainability Challenges;* b) *Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources;* c) *Research Advances on Systems-Based Analysis for Complex FEW Systems*; and d) *Sensors and Information Systems for Real-time Monitoring and Analysis and Modeling of FEW Systems.* Their recommendations are described in the body of the report and outlined in the executive summary.

APPENDIX I: Workshop Agenda

DAY 1: Hotel Regent Beijing, 99 Jinbao St., Dongcheng District, Beijing, China

DAY 2: Peking University Zhongguan Xinyuan Global Village, 126 Zhongguancun N St, Haidian, Beijing, China, 100871

Workshop Goals and Format

The goals of the workshop are to build a research platform that supports active engagement and joint approaches to global FEW challenges, with attention to urban centers, and to form a global FEW research and education community and provide initial groundwork for the formulation of some U.S.-China FEW partnerships.

The format consists of a series of 90-minute sessions that include platform presentations and discussions along a final wrap up session to summarize FEW Sustainability Challenges, Solutions and Potential Research Collaborations, building from the different sessions. Each session leader will moderate the dialogue after short presentations on the topics outlined below.

Research Questions/Discussion Topics will include:

3:45 pm- 4:00 pm **Introductory Remarks: Workshop Goals**

Nada ANID, Ph.D., *Professor and Dean, School of Engineering and Computing Sciences, NYIT* and **Chunmiao ZHENG, Ph.D.**, *National Research Chair, Peking University; Dean, School of Environmental Science and Engineering; South University of Science and Technology, Shenzhen, China*

SESSION 1: October 20, 2015 4:00 pm – 5:45 pm

FEW Nexus: Sustainability Challenges

This session will advance the understanding of the interactions among FEW resources recognizing their inter-related nature and feedback mechanisms. Participants will also consider sustainability challenges, responses to stressors and coupling affecting FEW resources as part of a dynamic and interrelated structural system.

4:00 pm – 5:45 pm Session 1: FEW Nexus: Sustainability Challenges

Chair:
Jimmy TRAN, Ph.D., *Program Manager, China Energy Group, Energy Analysis and Environmental Impacts Division, Energy Technologies Area, Lawrence Berkeley National Laboratory*

Presenters:

Junguo LIU, Ph.D., *Professor of Hydrology and Water Resources, Beijing Forestry University, and Visiting Scholar at the Institute for Applied Systems Analysis (IIASA) in Austria*

Lijin ZHONG, *Senior Associate, China Water Lead, Water Program, World Resources Institute*

Devinder MAHAJAN, Ph.D., *SBU/BNL Joint Appointment, Professor and Co-Director, Chemical & Molecular Engineering, Stony Brook University, SUNY*

Paul ANID, Ph.D. Vice President, Water Quality Management Services, HDR

DAY 2: Global Village, Peking University, Beijing, China

October 21, **2015**

9:00am- 9:15am **Introductory Remarks: Workshop Goals**

Nada ANID, Ph.D., *Professor and Dean, School of Engineering and Computing Sciences, NYIT* and **Chunmiao ZHENG, Ph.D.**, *National Research Chair, Peking University; Dean, School of Environmental Science and Engineering; South University of Science and Technology, Shenzhen, China*

SESSION 2: October 21, 9:15am- 11:00am

Impacts of Urbanization and Anthropogenic Disruptions on Vital FEW Resources

Increased disruptions to, and competition for, resources that sustain life have a significant impact on the livelihoods of large populations and the environment. Advancing the understanding of the interactions among FEW resources requires a systems-based approach that recognizes their inter-related nature and feedback mechanisms. For example, 71% of global freshwater resources and 30% of total energy consumed globally are used for agriculture and food production. This session will highlight technological breakthroughs and ecological deterioration of water bodies that are vital for fisheries and other activities, as a result of growing urbanization and agricultural development. Restoration approaches to sustainable FEW resources and environments will be proposed.

Session Leader and Presenter:

Sarah MEYLAND, JD, *Associate Professor, Environmental Technology & Sustainability, School of Engineering & Computing Sciences, NYIT*

Other Presenters:

Joshua B. SPERLING, Ph.D., *Research Fellow, Urban Futures Program at the National Center for Atmospheric Research, and Adjunct Professor, University of Colorado*

Josh WEINBERG, *Program Manager, Water, Energy and Food, Stockholm International Water Institute.*

Zhao XIA, Ph.D., *Associate Professor, Department of Geographic Science, Qinghai Normal University.*
Shenglong ZHANG, Ph.D., *Assistant Professor, Life Science, College of Arts & Sciences, NYIT*
Guangwei ZHU, *Deputy Director, CAS Lake Tai Eco-Research Station and Dept. of Hydrology and Hydrodynamics, Nanjing Institute of Geography and Limnology, CAS*

11:00am to 11:15am BREAK

SESSION 3: October 21, 11:15am-1:00pm

Research Advances on Systems-Based Analysis for Complex FEW Systems

This session will explore research advances for FEW systems protection, in particular the integration of heterogeneous data and uncertainties for systems-based modeling and analysis of FEW systems. Researchers will also address challenges in the analysis and protection of FEW resources utilizing mathematical modeling and GIS techniques.

Session Leader and Presenter:
Xiaohui (Sean) CUI, Ph.D., *Dean and Professor, International School of Software, Wuhan University*

Presenters:
Bernie ENGEL, Ph.D., *Professor and Head, Agricultural and Biological Engineering, Purdue University*
Linghao HE, *Sustainable Energy Technologies, Brookhaven National Laboratory*
Zhongming LU, Ph.D., *Brook Byers Institute for Sustainable Systems, School of Civil and Environmental Engineering, Georgia Institute of Technology*
Yi ZHENG, Ph.D., *Associate Professor, Department of Energy & Resources Engineering College of Engineering, Peking University**

1:00 – 2:15pm LUNCH

Session 4: October 21, 2:15pm- 4:00pm

Sensors and information systems for real-time monitoring and analyses of FEW systems

This session will focus on advances in the integration of IT and cyber-physical systems for real-time water quality monitoring and analysis. The effective management of FEW resources implies increased coordination among public agencies, city officials, farmers, and consumers as well as synergistic activities to optimize resource use. Advances in sensors and other information systems for real-time monitoring can enhance FEW resources management by supporting analyses of FEW system interactions.

Session Leader:

Jie LIU, Ph.D., Associate Professor, College of Engineering, and Center for Water Research, Peking University

Presenters:

Babak D. BEHESHTI, Ph.D., *Associate Dean & Professor, School of Engineering & Computing Sciences, NYIT*

Fang LI, Ph.D, *Asst. Professor, School of Engineering and Computing Sciences, NYIT,*

Ziqian DONG Ph.D., *Asst. Professor, School of Engineering and Computing Sciences, NYIT,*

Xiaoliang MENG, Ph.D., *Associate Professor, Director, Joint International Center for Resource, Environment Management and Digital Technologies (JIC-REDT), International School of Software, Wuhan University*

Alan MICKELSON, Ph.D., *Associate Professor of Electrical Engineering, Department of Electrical and Computer and Energy Engineering, University of Colorado at Boulder*

Jonathan VORIS, Ph.D., *Assistant Professor, School of Engineering and Computing Sciences, NYIT*

3:00pm to 3:15am BREAK

3:15pm-5:00pm

Session 5: "Closing Session to Explore Future Research Directions"

Session Leaders:

Nada ANID, Ph.D., *Professor and Dean, School of Engineering and Computing Sciences, NYIT* and **Chunmiao ZHENG, Ph.D.**, *National Research Chair, Peking University; Dean, School of Environmental Science and Engineering; South University of Science and Technology, Shenzhen, China*

Presenters:

Jimmy TRAN, Ph.D., *Program Manager, China Energy Group, Energy Analysis and Environmental Impacts Division, Energy Technologies Area, Lawrence Berkeley National Laboratory*

Sarah MEYLAND, JD, *Associate Professor, Environmental Technology & Sustainability, School of Engineering & Computing Sciences, NYIT*

Xiaohui (Sean) Cui, Ph.D., *Dean and Professor, International School of Software, Wuhan University.*

Jie LIU, Ph.D., *Associate Professor, College of Engineering, and Center for Water Research, Peking University.*

Appendix II: Participants and Affiliated Organizations

Session Leaders:

Nada Anid, Ph.D., Professor and Dean, School of Engineering and Computing Sciences, NYIT
Xiaohui (Sean) Cui, Ph.D., Dean and Professor, International School of Software, Wuhan University
Sarah MEYLAND, JD, Associate Professor, Environmental Technology & Sustainability, School of Engineering & Computing Sciences, NYIT
Jimmy TRAN, Ph.D., Program Manager, China Energy Group, Energy Analysis and Environmental Impacts Division, Energy Technologies Area, Lawrence Berkeley National Laboratory
Chunmiao ZHENG, Ph.D., National Research Chair, Peking University; Dean, School of Environmental Science and Engineering; South University of Science and Technology, Shenzhen, China

Government & Agency Participants:

Bruce HAMILTON, Ph.D., Program Director, National Science Foundation
Xiaojuan SHI, Director, Department of Pollution Prevention and Control, Ministry of Environmental Protection, China
Nancy SUNG, Ph.D., Program Directors, National Science Foundation
Yuanming ZHENG, Project Manager, Department of Earth Sciences, National Natural Science Foundation of China

Presenters:

Paul ANID, Ph.D., Vice President, Water Quality Management Services, HDR
Babak D. BEHESHTI, Ph.D., Associate Dean & Professor, School of Engineering & Computing Sciences, NYIT
Ziqian DONG, Ph.D., Asst. Professor, School of Engineering and Computing Sciences, NYIT
Bernie ENGEL, Ph.D., Professor and Head, Agricultural and Biological Engineering, Purdue University
Linghao HE, Sustainable Energy Technologies, Brookhaven National Laboratory
Fang LI, Ph.D., Asst. Professor, School of Engineering and Computing Sciences, NYIT.
Jie LIU, Ph.D., Associate Professor, College of Engineering, and Center for Water Research, Peking University
Junguo LIU, Ph.D., Professor of Hydrology and Water Resources, Beijing Forestry University, and Visiting Scholar at the Institute for Applied Systems Analysis (IIASA) in Austria
Zhongming LU, Ph.D., Brook Byers Institute for Sustainable Systems, School of Civil and Environmental Engineering, Georgia Institute of Technology
Xiaoliang MENG, Ph.D., Associate Professor, Director, Joint International Center for Resource, Environment Management and Digital Technologies (JIC-REDT), International School of Software, Wuhan University.

Devinder MAHAJAN, Ph.D., SBU/BNL Joint Appointment, Professor and Co-Director, Chemical & Molecular Engineering, Stony Brook University, SUNY
Alan MICKELSON, Ph.D., Associate Professor of Electrical Engineering, Department of Electrical and Computer and Energy Engineering, University of Colorado at Boulder
Joshua B. SPERLING, Ph.D., Research Fellow, Urban Futures Program at the National Center for Atmospheric Research, and Adjunct Professor, University of Colorado
Jonathan VORIS, Ph.D., Assistant Professor, School of Engineering and Computing Sciences, NYIT
Josh WEINBERG, Program Manager, Water, Energy and Food, Stockholm International Water Institute.
Zhao XIA, Ph.D., Associate Professor, Department of Geographic Science, Qinghai Normal University.
Shenglong ZHANG, Ph.D., Assistant Professor, Life Science, College of Arts & Sciences, NYIT
Yi ZHENG, Ph.D., Associate Professor, Department of Energy & Resources Engineering College of Engineering, Peking University
Lijin ZHONG, Senior Associate, China Water Lead, Water Program, World Resources Institute
Guangwei ZHU, Deputy Director, CAS Lake Tai Eco-Research Station and Dept. of Hydrology and Hydrodynamics, Nanjing Institute of Geography and Limnology, CAS

Other Participants:

Merritt COOKE, Founder and Chairman, China Partnership of Greater Philadelphia
Jing GAN, Lecturer at College of Architecture and Urban Planning, Tongji University, Member of China Green Building Council and Column Editor of the Journal Urban Planning Forum, Tongji University, Shanghai
Zhongming LU, Post Doc, Georgia Institute of Technology
Marta PANERO, Ph.D., Director, Strategic Partnerships, SoECS, NYIT
Keith SCHNEIDER, Senior Editor Circle of Blue, New York Times
Joshua SPERLING, Ph.D., Research Fellow, Urban Futures Program at the National Center for Atmospheric Research, and Adjunct Professor, University of Colorado
Jennifer L.TURNER, Director, China Environment Forum; and, Manager, Global Choke Point Initiative, CEF Woodrow Wilson Center for International Scholars
Jie WANG, Vice President, Peking University
Xia ZHAO, Associate Professor, Qinghai Normal University
Zhen ZHONG, Humboldt Fellow, Chief of Environment Design Art Research Office, Professor, Xiamen University
Yong ZHOU, Director, Climate Change Research Center, Shandong Academy of Sciences, China
Jian ZHUO, Associate Chair and Professor, Dept. of Urban Planning, Tongji University