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Urban Infrastructures: Analysis and Modeling for their Optimal Management and Operation

November 30 – December 1, 2017

Organized by
New York Institute of Technology

In collaboration with
City University of New York
Stuttgart University of Applied Sciences, Germany

Program Director: Bruce Hamilton, Division of Chemical, Bioengineering, Environmental, and Transportation Systems (CBET), Directorate of Engineering, NSF

Workshop webpage: https://nyit.edu/events/urban_infrastructures

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This workshop benefited from significant contributions of 50 participants, including our U.S. partners, New York Institute of Technology (NYIT), City University of New York (CUNY), New York University (NYU), New Jersey Institute of Technology (NJIT), and Stuttgart University of Applied Sciences (HFT Stuttgart) from Germany. Special thanks go to the German Federal Ministry of Education and Research for its sponsorship.

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EXECUTIVE SUMMARY

The "*Urban Infrastructures: Analysis and Modeling for Their Optimal Management and Operation*" workshop was supported by the National Science Foundation and organized by the New York Institute of Technology School of Engineering and Computing Sciences, in collaboration with City College of New York of the City University of New York, and Stuttgart University of Applied Sciences (HFT Stuttgart), Germany. It was held on November 30th and December 1st, 2017, at New York Institute of Technology's Manhattan Campus in New York City.

The workshop offered a platform for multidisciplinary partnerships among researchers at the forefront of scientific research in sustainability in the United States and international partners. It was convened to explore scientific challenges of mutual interest, while addressing fundamental research questions of global significance in the fields of sustainability, engineering, social and natural sciences, and cyber, physical, and information systems.

The overarching goal of the workshop was to stimulate research on the optimization of interrelated urban infrastructure systems and processes for the resilient and sustainable provision of food, energy, and water (FEW). It also aimed to identify technical, socio-economic, and policy obstacles for this optimization. Over 50 participants from academia, national laboratories, government agencies, urban planning and development, and international partners met at NYIT to explore scientific, technical, socio-economic, and policy synergies in critical infrastructure systems and processes for sustainable urban development. Participants sought to develop a shared urban data and modeling framework to help cities analyze and characterize FEW infrastructure systems and their nexus interrelationships in order to identify synergies to minimize energy and materials use and waste generation.

Specific objectives of the workshop included the following: 1) build a research agenda that supports active engagement and joint approaches to resilient urban interdependent critical infrastructure systems and processes; 2) explore solutions for innovative urban infrastructure synergies for sustainable, green, and livable cities and the optimal provision of FEW goods and services; and 3) form a global research and education community, with links to local stakeholders, and share actionable agendas for change.

The workshop was structured with seven 1.5 - hour sessions, each featuring three to five selected speakers. The talks focused on various topics on FEW infrastructure and challenges. The schedule included a 75-minute open discussion with all the participants at the end of the presentations to explore research challenges, open questions, potential collaborations, and future business.

Session 1: System-Based Approaches

This session focused on systems-based approaches to understand the complex interdependencies of urban critical infrastructure systems that provide food, energy, and water. These system-based approaches looked into the interdependencies of urban food distribution, water, waste, and energy within cities, which are subject to increasing demands and extreme climate conditions that may affect their supply. Speakers engaged in a discussion of how system-based approaches may be leveraged to optimize urban infrastructure systems for FEW supply from industry ecology and urban designer points of view. The panel concluded that there was a need for System Integration Models that explore how to integrate physical modeling and decision-making environments and institutional arrangements–whether organizations may be brought together to manage these resources collectively, while bridging decentralized and centralized arrangements.

Session 2: End-User Perspective: What Stakeholders Want to See

This session focused on approaches and participatory models to engage stakeholders to understand what policy makers need for optimizing the resources and management of urban interdependent critical infrastructure systems. Optimization of regional and local FEW systems, which takes into account their interdependencies, may be accomplished via integration based on co-decision, which in turn aims to simultaneously optimize multiple interconnected systems. The session included a discussion of tools to help stakeholders in visualizing and understanding the complex interdependencies and demonstrate the potential for synergistic co-benefits and coordinated decisions supporting integrated infrastructure systems. The panel emphasized the important convergence of challenges and opportunities facing water and electricity sectors, raising the possibility of an integrated framework for such topics as demand management, decentralized sources, investments under uncertainty, and consumer behavior, all of which require new data analytics and integrated modeling tools. Both the water and electricity sectors share a mandate to provide clean, affordable, and reliable service to their customers. While both sectors require massive infrastructure, decisions on when and what to build and how to operate are very difficult. Capital investment decisions are tough because of a) multiplicity of investment alternatives, b) uncertainty on which alternative will end up being preferable, c) long lead times, d) high capital requirement, e) long life time of the infrastructure once built. The following points were highlighted in this session:

- We need distributed resources and policies and markets that reward their contribution to affordability, reliability, and environmental sustainability: It is clear that Distributed Energy Resources (e.g., roof-top or community scale solar PV) can make important contributions to the reliability and resiliency of the system. The same idea applies to water resources (e.g., grey water can be used in situ) but due to lack of policies and market forces there are fewer examples of "distributed water resources."

- Increased availability of data collection systems and data analytics opens great opportunities for planning of capacity expansion and operations and for the consideration of programs of end-use energy efficiency, demand response, demand-side management: smart meters and other systems for collecting data on how users consume water/electricity and react to incentives and pieces of communication can help develop useful bottom-up models of demand and can help characterize future uncertainty.

- We face the burden of demand uncertainty and the need for regulatory frameworks that allow the co-existence of centralized vs. distributed business models: Water and electric utilities must make capital investment decisions without knowing how net demand will grow. Distributed resources may pose a threat to the financial viability of centralized infrastructure. At the same time, the absence of pricing of resources in a way commensurate with the balance between demand and supply results in inefficiencies. How can we use the power of markets and creative design of financial mechanisms to deal with this?

- The power of aesthetics, design, education, and effective communication may alleviate or completely eliminate NIMBY concerns from the siting of facilities in the urban environment. When users are informed and educated about the impact of their choices they will respond positively and contribute to alleviate stress on the system. There is a wonderful research opportunity for better understanding consumer behavior, consumer response to communication, and the use of data analytics to design effective programs for consumer involvement.

Session 3: Models and Tools for Understanding the Evolution of Cities and Infrastructures
This session focused on modeling frameworks for the simulation of the impact of land use, climate change, and decentralization of critical (FEW) supply infrastructure in cities to ensure adequate food, energy, and water distribution and storage. The panel discussed whether their modeling scope was outpacing the necessary data granularity, as well as the challenges in existing, older cities like New York City, which is committed to reducing its greenhouse gas (GHG) emissions by 80 percent by 2050. Yet 80% of the buildings that exist in New York City today will still be there in 2050. While much of the urban development over the next 30 years will be occurring in new, emerging cities, the panel discussed how to obtain quality built environment data from existing cities. Ursula Eicker pointed out that the models were assuming a high-level of data availability, when in reality the specific data were not so available. Where to get missing data? Given the unavailability of key granular data at this time, the panel discussed the role of proxies to fill in for this missing granular data. Challenges that need to be addressed include multi-scale modeling and interaction and integration among models. The panel also discussed the approach of combining theoretical and empirical models to understand and learn human behavior. A new disciplinary approach may be set up to address the challenge holistically to understand how to integrate the various models.

Through these modeling platforms, the panel and audience discussed how cities can find new opportunities to share knowledge. How can city-city model platforms shape national agendas and investment on FEW and national infrastructure? The discussion then shifted to how cities can be nimble laboratories to test applied research. Participants discussed how cities can apply research developed within research institutions (including those at this NSF conference) so that it is rapidly tested and deployed.

Session 4A: Case Studies I: System Integration–Food & Water
This session focused on food vs. energy and water vs. energy infrastructural system planning with case studies to highlight the challenges and innovative approaches for sustainability and resiliency. The panel shared the experience of lessons learned from these case studies and also highlighted the importance of leveraging the social-ecological framework to have broader impacts. Participants also emphasized the need to understand better the interaction of social infrastructure with the food/energy/water infrastructure and the need to map out laws and regulations as a basis for driving the food, energy, and water nexus toward greater sustainability.

Session 4B: Case Studies II: Urban Districts–Energy
This session centered on outlining the research agenda pathways for cities to develop smarter and more resilient urban energy systems at the district level. The speakers presented work on various case studies focusing on microgrids and the role of the digitization of electric grids for improved control and energy management. Finally, panelists stressed the role of urban energy models to predict the evolution of urban

energy demand and accordingly design optimum grid infrastructure under changing demand patterns. The panel presented two different kinds of energy modeling: Utility modeling and Building Energy modeling. They are distinct in many aspects: objects are above or below ground, and the time scales are quite different in the microgrid and power grid models compared to urban models. Different research competences and groups are thus needed to define the interfaces between the models.

Care needs to be taken when combining modeling tools with very different focus. In the building sector, timescales are long. For example, it takes 30 to 40 years to pay back window replacement, more so in mild climates with little heating demand such as in San Francisco. Power grid control models are highly dynamic. The question thus remains how different sectors could cooperate more efficiently and why they should do so. Strategic utility infrastructure planning based on modeled demand scenarios might be a practical problem that allows cooperation between the modeling communities.

Session 5: City Data and Urban Informatics

This session focused on approaches for data collection (including sensor systems), correlation and analysis of urban data, data sources, repository structures, and application workflows. The discussion was structured to identify the best approaches for the integration of heterogeneous data into models for real-time analytics and scenario exploration, as well as for monitoring and forecasting. The panel highlighted the significance of leveraging sensors, energy data, and geographic information systems and other tools for energy efficiency and water quality monitoring and argued for the need to optimize the sensing and computational architecture of these systems. The panel raised a number of questions and issues that need to be researched further, including the following:

- Data quality: is the data giving the right information?
- Data gathering: what are the best practices to obtain the right information?
- Data transformation: how do we transform the data so that it is useful?
- Data granularity: what level of detail is needed and how they depend on the level of analysis.
- Data diversity and integration of algorithms such as artificial intelligence for data interpretation.
- How to model and integrate green energy into systems.
- The means to incorporate geographical tools to improve modeling, resolution, and quality of data.
- Planning with energy efficiency in mind.

Session 6: Wrap-up

The workshop participants identified several issues that merit further research and/or agreement during the wrap-up session. They are organized below based on different thematic concerns.

Data Collection, Modeling, and Analytical Tools

Participants agreed that there is a need to continue developing broad, interdisciplinary frameworks that provide a common language to describe resource system attributes and to test the contexts and scales where particular theories and models provide useful insights. One challenge is to understand the research questions, methods, and challenges in other domains, as well as those associated with one's own research. Some participants suggested that it is important to start by aligning objectives in modeling infrastructure and data analysis and then look for common goals on different existing projects to identify the general and specific research interests.

Common challenges identified by researchers engaged in different projects include the following:

- What are the existing protocols for integrating models from the various sectors in cities (energy, water, transport, food), as well as these systems' models, data, and results across disciplines without having to reinvent or remake them?
- What are the best techniques for deploying sensors efficiently and securely and the best practices for integrating IoT sensor networks' data with existing spatially extensive datasets and remote sensing while addressing security and privacy?
- What are the best tools and methods for disaggregating monolithic models using web services?
- How do we deal with uncertainty, data formatting, and calibration when modeling urban systems (e.g. energy systems, buildings' energy models)?
- How can business models be derived, for example, from efficiency and renewable innovations?

Stakeholders / Decision Making Processes

Participants discussed how to use optimization as a tool to generate adequate information to support the (design) decision-making process of the complex FEW systems under consideration. Additional participants highlighted the importance of integrating "soft" infrastructure (people, institutions, culture, etc.) into these discussions of models that promote sustainable urban infrastructure. Others asked how to expand existing frameworks for the assessment of environmental sustainability of FEW systems to account for economic and social justice metrics. An important concern is how to evaluate stakeholder engagement methods for FEW by and across sectors.

Some added that it is important to explore how modeling can support decision-making and lead to real change. Participants asked how data and corresponding models could reach policy makers and planners at a regional scale to inform symbiotic infrastructure development. One participant recalled the presentation on the Linderburgh, Germany case study, highlighting that integrating stakeholders to shape the analytical modeling helped to remove barriers for implementation later on (e.g. their Clean Energy implementation plan). In closing, many agreed that it is important to first define the indicators that decision-makers really want and need.

Research Dissemination

Several participants argued that there is a need to transfer our work and findings and promote the ideas of more sustainable development to the less developed world, where sustainability is not a priority or may be financially stressful.

Others asked about the best means to integrate outcomes from individual innovative projects, undertaking system integration meaningfully into these models. This would include the issue of how to scale effectively up from the granular to regional approach of modeling with respect to human behavior and decision-making. A key question is where and how long a model would apply, in particular under different contextual and socioeconomic conditions. Given the plethora of models available for practitioners (outside of academia), two significant issues are (a) how do we effectively convey limitations of models and (b) provide decision support (for models) so that researchers know when and what models to use? Participants also asked about the need to agree on the best practices to create incentives for data sharing with the academic community.

Research Gaps
Participants also identified several research gaps that should be addressed in order to advance research projects, including:

- How can we include social aspects into engineering curricular programs, to help address the UN Sustainable Development Goals?
- How can we enhance the security and trustworthiness of urban data obtained from both physical and crowd/human sensors?
- How can we make data available and understandable across disciplines in order to minimize losses across disciplines?
- How can detailed, granular modeling be combined with high level decision support models, and how do we validate these models?
- How do we ensure equity for a region, a city to a global scale, in the policy and decision-making process?

Potential Collaborations:
Participants discussed potential avenues for future collaboration. Some argued that the two most important areas on which the various teams should work together are defining systems integrations and problem-centered approaches to address a human need for optimal decision-making and defining how multiple data sources in urban areas can be harmonized (internationally).

A significant contribution would be to formulate appropriate system-of-systems optimization problems and use practical yet rigorous coordination methods to solve them. Some proposed to identify facilities that would benefit from an industrial ecology.

Several participants supported the idea of focusing the research and implementation work based on a number of "innovative cities" (or City as Lab projects) for joint urban district research and as active focal points for explicit cross-comparisons (New York, San Francisco, Miami, Stuttgart).

The participants also could leverage connections to eco-district networks (e.g., American Institute of Architects or additional practitioners) to scale up and strengthen the implementation potential and impact of these projects. Other linkages included the C40 research teams and other international sustainable city networks (e.g., in New York, San Francisco, Miami, Atlanta, Stuttgart, Vienna).

BACKGROUND AND GOALS OF THE WORKSHOP

As cities across the globe grow and undergo rapid change due to rising demographic and urbanization trends, they face common metabolic challenges for the sustainable provision of resources such as energy, water, and food supplies to ensure healthy, socially balanced, and economically productive communities. In this context, communities and decision-makers need novel approaches and tools to analyze and optimize the flows of materials and energy within cities.

Various system-based approaches such as Infrastructure Ecology (IE), Input-Output (I-O), or Urban Metabolism models can help identify, quantify, and visualize multiple interdependent, cross-sectoral, and cross-media interactions, as well as reciprocities of urban infrastructure systems and processes for the efficient provision of vital resources within cities.

Urban engineered and infrastructure systems, situated at the intersection of cities, populations, and nature, represent unique opportunities (and challenges) to foster sustainable and resilient pathways in cities across the world. These engineered systems provide structure for the flow of materials and energy in cities and influence their urban metabolism (Kennedy et al, 2007; Girardet, 2006). At the same time, the flow of resources is shaped by demographic and climate change trends, as well as urban socio-technical systems and environmental policies.

One path for cities to achieve sustainability and resiliency is to identify and develop circular economies that aim at decreasing their dependence on a vast throughput of resources. The safe and reliable provision of goods and services in urban centers requires targeted action at key points for intervention to interrupt the linear throughput of materials and increase synergistic effects.

These actions, fostering "infrastructural symbiosis," may leverage the proximate relationships of urban Interdependent Critical Infrastructure (ICI) systems, and involve city residents in recognizing that waste is a resource, and that energy and materials may be recovered to minimize the need for new inputs. From an infrastructure perspective, they include understanding the patterns that connect infrastructure and human services (Herndon, 2017) and finding opportunities for closed-loop material flows, energy cascades, and regeneration of natural assets (Brown & Stigge, 2017).

Key questions that may be explored through case studies include: how can cities encourage change in infrastructure systems that mediate the flow of vital resources in urban centers? what type of cross-sectoral coordination measures are possible?, and what are the best innovative solutions for promoting increased infrastructure linkages (e.g., technologies, policies, practices and behaviors, or community engagement) or for integrating decentralized infrastructure systems and processes (e.g. low impact development, urban agriculture) so as to reduce the material throughput of urban centers?

By engaging multi-disciplinary experts working on various aspects of designing, managing, and optimizing urban infrastructure systems and processes, the workshop was able to provide a platform for informed exchange about best approaches to the research and management of the global resource base that sustains populations in urban centers. The participants, including scientists and other stakeholders, worked together to incorporate their visions into outlining key research questions that address the need for improving the metabolism of urban centers.

Dr. Nada Marie Assaf-Anid, *Professor and Dean of the School of Engineering and Computing Sciences at NYIT*, offered welcoming remarks and outlined the main goals for the 2-day NSF workshop.

The overarching **goals** of the workshop were to

- Stimulate research on the optimization of interrelated urban infrastructure systems and processes for the resilient and sustainable provision of food, energy, and water (FEW).
- Identify technical, socio-economic, and policy obstacles for this optimization.
- Explore scientific, technical, socio-economic, and policy challenges to defining pathways for integrated critical infrastructure systems and processes for the provision of vital resources in urbanized regions.
- Develop a shared urban data and modeling framework to help cities analyze and characterize FEW infrastructure systems and their nexus interrelationships in order to identify synergies to minimize energy and materials use and waste generation.

Dr. Assaf-Anid then stated the **objectives and expected outcomes** of the workshop:

Objective 1: Build a research agenda that supports active engagement and joint approaches to resilient urban ICI systems and processes (for the provision of water, energy, food, and transport, as well as human and environmental health). Define scientific, engineering, data, and stakeholder engagement challenges to the optimal management of interrelated critical infrastructure systems, as they relate to urban centers.

Outcomes of Objective 1:

- Determine the best modeling and analytical approaches to the optimal management of interdependent infrastructure systems that provide vital resources and services in urban centers.
- Define a modeling framework for the simulation of the impacts of land use, climate change, and decentralization of critical (FEW) supply infrastructure in cities with different densities and under multiple constraints to ensure adequate energy, water and food distribution and storage capacity.
- Identify case studies and best practices that can serve to advance the stated research agenda.

Objective 2: Explore solutions for innovative urban infrastructure synergies for sustainable, green, and livable cities and resource provision systems and processes.

Outcomes of Objective 2:

- Discuss the role of infrastructure and technological innovations in addressing and fostering optimal use of resources in cities, such as zero energy districts, urban agriculture production, and/or closed loop water systems.
- Investigate information and cyber physical systems, such as sensors, sensor networks, and remote sensing, for enhanced real-time data collection, analysis, monitoring, and predictive modeling of critical infrastructure systems that inform decision-making.
- Determine best models for evaluation of stakeholders' preferences about specific policy proposals, as well as those for informing and sharing data and findings with the broader community, including visualization, 3-D simulation applications, and other tools.

Objective 3: Form a global research and education community, with links to local stakeholders, and share data and actionable agendas for change.

Outcomes of Objective 3:

- Study the suitability of approaches that involve urban stakeholders, to co-identify and co-produce knowledge on the key features and variability of urban critical infrastructure systems, bridging science to implementation by integrating behavioral factors for broader impacts. Identify key actors to support implementation of an integrated approach to optimal resource management and discuss how the integration may be achieved.
- Develop a mechanism to connect the research and educational efforts of all participants and facilitate the formation of partnerships. Leverage the capacity of all leading institutions in education and service/outreach to help engage participants across urban centers.
- Determine best models for the promotion of open data and data sharing across participating institutions and entities.

PROGRAM HIGHLIGHTS

SESSION 1: SYSTEMS-BASED APPROACHES

This session focused on systems-based approaches to understand the complex interdependencies of urban critical infrastructure systems that provide food, energy and water. These system-based approaches looked into the interdependencies of urban food distribution, water, waste, and energy within cities, which are subject to increasing demands and extreme climate conditions that may affect their supply.

Dr. Marta Panero, *Director of Strategic Partnerships at NYIT's School of Engineering and Computing Sciences (SoECS)*, moderated the session and engaged the speakers in a discussion of how system-based approaches may be leveraged to optimize urban infrastructure systems for FEW supply. **Dr. Joshua Sperling**, *Researcher on Urban Futures & Energy-X Nexus at the National Renewable Energy Lab*, served as the respondent for this session.

Ming Xu, Ph.D., Associate Professor and Director of China Programs, School of Environment & Sustainability, University of Michigan, Ann Arbor, MI

Hillary Brown, FAIA, Professor and Director, MS Program in Sustainability in the Urban Environment, Bernard and Anne Spitzer School of Architecture, City College of New York, CUNY

Osvaldo A. Broesicke, E.I.T, Graduate Research Associate, Brook Byers Institute for Sustainable Systems, Georgia Institute of Technology

Session 1 Presentation Summaries:

Ming Xu, Ph.D., *Associate Professor and Director of China Programs, School of Environment & Sustainability at the University of Michigan, Ann Arbor, MI,* presented on "Urban FEW Nexus – A Material and Energy Flow Perspective." This NSF-sponsored project considers cities as sinks of energy and resources as well as a major source for emissions. Dr. Xu emphasized the central position of infrastructure systems, which mediate the interaction between humans and the environment. He added that the field of ecology may be used as a guiding principle to understand the interdependencies between different infrastructure systems (e.g. energy and water). This forms the basis for a relatively new system-based approach, "Infrastructure Ecology," which is leveraged to understand the key infrastructure dynamics affecting urban centers. Dr. Xu proposed that the first step is to develop a baseline, quantifying the flow and stocks of materials of a socioeconomic system, focusing on functions of each system, such as:

- Food systems: nitrogen/phosphorous fixation, production, processing, retailing, consumption, waste management.
- Energy systems: Extraction, processing, electricity generation, fuel production, consumption, emissions.
- Water systems: Systems for fresh water, treatment, distribution, consumption by waste water treatment and residual process discharge.

This is depicted as an input and output model of the FEW systems in Figure 1 below.

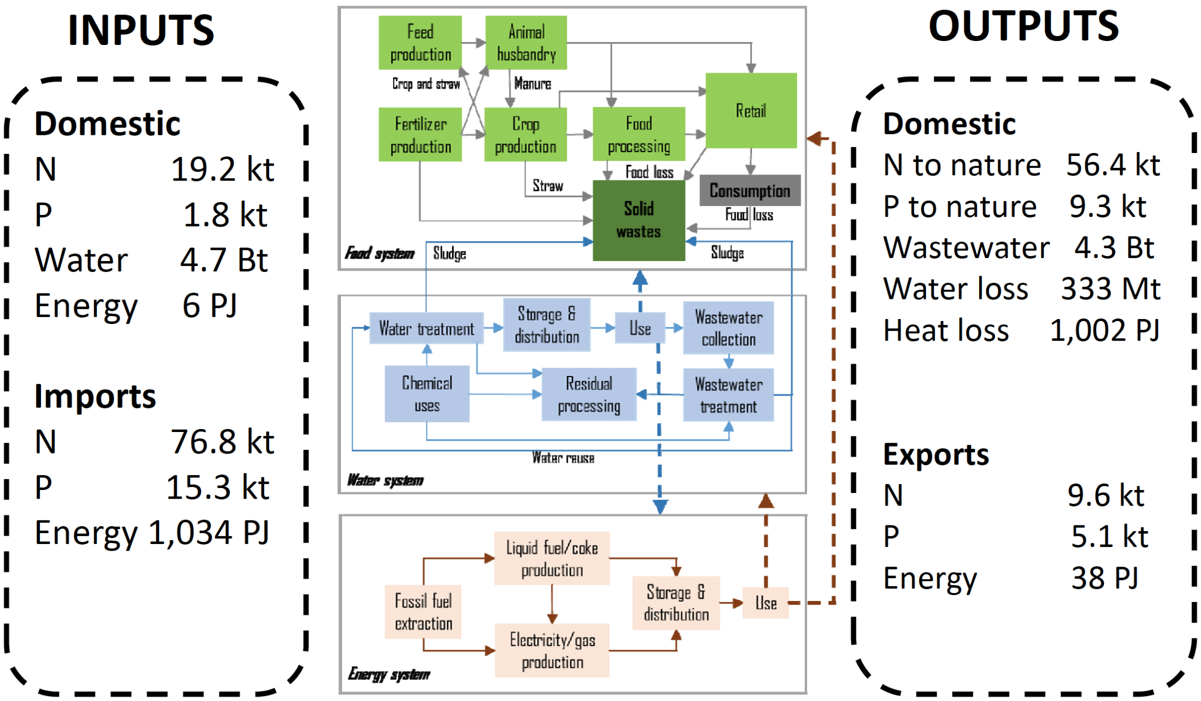

Figure 1. Input and Output of FEW systems

Dr. Xu then presented a case study of metropolitan Detroit, MI. For this study, he used network analytical tools to highlight structural features of the FEW networks. This case may be replicated in several cities to find interesting patterns and gain a better understanding of the key variables that affect cities' sustainability and resiliency. The following questions emerged from this research:

a) Is there a simple indicator to measure the efficiency or resilience of an urban FEW nexus? To address this question, we need a common and consistent unit (e.g., emergy, exergy) and network analysis to identify critical nodes and components.

b) What key components of the FEW networks are used for its efficiency and resilience? Dr. Xu recommended streamlining the data collection process for case studies to facilitate comparisons. That can be done by developing online or Excel tools to be shared broadly.

Hillary Brown, FAIA, *Professor, and Director, MS Program in Sustainability in the Urban Environment, School of Architecture, City College of New York, CUNY,* presented on "Infrastructures Symbiosis: Reciprocities among Urban Systems." Her work focuses on urban infrastructures analysis and modeling for their optimal management and operation. She argued that we need to look at our legacy infrastructures and find pathways to upgrading or reinventing them. A model based on the natural environment may be used to develop a better understanding of their interdependencies, as they are highly coupled.

This model may:

1. Reflect self-organized ecosystems services like water purification, waste digestion, biomass production

2. Propose pathways to organize collectively and cooperatively (ecologically)

3. Help us pursue opportunistic relationships and align and integrate technologies synergistically, for example:

- Closed loop cycling of energy and materials (e.g., Kalundborg, Denmark; Sweden)
- Biogas recovery from organic waste and wastewater such as in Lille, France, where bio-waste is used to create biofuel by bio-digestion, with the residual used as organic fertilizer. They centralized the refueling / overnight bus depot and used barges for waste transport, thus reducing vehicle miles travelled. The operation includes a visitor center.
- East Bay municipal utility district wastewater treatment plant (WWTP) in Oakland, CA. The first one utilizing bio-digestion of sewerage coupled with food and restaurant waste, wineries and poultry residuals, and co-digesting to produce more energy.
- Agro-energy remediation of hydropower reservoir in Ajurucaba, Brazil, where 33 small-scale farms are conducting onsite anaerobic bio-digestion and producing combined heat and power (CHP) energy from the biogas. The heat from CHP is utilized for drying crops, reducing farmers drying costs by 90%.

The key question then is how public use functions can be introduced at some of these polyfunctional facilities. Some projects are already doing so, such as the Jamaica Bay, NY, wastewater facility to recover methane for biogas to fuel MTA CNG buses, which exhibits infrastructure optimization principles--multifaceted, lower emissions energy, adaptive, soft path, and community friendly.

Osvaldo Broesicke, *Research Scientist at Georgia Institute of Technology,* presented on "Infrastructure Ecology: Emergent Properties from Current Paradigm in Infrastructure Systems," noting that these system properties result from collective interactions of its constituting parts or by different individuals. Infrastructure Ecology views a city as a complex adaptive ecosystem that integrates urban infrastructure as a "system of systems" and:

1. Allows us to reorganize energy and resource flows while considering potential synergistic effects arising from infrastructures symbiosis.
2. Applies tools and models from the transdisciplinary field of infrastructure ecology and integrates stakeholder needs throughout the design, planning, and implementation process.

He discussed a case study in Atlanta, GA, which applied an ecosystem network analysis (ENA) to understand different energy and growth scenarios (2005-2030), looking at the system from an ecological perspective, and helped to find an optimum system. The resulting infrastructure ecology road map helps us with:

- Developing sustainable and resilient urban infrastructure and identifying sustainable and resilient alternatives.
- Social decision making, assisted by big data analytics based on collecting data from social networking sites.

- Predicting the demand for urban infrastructures, relying on agent-based modeling. This allows us, for example, to simulate the adoption rate for more sustainable urban development (MSD). Agent choices may include a 40% reduction in potable water demand from centralized, compact MSD, as compared to Business as Usual (BAU), with 36% increase in net property tax revenue generation in MSD as compared to BAU. Moreover, when combined cooling, heating, and power (CCHP) is included in new and existing commercial and residential buildings, the potential for reducing energy use and emissions, as well as water used to create energy is highly increased, and with CCHP net metering, even more savings result.
- Evaluating sustainable and resilient performance.
- Building the infrastructure and accessing actual performance.

In terms of future work, Broesicke suggested looking into identifying sustainable alternatives for multi-dimensional design optimization. He mentioned architectural studies that consider different designs, where the goal is to identify Pareto efficient combinations–up to a point where no one objective can be improved without reducing the efficiency of another one. They are also exploring the synergistic effects of infrastructure ecology. Using the "MDO" tool, they can combine various technologies in order to quantify or observe potential resulting changes.

The session respondent, **Josh Sperling**, Ph.D., *Researcher, Urban Futures & Energy-X Nexus, National Renewable Energy Lab*, emphasized the need for System Integration Models that explore how to integrate physical modeling and decision-making environments. Another important factor to consider is institutional arrangements–whether organizations may be brought together to manage these resources collectively, while bridging decentralized and centralized arrangements.

SESSION 2: END-USER PERSPECTIVE: WHAT STAKEHOLDERS WANT TO SEE

This session focused on approaches and participatory models to engage stakeholders to understand what policy makers need for optimizing the resources and management of urban interdependent critical infrastructure systems. Optimization of regional and local FEW systems, which take into account their interdependencies may be accomplished via integration based on co-decision, which in turn aims simultaneously to optimize multiple interconnected systems. The session included a discussion of tools to help stakeholders in visualizing and understanding the complex interdependencies and demonstrate the potential for synergistic co-benefits and coordinated decisions supporting integrated infrastructure systems.

The session moderator, **Michael Bobker**, *Executive Director of the CUNY Building Performance Lab and Associate Director of the CUNY Institute for Urban Systems,* engaged the speakers in a conversation on these issues, and **Dalia Patino-Echeverri, Ph.D.,** *Gendell Family Associate Professor, Environmental Sciences and Policy, DIBS, Duke University*, offered respondent remarks.

Newsha Ajami, Ph.D., Director, Urban Water Policy, Senior Research Associate, Stanford Woods Institute for the Environment
John L. Lee, Deputy Director, Mayor's Office of Sustainability, New York City Government

Jason Bregman, Associate, Environmental Planning and Design, Michael Singer Studio

<u>Session 2 Presentation Summaries:</u>

Newsha Ajami, Ph.D., *Director, Urban Water Policy, Senior Research Associate, Stanford Woods Institute for the Environment*, presented on "A New Governance Regime for the Evolving Urban Water Infrastructure." She highlighted the varying perspectives of municipalities and municipal water authorities around the San Francisco Bay, as water utility managers face increasing uncertainty about the water supply. She argued that a new paradigm is needed to ensure resource diversification, such as conservation, water reuse, rainwater capture, and other forms of green infrastructure. These water conservation, modeling of innovative policies approaches are being promoted through municipal agencies joined together as the Bay Area Water Supply and Conservation Agency (BAWSCA, http://bayareaconservation.org/). Her team has developed a set of visualization and other stakeholder engagement tools, including interactive maps on a web portal, conservation incentive programs, educational materials, metrics for green infrastructure, compiled indicators, and a market platform for tradeable water credits to engage stakeholders. Her research suggests that increased media coverage of regional water issues is a strong driver of water conservation action. In terms of effective stakeholder engagement, Dr. Ajami suggested that it takes time and patience to build relationships and trust, and it requires commitment from all parties involved. In concluding, she suggested that researchers have to find a project/problem that is mutually interesting and valuable and need to show stakeholders the value academia brings, such as creative and innovative tools.

John L. Lee, *Deputy Director, Mayor's Office of Sustainability, New York City Government*, presented on "New York City Sustainability Projects." He focused on New York City's post-Sandy approaches to planning and development of infrastructure projects for urban resilience in the face of extreme climatic events. This has involved a large amount of mapping of the city's underlying physical characteristics and exposures; and a socio-economic overlay has been important also to underscore the at-risk-populations. The need to understand and visualize multiple dimensions simultaneously has led to a "layering" approach to mapping that is carried further into conceptualizing projects at the community scale, especially in the energy sector, such as micro-grids employing various technologies. Local energy development is not only important for bringing greater resiliency, but also for local economic development and jobs. Rather than just building energy models, for which the city has many, he recommended that the models have to be clearly related to realistic planning, policy, and political needs for them, so that they would be useful at the level of mayoral thinking.

Jason Bregman, *Associate, Environmental Planning and Design, Michael Singer Studio*, presented on "Infrastructure and Community – How can we Live with What Sustains Us?" He brought a landscape art and design perspective to the topic of infrastructure. He showed works from a broad portfolio of municipal infrastructure engagements, pointing out that in the second half of the nineteenth century, cities were proud of their infrastructure public works and showed them off as monuments. Stakeholders need to be brought once again to a new sense of engagement, this time informed less by a philosophy of progress than by one about the city's relationship to its natural environment. He then proceeded to present on different infrastructure systems that have been integrated into the fabric of the community, such as an innovative wastewater treatment facility design that became a public amenity.

Respondent **Dalia Patino-Echeverri** provided comments on points raised by the panel, highlighting the important convergence of challenges and opportunities facing water and electricity sectors, raising the possibility for an integrated framework for such topics as demand management, decentralized sources, investments under uncertainty, and consumer behavior, all of which require new data analytics and integrated modeling tools. The following points were highlighted:

- Both the water and electricity sectors share a mandate to provide clean, affordable and reliable service to their customers. While both sectors require massive infrastructure, decisions on when and what to build and how to operate are very difficult. Capital investment decisions are tough because of (a) multiplicity of investment alternatives, (b) uncertainty on which alternative will end up being preferable, (c) long lead times, (d) high capital requirement, and (e) long life time of the infrastructure once built.

- We need distributed resources and policies and markets that reward their contribution to affordability, reliability, and environmental sustainability: It is clear that Distributed Energy Resources (e.g., roof-top or community scale solar PV) can make important contributions to the reliability and resiliency of the system. The same idea applies to water resources (e.g., grey water can be used in situ), but due to lack of policies and market forces there are fewer examples of "distributed water resources."

- Increased availability of data collection systems and data analytics opens great opportunities for planning of capacity expansion and operations and for the consideration of programs of end-use energy efficiency, demand response, and demand-side management: smart meters and other systems for collecting data on how users consume water/electricity and react to incentives and pieces of communication can help develop useful bottom-up models of demand and can help characterize future uncertainty.

- We face the burden of demand uncertainty and the need for regulatory frameworks that allow the co-existence of centralized vs. distributed business models: Water and electric utilities must make capital investment decisions without knowing how net demand will grow. Distributed resources may pose a threat to the financial viability of centralized infrastructure. At the same time, the absence of pricing of resources in a way commensurate with the balance between demand and supply results in inefficiencies. How can we use the power of markets and creative design of financial mechanisms to deal with this?

- The power of aesthetics, design, education, and effective communication may alleviate or completely eliminate NIMBY concerns from the siting of facilities in the urban environment. When users are informed and educated about the impact of their choices they will respond positively and contribute to alleviate stress on the system. There is a wonderful research opportunity for better understanding consumer behavior, consumer response to communication, and the use of data analytics to design effective programs for consumer involvement.

Session 3: Models and Tools for Understanding the Evolution of Cities and Infrastructures

This session focused on modeling frameworks for the simulation of the impact of land use, climate change, and decentralization of critical (FEW) supply infrastructure in cities to ensure adequate food, energy, and water distribution and storage. **Dr. Ziqian (Cecilia) Dong**, *Associate Professor, Department of Electrical and Computer Engineering, School of Engineering and Computing Sciences, NYIT*, moderated this session. **Jeffrey Raven**, *FAIA, LEED BD+C, Associate Professor and Director of the Graduate Program in Urban & Regional Design, School of Architecture and Design at NYIT*, served as the session's respondent.

> **Yimin Zhu**, Ph.D., Pulte Homes Endowed Professor, Bert S. Turner Department of Construction Management, College of Engineering, Louisiana State University
> **Vatsal Bhatt**, Ph.D., Senior Energy Policy Advisor, Brookhaven National Laboratory
> **Ali Mostafavi**, Assistant Professor, Department of Civil Engineering, Texas A&M University

<u>Session 3 Presentation Summaries:</u>

Yimin Zhu, Ph.D., *Pulte Homes Endowed Professor, Bert S. Turner Department of Construction Management, College of Engineering, Louisiana State University*, presented on "Data Sharing and Data-Driven Discovery for Sustainable Buildings using Virtual Information Fabric Infrastructure." His presentation described the data fragmentation issues that the research community has been facing for decades. Privacy, ownership, and varying semantics across multiple disciplines all contribute to data fragmentation. His research has focused on modeling for a sustainable eco-community, including a modeling tool for data sharing called Virtual Information Fabric Infrastructure (VIFI). VIFI can be considered as a middleware that provides a cyberinfrastructure to facilitate data-driven discovery from distributed, fragmented datasets–without requiring movement of massive amounts of data or exposing sensitive raw datasets to end users. VIFI is used as a platform to integrate a predictive model with observational data. He presented on how VIFI was used on a case study of sustainable human-building ecosystems, a pilot study on human behavior and lighting consumption in a building. A traditional lighting usage prediction model by Hunt is a stochastic model that does not consider context information. Using virtual reality (VR), users were placed in a VR environment to monitor their behavior under different scenarios to evaluate their light switching behavior. The study showed that the stochastic prediction model by Hunt did not match the actual use case observed in the VR experiment. This further proves the limitation on modeling approaches using historic data and the changing human behavior. The challenges we face in the big data era remain what contextual and human behavioral factors significantly impact the predictive models and how to address these factors in modeling approaches.

Vatsal Bhatt, Ph.D., *Senior Energy Policy Advisor, Brookhaven National Laboratory*, presented "A Bottom-up Approach for the Analysis of Energy and Water Systems: MARKAL Models for Energy and Water Systems' Modeling." Dr. Bhatt described the development of energy-water-climate change systems' modeling for long-term national, regional, and urban analysis. New York City MARKAL is an initiative with funding from the New York State Energy Research and Development Authority (NYS NYSERDA). MARKAL is a family of models developed at the Brookhaven National Laboratory in collaboration with the International Energy Agency (IEA). This project has built a Northeast Regional Earth System Model (NE-RESM) that improves the understanding and capacity to forecast the implications of human interactions for the region's environment, ecosystem services, energy, and economy. The MARKAL model helps mitigate effects of future shocks such as those caused by extreme climate events. Emerging themes included addressing the access to current data, identifying the role of artificial intelligence through sensor data, and ensuring the right scale of the model for different case studies. Further development of the model includes suggestions on systematic optimization and its impact on the sustainable outcome. MARKAL is used as a large-scale system model to engage policy makers to make informed decisions on predictive scenarios of certain stressors the infrastructure may face.

Ali Mostafavi, Ph.D., *Assistant Professor in the Department of Civil Engineering at Texas A&M University*, presented on "System of Systems Modeling of Urban Infrastructure Resilience." His Infrastructure System-of-Systems (I-SoS) Lab researches solutions of challenges pertaining to sustainability and resilience of civil systems. Examples of these challenges include demand-supply disparity, decay of reliability and resilience in infrastructure networks, need for water and energy efficient facilities, protection of communities during extreme events, and an efficient use of limited natural, physical, human, and financial resources. These problems are often large in scale and multidisciplinary, thereby requiring multidisciplinary solutions. His team research focuses on different research thrusts to create transformative solutions for these grand challenges based on System-of-Systems (SoS) analysis, computational simulation, and quantitative data analysis models. Three case studies were presented at the talk:

Case Study 1: *Road Networks Resilience Under Sea Level Rise (SLR) Impacts in Southeast Florida*
The simulation shows interactions between stressors, physical road network, and human decision-making often made under deep uncertainty. Scenarios of sea level rise and its impact on road network flooding were demonstrated through visualization. Economic impact was also predicted vs. various decision-making such as installation of water pumps, which costs $5M for installation but prevents much more costly infrastructure damage in the long term when SLR impacts will be exacerbated.

Case Study 2: *Water Systems Resilience to Saltwater Intrusion in the Southeast of Florida*
Their simulation work shows potential impact of saltwater intrusion on water wells, as well as the current wells that need to be retrofitted to address this issue.

Case Study 3: *Achieving Resilience through Demand-Side Water Conservation using Agent-Based Modeling*
The model provided scenario-based simulation on social adoption of water conservation technology, pricing policy, and other interventions to study regional water sustainability. It added human behavior into the modeling tool to estimate the percentage of adopters over time for certain policy and incentives.

<u>Respondent:</u> **Jeffrey Raven, FAIA**, responded by asking if these models' ambitious scopes were missing key data sets from existing cities. The panel discussed whether their modeling scope was outpacing the necessary data granularity, as well as the challenges in existing, older cities like New York City, which is committed to reducing its greenhouse gas (GHG) emissions by 80 percent by 2050. Yet 80% of the

buildings that exist in New York City today still will be there in 2050. While much of the urban development over the next 30 years will be occurring in new, emerging cities, the panel discussed how to obtain quality built environment data from existing cities. Ursula Eicker pointed out that the models were assuming a high-level of data availability, when in reality the specific data were not so available. Where to get missing data? Given the unavailability of key granular data at this time, the panel discussed the role of proxies to fill in for this missing granular data. Challenges that need to be addressed include multi-scale modeling and interaction and integration among models. The panel also discussed the approach of combining theoretical with empirical models to understand and learn human behavior. A new disciplinary approach may be set up to address holistically the challenge to understand how to integrate the various models.

Through these modeling platforms, the panel and audience discussed how cities can find new opportunities to share knowledge. How can city-city model platforms shape national agendas and investment in FEW and national infrastructure? The discussion then shifted to how cities can be nimble laboratories to test applied research. Participants discussed how cities can apply research developed within research institutions (including those at this NSF conference) so that it is rapidly tested and deployed.

SESSION 4A: CASE STUDIES I: SYSTEM INTEGRATION – FOOD & WATER

Participants were engaged in a moderated discussion by **David Nadler, Ph.D**., *Associate Professor and Chair of Environmental Technology and Sustainability, School of Engineering and Computing Sciences, NYIT*. This session focused on food vs. energy and water vs. energy infrastructural system planning with case studies to highlight the challenges and innovative approaches for sustainability and resiliency. **Carli Flynn, Ph.D.**, *Postdoctoral Fellow, Golisano Institute for Sustainability, Rochester Institute of Technology*, offered final remarks as a respondent.

Weslynne S. Ashton, Ph.D., Associate Professor, of Environmental Management and Sustainability, Stuart School of Business, Illinois Institute of Technology
Adam Hinge, President, Sustainable Energy Partnerships, and Adjunct Professor, Columbia University
Alfred Helble, AH Consultant, CITYtrans, Stuttgart, Germany
William (Bill) Solecki, Professor, Graduate Geography Advisor, and Founder Director, Emeritus, Institute for Sustainable Cities, CUNY

<u>Session 4A Presentation Summaries:</u>

Weslynne S. Ashton, Ph.D., *Associate Professor, Environmental Management and Sustainability, Stuart School of Business, Illinois Institute of Technology*, presented on "Reinvigorating Urban Infrastructures at the FEW Nexus." She discussed a case study for equity and justice issues concerning where infrastructure is placed within the inner city of Chicago, Illinois, showing how old industrial infrastructure can be utilized to reinvigorate local economies. Her case study covered "The Plant," a former meat packing factory that has been converted into a collaborative community of food and beverages businesses. Twenty small start-up businesses leased space in this converted building and have established material, energy, and water trades. A circular economy has taken root in this case study through the connecting of food producers via their inputs and outputs, representing a small-scale replica of an industrial ecology park. Beyond the material and energy flows, this project is also addressing social and human capital flows.

Adam Hinge, *President, Sustainable Energy Partnerships, and Adjunct Associate Professor of International and Public Affairs, Columbia University,* presented on "Energy Infrastructure Planning at the Hunts Point Food Distribution Center (a Microgrid Study)." He described a microgrid study for the Hunts Point Food Distribution Center in Bronx, New York. This 329-acre site and its buildings provide sixty percent (60%) of metropolitan New York's produce, meat, and fish. The marketplace is located in a 100-year flood zone and is not equipped with backup generators. In the event of a power loss, their inventory could only be preserved for a few hours. Mr. Hinge showed results of a feasibility study that could prevent power issues in the future, comprising solar photovoltaic (PV) panels that would be installed on large, flat, and unused roofs, providing the base electricity demand during peak business hours. Combined heat and power (CHP) turbines would be used to meet the needs for the marketplace's refrigeration requirements. Energy and materials flows would transfer between an anaerobic digester, vertical farming, and the markets operating on site. This microgrid shows a high potential for energy, cost, and greenhouse gas reductions.

Alfred Helble, *AH Consultant, CITYtrans, Stuttgart, Germany*, presented on "Linking of the Energy and Water Sector in Urban Systems," highlighting the synergistic potential by linking energy and water flows at wastewater treatment plants. He presented data from municipal wastewater treatment plants in Germany, providing background in the legal framework as specified in the Water Framework Directive (WFD) along with general water supply data.

Potentials for reducing wastewater treatment plants' energy demand include upgrading CHP in existing digesters, optimizing electricity yield in the higher-class sizes of treatment plants, and converting from aerobic to anaerobic sludge stabilization. Mr. Helble stated that a dynamic process control and improved automation in the wastewater and sludge treatment processes may help stabilize the grid. He proposed that using best achievable technology (BAT) for secondary wastewater treatment should be a prerequisite for the efficient and economic operation of advanced and emerging techniques.

William (Bill) Solecki, Ph.D., *Professor, Graduate Geography Advisor, and Founder Director, Emeritus, Institute for Sustainable Cities, CUNY*, presented "Jamaica Bay, New York: Ecosystem Services–Past, Present, Future," discussing the history of ecosystem services for Jamaica Bay in New York. A number of municipal wastewater treatment plants discharge effluent into Jamaica Bay and there had been an extreme loss to the local ecosystem. This bay has gone from being a watershed to a sewershed. This case study presents a foundation for policy evaluation shifts required to develop resiliency efforts and the possibility for transformative environmental management. Upgrades to wastewater infrastructure and natural attenuation programs, such as oyster farming in the bay, have helped to pave the way for its restoration.

Carli Flynn, Ph.D., *Postdoctoral Fellow, Golisano Institute for Sustainability at the Rochester Institute of Technology*, responded by summarizing the lessons learned from the case studies and also highlighting the importance of leveraging the social-ecological framework to have broader impacts. She pointed out that the interaction of social infrastructure with the food/water/energy infrastructure and the mapping out of laws and regulations as a basis for driving the food, water and energy nexus are crucial for its sustainability.

SESSION 4B: CASE STUDIES II: URBAN DISTRICTS-ENERGY

This session centered on outlining the research agenda pathways for cities to develop smarter and more resilient urban energy systems at the district level. The speakers presented work on various case studies focusing on microgrids and the role of the digitization of electric grids in improved control and energy management. Finally, the session stressed the role of urban energy models to predict the evolution of urban energy demand and accordingly design optimum grid infrastructure under changing demand patterns. Moderated by **Ursula Eicker**, **Ph.D.**, *Professor, Building Physics, University of Applied Sciences, HFT, Stuttgart, Germany,* the session featured three speakers, with CUNY **Professor Michael Bobker** as the respondent for this session.

Roberto Rojas-Cessa, Ph.D., Professor, Electrical and Computer Engineering, Newark College of Engineering, New Jersey Institute of Technology
Ahmed Mohammed, Ph.D., Assistant Professor, Electrical Engineering, Grove School of Engineering, City College of New York, CUNY
Yixing Chen, Ph.D., Senior Scientific Engineering Associate, Lawrence Berkeley National Lab

<u>Session 4B Presentation Summaries:</u>

Roberto Rojas-Cessa, Ph.D., *Professor, Electrical and Computer Engineering, Newark College of Engineering, New Jersey Institute of Technology,* discussed *"*Digitizing the Electric Grid: Improving the Power Grid.*"* Digitization increases knowledge on the distribution of electrical energy and thus allows us to improve grid control for increased resilience and reliability. Eventually, optimum grid control might lead to more economical operation. Current smart grid solutions use monitoring methods for power balance evaluation, integrating sensor information for data analytics. However, smart metering is not enough for stable operation, and more precise control of energy integration and distribution is needed. The monitoring thus has to evolve from energy flow to power/energy packet monitoring. This means we have to know who produces and consumes the energy; i.e. every energy packet is addressed and sent to a user in a controllable delivery grid: the user requests energy, and the provider grants the energy to cover a specific load. Customer access points then connect to a local access power switch and a digitized power router.

The new approach of digital grids allows an effective management of green energy sources, such as for stationary or mobile electric vehicle batteries. Finer control of energy integration and distribution leads to a more reliable and controllable delivery grid. The main features of the digital grid are:

- Uses power/energy packets.

- Fuses data and power.
- Provides energy only when requested.
- Addresses energy to a user.
- Assigns energy proactively and at a discrete level.

The equipment needed includes power routers and a power switch or power gateway. The concept of power packets was discussed in 1993 with the introduction of small generators. In 2012 network-controlled power routers were developed, and in 2014 a network-controlled power router was demonstrated. Lessons learned from many test cases were that the energy demand could be reliably covered, that the rapid absorption of energy is a challenge, and that reactive loads are more complex to switch. Technology delivery drivers are pricing and storage level priorities. In summary, a digital grid leads us to the Internet of Things and does not only concern the control of the power supply but a new formation of the grid. Digital grids are suited for smart cities and smart buildings and allow us to manage small and intermittent energy generators and integrate electrical vehicles. Open questions remain on policy, engineering, and economy.

Ahmed Mohammed, Ph.D., *Assistant Professor, Electrical Engineering, Grove School of Engineering, City College of New York, CUNY*, presented “Microgrids in New York City.” He showed that many microgrid activities take place in NYC, with many topics arising such as the sizing, placement, and control of different technologies such as CHP, energy storage, and photovoltaics. New York leads the nation’s effort to develop community microgrids though the NY Prize Microgrid Competition.

The principal barriers for microgrids’ implementation are policy based on the one hand and improved control needs on the other hand. NYSERDA project reports show that typical microgrid owners and operators include fixed military bases, university campuses, corporate research facilities, hospitals, airports, industrial plants, hotels, municipalities, and planned residential communities. Today´s main reasons for investment are that cost and maintenance of microgrids are lower than the cost of service interruptions.

When CHP and thermal energy storage are included, complete microgrid assets often can be justified through energy savings alone. Examples are landlord/tenant microgrids or independent provider microgrids. One of the problems is that some microgrid revenue streams cannot be captured by non-utility microgrid owners.

Reliability of microgrids is characterized by the redundancy of generation. N-1 and N-2 reliability are to be considered based on the negative consequences associated with failures. N-1 reliability means that if one big generator is lost, the network still works, N-2 reliability that 2 devices can be lost and the network will still work.

To further support microgrid implementation within NY Prize, three stages are addressed:

- Customer support for feasibility studies.
- Audit grade engineering design and business planning (ongoing--expected to conclude by mid-2018).
- Project build-out and operational microgrid.

The NY Prize is open to communities across New York State. Conditions are that applicants must include the local electric distribution company and more than one entity that will benefit from the microgrid. Lead respondents may include teams of universities, counties, schools, hospitals, and critical facilities.

Yixing Chen, Ph.D., *Senior Scientific Engineering Associate, Lawrence Berkeley National Lab*, presented on "CityBES – A Data and Computing Platform for City Buildings." He noted that buildings in the city consume 30 to 70% of primary energy. Reducing the building energy consumption to less than 50% is a major goal for urban decarbonization strategies. The CityBES energy savings web-based platform was developed to support city building efficiency plans. The target is for the stakeholders to create their own dataset to create and evaluate energy retrofit scenarios for city buildings. The platform includes visualization of existing buildings' performance data and detailed energy modeling and interactions with the urban climate. 3D GIS visualization and color coding for energy are done based on different profiles with functions provided, such as filtering or highlighting buildings or comparing performance with other buildings. The data format used is CityGML. The EnergyPlus and OpenStudio simulation engine is used for modeling. Use cases of the platform are energy benchmarking, energy retrofit analysis, and improving building operation. Challenges are different data formats and limited monitoring of data for validation.

A case study was carried out in San Francisco to find out what kind of investments can be designed for San Francisco. A master building data set was created by mapping and integration of various data. Through further simplification and integration processes, a user could produce end products in different formats. The platform is still in development, for example to improve the visualization capabilities of the platform. It provides features such as measurement site EUI for benchmarking. Ongoing projects include the Hunter Point Shipyard, the Concord Naval Base, and a science project funded by the USDOE Office of Science.

The major challenges encountered may be summarized as:

- Data–big data problem integrating diverse sources with different temporal and spatial resolutions, quality, and structure/format.
- Modeling–integration of multiple domain models with different scales and resolutions.
- Simulation–an exascale computing problem including transportation and urban atmosphere.

CityBES is freely available at CityBES.lbl.gov

<u>Respondent:</u> **Michael Bobker** pointed out two different kinds of energy modeling disciples addressed in the session: Utility modeling and Building Energy modeling. They are distinct in many aspects: objects are above or below ground, and the time scales are quite different in the microgrid and power grid models compared to urban models. Different research competences and groups are thus needed to define the interfaces between the models.

Care needs to be taken when combining modeling tools with very different focus. In the building sector timescales are long. For example, it takes 30 to 40 years to pay back window replacement, more so in mild climates with little heating demand such as in San Francisco. Power grid control models are highly dynamic. The question thus remains how different sectors could cooperate more efficiently and why they should do so. Strategic utility infrastructure planning based on modeled demand scenarios might be a practical problem that allows cooperation between the modeling communities.

SESSION 5: CITY DATA AND URBAN INFORMATICS

This session focused on approaches for data collection (including sensor systems), correlation and analysis of urban data, data sources, repository structures, and application workflows. The discussion, moderated by **Dr. Roberto Rojas-Cessa,** *Professor, Newark School of Engineering, New Jersey Institute of Technology*, was structured to identify the best approaches for the integration of heterogeneous data into models for real-time analytics and scenario exploration, as well as for monitoring and forecasting. **Brunilde Sansò, Ph.D**., *Professor, Telecommunication Networks, Department of Electrical Engineering, École Polytechnique, Montréal*, offered remarks as a respondent on this session.

Ziqian (Cecilia) Dong, Ph.D., Associate Professor, Electrical and Computer Engineering, School of Engineering and Computing Sciences, NYIT

Ursula Eicker, Professor, University of Applied Sciences, HTF, Stuttgart, Germany

Michael Flaxman, Founder and CEO, Geodesign Technologies

Andrew Parker, Researcher III, Mechanical Engineering, National Renewable Energy Lab

Masoud, Ghandehari, Ph.D., Associate Professor, Civil and Urban Engineering, Center for Urban Science and Progress, Tandon School of Engineering, New York University

<u>Session 5 Presentation Summaries:</u>

Ursula Eicker, Ph.D., *Professor, University of Applied Sciences, HTF, Stuttgart, Germany*, presented on "Urban Data and Workflows for Building Sector Transformation Strategies." Her presentation focused on the issues of data and the complexity of integrating these data for modeling. She also discussed the role of urban modeling tools for decision making and monitoring of climate protection measures that were applied in a case study project in Ludwigsburg, Germany, leveraging a 3D-CityGML model, including energy expenditure of 39 communities in that region.

Dr. Eicker highlighted the importance of developing appropriate energy measures and working with the regional government to implement sustainable infrastructure measures, emphasizing the need for data collection and correction for the models. She also mentioned that her team has designed a tool to combine different simulation applications to automate the process–a workflow manager to run processes such as cleaning and other data operations and/or an automated workflow to generate simulated heating and cooling networks. She noted that data on energy consumption are sparse and not digitized and discussed the challenges and scenarios for urban modeling, such as retrofit scenarios for energy efficiency and their cost. Dr. Eicker concluded by emphasizing that working with the regional government helps by speeding up implementation of sustainable infrastructure, such as maximizing renewable supply, analyzing building sector efficiency potentials, developing more realistic cost estimates, and developing roadmaps for the energy transition.

Michael Flaxman, *Founder and CEO, Geodesign Technologies*, presented on "Continuous Monitoring of Urban Dynamics Using Remote Sensing." He stated that Geodesign engages stakeholders in multicriteria decision making. Conventional remote sensing (RS) has made relatively modest contributions to the understanding of urban dynamics. There are some challenges on how to evaluate complex trade-offs, and visualizations and simulations can help when engaging stakeholders. He presented on some procedural tools for design that embed relevant science, an explicit model to consider multiple adaptation options, their consequences, and costs, and data visualization techniques. He discussed a case study in China that advanced a major initiative for addressing urban cities' challenges, particularly flooding.

Ziqian (Cecilia) Dong, Ph.D., *Associate Professor, Electrical and Computer Engineering, School of Engineering and Computing Sciences at NYIT,* presented on "Data Challenges and Real-Time Autonomous Sensing Systems." She discussed the challenges of current water quality monitoring methods and related datasets and introduced an autonomous real-time water quality monitoring system designed as an alternative to conventional monitoring systems. The system provides a more cost effective environmental data monitoring approach by integrating digital and mechanical sensor devices connected through various communication networks, both wired and wireless. Then, Dr. Dong presented a case study on data availability to measure water quality on Long Island and discussed some challenges on data availability for simulation and modeling and solutions to address them.

Andrew Parker, **Ph.D.**, *Researcher III, Mechanical Engineering, National Renewable Energy Lab,* presented on "Peña Station NEXT – Modeling a New Zero Energy Urban District." The NEXT project is a 400-acre site in Denver, Colorado. This project included a plan to build 100 buildings and 6M sq. ft. of space for commercial development. He commented that working with key project stakeholders from the outset ensured that solutions meet the practical limitations and concerns that are sometimes ignored in scientific research. Dr. Parker commented that NREL is partnering with Panasonic Corporation and Xcel Energy to simulate and optimize the energy load profile of the Peña Station NEXT. In the project, the team included the interested developer, NREL, and the Tenant & District Tech Company. He also commented that some scenarios were modelled with a lot of assumptions; the approach took the geometry of the buildings and made assumptions about construction practices based on code requirements for modeling. The project included analysis of current problems like overheating of electrical lines and under voltage situations. In summary, the main points of this analysis include reviewing the initial findings, including how building design influences electrical grid infrastructure, and distributed photovoltaic and energy storage.

Masoud, Ghandehari, Ph.D., *Associate Professor, Civil and Urban Engineering, Center for Urban Science and Progress, Tandon School of Engineering, New York University,* presented on "City Data and Maturity - Urban Informatics in New York City." His presentation focused on the maturity of the New York city data inventory. In an attempt to bring fidelity to aggregate data models, he noted three main challenges: (a) increasing the spatial granularity of information, (b) increasing the diversity of information, and (c) developing methodologies for data integration, adding that the methodology for integration is the backbone of these models. Some selected examples of city scenarios such as like flooding were presented, and Dr. Ghandehari showed that a time series analysis exhibits steady-state fluctuations. He discussed a methodology that allows one to observe the amount of methane gases released to the environment (due to maintenance and malfunction of refrigeration appliances). He also discussed data observed on city waste streams and discussed the challenges of obtaining such data. In closing remarks, Dr. Ghandehari discussed opportunities for correlative analysis with applications of value to urban health and infrastructure resilience.

In response to the presentations, **Brunilde Sansò, Ph.D**., highlighted the significance of leveraging sensors, energy data, and geographic information systems and other tools for energy efficiency and water quality monitoring and argued for the need to optimize the sensing and computational architecture of these systems. She then raised a number of questions and issues that need to be addressed and further researched, including:

- Data quality: is the data giving the right information?
- Data gathering: what are the best practices to obtain the right information?
- Data transformation: how do we transform the data so that it is useful?
- Data granularity: what level of detail is needed and how they depend on the level of analysis.
- Data diversity and integration of algorithms such as artificial intelligence for data interpretation.
- How to model and integrate green energy into systems.
- The means to incorporate geographical tools to improve modeling, resolution, and quality of data.
- Planning with energy efficiency in mind.

During the Q&A session, a few questions for Dr. Parker were raised on when he started to evaluate different scenarios of designs and the scalability of the proposed methods at large scale. Dr. Parker responded that "all the analysis depends on the developers. They figure out what type of property will sell, etc." Regarding scalability, Dr. Parker responded that it was necessary to make software user-friendly so it doesn't require lot of expertise to use, with built-in functions, and make it open source. Dr. Eicker commented that standardized workflows should also facilitate scaling existing methods for large scale adoption. She also raised the question on how one can extract sensor data and validate it with real data.

SESSION 6: WORKSHOP WRAP-UP: RESEARCH AGENDA, OPPORTUNITIES, AND NEXT STEPS

During the final session of the workshop, participants engaged in a discussion on a shared research agenda that supports active engagement and joint approaches to the optimal management of interrelated critical infrastructure systems in urban centers. The group explored areas of collaboration, funding opportunities, opportunities for working with municipalities and projects in-development, plans for obtaining data for further research and/or case studies, and taking next steps for engaging stakeholders.

Chair: Nada Marie Assaf-Anid, Ph.D., *Professor and Dean, School of Engineering and Computing Sciences, NYIT*

The workshop participants identified several issues that merit further research and/or agreement. They are organized below based on different thematic concerns.

Data Collection, Modeling, and Analytical Tools

Participants agreed that there is a need to continue developing broad, interdisciplinary frameworks that provide a common language to describe resource system attributes and to test the contexts and scales where particular theories and models provide useful insights. One challenge is to understand the research questions, methods, and challenges in other domains, as well as those associated with one's own research. Some participants suggested that it is important to start by aligning objectives in modeling infrastructure and data analysis and then look for common goals on different existing projects to identify the general and specific research interests.

Common challenges identified by researchers engaged in different projects, include:

- What are the existing protocols for integrating models from the various sectors in cities (energy, water, transport, food), as well as these systems' models, data, and results across disciplines without having to reinvent or remake them?
- What are the best techniques for deploying sensors efficiently and securely and the best practices for integrating IoT sensor networks' data with existing spatially extensive datasets and remote sensing while addressing security and privacy?
- What are the best tools and methods for disaggregating monolithic models using web services?
- How do we deal with uncertainty, data formatting, and calibration when modeling urban systems (e.g. energy systems, buildings energy models)?
- How can business models be derived, for example, from efficiency and renewable innovations?

Stakeholders / Decision Making Processes

Participants discussed how to use optimization as a tool to generate adequate information to support the (design) decision-making process of the complex FEW systems under consideration. Additional participants highlighted the importance of integrating "soft" infrastructure (people, institutions, culture, etc.) into these discussions of models that promote sustainable urban infrastructure. Others asked how to expand existing frameworks for the assessment of environmental sustainability of FEW systems to account for economic and social justice metrics. An important question is how to evaluate stakeholder engagement methods for FEW by and across sectors.

Some added that it is important to explore how modeling can support decision-making and lead to real change. Participants asked how data and corresponding models could reach policy makers and planners at a regional scale to inform symbiotic infrastructure development. One participant recalled the presentation on the Linderburgh, Germany case study, highlighting that integrating stakeholders to shape the analytical modeling helped to remove barriers for implementation later on (e.g. their Clean Energy implementation plan). In closing, many agreed that it is important to first define the indicators that decision-makers really want and need.

Research Dissemination

Several participants argued that there is a need to transfer our work and findings and promote the ideas of more sustainable development to the less developed world, where sustainability is not a priority or may be financially stressful.

Others asked about the best means to integrate outcomes from individual innovative projects, undertaking system integration meaningfully into these models. This would include the issue of how effectively to scale up from the granular to regional approach of modeling with respect to human behavior and decision-making. A key question is where and how long a model would apply, in particular under different contextual and socioeconomic conditions. Given the plethora of models available for practitioners (outside of academia), two significant issues are: (a) how do we effectively convey limitations of models, and (b) provide decision support (for models) so that researchers know when and what models to use? Participants also asked about the need to agree on the best practices to create incentives for data sharing with the academic community.

Research Gaps

Participants also identified several research gaps that should be addressed in order to advance research projects, including:

- How can we include social aspects into engineering curricular programs, to help address the UN Sustainable Development Goals?
- How can we enhance the security and trustworthiness of urban data obtained from both physical and crowd/human sensors?
- How can we make data available and understandable across disciplines in order to minimize losses across disciplines?
- How can detailed, granular modeling be combined with high level decision support models, and how do we validate these models?
- How do we ensure equity for a region, a city to a global scale, in the policy and decision-making process?

Potential Collaborations:

Participants discussed potential avenues for future collaboration. Some argued that the two most important areas on which the various teams should work together are defining systems integrations and problem-centered approaches to address a human need for optimal decision-making and defining how multiple data sources in urban areas can be harmonized (internationally).

A significant contribution would be to formulate appropriate system-of-systems optimization problems and use practical yet rigorous coordination methods to solve them. Some proposed to identify facilities that would benefit from an industrial ecology.

Several participants supported the idea of focusing the research and implementation work based on a number of “innovative cities” (or City as Lab projects) for joint urban district research and as active focal points for explicit cross-comparisons (New York, San Francisco, Miami, Stuttgart).

The participants also could leverage connections to eco-district networks (e.g., American Institute of Architects or additional practitioners) to scale up and strengthen the implementation potential and impact of these projects. Other linkages included the C40 research teams and other international sustainable city networks (e.g., in New York, San Francisco, Miami, Atlanta, Stuttgart, Vienna).

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APPENDIX

A. Workshop Agenda

Day 1: November 30, 2017

2 – 2:15 p.m.	**Welcome and Workshop Goals** Nada Marie Anid, Ph.D., Dean, School of Engineering and Computing Sciences, NYIT
2:15 – 3:45 p.m.	**Session 1: System-Based Approaches** This session will focus on systems-based and holistic approaches that provide pathways for the optimal management of urban critical infrastructure (ICI) systems for FEW supply. These approaches will lead to a fundamental understanding of interdependencies between urban infrastructure systems and help develop deeper understanding of the function and interaction of urban food distribution, water, waste, and energy, within cities subject to increased demands and under extreme conditions. Ming Xu, Ph.D., Associate Professor, and Director of China Programs, School of Environment & Sustainability, University of Michigan, Ann Arbor, MI Hillary Brown, FAIA, Professor, and Director, MS Program in Sustainability in the Urban Environment, Bernard and Anne Spitzer Sch. of Architecture, City College of New York, CUNY Osvaldo A. Broesicke, E.I.T, Graduate Research Associate, Brook Byers Institute for Sustainable Systems, Georgia Institute of Technology
3:45 – 4 p.m.	Break
4 – 5:30 p.m.	**Session 2: End-User Perspective: What Stakeholders Want to See** This session will focus on approaches and participatory models to co-produce knowledge on the key features and variability of urban critical infrastructure systems. Optimization of regional and local FEW systems that take into account their interdependencies may be accomplished via integration based on co-decision, which aims to simultaneously optimize multiple, interconnected systems. The session will include a discussion of tools to support stakeholders in visualizing and understanding the complex interdependencies and potential for synergistic co-benefits and coordinated decisions supporting integrated infrastructure systems. Newsha Ajami, Ph.D., Director, Urban Water Policy, Senior Research Associate, Stanford Woods Institute for the Environment John L. Lee, Deputy Director, Mayor's Office of Sustainability, New York City Government

	Jason Bregman, Associate, Environmental Planning and Design, Michael Singer Studio
5:30 – 6:15 p.m.	Networking Reception

Day 2: December 1, 2017

8 – 8:30 a.m.	Breakfast
8:30 – 10 a.m.	**Session 3: Models and Tools for Understanding the Evolution of Cities and Infrastructures** Presenters will review and lead a discussion of modeling frameworks that simulate the impacts of land use, climate change, and the decentralization of critical supply infrastructure in cities to help ensure adequate FEW distribution and storage. **Yimin Zhu, Ph.D.**, Professor, Pulte Homes Endowed Professor, Bert S. Turner Dept. of Construction Management, College of Engineering, Louisiana State University **Vatsal Bhatt, Ph.D.**, Senior Energy Policy Advisor, Brookhaven National Laboratory **Ali Mostafavi**, Assistant Professor, Texas A&M
10 – 10:15 a.m.	Break
10:15 – 11:45 a.m.	**Session 4a: Case Studies I: System Integration** Participants will discuss potential case studies in various cities to help identify key research questions, best management practices, and best points for optimal supply of resources within city boundaries, with an emphasis on those interventions that increase infrastructure linkages and close resource loops. Case studies to be discussed include: a) wastewater/microgrid integration projects; b) urban agriculture and food distribution networks; c) urban scale energy use and mapping; and d) low impact development. **Weslynne S. Ashton, Ph.D.**, Associate Professor, of Environmental Management and Sustainability, Stuart School of Business, Illinois Institute of Technology **Adam Hinge**, President, Sustainable Energy Partnerships, and Adj. Prof., Columbia University **Alfred Helble**, AH Consultant, CITYtrans, Stuttgart, Germany **William (Bill) Solecki**, Professor, Graduate Geography Advisor, and Founder Director, Emeritus, CUNY Institute for Sustainable Cities, CUNY

11:45 a.m. – 12:30 p.m. Lunch Session

12:30 – 2 p.m.

Session 4b: Case Studies II: Urban Districts – Energy
This session will focus on outlining the research agenda pathways for cities to strengthen energy usage and generation at the district level. Case studies will focus on microgrids, digital grids and urban energy models.

Roberto Rojas-Cessa, Ph.D., Professor, Electrical and Computer Engineering, Newark College of Engineering, New Jersey Institute of Technology

Ahmed Mohammed, Ph.D., Assistant Professor, Electrical Engineering, Grove School of Engineering, City College of New York, CUNY

Yixing Chen, Ph.D., Senior Scientific Engineering Associate, Lawrence Berkeley National Lab

2 – 2:15 p.m. Break

2:15 – 3:45 p.m.

Session 5: City Data and Urban Informatics
This session will focus on approaches for data collection (including sensor systems), correlation and analysis of urban data, data sources, repository structures, and application workflows. The discussion will attempt to identify the best approaches for the integration of heterogeneous data into models for real-time analytics and scenario exploration, as well as for monitoring and forecasting.

Ziqian (Cecilia) Dong, Ph.D., Associate Professor, Electrical & Computer Engineering, School of Engineering & Computing Sciences, NYIT

Ursula Eicker, Professor, University of Applied Sciences, HTF, Stuttgart, Germany

Michael Flaxman, Founder and CEO, Geodesign Technologies

Andrew Parker, Researcher III, Mechanical Engineering, National Renewable Energy Lab

Masoud Ghandehari, Ph.D., Associate Professor, Civil and Urban Engineering; Center for Urban Science and Progress, Tandon School of Engineering, New York University

3:45 – 4 p.m. Break

4 – 5:15 p.m.

Session 6: Workshop Wrap-Up: Research Agenda, Opportunities, and Next Steps
During the final session of the workshop, participants will elaborate a shared research agenda that supports active engagement and joint approaches to the optimal management of interrelated critical infrastructural system in urban centers. We will review funding opportunities, opportunities for working with municipalities and projects in-development, plans for obtaining data for further research and/or case studies, and next steps for engaging stakeholders.

B. Workshop Participants

Newsha Ajami, Ph.D., Director, Urban Water Policy, Senior Research Associate, Stanford Woods Institute for the Environment

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Vatsal Bhatt, Ph.D., Senior Energy Policy Advisor, Brookhaven National Laboratory

Honey Berk, Managing Director, Building Performance Lab, CUNY

Michael Bobker, Executive Director of the CUNY Building Performance Lab and Associate Director of the CUNY Institute for Urban Systems

Jason Bregman, Associate, Environmental Planning and Design, Michael Singer Studio

Osvaldo A. Broesicke, Graduate Research Associate, Brook Byers Institute for Sustainable Systems, Georgia Institute of Technology

Hillary Brown, FAIA, Professor and Director, MS Program in Sustainability in the Urban Environment, Bernard and Anne Spitzer School of Architecture, City College of New York, CUNY

Selina Wenbo Cai, Ph.D., Assistant Professor, Mechanical and Industrial Engineering, NJIT

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Howei Cao, Ph.D., Assistant Professor, Computer Science, School of Engineering and Computing Sciences, NYIT

Roberto Rojas-Cessa, Ph.D., Professor, Electrical and Computer Engineering, Newark College of Engineering, New Jersey Institute of Technology (NJIT)

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