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A workshop on transitioning cities at the food-energy-water nexus

Lara J. Treemore-Spears[1] · J. Morgan Grove[2] · Craig K. Harris[3] · Lawrence D. Lemke[4] · Carol J. Miller[5] · Kami Pothukuchi[6] · Yifan Zhang[7] · Yongli L. Zhang[8]

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Abstract Metropolitan development in the USA has historically relied on systems of centralized infrastructure that assume a population density and level of economic activity that has not been consistently sustained in post-industrial urban landscapes. In many cities, this has resulted in dependence on systems that are environmentally, economically, and socially unsustainable. Reliance on this deteriorating social and physical infrastructure results in waste and decreased efficiencies. While numerous cities could exemplify this trend, the present work highlights two compelling cases: Detroit, Michigan and Baltimore, Maryland. The paper provides important feedback from a recent workshop held with experts of both practical and academic backgrounds from both cities. The workshop focused on sustainability of the food-energy-water nexus within the context of transitioning urban landscapes, economies, and governance processes associated with post-industrial cities. The pursuit of environmental, economic, and social sustainability—especially in relation to food, energy, and water—is particularly challenging in aged and deteriorating post-industrial urban settings, and the importance of such cities to the global economy demands that attention be focused on research and education to support this mission. Given their age, geographic locations, and complex social-ecological histories, the examination and comparison of the cities of Detroit and Baltimore in the workshop described here provided a unique opportunity for evaluation of research, education and outreach needs, and opportunities in food, energy, and water (FEW) sustainability.

Keywords Urban vacant land transformation · Environmental justice · Sustainability · Food-energy-water nexus

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✉ Lara J. Treemore-Spears
treemorespears@wayne.edu

[1] Healthy Urban Waters Program, Wayne State University, 5050 Anthony Wayne Drive, 2157 Engineering, Detroit, MI 48202, USA

[2] United States Department of Agriculture Forest Service, Northern Research Station, Baltimore, MD, USA

[3] Department of Sociology, Michigan State University, East Lansing, MI, USA

[4] Department of Geology and Environmental Science Program, Wayne State University, Detroit, MI, USA

[5] Civil and Environmental Engineering, Wayne State University, Detroit, MI, USA

[6] Department of Urban Studies and Planning, Wayne State University, Detroit, MI, USA

[7] Department of Nutrition and Food Science, Wayne State University, Detroit, MI, USA

[8] Department of Civil and Environmental Engineering, Wayne State University, Detroit, MI, USA

Background

In an attempt to identify pathways to sustainability in food, energy, and water systems in deteriorating post-industrial urban settings, a group from the Detroit and Baltimore metropolitan regions proposed a workshop to the National Science Foundation that resulted in the effort described in this paper (NSF Award Number 1541869). Given their age, geographical locations, and complex social-ecological histories, the cities of Detroit and Baltimore provided the workshop context, with specific examination and comparison of their research, education and outreach needs, and opportunities in food, energy,

and water (FEW) sustainability. Workshop design and participation is described in the "Workshop design" section.

Dramatic shifts in population and economies in Detroit and Baltimore have resulted in substantial social change and enormous deteriorating physical infrastructure, with Detroit's population in 2010 less than half of what it was in 1960 and Baltimore's population reduced by a third. The sustainability of current physical infrastructure is in question because it was designed for substantially more residents, much more robust industrial usage, and the resulting larger tax base that could be counted on to support this system in the past. The shrinking inner-city tax base has been problematic for maintaining social services, contributing to the abandonment of the urban core and other unsustainable social changes. In Detroit, 20 to 40 mi^2 of land were estimated to be vacant in 2010 (14 to 30 % of the total land area depending on how it is measured), an area larger than many small cities—the lower estimate from Detroit Future City 2012, consistent with average city land vacancy estimates from the Brookings Institution (Pagano and Bowman 2000), and the higher estimate from Gallagher 2010. This area consisted of 150,000 vacant properties, of which 2/3 were land and the rest contained buildings (Detroit Future City 2012). The Baltimore Office of Sustainability estimated 14,000 vacant lots and 16,000 abandoned houses in 2013 (City of Baltimore 2015), representing about 2 % of the land area (Pagano and Bowman 2000). This population shift presents both challenges and opportunities for innovations in sustainability. Key relevant and contrasting features of these two cities include the following: remaining construction density (high: Baltimore; low: Detroit), housing construction type (brick: Baltimore; frame: Detroit), recycling availability (high: Baltimore; low: Detroit), vacant land area (low: Baltimore; high: Detroit), watershed (Chesapeake Bay: Baltimore; Lake Erie: Detroit), and city governance structure relating to these topics.

Efforts toward sustainability often focus on the efficiency of individual processes or singular entities such as an electrical grid, a sewer system, an individual building, or an educational system. In contrast, this workshop sought to discuss applied integrative systems-wide approaches addressing the relationships between food, energy and water sustainability practices. For example, projects were examined that recapture waste food and water both to support urban food production and to reduce energy demands for water treatment and waste transport. As urban areas examine how to be more sustainable at a city-wide and regional scale, they are evaluating and pursuing possibilities for more efficient use of energy and other resources, and new designs for future flexible, efficient communities that integrate a more diverse set of urban services and values. By addressing these and other fundamental needs, there is hope that optimizing sustainability at a larger community or global level will extend beyond individual sustainable buildings, gardens, open spaces, and systems. This interest in and need to improve urban sustainability at the food-energy-water nexus has the potential to inform and guide the most effective additional research and education efforts.

Beyond their industrial heritages and waterfront locations, Detroit and Baltimore share important similarities in infrastructure, emerging land-use trends, and social structures that shape their food, energy, and water sustainability efforts. For example, both cities have large drinking water service utilities: the Detroit Water and Sewage Department (DWSD) serves 4 million people over a service area of 1079 mi^2 with an average daily water use of 610 million gallons; the Baltimore Department of Public Works serves 1.8 million people over a service area of 560 mi^2 with a daily average consumption of 225 million gallons. Within their drinking water distribution systems, Baltimore has significantly greater storage, while DWSD relies almost exclusively on "on-demand pumping." Waste water removal in both Detroit and Baltimore also requires pumping, with associated energy demand. For water disposal, DWSD serves a 946-mi^2 area utilizing a combined sewer overflow (CSO) system with capacity to treat stormwater runoff from small rainfall events while allowing both waste water and stormwater to overflow into surface waters during large events, with its waste water facility treating an average of 710 million gallons per day (DWSD 2003; 2014); Baltimore has a municipal separate storm sewer system (MS4), which discharges stormwater into local waterbodies via its own system while an average of 250 million gallons per day of wastewater is handled and treated separately (Baltimore City 2006). Both cities have faced challenges as flood water has overwhelmed city infrastructure, with the Detroit metropolitan area receiving more than $240 million in federal disaster assistance from the Federal Emergency Management Agency (FEMA) from a single large storm in August 2014, and Baltimore County receiving FEMA disaster recovery funding following Hurricane Sandy in 2012.

In addition, like many contemporary urban areas, Baltimore and Detroit employ redevelopment strategies designed to achieve an urban land-use mix combining housing with commercial, cultural, and recreational spaces typifying urban development trends emerging in the 1980s (Gospodini 2006). The more recent and related process of transitioning vacant land into urban gardens, green/blue infrastructure, and farms for agricultural production is challenged, however, by a history of segregation and abandonment, predominantly by white middle- and upper-class households, which has resulted in persistent racial tensions between outlying metropolitan areas and impoverished urban centers. Moreover, separate economic and social opportunities for people of different races in their respective regions, coupled with an overall lack of opportunity and high social service needs in the urban core complicate efforts to form effective partnerships and governance structures to address issues of environmental justice and

social equity. These challenges sometimes inhibit implementation of sustainable solutions at the food-energy-water nexus in Baltimore and Detroit, but positive examples of collaborative progress also exist.

These variations and similarities provide multiple opportunities for demonstrating alternative practices for food, energy, and water systems in urban centers that are transitioning from a heavily industrial past to a sustainable future. In addition, as theoretical frameworks for this movement toward sustainable cities are refined (Bizikova et al. 2013; Newell and Cousins 2015), they must ultimately be tested and evaluated through the actions of practitioners such as those who attended this workshop. The practitioner insights generated during the 2-day workshop described in this paper identify gaps between knowledge and practice that may be useful to guide further inquiry and outreach.

Fig. 1 FEW nexus logo for 2015 workshop in Detroit

Workshop design

The workshop was designed to bring together academics and practitioners from Detroit and Baltimore to collaborate around challenges for food, energy, and water sustainability in post-industrial urban areas and was held on October 14–16, 2015, at Wayne State University in Detroit. The goal of the workshop was to discuss and envision integrative solutions that foster safer, more secure, and more efficient use of resources within the food-energy-water nexus. The workshop organizing group was multidisciplinary and included six faculty from Wayne State University (WSU) in the departments of Civil and Environmental Engineering, Geology, Nutrition and Food Science, Urban Studies and Planning, and Political Science; a scientist and team leader from the United States Department of Agriculture Forest Service Northern Research Station Urban Field Station in Baltimore (USDA); and two WSU staff for the Urban Watershed Environmental Research Group (UWERG) funded by the Erb Family Foundation. Two group planning meetings provided the workshop outline, followed by speaker and discussion-leader scheduling and discussion session design. Conference calls between discussion session leaders brought the team together just prior to workshop implementation, to refine discussion session design. Guiding workshop principles—including the workshop agenda and graphic representation of the food-energy-water nexus shown in Fig. 1—were distributed a month in advance of the workshop to prepare participants for the discussions.

During the workshop, short presentations of 10 to 45 min each by practitioners from both Baltimore and Detroit provided context for all participants, interspersed with discussion sessions that fostered integrative brainstorming and synthesis. Meals and tours of FEW-related destinations in Detroit provided additional opportunity for discussion and networking. Speakers, discussion leaders, and participants included representatives of non-profit community organizations, city and state government, utility operators, and industry (66 % of participants), and the remainder were university faculty and graduate students.

Discussion sessions were designed to foster interdisciplinary collaboration between both academics and practitioners. Participants were distributed across four simultaneous discussion groups, and a balance of people with complementary disciplinary experience and social familiarity with each other were placed in each group. Participants stayed in their same discussion groups to maintain continuity across the 2 days. Because of the diversity of representation across the 60 people who attended at least one of the sessions, an attempt was made to place each person in a group that had at least one person with whom they were already familiar, but to avoid placing many people from a single discipline or organization in the same group.

Discussion progressed from the pressing challenges for FEW sustainability in urban areas to the actions being taken, documenting interactions at the FEW nexus and information gaps that exist. Synthesis of these discussion topics identified what is working and what is not, with explanations for both the problems and successes, and identification of the top ideas for additional work. After synthesis of these ideas in small groups, the members of the entire large group were provided with four "sticky dots" to vote on the most important ideas for additional development. The small groups then reconvened to summarize the preferred "pathways to action" and identified needs for additional research and improved processes.

Workshop products and key emergent themes

The themes identified in the workshop presentations and throughout the small and large group discussions culminated in four unifying concepts—partnerships and governance

structures, racial justice, integrative metrics, and land transformation. These concepts provide the outline for the summary in this section of key challenges, opportunities, preferred pathways, successes, and needs for improved sustainability of food, energy, and water systems in urban areas. This summary is based on workshop discussions and includes themes and examples generated by participants throughout the workshop, with a limited amount of supporting literature review.

Partnerships and governance structures

The disconnects between stakeholders and between the institutions and organizations that represent them are central contributors to unsustainable activity. Water, energy, and food systems can be in conflict within governmental structures, between the city center and outlying areas, between utility providers and utility users, and between many of the other societal divisions that co-exist in post-industrial cities. At the same time, resources such as air, water, energy, and biota readily cross socio-political boundaries, as does soil and water contamination and the responsibility for energy and water infrastructure.

Partnerships at the FEW nexus in urban areas must address these shared resources and challenges in the context of climate change, urban food insecurity, and health problems because of the influence of these challenges on FEW sustainability and the societal and environmental costs of failing to address them. Successful partnerships as identified in the workshop are defined by sustained and deliberate actions that "meet people where they are;" obtaining stakeholder representation and buy-in around collaboratively developed goals, strategies, and actions and timely feedback. This process requires translating scientific language and concepts to achieve urban relevance, articulating stakeholder group interests, resolving past distrust and misperceptions among groups, balancing demands for immediate action with strategies for long-term effectiveness, and developing adequate capacity and strength for long-term governance. The preferred pathways for forming, utilizing, and sustaining effective partnerships at the FEW nexus are illustrated by the following examples provided by workshop participants.

Generating local interest in sustainable food-energy-water technologies and building capacity for the use of those technologies is happening at universities through hands-on multidisciplinary applied learning projects that interact with the surrounding community. For example, in the Detroit metropolitan area, Oakland University's Campus Student Organic Farm creates a living laboratory for community and student outreach on sustainable living in the urban context. Connections to numerous interdisciplinary educational programs foster applied STEM learning on solar and wind power, storm water management, organic waste recycling, human health and nutrition, and the economics of small-scale sustainable agricultural production. Students gain direct experience managing parts of the urban FEW nexus, including solar power for a 30-by-96-ft hoop house, food waste recapture for soil fertility restoration, and stormwater recapture to reduce dependence on energy-intensive municipal water supplies for watering plants. Key factors in partnership effectiveness have been consensus-building around community needs, active and ongoing partner engagement, and incremental implementation to build success and support gradually.

University Programs are complementing this hands-on food-energy-water technology training with the examination of different social structures that both challenge and support the use of these advances. Since 2008, SEED Wayne, a campus-community collaborative organized around sustainable food systems, has engaged Wayne State students as leaders in urban agriculture, fresh food retail and entrepreneurship, community nutrition advocacy, and food policy and planning (http://clas.wayne.edu/seedwayne/). Training in collaboration among campus academic and operations units as well as with community organizations and businesses happens both on campus and out in the community. Educational activities include student-led workshops, engaged learning in projects designed and implemented by students, action research by individual or small groups of students, field trips to food and agricultural sites, and supervised class team projects in a variety of departments (such as Anthropology, Urban Planning, and Social Marketing). Partnerships with local urban food-related businesses inform students about the challenges to earning a profit that may be met by water and energy efficiency, food waste recapture, and soil renewal practices. Non-governmental organization and government partners inform students about policy innovations to make healthy food more affordable and accessible to food-insecure neighborhoods. Reciprocally, research and innovative practices envisioned by students inform practitioners about ideas on the forefront of the FEW nexus (Pothukuchi 2015a, b; Pothukuchi and Molnar 2015).

As partnerships evolve through the process of building stakeholder relationships and trust, needs are sometimes defined that can be addressed only through collaborative effort. In the case of academic and community partnerships, the need for applied studies can be identified by community members, and the physical and social resources and environment provided by the community create the unique opportunity for that work. For example, there is an ongoing USDA-funded project involving both WSU and Oakland University addressing food safety and sustainability in Detroit urban agriculture. The project is a collaborative effort between academia and community partners and aims to identify physical, chemical, and biological contamination in soils and vegetables in urban agricultural production (Ravansari et al. 2015). By studying the legacy impacts of unsustainable energy production and other

processes on urban soils and integrating this knowledge into urban university and public school curricula on urban food production, this academic/community partnership is directly addressing community needs for scientifically informed approaches to FEW sustainability.

Other partnerships may be financially driven but can be sustained through shared values and mutual benefits. The increase in community land trust engagement in vacant land redevelopment in Baltimore is creating greener and more communally managed spaces that contribute to neighborhood food security, stormwater treatment, and urban heat and pollution mitigation (Chen 2015; Baltimore Green Space http://baltimoregreenspace.org/; Sherman 2015). This innovative pairing of affordable housing with community open space supported by land trusts has a unique opportunity for success in places where land is relatively inexpensive, and community resources for redevelopment are limited.

A growing number of partnerships between regional, city, and neighborhood non-profit organizations have created robust community connections that support innovation at the FEW nexus. These partnerships are effective because of their pooled resources, multidisciplinary collaboration, consensus-building processes, partner representation, expanded capacity, and accountability. In one example, Michigan Community Resources teamed with Keep Growing Detroit and various community development organizations to develop models for economically sustainable vacant lot transformation by community groups that were practical and had low barriers to entry (MCR 2015). The flexible model utilized for this partnership allowed initial ideas to evolve from "urban food garden" to "grow flowers instead of food" in order to serve the expressed community need for a cash crop that required low maintenance and inputs, and address concerns about soil contamination. It is important to keep this level of flexibility and responsiveness in mind when nurturing partnerships, understanding that one of the broader goals is a sustainable relationship rather than a specific food, energy, or water outcome.

Environmental justice and social equity

Racial inequity is a pivotal source of conflict between people that must be addressed in order for sustainability work in legacy cities to be successful. As a result of decades of land-use transition in and around urban centers, poverty and lack of economic opportunity is concentrated in minority neighborhoods: spatial racism (Lord and Norquist 2010). This economic and racial segregation occurs consistently in many cities across the USA, including Detroit and Baltimore. Such inequity perpetuates conflict that interferes with the development of sustainable collaborative regional partnerships. Inequity also fuels unsustainable social, economic, and political systems, exemplified by water rate structures and a property tax foreclosure system in Detroit that place excessive burden on impoverished citizens. For example, in Baltimore, minority borrowers were steered into subprime mortgages during the housing boom, which affected the high rates of foreclosure in urban neighborhoods and corresponding neighborhood instability, harming individuals and the city as a whole (Broadwater 2012). The challenges faced as a result of these patterns are a strong undercurrent throughout all systems in these transitioning urban areas, including those systems relating to food, energy, and water.

Racial justice is therefore essential for the success of sustainable food, energy, and water systems in urban areas. Changes to address justice and racial inequity in these systems are being developed in Detroit, Baltimore and other cities, as exemplified by the following collaborative projects discussed at the workshop. While each of the highlighted programs may be addressing only one or two components of the food-energy-water nexus, the practitioners who are engaged with program design and implementation are often working across all nexus areas, and system-wide thinking about sustainability drives each of these programs forward.

Alternative policies and systems for equitable and socially sustainable funding of food, energy, and water are important because of the economic disparities that currently drive existing social inequities. Examples of institutionally implemented systems that are being developed include "Water Affordability" rate structures based on ability to pay, which are being investigated and incrementally implemented by entities such as the Water Revenue Bureau of the City of Philadelphia. This is projected to result in higher total revenues than in "single rate" systems (Colton 2005), creating more sustainable funding and reversing social inequity. The Fresh Food Share Program, a collaborative of several organizations including Eastern Market and Gleaners Community Food Bank in Detroit, has created analogous food pricing structures that provide bulk purchase and subsidized pricing for low-income individuals, while also allowing higher prices to be charged to people with the means to pay for them (http://ffs.tdmonster.net/). Similarly, the urban-farmers-market-based Double Up Food Bucks program matches food stamp program benefits to increase consumption of locally produced fresh produce by low-income households, while simultaneously supporting local agriculture. This program creates social value for urban growers who want to be relevant to the city's food security needs by selling to low-income inner-city residents without being forced to find markets in wealthier communities in order to make a living (http://www.doubleupfoodbucks.org/).

While examples of socially equitable energy pricing were more difficult to identify, methods for consumers to select greener and more efficient power sources from the grid are being developed and tested (Harris et al. 2015; Wang, Wang

et al. 2014). Demand-side systems such as these for influencing pollutant emissions from power generation have the unique capability of providing direct feedback from the public to the utilities about their preference for sustainable and environmentally just sources of power. This is particularly important feedback for underrepresented groups in urban areas to be able to provide, given the concentration of high-pollution-producing industries and power plants in their neighborhoods and the real or perceived burden on their health that results (Hultin et al. 2010; Schwartz and Morris 1995; Wilson et al. 2005).

Also on the individual and neighborhood level, community empowerment to take action toward energy and water conservation is as much about equity as sustainability. To support these individual and community actions, the non-profit organization EcoWorks in Detroit trains individuals to reduce energy use, engages youth in service learning, empowers neighborhood sustainability initiatives, and creates jobs through reclaiming building materials (http://www.ecoworksdetroit.org/). Deconstructing buildings—instead of demolishing them—is being done also in Baltimore at Humanim, which cites as benefits of this practice: the creation of up to 8 times more jobs per project than demolition, reduced greenhouse gas emissions and groundwater pollution by diverting waste from landfills, reduced transportation energy cost by using local-source reclaimed materials, and economic benefits by using lower cost and in some cases higher-quality reclaimed materials (http://www.humanim.com/). Similar to EcoWorks, the Baltimore Energy Challenge, a successful peer-to-peer network, teaches low-to-no-cost ways to save energy to residents, businesses, and non-profits through a grassroots effort in neighborhoods and schools (https://www.baltimoreenergychallenge.org/). The City of Baltimore is addressing the energy needs of low-income residents through a coordinated approach that aligns community partners, energy assistance and efficiency grants and low-interest loans, tree plantings, and education programs through Baltimore City's Office of Sustainability. Because programs start at the individual and neighborhood level, are supported by city and state resources, and are guided by a philosophy of empowerment and community development, these programs help resolve social justice issues while promoting sustainability. As communities develop their own process of thinking about and realizing the benefits of sustainable action in one area of the FEW nexus, such as energy and water conservation, community leaders are seeing that other areas like rainwater recapture and urban gardening naturally become more intuitive and acceptable in these communities.

Techniques for uniting decision-makers and community members to improve environmental justice and social equity are being actively applied in Baltimore. As an example, Deep Blue—an innovative public-private partnership initiated in October 2015—engages five neighborhoods representing a diverse mix of under-served communities to comprehensively address stormwater, greening, and targeted public health goals through collaborative listening, planning, and implementation. The program uses an effective community-based approach that breaks the cycle of planning fatigue through the development of both immediate and longer term solutions (http://www.bluewaterbaltimore.org/blog/deep-blue/). Access to healthy food in urban centers also has become a priority for intervention in Baltimore, where the city-run Neighborhood Food Advocates Program facilitates education and training, leadership development, and community organizing projects with residents in food insecure neighborhoods. Through this program, middle school students are trained about healthy food choices and are partnered with corner stores to conduct outreach through art and media, and the Virtual Supermarket program supports three site-based grocery delivery locations in neighborhoods with limited access to fresh and healthy foods (http://www.baltimarket.org/), engaging residents in issues of food security and sustainability by providing them with services that increase their access. Career development programs are another important way in which decision-makers work to correct social inequity by creating tangible opportunities at the FEW nexus. For example, the Baltimore Center for Green Careers, a non-profit job training program, is expanding to include solar power technology training with the promise to provide full-time jobs to low-income residents who graduate. Since 2009, 91 % of their graduates have been placed into full-time employment, earning between $12 and $20 per hour, higher than the city's living wage of $11.46 per hour (Baltimore Brew 2014). These programs all exemplify how decision-makers and innovative programming can advance sustainability in food, energy, and water systems while restoring environmental justice.

Another approach to improving equity involves alternative dispute resolution to directly address racial and other conflicts that threaten access to food and other resources. Examples in Detroit include mediation between food store owners and customers—who often represent different races and ethnic groups—to develop mutually agreed-upon behavioral norms and values that support continued store operations. Emphasizing community interdependence and the importance of personal responsibility and commitment to maintaining relationships—utilizing "harmony framework" mediation practices—has maintained food access in neighborhoods that were at risk of store closure. Conflict resolution strategies such as stakeholder negotiations, mediation, inter-cultural dialogue, and interest-based bargaining that have been effectively employed for land use and other environmental challenges are being taught to university students at WSU in the Environmental Studies and Peace and Conflict Studies programs and adapted for social justice disputes. The model for neighborhood conflict resolution provided by the Community Conferencing Center develops similar skill sets in Baltimore (http://www.communityconferencing.org/). Analogous

approaches are likely to be helpful in resolving culturally based differences about urban innovations at the FEW nexus such as natural landscaping for stormwater treatment, neighborhood solar and wind power installations, and waste stream recapture.

Shared public gathering spaces designed and maintained at the neighborhood level to bring people together are essential components of creating social equity, and these spaces can also support innovative food, energy, and water projects. Food gardens and markets have the benefit of satisfying basic human needs while connecting people of different ages, classes, and races around hands-on experiences using the culturally uniting concept of food. Projects that invite community discussion and consensus about needs prior to implementation—such as the Earthworks Urban Farm, Brightmoor Community Garden, Growtown, Penrose Market Garden and Lafayette Greens projects, and the Michigan Community Resources vacant land adaptive re-use planning process in Detroit—and then proceed to create social communities during their implementation and maintenance have the greatest potential for sustainability. The connections of K-12 schools to each other in both affluent and disadvantaged neighborhoods and to hands-on community spaces—such as through the Green Schools programs offered by the Baltimore Office of Sustainability and Maryland Association for Environmental and Outdoor Education, exemplified by Great Kids Farms and Real Food Farm—have a positive physical and social impact on their immediate community and on bridging the gaps between communities.

Integrative metrics

Legacy problems in post-industrial urban areas such as land and water pollution, infrastructure deterioration, and food insecurity—along with complex global problems such as climate change and human population shifts—all challenge the use of conventional metrics when viewed from the perspective of the food-energy-water nexus and related governance needs. Effective decision-making to address these issues requires scientific understanding of the factors affecting food, energy, and water sustainability. Such an understanding inherently rests upon the ability to measure interrelationships among natural, engineered and societal components. The Baltimore Ecosystem Study (BES) was discussed during the workshop as providing a framework for understanding biophysical, social, and built components of the urban ecosystem. By evaluating patch dynamics, watersheds, and humans as one of the resource bases of the system, new understanding of how to increase urban sustainability at the FEW nexus is emerging. Concepts of urban regionalism where city dwellers have access to and responsibility for the resources on which they depend are key to this understanding (Pickett and Cadenasso 2006). Watersheds, floodplains, connecting corridors, green buffers, green stormwater management infrastructure, and parks are particular areas of study for FEW-related BES human ecosystem research (Grove et al. 2015).

In addition, the need for sustainable practices applied across multiple disciplines requires new methods of collaborative study, evaluation and implementation, and related institutional re-alignment of disciplinary thinking. For example, urban landscapes in transition present specific opportunities to implement alternative redevelopment strategies aimed at enhancing FEW system stability. Methods and metrics are therefore needed to measure and determine the outcomes and benefits of proposed or selected programs and to compare and contrast results from an array of different models of greening. Moreover, it is essential to understand how these outcomes relate to one another and to describe and quantify the scale of their impacts.

The rapid innovation of systems at the FEW nexus demands innovation in metrics relating to food security, water and energy footprints and security, economics, transportation, environmental impact, urban ecology, human health, climate change, and social impact, among others. Conventionally designed processes and systems fall short of optimizing sustainability across these fronts because they are largely based on compartmentalized science and employ metrics that focus predominantly on individual aspects of food, energy, or water systems (e.g., increased food production, reduced energy usage, or reduced water utilization). Comparative analyses of social networks and physical resources that support sustainable activities may be a promising integrative approach for the development of new metrics across systems (Romolini et al. 2013).

Although significant advances have been made in areas such as systems analysis (Blanchard and Fabrycky 1990; Whitten et al. 1997; Walker et al. 2014) and life cycle assessment (Guinée 2002; Finnveden et al. 2009), additional progress is hampered by a deficiency of metrics that effectively bridge integrated systems across the FEW nexus. In addition to being SMART (specific, measurable, achievable, relevant, and timely), new integrative metrics must be capable of measuring interrelated FEW system components using cross-cutting measures (e.g., measuring food in water units, and water in energy units). Such metrics will require new methods to commensurate costs and benefits of processes and activities spanning the FEW nexus. Metrics to evaluate progress in addressing economic inequities and social injustice will also be essential for measuring social change relating to sustainability (UN-HABITAT 2014; http://unhabitat.org/urban-initiatives/initiatives-programmes/city-prosperity-initiative/).

Other examples of effective metric development and use discussed during the workshop include Data Driven Detroit (D3), a Low-Profit Limited Liability Company that is building advanced and continuously updated data collection and

management systems to track neighborhood conditions in cities (http://datadrivendetroit.org/). Data sets are combined, synthesized, analyzed, and presented on interactive platforms using maps and infographics to provide easy access to essential information. For example, the D3 Motor City Mapping Project engages citizens in collecting data on properties to help define the scope and challenge of blight in Detroit. These data support a dialogue about property and engage people in the process of generating a living dataset and inform a comprehensive blight elimination plan authored by the Detroit Blight Removal Task Force and supported by the public. Ongoing citizen interaction with this scientific data collection tool has social resonance because of its community impact. The maps created by such efforts integrate visual metrics that capture and relate property variables relevant to urban food, energy, and water systems geospatially and over time.

Community stakeholder engagement in metric development during project design also has substantial benefits because local knowledge and neighborhood support may both be keys to project success. For example, the Detroit Water and Sewerage Department and Detroit Land Bank Authority involved scientists and the public during the design and implementation of innovative vacant land transformations when planning for the demolition of vacant housing in 2013 (Nassauer et al. 2015). By refining citizen engagement approaches and forging new relationships between city departments and between policy-makers and academia, green infrastructure was installed with a study plan in place for evaluating stormwater quality, hydrology, toxicology, and social benefits. In addition, the project design benefited from residents' understanding of neighborhood flooding problems, perceptions of potential plantings, and concerns about how the project could benefit or harm their personal well-being.

Use of metrics in decision-making was highlighted during the workshop, such as in planning and implementation processes in Baltimore that are based on data and community input, and designed with feedback loops after sustainability practices are incorporated into government operations to inform future plan modifications. Initial food, energy, and water systems analysis provides detailed mapping of system structure and relationships to inform the development of strategies, actions, and priorities. The Baltimore Neighborhood Indicators Alliance transforms this information into reliable and actionable quality of life indicators that are integrated into resources and tools to make the data accessible to the public (http://bniajfi.org/). Furthermore, the City of Baltimore Sustainability Commission's Genuine Progress Indicators (GPI) quantify economic well-being based on benefits received from the availability of goods, services, and social and community assets, along with social and economic costs that are often hidden from view including environmental degradation, homelessness, poverty, and crime. Baltimore's GPI are being used to quantify benefits associated with major policy changes such as those related to climate action, stormwater, and living wages (http://sustainable-economy.org/solutions/baltimore-genuine-progress-indicator/). In addition, the STAR Community Rating System (Sustainable Tools for Assessing and Rating) used in Baltimore is built on an integrated framework of sustainability goals, objectives, and evaluation measures. Overall, STAR certification is an integrated measure of sustainability at the community level that also includes specific metrics for success over time, helping communities identify gaps, and prioritize investment. Since STAR's release in 2012, approximately 40 communities including Baltimore have attained STAR certification (http://www.starcommunities.org/). This integration of measurements positions decision-makers to understand both the complex inter-relationships in urban systems and the progress that is being made toward meeting challenges for urban food, energy, and water sustainability.

The development of integrative metrics to support effective innovations at the food-energy-water nexus will benefit from the effective engagement of scientists and all relevant stakeholder groups during the design and implementation of applied projects, and ongoing dialogue between scientists, policy-makers, non-profits, community organizations, and citizens to ensure that the science will connect with societal needs at various timeframes, scales, and locations. Versatile, transparent, and complementary metrics are needed to inform multidisciplinary approaches. Indeed, multiple metrics will be needed to identify the impact of individual program implementation components.

Land transformation

The legacy of post-industrial urban land use has created immense challenges as well as opportunities for sustainable redevelopment and maintenance of cities and their infrastructure. A common issue encountered in these transitioning urban centers is the fragmented nature of the remaining neighborhoods. This fragmentation in Detroit was evaluated in 2009 by Data Driven Detroit and reported in interactive reports on its web site, which found 27 % of Detroit's 343,849 residential parcels to be vacant, with vacancy rates greater than 50 % in substantial portions of the City. Two-thirds of these vacant residential parcels were free from structures, but the interspersed occupied parcels, together with varied ownership by multiple foreclosing entities, have complicated the redevelopment process. Gradual administrative changes by city, county, and state government are moving Detroit toward an ability to capitalize on opportunities for consolidated land use change that encourage sustainable systems at the urban FEW nexus. Baltimore during this time period had more vacant structures than vacant land, but their streamlined code enforcement

processes and partnership strategies resulted in more efficient neighborhood stabilization through programs such as Vacants to Value (http://www.vacantstovalue.org/Default.aspx). Centralized supporting governmental and non-governmental systems also fostered coordinated "green" land transformations, as discussed in this section.

The workshop examined many potential alternative uses for vacant land spaces that could result in greater food, energy, and water sustainability. These included energy development and storage, community gardens and higher-tech vertical gardening, green infrastructure such as tree plantings for cooling buildings or generation of biofuels, and native landscaping for stormwater treatment and flood control. Assistance to governments in planning for such repurposed land use comes from a variety of sources, including philanthropic foundations, commercial and industry partners, non-governmental organizations, academia, and community block clubs. For example, the non-profit group Detroit Future City developed the Field Guide for Vacant Lots as a tool kit to assist in on-the-ground lot transformation. This online resource provides step-by-step instructions to support neighborhoods in the transformation of vacant land to safer, cleaner, and more productive use (Detroit Future City 2015). Baltimore City's Growing Green Initiative is transforming vacant land in partnership with residents, neighborhoods, non-profits, and developers to reduce stormwater runoff, grow food, and create community spaces that promote greater urban sustainability. The city's Green Pattern Book (City of Baltimore 2015) is a tool for fostering these partnerships. The combination of land and buildings that could be repurposed, a culture of urban entrepreneurship, creative partnerships at the grassroots, and a growing vision for urban reinvention are together creating new opportunities for the implementation of innovative sustainable land transformation in post-industrial cities.

In locations where major land-use change is ongoing, temporary measures with known limited lifespans (e.g., solar panels) and collaborative pilot projects (e.g., "safe to fail" test solutions) may serve a valuable role in a transition toward sustainability. Financial incentives for these temporary measures should acknowledge their vital role, while also serving a balance between short medium- and long-term objectives. Comprehensive planning that includes effective community and stakeholder input and support, informed by social science and analysis of physical systems, is essential for developing these objectives and communicating about the preferred pathways for FEW sustainability. Monitoring, evaluating, and scaling-up after implementation of pilot projects is also essential for long-term durable change.

Identifying new ways to use urban land that reduce energy and water requirements for food production, distribution and waste management is essential for FEW sustainability. Adaptation of existing technology and practices to somewhat more sustainable approaches has been a logical first step at many points of interaction in the urban food-energy-water nexus, including nutrient and organic matter recapture from human waste streams. These ideas have been implemented in both Detroit and Baltimore through energy-recapture from waste incineration and landfill methane production, and sewage-sludge pelletizing for fertilizer use that also reduces the water content and associated energy required for sludge disposal. The practice of locating these systems close to urban centers or along waterways reduces the energy cost of waste transport, but may have negative social and environmental consequences. In addition, the conventional practice of combining waste streams can result in extra costs for contaminant removal, or limitations on the end uses of recaptured waste products. For example, sewage sludge pellets may not be authorized for use in areas where stormwater can collect (which is nearly everywhere in the topographically-uniform land area of Detroit), or on fields used for human food production. Innovations to reduce these negative consequences will also be important for advancing the practicality of waste recapture at the FEW nexus.

To further address contamination, the technical and logistical challenges for food-energy-water sustainability in post-industrial urban areas because of the legacy of environmental degradation are being investigated, with emphasis on achieving a complete understanding of the source, quantity, transport, deposition, and degradation characteristics of each suite of contaminants and their associated health impacts. Historical emissions from automobiles have resulted in urban areas with wide-spread lead contamination that directly impacts human health (Laidlaw and Filippelli 2008). The presence of lead (Pb)-contaminated soil in urban centers and the associated risk to human health presents a potential problem for burgeoning urban gardening movements (Kachenko and Singh 2006; Leake et al. 2009; Clark et al. 2008). A similar relationship exists between coal-fired power plants and air emissions such as mercury. Intense reliance on energy from coal in the Midwest has resulted in extensive mercury contamination to the Great Lakes. The enormous Great Lakes freshwater fishery is a critical food resource for millions of residents throughout the Midwest, particularly low-income people that live in urban centers such as Detroit. The necessary risk-based limits on levels of fish consumption—and the health impacts on those who do not observe those limits—have long-term effects on food sustainability and social self-sufficiency for the most vulnerable people in these urban areas (Kalkirtz et al. 2008; Kashian et al. 2007).

Methods for reducing Pb ingestion risk associated with building demolition (Jacobs et al. 2013) and urban gardening (Bugdalski et al. 2014; Ravansari et al. 2015) remain critical research needs for food- and stormwater-related urban lot redevelopment. Detroit faces the challenge of transitioning over 50,000 vacant buildings through the demolition and land redevelopment process, and Baltimore a smaller but still

Table 1 Recommended future work identified by workshop participants

Topic	Recommended research and process improvements
Policy development and governance structures	• Develop partnership and governance methods and policies that address imbalanced power dynamics. This may include documenting differences in political, social, and economic power among stakeholder groups, publicly acknowledging and discussing those differences, developing methods for managing inequality during group processes, and clarifying procedures for participation, agenda-setting, and timelines. Define fair decision-making practices informed by power differences between stakeholders. • Develop policies and governance structures to support innovative practices at the FEW nexus, particularly zoning, building codes, land management ordinances, alternative energy production/distribution/storage, and water storage. • Provide better support for new land-use practices within existing governance processes, particularly for consolidation of parcel ownership, foreclosure/redistribution of vacant land and buildings, redevelopment planning, and urban land stewardship. • Integrate centralized planning processes with effective and efficient neighborhood-level implementation of innovative urban land use to foster the long-term sustainability of innovative practices.
Community engagement and knowledge transfer	• Develop methods for instilling values and creating community across racial and economic lines, particularly creating regional connections across political boundaries that contribute to the development of unified, equitable, and sustainable approaches at the FEW nexus. • Redesign funding strategies and practices to foster long-term engagement, community partner support, interdisciplinary workforce development, and pairing of on-the-ground action with academic research. • Document the extra time it takes to work via multidisciplinary partnerships, and the benefits of effective partnerships, to foster an understanding of best practices for partnership development and maintenance. • Document best practices for community engagement, with an emphasis on the local knowledge base and developing leadership from within communities. • Develop, implement, and evaluate programs to connect inner-city youth with academic, economic, and social opportunities relating to food, energy, and water sustainability. • Practice scaling-up pilot projects, particularly urban agriculture, green infrastructure, and alternative energy production. The progression from "proof-of-concept" through community engagement and large scale implementation is essential for building trust and capitalizing on momentum developed during pilot projects. Document outcomes and transfer knowledge on both the successes and failures.
Group processes	• Develop a common language and modes of expression throughout different communities, institutions and academic disciplines, including the following: training on dialogue processes; collaborative multidisciplinary development of ground rules (e.g. use of acronyms, methods of communication about specialized fields); best practices for engaging disadvantaged groups of people; methods of communicating about different values; identifying mutual interests among partners and making a concerted, deliberate effort to bring diverse groups together to create community, academic, and government dialogue.
Support for innovation	• Support and train disadvantaged people for FEW entrepreneurship, with emphasis on empowerment toward self-reliance and co-operative economics rather than conventional "job training." Develop opportunities in urban solar and wind technology, management and maintenance of green infrastructure, high-value and value-added urban agricultural crops and crop processing, and co-operative retail and other economic structures that return value to the community. • Within academic institutions of higher education, review and potentially revise academic reward and incentive structures for faculty, especially junior faculty who may bring cutting-edge ideas, to align with the need for innovation at the FEW nexus.

Table 1 (continued)

Topic	Recommended research and process improvements
Integration of science and decision-making	• Develop methods of using data and technology to make partnerships easier and more effective. • Develop mechanisms by which policy making is based on sound science and conducted in collaboration with all stakeholder groups. • Develop clear definitions for food-energy-water sustainability in post-industrial urban areas that address issues of affordability, access, quality, timeframe, and scale as dimensions of ecological, economic, and social sustainability and resilience. • Develop metrics that commensurate to one or more common measures both the costs (such as environmental and human health burdens) and benefits (such as FEW services and public participation) of processes and activities. • Through scientific analysis of outcomes, identify best practices—particularly through the lenses of decision-maker and stakeholder interests—for scaling-up implementation of FEW sustainability practices.
Methods of measurement and analysis	• Compare various methods and models for greening post-industrial cities and document the proposed/ideal relative to the actual processes of change. Utilize both quantitative and qualitative analyses of the outcomes of economic, social, technological, and land-use innovations to document what practices result in the greatest benefits and identify the factors in their success. • Develop tools and metrics to describe and quantify the spatial, social, and temporal variability of outcomes over time, such as through geographic information systems (GIS) that integrate metrics over both spatial and temporal scales. Evaluate both the timing and robustness of change following the implementation of innovative practices across multiple disciplines and through many different potential underlying factors, in order to predict outcomes, thresholds, and corresponding changes in related things. • Develop and test appropriate denominators, baselines, and/or indices to normalize metrics and facilitate appropriate comparisons within and between cities. Potential denominators or baselines include land area, land use, population density, and household income. Potential indices include environmental health and degradation, human health, access, and opportunity. • Develop better metrics for the effects of green infrastructure on mitigating the effects of climate change and for social resilience, predicting social cohesion and the likely acceptance and success of innovative greening and decision-making practices. • Develop approaches for social network mapping and integration of large datasets to help in understanding complex food-energy-water system dynamics. • Develop approaches for understanding urban socio-ecological systems for FEW sustainability, particularly pollinator/plant and pest/biocontrol relationships for urban agriculture, ecological soil/water/biota/land-use interactions for green spaces, and ecosystem services in general.
Urban re-design and retrofit	• Re-design city services to address: ○ How to sustainably provide infrastructure and services in urban areas that have experienced too great a population decline to justify the current amount of legacy infrastructure and anticipated future demand; ○ The impact of water and energy rate structures on affordability and equity; ○ Incorporation of new practices in sustainable technology outside the box of existing systems, such as for water treatment/storage to conserve energy and support urban food production. ▪ Design integrated systems and technologies to reduce the overall cost of delivering multiple services to city residents, businesses and institutions, particularly re-designing older system to consider the need for resiliency. • Develop best practices for low maintenance and socially acceptable urban FEW land uses such as green infrastructure, urban forests, and stormwater recapture.

Table 1 (continued)

Topic	Recommended research and process improvements
	• Develop affordable retrofits for older buildings such as composting toilets, cooling roof materials, and energy efficiency systems. • Develop new energy production/distribution/storage systems appropriate for urban areas and supporting related business development opportunities.

substantial number, with many of those buildings and the surrounding soil contaminated by Pb on a decreasing gradient from the city center outward (Laidlaw and Filippelli 2008;Schwarz et al. 2013). Resuspension and accidental ingestion of Pb-contaminated particles either from existing indoor or outdoor sources (Paustenbach et al. 1997; Clark et al. 2008; Pingitore et al. 2009; Harris and Davidson 2005) or from ongoing atmospheric deposition—such as through the consumption of Pb-containing aviation gasoline used by piston engine aircraft—continues to have a documented effect on public health (McElmurry et al. 2015; Zahran et al. 2013). Ongoing research to evaluate human health risks and identify best practices continues to be an important pathway to improving the sustainability of food, energy, and water systems in post-industrial cities.

Need for additional work

The successful projects described above by workshop participants—and the challenges they experienced during the implementation of these projects—highlight the need for improved processes and additional research. Table 1 summarizes the needs at the nexus between food, energy, and water systems that were identified during the workshop. These recommended improvements are in areas of active research and practice and illustrate some of the perceived gaps for effective implementation of sustainability efforts at the FEW nexus, particularly in the cities of Detroit and Baltimore.

Summary and recommendations

Practitioners and academics who are working on food, energy, and water sustainability in Detroit, Michigan, and Baltimore, Maryland, gathered in Detroit for a 2-day workshop in October 2015 sponsored by the National Science Foundation and Erb Family Foundation. The workshop goal was to collaborate on integrative multidisciplinary solutions for post-industrial urban areas that could result in greater sustainability within the food-energy-water nexus. Discussion progressed from the examination of challenges for sustainability to documentation of the actions being taken and identification of both the problems and successes in the current practices. Synthesis of these ideas resulted in the pathways to action and needs for additional research and improved processes that were identified in this article.

Examination of similarities and contrasts in challenges and solutions to promote sustainable food, water, and energy systems in Baltimore and Detroit highlight the need to (1) develop effective partnerships and governance structures, (2) address longstanding racial justice issues, (3) devise integrative FEW metrics to evaluate alternative greening models and understand the underlying complex urban systems, and (4) identify preferred pathways for renewal and development in transitioning urban landscapes. Initiatives engaging citizens, governments, academia, and public and private enterprise provide a means to support environmentally, economically, and socially sustainable FEW systems in these cities and other post-industrial urban areas.

Continuing collaboration between Detroit and Baltimore is anticipated to serve as a model for similar cities where efforts to share information, build partnerships, establish integrative metrics, and develop innovative approaches for food, energy, and water sustainability are underway. Examples include expansion of Long-Term Ecological Research in urban areas—such as that conducted in the Baltimore Ecosystem Study—to other metropolitan areas like Detroit, creating partnerships between academia and practitioners to integrate scientific information into decision-making processes and community action. Through such collaborations, best practices and communication tools are expected to emerge, for use by all cities with similar challenges. In addition, innovations that extend outside the box of existing practices can be better identified in multidisciplinary settings, in partnership with people from different areas of practice. In Detroit, these innovations began at the neighborhood and community level due to a long period of urban neglect and decline that culminated in emergency manager oversight of city government and municipal bankruptcy in 2014. The subsequent investment in rebuilding Detroit is creating new opportunities for integrating sustainable practices into urban re-design. Through this form of collaboration, new opportunities can be identified for addressing challenges that have not yet been conceptually or pragmatically resolved. The workshop described here was an effective first step

toward establishing this collaborative process, and it is hoped that this work can continue.

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