Scaling Up Agriculture in City-Regions to Mitigate FEW System Impacts

Developed in Support of an NSF-Funded Workshop Entitled "FEW Workshop: "Scaling Up" Urban Agriculture to Mitigate Food-Energy-Water-Impacts" Held at the University of Michigan, Ann Arbor October 5-6, 2015

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Abstract

With dramatic growth of urban areas and the majority of the world's population now living in urban settings, cities have become dominant demand drivers in global food-energy-water (FEW) cycles. Globalization processes have intertwined cities with distant geographies through system interactions that include the exchange of food, energy, water, materials, capital, and the like. Through food consumption, city and 'hinterland' have become highly interconnected and interdependent across spatial, temporal, and jurisdictional scale. Growing awareness of the myriad environmental and socio-economic impacts associated with this food production-consumption nexus has sparked an *urban agricultural renaissance*. This white paper entitled, "Scaling Up Agriculture in City-Regions to Mitigate Food Energy Water Impacts," is the result of a workshop sponsored by the National Science Foundation and held at the University of Michigan on October 5-6, 2015. The document summarizes current knowledge with respect to urban agriculture on: 1) food supply and security; 2) water quality and re-use; 3) energy use; 4) biodiversity and ecosystem health; 5) and equity and governance. Prior to the workshop, working groups prepared on these five issues regarding the state of knowledge, level of implementation, and interactions with other FEW systems. A sixth working group evaluated potential integrative frameworks and modeling approaches to assess urban FEW system interactions. This analysis is also included in this white paper. To uncover the linkages between physical, social, economic, and ecological systems, the project team and workshop participants included a multidisciplinary collection of geographers, engineers, ecologists, biologists, earth systems analysts, complexity modelers, planners, computer scientists, public health policy experts, and others. The white paper concludes by identifying fundamental research needs in order to transition urban food-energy-water systems so that they are more integrated, sustainable, resilient, and equitable.

1 Introduction

The idea of growing food in cities is not a new one. Urban agriculture (UA) has been practiced throughout the world since the dawn of urbanization. Indeed, agriculture and urbanization are deeply interconnected, with agriculture allowing for the creation of cities, and cities requiring agriculture to feed the concentrated population (Mougeot 2005; Steel 2013). Similar to today, the specific composition of early urban agro-systems was shaped by the regionally specific environmental, economic, and socio-political conditions. Mesoamerican cities during the Classic Maya period (late first millennium CE) and Byzantine Constantinople alike had large sections of the urban landscape devoted to agriculture, where clusters of households collectively farmed land (Barthel and Isendahl 2013). Similar practices have been documented in the ancient Khmer civilization of Southeast Asia (Fletcher 2009), and among the Aztecs of Highland Mexico (Isendahl and Smith 2013). In addition to garden agriculture, cities included fruit tree orchards and other agro-forestry systems, swidden cultivation, and livestock. Mayan UA was especially well-developed, including integrated social structures that governed its production from the city-scale to the individual household and a range of water management strategies, from open reservoirs to underground water cisterns (Isendahl 2012; Scarborough 1998). These civilizations also had well-developed waste-to-food systems in place, with fertilizer made from organic human waste, rubbish, and manure (Ljungqvist et al. 2010). In medieval European cities, kitchen gardens and animals on both sides of the walled cities provided vegetables and animal products for city-dwellers, complementing the larger scale production taking place in surrounding fields (Jacobs 1970; Steel 2013).

In the modern age, UA has been associated with the socioeconomic and demographic shifts arising from rapid urbanization related to the Industrial Revolution (Lawson 2005; N McClintock 2010). In Britain the promise of employment attracted rural residents to the growing agglomerations of factories and worker housing. At the same time as subsistence and smallholder agriculture production was undermined and rural dwellers systematically pushed off the land by legislation progressively "enclosing" the collectively-managed commons, thus excluding farmers from the land base upon which they depended (H. R. French 2000; Shaw-Taylor 2001; Williams 1970). The urban population thus skyrocketed during the 19th century, and in Britain, the urban population surpassed the rural population in the 1850s. Allotment gardens were established on the urban periphery of European cities to provide workers with space for small subsistence gardens (Crouch and Ward 1988).

UA in North America shares much of this history. Planning documents for early American cities intentionally placed UA as a key component in civic life and food supply (Vitiello and Brinkley 2013). Philadelphia, Baltimore, and Boston enjoyed planned commons for animal pasturing, communal gardens, and designated areas for private gardening. In the west, Spanish settlements were constructed following planning documents that specified the distance of resident housing to farmland and gardens to make food transport efficient. While prominent in colonial era planning, UA fell out of favor in the late 1800s as technological advances like refrigerated rail enabled the transportation of food over long distances, removing the necessity to rely on nearby production (Bassett 1981; Cronon 1991; Horst, Brinkley, and Martin, forthcoming; Lawson 2005; McClintock 2010).

However, UA persisted as a way for rural migrants to cope with life in the city; in the US and Canada, the population shifted from predominantly rural to urban in the 1910s and 1920s, respectively.

While historically only a modest proportion of humanity lived in cities, the majority of people living in industrial countries live in urban areas and rapid urbanization is occurring in the Global South. Globally, more than half of humanity now lives in urban areas and this is expected to increase to nearly two-thirds of the human population by the middle of this century (United Nations Department of Economic and Social Affairs 2014). Resource consumption patterns have significantly changed with urbanization; urban dwellers consume more meat and processed foods and more reliant on purchasing (rather than producing) food. Increasing rates of urban poverty thus exacerbate food insecurity (Davis 2009). Significant changes are needed to accommodate the increased urban population and to alleviate poverty. Food production is expected to increase by more than 50% by the middle of this century to accommodate increased population and changing lifestyles (Davis 2009).

Agriculture *within and adjacent to* areas of dense human habitation facilitated organization of the local food-energy-water (FEW) system to capture inherent synergies. We refer to this urban and peri-urban region as the “city-region”, a term in economics and urban planning that dates back to the late 1930s to denote a metropolitan area and its hinterland, typically an urban area with multiple administrative districts but sharing resources such as water and energy infrastructure (Ravetz 2000). For example, recycling of human waste as a source of nutrients for agriculture allowed the fertility of agricultural lands to be maintained while minimizing local water pollution. While many argue that the current agri-food system -- with large-scale food production occurring at a significant distance from urban centers -- is a function of market forces and therefore the most economically efficient solution, this argument neglects the fact that many aspects of the current agricultural system distort the true economic picture. These include both the significant subsidies provided to agriculture and tolerance of important economic externalities, such as subsidized energy production from fossil fuel and pollution.

It is therefore possible that re-localizing agriculture in and around population centers can result in a more resource- and cost-efficient system by allowing inherent synergies in the FEW system to be re-captured. This White Paper presents the results of a National Science Foundation (NSF) funded workshop held October 5-6 at the University of Michigan entitled “Scaling Up” Urban Agriculture to Mitigate Food-Energy-Water-Impacts[1]. The purpose of this workshop was to investigate three hypotheses[2], as articulated in the funded proposal:

Hypothesis #1: *Scaling-up urban agriculture and its associated energy and water systems can produce multiple benefits in urban environments while, at the same time, mitigate a range of broader environmental and socio-economic impacts.*
Key Questions: What are the anticipated benefits and impacts? What are the challenges? What does the system look like in different geographies and different scales, including: household, neighborhood, city, and beyond? How will climate change alter the system, its benefits and impacts?

Hypothesis #2: *Urban FEW systems can be evaluated using integrative approaches which consider material flows along with ecological and socio-economic factors to delineate complex dynamics and inform how to move toward implementing a more integrated system.*
Key Questions: What are the elements from social, physical, chemical and biological processes that feed into the model, and how well are they understood?

Hypothesis #3: *Although Urban FEW systems are complex, there are discrete “tipping points” that can initiate a rapid transition to alternative states.*
Key Questions: What are these tipping points and how do they influence the final performance state? How do they differ for cities in industrialized versus industrializing countries?

[1] Original title. The white paper was revised as a result of workshop and subsequent analysis, with the revised title used throughout this document.
[2] Hypotheses revised as a result of workshop and subsequent analysis.

Summary analyses and outcomes from the workshop are presented in this White Paper. Further documentation is available, referred to in the text of this White Paper, and included in the list of references.

1.1 Methodology

The methodology used to conduct this workshop was as follows:

1. Recruit an interdisciplinary group of subject matter experts in a variety of disciplines required to investigate the hypotheses listed above.
2. Drawing on the subject matter experts recruited above, form six working groups to prepare working group papers addressing six knowledge areas relevant to the October 5-6 workshop. The working group papers served to expand the collective knowledge base of the subject matter experts to facilitate constructive multi-disciplinary discussions at the workshop. Several of the project Co-Principal Investigators (Co-PI's) served as leaders of individual working groups, and select others were recruited to lead the remaining working groups. The working group leaders were assembled into a core group to manage the intellectual component of the project.
3. Distribute the working group papers prior to the October 5-6 workshop so that the individual subject matter experts can become familiar with the broader range of topics to be considered.
4. Conduct the workshop.
5. Convene the core group to synthesize the results of the workshop into this White Paper.

1.2 Working Groups

Six working groups were formed and were assigned the following topics:

Working Group #1: Urban Agriculture and Water
Working Group #2: Urban Agriculture and Energy
Working Group #3: Urban Agriculture and Food Supply
Working Group #4: Urban Agriculture and Ecosystems
Working Group #5: Urban Agriculture Socio-Economic Dynamics
Working Group #6: Integrated Urban Metabolism Framework

The working groups were generally asked to address the following six topics:

1. What is the state of knowledge in your assigned topic area?
2. What is the current state of implementation?
3. What are the interactions with other components of the urban FEW system?
4. What are the interactions with the broader FEW systems?
5. If urban agriculture is to be scaled up by (a) 100% or (b) 500%, what are the expected impacts on the urban and broader FEW systems?
6. What is the anticipated impact of climate change on urban agriculture systems and their associated FEW systems?

The six individual working group papers were assembled into a single document and distributed to workshop participants October 3

Urban FEWS Participant Diagram

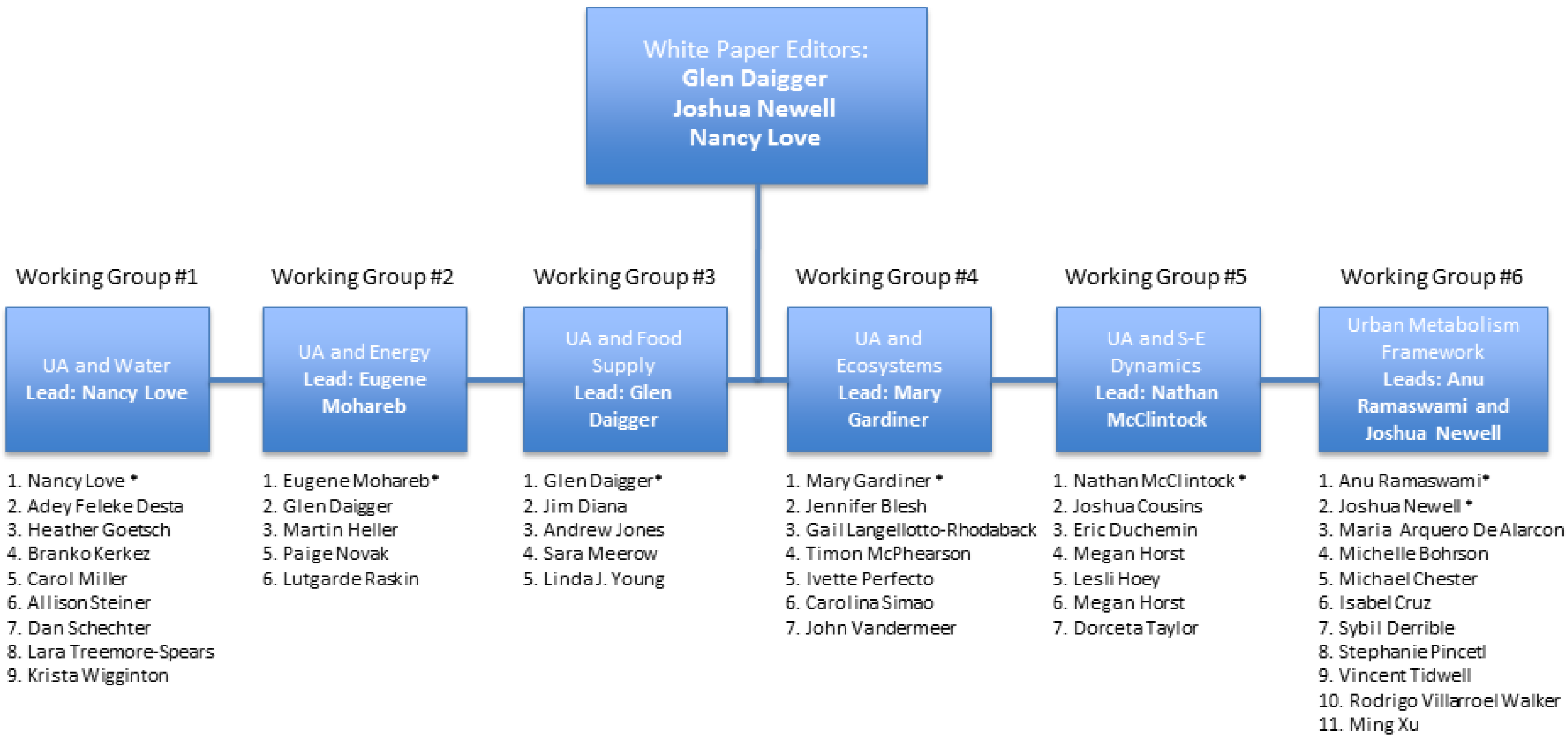

Figure 1 Workshop Participants by Working Group

1.3 Workshop

The workshop consisted of invited lectures designed to provide further information broadly relevant to the workshop participants, opportunities for the working groups to meet and further improve their input to the workshop, and interactive sessions where "mixed" multi-disciplinary groups met in breakout sessions to address elements of the three initial hypotheses and also to begin the task of identifying knowledge gaps and research that can address these gaps. The report back sessions provided significant input to the core group as it subsequently synthesized the workshop results into this report. A copy of the workshop agenda is attached as Appendix 1, and the participants in the breakout groups are summarized in Figure 1 (pre-conference defined topical breakout groups) and Table 1 (Mixed discipline breakout groups). A full listing of all workshop participants, with affiliations and contact information is provided in Appendix 2, and a photograph of the participants is provided on the cover.

Table 1 Mixed Discipline Breakout Groups

Group A	Group B	Group C	Group D	Group E	Group F
Joshua Newell Krista Wigginton Vincent Tidwell Gail Langellotto-Rhodaback Megan Horst Isabel Cruz Adey Desta Feleke	Eugene Mohareb Carol Miller Paige Novak Josh Cousins Carolina Simao Sybil Derrible Galen Fisher Michelle Landes (USDA)	Glen Daigger Allison Steiner Richard Plunz Mike Chester Ivette Perfecto Mary Carol Hunter Brandi Schottel Jim Diana	Nancy Love Martin Heller Andrew Jones R. V. Walker Anu Ramaswami Jennifer Blesh Dorceta Taylor Maria Arquero de Alarcon	Nathan McClintock John Vandermeer Lutgarde Raskin Stephanie Pincetl Sara Meerow Dan Schechter	Mary Gardiner Linda J. Young (USDA) Branko Kerkez Lesli Hoey Ming Xu Eric Duchemin

1.4 White Paper Organization

The White Paper is organized into six sections and a number of supporting appendices. The first section introduces the purpose of the White Paper and the methodology used to prepare it. The second section draws on the working group papers to present a succinct assessment of existing knowledge relevant to the topics addressed in the workshop. Section three builds on information presented in the working group papers and the results of the workshop to identify synergies that can be created by further integrating the FEW system by scaling up agriculture in the city-region. Section four investigates integrative approaches that can potentially be used to better understand FEW systems in the city-region. Section five addresses how development of the working group papers and the workshop informed evaluation of the three initial hypotheses, and section six presents research gaps identified.

2 Current State of Knowledge Relative to City-Region Food Systems

This section presents a summary of the working group papers prepared in advance of the October 5-6 workshop, which were based on an understanding of potential issues at the time of their preparation. Further knowledge areas became obvious as the workshop and subsequent analysis progressed, as summarized in section six of this White Paper.

2.1 Agriculture and Water

Nancy Love, University of Michigan (Working Group Leader)

Adey Feleke Desta, Addis Ababa University
Branko Kerkez, University of Michigan
Gail Langellotto-Rhodaback, Wayne State University
Andrea McFarland, University of Michigan
Carol Miller, Wayne State University
Dan Schechter, Detroit Water and Sewage Department
Allison Steiner, University of Michigan
Krista Wigginton, University of Michigan

Water is required for all forms of agriculture. The quantity and quality of water required for various agricultural products is well known and defined in practice. Rain fed agriculture uses natural rainfall, but agricultural water needs can be supplemented by the further capture and storage (for later use) of rainfall (typically referred to as rainwater harvesting) and reclamation of used water (also referred to as wastewater) generated by domestic, commercial, and industrial uses. Figure 2 illustrates the supplemental water sources available to agriculture in the city-region. These include urban stormwater, along with individual used water fractions. The used water fractions include yellow water (urine), black water (used water from toilets, and sometimes also some fractions of kitchen waste), grey water (washing water from domestic and commercial sources), and industrial used water. These sources, which are substantial in some cases, can supplement rainfall to maximize the yield from agriculture in the city-region.

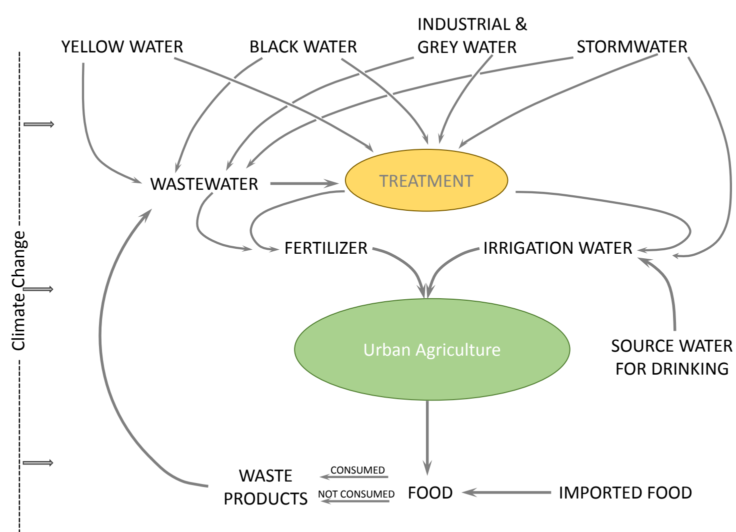

Figure 2. Interactions between Urban Water Sources and Agriculture Within the Urban Area and the Adjacent City-Region.

As Figure 2 illustrates, important nutrient sources are also available in urban areas which can be collected and used in adjacent agriculture. These include the macro-nutrients nitrogen and phosphorus, along with important micro-nutrients. Separation of human urine and feces at the source is an emerging practice to facilitate recovery of nutrients in urine or urine-derived products (Eggen and

Maurer 2009). Since urine contains nearly 80% of the nitrogen and 65% of the phosphorus in human waste, keeping urine separate from feces and avoiding use of water to dilute the nutrients allows these nutrients to be recovered and processed in a way that generates a very useful fertilizer. The first nation-wide deployment of source separated urine to fertilize crops is underway in Vermont by the Rich Earth Institute (http://richearthinstitute.org/). The safety of various urine processing methods to make urine pathogen-free prior to application is under investigation in the US (Wigginton et al., n.d.). Prior work in Switzerland has shown that some virus and helminth pathogens can survive and remain infective when urine is processed into struvite, a solid precipitate that recovers nitrogen and phosphorus for use as a fertilizer (Decrey et al. 2011). More research is needed to achieve nutrient recovery from human waste for fertilizer production.

Urban used water streams also contain organic matter which can be combined with agricultural residues and urban food waste in anaerobic digestion processes to produce biogas as an energy source (Grady et al. 2011) Of course, food consumed in the urban area is the principal source of nutrients and organic matter in the used water from the urban area, thus illustrating the connected nature of such a system. Organic residuals, particularly those remaining after anaerobic digestion of organic residuals from the urban agricultural areas, can also be used in agriculture to provide needed nutrients and improve soil characteristics, especially soil structure and water holding capacity.

The requirements to treat urban used water for agricultural use, including for crops that are consumed without cooking (which inactivates the vast majority of pathogens) are well established (WHO Scientific Group 1989; United States Environmental Protection Agency 2012; National Academies 2012) Monterey, California is a long-standing example, where wastewater from the City of Monterey is reclaimed to meet state of California Title 22 requirements and then used extensively to irrigate adjacent food crops, including avocados and strawberries. This practice was initiated decades ago to replace the use of groundwater for irrigation because pumping was lowering the groundwater level close to the California coast, leading to seawater intrusion. The use of reclaimed wastewater for irrigation in the Monterey region has been extensively studied and demonstrates that such practices are safe (Crook 2004).

Use of highly or moderately treated wastewater effluent for urban agriculture is mostly applied in developing countries, both intentionally and unintentionally. A case study in Addis Ababa, the capital of Ethiopia, illustrates that food production in the city-region is common and constitutes a significant fraction of food consumed in the city. For example, 30% of vegetables (including 60-70 percent of leafy vegetables), 60-70 percent of milk and 40-60 percent of eggs consumed in the city come from urban or peri-urban farms (United Nations Environmental Program 2014). However, the city-region food industry is challenged by the poor quality of irrigation water. Addis Ababa receives about 45 inches of rain a year, mostly between June and September. Therefore, the primary source of water to support the urban agriculture industry in the city is from surface water that flows through the city. The main source, the Akaki River, is a highly polluted river that receives both inadequately treated wastewater and untreated industrial wastewaters, yet it serves as the primary irrigation source for urban crops. Furthermore, inadequate urban drainage leads to substantial flooding in the city, which can also adversely impact urban farms. Therefore, while there is a growing and vibrant city-region farming industry in the Addis Ababa, food safety and quality is often compromised due to inadequate water resource management, and mimics a common occurrence in cities within developing countries.

In summary, a long history with use of reclaimed water (from used water sources) to irrigate crops in arid regions of the US and world exists and has proven safe when properly implemented but can create significant public health concerns if not. Those experiences have revealed that the nutrients truly benefit crops; however, loss of micronutrients and build-up of salts and metals over time require careful management. Monitoring of trace metals and other chemicals for urban agriculture systems that rely on reclaimed nutrients and water is needed in parallel to maintain the quality of the farmed product (Mohammad Rusan, Hinnawi, and Rousan 2007).

2.2 Urban Agriculture and Energy

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Xavi Fonoll, University of Michigan
Martin Heller, University of Michigan
Paige Novak, University of Minnesota
Lutgarde Raskin, University of Michigan

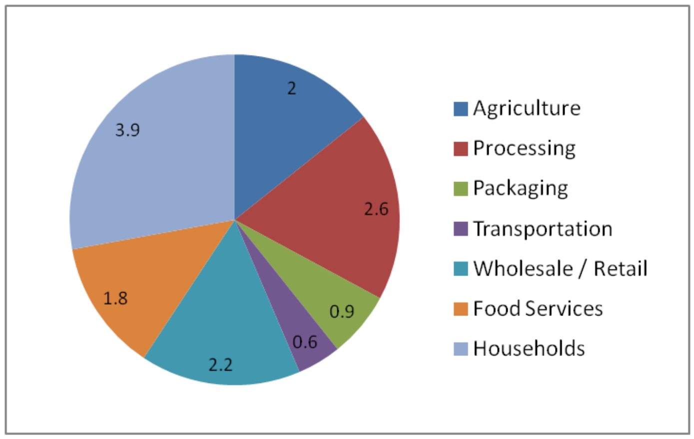

Figure 2 Energy Consumption in the Food System 2002
Source: (Canning et al. 2010)

The US food system encompasses a broad collection of energy end-users. Starting from the agricultural phase through transportation of food to retailers and households, and culminating in waste handling, the current predominantly linear structure of the food system is highly dependent on energy inputs for the production, processing, distribution, consumption and disposal of food products. Canning et al. (2010) estimate that 14.4% of total US energy consumption in 2002 was food-related. Figure 3 provides a breakdown of this consumption. The United Nations Food and Agriculture Organization (FAO) estimates that over 75% of energy use in the food system of developed nations occurs beyond the farm gate (Food and Agriculture Organization 2013).

In support of urban agriculture's resurgence, proponents have suggested that a number of energy benefits are realized through food production within cities (Howe and Wheeler 1999; Garnett 1997; Smit and Nasr 1992; Kulak, Graves, and Chatterton 2013). They most commonly highlight savings in transportation energy and energy inputs of food waste/loss, but also include additional biomass provision from silviculture or tree plantations to offset energy imports (Smit and Nasr 1992), easier exploitation of resources (Zhang, Bi, and Clift 2013), and lower-intensity production (Kulak, Graves, and Chatterton 2013). Additionally, waste generated by urban agriculture and food consumption can produce biogas through anaerobic digestion or landfill disposal.

Thebo et al. (2014) estimate that there was 67 Mha of urban agriculture globally in 2000 (5% of the global arable land in that year; FAO 2010), with roughly 1/3 of this number being irrigated. There are a variety of approaches to and scales of urban agriculture, each with different impacts on energy use. Mok et al. (2014) identified three distinct scales of agriculture in urban systems (in order of decreasing size): small commercial farms (e.g., Lufa Farms of Montreal, Canada) and community supported agriculture, community gardens, and backyard gardens. Operations across all scales have the potential to produce animals and animal products. As well, these scales differ in terms of structure, inputs, and productivity; as a result, their net impact on life-cycle energy demand also varies. In addition to the potential reduction in transportation and food waste that may be possible through local food production, other energy related benefits associated with the various forms of urban agriculture have been described in Table 3. Numerous studies have challenged the common assumption that "localizing" food production results in reduced transport energy use and GHG emissions, and effects on distribution networks need to be evaluated on a case basis to justify such a claim (Coley, Howard, and Winter 2009; Edwards-Jones et al. 2008; Pirog et al. 2001; Nicholson et al. 2015)

Table 2 Type of Urban Agriculture, Potential Beneficial Energy Impacts Relative to Intensive Industrial Agriculture

Type of Urban Agriculture	Potential Beneficial Energy Impacts	Requirements for Upscaling	Sources
Residential Gardens	· On-site end-consumption · Greater labor intensity of production	· Knowledge dissemination for production, preservation	(Altieri et al. 1999; Kulak, Graves, and Chatterton 2013)
Allotment Gardens	· Greater labor intensity of production	· Municipal allocation of green space	(Leach 1975)
Rooftop Agriculture	· Thermal transfer from rooftop · Improved yield · Onsite waste diversion	· Building code changes (structural, utilities)	(Sanyé-Mengual et al. 2015; Saiz 2006; Specht et al. 2013; Grard et al. 2015)
Industry/Residence-Integrated Greenhouse	· Improved yield · Waste heat/CO_2 utilization · Onsite waste diversion	· Inventory of urban resource streams · Zoning by-laws to enable co-location of agriculture with resources	(Zhang, Bi, and Clift 2013)
Vertical Farms	· Improved yield · Onsite waste diversion (e.g., waste-to-feed for onsite livestock)	· Potential for on-site nutrient cycling	(Despommier 2013b)
Peri-Urban Land Preservation	· Preservation of higher-yielding prime agricultural land	· Legal protection of peripheral farmlands	(Francis et al. 2012; Krannich 2006)

Urban agriculture has the potential to affect energy-related components of the FEW system within urban boundaries and beyond. Suggested impacts which increase (upward pressure) and decrease (downward pressure) energy use, both within and beyond the urban boundary, are presented in Table 3. It is important to note that energy demand for services required in urban agriculture can differ from those provided though open field agriculture. In one case, irrigation systems are estimated to require 0.63MJ/m^3 in an open-field agricultural system (Hatirli, Ozkan, and Fert 2006), while a municipal water system in Toronto requires 2.3-2.5 MJ/m^3. The types of energy use can also vary, which can have GHG implications. For example, Ontario's field crop irrigation is typically powered by diesel systems, while greenhouse irrigation is generally powered by electricity (Carol 2010).

Given that urban agriculture is likely to involve the use of greenhouses or other controlled growing environments in some locations, it is important to examine the life cycle energy demand of such structures. There is uncertainty with respect to changes in energy intensity from shifting to controlled-environment agriculture from open fields. Some studies have found that tomatoes produced by open-field agriculture tend to be less energy intensive than greenhouse crops; Martínez-Blanco et al. (2011) found that life cycle cumulative energy inputs per ton of tomato produced in Catalonia was 113% greater when compared with open-field production (considering operations using mineral inputs only). On the other hand, Kuswardhani et al. (2013) found that energy demand per unit mass in Indonesia was higher for open-field tomato and chili production, but lower for lettuce. In addition, tomato production studies in Antalya, Turkey suggest that energy requirements for greenhouse tomato production were approximately 10% lower than that in open fields (Esengun et al. 2007; Hatirli, Ozkan, and Fert 2006). Inputs required will be crop and climate dependent, emphasizing the need for consideration of seasonality and crop variety selection. With respect to soilless production systems, Albaho elt al, 2008) state that aeroponic systems require an uninterrupted electrical supply, but it is unclear as to whether this energy demand is offset by lower inputs and higher yields relative to conventional controlled-environment agriculture.

Table 3 Estimated Energy Impacts in the Broader FEW System

Within Urban Boundaries	Beyond Urban Boundaries
Upward Pressure	***Upward Pressure***
Water/wastewater treatment Labor (paid or unpaid)	Construction materials (e.g., steel framing, LDPE sheeting, polycarbonate glazing)[1,2]
Downward Pressure	***Downward Pressure***
Transportation Waste disposal	Irrigation water (through controlled-environment agriculture) Inorganic inputs Machinery / capital Packaging materials

[1](Martínez-Blanco et al. 2011); [2](Kulak, Graves, and Chatterton 2013)

Examining comparisons across geographic areas, Stanhill (1980) suggested that a UK-based greenhouse operation had a fossil energy demand that was nearly 100 times greater than a Californian open-field tomato operation. Meanwhile, Carlsson-Kanyama et al. (2003) estimated that energy demand from farm to retail for tomatoes grown in a Swedish greenhouse was 1,100% greater those produced in an open field in southern Europe. These suggest that careful consideration of local climate must be taken when pursuing urban production of selected crops.

Packaging material demand can also be reduced in urban agriculture operations (Garnett 1999). For example, the climate impacts of embodied energy of polyethylene terephthalate clamshells and polystyrene trays used in tomato packaging were estimated to be 25% and 100% greater per unit mass of tomato than loose packaging (US Environmental Protection Agency 2010). However, the authors also note that modified-atmosphere packaging has the potential to increase shelf-life, which would reduce waste as well as GHGs associated with the tomato production and disposal. Further examination is required into whether the use of certain packaging approaches can result in a net energy savings when accounting for avoided waste and marginal energy requirements savings.

2.3 Urban Agriculture and the Food Supply

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Jim Diana, University of Michigan
Andrew Jones, University of Michigan
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Linda J. Young, USDA

Studies conducted in the Global North suggest that a large portion of city dwellers engage in UA. While there has been a significant expansion of community gardens and commercial agriculture in cities over the past decade (Drake and Lawson 2014; Rogus and Dimitri 2015), most urban food production continues to take place at the residential scale. But as Taylor and Lovell (2014) point out, scholarship on residential food production in the Global North is sparse, and the scale of home gardening is rarely quantified. Estimates vary considerably within and across countries of the Global North. One study estimated that about 25% of urban and suburban households – about 30 million overall – in the US produce some of their own food (National Gardening Association 2014), while a study in Ohio reported 39 to 41% of urban and suburban residents had a household food garden (Schupp and Sharp 2012). A Canadian study of domestic food production came to similar conclusions: 40% of Toronto residents and 44% of Vancouver residents reported that someone in their household grew food (Farmer 2002), while a 2013 survey conducted by the City of Montreal reported 42% of people produced food at home (Guitart, Pickering, and Byrne 2012; Kremer and DeLiberty 2011; de Montréal 2013). Current food gardening households are spread fairly evenly across income levels, i.e., growing your own food isn't an activity of only the rich or the poor. An analysis by Zumkehr and Campbell (2013) indicated that 90 % of food crops could be grown within 100 miles of urban areas in the U.S.

Current approaches to UA take a variety of forms at various scales: container gardens on balconies or patios, front or backyard single family home gardens or shared private gardens (e.g. in apartment buildings), community gardens, fruit trees and orchards, for-profit market gardens and farms of various sizes, animal-raising (e.g. chickens, goats), mushroom production, beekeeping, aqua and hydroponics, greenhouse, rooftop, and vertical farming. Management practices and the organization of labor differ considerably both between and within these different types of UA, as does the extent to which they are engaged in the market economy. Given such diversity, it is important to recognize that socio-economic concerns are often specific to particular forms. In short, it is important not to treat UA as a singular practice. Close attention needs to be paid to the particularities of the form of UA being considered, including who is engaged, and who it benefits (and conversely, whose interests might it threaten). Further, it is important to situate the particular form within the broader social, political, economic, and cultural context that takes history and geography seriously, in essence to ask why is it happening in a particular place and time.

UA has recently been brought to the attention of a broader range of the public. While some have dismissed UA as a cyclical trend in reaction to various crises (Bassett 1981), new means to significantly intensify urban agriculture are currently being developed and are in various stages of implementation. These relatively new developments show great progress to significantly enhance what can be accomplished in the field. As indicated in Table 4, a variety of UA practices and technologies are available, each with their own characteristics.

Notably, the highest levels of research and implementation of UA have occurred internationally. Many European cities have conducted extensive research on their respective urban food systems (Kennedy, Cuddihy, and Engel-yan 2007; La Rosa et al. 2014; Neset, Bader, and Scheidegger 2006;

Ernwein 2014). Furthermore, the most prolific urban agriculturalists are in developing nations (Badami and Ramankutty 2015; Armar-Klemesu 2000), including extensive production in West Africa and parts of Latin America.

In the United States and Canada, well-established green, liberal-leaning cities have historically led the UA movement. Seattle's P-Patches from the 1970's (Horst 2008) Portland's Community Gardens Program (Balmer and Peterson 2005), Vancouver (Kaethler 2006) and Toronto (MacRae et al. 2010) all have long standing urban gardens and agriculture projects. More recently, research and program interests have included a broader diversity of city typologies (i.e., urban configurations and forms), examining the potential of scaling up existing UA and taking seriously the implications on local and regional food systems.

A major factor in the implementation of UA is the type of metropolitan landscape in which it is situated. Every city faces challenges and takes advantage of opportunities unique to its own particular circumstances. In the United States there are as almost as many states of implementation as there are cities, however two prevailing paradigms show considerable promise for the scaling of operations in the near future.

In so-called "shrinking" post-industrial cities, stakeholders are increasingly looking toward ground-based UA to fill the spatial void. In these locations, primarily in the Rust Belt and Midwest, land and building vacancy offers opportunities to increase self-reliance, industrial remediation, address any food desert conditions and create better, smaller, greener cities. Major efforts are underway in Detroit (Detroit Future City 2012), Cleveland (S. S. Grewal and Grewal 2012a), Milwaukee (Broadway 2009), Chicago (Taylor and Lovell 2012) and Baltimore (Hu et al. 2011).

In higher density metropolises that offer greater potential markets but struggle with site availability and adequacy, attention is turning toward higher-tech approaches. These newer technologies and practices remain in very early stages but have demonstrated compelling potential to be explored further (Ackerman 2012a; Ackerman et al. 2014; McClintock, Cooper, and Khandeshi 2013a). For example, vertical farming, which combines hydroponics, aeroponics, greenhouse farming and several other technologies, has had a long history as a theoretical construct (Despommier 2013a). Only lately have private and public interests actively pursued this concept. A handful of commercially viable vertical farms currently exist in the US (Despommier 2013a), but interest is growing. Analyses indicate that UA offers significant potential to contribute to the urban food supply, as indicated by recent analyses summarized in Table 5.

Table 4 Urban Agriculture Technologies and Types

Method	Description	Application	Major Inputs	Impact
Conventional agriculture	In urban areas, generally refers to ground-based commercial farming within city limits.	Relatively low-investment and thus very relevant in shrinking cities with plenty of available land. Can also be relevant in post-industrial sites in need of remediation.	Land, equipment, labor	--
Greenhouse agriculture	Conventional agriculture within transparent, light structures that mitigate climatic conditions to maximize efficiency of crop production and yield.	Environmental manipulation extends growing season, particularly in places with difficult or harsh winters. Some greenhouses provide conditions for warm weather crops to grow in cold weather locales.	Land, greenhouse structure	Extended growing season, increased variety of crops.
Community gardens	A type of urban agriculture that uses public or semi-public lands for collective cultivation.	Prevalent in residential neighborhoods without yard space, educational areas, etc.	Community buy-in on production, participation and consumption; land	--
Private residential gardens	A bottom-up technique for home self-sufficiency	Areas where the single-family home typology dominates the urban or suburban landscape. Crop selection is specifically suited to personal needs.	Homes with front or backyards; promotional campaigns to codify widespread collective action	Productivity does not increase significantly, but leveraging small-scale sites offers most effective scale-up opportunities.1
Rooftop gardens	Utilizing	Heavily developed areas with little groundspace; often on commercial or industrial roofs with ample square footage.	Building with roof access and sufficient sunlight coverage.	
Hydroponics	A method of growing plants without soil, instead using mineral nutrient water solutions to provide major inputs. Various sub-techniques include: passive sub-irrigation, deep-water culture, medium culture, static	Usually conducted indoors with highly controlled conditions.		

	and. continuous flow solution culture to name a few.			
Aeroponics	A method of growing plants in an air or mist environment without an aggregate growing medium.	A particular sub-technique of hydroponics gaining traction and relevance in combination with vertical farming, explored in NASA experiments.		Up to three times plant growth compared to soil culture.2
SPIN farms	Small Plot Intensive Farming; intensive crop rotation on relatively diminutive plots. Allows for high-yield and low investment.	Small-scale sites less than an acre; particularly aimed at the home or community gardener.	Labor	Can generate $50,000 - $65,000 produce revenue on 0.5-1.0 acre farm ($18-20/hour labor).3
Vertical farms	Farming within a greenhouse skyscraper or on vertically inclined surfaces, combining greenhouse and controlled environment techniques such as hydroponics.	Best deployed in urban areas where population density and real estate market forces make untenable the vast quantities of land needed for conventional urban agriculture.	High initial capital investment; highly skilled personnel with specialized knowledge; large building with ample and diverse deployment of lighting technologies.	A one-square-block farm 30 stories high could yield as much food as 2,400 outdoor acres, with less spoilage.4

Table 5 Summary of Potential Impacts Calculated in North American Studies

Location	Potential Impact	Assumptions	Limiting Factor(s)	Reference
Cleveland, OH	100% Honey 94% Eggs and poultry 46-100% Produce	Uses 62% available industrial/commercial rooftops, 80% vacant lots and 9% of occupied residential lots.	Produce yields depend on production techniques employed, conventional, intensive and hydroponic are all evaluated.	Grewal and Grewal 2012b
Detroit, MI	42% Fruits 76% Vegetables	Less than 600 acres needed with storage and extension. Over 4,800 suitable acres identified in study. Estimated population 835,000; considers current and recommended consumption.	Seasonal constraints; commercial yields vs. low biointensive vs. high biointensive; conservative estimates by authors on hoop house efficiency, crop density and available land. Concurrent study shows 24,711 acres suitable vacant land (Dowie 2010.)	Colasanti and Hamm 2010
New York, NY	2.1% of total city population (174,000 people).	Potentially suitable vacant land estimated at 4,984 acres. 70% average lot coverage.	Availability of land and high density of population. 162,000 to 232,000 acres of land are required. Warm weather produce needs not considered.	Ackerman 2012
Oakland, CA	5-10% of produce for the city's population.	1,201 acres can be found over 495 aggregated public land sites. Estimated population: 423,000.	Land requirements not sufficient.	McClintock, Cooper, and Khandeshi 2013
Toronto, ON	5-10% of produce for the city's population.	Organic production to fulfill municipal environmental objectives. Existing farms (2,652.7 acres) and small plots (1-5 acres) would have to be supplemented by hydro corridors, institutional land and rooftop.	Producing 100% of Toronto's produce would require 57,250 acres. Land extensive crops make the study goal of 10% difficult to accomplish.	McRae et al. 2010
United States	90% food demand met with local crops from within 100 miles.	Estimations based on caloric requirements of urban dwellers, caloric productivity of farmlands. Model covers 150 years of data simulation.	Decreasing local food potential over time, most substantially in coastal cities.	Zumkehr and Campbell 2015

2.4 Urban Agriculture and Ecosystems

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In the United States, greater than 80% of the population now lives in cities, reflecting a global trend toward urbanization (UN, 2014), which is largely considered to threaten biodiversity and ecosystem services through habitat loss and fragmentation (Hooper, Iii, and Ewel 2005; McDonnell and Hahs 2013). Urban landscapes are characterized by high levels of habitat fragmentation, high proportions of impervious surfaces, elevated pollution levels, and changes in local climates (such as heat island effects) relative to their surroundings (McIntyre et al. 2001). All of these factors influence the diversity, abundance, and activity of organisms found in urban areas. Conservation has traditionally focused on preserving and restoring habitat within rural landscapes, yet, with so much of the Earth's surface shaped by human activity, it is critical to understand how to preserve and promote species in human-dominated ecosystems such as cities (Vitousek et al. 1997; Miller and Hobbs 2002; McDonald 2008; McDonnell and Hahs 2013).

Plants serve as the foundation of most food webs and, thus, play a dominant role in determining species richness and community structure of organisms at higher trophic levels. An essential step to understanding the ecology of UA systems is to document the floral community on urban farms and in urban gardens. Habitat surveys along urban to rural gradients have shown that plant communities are generally more species-rich in areas with moderate and high levels of urbanization, compared to more rural habitats (McKinney 2008), perhaps because of the intermediate levels of disturbance and habitat diversity of urban landscapes (Porter, Forschner, and Blair 2001).

Food gardens are potentially important repositories of wildflowers and culturally-important food crops that would otherwise be unlikely to persist in an urban landscape. However, urban gardens have also been identified as key source of invasive plants (Reichard and White 2001; Smith, Thompson, and Hodgson 2006). Striking a balance between promoting and conserving biodiversity with limiting biological invasions will remain a challenge for urban farmers and gardeners.

Vegetables are the most common plant type cultivated and conserved on urban farms and in urban gardens (Blaine, Dawes, and Snider 2010; Matteson and Langellotto 2010; Taylor and Lovell 2014). Urban garden surveys (Finster, Gray, and Binns 2004; Saldivar-Tanaka and Krasny 2004; Matteson and Langellotto 2009; Pawelek et al. 2009; Taylor and Lovell 2014) have conservatively documented 99 species of plants being tended by urban gardeners. However, these surveys concentrated on edible varieties (Saldivar-Tanaka and Krasny 2004; Finster, Gray, and Binns 2004; K. Matteson and Langellotto 2009), ornamental species (Pawelek et al. 2009), or on assemblages of culturally-unique food crops (Taylor and Lovell 2014). In terms of the comprehensive plant community, surprisingly little is known regarding richness and composition of urban farms or gardens in the United States. We know even less about how these plant communities both influence and are influenced by a complex suite of socio-economic (Luck, Smallbone, and O'Brien 2009) and ecological factors, including: (1) management decisions; (2) habitat diversity in urban and suburban landscapes, (2) the regional plant species pool, (3) plant species' ability to colonize and persist in urban gardens and farms, (4) human tolerance of weedy plant species, (5) natural and human-mediated disturbance, and (6) soil and nutrient management practices.

There is widespread interest in advancing understanding regarding how microbial community composition and diversity impact ecosystem (Clarholm 1985; Coleman 2008; Gregorich, Drury, and Baldock 2001) Specific prescriptions for managing plant-microbe interactions to support a given ecosystem function or set of functions are only in the early stages of development. We have the greatest information about certain symbiotic associations; for example, interactions between legumes and rhizobia bacteria, or between plants such as corn and mycorrhizal fungi. But, understanding the functions of free-living microbes and microbial diversity in the rhizosphere – the zone between plant roots and the soil – is currently an important research frontier (McNear Jr. 2013).

Microorganisms in the plant root zone, and the ecological interactions that occur with higher levels of soil food web (trophic) complexity, support a range of ecosystem functions including soil aggregation, water holding capacity, carbon (C)-storage, and nutrient cycling (e.g., Clarholm, 1985; Drinkwater and Snapp, 2007). Plant roots leak labile C substrates, which are an energy source for microorganisms. These C inputs thus fuel microbial processes, such as decomposition of soil organic matter and nutrient turnover, which help to support crop production by increasing plant nutrient acquisition.

Beyond just root exudates, more diverse plant communities (e.g., cover crops, diverse crop rotations) supply a greater diversity of above- and below-ground residue inputs to soil, which likely support greater microbial diversity and soil food web complexity. In addition, industrial agricultural practices, such as intensive tillage, monocultures (i.e., reduced plant diversity in space and time), and chemical inputs, dramatically alter the soil environment, and have likely unintentionally selected for different microbial communities than the ones that evolved in natural or low-input agricultural systems (Drinkwater and Snapp 2007).

As is true for other managed ecosystems, while humans exert direct control over urban garden plant communities, they likely only have indirect control over microbial diversity. One critical issue that may be an important driver of microbial diversity in UA soils is heavy metal contamination. Toxic levels of metals in soils can reduce the number, diversity and activity of soil organisms, with cascading effects on microbial functions such as soil organic matter decomposition and nitrogen mineralization (Filip 2002).

In addition to potential impacts on the soil microbiome, contaminants are a food safety and health concern for growing food in urban settings. The most ubiquitous contaminant in urban soils is lead. The addition of lead to gasoline and paint was phased out in the 1970s; however, lead remains bound to soil as very small, insoluble (Clark, Brabander, and Erdil 2006). Other sources of contaminants include former pesticide use, industrial waste, treated lumber, petroleum spills, and landfills. Since lead is very insoluble it persists in soil and accumulates at the surface, unless gardening or farming activities mix it into deeper layers, for example, through tillage. The bioavailability of lead in soils depends on a suite of factors including the concentration of lead in soil, soil chemical properties and mineralogy, texture, pH, soil organic matter, and soil moisture and temperature (CWMI, 2009). These constituents not only affect biodiversity, but are also an important consideration for food quality.

To sustainably produce food in cities, it is critical to understand the factors influencing the occurrence of herbivore pests. Yet, there has been little focus on documenting if factors unique to urban production influence pest outbreaks and yield loss. Examination of ornamental plant pests in cities has demonstrated that increasing landscape plant diversity often decreases the severity of outbreaks (Hanks and Denno 1993; Shrewsbury and Raupp 2000; Shrewsbury and Raupp 2006; Tooker and Hanks 2000). Practices such as composting, less intensive weeding, reduced pesticide use, and maintaining plant diversity have been shown to increase arthropod richness in urban gardens (Jaganmohan et al. 2012), likely favoring greater richness or predators and parasitoids and reduced pest damage.

Maintaining a rich and diverse fauna of natural enemies is critical to sustainable pest management. The vast majority of urban agroecosystems were created from vacant lots, and several studies have examined how this change influences arthropod communities. Research conducted in Akron, Cleveland, and Toledo, OH and Detroit, MI found similar abundances or activity densities of several above-ground and ground-dwelling natural enemy groups among vacant lots and urban agroecosystems (Uno, Cotton, and Philpott 2010; M. Gardiner 2013). However, conversion of vacant land to agriculture can negatively impact some predatory taxa such as natural cavity-nesting ants (*Formicidae*), long-legged flies (*Dolichopodidae*), sheetweb spiders (*Linyphiidae*) and harvestmen (*Opiliones*) (Uno, Cotton, and Philpott 2010; M. Gardiner 2013; Burkman and Gardiner 2015). Garden construction can also reduce soil food web productivity, as indicated by reduced total nematode abundance, free-living nematode abundance and the number of nematode genera found within 1-2 year old garden sites (S. Grewal et al. 2011). However, these appear to be short-term impacts as established gardens (15-30 years of cultivation) and vacant lots in Cleveland Ohio had similar nematode communities (Grewal et al. 2011).

Matteson and Langellotto (2009) report that 92% of crops commonly grown in New York City community gardens require or benefit from bee pollination services. Urban garden sites host a variety of pollinators, and with proper management can become key sites for pollinator conservation. Urban gardens in New York City's Bronx and east Harlem, for example, were found to host 54 bee species, comprising 13% of the total bee fauna of New York State (K. C. Matteson, Ascher, and Langellotto 2008). Matteson et al. (2008) noted their urban garden sites were characterized by more cavity-nesting and exotic species than rural areas. In northwest Ohio, 66 bee species were found in residential backyard urban gardens (Pardee and Philpott 2014). Current surveys in St. Louis boast the highest number of bee species found in North American urban gardens, with 108 bee species catalogued to date (pers. comm. Dr. Gerardo Camilo). In the United States, a larger number of studies have quantified pollinator communities in other urban green spaces (e.g. parks, cemeteries, natural area remnants, etc.) (Cane et al. 2006; Frankie et al. 2009; Lowenstein et al. 2014; Winfree, Griswold, and Kremen 2007). Many of these studies found diverse assemblages of pollinators, indicating that given adequate floral and nesting resource levels, urban gardens have great potential to conserve diverse pollinator populations (Blackmore and Goulson 2014).

Several studies have examined factors influencing bird and bat community composition in urban gardens. The size of a garden habitat is a key factor, with larger sites supporting greater avian diversity (Heezik, Smyth, and Mathieu 2008; Strohbach, Lerman, and Warren 2013). Garden heterogeneity, including high tree and shrub richness and a high proportion of native vegetation, can increase diversity of insectivorous birds in urban areas (French, Major, and Hely 2005; Andersson, Barthel, and Ahrné 2007). Further, Good (2000) found that planting fruit/seed bearing plants, limiting chemical use, constructing compost heaps and providing feeders increased bird and vertebrate abundance and diversity. Urban gardens can also provide important habitat for amphibians; Carrier and Beebee (2003) surveyed rural and urban populations of the common frog *Rana temporaria*, and found that urban populations had fewer decreases and more increases than rural ones (Carrier and Beebee 2003). The creation and management of urban agroecosystems may also provide habitat for animals such as feral cats, dogs, rats and other rodents, which have been demonstrated to have a significant negative impact on bird populations as well as other wildlife (Sims and Evans 2008; Beckerman, Boots, and Gaston 2007). Attracting wildlife to urban farms may also influence risks posed by wildlife pathogens, as transmission of some diseases increasing in urban-adapted hosts (Bradley and Altizer 2007).

We currently lack a mechanistic understanding of biodiversity-ecosystem function relationships within urban agroecosystems, which mirrors lack of study in other urban ecosystems. Most of the work conducted has focused on the relationship between predator community composition and resource capture of prey. Yadav et al. (2012) and Gardiner et al. (2014) used sentinel or indicator prey to compare predation rates amongst vacant lots and community gardens. Yadav et al. (2012) found reduced mortality of the moth larvae within community gardens, as well as differences in the composition the natural enemy community. Gardiner et al. (2013) used moth eggs and fly pupae as indicators of above-ground and ground-level predator activity. Generalist predators significantly reduced the abundance of all indicator prey present within both garden and vacant lot habitats. Overall, predatory function was maintained within community gardens relative to vacant lots (Gardiner, Burkman, and Prajzner 2013). The extent of egg biocontrol supplied was low in early summer but increased late in the growing season. Farm location can also influence the activity of natural enemies. Quispe and Fenoglio (2015) found that farming on green roofs led to a reduction in parasitism of a leafminer versus rates measured in ground level gardens. Building on these studies, examination of crop-specific pest-natural enemy interactions and the impact of pest suppression on food system sustainability is a key area for future research. Likewise, little is known of the effects of urban specific factors, such as wind trajectories (due to buildings and other urban infrastructure), temperature (heat island effects), and spatial configuration of urban gardens on the dispersal of pollinators, herbivores and their natural enemies in urban landscapes.

It has been proposed that urban gardens contribute to food security and to the conservation of agrobiodiversity, which in turn contributes to human nutritional diversity. The evidence to support this is thin but growing (Lovell and Taylor 2013). Studies of home gardens from all over the world suggest that these gardens are hotspots of agrobiodiversity, with the average number of species cultivated reaching 45 in Ghana (Bennett-Lartey 2002) and ranging from 20 to 103 in the Mekong Delta of Vietnam (Trinh et al. 2003). However, these home gardens are found both in urban and rural areas and most of the studies come from rural areas in the tropics where agrobiodiversity is generally high. The small amount of research available suggests that urban gardens and home gardens may conserve agrobiodiversity both at the species and genetic level (WinklerPrins 2003). For example, for the allotment gardens in the UK, Gilbert (2013) showed levels of edible plant species richness close to those reported for tropical gardens in South America. Home gardens have been shown to have high genetic diversity. In Cuba 59 landraces of lima beans were reported from home gardens (Castiñeiras et al. 2007), while studies of home gardens in Italy documented 10 varieties of asparagus, 10 varieties of potatoes, 38 varieties of apples, 21 varieties of cherries and 29 varieties of pears (Pavia et al. 2009; Laghetti, Miceli, and Cifarelli 2004). Although genetic diversity is rarely measured in studies of urban agriculture, it has been shown that urban gardens help conserve heirloom and folk varieties through the practice of seed saving, although commercial seed availability tend to reduce this activity (Gilbert 2013). Molecular analyses detected high diversity among landraces of tomatoes, cowpeas, celery and runner beans in smallholdings in Italy (Negri and Tosti 2002; Tosti and Negri 2005), although most of these were in rural smallholdings and not urban gardens. In Alta Verapaz, Guatemala, the diversity of Capsicum from home gardens was similar to that preserve in local gene banks and the home garden populations were richer in rare alleles and infrequent genetic variants (Guzmán et al. 2005). It has been argued that home gardens should be considered sites of insipient crop domestication and in situ conservation since they are frequent sites of experimentation, where decisions are made about which plants should be left to prosper and which ones should be eliminated (Aguilar-Støen, Moe, and Camargo-Ricalde 2009; Galluzzi, Eyzaguirre, and Negri 2010; Bennett-Lartey 2002; Trinh et al. 2003)

2.5 Urban Agriculture and Socio-Economic Dynamics

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Four key points are crucial when considering the socio-economic dynamics of UA. First, It is important to situate UA within the broader social, political, economic, and cultural context- i.e. to understand why people participate. Given its role as a coping strategy, UA has often ebbed and flowed in time with economic prosperity, spreading during times of economic crisis and austerity and ebbing when the economy improves. During the economic recessions and depressions of the 1890s, 1930s, and 1970s, as well as during both World Wars, UA saw marked increases in the US (Bassett 1981; Lawson 2005; N McClintock 2010). During WWII, 5 million gardeners are estimated to have grown $520 million worth of food and 42 percent of the country's vegetables in Victory Gardens (Lawson 2005). Not only did UA supplement diets, it also served as a social "safety valve" to keep hungry populations from partaking in food riots in response to rising food prices

UA was not only a result of economic hardship, however (Moore 2006). Even in more bountiful times, UA was integrated into the urban landscape. Many factories provided gardens for workers, and the single-family homes increasingly available to workers had yards large enough for small kitchen gardens. One way UA was used was for social engineering, e.g., training school children and immigrants to work efficiently and obediently while instilling American entrepreneurial values. UA was also instrumental in the City Beautiful movement that emerged from public health/hygienist efforts to clean up the urban environment (Bassett 1981; Lawson 2005).

While economic uncertainty certainly spurred interest in UA in the 1970s and again in the late 2000s, other factors have contributed to its popularity during these more recent times. The rise of the counter-culture and the environmental and anti-war movements during the 1960s fostered a do-it-yourself, back-to-the-land ethic that also inspired urban dwellers less willing to move to the numerous communes arising in the countryside. At the same time, radical activists of color, including the Black Panthers, launched inner-city food programs and maintained gardens as a means of self-sufficiency to buffer against dire economic conditions and systemic racism (Alkon 2012; Potorti 2014). Not long after, concern over the chemical-intensive Green Revolution technologies developed to feed a growing population fueled a vibrant sustainable agriculture movement. Soon thereafter, during the so-called "urban crisis" and economic recession of the 1970s, community activists began to transform vacant properties into community gardens, to create green space and build community. Most recently, the current wave of UA has emerged from the confluence of numerous social movements and cultural changes, including: the rise of the anti-hunger/community food security movement arising in the wake of the rollback of the social safety net since the 1980s; the rise of the sustainable development agenda and its emphasis on urban greening; growing public awareness of the social and environmental externalities of the industrial agri-food system; and the growing popularity of locally grown, organic produce; and a concomitant culinary revolution prizing farm-to-table, slow food (Fairfax 2012; Lyson 2004). The economic downturn of the late 2000s further spurred UA's popularity (Schupp and Sharp 2012; Tavernise 2012).

Second, recent reviews of UA research have helped identify the potential socio-economic benefits and functions of UA (Draper & Freedman, 2010; Guitart et al., 2012; Taylor & Lovell, 2014). These include: enhanced health and nutrition, greater food security, additional income, community-building and community development, education and knowledge transfer, cultural, and connections to broader movements for food democracy and food sovereignty. However, such benefits may be overstated and are context-specific, i.e., they are true in certain situations and for certain problems, and for some, but not all, forms of UA. For example, health, food security and income benefits are primarily reported in low-income countries where households spend significant amounts of their income on food – as high as 60% in some countries, compared to less than 10% in the United States (Zezza and Tasciotti 2010) where urban land values, employment opportunities, and standards of living are different. While UA has enabled community-building by African Americans in Detroit and Latino communities in New York, the motivations of well-meaning UA advocates who pursue work in low-access communities often do not correspond to the expressed needs of community members (Alkon, 2012; Guthman, 2008; Lyson, 2014; Ramírez, 2015; Slocum, 2006). There is also evidence that UA is often dominated by – and disproportionately benefits – a predominantly white, educated, and affluent population, often by invoking environmental-, ecological-, and sustainability-oriented discourse (Alkon & Agyeman, 2011; Allen, 2010a; Guthman, 2008; Ramírez, 2015; Slocum, 2006). Despite these limits and complexities, practitioners and scholars emphasize that UA can play a role in connecting people to for food democracy and food sovereignty. UA participants may engage in conversation about who controls and shapes the food system, and ultimately be empowered to take ownership of the food system and the urban environment (McClintock, 2014). Community gardens and urban farming projects can be seen as ways of developing resistance, building community, establishing alternatives to the corporate food system (Lindemann, 2014) land forging the "right to the city (Purcell & Tyman, 2014).This complexity suggests the need for a nuanced and sophisticated understanding of the potential of UA in fostering socio-economic benefits.

Third, policy can offer opportunities to scale up UA, However, such policy must be executed thoughtfully to not exacerbate the aspects of UA that researchers have critiqued. Throughout the world, different governments at different levels have varying approaches to UA. Particularly in North America, municipal-level governments have, in recent decades, begun taking actions to encourage and support UA activities. Main strategies have included long-range planning, removing regulatory barriers, and providing land, government staff and/or funding for UA projects and programming. Often, one identified goal for such policy change is to encourage the potential socioeconomic benefits of UA, such as increased health, food security, youth empowerment, and community-building. Some governments have responded to some of the critiques previously discussed. As one example, the City of Seattle used to fund community gardens through a grant process (Horst 2015). However, both through outsider comment and its own analysis, city staff realized the process tended to reward communities that were well-off and educated. Subsequently, the City has made changes to prioritize new investments in lower income, diverse neighborhoods. Other cities have similarly paid explicit attention to these kinds of socio-economic issues (ref).

Policy sometimes (unintentionally or not) leads to contradictory outcomes. One critique of the recent focus on urban food is that policies privilege certain forms of UA above others. Notably capital-intensive commercial forms or aesthetically conscious "edible landscaping" are privileged. This disproportionately benefits young, white UA practitioners, rather than poor or immigrant practitioners (Cohen and Reynolds 2014; Reynolds 2009). Another critique of UA policy and planning points to failures of the participatory process. Planners and local government often initiate participatory processes (ranging from listening sessions to ongoing multi-stakeholder Food Policy Councils) in attempts to involve broader population and diverse communities in UA issues. While participatory planning is idealized as a way to hear a diversity of voices and have many interests represented, it often does not achieve those ideals. As Purcell (2009) points out, participatory planning processes do not necessarily challenge existing power relations, and they even tend to rob minority interests of their capacity to dissent. In food systems planning processes specifically, researchers have identified the lack of and challenges to engaging diverse community members in food systems planning (Coplen 2015). Additionally, Purcell's (2009) concern about obscuring structural power relations also seems to bear out more broadly in many UA policy situations. While empowering marginalized people to transform their individual lives, attention to UA often fails to explicitly challenge the systemic conditions that produce marginalization and food insecurity (Pudup 2008). The emphasis on "growing-your-own" reinforces neoliberal (i.e., anti-welfare, market-centric) notions of personal responsibility and self-improvement, and disproportionately impacts low-income people who are not only more food insecure, but also more strapped for time, energy and resources.

Finally, there is a need for researchers and policymakers to pay ongoing attention to who has power over UA and who benefits. If these questions are not asked, UA may perpetuate an inequitable system that is legitimated through progressive, feel-good narratives about the positive impact that UA can have (Reynolds 2015). Already, there is evidence that white-led UA organizations disproportionately receive grant funding and other support from public and private sources (Cohen & Reynolds 2014, 2015). Another potential problem is that UA could be subsumed by corporate agri-food. Furthermore, corporate food interests are now financing and sponsoring UA operations, and in return benefitting from the appearance of their commitment to sustainable and just food production.

3 Integrative Approaches to City-Region FEW Systems

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Food, energy, and water (each a complex, dynamic system) have traditionally been studied by different disciplines and managed as independent sectors, with insufficient consideration to linkages and potential synergies. 'Scaling-up' urban agriculture will significantly reshape the food, energy, and water flows, both within the urban consumption boundary and beyond to more distal production geographies. Research streams – food supply and use, water supply and use, energy use, ecosystem health, socio-economic welfare, land use considerations and governance – reflect particular disciplinary-based expertise and topical foci. Consequently, the linkages between these physical, social, economic, and ecological systems are not well understood. Similarly, urban infrastructures (e.g. energy, water, food) have traditionally been studied and managed as independent systems in isolation (Ramaswami 2006). As with urban agriculture, however, these infrastructures are highly interdependent; like food webs, they combine to form an infrastructure ecology (Xu et al. 2012). Like infrastructure, urban FEW interactions need to be understood as complex, emergent, and adaptive (or inadaptive) systems nested within a broader socio-economic context. Indeed, one of the primary challenges is that these interactions have become interconnected in ways that we haven't mapped and delineated yet.

With respect to integrative FEW system modeling, there are a great many research challenges and needs g. Some priority challenges include the following: 1) integration across temporal, geographic, and jurisdictional scales; 2) integration of socio-economic, physical, and ecological systems; 3) understanding the dynamic interactions within and between food, energy, and water; 4) management and integration of heterogeneous data; 5) Data visualization and visual analytic; and 6) Scenario development, decision-support, and collaborative planning. To date, studies have largely examined material and energy flows of the individual FEW systems; but comprehensive studies on the interactions of components of the FEW systems as an integrated whole are only now emerging.

Understanding the full range of FEW impacts associated with scaling-up urban agriculture necessitates an integrated conceptualization of the urban system as a complex, adaptive system. But the associated complexity extends beyond the expertise of a particular discipline or sector. The challenge, therefore, is to develop an integrative framework: one that allows the natural science, social science, and physical science (engineering) communities to communicate and collaborate effectively, thereby leveraging their respective disciplinary strengths and expertise. Interestingly, the various physical, natural science, social science, and engineering communities that interact with these systems bring similar methods of analysis to evaluate them "flows" of mass, energy, water, information and influence, within a vast "network." An opportunity exists, therefore, to bring the relevant disciplines together to identify benefits, challenges, and transition pathways for "scaling-up" urban agriculture and its dynamic impacts on the productivity and efficiency of FEW systems.

The purpose of this section, therefore, is to present some promising integrative approaches to urban FEW system modeling. We detail the present state of development, as well as identify additional needs to expand and diversify these efforts.

3.1 Urban Metabolism Approaches: Three Ecologies

Numerous scholars have identified the "urban metabolism" concept as especially appropriate for interdisciplinary collaboration (Kennedy et al. 2011, 2012; Broto et al. 2012; Pincetl et al. 2012; Ramaswami et al. 2012). Although the concept travels across the engineering, natural science, and social science community, urban metabolism research has evolved into a series of relatively distinct research frameworks amongst various disciplines, with varying definitions, theories, models, and emphases. Reviewing the urban metabolism research over a 49-year period (1965-2014), Newell and Cousins (2015) identified the formation of three distinct scholarly islands or "ecologies" of urban metabolism: 1) industrial ecology; 2) political ecology: and (3) urban ecology.

Industrial ecology focuses on the quantification of material and energy stocks and flows into, within, and out of cities, using accounting methodologies such as material flow analysis and life cycle assessment (Kennedy, Cuddihy, and Engel-yan 2007). Within industrial ecology, urban metabolism is defined as 'the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste' (Kennedy, Cuddihy, and Engel-Yan 2007: 44). Reflecting particular disciplinary and topical emphases, a primary criticism of this approach has been the often overriding focus on quantifying the materials/energy inputs and wastes/emissions outputs across the city boundary, with insufficient attention to how socio-economic and socio-ecological processes within the cities drive these distal resource flows (e.g. teleconnections). Obviously, urban FEW flows occur only because there is demand for them. Effectively, these demand-creating processes are "black-boxed" in traditional urban metabolism modeling, but understanding how these consumption drivers (whether they be socio-economic, demographic, geographic, or due to the urban form itself) shape the resulting material and energy flows is essential if to transition toward sustainable and resilient cities. Second, although the resource flows are hypothetically connected to distal production and consumption spaces (e.g. 'the hinterland'), much of the urban metabolism work in industrial ecology has been largely aspatial with respect to grounding the origins of water, food, materials, and energy flows in specific geographies.

In political ecology, closely aligned with human geography and anthropology, scholars focus on interwoven knots of social and natural processes, material flows, and spatial structures that form the urban metabolism (Heynen, Kaika, and Swyngedouw 2006). This community of scholars utilizes the metaphor to unveil uneven power relationships shaping urban space, with the normative goal of fostering more sustainable and democratic forms of urban environmental governance and policy making (Keil and Desfor, 2003; Swyngedouw, 2004; Swyngedouw and Heynen, 2003). McClintock's (2010) work reveals, from ecological, social, and individual perspectives, how urban agriculture is both an outcome of the rift's alienating forces and an attempt to ameliorate it by reconnecting urbanites with food production.

In this research, there are three emphases that have become limitations with respect to advancing urban metabolism research. First, although urban areas are conceptualized as a hybridized socio-natural process, the focus is clearly on the social and political dynamics shaping urban metabolisms. This has led critics to ask where is the ecology in much of the political ecology research (Walker 2005). Second, the research exhibits a 'methodological city-ism' that conceptualizes the spatio-temporal dimensions of planetary urbanism, but paradoxically maintains an empirical focus that privileges bounded conceptualizations of the city (Angelo and Wachsmuth, 2014). This has resulted in case studies that focus on the city proper, rather than how the processes of urbanization occur at other sites and scales, or in delineating linkages between cities and the more distal sites of resource extraction and production that help sustain them. Third, qualitative approaches dominate this urban metabolism research, relying on either some combination or individual aspect of discourse and document analysis, archival methods, interview data, and participatory observation. Some of the research does engage with quantitative approaches (Heynen 2006; Cousins and Newell 2015), but these studies are a minority in the political ecology tradition.

In the field of urban ecology, which is strongly influenced by ecology and urban planning, the urban metabolism concept has been used with less persistence, which is somewhat surprising given the highly cited work on urban metabolism by ecologists and system ecologist EP Odum's continued influence in industrial ecology (Newell and Cousins 2015). For some ecologists, Odum's ideas are outmoded and misapplied with respect to the ecology of the city (Golubiewski 2012). A reading of the highly cited work in urban ecology indeed reveals ambivalence towards the metabolism concept, deploying it for its metaphorical power yet being cognizant of its contested status vis-à-vis cities within the ecology discipline (Newell and Cousins 2015). Thus Grimm et al. (2008) acknowledge the debate about its appropriateness but highlight its utility as a method to quantify resource consumption trends. Decker et al. (2000) use the term similarly in their synthesis of the material and energy flows of 25 world cities, as do Ngo and Pataki (2008) in their longitudinal mass-balance analysis of Los Angeles County's fuel, water, and food flows.

Rather than metabolism, urban ecologists such as Golubiewski (2012) propose 'ecosystem' – an assemblage of organisms interacting with the physical environment within a specified area (Likens, 1992; Tansley, 1935) – as the appropriate metaphor to characterize and model urban systems. Although industrial ecology and urban ecology are both rooted in systems thinking, the ecosystem concept Golubiewski proposes is informed by a complex systems theorization in which humans are integral components of an urban socio-ecological matrix (Alberti 1999; Grimm et al. 2000). Biotic and abiotic entities interact within a fairly bounded system to generate the emergent patterns and processes that define an urban ecosystem (Golubiewski, 2012). Research has focused, therefore, on understanding and modeling the complex patterns and processes of coupled human-ecological systems within urban areas (Grimm et al. 2008). Ecosystem-based urban models focus on simulating dynamic interactions between these socio-ecological entities. When operationalized empirically as a model, the ecosystem concept has led to prioritization of urban ecosystem complexity (and spatially bounded processes) at the expense of the more unbounded (and distal) flows coursing through the city. An emerging research theme is ecosystem service valuation of these urban systems (Hubacek and Kronenberg 2013). As with industrial ecology, the urban ecology enterprise is largely devoid of political concerns (e.g. uneven capitalist development, equality, and justice), and even the physical constraints of human infrastructure.

3.1.1 Developing an Interdisciplinary Urban Metabolism Approach

In traditional IE metabolism modeling, the interactions between stocks and flows, such as food, energy, and water, have not been prioritized. Rather the emphasis has been on quantifying as many material and energy flows as possible, often without looking at the interactions between and without looking at them as dynamic system that adapt over time (e.g. temporal snapshots of individual flows). In addition, IE urban metabolism studies have not incorporated socio-economic dynamics and ecological systems in the modeling efforts of the various cities. Finally, these urban metabolism studies have been largely of specific cities rather than across a wide-swath of cities.

With development, the urban metabolism concept holds particular promise as an integrative framework to characterize complex urban FEW system interactions. Each of these three 'ecologies' offer particular disciplinary strengths and, if integrated using urban metabolism as a boundary object (Newell and Cousins 2014), these integrated ecologies could greatly increase understanding of urban FEW systems – effectively integrating knowledge from social science, natural science, and engineering through a shared language and empirical focus. Toward that end, Figure 3 provides a conceptual schematic of the "urban metabolism" system that combines the respective expertise of these three ecologies. Essentially, in this schematic, the urban metabolism is composed of four subsystems—governance networks, networked material and energy flows, urban infrastructure and form, and socioeconomic dynamics. These subsystems are themselves, multi-scalar, networked, and often strongly coupled.

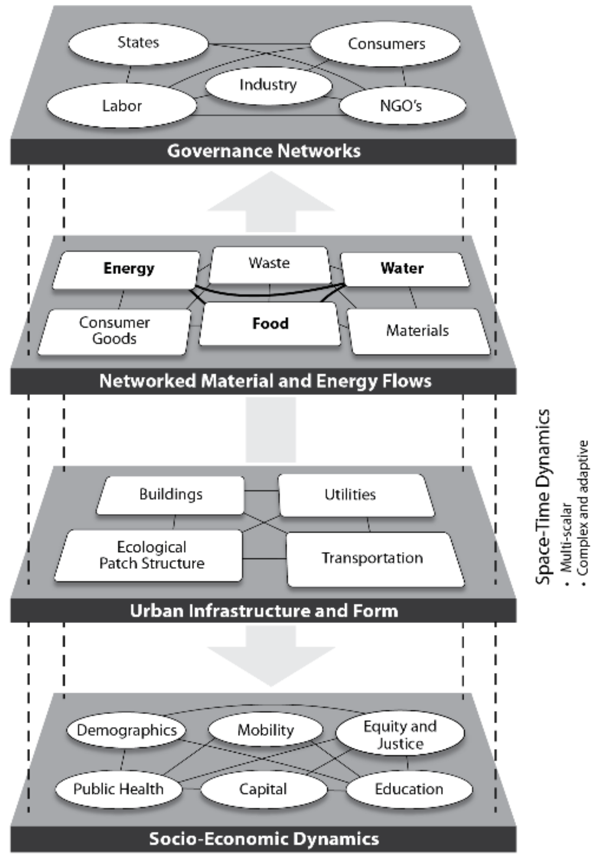

Figure 3 Conceptual Schematic of the Urban Metabolism
Source: (Meerow, Newell, and Stults 2016)

3.2 Socio-Ecological Infrastructure Systems Framework

As a way to better capture cross-scale interactions of the urban metabolism and incorporate social systems and actors, Ramaswami et al (2012b; 2012a) have developed a social-ecological-infrastructure (SEIS) framework. In the biophysical subsystem, the SEIS framework integrates direct material and energy flows with life cycle assessment to articulate transboundary infrastructure supply chain water, energy, and greenhouse gas (GHG) emission footprints of cities. These infrastructure footprints make visible multiple resources (water, energy, materials) used directly or indirectly (embodied) to support human activities in cities. The footprints are the result of multi-sectoral infrastructure systems analysis, including the supply and use of energy, water, food, transportation, and built environment materials (Ramaswami et al. 2008; Chavez et al. 2012; Chavez and Ramaswami 2013). These studies inform cross-scale and cross-infrastructure sector strategies for enhancing sustainability, as well as address multi-scalar public health risks and supply chain risks posed to urban residents and infrastructures. These risks range from lack of basic infrastructure provisions in the sectors noted above, including in FEW services, as well as other urban risk factors related to water and air pollution, extreme heat, cold and precipitation events, and supply chain risks such as risk to FEW supplies due to climate and other extreme events. In this manner the footprints address environmental sustainability as well as health risks and resilience.

In the social subsystem, multiple theories drawn from the social sciences explore interactions between three actor categories—individual resource users, infrastructure designers and operators, and policy actors—as they shape interactions of infrastructure with environmental sustainability, risk and human well-being outcomes. The SEIS framework has been applied to understand sources and strategies to reduce GHG emission from cities. Spatial mapping of urban supply chains is underway, as well as assessment of the interactions of environmental and health risk impacts. By enabling a number of theories and frameworks from the social sciences, the SEIS framework incorporates theories shaping consumption, environmental awareness and health risk perceptions of individuals. These theories and perspectives are drawn from economics and political science and urban planning and public affairs to inform the interactions between infrastructure operators and policy actors including, media, government, non-governmental officials. Operationalizing the interactions between the social and the biophysical system can be achieved through a number of research designs that span the multiple disciplines involved. Ramaswami and colleagues are starting to use the SEIS framework to analyze urban food systems from this systems-based, multi-scalar, multi-actor perspective.

3.3 Multi-Sectoral Systems Analysis

Understanding synergies and antagonisms among the many components of the urban system increases the chances of maximizing the impact of technology and policy options. Conversely, ignoring these interactions can reduce the positive impact of interventions that are implemented in an uncoordinated and isolated fashion. A widely used approach for understand these interactions is systems analysis. The Multi-sectoral Systems Analysis (MSA) modeling framework incorporates both systems analysis and Substance Flow Analysis (Brunner and Rechberger 2004).

MSA involves five sectors (i.e., energy, water, food, forestry and waste handling) and it has been applied primarily to understand the cross-sectoral and nexus ramifications of implementing certain technologies and policy. The MSA approach has been applied to urban areas such as Atlanta, London, and Suzhou, China (Villarroel Walker and Beck 2012; Villarroel Walker et al. 2014) MSA went further beyond estimating bulk flows of materials by calculating the energy, water and nutrient (C, N and P) content in flows, with the purpose of exploring the FEW nexus. The cases of Atlanta and London investigated options in the water sector that help producing flows with fertilizer – that could potentially provide nutrients for urban agriculture – and energy value. A study of the Upper Chattahoochee Watershed involved, in addition to a fifth of metro Atlanta, significant agricultural activity – largely the poultry industry – as a way to compare the role of urban and rural systems in the metabolism of energy, water, and nutrients. MSA's application in Suzhou, China analyzed various waste management options to maximize the recovery of nitrogen and phosphorus. The London case study was the first time that MSA included the impact of endogenous production of fertilizer – as opposed to conventional production of fertilizer via mining and the Haber-Bosch process – in terms of GHG and the potential monetary benefits of implementing four technological/policy options in the water sector. All these applications have in common the

Coupling MSA with Regionalized Sensitivity Analysis (RSA) introduces an alternative way of analyzing FEW systems. In this case, the starting point is the definition metrics and targets (e.g., nutrient recovery, urban agricultural production, and water savings metrics). The MSA/RSA approach reveals which features of the urban system (represented by model parameters) are crucial for reaching targets. Identifying these key parameters provides information about what technologies and policy instruments might need to be deployed in order to reach desired targets. Initial research was carried out in metro Atlanta, with the objective of closing the nitrogen cycle (R. V. Walker and Beck 2011). Ongoing research is being done to expand the London study and identify what is important (technology, policy, diet, or climate) for achieving renewable energy, nutrient recovery, and water saving targets (Villarroel Walker et al. 2016). One of the strengths of this approach is that it integrates the technical aspect of various socio-economic sectors, all relevant to urban agriculture.

3.4 System Dynamics Modeling

System dynamics employees a commodity balance, stock and flow approach to analyzing complex interacting systems. In this way, system dynamics methodology is synergistic with other modeling approach, including the urban metabolism approach. System dynamics is a systems-level modeling methodology developed at the Massachusetts Institute of Technology in the 1950s as a tool for business managers to analyze complex issues involving the stocks and flows of goods and services (REF). System dynamics is formulated on the premise that the structure of a system – the network of cause and effect relations between system elements – governs system behavior (Richardson 2013). “The systems approach is a discipline for seeing wholes, a discipline for seeing the structures that underlie complex domains. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots, and for seeing processes rather than objects” (Simonovic and Fahmy 1999). The strength of system dynamics is its ability to examine how the system structure influences decisions and how systems react to these decisions over time.

While system dynamics modeling has its roots in business management, its application has broadened, ranging from electro-mechanical control system, effects of economic development to applications in ecology, psychology, physiology and energy policy studies (Sastry and Sterman 1993). System dynamics has been recently used to explore the rural-urban divide; specifically, the sustainability of community-managed irrigation systems in northern New Mexico (Fernand et al. 2012; Turner and Tidwell 2015). These systems, which have survived centuries despite the arid environment in which they reside, are threatened by regional population growth, urbanization, gentrification, economic development, climate change, among others. This coupled human-natural system was conceptualized by four interacting subsystems: hydrology, ecosystem, land use/economics, and sociocultural. Combining field data, surveys and simulation have helped to identify tipping points for non-sustainability and thresholds for sustainable resource use and community longevity.

3.5 Complexity Modeling – Network Analysis

Network analysis is widely used to infer the causality between the structure and functionality of a complex system (Barabási and Albert 1999; Newman 2003; Newman 2010; Strogatz 2001; Watts and Strogatz 1998). A complex system, such as urban FEW systems, often involves heterogeneous components interacting with each other. A network representation regards the system as a network in which there are nodes interconnected by links. This provides a wiring diagram for the complex system, therefore enabling further investigation. Network analysis describes structural features of a network (e.g., the importance degree of individual nodes and links, clusters) and relate these structural features to network functionalities or properties. As a result, one can identify structural features that are correlated to particular network functionalities or properties, and potentially redesign the network to enhance desired functionalities or achieve desired properties. Network analysis has been applied in many fields, such as the economy (Blöchl et al. 2011; Hidalgo and Hausmann 2009; Kagawa et al. 2013; McNerney, Fath, and Silverberg 2013; Xu, Allenby, and Crittenden 2011), environment (Liang, Feng, and Xu 2015; Liang, Qu, and Xu 2016), transportation systems (Derrible 2012; Guimerà et al. 2005), water consumption modeling (Ahmad and Derrible 2015), food webs (Krause et al. 2003), and social networks (Birke 2013; Girvan and Newman 2002; Kim and Perez 2015). In particular, there is a branch of network analysis specially focusing on resources and environmental emissions, known as ecological network analysis (ENA) (Chen and Chen 2012). ENA analyzes the interdependence of nodes and importance degree of nodes within ecological networks. Moreover, ENA can assess the effectiveness of policies to be implemented in a network (Lu et al. 2015). The discipline of network science is seeing a rapid growth of knowledge on network-of-networks type systems, often called “multiplex” (De Domenico et al. 2013), that will also be relevant to study urban FEW systems. Indeed, as an integrated FEW system, a city can be considered as a complex network. Nodes of this network can be processes, and links are material and energy flows among processes. Network analysis techniques can be applied to uncover structural features of this FEW network, e.g., identifying critical processes and inter-process connections that have large impacts on urban nitrogen and phosphorus flows, energy flows, and water flows. It can also be used to evaluate the outcomes of policy scenarios.

3.6 Heterogeneous Data Integration

Understanding urban FEW systems requires the management of massive and diverse datasets, including their storage and integration. Those datasets are available from federal sources (e.g., USGS, NASA, EIA), from state and city sources, and from geospatial clearinghouses, tables, and linked open data (LOD) that are available on the web, and come in different formats, resolutions, monitoring frequencies, identifiers and geo-references. Figure 5 illustrates the variety of the datasets that need to be considered for each conceptual schematic layer.

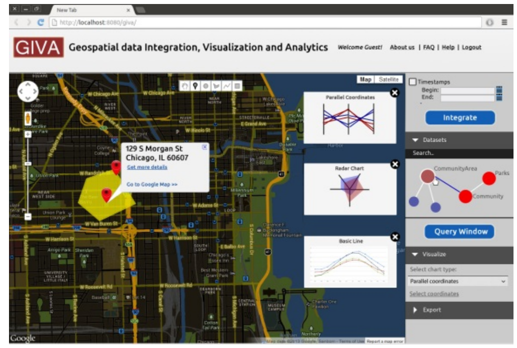

Figure 4 GIVA Visual Interface Design

Geographically, data can be point-based, but it is more often zone-based. Zones can sometimes aggregate into parent zones, as is the case with census blocks that aggregates into census tracts that then aggregate into municipalities and so on and so forth, but this is not always the case. In fact, most data sets that do not come from governmental agencies will then to adopt other units of analysis, e.g., the municipal neighborhood, the Traffic Analysis Zone, the Park, or even the pixel when using images from remote sensing data. Being able to aggregate or disaggregate these data to workable units to perform a comprehensive study of the metabolism of a city at a high resolution becomes difficult; studies tend to either concentrate on one unique energy or resource (Pincetl et al. 2015) as opposed to performing a full urban metabolism analysis, or focus on a selected few neighborhoods (Codoban and Kennedy 2008). Furthermore, this task becomes more challenging when a temporal element is added to the study, since zonal boundaries tend to change; even the Census Bureau updates its boundaries for every decennial census. While waiting for the "perfect" datasets is meaningless, new techniques must be developed to overcome some of these challenges

Scholars at the University of Illinois-Chicago have been designing and developing a semantic framework, *GIVA*, for *Geospatial and temporal data Integration, Visualization, and Analytics* (I. Cruz, Ganesh, et al. 2013). Given a geographic region and a time interval, GIVA addresses the problem of accessing simultaneously several datasets and of establishing mappings between the underlying concepts and instances, using automatic methods. These methods must consider several challenges, such as those that arise from heterogeneous formats, lack of metadata, and multiple spatial and temporal data scales. A web interface lets users interact with a map and select datasets to be integrated, displaying as a result reports where values pertaining to different datasets are compared, analyzed, and visualized. GIVA has been motivated by the data integration needs of an Urban Metabolism-project funded by an NSF CyberSEES project.[3] Figures 5 and 6 display respectively the architecture and visual interface design of GIVA.

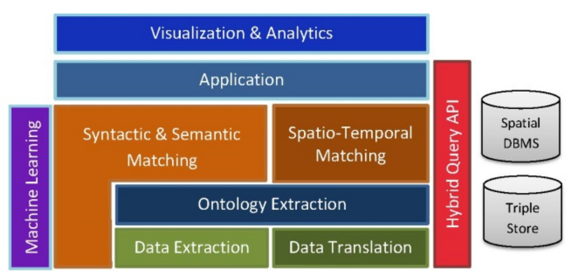

Figure 5 Architecture of the GIVA Framework

Within GIVA, a central functionality is centered around *matching*, the identification of correspondences among concepts, properties, and instances, using syntactic and semantic

[3] NSF Award #1331800, CyberSEES: Type 2: Data Integration for Urban Metabolism (PI: M. I. Cruz, co-PIs: T. Theis, N. Ai, S. Derrible, S. Dorevitch).

characteristics of the data, a process called *ontology matching*. The ADVIS Laboratory has implemented software for ontology matching, namely AgreementMaker (Cruz, Palandri Antonelli, and Stroe 2009; Cruz, Palmonari, et al. 2013) and AgreementMakerLight (Faria et al. 2013) that have been ranked first among the best such systems in the world (Shvaiko and Euzenat 2013). However, for spatial and temporal data, the challenges are enhanced by the multiple temporal, geographic, and jurisdictional scales (see Section 2.1).

Another major challenge within GIVA pertains to the extraction of information from web tables, which are heterogeneous in structure, concepts, and metadata. One of the challenges in semantically extracting geographic data is the need to resolve these heterogeneities so as to uncover a conceptual hierarchy, metadata associated with instances, and geographic information (Cruz, Ganesh, and Mirrezaei 2013). In a complex data integration task, we need to allow for a community of users to cooperate, for example in establishing correspondences among concepts in a variety of datasets in an iterative fashion. The ultimate objectives are effectiveness—improving the quality of the results as a function of the number of user interactions—and robustness—making the system as much as possible impervious to user validation errors (Cruz et al. 2014).

3.7 Data Visualization and Visual Analytics

Visualizing urban FEW systems therefore becomes fundamental for developing information processing in the context of different stages of scientific research and decision-making. A use-based approach has long been proven to be an effective way to reinforce human understanding of abstract data, including for georeferenced data (MacEachren and Kraak 1997). A traditional technique to project multiple variables onto a 2D graph is Multi-Dimensional Scaling (MDS), which creates an artificial distance for each point, calculating two coordinates that are then plotted on typical x-y axes. Another traditional technique is to assign one value per entity (e.g., one value for multiple variables for one zone) by calculating the area of a polygon formed on a radar / star chart; a 2D graph is essentially given as many axes as there are variables, and each value on each axis are linked forming a polygon. This technique, however, requires that each variable is first standardized, and it also does not typically account for weights.

Although an old concept, Fisher Information (FI) has recently been adapted to the study of system sustainability (Ahmad et al. 2015). The FI of individual entities is calculated over a period of time and plotted. It essentially integrates multiple variables together by defining them as system state and it determine how system states evolve over time. FI is then plotted against time, and when smoothed (using a block average technique), it can output insightful information on the overall behavior of a system; it requires clean data sets with no missing values and no errors, however.

In GIVA, we are implementing interactive maps and plots for multidimensional visualizations, such as star plots and parallel coordinates graphs, where users will be able to display one or multiple variables simultaneously as shown in Figure 3. Finally, a visualization component should also support the domain experts in their analytic tasks. For example, in the domain of ontology matching, we are developing interactive methods supported by visual analytics (Aurisano, Nanavaty, and Cruz, n.d.).

3.8 Scenarios, Decision-Support and Collaborative Planning

Developing management models that are both scientifically sound and publicly acceptable is often fraught with difficulty. If such models are developed “behind closed doors”, their operation, application and utility can appear obscure to stakeholders (Driessen and Glasbergen 2002). Rather, an open and participatory model development process can help overcome such problems by building familiarity, confidence and acceptance in the models, while allowing a more diverse group of participants to engage in the planning process (van den Belt 2004). The goal is to develop tools that are a tangible manifestation of the common understanding of a wide range of stakeholders, who in turn feel a sense of common, shared ownership and confidence in the resulting models (Tidwell, Vincent C., van den Brink

2008; Cockerill et al. 2007). In turn, this confidence will be conveyed to policy makers and the public contributing to widespread consensus in ensuing management decisions.

Effective stakeholder engagement generally requires use of more than just a model; that is more than a mathematical representation of a real-word system. Rather, the model needs to be accompanied by tools to help stakeholders access information to improve decision-making. In particular, a model decision support system (DSS) is required, which is the portal by which the expert or participant structures model input to simulate future desired conditions (Capdevila, Valdes, and Gupta 2011). A DSS is also needed to assist with the presentation and visualization of model results. There are a variety of cooperative modeling exercises supported with an accompanying DSS targeted at the shared needs of food, energy and water producers, resource managers, regulators and decision makers (Renger, Kolfschoten, and Vreede 2008). The DSS integrates analysis and optimization capabilities to identify trade-offs, and "best" alternatives among a broad list of FEW options and objectives. In each case the DSS was formulated in a modular architecture, facilitating tailored analyses over different geographical regions and scales (e.g., national, state, county, watershed, NERC region). Interactive interfaces allowed direct model control and access to real-time results displayed as charts, graphs and maps. Ultimately the open and interactive DSS provided a tool for evaluating competing policy and technical options relevant to the FEW nexus.

3.9 Conclusion

There are a range of integrative modeling approaches and frameworks available to better understand urban FEW systems. They each have certain strengths and weaknesses and disciplinary-bound orientations and structures. The challenge is to develop a framework that truly enables all relevant disciplines to contribute to a robust understanding of these complex systems.

4 Analysis of Synergies and Opportunities

As illustrated by some of the assessments summarized in Table 5, a significant portion of the human food requirement, especially for fruits and vegetables and some protein needs through aquaculture, could be met through agriculture in city-regions. The results of recent simulation modeling (Zumkehr and Campbell, 2015) suggest that up to 90% of food demand in U.S. urban areas can be met with local crops from within 100 miles. These results further suggest that most areas of the country could feed 80-100% of their populace with food raised within 50 miles. Using this definition of UA (both within and adjacent to the urban area), the impact of up-scaled agriculture in city-regions could be quite significant.

Scaling-up agriculture in the city-region can create significant FEW system opportunities, several of which have already been identified but will be summarized here. Figure 6 illustrates the potential interactions between food, energy, and water material flows in the city-region, illustrating potential synergies related to these material flows. Increased UA would allow used water from the urban water cycle to serve as a source of water for agriculture. While some may argue that UA uses too much water, especially in areas facing drought, water-sensitive UA practices may actually be models of water conservation and reuse. Nutrients from the urban water cycle could also provide the nutrients needed for agriculture, either directly in the pre-treated urban used water used for agriculture, or using nutrients recovered from the urban water cycle. Use of reclaimed used water for agriculture would also decrease the discharge of the pollutants contained in the used water to local water bodies. The residuals from agriculture (biomass and packaging materials), along with residuals from urban used water treatment, can serve as inputs to biological and thermal energy production. This should be done in a manner, however, that doesn't affect soil quality, as removing plant residues can reduce soil organic matter and soil fertility. Of course, water is needed for thermal energy production (cooling), and any reduction in thermo-electric power generation would, indirectly, reduce water demand.

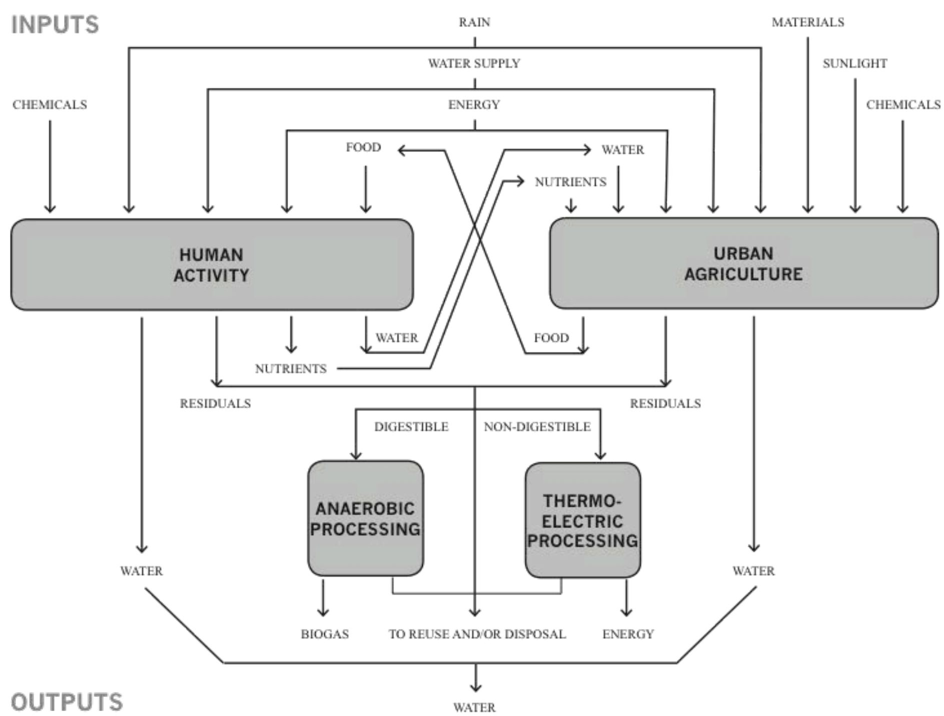

Figure 6 Urban Agriculture Food-Energy-Water Interactions

With increasing extreme weather events and uncertainty of water availability, agriculture production in the US has the potential to be negatively affected by climate change (US National Climate

Assessment 2014). Agriculture in city-regions has the potential to mitigate these impacts if an industrial ecology approach is taken, where controlled-environment agriculture systems use inputs that are predominantly from urban waste streams (e.g., flue gas, wastewater, biosolids). Zhanget al (2013) present one such system where natural gas demand can be reduced through the integration of manure disposal systems and greenhouse operations. Many sources of waste heat and carbon dioxide exist within the urban systems, from residences to industrial operations to electricity generation. Where natural gas is employed in these applications, greenhouse operations can utilize the relatively clean exhaust as a heat source, as well as CO_2 for crop fertilization.

Controlled-environment production systems can potentially protect crops from the climate variability and extremes that would otherwise affect open-field production systems. These more secure (and potentially higher yielding - see Martínez-Blanco et al. 2011) operations would bring greater certainty in yields, as well as improved resilience, relative to the uncertainty of the broader food supply chain that is vulnerable to the anticipated increasingly severe impacts of climate change. Of course, there are challenges in that these types of production systems can use more energy.

Although waste should be minimized, there will always be food and crop waste that can serve as feedstock for bio-energy production. Levis & Barlaz (2011) assessed the environmental performance (GHG emissions, NOx, SO2 and net energy demand) of food waste disposal in nine common waste management systems and found that anaerobic digestion of waste performed best for each metric. Additionally, given a 2010 estimate of 190 kg of food discarded per capita at the retail and consumer levels, a substantial opportunity exists to utilize this wasted/lost food for electricity and heat production(Buzby, Farah-Wells, and Hyman 2014). Considering the proximity to end users of heat and electricity, cogeneration using biogas from anaerobic digestion facilities could become more economically attractive in an urban context.

The IPCC (2006) suggests a methane (CH_4) generation potential of between 0 - 8 g CH_4 per kg of wet waste; assuming a value of 5 g CH_4 per kg of wet waste, and a US population of 322,750,000 (US Census, 2015), this amounts to approximately 300 kt CH_4 generation each year. Using estimates of 184 kWh of electricity generated and 810 MJ of heat per tonne of wet waste (from Møller et al. 2009), this quantity of food waste has the potential to provide electricity for 2.6 million Nissan Leaf all-electric vehicles,[4] and the equivalent heating demand for over 700,000 Michigan homes[5], respectively. Additionally, situating anaerobic digesters near UA operations could enable reuse of digestate (such as in Garfí et al. 2011) and reduce transportation costs for waste diversion. However, policy interventions will be necessary to encourage broader investment in anaerobic digestion (Binkley et al. 2013).

A variety of scenarios could be imagined with regard to biodiversity. Regarding the biological aspects, there will be an enormous difference if the scaling up is conducted using agro-ecological principles and practices or using conventional industrial agricultural practices. Likewise, the scale of production will affect biodiversity and the ecosystem functions that it can provide to urban agriculture. Here it is important to distinguish between "scaling up" versus "scaling out." Both cases refer to a significant increase in the production of food within the urban landscape but scaling up assumes the establishment of large scale farms while scaling out implies many more small-scale farms distributed across the urban and peri-urban landscape. Obviously, the size and configuration of the urban farms will impact biodiversity and ecosystem function differently. If UA is scaled up using chemical-intensive practices, it would likely increase nutrient pollution of waterways and pesticide contamination. If scaling up is done incorrectly, nutrient leaching into the aquifer and pesticide contamination could become

[4] Assuming 15,000 miles per year, Leaf mileage of 29 kWh/100 miles (http://www.fueleconomy.gov/)
[5] Average Michigan home consumes 123 million BTU, 55% for heating http://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/mi.pdf

widespread. Intercropping is a common component of urban gardens, and it would be an excellent outcome if this practice was continued as scaling up and/or scaling out occurs.

Indeed, it is important to consider the specific social configurations of production when considering such feedbacks, as particular forms of agriculture may result in particular ecological feedbacks when scaled up. Scaling up commercial UA ultimately poses the same risks as it does in rural areas, since market pressures of commercial marketing at a large scale create pressures to side-step ecologically sound methodologies in order to lower costs of production (particularly labor). Simply scaling up and/or shifting production closer to the city without commitment to increasing agroecological practices risks maintenance of the status quo. An increase in small gardens, on the other hand, might result in a different set of concerns at the landscape-scale. Currently, the general scientific consensus is that the urban landscape is a heterogeneous mixture of habitats, where most pests and their natural controls exist in a metapopulational structure. An increase of small gardens could increase inter-garden migration rates to the point that metapopulation structure could be interrupted, with unpredictable consequences. . At the same time, such large-scale expansion could also dramatically decrease urban heat island effects. These potential trade-offs must be studied and considered

Equally important to consider are the social structures, institutions, and dynamics as scaling up occurs. While UA might lead to increased food sovereignty, empowerment, and all of the other benefits listed in Section 2.5 above, policy and governance must be executed thoughtfully using equity as a guiding concern, so as to not exacerbate the various negative ramifications identified by researchers. When discussing the scaling-up of UA governance, the political and social systems that create inequities and precariousness must be addressed (Cohen and Reynolds 2015) so that efforts to scale up UA re-inscribe paternalistic, colonial patterns of oppression of people of color. Moreover, UA may ultimately perpetuate the status quo, particularly if governance and management over localized production is centralized, as is the case in the current, vertically integrated agri-food system (Hendrickson and Heffernan 2002). UA could easily be subsumed by corporate agri-food (as many organic food companies have been (Guthman 2004). Corporate food interests are already financing and sponsoring UA operations, and in return are benefitting from the appearance of their commitment to sustainable and just food production, an appearance that typically does not align with their broader business practices.

Debates are ongoing about whether limited vacant land should be used for UA, rather than other social goals such as affordable housing or denser housing, which would support transit. Such efforts should not be pitted against one another, but rather seen as complementary aspects of a vision of sustainable and just urban regions. Potential space for UA should include not only vacant lots, but also fringe spaces, underused rights-of-way, rooftops, school lots, and more. At the same time, care must be taken that such efforts do not contribute to and/or exacerbate processes of "eco-gentrification" and displacement (Nathan McClintock 2014). Using an equity lens when scaling up city-region agriculture will help mediate many of these negative socioeconomic consequences of re-localization of agriculture in and around urban centers.

This analysis of synergies thus allows for the evaluation of the three overarching hypotheses evaluated in the workshop. Here they are re-stated based on outcomes from the workshop and briefly assessed.

Hypothesis #1: Scaling-Up Agriculture in the City-Region, and Its Associated Energy and Water Systems, Can Produce Multiple Benefits in Urban Environments While, at the Same Time, Mitigate a Range of Broader Environmental and Socio-Economic Impacts.

The potential for these benefits has been documented in this White Paper. There are also potential drawbacks and challenges that need to be addressed as well. Significant material flow synergies are created by locating agriculture within and adjacent to urban areas that can reduce water use, enable nutrient recycling, produce energy, and decrease net energy requirements. Lower water use, increased material recycling, and reduced use of fossil fuels will also reduce associated pollution and other adverse environmental impacts. Up-scaled urban and peri-urban agriculture additionally offers the potential to increase biodiversity and the net environmental services in city-regions, as well as important social equity and food access opportunities. But, depending on the approaches and technologies used, the opposite is also possible. Up-scaling agriculture in the city-region is almost certain to have both positive and adverse socio-economic effects. This is, again, an area requiring significant additional research and attention during implementation. The broader impacts on the overall food production system also need to be considered, as increasingly locating agriculture within and adjacent to urban areas will have significant impacts on rural areas and, in fact, the entire agricultural system. It also needs to be recognized that significant up-scaling of agriculture in the city-region will require time, and during this extended transition period rural agricultural practices will evolve and overall production is likely to expand. Thus, approaches to up-scaling agriculture in the city-region must be evaluated relative to future rural agricultural systems and with increased overall food production, rather than simply to the current food supply system.

Much remains to be learned in this regard, as will be addressed Section 6 research gaps. Maximizing the benefits and minimizing adverse impacts will require close attention and careful management of the actual approaches take.

Hypothesis #2: Urban FEW Systems Can Be Evaluated Using Integrative Approaches that Consider Material Flows Along with Ecological and Socio-Economic Factors. This can enable the Delineation of Complex Dynamics and Inform How to Move toward Implementing a More Integrated System

Agriculture systems at any scale are complex systems, with all of the inherent difficulties to characterize, understand, and analyze them. The importance of not only material flow but also ecological and socio-economic factors are clearly illustrated above and were highlighted at the workshop. A variety of integrative approaches are available, each with their strengths and weaknesses, but none appears to yet be truly comprehensive. The need for an integrative evaluation approach is further emphasized by the recognition that up-scaled agriculture in the city-region must be asssessed relative to future scenarios, not the current situation. Up-scaled agriculture in the city-region will not necessarily result in less rural agriculture, but may simply reduce expansion of rural agriculture in response to growing food demands. The structure of rural agriculture is also likely to evolve, and increased UA may affect the trajectory for rural agriculture. These considerations illustrate the complexity of the required analyses.

Hypothesis # 3: Although Urban FEW Systems are Complex, There are Discrete "Tipping Points" That can initiate a Rapid Transition to Alternative States

Agriculture in the city-region has ebbed and flowed over the centuries. What is uncertain is the precise nature of such tipping points and their causes, and how such knowledge can be used to create transitions to select systems. One would hope that the development of improved integrative approaches, as addressed in the context of Hypothesis #2 could lead to greater insight and increased predictive capability. This will also be further addressed in the following section.

5 Research Gaps

The results of this workshop indicate that up-scaling agriculture within the city-region (referred to here as urban agriculture, or UA) can provide significant potential FEW synergies from a mass flow perspective. Significant opportunities also exist to increase the ecosystem services provided by urban areas, as well as to contribute to the socio-economic condition within the urban area (and potentially beyond), but adverse impacts are also quite possible depending on the specific approaches taken. The results also demonstrate that significant opportunities exist to up-scale UA within a variety of city-regions and, indeed, this is already happening. These on-the-ground activities provide a rich set of research opportunities, which must be complimented by other research to provide a vastly improved knowledge base so that the opportunities offered by up-scaled UA can be fully captured. This leads to a discussion of the principal research gaps.

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5.1 Gaps in Integrative Approaches

The first set of research gaps address *Integrative Approaches Which Consider Material Flows Along with Ecological and Socio-Economic Factors*, referred to in the proposal for this workshop as *urban metabolism* (UM) but refined through the workshop as described in Sections 4 and 5, above. As discussed in Section 4, multiple integrative approaches exist, each with their corresponding utility. The model initially presented in the workshop proposal identified four topic elements, as follows:

- Governance Networks
- Networked Material and Energy Flows
- Urban Infrastructure and Form
- Socio-Economic Dynamics

It appears likely that any relevant integrative research approach would incorporate all four, at least to some extent. Ideally, integrative approaches would be scalable. In its simplest manifestation it would capture the essential components of the complete urban FEW system conceptually, while allowing such a conceptual model to be upgraded, as needed, to both incorporate added detail and also allow essential components and their interactions to be quantified. The ideal interactive approach would also allow for assessment of impacts on the broader FEW system, beyond the city-region, to be assessed. As discussed in Section 4, while integrative approaches exist, none fully meet these objectives at this time. Thus, more research is needed to fully develop a relevant and widely useful integrative approach. Some important questions to address in developing such an integrative approach include:

- How do we incorporate socio-economic dynamics into an integrative urban FEW framework?
- How do we incorporate ecological structure and function into an integrative urban FEW framework?
- How do we understand the complex interactions within and between FEW systems in urban areas?

- How do we consider varying temporal, geographic, and jurisdictional scales?
- How do we develop scenarios, decision support, and collaborative planning?
- How do we assess the indirect/trans-boundary impacts of up-scaling UA?

These questions provide a rich source of specific research questions for future research.

5.2 Urban Agriculture Technologies and Approaches

There is limited quantitative understanding of the resource needs (energy, water, seed, nutrients, labor) of the varying types and scales of urban agriculture, including the current source of these resources and what alternative sources exist in available urban streams. For example, supplementary heating in a controlled-environment is a necessary input for year-round production in cold climate cities. Large energy consumers (e.g., electricity generation stations, food processing facilities) that produce ample waste heat could provide this needed heat source through combined heat and power (CHP) operations. Additionally, flue gases that are high in CO_2 could serve to fertilize these controlled-environment crops, but an assessment of compatibility of urban sources is needed. Another example of an input stream to urban agriculture and aquaculture would be wastewater, though standards for usage in the various scales and operations must be investigated further. As well, further understanding is needed of whether centralized and decentralized wastewater treatment and separation of solid and liquid components of wastewater might be more appropriate for specific agricultural scales and operations.

A further extension could be analysis of eco-industrial parks that would, not only grow food, but also process it into commercial products for broad and sustained use (i.e. outside of the growing season). Examination of these opportunities would provide the potential to formalize the exploitation of what would otherwise be an urban waste stream so that these mutually-beneficial operations can simply and efficiently coalesce into an industrial ecosystem. An exhaustive review is needed of the type of industries that would support mitigation of impacts in FEW systems, as well as the treatment requirements of waste streams that would need to occur to enable this resource usage. Further to this, the effect of climate and other physical geographical characteristics on the FEW impacts of urban agriculture need to be better understood. A limited number of case studies (Kulak, Graves, and Chatterton 2013; Sanyé-Mengual et al. 2015) quantify the life-cycle resource needs for a few European locations, but variation across US city-regions requires further investigation. The question of the desired characteristics of an urban typology (considering demographics, income, development history, economic sectors, and urban form) could potentially be answered through addressing these knowledge gaps.

In short, a complete assessment of the resource needs of various UA forms and technologies is needed to further quantify potential synergies and identify opportunities. This extends, not only to the production of food in the city-region, but also the potential to integrate this into a food processing industrial eco-system.

5.3 Ecosystem Impacts

As detailed in Section 2.4, numerous questions exist concerning the ecosystem and environmental impacts of up-scaled UA. The increased biological activity and bio-diversity which could be created through up-scaled UA could create numerous ecosystem benefits and provide a variety of highly desirable ecosystem services. Likewise, these opportunities may be minimized with some forms of UA. While some general and specific hypotheses can be offered based on current knowledge, the existing knowledge base to evaluate them is quite limited. Most studies have focused on UA as currently practiced, which is at a much smaller scale compared to what is envisioned in this analysis. Detailed field studies of existing UA systems are needed, with a focus on locations where more dense forms of UA are practiced. The development of conceptual, and eventually quantitative (see comments on integrative approaches above), approaches to evaluate ecosystem impacts are also needed to assess the potential impacts when more extensive UA is practiced within the city-region and to support the development of improved interactive approaches, as discuss in Section 6.1. Further field studies will then be needed as these denser forms of UA are more extensively deployed within city regions.

Many relevant questions need to be addressed regarding UA's benefits. Which types and forms of UA are able to increase biodiversity, and which ones decrease it? What range of ecosystem services can be provided by various types and forms of UA and how do these compare to current green infrastructure? Can the water quality improvement, economic development, enhanced urban aesthetics, and heat island benefits of green infrastructure be added to the other ecosystem and socio-economic benefits directly ascribed to UA? What are the interactions of various forms and types of UA, especially as the extent and density of their deployment increases in the city-region?

UA can also have deleterious ecosystem impacts. While UA can provide opportunities for nutrient recycling, input-intensive UA can result in increased run-off of nutrients and agricultural chemicals which can adversely impact local water bodies. What are the cumulative implications on soil, air, and water quality from the various forms of scaled-up UA? The environmental conditions within the city-region can also adversely impact the quality of food produced. What are the effects of urban levels of soil, air, and water pollution in the city-region on food quality? Alternatively, can up-scaled UA be used to remediate city-region soil, air, and water?

The alternative to up-scale UA in the city-region is increased agriculture in rural areas to meet expanding food needs. What are the ecosystem impacts of current forms of rural agriculture, in comparison to those of various forms of UA? How are the ecosystem impacts of rural agriculture likely to change in the future, either with the continuation of current rural agriculture capacities or, of greater concern, with a significant increase in rural production to meet future demand? This analysis recognizes that up-scaling UA will require time, so comparative analyses must contrast these various "futures", not just the current situation. The objective, of course, is for up-scaled UA in the city-region to provide net ecosystem benefits relative to providing the same (or reduced?) capacity of rural agriculture.

5.4 Socio-Economic Impacts

Numerous questions also exist concerning the socio-economic impacts of up-scaled UA, as addressed in Section 2.5. Many questions consider who has power over and who benefits from UA, especially if it were to scale up. How do the benefits and disadvantages vary for different forms, types, and scales of UA? How are the benefits and disadvantages distributed (intentionally or not) among communities and people? What social structures, government systems, and institutional configurations catalyze the growth of UA and encourage its effective implementation of UA, , and which ones tend to limit its implementation and expansion? What policies encourage UA and support achievement of the most desirable socio-economic outcomes? What types of social structures catalyze the growth of UA, and what are the social and environmental justice feedbacks from scaling up? How can diverse people engage in decision-making over UA?

Other questions also arise related to the broader economic impacts of up-scaled UA. Are the economic benefits sufficient to justify dramatically up-scaled UA, compared expanding rural agriculture needed to meet the increased food demand projected for the future? How will up-scaled UA affect rural agriculture socio-economic systems? Can the growth of agroecological UA be decoupled from resource shocks and capital flight so that the scalable pursuit of this food production is sustained over time? These questions lead to the key questions about factors which can create tipping points for dramatically up-scaled UA within the city-region. What are they, and can they be influenced to affect the pace of implementation?

5.5 Implementation

Assuming that significant up-scaling of UA in the city-region is found to be desirable, what steps can be taken to accelerate its adoption? The discussion of tipping points is relevant to this research area, but further questions remain. What is the role of the public sector in accelerating scale-up? Of non-governmental organizations and community-based grassroots initiatives? How can private sector capital and expertise be leveraged? In what locations and under which circumstances will scaling up UA provide the greatest benefit within the city-region and the greatest overall benefit?

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Appendices

Appendix 1: Agenda

Scaling Up Urban Agriculture to Mitigate Food-Energy-Water Impacts
University of Michigan

October 5-6, 2015 for workshop
Michigan League, 911 N. University Ave, Ann Arbor, Michigan

October 6-7, 2015 for Core Writing Group
Michigan League and Michigan Memorial Phoenix Lab, 2301 Bonisteel Blvd, Ann Arbor (North Campus)

	Time	**Activity**
Monday, Oct 5	7:30 – 8:30	Working Group Leaders Only – Orientation breakfast, Henderson Room
	8:30 – 8:45	Welcome, Introductions, Workshop Scope, Henderson Room
	8:45 – 9:15	Keynote #1 – Anu Ramaswami – working in interdisciplinary groups, Henderson Room
	9:15 – 10:15	Working groups meet, breakout rooms
	10:15 – 10:45	BREAK
	10:45 – 12:00	10 minute presentations by six working groups, Henderson Room
	12:00 – 1:30 pm	Lunch plus Keynote #2 (by pre-recorded video): Luis Bettencourt, Santa Fe Institute. "Cities, Scaling and Sustainability: Implications for Food", Henderson Room
	1:30 – 2:00	Core group summarizes key elements from working groups and further defines breakout activities, Henderson Room
	2:00 – 3:00	Mixed discipline groups – identify linkages and prioritize most important components, breakout rooms
	3:00 – 3:30	Break
	3:30-4:30	Mixed discipline group discussions – work through hypothetical case study. Breakout rooms
	4:30 – 5:30	Report out via panelist discussion by designated group leaders, Henderson Room
	5:30-6:30	Break
	6:30 – 8:30	Dinner with Presentation by Ashley Atkinson, Co-Director of Keep Detroit Growing, Henderson Room.
Tuesday, Oct 6	8:00 – 8:30	Continental breakfast, Henderson Room
	8:30 – 9:15	Keynote # 3 – Isabel Cruz, University of Illinois-Chicago. "Data Integration for a Dynamic Urban FEW Metabolism", Henderson Room
	9:15 – 10:00	Mixed discipline groups: identify research needs, breakout rooms
	10:00 – 10:30	Break
	10:30 – 12:00	Continue Report out on research needs and conduct a prioritization exercise, Henderson Room
	12:00 – 1:00	Lunch with NSF and USDA panelists to talk about the future of the FEW initiative and the national research agenda, Henderson Room
	1:00 – 3:00	Original Working Groups: revise sections for report, breakout rooms
	3:00 – 3:30	**Majority of participants excused**, break

Core Writing Group (Working Group Leaders and co-PIs) only

Tuesday, Oct 6	3:30 – 4:30	Core Writing Group remain, read documents, Room 4
	4:30 – 5:30	Core Writing Group reports on status of respective sections, Room 4
	5:30 – 7:00	Break
	7:00 – 9:00	Dinner at Sava's Restaurant (216 S. State Street, Ann Arbor) for Core Writing Group members
Wed, Oct 7	Venue: Energy Institute, 2301 Bonisteel Blvd, Ann Arbor (North Campus)	
	8:00 – 10:00	Writing continues (continental breakfast and beverages offered)
	10:00 – 10:30	Break
	10:30 – 12:00	Report out on status and content of written sections; identify work to be done and schedule
	12:00	Dismissed (healthy boxed lunch provided to accommodate travelers)

Appendix 2: Workshop Participants

Urban Food-Energy-Water Systems: List of Workshop Participants							
Working Group #1: Urban Agriculture and Water							
Name	**Title**	**Email**	**Mailing Address**	**Discipline**	**Affiliation**	**Institution**	**Expertise**
Nancy Love	Professor, WG#1 Lead	nglove@umich.edu	Department of Civil and Environmental Engineering 1351 Beal Avenue, 183 EWRE Ann Arbor, Michigan 48109-2125	Engineering	Civil and Environmental Engineering	University of Michigan	*Environmental biotechnology and water quality, chemical stressors*
Adey Desta	Assistant Professor and UMAPS Scholar	adey.desta@gmail.com	Addis Ababa University College of Natural Science Kebena Addis Ababa Ethiopia	Biotechnology	Institute of Biotechnology	Addis Ababa University, Ethiopia	*Water quality and microbiological issues associated with source-separated wastes for fertilizer*
Heather Goetsch	Research Assistant on REFRESCH	hgoetsch@umich.edu	Department of Civil and Environmental Engineering 1351 Beal Ann Arbor, Michigan 48109-2125	Environmental Engineering	Civil and Environmental Engineering	University of Michigan	*Resource recovery with water*
Branko Kerkez	Assistant Professor	bkerkez@umich.edu	Department of Civil and Environmental Engineering 2350 Hayward Street Ann Arbor, Michigan 48109-2125	Engineering	Civil and Environmental Engineering	University of Michigan	*Urban water system architecture; system modeling and management*
Andrea McFarland	Ph.D. student	amcf@umich.edu	Department of Civil and Environmental Engineering 1351 Beal Ann Arbor, Michigan 48109-2125	Environmental Engineering	Civil and Environmental Engineering	University of Michigan	*Green infrastructure and water quality*
Carol Miller	Professor	cmiller@eng.wayne.edu	Civil and Environmental Engineering Wayne State University 2100 Engineering Building Detroit, MI 48202	Engineering	Civil and Environmental Engineering	Wayne State	*Urban hydrology, stormwater management*
Allison Steiner	Assoc Professor	alsteine@umich.edu	Space Research Building 2455 Hayward Street Ann Arbor, MI 48109-2143	climate scientist	CLaSP (formerly AOSS)	University of Michigan	*biosphere-atmosphere interactions; regional climate modeling*
Dan Schechter	Superintendent of Engineering	dschecht@dwsd.org	Wastewater Operations Group, Detroit Water and Sewerage Dept, 9300 West Jefferson Ave, Detroit, MI 48209	Engineering	Utility Management	DWSD	*wastewater and stormwater management, utility management*
Lara Treemore-Spears	Program Coordinator, Water Program	treemorespears@wayne.edu	Wayne State Water Program	Natural Resources		Wayne State	
Krista Wigginton	Assistant Professor	kwigg@umich.edu	1351 Beal Avenue, 181 EWRE Ann Arbor, Michigan 48109-2125	Engineering	Civil and Environmental Engineering	University of Michigan	*Environmental biotechnology, water quality, antibiotic resistance, viruses*

Urban Food-Energy-Water Systems: List of Workshop Participants

Working Group #2: Urban Agriculture and Energy							
Name	**Title**	**Email**	**Mailing address**	**Discipline**	**Affiliation**	**Institution**	**Expertise**
Eugene Mohareb	Lecturer, WG#2 Lead	e.mohareb@reading.ac.uk	School of the Built Environment University of Reading, Whiteknights P.O. Box 217 Reading, Berkshire RG6 6AH United Kingdom	Industrial Ecology	School of the Built Environment	University of Reading	*Urban food and greenhouse gas emissions*
Glen Daigger	Professor	gdaigger@umich.edu	Department of Civil and Environmental Engineering 2350 Hayward Street Ann Arbor, Michigan 48109-2125	Engineering	Civil and Environmental Engineering	University of Michigan	*Urban water and resource management, urban infrastructure*
Martin Heller	Core Staff	mcheller@umich.edu	School of Natural Resources & Environment University of Michigan 3012 Dana Building 440 Church Street Ann Arbor, MI 48109-1041	Industrial Ecology	School of Natural Resources and Environment	University of Michigan	*Life cycle assessment of food systems*
Paige Novak	Professor	novak010@umn.edu	Department of Civil, Environmental, and Geo- Engineering 500 Pillsbury Drive S.E. Minneapolis, MN 55455-0116	Engineering	Civil and Environmental Engineering	University of Minnesota	*Biological wastewater treatment, resource recovery, hazardous substance biodegradation*
Lutgarde Raskin	Professor	raskin@umich.edu	Department of Civil and Environmental Engineering 1351 Beal Avenue, 107 EWRE Ann Arbor, Michigan 48109-2125	Engineering	Civil and Environmental Engineering	University of Michigan	*Biological water and wastewater treatment, aquaculture, bioenergy*

Urban Food-Energy-Water Systems: List of Workshop Participants							
Working Group #3: Urban Agriculture and Food Supply							
Name	**Title**	**Email**	**Mailing address**	**Discipline**	**Affiliation**	**Institution**	**Expertise**
Glen Daigger	Professor of Engineering Practice, WG#3 Lead	gdaigger@umich.edu	Department of Civil and Environmental Engineering 2350 Hayward Street Ann Arbor, Michigan 48109-2125	Engineering	Civil and Environmental Engineering	University of Michigan	*Urban water and resource management, urban infrastructure*
Alexandra Chen	Research Assistant for the project	alexlc@umich.edu	Department of Civil and Environmental Engineering 2350 Hayward Street Ann Arbor, Michigan 48109-2125	Engineering and Architecture		University of Michigan	
Jim Diana	Professor and Director of Michigan Sea Grant	jimd@umich.edu	School of Natural Resources and Environment University of Michigan G128a Dana Building 440 Church Street Ann Arbor, MI 48109	Fish Biology	School of Natural Resources and Environment	University of Michigan	*Sustainable aquaculture, fish ecology*
Andrew Jones	Assistant Professor	jonesand@umich.edu	3846 SPH I 1415 Washington Heights Ann Arbor, MI 48109-2029	Public Health	School of Public Health	University of Michigan	*Childhood nutrition, Environmental Health, Food Security*
Sara Meerow	PhD Student	sameerow@umich.edu	School of Natural Resources and Environment University of Michigan G128a Dana Building 440 Church Street Ann Arbor, MI 48109	Geography	SNRE	University of Michigan	*Green infrastructure/urban ag*
Linda J. Young	Chief Mathematical Statistician and Director of Research and Development	linda.young@nass.usda.gov	USDA-NASS 1400 Independence Ave., SW Washington, DC 20250	Statistics and Environmental Science	N/A	USDA	*Agriculture, Environment and Statistics*

Urban Food-Energy-Water Systems: List of Workshop Participants

Working Group #4: Urban Agriculture and Ecosystems

Name	Title	Email	Mailing address	Discipline	Affiliation	Institution	Expertise
Mary Gardiner	Associate Professor, WG#4 Lead	gardiner.29@osu.edu	203B Thorne Hall OARDC Wooster, OH 44691	Entomology	Food, Agricultural and Environmental Sciences	Ohio State University	*Urban ag and ecosystem services*
Jennifer Blesh	Assistant Professor	jblesh@umich.edu	School of Natural Resources and Environment University of Michigan 2572 Dana Building 440 Church Street Ann Arbor, MI 48109	Ecology	School of Natural Resources and Environment	University of Michigan	*Agroecology, soil science, nutrient management*
Gail Langellotto	Associate Professor	gail.langellotto@oregonstate.edu	OSU Campus Department of Horticulture 4017 Ag and Life Sciences Bldg Corvallis, OR 97331	Urban and Community Horticulture	Department of Horticulture	Oregon State University	*Horticulture/urban and community horticulture*
Timon McPhearson	Assistant Professor	mcphearp@newschool.edu	The New School 66 West 12th Street New York, NY 10011	Urban Ecology	Environmental Studies	The New School	*Urban ecosystem services*
Ivette Perfecto	Professor	perfecto@umich.edu	School of Natural Resources and Environment University of Michigan 3531 Dana Building 440 Church Street Ann Arbor, MI 48109	Ecology	School of Natural Resources and Environment	University of Michigan	*Role of agriculture in conserving biodiversity, food sovereignty*
Carolina Simao	PhD Student	simao@umich.edu	School of Natural Resources and Environment University of Michigan 3531 Dana Building 440 Church Street Ann Arbor, MI 48109	Ecology	School of Natural Resources and Environment	University of Michigan	*Urban Pollination*
John Vandermeer	Professor	jvander@umich.edu	Department of Ecology and Evolutionary Biology University of Michigan Ann Arbor, Michigan 48109	Ecology	Department of Ecology and Evolutionary Biology	University of Michigan	*Forest ecology, tropical agroecology*

Working Group #5: Urban Agriculture Socio-Economic Dynamics

Name	Title	Email	Mailing address	Discipline	Affiliation	Institution	Expertise
Nathan McClintock	Assistant Professor, WG#5 Lead	n.mcclintock@pdx.edu	Toulan School of Urban Studies and Planning Portland State University P.O. Box 751-USP Portland, OR 97207	Geography	Urban Studies & Planning	Portland State University	*urban agriculture, food systems planning, food justice, urban political ecology*
Joshua Cousins	PhD Student	jojaco@umich.edu	School of Natural Resources and Environment University of Michigan 1064 Dana Building 440 Church Street Ann Arbor, MI 48109	Geography	School of Natural Resources and Environment	University of Michigan	*Sustainable Redevelopment Projects, Urban Political Ecology, Local Food and Landuse*
Eric Duchemin	Adjunct Professor and Lecturer	duchemin.eric@uqam.ca	Institut des sciences de l'environnement de l'UQAM C.P. 8888 succursale Centre-ville Montreal, Quebec H3C 3P8	Environmental Science	Institut des sciences del'environnement	l'Université du Québec a Montréal	*Land Use, Land Use Change, Urban Agriculture and Urban Management*
Lesli Hoey	Assistant Professor	lhoey@umich.edu	Taubman College of Architecture and Urban Planning University of Michigan 2000 Bonisteel Blvd Ann Arbor, MI 48109-2069	Urban Planning	Architecture and Urban Planning	University of Michigan	*Food systems policy and planning*
Megan Horst	Assistant Professor	mhorst@pdx.edu	Portland State University Urban Studies and Planning PO Box 751 Portland OR 97207	Urban Planning	Urban Studies and Planning	Portland State University	*Local planning and policy making for sustainable food systems*
Dorceta Taylor	Professor	dorceta@umich.edu	University of Michigan 2576 Dana Building 440 Church Street Ann Arbor, MI 48109-1115	Sociology	School of Natural Resources and Environment	University of Michigan	*Urban Agriculture, food access, environmental justice*

Urban Food-Energy-Water Systems: List of Workshop Participants

Working Group #6: Integrative Approaches to Understanding City-Region FEW Systems

Name	Title	Email	Mailing address	Discipline	Affiliation	Institution	Expertise
Anu Ramaswami	Professor, WG#6 co-Lead	anu@umn.edu	Humprey School of Public Affairs 130 Humphrey School, Office 154 301 19th Ave. S. Minneapolois, MN 55455	Industrial Ecology: Engineering	Humphrey School of Public Affairs	University of Minnesota	*Urban sustainability, urban footprinting and metabolism; urban infrastructures*
Joshua Newell	Assistant Professor, WG#6 co-Lead	jpnewell@umich.edu	School of Natural Resources and Environment University of Michigan 1064 Dana Building 440 Church Street Ann Arbor, MI 48109	Geography	School of Natural Resources and Environment	University of Michigan	*Urban metabolism theory and modeling, interdisciplinary research, green infrastructure*
Maria Arquero De Alarcon	Assistant Professor	marquero@umich.edu	Architecture and Urban Planning Design	Architecture and Urban Planning	Taubman College	University of Michigan	*urban form, urban typologies and visualization*
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Mike Chester	Assistant Professor	mchester@asu.edu	School of Sustainable Engineering and the Built Environment College Avenue Commons 660 S. College Avenue Tempe, Arizona 85281	Civil Engineering	Civil, Environmental and Sustainable Engineering	Arizona State University	*Urban infrastructure for resilience and sustainability*
Isabel Cruz	Professor	ifc@cs.uic.edu	The University of Illinois at Chicago College of Engineering Department of Computer Science Science and Engineering Offices 851 South Morgan Street (M/C 152) Chicago, Illinois 60608-7053	Computer Science	Computer Science	University of Illinois at Chicago	*Data integration for urban resilience and sustainability*
Sybil Derrible	Assistant Professor	derrible@uic.edu	842 W. Taylor Street (M/C 246) 2095 Engineering Research Facility Chicago, Illinois 60607-7023	Sustainable Urban Systems	Civil and Materials Engineering	University of Illinois at Chicago	*Complexity theory, network science, geospatial analysis, urban metabolism*
Stephanie Pincetl	Director and Professor-in-Residence	spincetl@ioes.ucla.edu	UCLA Institute of the Environment and Sustainability La Kretz Hall Suite 300 Los Angelese, CA 90095-1496	Urban Planning	Institute of the Environment and Sustainability	UCLA	*Environmental and social justice; environmental regulation*
Vincent Tidwell	Distinguished Member of Technical Staff	vctidwe@sandia.gov	Sandia National Laboratories, New Mexico P.O. Box 5800 Albuquerque, NM 87185	Earth Systems Analysis	N/A	Sandia National Laboratories	*Hydrology and climate change, Systems dynamics modeling*
Rodrigo Villarroel Walker	Energy and Climate Associate	rvwalker@wri.org	World Resources Institute 10 G Street NE Suite 800 Washington, DC 20002	Urban Systems Analysis	N/A	World Resources Institute	*FEW Nexus Framework, Urban Energy Systems*
Ming Xu	Assistant Professor	mingxu@umich.edu	School of Natural Resources and Environment University of Michigan 3006 Dana Building 440 Church Street Ann Arbor, MI 48109	Sustainable Engineering & Industrial Ecology	School of Natural Resources and Environment	University of Michigan	*Industrial Ecology, Complex Sustainability, Environmental Impacts of Emerging Technology*

Participants

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