The Plant – An Experiment in Urban Food Sustainability

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Abstract: Indoor farming and food production systems present a unique opportunity for altering the sustainability of the urban food landscape through innovations in food, energy, and water (FEW) flows. Compared to traditional farming, growing indoors has been shown to be significantly more efficient with water usage and can reduce the amount of organic waste in runoff. However, indoor farming requires large amounts of energy for lighting and climate control, which can in turn exacerbate environmental impacts. Many experiments in indoor farming are taking place in cities across the world. This article presents a case study of *The Plant*, a renovated former meat-packing facility in Chicago's South Side, which is being repurposed into a collaborative community of food businesses committed to reducing waste. We utilize a Material Flow Analysis (MFA) framework to gather and analyze the FEW flows, but we also illustrate the social impacts, which are important as part of the broader sustainability impacts of the facility. Furthermore, we discuss the challenges in assessing the flow of FEW resources in experimental facilities such as *The Plant*, and we emphasize the need for ongoing study of such systems in order to determine a path towards sustainable management of food, energy, water and waste in cities.

Novelty or Significance: This article provides the first comprehensive Material Flow Analysis of *The Plant*, an unconventional and highly experimental food production facility in Chicago. While there are a growing number of vertical farming and sustainable food incubation facilities in North America and Europe, data on their material and energy use have not been systematically analyzed. The study demonstrates the challenges of gathering and analyzing food, energy, and water (FEW) flows in such experimental initiatives, which nonetheless provide a promising path towards urban food sustainability by educating the public, creating learning opportunities, incubating food-based businesses and developing closed loop waste management strategies.

Key words: industrial ecology, sustainability, waste management, water management, energy efficiency, circular economy

1. Introduction

Achieving sustainable food production in urban settings has become an urgent challenge (van Veenhuizen, 2006, de Zeeuw and Dubbeling, 2010). There are numerous on-going experiments to address different aspects of the urban food challenge, including growing food in both traditional and innovative ways while reducing their environmental footprint, and improving access and consumption of fresh fruits and vegetables (van Veenhuizen, 2006). Urban agriculture projects are being developed to address multiple objectives such as increasing 'green' job opportunities, improving the availability of healthy local food, and combatting problems such as poverty, poor health and obesity (van Leeuwen et al., 2010). Leading scholars surmise that one solution is unlikely to meet the needs of every place, therefore local adaptation and best technological practices must be developed for different regions to suit climatic, ecological, sociocultural, and economic systems (Pretty, 2009). Some authors argue that urban food production is unlikely to meet the nutritional needs of large urban populations, but it can create important knowledge about food sustainability and build social capital needed to manage sustainable urban food systems (Martin et al., 2016).

Vertical or indoor farms use urban infrastructure, either already built or newly constructed, to house diverse farming activities and connect them to nearby urban consumers (Despommier, 2004). There are now dozens of vertical farming projects around the world, some, such as Gotham Greens and Farmed Here, both in Chicago, are now commercially viable at significant economic scale. Key environmental benefits are thought to include lower uses of fertilizers and pesticides common in conventional farming, as farmers can better manage the delivery of nutrients and protection from pests in these closed systems. Water can be used more efficiently, as irrigation and evaporation losses are reduced, and production can be adapted to the exact conditions needed by different crops, when compared to field systems. Significant drawbacks include high energy consumption and the need to artificially maintain precise climatic and light regimes to effectively grow different plant species (Ehrenberg, 2008).

Thus, food, energy, and water (FEW) resources need to be coordinated in order to create sustainable urban food systems. One potential strategy is Industrial Symbiosis (IS), or the shared management of resources, including water, energy, waste and by-products, among distinct firms in a defined geography (Chertow 2000). Benefits of IS include the creation of local circular economies, resulting in resource use reductions, new revenue streams as well as growth in institutional capacity, innovation, social capital, and resilience. The concept has been applied to integrated food-energy systems (IFES) that grow food crops and/or live animals, reuse organic waste from one process into another, and generate energy from the waste organic materials, which are symbiotically reused back in the system (Gerst et al 2015).

In this article, we examine how urban farming and food production facilities operate by applying a Material Flow Analysis (MFA) approach to quantify food, energy, water (FEW) and other material flows, as well as by illustrating the broader social impacts. We utilize a single case study of *The Plant*, an experiment in urban food sustainability with diverse food and agriculture businesses housed in a repurposed meat-packing facility on Chicago's South Side. *The Plant* has become a hub for envisioning and experimenting with sustainable urban food systems, including the use of the industrial symbiosis concept for creating circular economies, closing material and energy loops between different businesses housed at the facility (Mulrow et al., 2016). The methodology used for gathering material and energy flows, and social impact data is first described. The results of the MFA and social impact data are then presented and analyzed. Finally, the challenges of conducting a MFA on an unconventional facility like *The Plant*, and implications for studying urban FEW sustainability are discussed.

2. Materials and Methods

In Summer 2016, the research team worked towards the development of a data collection methodology for FEW data at *The Plant*. The goal was to identify and quantify FEW resources consumed, wastes generated by individual tenants and the facility as whole, and waste disposition and reuse among various tenants within the facility.

2.1. Material Flow Analysis

Material Flow Analysis (MFA) is based on the law of conservation of mass and energy, and it is useful for understanding the consumption, transformation, storage and disposal of various resources in a system. MFA is used to identify opportunities for increasing the efficiency and productivity of resource use, as well as quantifying currently disposed materials that could be beneficially reused (Graedel and Allenby, 1995).

MFA is performed using five global steps (Baccini and Brunner, 2012):

1) Identify the aim of the study and the questions that will lead it.
2) Define the system of the study in terms of geography, actors, time period and materials to be examined.
3) Acquire data by measuring material and energy flows on-site and off-site, and estimating flows through secondary data, interviews and routine observations.
4) Analyze the results with tables and static or dynamic graphics.
5) Discuss the results compared with other studies and standards, eventually making a recommendation concerning sustainability and/or efficiency.

FEW flows were collected in June 2016 at *The Plant* through interviews and administration of questionnaires to fourteen out of sixteen tenants that were operating at the time. The questionnaires (Supplement 1) asked tenants to provide data on all their inputs and outputs for the months of March, April and May 2016. Tenants were also asked to specify how they dealt with the different types of wastes, in particular whether any wastes were sold or given to other businesses at *The Plant*, or whether the wastes were recycled, composted, or landfilled. They were also asked about plans to improve their organization's sustainability. MFA diagrams were created for each of the companies to capture the full range of inputs and outputs. Energy, water, and material flows were then aggregated to provide a comprehensive view of how these resources were consumed and transformed in the system. The three-month period was chosen because it was close to the on-site presence of the researchers undertaking the survey, thus making it easier for businesses to recall what they did. This period was also preferred since it was the beginning of the harvesting season and urban farmers had data to report (see Table 1).

2.2. Overview of *The Plant*

2.2.1. The Plant

The Plant refers an industrial building on Chicago's South Side that is owned and operated by Bubbly Dynamics, a for-profit, social enterprise that is home to diverse group of food businesses (Plant Chicago, 2016). Plant Chicago is a non-profit organization located inside *The Plant*, whose mission is to develop circular economies. Plant Chicago provides educational programming, runs a year round farmers market, and conducts research around closing waste loops. The term "*The Plant*" has no official status and it is normally used to refer collectively to the facility and its tenants (i.e., Plant Chicago and the businesses that operate in *The Plant*).

In 2010, Bubbly Dynamics purchased and began renovating the facility, a vacant 93,500 sq-ft. (12,000 m^2) former meat packing plant in Back of the Yards neighborhood in Chicago's South Side. Bubbly Dynamics made a conscious decision to repurpose the existing infrastructure through deconstruction, recycling of materials and renovation. By 2016, Bubbly Dynamics had leased or renovated almost half of the commercial spaces in the facility. An equally important aim was to promote "closed loop models" of urban agriculture through demonstration farms and educational programming. Fundamental to its planned design was the use of organic waste from on-site and off-site businesses to generate all of its own energy using anaerobic digestion, as well as by-product synergies among tenants.

2.2.2. Plant Chicago

At the core of the facility is a non-profit, Plant Chicago, that promotes circular economy principles and systems thinking through tours and workshops, hosts research and development projects (aquaponics, bio-fermentation, mushrooms lab, algae farming, composting, farming, among others), and creates marketplaces for businesses to engage in the circular economy. To achieve its social mission, Plant Chicago hosts facility tours for educational groups and the public, as well as a year-round farmers' market that features some of the products grown or made on site, as well as select products from the surrounding community. They also host numerous local and international interns, who conduct research on projects of interest to Plant Chicago or other tenants in the building, thus increasing interns' knowledge and creating substantial social impacts.

2.2.3. Tenant Businesses

Individual businesses join the building on an on-going basis, as commercial spaces are renovated. Some require specialized facilities or equipment, such as a cold room. In some cases, Bubbly Dynamics makes the investment and builds out the spaces to tenant specifications, while in others, the tenants install the necessary equipment themselves. Tenants contribute to *The Plant* in their own way; with more or less involvement depending on their personal interest and business type: for example by exchanging wastes or using responsible business practices. In April 2016, the different tenant businesses located in the building and their main activities consisted of the following:

Table 1: Tenants of *The Plant* from March 2016 to May 2016

Industry	Business Name	Description	Number of Symbiotic Ties
Real Estate Developer	Bubbly Dynamics	Building owner and operator; developer and reconstruction	3
Education, Research & Development	Plant Chicago (non-profit)	Sustainability research and education; advocate for circular economy systems; community engagement	3, 1*
Agriculture/ Farming	Bike-a-Bee	Beekeeping and beekeeping education/consulting	1*
Agriculture/ Farming	Farm Box	Vertical indoor farming R&D - greens	0
Agriculture/ Farming	Fruiting Mushrooms	Indoor mushroom farming	3, 2*
Agriculture/ Farming	Mycofloral Farm	Cut flowers	1
Agriculture/ Farming	New Magnolia Garden Center	Seedlings	0
Agriculture/ Farming / Consulting	Nick Greens	Indoor farming R&D - greens	1
Agriculture/ Farming	Patchwork Farms	Urban outdoor farming – seasonal produce	2
Agriculture/ Farming	Pleasant Farms	Urban outdoor farming – seasonal produce and herbs	1
Agriculture/ Farming ; compost collection	The Urban Canopy	Urban outdoor (seasonal produce) and indoor farming (wheat grass) Fruits and vegetables merchant	2
Beverage Producers	Arize Kombucha	Kombucha tea brewery	1, 2*
Beverage Producers	Whiner Brewery	Craft beer brewery	5

	Just Ice	Hand-crafted cocktail ice preparation	2
Food Producers	4 Letter Word Coffee	Coffee roasting	2
Food Producers	Pleasant House Bakery	Artisanal bread and pastries	5, 2*
Food Distributors	Great American Cheese Collection	Artisanal cheese distribution	0
	Rumi Spice	Afghan saffron distribution	1*

*Note: Symbiotic ties represent the number of different materials (typically by-products) sent or received from different actors, with * indicating a planned synergy*

3. Results

3.1. Individual Food, Energy, Water and Material Flows

Thirteen of the sixteen tenants at *The Plant* participated in the study and provided data about their material, food, energy and water inputs and outputs for the three months of the study only. Three of these are presented here as samples of the diversity of activities at *The Plant*. They also highlight some of the significant challenges we have had collecting accurate data.

3.1.1. Pleasant House Bakery

Before it moved its food preparation and baking operations to *The Plant* in 2013, Pleasant House Bakery was a well-established business in Chicago with a solid customer base. During the study period, they prepared two main products at their facility within *The Plant*: pies sold at their sister restaurant, Pleasant House Pub, and breads sold on site and locally. The bakery was able to give a high level of detail about their inputs and outputs because they were tracking most of their material flows; which was not the case for the majority of tenants. Figure 1 shows the diversity of products and small flow quantities, which make them difficult to track consistently.

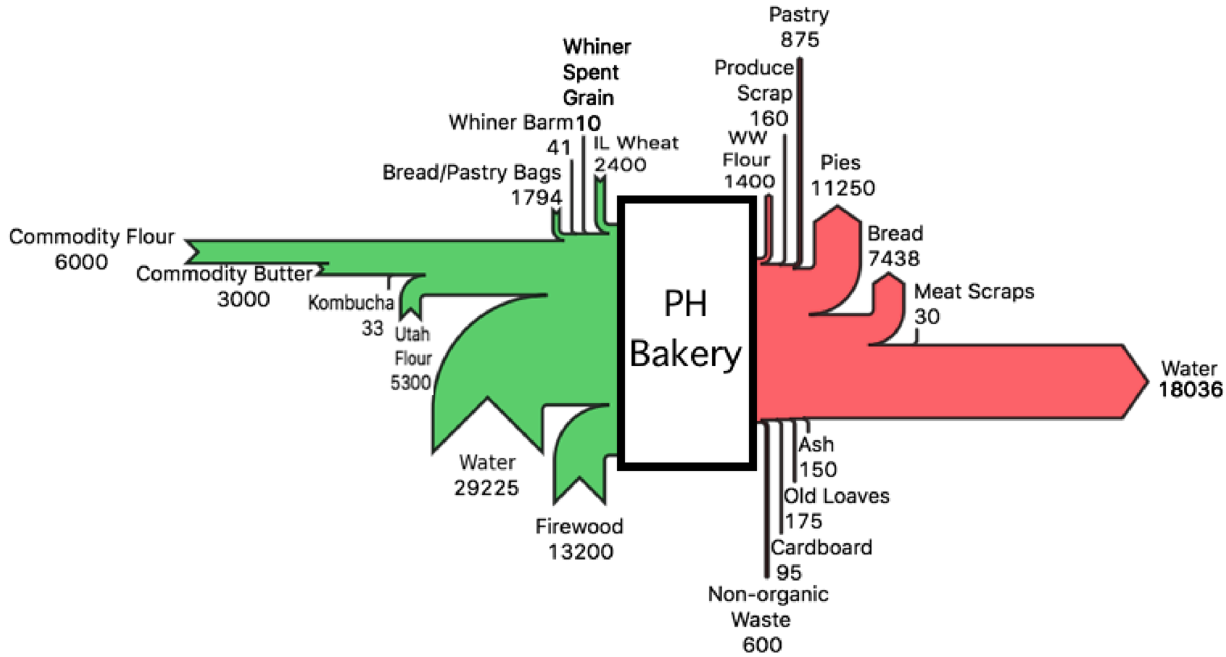

Figure 1. Material flows at Pleasant House Bakery in March–May 2016.

3.1.2. Nick Greens – R&D indoor farm

Nick Greens was an indoor farming business that cultivated microgreens, sprouts, and salad greens hydroponically. The founder, Nick Greens, learned about indoor farming techniques as a volunteer with Plant Chicago. In 2013 he launched his own business focused on supplying microgreens to local restaurants. Mr. Greens has experimented with a variety of growing media, fertilizers, packaging, and finished products. The business had recently partnered with a local high school to establish a learning laboratory to introduce students to plant biology and indoor growing techniques. For the three-month period of this study, production at Nick Greens utilized rock wool media supplemented with liquid organic fertilizer and burlap from the on-site coffee roaster business (Figure 2).

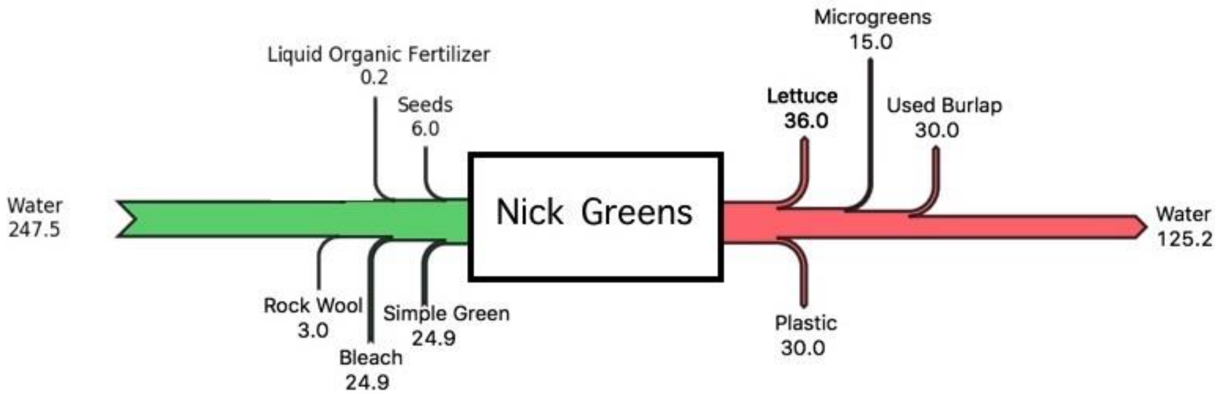

Figure 2. Material flows at Nick Greens in March–May 2016.

3.1.3. Plant Chicago

Plant Chicago had two demonstration scale food production activities—an indoor aquaponics farm and a mushroom lab. In both, staff and invited researchers were continuously experimenting with process improvements to increase efficiency as well as with new growing media and techniques to generate new knowledge about these systems.

Like most businesses growing plants, the main input and output by weight is water. With two distinct activities, it is useful to visualize these activities separately (Figure 3). During the study, 29,868 lbs of water were estimated to grow mushrooms from inoculation to finished product. However, wastewater output from this operation was estimated at 42,896 lbs. This discrepancy between inflows and outflows highlights a problem faced between different measurement versus estimation methods. In this case, the total water input was calculated from Bubbly Dynamics' water bills, with separate water meters for the mushroom lab and the indoor farm. Even if the bills gave a precise measurement, they were given by the city every two months and the monthly amount had to be estimated from the lab activity. The water output was estimated from cross-referencing the autoclave usage, its operation manual and professionals' estimations.

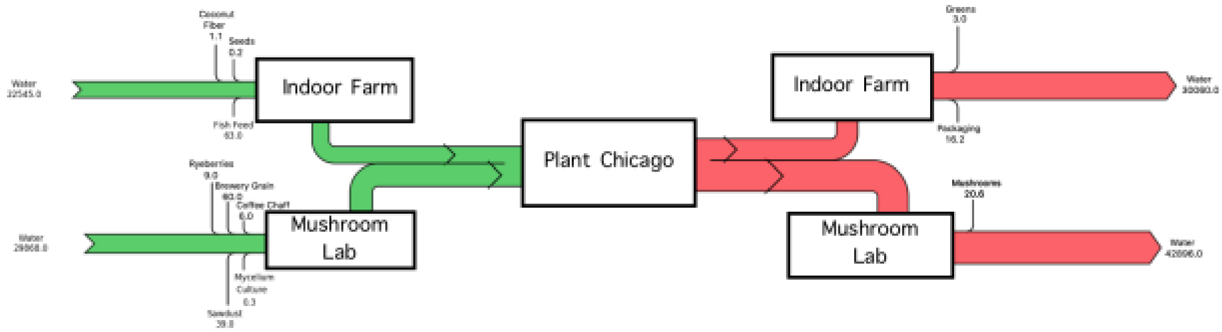

Figure 3. Material flows at Plant Chicago in March–May 2016.

3.2. Facility-wide Energy Flows

Electricity consumption data was obtained from individual firms, based on their monthly metered consumption and electricity bills. All firms in the facility did not measure their electricity consumption and some did not wish to disclose their information. Many paid a flat fee as part of their rental leases. The facility-wide energy flow diagram (Figure 4) only includes those businesses that had individual meters and disclosed their consumption. The total reported electricity consumption from the months of March to May 2016 was 78,903 kWh. Pleasant House Bakery and Whiner Brewery were the largest electricity consumers with 24,939 kWh (32% of the total) and 22,424 kWh (28%) respectively. The bakery also consumed wood to heat the oven, but this fuel source was not quantified in this study. An anaerobic digester was in construction, with an expected completion in 2018. At full operation, the digester is expected to produce approximately 4,000 MWh, 25% of which would be used to meet the needs of the businesses at *The Plant*, with the excess sold to the local electric utility.

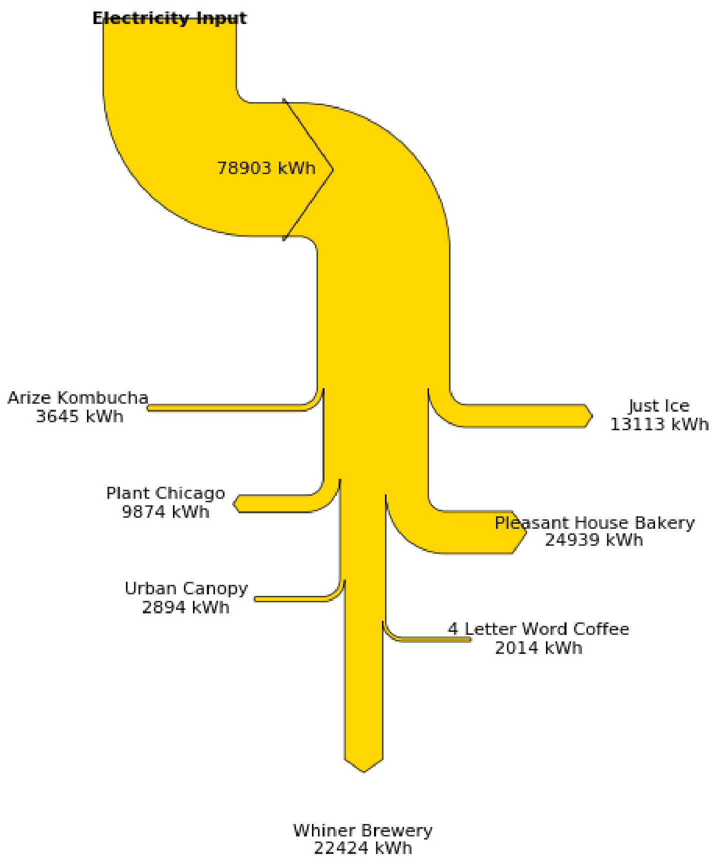

Figure 4. Reported electricity consumption at The Plant in March–May 2016.

3.3. Facility-wide Water Flows

Water consumption data were obtained in two ways: 1) Bubbly Dynamics used meters to measure consumption for most tenants and 2) some tenants estimated their own consumption based on their operations. The diverse sources of data led to significant errors in the water balance calculations. When there was a gap between the water going in and out of a system, it was labeled as "estimated losses"; in addition, none of the businesses reported the water content of finished products or water evaporation, sometimes including it in the wastewater amount (Figure 5).

Two businesses used more than half of the 87,240 gallons of water supplied to the facility in the three-month period: Whiner Brewery used 38,170 gallons (44% of the total) and Just Ice used 20,503 gallons (24%). At the time of the study, the brewery was not yet authorized to sell their beer and were storing some beer in barrels and discarding the rest down the drain. When they reach normal operations, it is estimated that about 15% of *The Plant*'s water inflow would go into the beer sold. Subsequent research projects at Plant Chicago will analyze the brewery's wastewater to evaluate its potential for reuse within *The Plant*. The ice business used a significant amount of water but had a highly efficient process with almost 65% of its inputs going to the finished product. They were planning to pump over-mineralized wastewater up to the urban gardens.

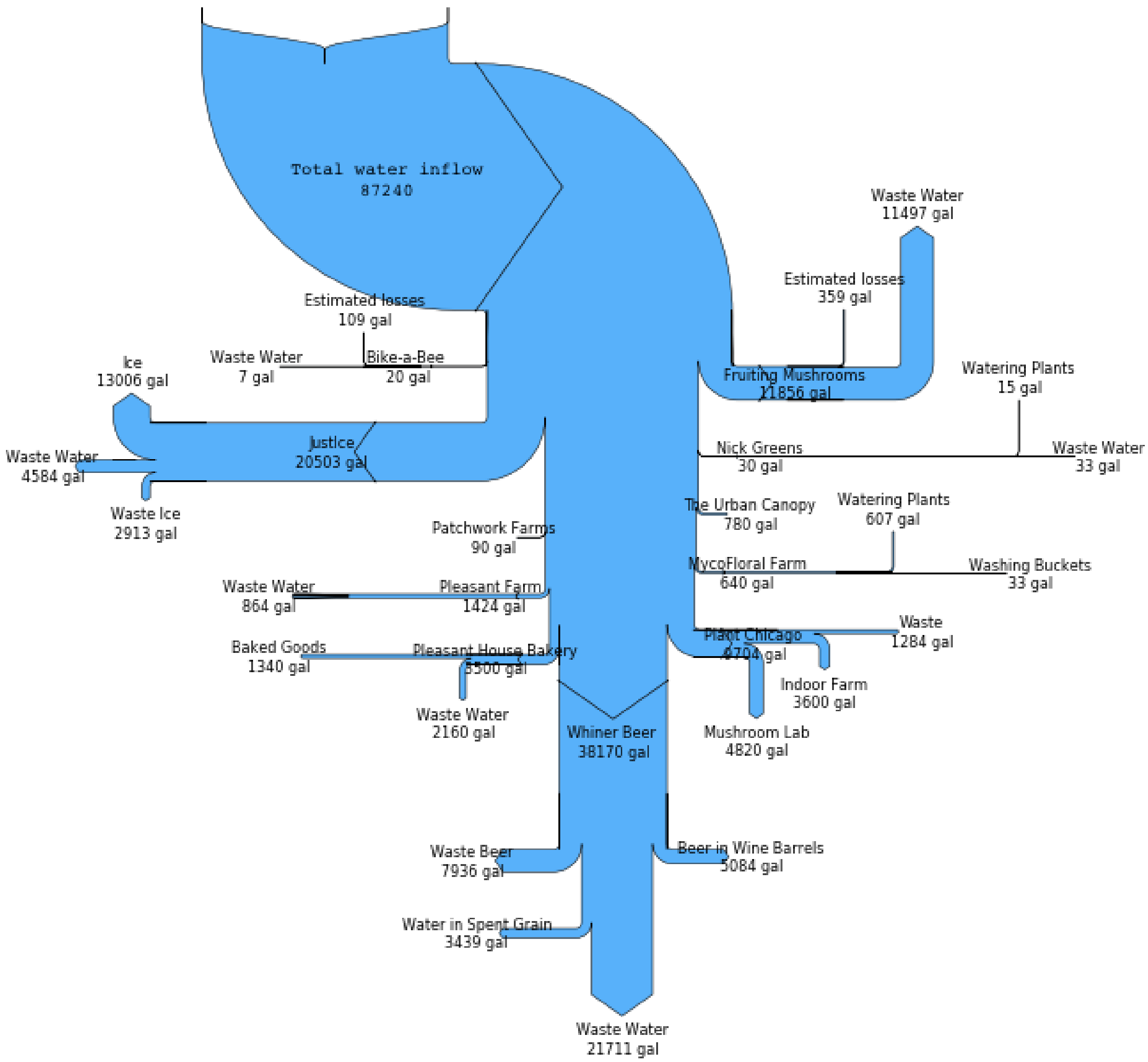

Figure 5. Reported water consumption at The Plant in March–May 2016.

3.4. Facility-wide Food and Material Flows

Approximately 59,810 lbs of materials were brought into *The Plant* from outside sources in March-May 2016, while 137,513 lbs of materials were generated as outputs (Table 2). However, 57,065 lbs (42%) of wastes were directly reused on site and 80,448 lbs (58%) left the facility. Of the materials that left the site, 35,211 lbs (26%) left as final products, 42,817 lbs (31%) were sent to the landfill, and the remaining 43% was recycled. Material flows to the landfill and final products were composed of multiple, small streams of materials, whereas almost 98% of the material reused on site were spent grains from the brewery that were composted.[2] For this study, a mass balance was not achieved as the reported outflows were one-third more than the reported inflows. This was due to differences in sources for input and output data, direct measurement versus estimation, unaccounted materials inventory prior to the beginning of the study, and unaccounted water content in products or losses.

Table 2: Material and water total estimated usage from the months of March to May 2016 at The Plant

		Inflows	Outflows
Material flows	Materials (lbs)	59,810	
	To Landfill (lbs)		42,817
	To Recycling (lbs)		697
	To Composting (lbs)		1,723
	On site reuse (lbs)	*57,065*	*57,065*
	Sold goods (lbs)		35,211
	Total materials (lbs)	59,810 (*116,875*)	80,448 (*137,513*)
Water flows	Water (gal)	87,240	
	Water (lbs)	729,326	
	Waste water (gal)		45,086
	Wastewater (lbs)		376,919

Notes: 1 lb ~ 0.45 kg; 1 gallon ~ 3.8 liters. Materials reused on site are included the bracketed numbers for the total mass of material inflows or outflows. Some 20,638 lbs of input materials were not balanced by outflows in the study. Similarly, for the water flows, some 42,154 gals (352,407 lbs) of water leave the facility as water content in products or are unaccounted losses in the system. Source: Chancé, 2016.

[2] Composting activity at *The Plant* was separated in two categories: "Composted" represents all food scraps that were collected and composted but were not yet reused by any of the tenants; "Reused on site" refers to all materials reused symbiotically by other tenants on site (as shown in Figure 6), including spent grains that were composted and then used by an on-site farm.

Analysis of the data from the questionnaires provided significant insight into the processes occurring at *The Plant*. In particular, it helped to visualize the flows between the businesses and the potential reusable wastes, to show the businesses that they were part of a more global system, thus increasing awareness of the “closed loop system”. The questionnaires also identified the projects that the building owner and tenants planned to implement in the short and long terms, such as building a landscape berm at the back of *The Plant*, collecting rain water for a rooftop bee water and flower garden, or increasing recycling and reduce wastes.

3.5. Industrial Symbiosis at *The Plant*

Figure 6 highlights industrial symbiosis linkages among tenants at *The Plant*. The flow quantities are small, on the order of 20-50 pounds per material flow. In fact, several of these flows were only uncovered during interviews as the tenants did not think they were significant enough to be worth mentioning, much less quantifying on their questionnaires. The largest synergy is the flow of 56,000 lbs of spent grain from Whiner Brewery to Bubbly Dynamics for on-site composting over the three months and the 53,663 lbs of compost going from Bubbly Dynamics to Mycofloral Farm. Whiner sent spent grains to three other tenants as well as “barm” (fermentation residues) to one of them. However, the most “symbiotic” actor was Pleasant House Bakery, which received four by-products from four other tenants into its process and sent one by-product (ash) to Bubbly Dynamics for detergent production. Fruiting Mushrooms was also highly symbiotic, with three by-product inflows and one by-product outflow. Plant Chicago was exploring a potential synergy to convert spent grain from Whiner Brewery to make “biobricks” that could be burned in Pleasant House Bakery’s wood oven. Depending on the size of the business, reusing even a little bit of some material into its process could represent substantial raw material, waste disposal and transportation cost savings.

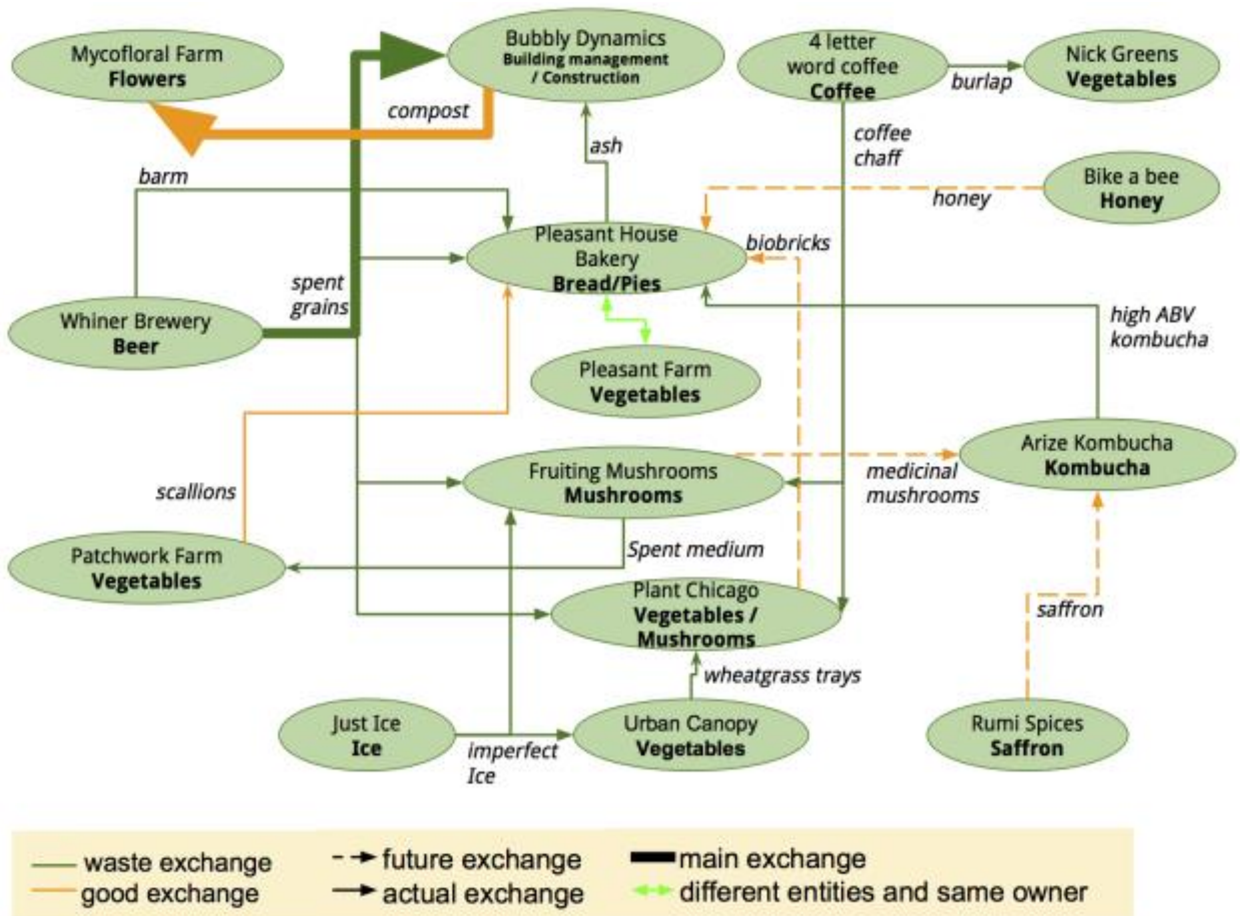

Figure 6. Industrial symbiosis at The Plant.

3.6. Social Impacts

Close interaction among tenants provided many opportunities for shared learning and collaboration, which built both human and social capital. We surmise that the close physical proximity and "short mental distance" or similarities in worldview among tenants created opportunities for experimenting with new ways to reuse wastes and collaborate at the facility level (Ashton and Bain 2012, Velenturf and Jensen 2015).

Plant Chicago developed educational programming and public tours to share knowledge about sustainable urban food production to younger generations and the general public. In the 2014-2015 school year 1,029 students in grades K-12 visited *The Plant* on field trips, while 2,883 visited in the 2015-2016 school year. Plant Chicago offers free programming to residents of Back of the Yards, the predominantly low-income neighborhood that surrounds *The Plant*. In 2015, there were approximately 4,700 visitors to *The Plant* through tours and education programs, and they were on target to receive 8,000 visitors by the end of 2016. Plant Chicago's coordination of a year-round farmers' market also builds connections among tenants, and between *The Plant* and the surrounding community. The farmers' market attracts between 150 and 300 attendees per market. Local participation grew in 2016, with 30% of attendees coming from neighborhoods that surround *The Plant*, up from 8% the previous year. In addition, 9-12 interns per year and approximately 45 volunteers spent time learning about the operations of different businesses and helping them to improve their activities. Four former interns launched their own enterprises on site, and more have launched projects elsewhere in Chicago.

4. Discussion

In principle, the MFA approach provides comprehensive data about resource use, consumption, transformation and recycling in a system of any size. In this study, the MFA enabled a systematic evaluation of each individual tenant's FEW and other material inputs and outputs.

It revealed that there were high-energy demands from only a few tenants, those with high heating and cooling requirements. Bubbly Dynamics, the building owner, had begun construction of an anaerobic digester, which was expected to be completed in 2018. The bulk of the organic waste from the facility, as well as by-products from other food producers, distributors and retailers around the city would provide the feedstock for generating biogas, electricity and bio-solids that could be used in the facility, with the goal to make *The Plant* a net-zero energy facility.

Surprisingly a large quantity of water appeared to be wasted across all tenant operations. Bubbly Dynamics was considering building a secondary water system at *The Plant*, which could divert all the reusable wastewater from tenants to uses such as watering the outdoor gardens. Investigating and demonstrating the water usage through MFA provides valuable knowledge to the building owner and tenants to evaluate the potential for water recycling and develop action plans.

It also revealed the material wastes generated were a little more than twice the flow of final goods sold. More than half of these wastes were however being productively reused, either on site through composting or industrial symbiosis, or conventional recycling. But one-third of the solid wastes from the facility was destined for landfills, suggesting that there may be large opportunities for implementing waste reduction and on-site and off-site recycling strategies.

Conducting an MFA in this facility encountered many challenges. Discrepancies in data validity arose for a number of reasons including: 1) small businesses do not typically measure their material and energy inputs and outputs; 2) the questionnaires asked business owners to recall MFA data from the previous three months, and some details were likely forgotten or unintentionally omitted; 3) some data were only available at the facility level, from the building owner, and as such material imbalances were found when one set of data came from measured sources and another came from tenant estimates; 4) not all tenants provided information or allowed publishing it; and 5) some data were given in volume units and did not have weight equivalencies.

Understanding the sustainability of food-related businesses in a facility like *The Plant* using an MFA approach was complicated by the fact that such business, especially the outdoors ones, are often highly seasonal, more so in a cool temperate city like Chicago. The period for the data gathering was March to May 2016, the beginning of the growing season for all the outdoors products. The farmers were mainly preparing soil, sowing and were barely harvesting yet, so the material flows reported were atypical of the average monthly or annual flows. Further, at the time of the study, a few businesses had recently moved in or started their operations such as Mycofloral Farm, Just Ice and Whiner Brewery, as such their data were not a true representation of the FEW flows once fully operational. Using this three-month period further required that the results have to be presented as a total for the entire period. There is not a logical way to calculate a monthly ratio or to extrapolate the data to a whole year for multiple reasons: the seasonality of many businesses, some tenants had just launched their operations, and finally, many businesses simply do not have steady inputs and outputs every month, making a monthly quantity non-representative of their activity.

A more effective data collection strategy would be to collect MFA data over a full year, or at least for the full duration of the peak summer growing season. Each tenant's flows could be tracked on a monthly basis for a full year of their operation, and monthly stocks (inventory) and flows aggregated by material types, and for total annual amounts. The main difficulty for yearly comparison would be the coming and going rhythm of tenant businesses in the facility. In fact, shortly after data collection, Fruiting Mushrooms had moved to another location. It may be difficult to collect data in an on-going manner from small businesses, as data collection is not typically a priority, thus a data collection strategy should be standardized and simplified, so as to make it easier for them to report this information on a regular basis: for example, by using an online survey with some tools to help them translate volumes into weights, also by finding a common scale for garbage data collection.

While there are few directly comparable projects to *The Plant* in terms of scale and complexity, we expect that other experimental food sustainability projects face similar challenges in measuring and reporting their sustainability impacts. La REcyclerie in Paris, France occupies an old train station that has been transformed in two distinct spaces: a for-profit restaurant and bar within the old building and an urban farm managed by a non-profit in the areas outside the train station. While the organization completed a sustainability audit in 2016, it has not been published (La REcyclerie, 2016). At The Urban Renewal Farm (TURF) in Dayton, Ohio volunteers grow seedlings inside an abandoned factory, transfer the seedlings to outdoor growing spaces, and sell the final produce in local markets (Bennish, 2016). GroOperative in Buffalo, New York is a worker-owned, vertical farming cooperative that was inspired by *The Plant* and started in 2013 with aquaponic systems (Maurer, 2013). As these organizations are still in the early stages of project development, it is highly unlikely that FEW data acquisition and management has been a priority.

A flexible approach needs to be employed to gather FEW data and understand the broader sustainability implications of these experimental facilities. While the "hard" data might indicate that such systems are a long way from being sustainable, studying their material and energy flows enables researchers and stakeholders to better understand their resource consumption patterns and identify opportunities for improvement. Similarly, the collected social impact "soft" data only partially quantifies the effect on urban communities, as it is difficult to ascertain long-term changes in individuals' attitudes to urban agriculture and food preferences, but is nonetheless useful to demonstrate how initiatives like *The Plant* are engaging and inspiring citizens. Indeed, a more thorough social impact assessment would incorporate viewpoints from the breadth of stakeholders, such as tour participants, employees of tenant businesses and policy-makers who have interacted with the facility.

5. Conclusion

The Plant is one example of an ambitious experiment promoting urban food sustainability through industrial symbiosis among tenants in food-based businesses in Chicago. There are many urban food sustainability efforts emerging across North America and Europe, which represent a significant opportunity to learn about how agricultural production and food preparation can effectively and sustainably be brought back into temperate cities, by utilizing the existing industrial building stock and urban infrastructure. There are many challenges in applying an MFA framework to measure and understand the food, energy, water, and other material flows in such systems, due to the size, seasonality, and changing composition of tenant businesses in the facility. While the production of food products, and overall contribution to sustainable FEW flows from a facility like *The Plant* to a city is fairly small. Indeed, urban communities may never become independent of rural agriculture, especially for products like wheat and corn, but there is a real ability to offset some products such as leafy greens. These facilities also increase knowledge and social capital by creating a space for shared learning about how to transition our food systems towards sustainability, particularly in urban communities where many citizens lack awareness about the origins and environmental impacts of the food they consume. An educated consumer base is necessary to effect systemic change in the sustainable management of the FEW nexus, and facilities like *The Plant* offer an opportunity to educate the public towards this transition.

6. Acknowledgements

EC's field research at *The Plant* was funded by France's INRA (Institut National de la Recherche Agronomique) and CIRAD (Organisme Français de Recherche Agronomique et de Cooperation

Internationale pour le Développement Durable des Regions Tropicales et Méditerranéennes) through the metaprogram “Transition to Global Food Security”, or GloFoodS and in particular the project P&G-City, focusing on MFA and waste management flows. JP is the executive director of Plant Chicago. JM was a former interim executive director of Plant Chicago in 2014-2015.

We thank the staff of Plant Chicago for hosting EC and JN, and providing introductions and guidance for working with *The Plant*’s tenants during the study. We also wish to thank all the tenants who generously provided their time and information about their businesses.

7. Literature citation

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