

**addressing FOOD, WATER, WASTE + ENERGY
yields in URBAN REGENERATIVE ENVIRONMENTS**

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Addressing Food, Water, Waste and Energy yields in Urban Regenerative Environments

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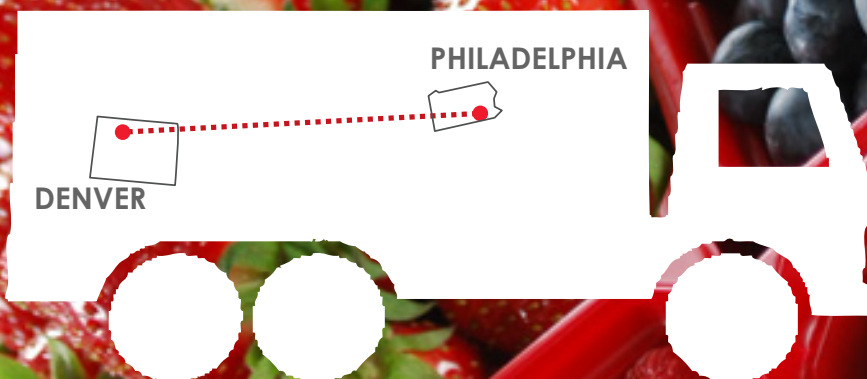
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1. ABSTRACT

“At the same time that we must respond to climate change and rising energy costs, we must also adjust our housing stock to fit a changing demographic and find more frugal form of prosperity. Such a transformation will require deep change, not just in energy sources, technology, and conservation measures but also in urban design, culture and lifestyles. More than just deploying green technologies and adjusting our thermostats, it will involve rethinking the way we live and the underlying form of our communities.” (Calthorpe, 2011)

Our cities are built dependent on centralized systems of water and waste management, food and energy production. This practice has proven efficient for a while; nonetheless as our cities expand with immense speed and population increases, severe issues of food access, waste accumulation, floods, water contamination and increased energy demand reveal the obsolescence of those systems. The solution does not lie anymore only in conservation and precautionary measures but in a diverse way of thinking and redesigning existing infrastructures. Through this thesis, several systems of urban agriculture, decentralized water management and treatment, as well as energy production from waste were identified and studied through literature and actual case studies. The ultimate goal of the research was to create a toolkit for urban regenerative environments, which will be used to introduce those systems to designers. The key component of the toolkit is the quantitative link between the spatial demands of each system and its efficiency.

**1500
FOOD
MILES**



2. INTRODUCTION

Urban density constitutes a critical part of the sustainable communities. Denser cities have reduced per capita use of resource, due to the limited needs in commuting. (Calthorpe, 2011) Nowadays, 28% of the energy consumed in US is due to transportation, (U.S. Department of Energy, 2011) hence it is really important to reduce commuting distances. Dense urban areas minimize commuting long distances, and therefore reduce the carbon footprint of a community. However, the idea of minimizing long distances and using local resources comes in conflict with the current model of globalization and the open global market. Consequently, working within a global framework we have to come up with local ideas.

In this global framework, cities and dense urbanized areas are expanding with immense speed, creating controversies about the quality of space produced. In 2000, China announced her intention to create 400 new cities, (an urban area as big as 24 times the size of the metropolitan area of London) until 2020 due to the intense immigration of rural population to the cities. (Eleni Katrini, Andreas Ventourakis, 2008) Under those terms, air and visual quality, human comfort and health, as well the connection to nature are often being compromised.

Cities are created with no local solutions for food supply and waste management. We spend 10.2 quadrillion Btus annually in the food production and distribution sector. (Heller & Keoleian, 2000) From the above energy consumption, 14% is consumed for transportation. (Hill, 2008) In the U.S. fresh produce is estimated to travel 1,500 miles from the growers to the consumers. (Hendrickson, 1996) The food transportations by airplanes, trucks and other means lead to increasing emissions of greenhouse gases and air pollution. For example the imports of fruits and vegetables in California in 2005, only by airplane, led to more than 70,000 tons of CO₂ to be released in the atmosphere. (NRDC, 2007) A main reason for food transportation is also the ability to provide certain types of fresh produce year round. However, in order for this fresh produce to stay intact while travelling, pesticides and toxic preservatives are added, which are harmful both to human health and the environment. Despite that, fresh produce still loses important part of its nutritious value from the moment it is produced to the moment it gets delivered.

Unfortunately, apart from being energy demanding, our current food system is full of contradictions. Based on the energy consumed and food miles travelled, it could be implied

that food is being uniformly distributed and available to everybody. Nonetheless, that lies far away from the truth. In 2009, there were more than 23 million people in U.S. who live in food deserts. (Bornstein, 2012) A food desert is defined by US Department of Agriculture (USDA) as “a low-income census tract where substantial number or share of residents has low access to a supermarket or a large grocery store”. (USDA, 2012) Food deserts are the aftermath of the disconnection between food production and actual demand. Food is mass produced far away from the cities where the actual demand is. That leads to problems of increased food production, bad distribution and consequently unmet demand. That means that we produce more food than we actually need, and a great part of us still stays hungry.

It is estimated that 1/3 of the food produced in the US is being thrown away before it is even eaten. (Martin, 2008) In 2010, 34,000,000 tons of food waste was created and almost all of it was thrown to the landfills. Each person produces 1 pound of food waste every day, leading food scrap to the second place as the largest source of waste to end up in landfills. (US EPA, 2010) On the other hand, the number of landfills in the US is diminishing significantly every year. From 1991 to 2007, landfills have been reduced by 2/3, creating issues of waste management and treatment. (US EPA, 2008) As landfills become fewer, waste has to travel greater distances to get treated. After March 2001, when Fresh Kills, the landfill of the City of New York closed, the waste produced by 8,175,133 people cannot be treated locally anymore and have to be transported to Ohio, Pennsylvania to get disposed, costing approximately as much as \$67.50 per ton. (Lipton, 2000) Moreover, the concentrated waste in specific areas leads to air, water and ground pollution, which compromise the health of the residents in surrounding areas. Neighboring regions of landfills can suffer up to 13.7% decrease of residential property values due to pollution and odor problems. (Ready, 2011) .

The current practices of urban development and structure have an effect on the hydrological cycle. The impermeable, concrete, dense urban clusters provoke environmental issues of climate change; with increasing floods and urban heat island effects that pose threats on human life. One of the major problems in dense urban centers is the incapability to retain the storm water. The expansive impermeable surfaces of concrete, asphalt along with the dense built environment result in flooding and polluted surface water. Flooding incidents are getting more and more frequent; only in 2004 there were more than 80 flood events in the US. (US DOE, 2008) Apart from the obvious risks that they include, they cause damages with great costs for infrastructure. It is estimated that floods cause an annual cost of damage of about \$6 billion. (National Geographic, 2012) Moreover, the repercussion of those floods is the overflow of the sewer systems, which in the case of approximately 772 cities in the US, which have combined sewer systems, leading to the contamination of the watersheds. (NPDES, 2012)

Finally, the buildings themselves contribute even more to the above urban complications. The construction industry, by creating buildings on a first cost base, ignores their performance,

Figure 1-2 :
US Food System Energy Use
Total: 10.25 Quadrillion Btu Source: Heller and
Keoleian. Life Cycle-Based Sustainability Indicators
for Assessment of the U.S. Food System. (2000)

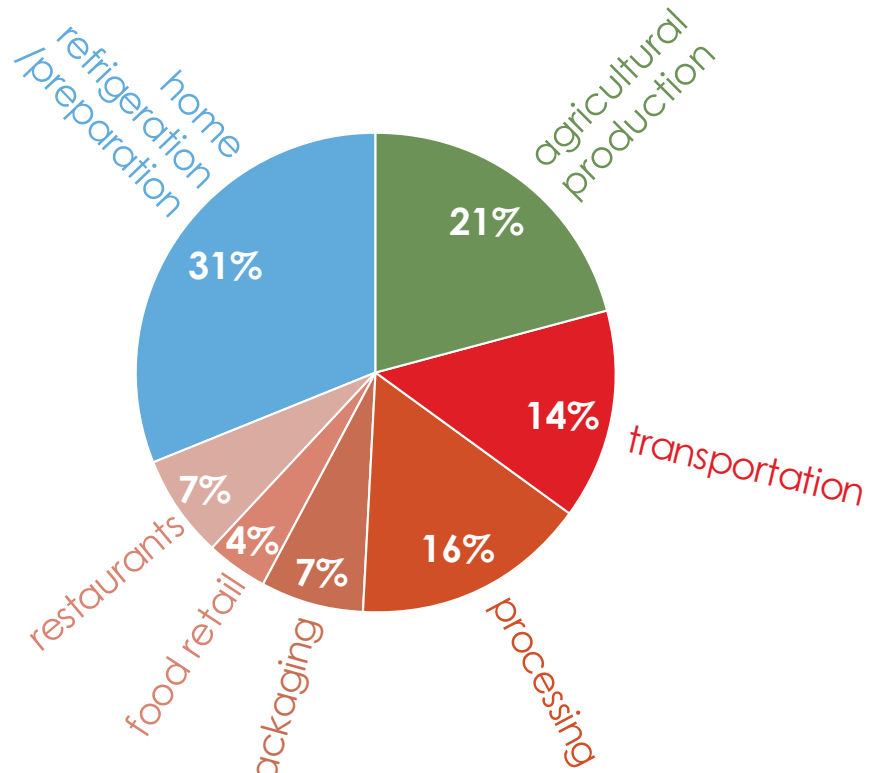


Figure 1-3 :
2010 Total Municipal Solid Waste Generation: 250
millions tons [Source: U.S Environmental Protection
Agency (EPA) data]

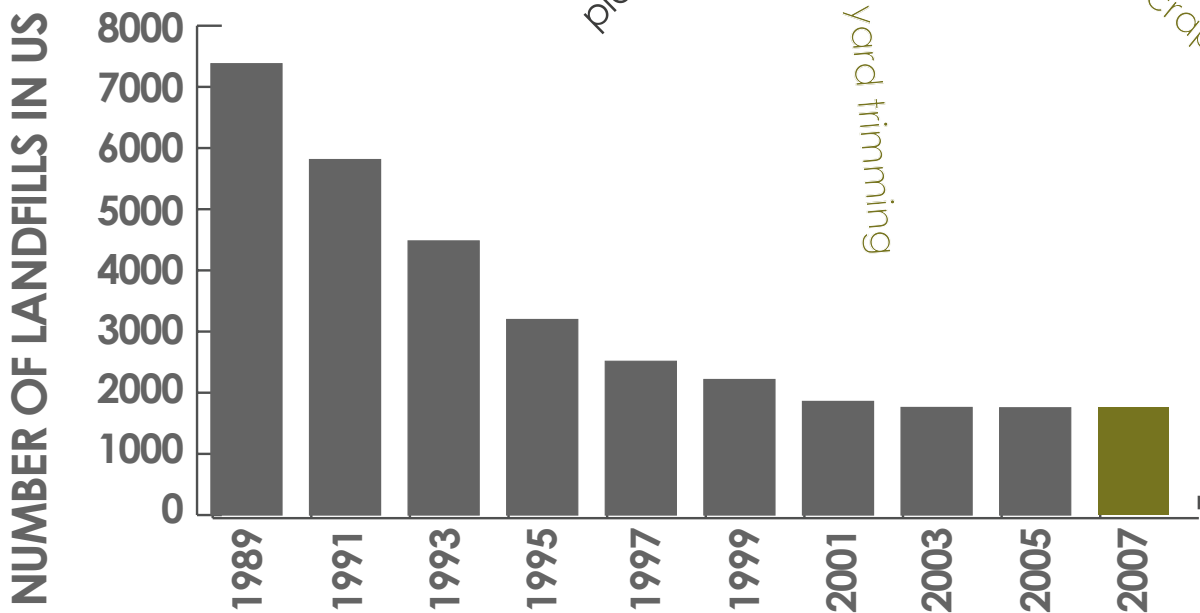
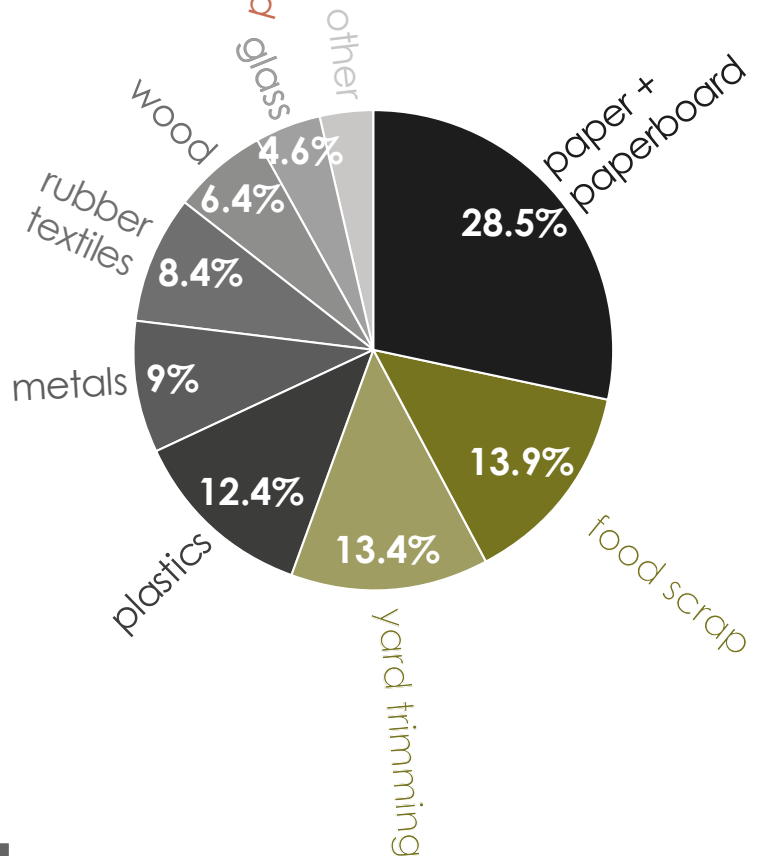


Figure 1-4 : Source: US ENvironmental Protection Agency data (EPA)

creating a high energy-demanding landscape. In the U.S., buildings are responsible for the 42% of the total energy consumption, resulting in greenhouse gas emissions which account for the 30% of the U.S. total. (EPA, 2011) The greenhouse gases emissions are due to the way we produce energy; through combustion of mostly coal or natural gas. Producing electricity through combustion and then distributing it through the grid, leads in serious energy losses that consist the 2/3 of the initially produced energy. (U.S. EIA, 2011)

The above examples question the efficiency of centralized systems. The emerging hypothesis from these statistics that will be analyzed in this synthesis is; **Will addressing food, water, waste and energy locally yield in urban regenerative environments? If it does, how designers and people related to the building industry can be updated about such environmentally sustainable decentralized systems?**

Figure 1-5 :
2011 Energy Consumption Estimates by Sector
[Source: US Energy Information Administration]

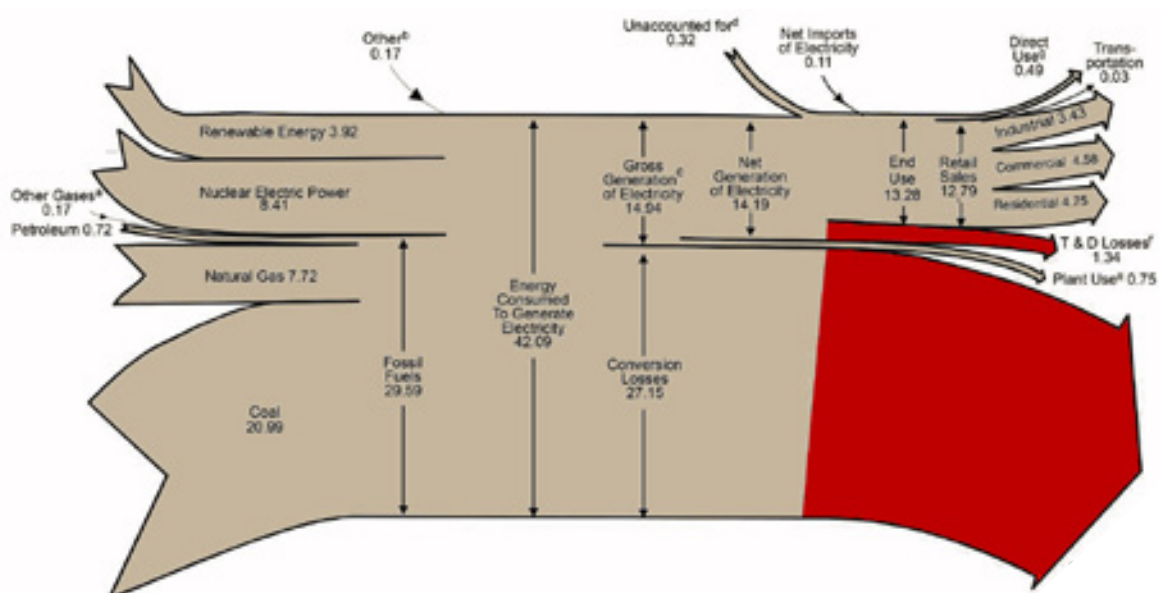
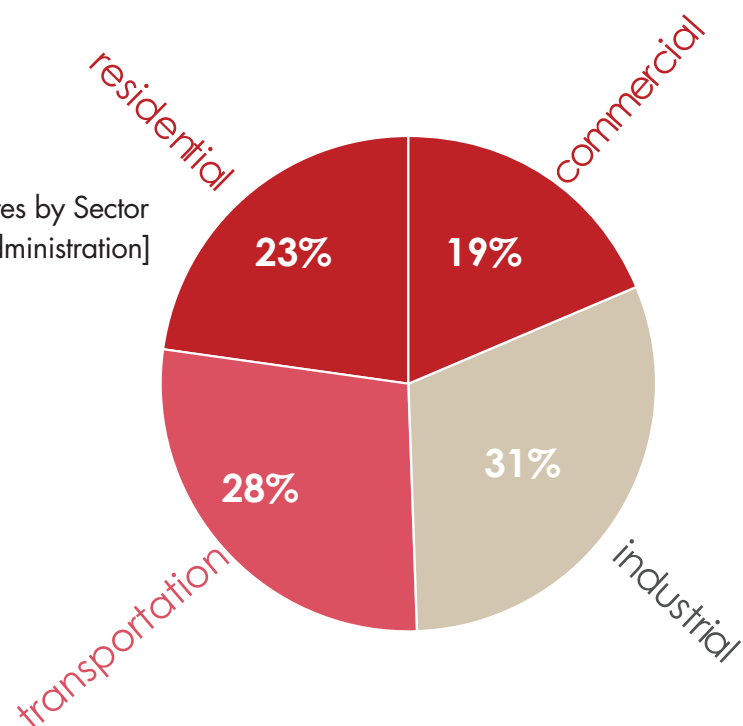


Figure 1-6 : Electricity Flow Chart [Source: US Energy Information Administration]

3. METHODOLOGY

3.1 SCOPE OF WORK

The scope of this research project is to identify technologies and case studies of urban food production, stormwater management, decentralized wastewater treatment and energy production from organic waste and present them through a comprehensive method. The representation of the case studies through the Toolkit for Urban Regenerative Environments aims at creating a link between the size of the systems, their performance and capability to a district, neighborhood or building level.

3.2 RESEARCH PROCESS

The process of the work is defined by three phases. The first phase was to delineate the different systems through literature review and data collection of recent or ongoing case studies. The second phase was to analyze, classify and document the case studies for the Toolkit of Urban Regenerative Environments.

The classification of the case studies selected was realized based on three parameters:

- 1. The type of the system:** food production, stormwater, wastewater treatment and energy from waste
- 2. The location of the system:** landscape, rooftop, window, whole building
- 3. The scale of the system:** building, neighborhood, district

Each case study has been documented along with the following details:

- Background story
- System Description
- Key dimensions
- System capacity or annual production
- Plan with graphic scale and general dimensions
- Supporting information, diagrams and images

Based on the above information the case studies are easily comprehended and there is a direct link between their spatial demands and capacity. The way that this is achieved for

each system is presented in the following table:

	Key Dimensions	Capacity
Food Production	Acres	Tons
Stormwater management	Acres	Inches/hour (iph)
Wastewater treatment	Acres	Gallons
Energy from Waste	Acres	Tons, MMBtu

The ultimate goal of this process is to provide the users of the toolkit with the ability to estimate the potential use of such a system in their projects based on their available space, building typology, community characteristics and other project demands.

Finally, as a proof of concept of the usability of the Toolkit as well as a way of investigation of the potentials of the systems presented, a design exercise was realized in a neighborhood in Philadelphia. Different systems were selected and applied in an area considered as a food desert in Northern Liberties, close to downtown Philadelphia. Through this exercise the applicability of the Toolkit was tested and the potentials of the systems in another neighborhood were identified.

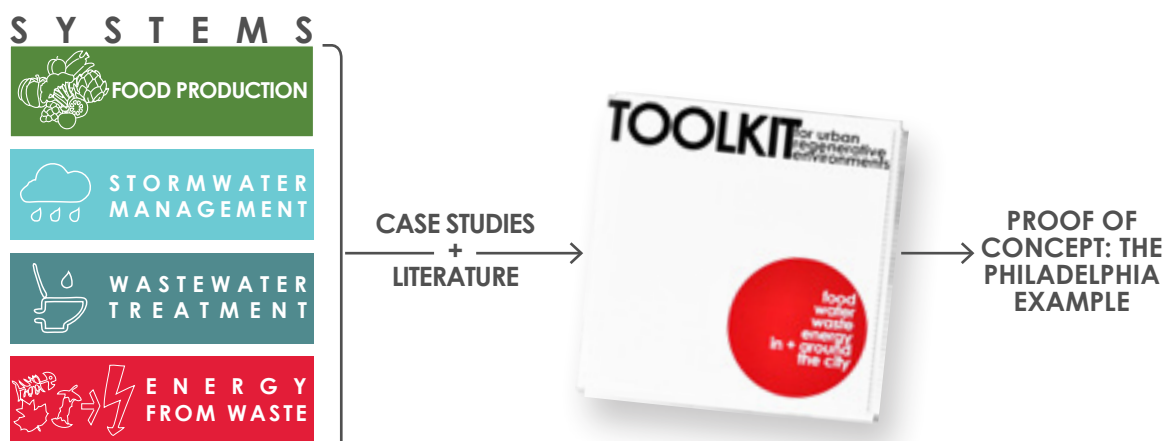


Figure 1-7 : Process of Work

4.1 FOOD PRODUCTION



4. SYSTEMS

4.1 FOOD PRODUCTION

In 1990, in half of the cities in developing countries, households would spend 50-80% of their average income on food (Mougeot, 1997). As far as food is concerned people in cities have fewer options than rural residents. The main reasons that lead to the increase of urban agriculture are: rapid urbanization, ineffective agricultural policies, bad food distribution, withdrawal of subsidies, reduction of wages, inflation, unemployment, lax urban regulations, civil strife and droughts (Mougeot, 1997). "Development policies nurturing rural-urban dichotomies have been needlessly starving cities" (Mougeot, 1993). Hence, the laws and legislations should be changed in a way that urban agriculture is developed to a point that low-income households' actual income is equivalent to food subsidy programs.

Agriculture in an urban environment is not cutting down economic development. On the contrary it provides new and different sources of development. It could take place in abandoned and undeveloped plots in the city, or even in land that is unsuited for building construction. The possibilities are endless; industrial and commercial rooftops, residential and commercial facades and so on. It creates job opportunities, for several people with different backgrounds. In many cases, urban farmers are not immigrants from rural areas that come to the city, but also city residents, who have been living in an urban context for more than 10 years (FAO, 2007). Most of them also have other part time or full time jobs.

Urban agriculture sometimes needs high technology and precision compared to the rural one, just because it is done under more difficult conditions, has to be more tolerant to environmental stress, has to be directly connected to market demand and behavior and also monitored for pollutants in order to protect public health. "Many highly valued systems must be adapted to smaller scale operations, such as hydroponics and stall feeding. Where poorer urban households have little land, technologies must be adapted to make more efficient use of tiny household spaces". (Mougeot, 1993)

4.1.1 Benefits of Urban Agriculture

As mentioned above, a lot of the implications generated within the urban context are tightly related to the lack of vegetation within our cities. The re-incorporation of both

ornamental and edible plants within the urban landscape can heal the polluted air, soil and water and generates bountiful harvest. These clearly provide benefits on all levels, social, environmental and economic.

Urban thermal benefits and Energy Savings

Green spaces, green roofs and facades, partly permeable and permeable surfaces and artificial lakes can help mitigate the Urban Heat Island and regulate temperature fluctuations. Plants have special properties that allow them to contribute to the temperature control, both on an urban level, as well as on a building level. Firstly, they are a key factor in the water cycle process. 80% of precipitation is transpired or evaporated by plants. In order to realize this process, plants transform solar radiation into energy. The process is called “evaporation cooling” and generates 2450 Joules per gram of H_2O evaporated [680 kWh/m³]. (Schmidt, 2003) 86% of the yearly solar radiation are transforming to energy by green areas like forests and meadows in evapotranspiration. Hence, it is obvious that by the limited green areas in urban environments, we minimize the percentage of solar radiation captured by the plants and increase the percentage of it transformed into heat. (Schmidt, 2003) Moreover by maximizing surfaces made by materials with high thermal mass, like concrete and asphalt, heat is captured, increasing the phenomenon of Urban Heat Island. Green surfaces have a greater potential of transforming radiation into another type of energy due to the fact that their foliage is a more complex surface. Their Leaf Area Indices (LAI) is five times greater than a simple plain surface. (Wilmer, 1990) That means that there is five times larger surface area in a foliage that can absorb radiation compared to a single surface. Consequently, incorporating vegetation within the urban areas is crucial in order to improve the microclimate and decrease the buildings’ energy loads.

Different vegetation design actions can lead to different outcomes. Trees’ canopies

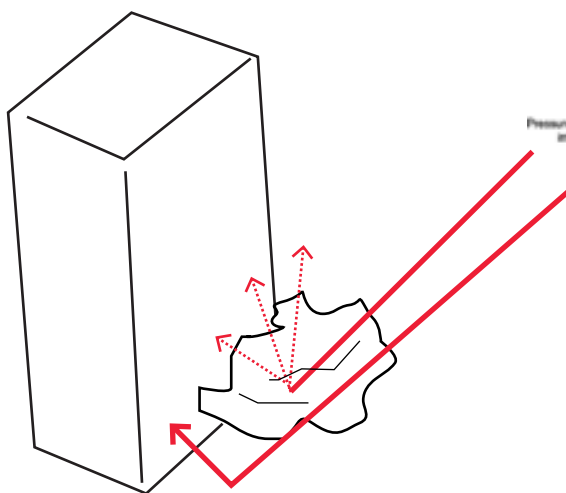


Figure 1-8 :
Low vegetation next to building

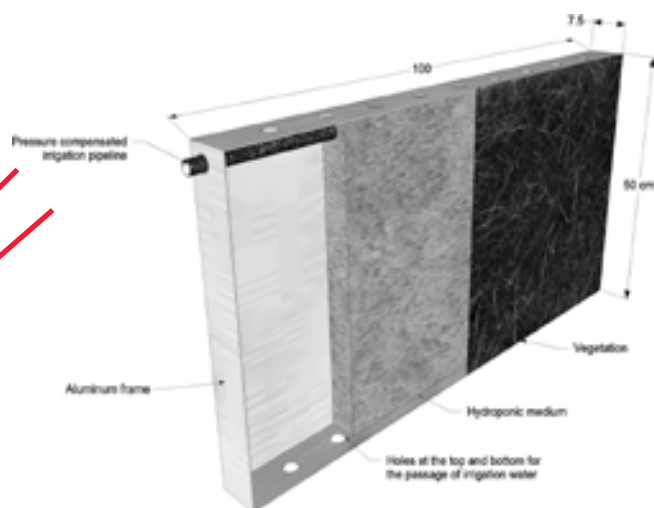


Figure 1-9 :
Cladding System of C.Y. Cheng et al experiment

next to buildings and horizontal or vertical vegetation facades minimize its solar heat gain by providing essential shading. (Givoni, 1991) That yields energy savings during the warm summer months, and if the vegetation is deciduous it provides solar access to buildings during the winter. Moreover, due to evapotranspiration, plants can lower the temperature around a building which leads to reduced heat gains due to infiltration and conduction. Shrubs and low vegetation next to a building minimize the amount of solar radiation that gets reflected to the building façade from the ground surface. (Figure 1-8) If the vegetation is implemented next to an exterior air conditioning unit, due to the drop in temperature, the system's COP could be improved. (Givoni, 1991) Finally, trees can be placed as a wind barrier and minimize heat losses during the winter.

Several studies have been conducted in order to evaluate the range of temperature reduction and the possible decrease of buildings' energy loads. On a building level, Parker J. H. in his studies has proved a 13.5 - 15.5 °C reduction in average wall temperature due to shading from shrubs and trees during the hot months, as well as a 10 - 12 °C surface temperature decrease due to vines climbing on facades. (Givoni, 1991) (Parker, 1983) However, his most important findings were about the impact of landscape on a building's energy consumption. The study was made on a mobile home, and the energy consumption of the air conditioners was measured during days with similar weather conditions both before and after the landscaping around the house. In the case of no vegetation surrounding the house, the average daily energy consumption for cooling was 5.56 kW. After the design action, the average daily consumption declined to 2.28 kW, resulting in 59% energy savings. During the afternoon's peak loads, the energy savings decreased slightly, reaching 57.5%. (Givoni, 1991)

Based on more recent studies, the cooling effect of a paneled green wall (temperature difference between the ambient air and the substrate surface) during the day would be 1°C, and it can reach up to 14°C. During the night the substrate would be warmer by 2 °C. (Figure 1-9) Moreover, the heat fluxes of a green wall are significantly lower than the ones of a bare concrete wall. (Cheng, Cheung, & Chu, 2010) The effects of green walls are also identified in N. H. Wong et al study, where 8 different green walls were compared and their performances were evaluated against a wall with no vegetation. What was observed is that the maximum surface temperature reduction was at noon, when the ambient temperature is the highest, reinforcing the benefits of the green walls. The greatest average reduction compared to the typical wall was about 10.3 °C and was achieved by a living wall (modular panel, vertical interface, mixed substrate) and a living wall with planter panels, angled interface and green roof substrate. (Wong et al., 2010)

The energy savings from a green roof can also be significant. Based on the comparison between an extensive green roof and a dark conventional one in Ottawa, Canada, the decrease between the average daily heat flows during the summer months (May to September 2011) was 75%, while during the winter the heat flow was almost the same for both roofs.

(EPA, 2012) (Figure 1-10) In a comparison study between a green roof and a light-colored one in central Florida, the decrease in the average rate heat flux was 40%, The energy consumption of the green roof was about 2.0 kWh per day lower than the light-colored roof. (EPA, 2012) However, it has to be taken into consideration that if the roof is over-insulated the heat flux differences will be minimal. Structures built by an older version of the building code, might have thinner layer of roof insulation. Hence, the incorporation of green roofs would have a greater effect on a retrofit. (Castleton, Stovin, Beck, & Davison, 2010) That stresses the benefits of incorporating vegetation on the rooftops of existing buildings. New technologies of lightweight soil can assist such attempts, addressing structural problems.

On neighborhood level, the effects of greenery are several; providing shade for building and paved surfaces, as well as for the pedestrians. The lack of vegetation on the street-line can make walking really difficult for pedestrians during the summer months. Moreover, the evapotranspiration of an irrigated park can create a really comfortable microclimate. Compared to green roofs, green walls seem to have the biggest effect on the urban canyon based on a simulation study for nine different cities. (Alexandri & Jones, 2008) However, due to the fact that parks and vegetation have effect in really small distances away from their limits, a big park would not have much effect on the urban temperatures. It is preferred to have an even distribution of vegetation in the urban context, than creating one gigantic park. (Givoni, 1991) That supports the idea of utilizing all available surfaces within the urban context for vegetation and food production.

Air Quality

Almost 25% of the US population lives in areas with increased levels of particle and ozone pollution. Increased mortality and health problems have been linked to ozone levels increase. (Bell, McDermott, Zeger, Samet, & Dominici, 2004) In Canada, 9500 premature

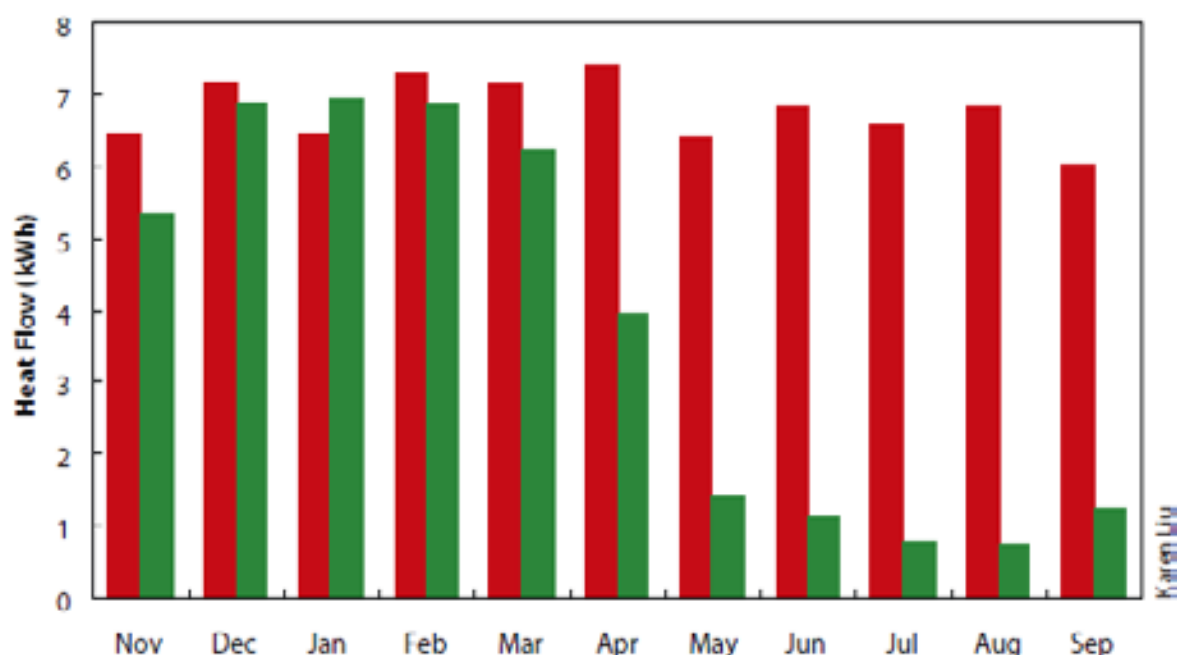


Figure 1-10 : Average daily energy demand due to observed heat flow through a green (green) and a conventional roof (red) [Source: EPA, 2012]

deaths, \$506.64 million costs increase in health care and costs due to loss of productivity were accounted as an outcome of the air pollution (OMA, 2005)(OMA, 2008). Two of the most common diseases due to air pollution is respiratory problems and cardiovascular diseases (Pope, Bates, & Raizenne, 1995)

Even though the benefits of green roofs as far as the air pollution abatement is concerned are not widely published, the abilities of plants to mitigate pollution are well stated:

- Plants intake air along with surrounding pollutants through their stomata, their leaves capture particulate matter and they can break down several organic compounds in their tissue. (Baker & Brooks, 1989)
- They also promote a decrease in surface temperatures due to the shade they provide and their transpirational cooling process. In that way they are diminishing the photochemical processes that create pollutants such as ozone in the air.
- They reduce the air temperatures, hence they reduce the need for air conditioning and consequently decrease the emissions from power plants. (Rosenfeld, Akbari, Romm, & Pomerantz, 1998)

Rooftops consist 40-50% of the total urban area and it is huge opportunity to replace all this impermeable surface area with vegetation (Dunnett & Kingsbury, 2004). It is calculated that 11 square feet of green roof can remove 2 kg of particulate matter (Johnston & Newton, 1993). Based on the data of LA City, a gasoline automobile produces 0.1 kg of particulate matter per year. Hence, 11 square feet of green roof could eliminate the annual air pollution produced by at least one car. Trees and shrubs are more effective than grass and sedum in cleaning air pollution just because of their more extended leaf surface area. Hence, intensive roofs are more effective than extensive. In Chicago, 1675 kg of air pollutants were removed within a one year period, by 19.8 ha of green roofs. From the above quantity, 52% was O₃, 27% was NO₂, 14% was PM₁₀, and 7% was SO₂. The highest removal occurred in May and the lowest in February. The annual removal per hectare of green roof is 85 kg of pollutants. (Yang, Yu, & Gong, 2008a)(Yang, Yu, & Gong, 2008b)

Tan and Sia (2005) conducted a field study in Singapore and measured the concentration of air pollutants in the air before and after the installation of a 43,055 square feet green roof. The results show that SO₂ in the air was reduced by 37% and particles by 6%. (Yang et al., 2008a) Based on a Currie and Bass (2005) assessment an area of 109 hectares of green roofs in Toronto could eliminate a total of 7.87 metric tons of air pollutants per year (Currie & Bass, 2008)

An important observation, when implementing vegetation in the urban context is that the filtration of plants is tightly related to its leaf coverage per unit area; the more leaf surface exposed the greater the filtration. Hence, dispersing plants instead of massing them together is preferable as far as pollution abatement is concerned. (Givoni, 1991)

Apart from the direct reduction of air pollutants, plants prevent air pollution indirectly by

reducing air temperatures, and consequently the need for air conditioning. It was predicted that tree shades and buildings with light-colored surfaces can reduce emissions from coal fired plants in Los Angeles leading to 10% smog reduction and 350 tons less NO_x per day (Rosenfeld et al., 1998). Due to the fact that buildings are responsible for 42% of total energy and 71% of electricity consumed, the ability of plants to reduce those demands would have a great effect on both pollution and energy consumption. (Rowe, 2011)

Health and Human Benefits

Apart from the environmental benefits of the vegetation in urban areas, plants and the practice of agriculture have a great impact on human health and social interactions. Biophilia is a well-grounded concept of human relationship to nature and its beneficial effects on human behavior and health. "Biophilia is the innately emotional affiliation of human beings to other living organisms. Life around us exceeds in complexity and beauty anything else humanity is ever likely to encounter." (Wilson, 1984) Studies have shown how the interaction and access to nature can improve the mental and social levels of human beings, as well as reduce stress and increase productivity. Stress tends to be reduced when people have access or view to nature, and people tend to feel psychologically better. (Grahn & Stigsdottir, 2010) That could even lead to economic benefits from reduced healthcare costs, as providing views and access to nature in a hospital could lead to over \$93 million annual savings. (Loftness, Heerwagen, & Painter, 2012)

In addition urban vegetation and agriculture offer other advantages. Several studies have highlighted the numerous benefits of urban agriculture; by facilitating access to healthy food while bringing together the community and strengthening the local economy (Blaine, T.W., Grewal, P, S., Dawes, A., Snider, D. 2010), and gardening can be a relaxing activity that reduces stress. (Kaplan, R. 1973)

Research on agriculture and farming in the city, with examples from North America and Western Europe, highlights these important points: 1. the correlation of growing food to consumption, 2. urban gardening and agriculture make city residents get involved with a healthy and recreational activity, 3. urban agriculture also creates healthy, safe and green neighborhoods. (Bellows, 2010) Urban agriculture's contribution to health was recognized for the first time in United Nations International Conference on Human Habitats in Istanbul in 1996. Nowadays, urban farming is spreading throughout North America, by people cultivating in vacant lots, parks, roofs, balconies etc. Moreover, one third of US farms are located within metropolitan areas and produce 3.5% of its demand.

It is estimated that a **1080 square feet plot can produce within 130-days period of temperate weather, most of one household's yearly needs for vegetables**, taking into consideration its nutritional requirements for vitamins A, C and B complex and iron. (Minnich, 1983) Possible places to grow food in a city are: parks, utility rights-of-way, bodies of water, roof tops, walls, fences, balconies, basements and courtyards. There

BOTTOM LINE BENEFITS OF BIOPHILIA

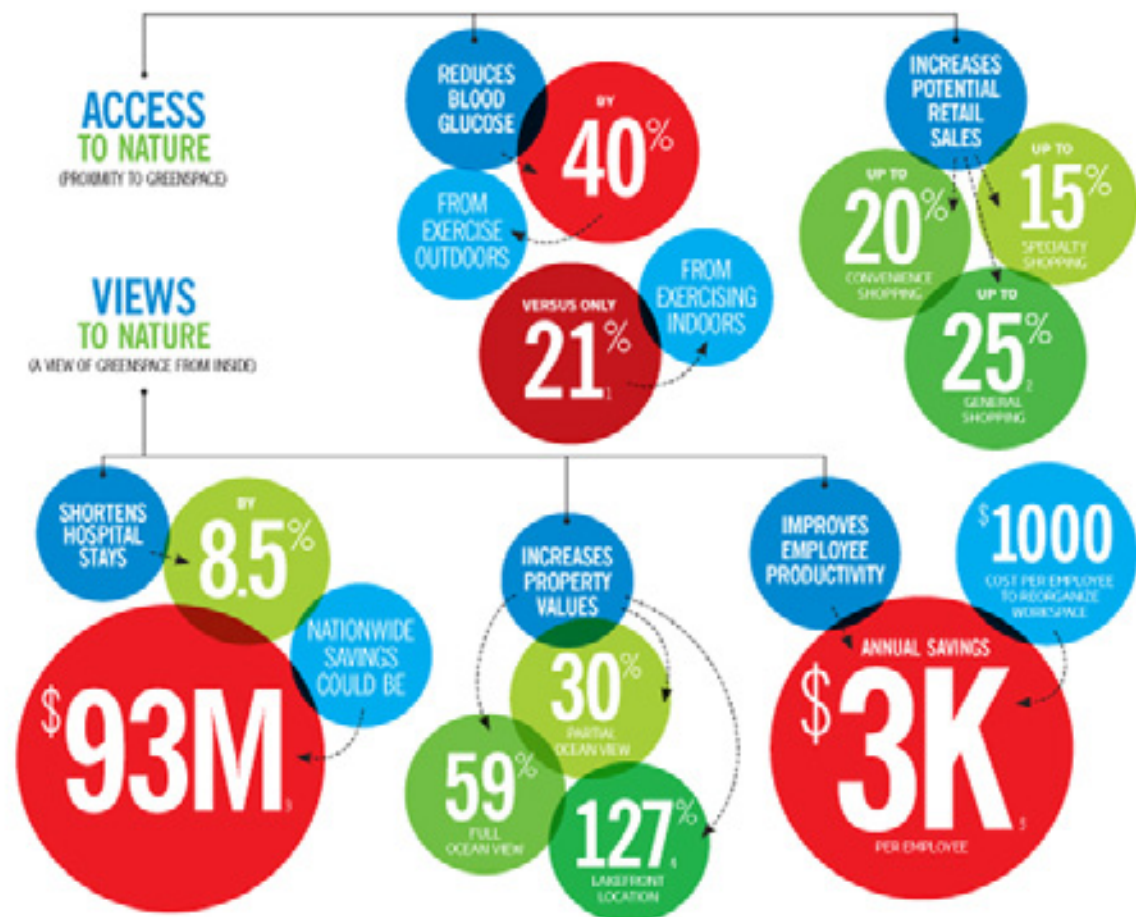


Figure 1-11 : Numbers are rounded to nearest whole. 1: Ohtsuka, 1998. 2: Wolf, 2005. 3: Machlin & Carper, 2007. 4: Heerwagen, 2006. 5: Hescong, 2003; Loftness, 2008 (Source: GreenSource, the magazine of Sustainable Design, March 2012, William Browning / <http://greensource.construction.com/opinion/2012/1203-bottom-line-benefits-of-biophilia.asp>)

are significant effects of urban agriculture on resident's diets. When people involved in agriculture are saving money by producing their own food, their dietary patterns and habits tend to improve. Fresh fruits and vegetables start to become a viable part of their diets. Hence, implementing agriculture also in schools, it will shift the children's diet towards more nutritional habits. Moreover, urban agriculture supports the demand of fresh products, with minimal transportation that preserve their nutritional elements. **It has been shown that a 5-10 days transportation and storage lag from production to consumption might end up to 30-50% losses of nutritional elements.** (Bellows, 2010)

Urban food gardening also provides some residents' demand for widely unavailable products. It also replaces farms on the city borders that are constantly threatened by new development, to meet urban population growths. As mentioned before, transporting food through great distances ends up with low quality food and increased CO₂ emissions. Consequently, urban agriculture can solve a significant percentage of local demand. It also brings people together, empowers them with skills and creates healthy and safer communities. Agriculture in education, can introduce children to biological and environmental studies early, provide them with unique skillsets, make them more sociable by creating an extracurricular hobby and avoid obesity and illnesses by providing the school's cafeteria with local fresh food.

4.1.2 Food production systems

Geoponics is the most traditional way of gardening for both edible and ornamental plants, and the growing medium is soil. However due to the increasing space limitations for agriculture along with the advance of technology, new ways of growing plants have come up, which depict a bright future for agriculture, especially in limited spaces of urban environments.

Geoponic Systems

Growing on soil is the most typical way of agriculture. Commonly the land is divided in beds which are no more than 4 feet wide. The length of the beds can vary, but the width should not surpass the 4 feet, so that all plants can be reached from both sides. There is the possibility of growing directly on the ground or having raised beds made out of wooden planks. However as the limitations of space can be a big issue, there are different ways of gardening that can increase the yield for a specified available area.

Succession planting is a common way of increasing yields; that means that after you harvest a crop you follow it with another type of crops on the same spot. Different plants absorb different nutrients from the soil, hence changing the crops on the same land leads to keep on a better quality of soil. That is the main problem of massive agriculture lands in rural areas. Mainly the same crops are being planted over and over, degrading the quality of land. That eventually leads to lower yields of poorer nutritional value.

Another technique for greater yields is intercropping. This technique allows you to plant more than one crop in a single place. However, only deep-rooted with shallow-rooted crops must be combined as they do not compete in available soil area. (Minnich, 1983)

Normally, single-row planting is considered as the typical way of gardening. However in order wide-row or double-row planting can achieve higher yields. Wide-row planting can yield up to four times more fresh produce and it requires 18" wide rows with 24"-30" space between them. Seeds are spread all over the bed without being laid out in rows. Even though the yield is lower per plant, the total yield per square foot is greater. Double-row planting is quite based on the same concept of having a more crowded bed. Every two rows of the same crop at a distance of 3" is kept instead of 15"-18" apart. (Minnich, 1983)

In the case of geoponics, it is understood that the type and quality of soil plays a significant role in the amount and quality of the yield. Loamy soil, full of organic matter, microorganisms and worms will have a good crumb structure which will allow the water and nutrients retention. Sandy soils cannot hold the water to a level accessible to the plants' roots and that is why they are not appropriate for agriculture. (Minnich, 1983) In the case of green rooftops, lightweight soils are being currently constructed to avoid overloading existing building structures. In the case of the Brooklyn Grange farm on the rooftop of an

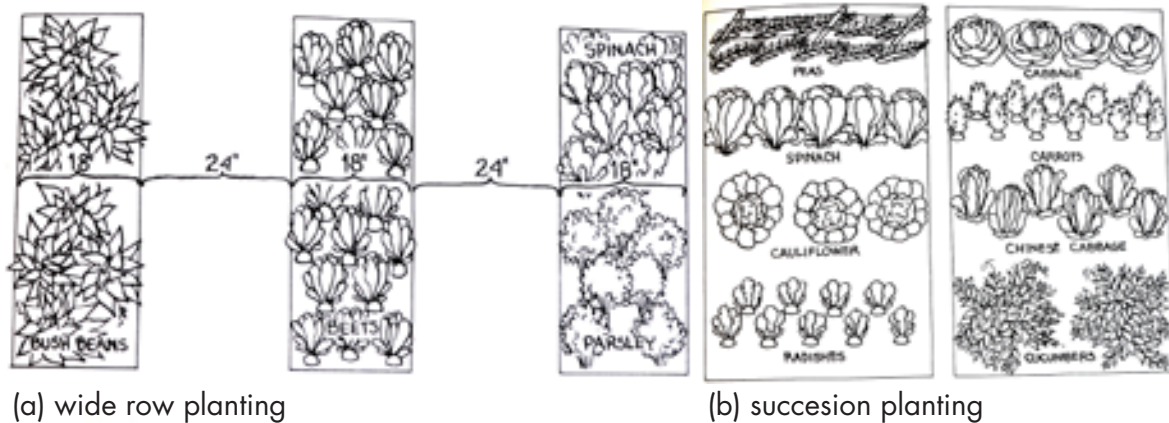


Figure 1-12: geponics on the ground [Source: J. Minnich, Gardening for Maximum Nutrition]

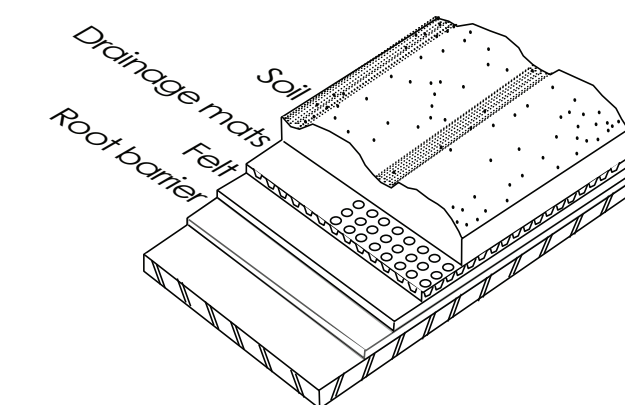


Figure 1-13: geponics on rooftops

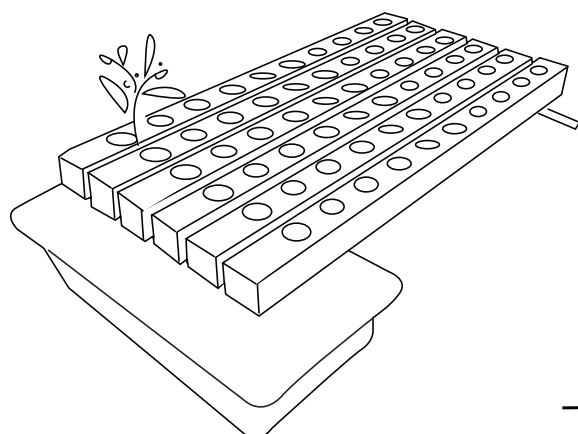


Figure 1-14: hydroponic trays

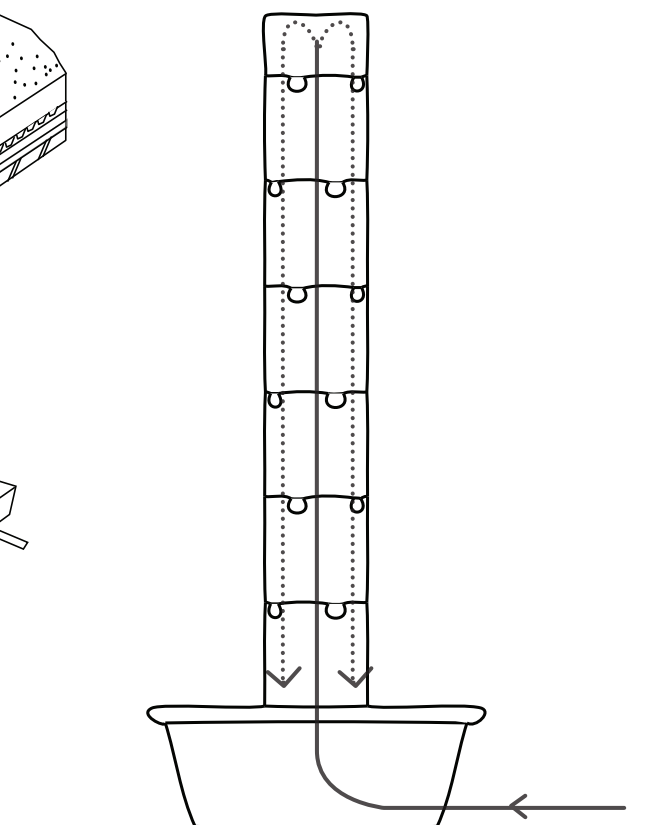


Figure 1-15: aeroponic tower and water movement

old industrial building, a lightweight soil was constructed out of compost and porous rocks. (Hobbs, 2012)

Hydroponic Systems

Another way of growing plants is without soil, but transmitting nutrients directly through water. This type of agriculture is called hydroponics. Hydroponic systems were initially used in the 1930's for scientific nutrition experiments. They started being used more widely in 1990's, as they were considered of great importance for space settlements by NASA, growing food in the deserts, vertical farming and producing food in large scale. (Sawyer, 2010a)

There are several hydroponic techniques. The most common is sub-irrigation, where the plants' roots are placed in an inert medium such as perlite, gravel, mineral wool or expanded clay, within a tray which is periodically flooded by water filled with nutrients. (NASA, 2010) This is an active system and water is pumped to the plants from a central water tank and gets recirculated many times. That is the main reason why even though active hydroponics is a water-based system, they can use up to only 10% of the water being used for typical geponic agriculture. (Hudson, 2011) Another active hydroponic technique is when the plants are placed in beds of glass wool or other similar material that stays floating on the surface of the solution. The roots of the plants penetrate this material and are constantly submerged in the solution. Again the water gets circulated. Finally, there is a passive hydroponic system, which is not that efficient, but it is easier to operate. In this kind of system the roots are placed in an inert medium such as sand, and the nutrient solution is poured in it in a regular basis. Excess nutrient solution must be allowed to drain. (NASA, 2010)

Hydroponics, especially when combined with a greenhouse can achieve great yields; 3 times greater or more compared to geponics. (National Vegetable Society, 2012) They can be used both for horizontal as well as vertical farming. Hydroponic trays for example can be placed next to each other or be stack on top of each other. Several hydroponic systems are: basic wick, non-circulating raft system or deep water, top feed/drip, nutrient film technique, ebb and flow, aeroponics and aquaponics.

Aquaponic Systems

The combination of hydroponics and aquaculture is considered as an aquaponic system. Aquaculture is the method of growing fish in a re-circulating system. In an aquaponic system, the water in the fish tank gets filled with ammonia due to their waste. The bacteria in both the fish tanks and the plants' water tanks are converting ammonia to nitrates, which are absorbed by the roots of the plants. Nitrates are nutrients for the plants. Moreover water gets filtrated from the roots and returns cleaner to the fish tanks. Water is pumped through

this cycle between the fish and the plants and also gets oxygenated. Oxygen is necessary for the survival of the fish. The different types of fish appropriate for aquaponics are: aquarium fish, tilapia, yellow perch, trout, catfish, bass, bluegill, carp, koi, goldfish and freshwater prawns. (Sawyer, 2010b)

Aquaponics is an efficient system, because it grows fish and plants in a closed waste to food cycle. The waste from the fish becomes the fertilizer for the plants. The most appropriate crops for aquaponics are: lettuce, tomatoes, cucumbers, zucchini, squash, strawberries, basil and watercress. Attention should be paid in the PH and temperatures of an aquaponic system. PH should be kept between 6-8 and temperature fluctuations should not exceed 3°F per day. (Sawyer, 2010b) The several aquaponic systems used today are: aquarium systems, barrel-ponics, IBC containers, raft method and towers.

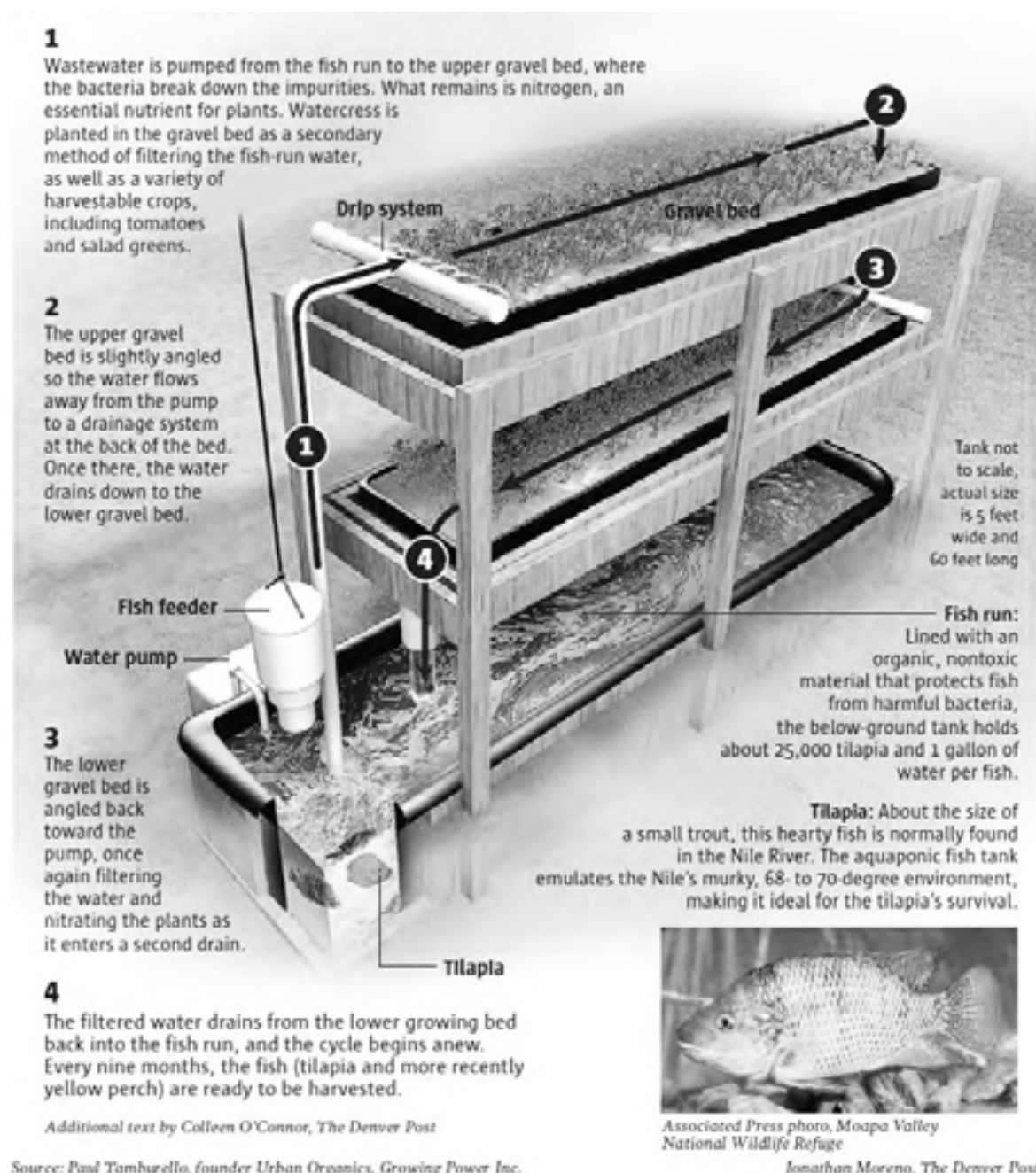


Figure 1-16 : Aquaponic system [Source: http://www.colostate.edu/Depts/CoopExt/Adams/gh/pdf/Intro_Aquaponics.pdf]

Aeroponic Systems

As mentioned above, aeroponics is actually a version of the hydroponic systems. The difference lays on the fact that the roots of the plants are not submerged into the solution, nor placed in an inert material. They are directly fixed and are hanging in the air. and water with nutrients gets sprayed to them. The unused solution gets recirculated, and in that way the amount of water used is even less.

The most typical example of aeroponics is the aeroponic towers. Plants are placed all along the height of the tower and their roots are placed in the inner part of the tower. There is a water tank at the base of the towers, and water gets pumped to the top from there. From the top, water drips slowly inside the tower, passing through the roots and providing them with nutrients. (Roth, 2010)

4.1.3 Implications of urban agriculture

Urban agriculture has great potentials of increasing a city's food self-resiliency. Based on research conducted by S. G. Grewal and P. S. Grewal, Cleveland could become 17.7% more self-reliant by weight and 7.3% by expenditure in total food and beverage consumption, if it used vacant lots, industrial and commercial rooftops as well as a small part of residential yards to grow fresh produce. (Grewal & Grewal, 2011) However, there are several limitations related to urban agriculture that need to be addressed.

There are several health risks related to urban agriculture. Heavy metals in soil such as lead, calcium, mercury, nickel and copper can be really dangerous for the plants and can be transferred to people through the produce. Consequently, it is of great importance to improve the soil quality through crop plantings and soil amendments. Cultivating fruit and eggplants or peppers, instead of green leafy vegetables can help, because the latter tend to absorb metals faster compared to the former. In addition, composting or adding calcium can reduce acidity. (Bellows, 2010) Another serious problem is air pollution from vehicles, railways, wood and coal burning, which can affect the quality of the plants.

Additionally, air pollution can affect the the natural processes and growing of the plants. The greenhouse gases affect the urban atmosphere more severely than rural locations. Due to this fact, plants can be deprived by UV A and UV B light. This part of the spectrum is really important for leaf formation as well as the photomorphogenesis. (Kefeli, 2012) At the same time, ozone depletion allows UV C to pass through the atmosphere which can be destructive for the plants. Finally, the chlorophyll grains, which are responsible for the photosynthesis of the plants, can be affected by the high concentration of acids, greenhouse gases and smog in the city. This can block the photosynthesis, distract the chlorophyll and block the leaf formation. (Kefeli, 2012)

**BATTERY PARK URBAN FARM, NYC**

Year: 2010

Website: www.thebattery.org/projects/battery-urban-farm/

Background:

Battery Urban Farm is located in the Battery Park Area of Manhattan. The idea of the farm started in 2010 by eight students from the Environmental Club of Millennium High School who wanted a vegetable garden. The Battery Conservancy found the idea exciting and now two years later, the farm serves more than 800 students and 11 schools. The goals of the farm are mainly educational and intended to create a strong sense of community in Downtown Manhattan. Students come in touch with gardening and growing techniques and learn to appreciate fruits and vegetables. The farm has the shape of a turkey as a tribute to Zelda, an American turkey that has resided in Battery Park since 2003. In order to protect the site, Scott Dougan's design included 5,000 reused bamboo poles that were placed along the turkey shape. To realize the farm, Battery Farm Conservancy had to bring 352 cubic yards of organic soil on site.

1-17



1-18



Figure 1-17 Source: 4.bp.blogspot.com/-MV8lbDiBeVw/T6U3DVT6tYI/AAAAAAAAA20/BVsYCg7B0So/s1600/spring_1.jpg

Figure 1-18 - Source: www.thebattery.org/wp-content/uploads/2012/05/59.jpg

System Description:

The farm's beds are 4 feet wide and are located 2-3 feet apart. Their length ranges between 5' to 32'

Key Dimensions: One acre (43,560 square feet)

Crops: 80 different varieties of fruits, vegetables and flowers: arugula (astro), basil (purple, genovese), bush beans (yellow, green, purple), pole beans (various Italian/French), (red, Chioggia), broccoli, carrots (orange, scarlet nantes), chard (bright lights), chives, cilantro, collards, cucumbers (diva, lemon), dill, eggplant (Italian, Asian, other), edamame, kale (curly winterbor, lacinato), kholrabi, lettuce (butter crunch, organic mix, mottistone, romaine—Jericho, rhazes), mint, okra, onion (scallions, King Richard leek, sweet), oregano, parsnips, peas (snap and pea), peppers (Italian, poblano, jalapeno, Asian, bell), radish (French breakfast, pink beauty), sage, spinach, strawberries, summer squash (zucchini, yellow crookneck, scallopini), tomatoes (big red type, green zebra, striped German, sun gold, purple heirloom), tarragon, thyme, turnips (Battery Urban Farm, 2012)

How much is produced? Approximately 3 tons* annually

Growing Season: April to November

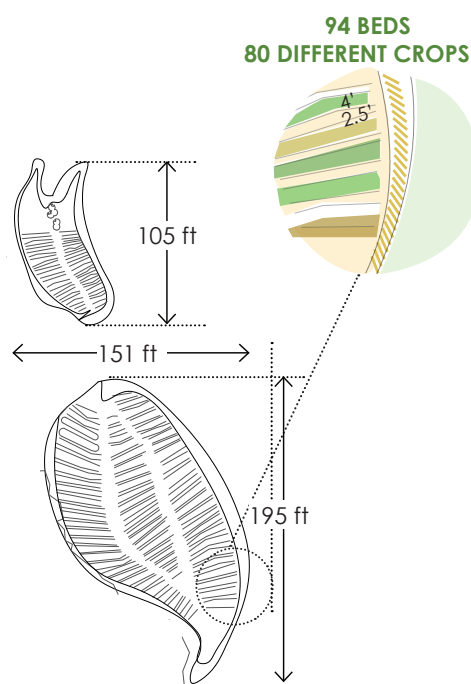
Who gets the produce? They sell their produce (150 lbs) to two downtown school cafeterias through the Garden to School Café Program. The schools are within a 3-4 miles radius. (PS 3 and PS 397) They also have a market on-site one Saturday, "Farm Saturdays", every month from 12-4pm. During "Farm Saturdays", workshops along with volunteer work take place.

Who is involved? By now about 800 students and 50 teachers from 13 different schools are involved in the farm

Where do they get their seeds?

[Johnny's selected seeds](#), [Hudson Valley Seed Library](#), [Baker Creek](#) and [Seed Savers](#).

Other important information: They compost on site in a three-bin compost system. People from the community can also bring their compost to the farm.



*Estimated value based on system, not from farm's data



ADDED VALUE, Brooklyn and Governor's Island

Year: 2003

Website: www.added-value.org

Background: Added Value started in 2003 as an initiative of the Red Hook Community that began in order to offer meaningful educational activities as well as job opportunities to the neighborhood's teenagers. In 2002, they identified an old empty baseball field that would become their farm. Now, with their second farm on Governor's Island, they serve as an educational and work field for more than 115 young people, they run educational programs for more than 280 elementary school students and workshops for more 1300 children annually. Finally a network of 3,850 people supports the farms by volunteering, donating and providing services. Added Value has managed to regenerate the Red Hook Community not only by giving them access to fresh food but by offering jobs, educational programs and creating economic activity on the area. ("Added Value," 2012)

System Description: The farm's beds are 4 to 6 feet wide with 2 to 3 feet distance between them. They also have a small hoop greenhouse on site.

Key Dimensions: About 4 acres (174,240 square feet)

Crops: They are producing all kinds of crops



Figure 1-19- Source: www.takeabite.cc/wordpress/wp-content/uploads/2008/08/23064333.jpg

How much is produced? 12 tons of fresh produce annually

Who gets the produce? They have three forms of distributions. Firstly, from June to October, they have a Saturday Farmer's Market on site where the neighborhood's residents can have access to fresh fruits and vegetables. Secondly, they are connected to the Community Supported Agriculture (CSA) network. The CSA network connects the residents with the local and regional farmers and farmers markets. Added Value provides over three tons of fresh food to the network. Finally, they have created stable partnerships with six restaurants in the Brooklyn area.

Who is involved? They set up a network of more than 25 partnerships, 3,850 volunteers and donors, as well as 152 working teens.

Other important information: Added Value has managed to regenerate the Red Hook Community not only by giving them access to fresh food but by offering jobs, educational programs and creating economic activity in the area. Currently, they are generating \$70,000 in revenue for youth stipends and creating a local economic activity of \$120,000. They have set up a network of more than 25 partnerships, 3,850 volunteers and donors, as well as 152 working teens.

In 2010, the community managed to sell produce worth of \$53,000, only from its 2.75 acres. That shows how the farm has regenerated the community and has brought food of higher nutritious value to a former food desert. (MacIsaac, 2011)





EAGLE STREET ROOFTOP FARM, Brooklyn

Year: 2009

Website: www.rooftopfarms.org

Background: In 2009, next to the East River in Brooklyn, the Eagle Street Rooftop Farm was set up on the rooftop of an old warehouse. The farm started as Rooftop Farms by the company Broadway Stages and the green roof design and installation firm Goode Green. The farm is owned and financed by Broadway Stages, a sound stage company which is known for their investments and outreach to the community of Greenpoint. Apart from growing and selling its produce, the farm accommodates a Farm-Based Education team in collaboration with a food education organization; Growing Chefs. Through this collaboration they offer educational and volunteer programs that are available for two days per week. The goal of the program is to make more young people aware of techniques related to planting seeds, composting, and growing chickens and bees.

System Description: The roof is layered with 2 inches of three built-up components; polyethylene, drainage mats, retention and separation fabrics. Above those layers 200,000 pounds of soil were placed that can hold up to 1.5" of rain. The farm was arranged by 16 north-to-south oriented beds that are 4-7 inches deep. Their width ranges from 30 inches to four feet with an aisle in the middle for access. The plants are watered manually with a hose,

1-20



Figure 1-20 Source: http://3.bp.blogspot.com/_U3l_wCXOtM8/TSsp_h7H4wl/AAAAAAAAAabs/zzzjP6MbZrg/s1600/7_21_10_EagleStreetAnnie9982.jpg

Figure 1-21 Source: http://brooklynhomesteader.com/37465_1546829914165_1337551152_31516885_8069720_n.jpg

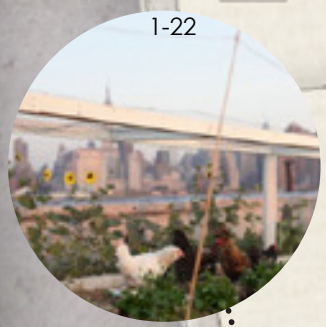
Figure 1-22 Source: http://2.bp.blogspot.com/_bTw6AyjGA8/TIediPr4Jel/AAAAAAAAAB78/FA5BsTnBirg/s1600/chickens1_novak_post.jpg

Figure 1-23 <http://vidasclass.blogspot.com>



beehives

1-21



1-22

henry (5' x 28'): 6 hens

100'

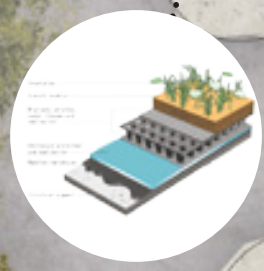
58'



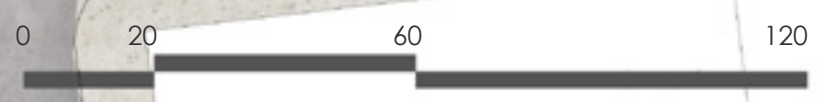
access to the rooftop



1-23



green roof detail



and for some of them rainwater is sufficient. The total cost of the green roof was \$60,000, which means an average cost of \$6/square foot.

Key dimensions: 0.14 acres (6,000 square feet)

Crops: The farm produces more than 30 crops; In 2011, the farm grew cucumbers, hot peppers, tomatoes, eggplants, spinach, radishes, kale, swiss chard, carrots, peas, beans, salad greens (lettuces, mustards, arugula) herbs (sage, tarragon, oregano, parsley, chives, cilantro, dill), and flowers (cosmos, zinnias, calendula, tobacco, daisies, hops). Additionally, the farm grew a small amount of corn and squash (winter and summer). (Novac, 2010) Three beehives are installed on the rooftop, and honey is harvested in partnership with Brooklyn Honey. The farm also has 6 hens that provide at least 4 eggs on any given day.

How much is produced?

Approximately 1.12 tons* of fruits and vegetables along with 1460 eggs

Who gets the produce?

The farm provides fresh products to several local restaurants and also sells a part of its produces to the Sunday farm market on-site. Moreover, they offer a CSA program (Community-Supported Agriculture) since 2010, and they are the first rooftop farm to have its own on-site CSA program. In a CSA program, members pay up front money before the growing season, so that the farms can buy seeds. The farms on the other hand, keep supplying them with fresh produce throughout the growing season. This arrangement directly connects the farmers and members and they both have direct benefits (Novac, 2010)

**Estimated value based on system, not from farm's data*



Figure 1-24 http://rooftopfarms.org/wp-content/uploads/2012/06/IMG_2170.jpg



BROOKLYN GRANGE, Queens

Year: 2010

Website: www.brooklyngrangefarm.com

Background: Brooklyn Grange is a privately owned and operated farm that has community and school outreach programs. When they started the idea of the Brooklyn Grange Farm, its founders were living and working in Brooklyn. They identified a rooftop and established their farm as an LLC. However, as their arrangement for the rooftop failed they had to look elsewhere. Afterwards they spotted a new rooftop located at Northern Boulevard in Queens. As they have already started the LLC business model and they did not want to confuse their fund raisers and partners, they kept the name as it was; the "Brooklyn Grange" farm in Queens!

The process of finding a rooftop of this size that could hold the extra weight of soil was really tedious and time consuming. (Hobbs, 2012) Currently, they are leasing the rooftop of the 1919 warehouse for the next 10 years and they hope to reach out to the community in addition to being a commercial farm. Several events can be organized on the farm such as brunches, lunches, dinners, educational tours for groups of up to 25 people and corporate retreats for a farming break!.



Figure 1-25 <http://brooklynexposed.com/images/sized/images/uploads/main/Brooklyn-Grange1-537x356.jpg>

System Description: They have spread 1.2 million lbs of soil over 20,000 linear feet of green roofing material. The building has a concrete slab that was inspected by engineers and architects, before the installation of 30 lbs of soil per square foot. The green roof system is provided by Conservation Technologies and its layers are the following: 1. Root barrier, 2. Layer of felt, 3. Drainage mats with cups for water retention, 4. Soil with organic components and lightweight porous stones. (Brooklyn Grange, 2012) The soil was specially made to be lightweight, to minimize extra loading for the old structure. Made out of compost and porous stones, they managed to create a 25% lighter soil compared to typical topsoil. (Hobbs, 2012) The beds are 7.5 feet deep and they have 1 foot distance between them.

Key Dimensions: 0.85 acres (37,258 square feet)

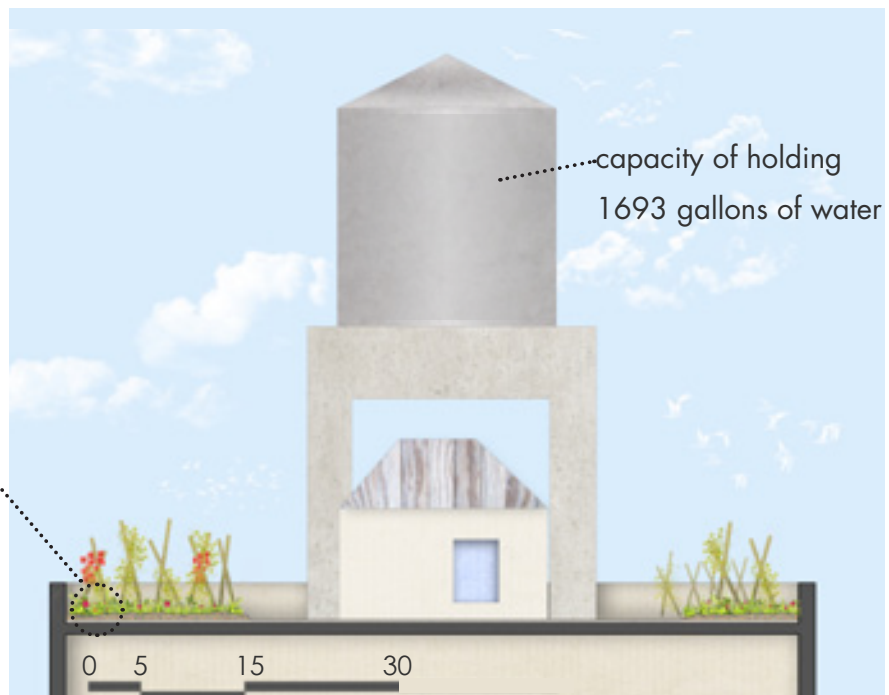
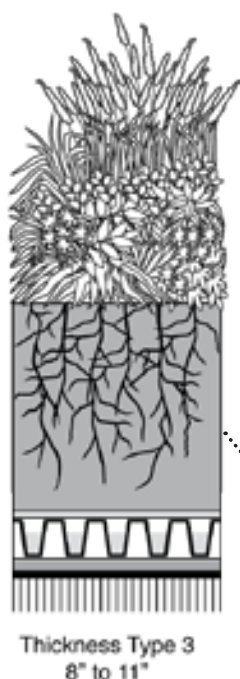
Crops: Their biggest crop is tomatoes, with 40 different varieties planted. They also grow salad greens, herbs, carrots, fennel, beets, radishes and beans. Moreover they raise chicken and have a beehive on the roof.

How much is produced? Approximately 7 tons (15,000 pounds) of fresh produce (Hobbs, 2012)

Growing Season: The farm is working 9 months per year. During the winter, they grow rye, buckwheat, vetch and clover.

Who gets the produce? They supply more than 8 restaurants within 4.7 miles radius and three markets within 2 miles radius.

Other important information: They are funded through private equity, loans, grassroots fund raising events and the website [Kickstarter.com](https://www.kickstarter.com).





139'

477'

Beds: 3-5
feet wide with
1 foot distance in
between



hosting area of events

0 20 60 120



GOTHAM GREENS, Brooklyn

Year: 2010

Website: www.gothamgreens.com

Background: In 2009, Viraj Puri and Eric Haley, recognizing the increasing need of fresh organic fruits and vegetables within the city, decided to begin a rooftop greenhouse with hydroponic system. The farm started successfully in 2010 on the rooftop of an old bowling alley. The 12,000 square feet greenhouse provides a perfectly controlled environment for the plants; it controls light, temperature, humidity, CO₂ levels and nutrition recipes for the plants. In that way, the high quality of the produce is always deliverable. The greenhouse is controlled by central computer system.

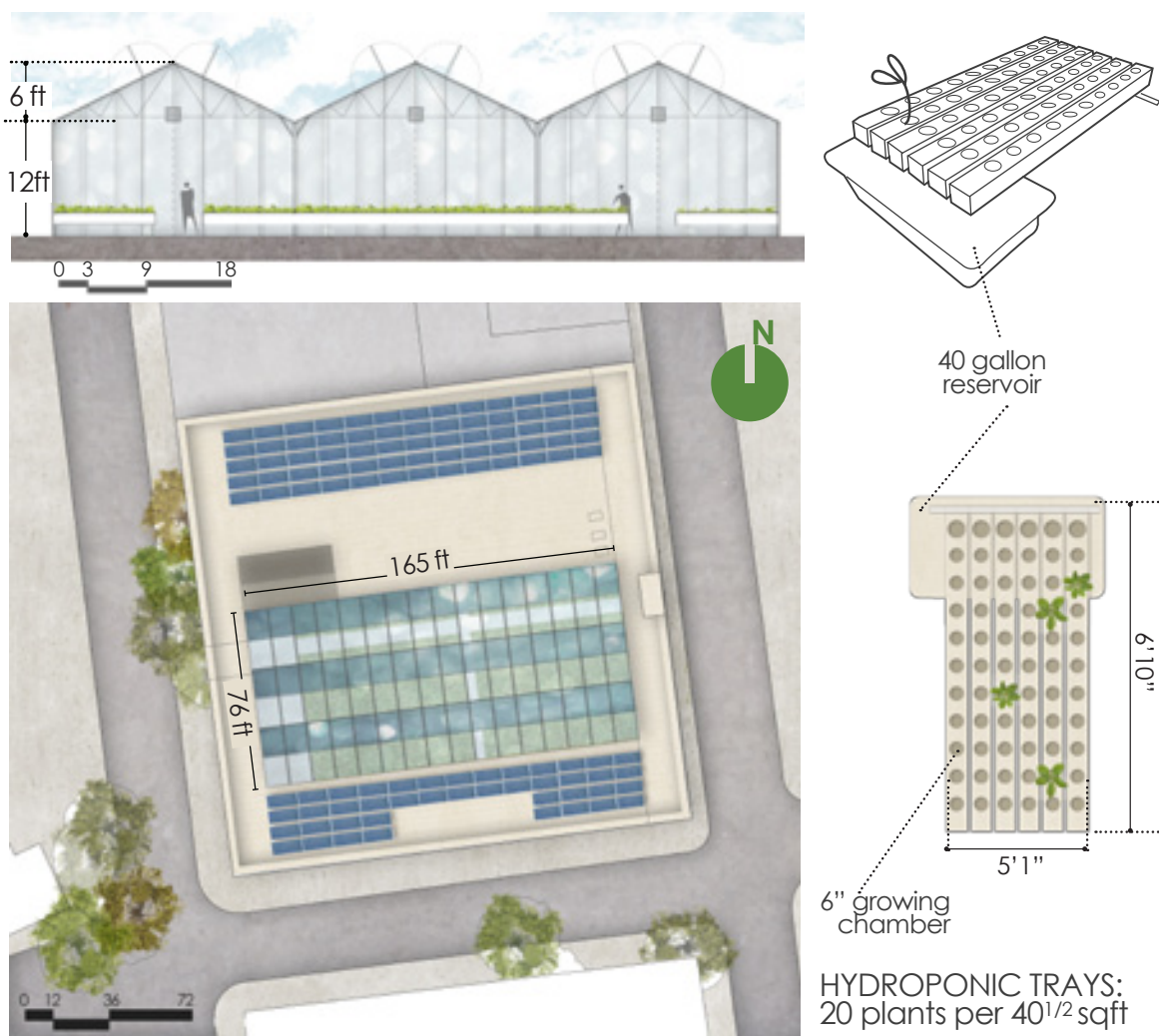
They provide fresh produce for several retailers and restaurants, including Whole Foods and D'Agostino.

System Description: A greenhouse is installed on the roof for the plants grow. The light, temperature, humidity, CO₂ levels and the nutrition recipes are all controlled by the owners, via a central computer system, leading to a high quality produce. ("Gotham Greens," 2012) It has three rows of vegetables with 2 walking aisles between them.

The crops are grown with a hydroponic system by General Hydroponics. ("GENERAL HYDROPONICS," 2012) Hence, the nutrition of the plants is controlled by the water passing through the system. Moreover, the water is gathered and reused more than once, leading to a water consumption of 10% of what is used in typical agriculture. (Hunt & Castle, 2012)



Figure 1-26 <http://bgponics.com/images/gotham-greens-hydroponic-rooftop-farm-place.jpg>



Key Dimensions:

The greenhouse is 76 feet wide, 160 feet long and about 18 feet high. It consists of 3 segments and it has a total area of over 0.27 acres (12,000 square feet)

Crops:

The farm produces only four crops; Baby Butter head Lettuce, Basil, Tropicana green leaf lettuce and Red Sails Red Leaf

Growing Season: Due to the controlled environment, the farm is able to work year round.

How much is produced? Approximately 40-80 tons annually

Who gets the produce? They supply retailers and restaurants. Within their regular clients are Whole Foods Market and D'Agostino.

Other important information:

Because of their increased energy demand due to the controlled environment of the greenhouse, they have installed a 55 kW grid-tied PV array on the roof. The system consists of 247 modules, placed at a 10° angle. There are PV panels both on the north and south side of the greenhouse and they cover an area of about 6,000 ft². The projected electricity production from the array is 64,858 kWh/year. (Meier & Puri, 2011)



BELL, BOOK & CANDLE, NYC

Year: 2010

Website: www.bbandcnyc.com

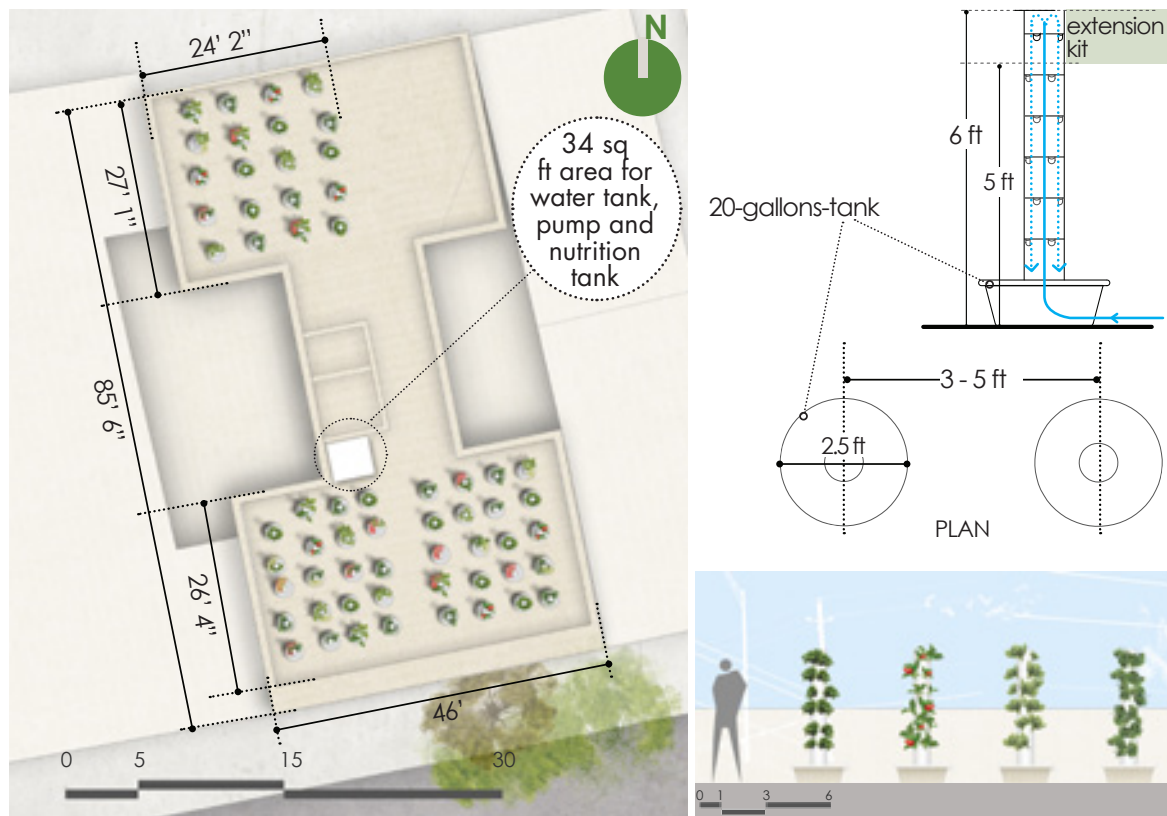
Background: In 2010, John Mooney, the chef of the restaurant Bell, Book & Candle in New York, decided to start up a rooftop garden in order to supply the kitchen with fresh fruits and vegetables every day. They have installed 60 aeroponic towers from the Tower Garden Company. As John Mooney says hydroponic towers were the best choice for them because the building is really old and they wouldn't be able to put soil on the roof.

As the produce is used directly in the kitchen of the restaurant for fresh meals, the menu changes slightly every day based on the available produce. The rooftop is on the sixth floor, and they transfer the produce down to the first floor with a hoist. The restaurant seats 94 people, and manages to get the 60% of its needs for fresh produce from the rooftop. (Krieger, 2010)

System Description: The system consists of 60 aeroponic towers with 28 plants each. The towers normally are 5 feet tall, they can carry 20 plants and have a footprint of 2' 6" diameter. In the Bell, Book & Candle's case they have incorporated the extension kit that makes the towers 6 feet tall and they can carry 28 plants each. The base of the tower is a 20-gallon tank.



Figure 1-27 <http://leconcierge.uol.com.br/imagens/blog/Bell%20Book%20and%20Candle%202.jpg>



There are two tanks with nutrients that supply the tubes that carry the water from the NY tap water to the towers. The nutrient supply is running on power supplied by a solar PV panel. After being enhanced with nutrients, the water moves to the main reservoir. The reservoir sits two feet above the ground, in order for the water to get distributed by gravity to the base of the towers.

The base of the towers is a 20 gallon tank that contains a low wattage submersible pump. The pump sends the water to the top of the tower through a central hose. Afterwards, water starts dripping slowly on the interior periphery of the tower where the roots of the plants are. The water, apart from providing the roots with the necessary nutrients, becomes highly oxygenated on its way down and ends up back to the reservoir. (Tower Garden, 2012) This process occurs for 3 minutes at 12 minute intervals. (Soil-less sky farming, 2011) This repeated process provides oxygen, water and nutrients to the plants. Based on research by NASA, this system can reduce the growing duration by half. (NASA, 2007)

Key Dimensions: With a distance of 3-5 feet between them, the 60 aeroponic towers can fit in 0.036 acres (1,584 sq ft)

Crops: 70 varieties of herbs, vegetables and fruits.

How much is produced?

The rooftop garden can carry 1,680 plants. Due to aeroponics some plants can be harvested as fast as within 1 week.



URBAN CANOPY, Chicago

Year: 2011

Website: www.theurbancanopy.org

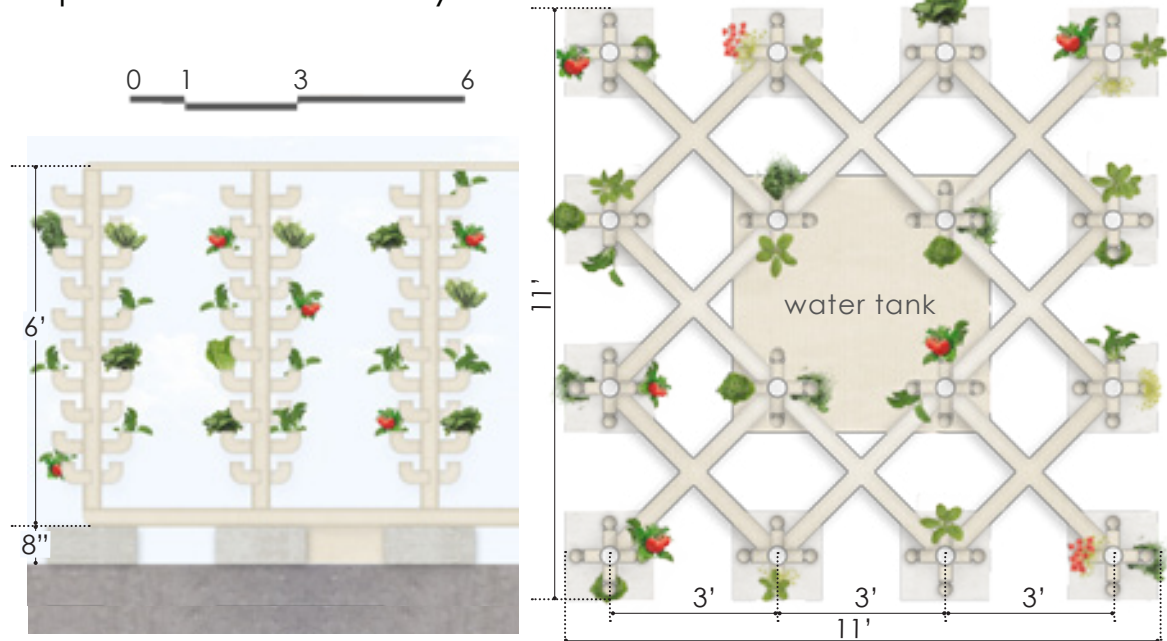
Background: : This is a startup project by Alex Poltorak that started in 2011. The purpose of the project is to create a do-it-yourself low-cost hydroponic towers system and share it with people that intend to get deeper into urban agriculture. As a part of the urban agriculture movement, Alex Poltorak is trying to achieve a low cost approach to hydroponics to engage more people to grow their own food. The towers are custom made, can hold twenty plants each and cost \$100.

The hydroponic towers are placed on a holistic approach project of urban agriculture; The Plant in Chicago. ("The Plant," 2012) Based on their research in 2011 they discovered that the middle towers need additional light. In 2012, a new model was redesigned in order to address those light issues.



Figure 1-28 Source: <http://www.youngfarmers.org/wp-content/uploads/2012/02/the-urban-canopy-pic.jpg>

plan + elevation of the system



System Description:

The system is designed and constructed by Alex Poltorak with the help of volunteers. It consists of 16 hydroponic towers constructed by PVC tubes. Each tower is 6 feet high and can hold 20 plants. Two plants are arranged every 6 inches, throughout the tower. The towers are placed on a distance of 3 feet between them. (Poltorak, 2012)

The hydroponic system is irrigated by a 50 gallon reservoir and a pump sends the water to the top of the towers and then let it drop down again, watering the plants slowly. The pumps are on timers and run for a few hours per day and not constantly. (Poltorak, 2012)

Key Dimensions:

Each hydroponic tower is 6 feet tall. The complex of 16 hydroponics towers next to each other, at 3 feet distance*, needs an area of 12 x 12 feet plus some space for the water tanks.

Crops: In 2011 the towers had mustard greens, kales, lettuces, chards, tomatoes, peppers, strawberries and several others.

How much is produced? The system can carry 320 plants

Other important information: Because the towers are made of PVC they can cost as low as \$100 each.



URBAN CANOPY, Chicago

Year: 2009

Website: www.windowfarms.org/

Background: The Windowfarms project was set up by the artists Britta Riley and Rebecca Bray in February of 2009 when they decided to grow their own fresh vegetables because they did not have access to farmer's markets in New York during the winter. The first system was set up in a 4' x 6' window and it produced 25 plants which led to a salad per week in the middle of the winter! In 2012, people can order the system online or receive the instructions for a do-it-yourself installation.

A great network of people who have already installed the system is set up online. They help new people who want to join the movement by sharing their experiences. The system gets reviewed and redesigned based on the feedback and insights of this growing community all over the world.

System description: The system consists of water bottles laid out in columns, a water reservoir, plastic tubes and a small pump that pumps the water to the top of the column and



Figure 1-29 Source: www.pixelache.ac/helsinki/wp-content/uploads/2010/02/2010-02-26-MG_7846-forweb.jpg

Figure 1-30 Source: www.surpresaria.com.br/voando/wp-content/uploads/2012/06/windowfarm41.jpg

lets it fall slowly through the plants. This is an easy-to-make hydroponic system that allows you to grow a good amount of plants throughout the year, as you can turn your window to a small greenhouse! The hydroponic system helps save space as the hydroponic containers can be smaller than a usual pot with soil. ("WindowfarmsTM," 2012) The irrigation system distribution has changed over the different versions. Version 1.0, has independent bottle-reservoirs hanging on the bottom of each column. Version 2.0 was standing on the floor, not hanging from the ceiling, and had a one gallon bottle reservoir on the bottom common for all the columns. Version 3.0 had both top and bottom reservoirs made out of PVC pipes, which were kept on the middle of the water loop. The water needs to be changed 2-3 times per week.

Key Dimensions: Fits in any window! The minimum space needed in order to grow one plant is 14" x 14". (Figure 1-31)

		glass area width													
		< 14"		14"-24"		24"-36"		36"-48"		48"-60"		60"-72"		72"-84"	
glass area		max # of plants	max # of columns												
	< 14"	1	1	2	2	3	3	4	4	5	5	6	6	7	7
	14"-24"	1	1	2	2	3	3	4	4	5	5	6	6	7	7
	24"-36"	2	1	4	2	6	3	8	4	10	5	12	6	14	7
	36"-48"	3	1	6	2	9	3	12	4	15	5	18	6	21	7
	48"-60"	4	1	8	2	12	3	16	4	20	5	24	6	28	7
	60"-72"	5	1	10	2	15	3	20	4	25	5	30	6	35	7
	72"-84"	6	1	12	2	18	3	24	4	30	5	36	6	42	7

Figure 1-32 Determining the amount of containers based on the available area Source: www.windowfarms.org/

Crops: Appropriate crops for this system are kale, lettuce, strawberries, basil, sage, peas, stevia, chamomile, dill, cress, swiss chard and squash.

How much is produced? The 1st system that had 12 plants, had a churn of 1 salad/week

Other important information: The system costs about \$40-175. It has an annual cost of \$1.58 per two columns, for the electricity used by the pump. The website for DIY instructions is <http://our.windowfarms.org/tag/officialhow-tos/>

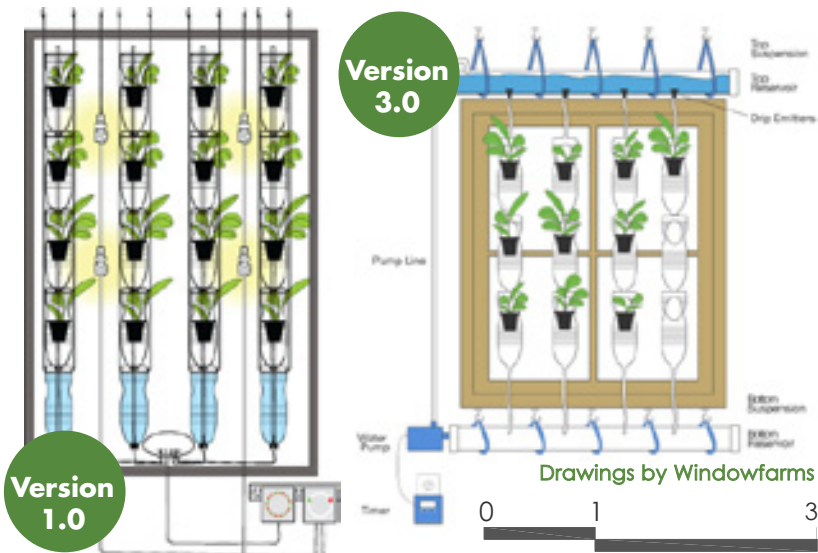


Figure 1-31

Version 1.0 has separate bottles as water tanks for each column. The extra bottles must be considered in the window area.

Version 3.0 has two water tanks; one on the top and one at the bottom of the columns made out of PVC tubes. Here the water tanks are not included in the window area.

Source: www.windowfarms.org/



PLANTLAB, Netherlands

Year: 1994

Website: www.plantlab.nl

Background: The PlantLab Company is working on a whole building approach that is going to revolutionize the way we produce food. They are building a system which can be used with the absence of natural light and they are constantly running experiments in order to create more nutritious food that can be grown locally within buildings in the city.

They are working on the system since 1994, researching ways to grow food in volume, both horizontally and vertically. A computer controlled hydraulic system moves trays around to make them accessible, provides the plants with the proper nutrients and can be accessed through the internet from everywhere. Since the technology uses artificial light for the plants, it creates the opportunity to grow plants in spaces with no natural light. Their hopes are to introduce this system to vacant buildings and revolutionize urban agriculture.

System description: The system consists of surfaces covered by trays that can be stacked on top of each other in a distance of 3 ft or less. Each tray can carry 96 plants. In that way it could be possible in a building of 1,000 square feet and 14 layers of plants on top of each other to produce 7 ounces of fresh fruits and vegetables per day. That amount of food is able to feed 140,000 people. (Michler, 2012) The system does not need natural sunlight, as each tray is lit by LED technology. The PlantLab team claims that the plants do not need



Figure 1-33 Source: http://i.huffpost.com/gadgets/slideshows/19146/slide_19146_263103_large.jpg?1303163915554

the whole light spectrum; in order to perform photosynthesis they mainly need red, blue and far-red rays. (PlantLab, 2011) Moreover the whole plant environment is totally controlled by a computer system called PlantLab OS. It controls climate; temperature, humidity, CO₂, airspeed, lighting patterns, irrigation and nutrients. It can also be controlled and technically diagnosed remotely via internet.

The system is hydroponic and the nutrition recipes are brought to the plants through the water. Each crop has a Plant-ID through which enables the system to track the progress of the plant and its needs. In that way it is possible to track and follow the progress of all plants in such a big, multilayered system.

Key Dimensions: The hydroponic trays dimensions are: 2' x 5'. If stacked vertically a distance of 3 ft or less should be provided between them depending on the crops.

Crops: With this system it is possible to grow any kind of fruit and vegetable as well as other plants too.

How much do they produce? The production depends on the set up of the system, and how many layers of plant trays it is possible to stack in a certain space. However, the company states that currently they are producing 2-3 times more than a greenhouse. (Kers, 2012) Based on that it can be estimated that they would produce about 296 tons/acre*.

**Estimated value based on system, not from farm's data*

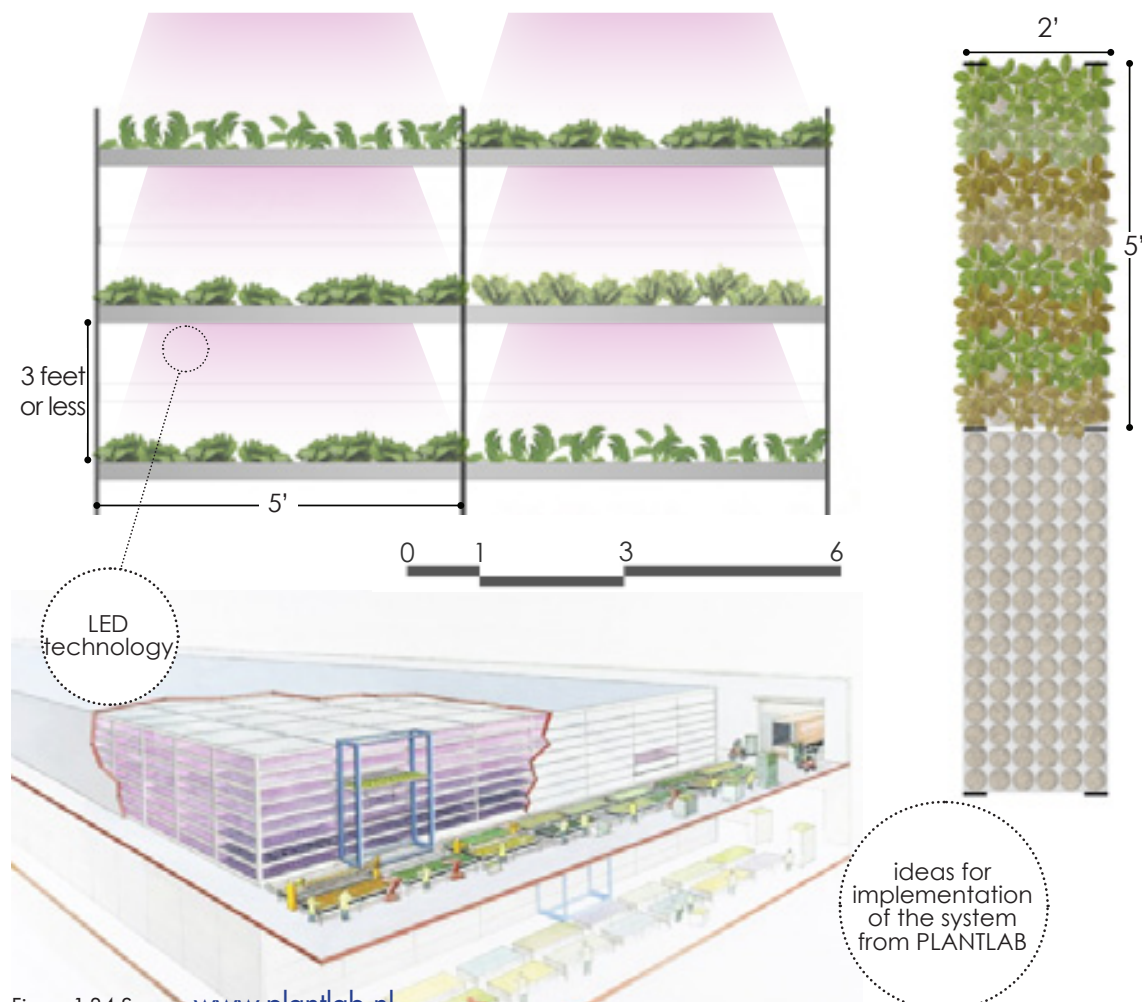


Figure 1-34 Source: www.plantlab.nl



THE PLANT, Chicago

Year: 2010

Website: www.plantchicago.com

Background: The Plant is a nonprofit organization founded by John Edel who has purchased an old meat-packing factory along with the 3 acres area around it. Its scope is to create a whole building approach of urban vertical farming in a net zero building. They started in 2010 and plan to complete the project by 2017. They are adopting several systems in order to achieve a holistic approach of producing food, treating waste and generating energy. The plan is to grow plants, tilapia fish, produce beer and tea in a way that the waste from one of them becomes the raw material and food for the other. Among their future plans is to install an anaerobic digester on site by 2015 that will produce biogas which will be burnt in a co-heat generation plant and will provide electricity along with heat for the brewery. The excess heat will be used by an absorption chiller in order to regulate the building's temperature.

At the same time they intent to house other sustainable food businesses by offering low rent and energy costs. They hope through this project to also create 125 job positions and regenerate a distressed neighborhood.

System description: Their system is a holistic approach of producing food, treating waste and generating energy. The plan is to produce plants, tilapia fish, produce beer and tea in



Figure 1-35 Source: http://farm9.staticflickr.com/8028/7434967416_dc7846d295_z.jpg



Figure 1-36 Source: <http://www.flickr.com/photos/plantchicago/7434966654/in/photostream>

a way that the waste from one of them becomes the raw material and food for the other. As shown in the diagram below, the plants will create oxygen (O₂) for the kombucha tea, and the CO₂ from the kombucha tea production will go back to the plants. The waste water from the fish tanks includes nutrients that feed the plants. Water from the fish tanks will pass through the plants to get cleaned, filtered and go back to the fish. The extra waste from the plants and fish tanks, as well as waste from the brewery, the food waste from the kitchen and waste from neighboring businesses will go to an anaerobic digester to produce biogas. The digester is planned to have a capacity of 27 tons per day. The biogas will then be burned in a combined heat and power plant and produce 400 KW of electricity at 29% efficiency along with heat used in the brewery. (McDowell, 2012) Excess heat will go to an absorption chiller for heating and cooling purposes of the building. (Bergstrom, 2010)

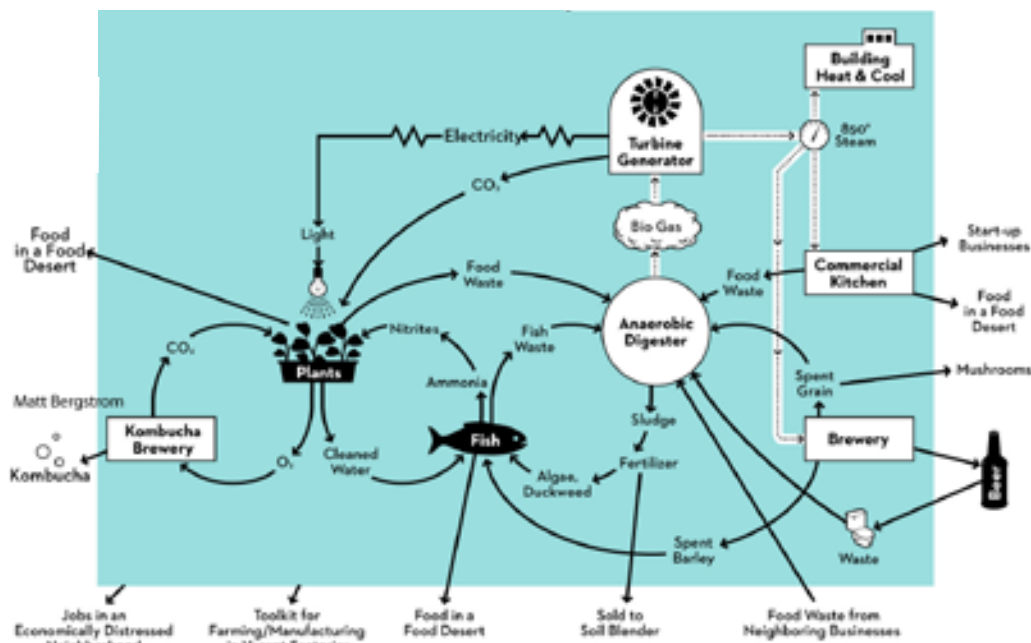


Figure 1-37 Source: www.plantchicago.com

The Plant will also take advantage of the adjacent plots on the site. This year (2012), they started their outdoor growing garden right next to the building. Currently, the only completed system is the aquaponic system, which is placed on the basement of the building. Aquaponics is a combination of aquaculture; fish farming, and hydroponics. There, in the basement, the plants are grown under LED lighting on boards floating above water tanks. The water reaches the plants, after a series of aerated tanks with tilapia fish in them separated by size. As mentioned above the water gets cleaned by the roots of the plants. Moreover, tilapia fish can live in salt-less water and can grow in a crowded tank, which is why this kind of fish is selected. Finally the waste water from the fish tanks, which includes ammonia, can be broken down by nitrifying bacteria to nitrites which are absorbed by the plants. Hence, the system works in a loop. As both hydroponics and fish farming can be water-demanding systems, combining them in a loop saves water and generates synergy.

Key Dimensions: The old meatpacking factory has an area of 93,500 square feet

Crops: They plan to produce all different kinds of crops, as well as keep beehives on site.

Links to other case studies:

Subway branch in Japan growing lettuce with hydroponics <http://inhabitat.com/japanese-subway-grows-lettuce-in-house-to-top-their-sandwiches/>

Brooklyn Grange expanding in a new 43,000 sq ft rooftop in Brooklyn Navy Yard http://gothamist.com/2012/08/02/brooklyn_grange_celebrates_first_ha.php#photo-1

TerraSphere is another company that is working on whole-building farming solutions <http://www.terraspheresystems.com/>

BrightFarms are building and operating farms close to supermarkets <http://brightfarms.com/>

A couple that is trying to grow 1 ton of food in their backyard and satisfy 58% of their needs. <http://www.urbanton.com/>

Dinette restaurant in Pittsburgh keeps a rooftop garden <http://dinette-pgh.com/rooftop-garden>

Marathon Farms in Philadelphia grow food in empty vacant lots and supply the neighbors <http://marathonfarm.wordpress.com/>

Emerald Street Urban Farm in Philadelphia are starting their local agriculture attempts through kickstarter <http://emeraldstreeturbanfarm.wordpress.com/>

Students of Harvard have set up and are taking care of their own community garden since 2009 <http://www.garden.harvard.edu/>

The Gary Comer Youth Center in Chicago has a rooftop garden. The produce is being used by students supplied to local restaurants and to the Center's café <http://organicgardenproject.com/blog/community-gardens/chicago-rooftop-haven-for-urban-agriculture/>

The Wisconsin University is currently building their new dorm; Lakeshore Residence Hall, which will host a rooftop greenhouse <https://fpm-www3.fpm.wisc.edu/cpd/UWBuildsGreen/LakeshoreResidenceHallFoodServicePhaseII/tabid/235/Default.aspx>

Coffee shop and workplace in London that is growing its own food onsite though aquaponics <http://farmlondon.weebly.com/index.html>

4.2 WATER MANAGEMENT AND TREATMENT



4.2 WATER MANAGEMENT AND TREATMENT

As our urban areas become more and more dense, the percentage of impermeable surfaces keeps increasing leading to an unfriendly water environment. Stormwater runoff is not absorbed into the ground and can rapidly accumulate leading to flooding events. Moreover, based on our current water systems, a significant amount of purified potable water is used for flushing toilets, washing cars and watering the lawn.

These kinds of uses could be easily addressed with non-potable water. Through a closer look on the percentages of residential water end uses, it is obvious that toilet flushing is the major water consumption of a household. (Mayer et al., 1999) ("Figure 1-38 Residential End Uses of Water (Source: American Water Works Association, Denver: AWWARF 1999)" (Figure 1-38)

Toilet flushing can be managed with non-potable water; harvested rainwater or treated wastewater (grey and black). Clothes washing can also be managed by treated harvested rainwater. The above actions would lead to a 48.4% reduction of potable water use in residential buildings. The possibilities of using non-potable water thereby reducing the potable water consumption are really great (Yudelson, 2009) if we also take into consideration other building types, and water usage for landscape and lawn irrigation as well as for car washing. Hence, designing for water conservation and reuse with decentralized systems is really important for our communities. (Figure 1-39)

Figure 1-39 Commercial Building End Uses of Water (Source: Environmental Building News; Data from American Water Works Association)

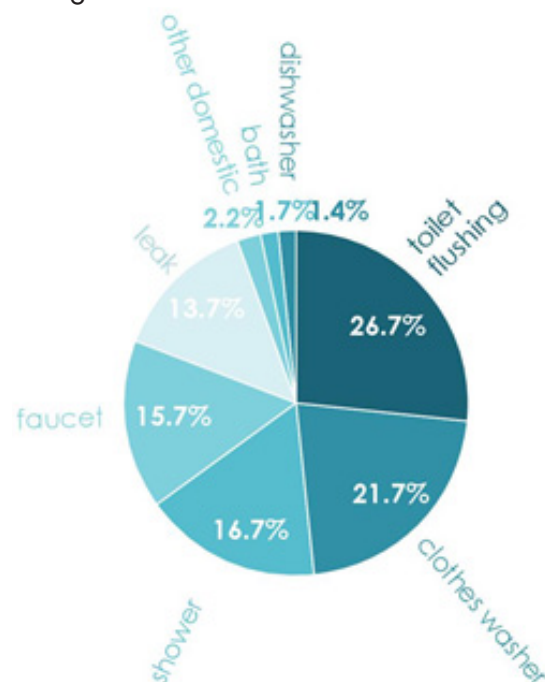
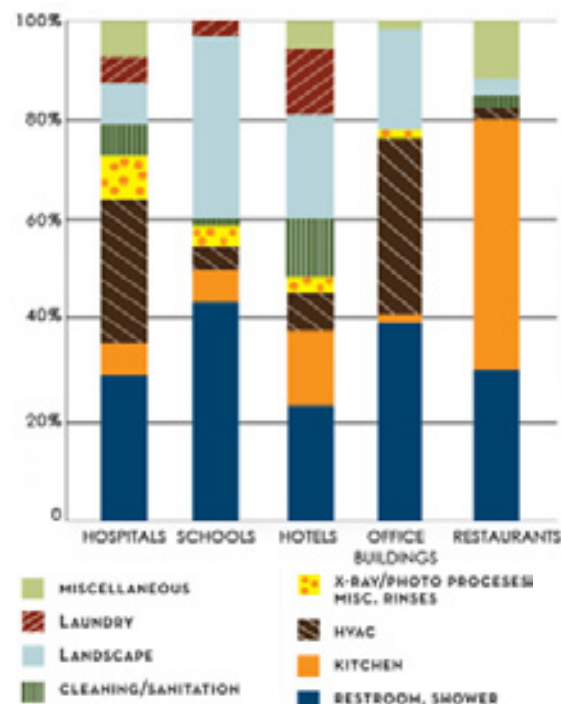


Figure 1-38 Residential End Uses of Water (Source: American Water Works Association, Denver: AWWARF 1999)



4.2.1 Water Typologies

Even though reusing water would lead to great benefits on both building and neighborhood scale, it is of great importance to understand the water flow, the different types of water, which of them have the possibility to be reused and where. There are three types of water that can be reused; the stormwater, the greywater and the blackwater.

- In the natural hydrological cycle, water would reach the ground surface during precipitation events and would get infiltrated to recharge the aquifers and it would get back into the atmosphere through evapotranspiration. This constant natural cycle keeps the amount of water between ground and the atmosphere balanced. However, as mentioned above, the stormwater runoff within the city can reach up to 55% of the precipitation due to increased impervious surfaces. (US Census Bureau, 2003) Stormwater is the runoff water from impervious surfaces during precipitation events. There are two different ways to deal with stormwater; one is to retain and infiltrate in order to recharge the aquifers and the second one is to harvest it for non-potable uses. Harvesting rainwater is a conservation strategy for drinking water by reducing its use for non-potable water uses. The harvested stormwater can be reused in landscape irrigation, car washing, toilet flushing, clothes washing machine (legal in some areas) and heating and cooling building systems (HVAC). (Wholly H₂O, 2012a) However, managing stormwater for infiltration is a more important strategy because it works as the missing link in the hydrological cycle in urban areas. It is of great importance to learn how to manage water locally, instead of creating more impervious areas and complicated infrastructures that remove the stormwater quickly from a site but create issues of water accumulation, low water quality in our watersheds and poor recharge of the aquifers.
- The wastewater from washing machines, dishwashers, sinks, hand washing, showers and bathtubs is considered as greywater. (USGS, 2012) Greywater needs a slight treatment in order to remove grease, oils and soap. The treated greywater can be reused for non-potable water needs like landscape irrigation, toilet flushing, clothes washing machines (legal in some areas) and heating and cooling building systems (HVAC).
- Finally, blackwater is considered the wastewater from urinals and toilets. Blackwater needs more treatment than stormwater and greywater in order to be reused. The typical blackwater treatment has four phases of contaminants removal; preliminary, secondary (that might be broken to aeration, biological treatment and filtration) and tertiary. Based on the level of treatment, blackwater can have different reuses. (Wholly H₂O, 2012b) (Figure 1-40)

The systems that manage and treat all of the above types of water are defined by four stages; collection, storage, treatment and distribution. The difference between them is that greywater and blackwater need demanding treatment process due to the fact that they

carry pollutants, solid waste, grease, soap etc. Stormwater harvested from the roof can be used after a slight filtration. In order for that to happen the catchment area must have the appropriate roofing material; metal, clay or concrete. Roofing materials such as asbestos, asphalt, copper, zinc and lead based paints might need further treatment. (Ramesh, 2011)

The opportunities of treating and reusing water onsite with decentralized water systems are varied and are becoming more sophisticated and efficient with technology advancement. However it is of critical importance to remember that in order to achieve significant water savings, reductions in water usage must be achieved through behavior changes and low-flow fixtures. The concept of reduce, reuse, recycle is applicable once again here. The same

Recycled Water Use	Treatment Level					
	Disinfected Tertiary Recycled Water	Disinfected Secondary 2.2 Recycled Water	Disinfected Secondary 2.3 Recycled Water	Undisinfected Secondary Recycled Water		
Irrigation for:						
Food crops where recycled water contacts the edible portion of the crop, including all root crops	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED		
Parks and playgrounds	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED		
School grounds						
Residential landscaping						
Unrestricted-access golf courses						
Any other irrigation uses not specifically prohibited by other provisions of the <i>California Code of Regulations</i>						
Food crops, surface-irrigated, above-ground edible portion, not contacted by recycled water		ALLOWED	NOT ALLOWED	NOT ALLOWED		
Cemetaries		ALLOWED				
Freeway landscaping						
Restricted-access golf courses						
Ornamental nursery stock and sod farms with unrestricted public access						
Pasture for milk animals for human consumption						
Nonedible vegetation with access control to prevent use as a park, playground or school grounds						
Orchards with no contact between edible portion and recycled water	ALLOWED	ALLOWED	ALLOWED	ALLOWED		
Vineyards with no contact between edible portion and recycled water				ALLOWED		
Non food-bearing trees, including Christmas trees not irrigated less than 14 days before harvest						
Fodder and fiber crops and pasture for animals not producing milk for human consumption						
Seed crops not eaten by humans						
Food crops undergoing commercial pathogen-destroying processing before consumption by humans						
Ornamental nursery stock, sod farms not irrigated less than 14 days before harvest						
Supply for impoundment:						
Nonrestricted recreational impoundments, with supplemental monitoring for pathogenic organisms	ALLOWED ²	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED		
Restricted recreational impoundments and publicly accessible fish hatcheries	ALLOWED	ALLOWED	NOT ALLOWED	NOT ALLOWED		
Landscape impoundments without decorative fountains					ALLOWED	
Supply for cooling or air conditioning:						
Industrial or commercial cooling or air conditioning involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED ³	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED		
Industrial or commercial cooling or air conditioning not involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED		

Figure 1-40 Recycled water uses, by treatment level by Bahman Sheikh and EBMUD (Source: Wholly H2O)

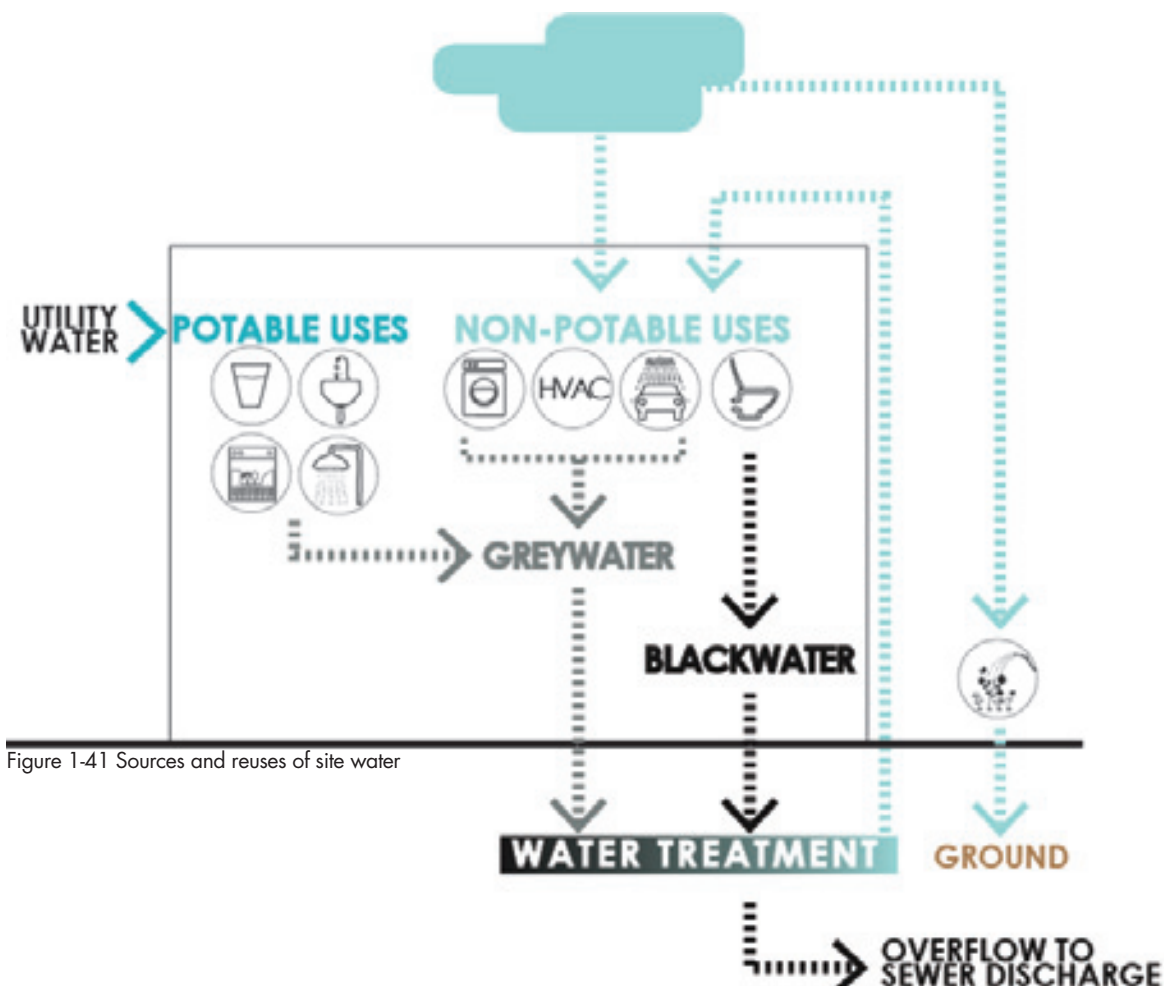


Figure 1-41 Sources and reuses of site water

approach should also be used on a neighborhood level; runoff reduction through collection and treatment using Low Impact Development approaches. (EPA, 2012b) (Figure 1-41)

4.2.2 Stormwater

The systems that manage water by enhancing and mimicking the natural hydrological cycle of infiltration and evapotranspiration are called green infrastructure. (U.S. EPA, 2008) In this chapter, green infrastructures, Low Impact Development practices (LID) and the way they treat and reuse the stormwater are going to be studied and analyzed through literature and case studies.

4.2.2.1 Benefits of stormwater management

Introducing points of infiltration within the urban context, such as bioswales in parking lots, stormwater planters, or other green infrastructures can reduce the amount of runoff water ending up at the central sewer system. That will minimize the frequency of the overflowing events and the eventual contamination of the watersheds leading to cleaner water. Moreover, as the water gets infiltrated; it recharges the aquifers enhancing the water supplies. Green infrastructure and water infiltration practices provide pollutant removal leading to higher levels of water quality. (U.S. EPA, 2008)

It is really common for stormwater management and treatment systems to include trees and vegetation that treat the water and release it back to the atmosphere. Hence,

the implementation of vegetation can lead to cleaner air, reduced air temperatures and mitigations of the urban heat island. (U.S. EPA, 2008) For example, rainwater harvesting from rooftops can be easily reused with minimal treatments for landscape irrigation, toilet flushing, car washing and cooling towers. That leads to reduced demand and consumption of potable water. Using non-potable water sources for toilet flushing and clothes washers, such harvested rainwater would lead to a 48.4% reduction of potable water use in residential buildings. (Yudelso, 2009)

Finally, managing stormwater locally can lead to significant cost savings. As the amount of the accumulated runoff water decreases due to local stormwater management solutions, the need of paving gutters, curbs and investments to increase the capacity centralized ponds or treatment plants is lower. (U.S. EPA, 2008) Managing and treating water in centralized infrastructure has higher levels of investments. Hence, managing the water locally with smaller and more natural infrastructure can lead to significant cost savings.

4.2.2.2 Stormwater management systems

Traditionally the systems for collection, storage, treatment and distribution of stormwater are separated. In reality, the systems actually overlap. Hence, rainwater harvesting systems and Low-Impact Development (LID) principles, in addition to collection and storage, will suggest significant treatment solutions also. (McDonald & McDonald, 2010) The several stormwater management practices include (U.S. EPA, 2008) (Strom & Nathan, 1998):

- Permeable sidewalks and porous asphalt
- Green roofs
- Infiltration planters
- Vegetated swales (bioswales)
- Rain gardens
- Vegetated strips
- Infiltration trenches
- Sand filters
- Detention and retention basins
- Sediment basins
- Infiltration basins
- Constructed wetlands

However, not all of the above systems are appropriate for an urban environment, as there are spatial limitations. On the table below, different stormwater measures are presented along with their area demands. (McDonald & McDonald, 2010) (Figure 1-42)

In order to select and design the appropriate stormwater practice, runoff volume and rate should be determined and calculated. There are two main methods of calculating the rough runoff volume; the Rational Method and the Modified Rational Method. (Strom & Nathan, 1998) The runoff volume calculations are strictly related to the specific location

Stormwater Treatment Measure	Typical Contributing Land Use	Area Demand	Drainage Area Size (acres)	Ground Water Elevation
Vegetative Practices				
Grassed Swales	Rural, commercial, residential, industrial, some urban types	Small	<10	Below facility
Vegetated Filter Strips	Rural commercial, residential, industrial, some urban types	Varies	< 10	Depends on type
Detention Facilities				
Detention Basins	Urban commercial, residential, industrial	Large	10 - 40	Below facility
Retention Ponds	Urban commercial, residential, industrial	Large	10 - 40	Near surface
Constructed Wetlands	Urban commercial, residential, industrial	Large	> 40	Near surface
Infiltration Facilities				
Infiltration Basins	Urban, commercial, residential, industrial	Large	< 10	Below facility
Infiltration Trenches/ Wells	Urban commercial, residential	Small	< 10	Below facility
Porous Pavements	Urban commercial areas with low vehicular traffic	Not applicable	< 10	Below facility
Filtration Practices				
Sand Filters	Urban, commercial, residential	Varies	<10	Depend on type
Bioretention Systems	Urban, commercial, residential, industrial	Large	10 - 40	Below facility

Figure 1-42 Different Stormwater Treatment Measures (Source: Stormwater Harvesting Guidance Document for Texas Water Development Board, McDonald et al. 2010)

because of the precipitation levels, slope, type of soil and size of the area. Stormwater solutions cannot be replicated without taking into consideration the above factors.

4.2.2.3 Stormwater management limitations

Some limitations need to be addressed during the selection process of the appropriate stormwater practice there are. Firstly, space availability can limit applicable practices. Especially, when trying to treat stormwater within a dense urban environment, spatial limitations can significantly reduce the amount of stormwater that can actually be treated. As mentioned above (Figure 1-42), within an urban environment the most appropriate solutions are vegetated swales (bioswales), infiltration trenches, infiltration planters and porous surfaces. However, such small solutions might also not be practical due to narrow streets and limited pedestrian areas.

Attention should also be paid to some stormwater practices when applied to cold climates. Permeable paving and asphalt can cause problems due to freezing temperatures and snow. Permeable asphalt is not advised in cold climates due to snow and the application of salt to melt it. (Graziano, 2012)



OREGON MUSEUM OF SCIENCE AND INDUSTRY PARKING LOT, Portland

Year: 1992 (Modified in 1996)

Website: www.oms.edu

Background: The Oregon Museum of Science and Industry had already designed its parking lots in 1990, when there were no requirements for stormwater management in Portland. Since then, the Portland Bureau of Environmental Services (BES) started looking into cases where stormwater management systems could be applied and asked the Museum to voluntarily redesign and reconstruct their parking lot area, in a way that the water is filtered from the car pollutants and infiltrated to the soil. The architects agreed to the proposal as the alteration was not affecting the project. By the end of the construction, OMSI saved \$78,000 from construction costs. The initial goal of the project, which was to filter the water from the parking lot's pollutants and to reduce the runoff water that ended up to the river, was successfully achieved.

System Description:

The runoff from the parking lot area drains to 10 different vegetated swales (bio-swales). The overflow from the swales moves in a storm sewer system that leads the water to Willamette River, next to the Museum.

The bio-swales have a width of 6-8 feet and their length ranges from 100 to 250 feet. The total length of the constructed swale is 2,330 feet. The curb cuts that lead the water from the parking lots to the swale are 12-inch wide and they have a 30 feet distance between them. Every 50 feet, wooden check dams are placed in the swale which increases the system's infiltration efficiency. (Portland Bureau of Environmental Services, 2005)

Key Dimensions: The bio-swales are 6 feet wide and 100-250 feet long. The total area of infiltration is 0.30 acres.

Precipitation: Portland has an annual precipitation of 43.01 inches

Catchment Area: 174,240 square feet (4 acres) of impervious parking area

Infiltration Rate: After measurements that took place in 2005, the infiltration rate of the swale was 7 inches per hour or greater.

Capacity: The swales have the capacity to filter and infiltrate 3,900,000 gallons of runoff water annually, diverting it from going into the sewer system.



Figure 1-43 Sketch by Helene Izembart & Bertrand Le Boudec, Waterscapes

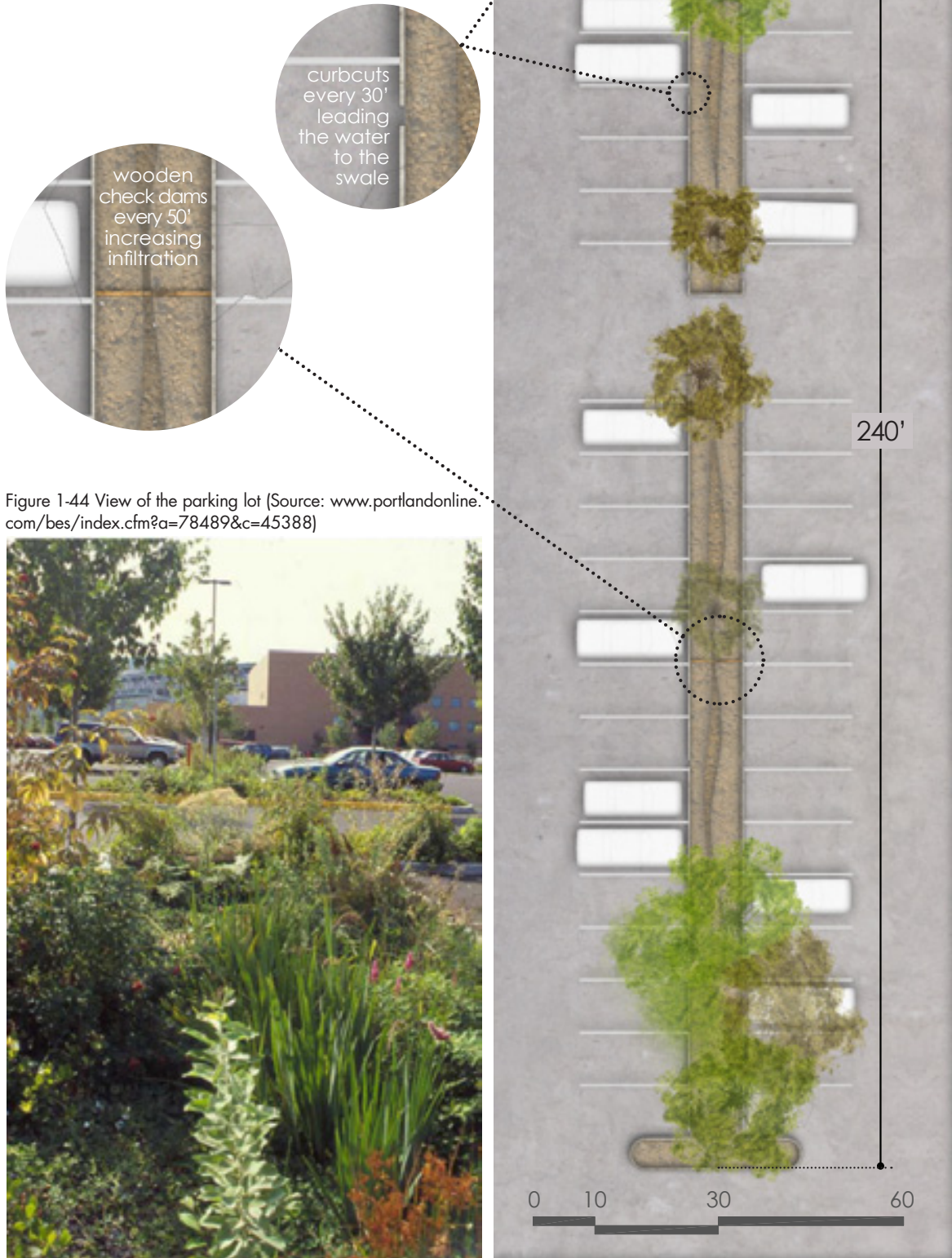


Figure 1-44 View of the parking lot (Source: www.portlandonline.com/bes/index.cfm?a=78489&c=45388)



SW 12TH AVENUE, Portland

Year: 2004

Website: web.mit.edu/facilities/construction/completed/stata.html

Background: The Green Streets are known as the streets where vegetation, along with other strategies, is used in order to manage stormwater and prevent it from accumulating. They help reduce problems in the streets and for the existing infrastructure. Portland has been a leader in implementing such strategies in the urban landscape. Managing stormwater, facilitating different types of mobility, incorporating vegetation and improving the urban amenities such as furnishings, lighting and paving have been a top priority for the city of Portland. One of the very first examples of Green Streets in Portland is that of the 12th Avenue between SW Montgomery and SW Mill streets. The project was constructed in 2005 and consists of 4 consecutive stormwater planters that substituted old typical planter boxes for the existing trees. The project cost about \$35,000 and requires low maintenance. The project's intentions were for it to be easily constructed so that it can be further implemented to more sidewalks and promote the idea of the Green Streets. (Portland Bureau of Environmental Services, 2006)



Figure 1-45 Source: <http://static.ecoo.it/625X0/www/ecoo/it/img/strade-verdi-portland-recupero-acqua-piovana.jpg>

Figure 1-46 Source: <http://greenbuildingchronicle.com/wp-content/uploads/tdomf/6595/TSW%20Bioswale.jpg>

A cross-sectional diagram of a street layout. From left to right, it shows a Sidewalk Zone, a Stormwater planter (a raised bed with grass and a blue line representing a water feature), and a Parking Egress Zone. Silhouettes of a person walking a dog and another person standing are shown on the sidewalk. A tree is positioned behind the stormwater planter. Below the diagram is a scale bar with markings at 0, 3, 9, and 18.

5'

3'

2'

18"

18'

6'

2'

3' 2 1/2"

asphalt berm directing water into the planter

curb cuts for runoff from sidewalks

concrete pad

sand set concrete pavers

ornamental trench grate

planted buffer zone

Z



Eleni Katrini | 67



SW 12TH AVENUE, Portland

Year: 2005

Website: www.portlandonline.com/bes/index.cfm?a=123776&c=45386

Background: : In order to manage the stormwater on campus and reduce the amount of polluted water reaching Charles River, a stormwater management, harvesting and reuse system was integrated with the construction of the Stata Center in MIT. That was mainly because of an underground tunnel system on campus that would make draining the new 7-acres Center to the main drainage system impossible. Hence, rainwater is harvested from the Stata Center site as well as the roofs from surrounding buildings (Building 56, 57 and part of 26). The bioswale between the buildings acts as a small oasis, featuring stone banks, plants and a footbridge that crosses above it. (Lanou, 2005)

System Description: The rainwater is harvested from the Stata Center site and the roofs from 3 surrounding buildings. It gets discharged into the basin through high and low level drains. The water first enters the wetland region from the high level drains and when it fills the overflow gets filtered by moving to the lower part of the basin. (MIT Department of Facilities, 2007) The water is stored temporarily in the basin and there are three pumps in the basement of building 57 that are responsible for the water distribution. The system along with the pumps is designed in a way that can manage and convey the stormwater on site from a 100-year rain event. That means that the water in the basin is not visible on the surface, except during 100-year storm event. (Padmanabhan, 2009) The system has three basic operations: A. Stormwater Drainage pumping, B. Water for toilet flushing and C. Irrigation for the wetland and landscape. There are two pumps, a low-flow and a high-flow pumps that are managing the water levels in the basin. Usually, the low-flow pump is active as most of the rainstorms have 1-inch precipitation or less.

The third pump in the basement of Building 57 is responsible for the toilet flushing. There is a tank between the city potable water supply and the toilet distribution pumps, which is constantly kept full with water drawn from the water basin by the third pump. The stormwater is cleaned up by multimedia sand filtration and ultraviolet sterilization and it is used only for toilets and urinals flushing. The pump will keep sending water to the tank, unless there is no water left in the basin. In that case the toilet flushing is served by the city's water distribution.

Finally, the wetland area in the higher level portion of the creek bed has to be always irrigated. During a rainwater event the water first passes by the wetland area and slowly moves to the lower part of the basin. However, during dry periods the water moves to the

lower part leaving the wetland area dry. To avoid this during a dry season, water from the lower part is pumped up to the wetland at a very low flow rate (1 gpm). That recirculation of the water also gives the opportunity of repeated biofiltration that polishes the water. The energy needed for the recirculation of the water by the pump is provided by PV panels located on the roof of Building 57. (MIT Department of Facilities, 2007)

Key Dimensions: The bioswale is 13,420 sq ft (220' x 61') (calculated in Google Earth)

Precipitation: Boston has an annual precipitation of 41.5 in

Catchment Area: The drained rooftop area of building 56, 57 and 26 is 0.57 acres (24,880 sq ft)

Stormwater managed: The bioswale can infiltrate the stormwater on site of a 100-year rain event.

Other important information: More than 5,000 gallons per day are used for flushing (Lanou, 2005) Moreover, the energy needed for the recirculation of the water by the pump is provided by PV panels located on the roof of Building 57.

Implications: Depending on the weather, the water might come out slightly colored. However, due to the fact that the water is only used for toilet flushing they have kept the system as it is. (Gonick, 2009)

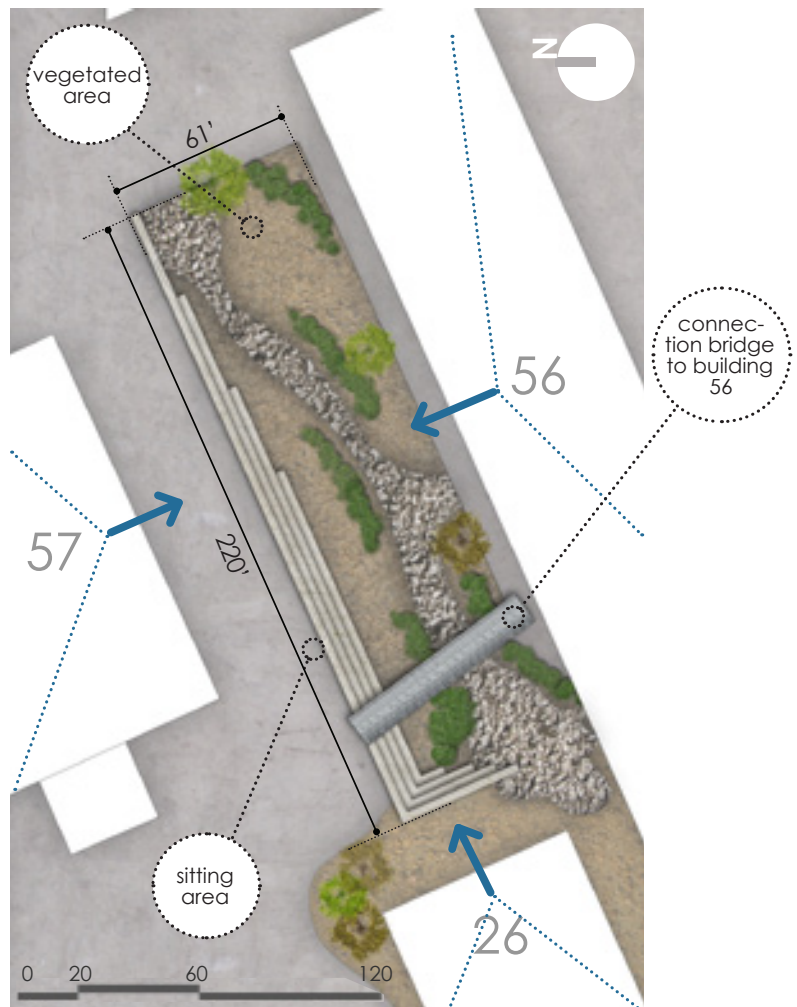
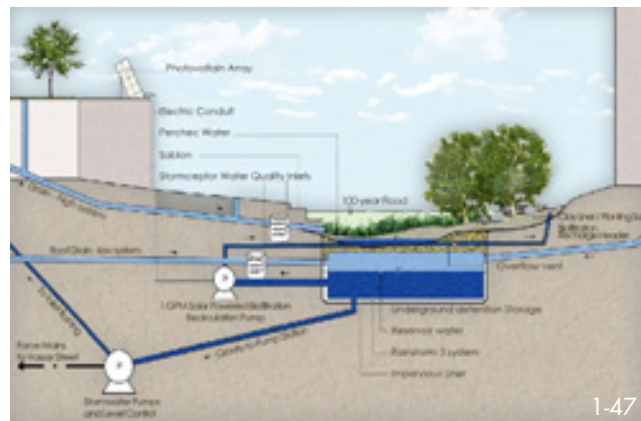


Figure 1-47 Source: MIT Stata Center

Figure 1-48 Source: www.artfulrainwaterdesign.net/files/193.jpg

4.2.3

DECENTRALIZED WASTEWATER TREATMENT



4.2.3 Decentralized wastewater treatment

Decentralized wastewater treatment facilities are the ones that treat wastewater onsite; close or at the same location where wastewater is generated. Wastewater is considered the water from the toilets and urinals, also called blackwater. However, wastewater can also have a more general meaning and include greywater, or even untreated stormwater. In this chapter, wastewater will be considered mostly the black and grey water. The systems analyzed here have combined systems for grey and black water, hence they will be put under one category.

4.2.3.1 Benefits of decentralized wastewater treatment

In many older cities in the U.S., sewage lines for stormwater and wastewater are combined. These archaic infrastructures are not capable of handling population growth. Centralized wastewater treatment plants are often incapable of managing the amount of influents, resulting in overflow that it is discharged into clean existing watershed. During extensive rainfalls and floods, the systems overflow and huge amount of wastewater ends up in our rivers and seas (Combined Sewer Overflow system). That problem cannot be solved easily with the way our modern cities are built. Having a constantly increasing urban population, and an expensive central wastewater system that was installed years ago, means that there is an inflexible system dealing with increasing demand.

The idea of decentralized wastewater systems across a city means that those systems would act as backup systems preventing the central plant from overflowing. Hence, the benefits of such an investment are several (Paladino and Company, 2008):

- Reducing demand, avoiding peak conditions and leading to cost savings
- Reusing water for non-potable applications and minimizing the water demands
- Onsite waste water treatment facilities are reliable and self-sufficient
- Minimizing health, safety and liability issues
- Deferred costs and expenses of infrastructure expansion in order to meet the increasing demand

Apart from the benefits on a public and district level, there are significant benefits for the investor and the developer too. First, there is a fee and expenses reduction from the reduced use of the municipal centralized system. Moreover, projects with onsite wastewater systems can apply for grants and funds from government resources and they end up having an increased market value (Paladino and Company, 2008). Finally, onsite wastewater treatment can increase the points in the LEED accreditation process.

4.2.3.2 Decentralized wastewater treatment systems

There are different wastewater systems but all of them are based on the same general process with four phases: Preliminary, Primary, Secondary and Tertiary phase. In each phase certain contaminants are being removed, producing water of higher quality levels. The preliminary phase consists mostly of screens that remove the bulk solids that could cause problems to the systems. The primary treatment level consists of a flow equalization tank that stabilizes the flow between the preliminary and the secondary phase. Here, suspended solids are removed through flotation or gravity settlement in sedimentation tanks. In the secondary treatment, pollutants and particulates are removed through mostly biological processes, increasing the quality of the water significantly. This phase includes systems like anoxic tanks, aeration tanks, filters and constructed wetlands. Finally the tertiary phase includes disinfection units, such as UV light systems, chlorine disinfection and other chemical processes, as well as odor abatement systems. After the tertiary phase the water is ready to be reused for non-potable uses. (Paladino and Company, 2008)

There are several systems that can treat wastewater. However due to spatial limitations, systems that use only natural processes are quite large and cannot be used in an urban context. For example, settling ponds, lagoons or constructed wetlands can be prohibitive in cities. Based on the above, the most compact decentralized systems that can be implemented in the urban context are:

- Membrane Bio-Reactor (MBR)
- Activated Sludge system
- Rotating Biological Contactor (RBC)
- Living Machine

The advantages and disadvantages of the above systems are identified in the following table:

System Type	Advantages	Disadvantages
Membrane Bio-Reactor	1. Most compact System 2. Most scalable to future capacity 3. Fully automated/Low maintenance	Higher level of operator training
Activated Sludge	Most common system	Higher energy use for mixing
Rotating Biological Contactor	Accepts highest pollutant load	1. Higher energy use for treatment 2. Potential for odor/noise
Living Machine	1. Visual Amenity – can be showcased 2. Quiet and low cost operation	1. High level of maintenance 2. Larger footprint/system size

Figure 1-49 Advantages and Disadvantages of treatment technologies (Source: Onsite Wastewater treatment systems: A technical Review, Paladino and Company, 2008)

In this chapter, from the above systems, only the Membrane Bio-Reactor and the Living Machine are going to be studied further. The Membrane Bio-Reactor was selected because it is a more compact system that can be scaled up based on future demands, and the Living Machine because of its potential to be used as a beautiful visual amenity within a neighborhood.

The living Machine

"A living machine is a device made up of living organisms of all types and usually housed within a casing or structure made of extremely light-weight materials." (Todd & Todd, 1994)

A living machine is a "compact" way to clean waste water through biological and natural processes, imitating the laws of nature without chemical procedures. Within the process both fauna and flora are taking part actively in order to create the right environment where the organic matter is being broken down. The system consists of three phases; the anaerobic septic tank, the closed aerobic reactor and a series of aerated tanks. (Melnik, Bettencourt, Sherr, & Komesch, 2004)

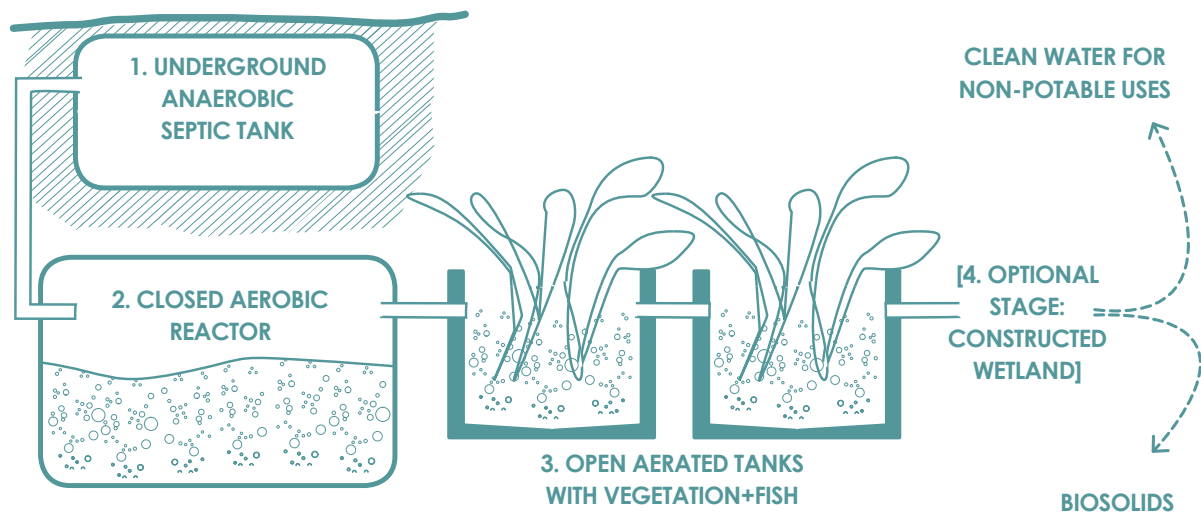
In the first phase, the anaerobic bacteria are digesting the organic matter. Here the temperature is playing a significant role; the average range must be between 55-65°C. Normally an anaerobic septic tank is located underground. From this process bio-solids are produced that can be used as fertilizer. Hence, a way of storing and using the bio-solids is identified during this phase to eliminate storage problems.

An anoxic reactor is placed in between the first phase and before the closed aerobic reactor in order to maintain an equilibrium pressure between the anaerobic and aerobic tanks. In that way the microorganisms from one tank do not infect the others. That automatically raises the efficiency of the machine. The second phase is the aerobic reactor, where air is pumped in the tank in order to maximize the oxidation. Here, the process of nitrification takes place where ammonia is turned to nitrates through aerobic bacteria. (Melnik et al., 2004) The third and last phase, contains a series of open aerated tanks in succession. The tanks have different sizes and they are set that the water goes from a smaller tank to a bigger one. The number of tanks depends on the volume of wastewater treated per day. Normally a living machine should have at least 2 aerobic tanks, but they can be even more. However, more tanks means bigger investment cost.



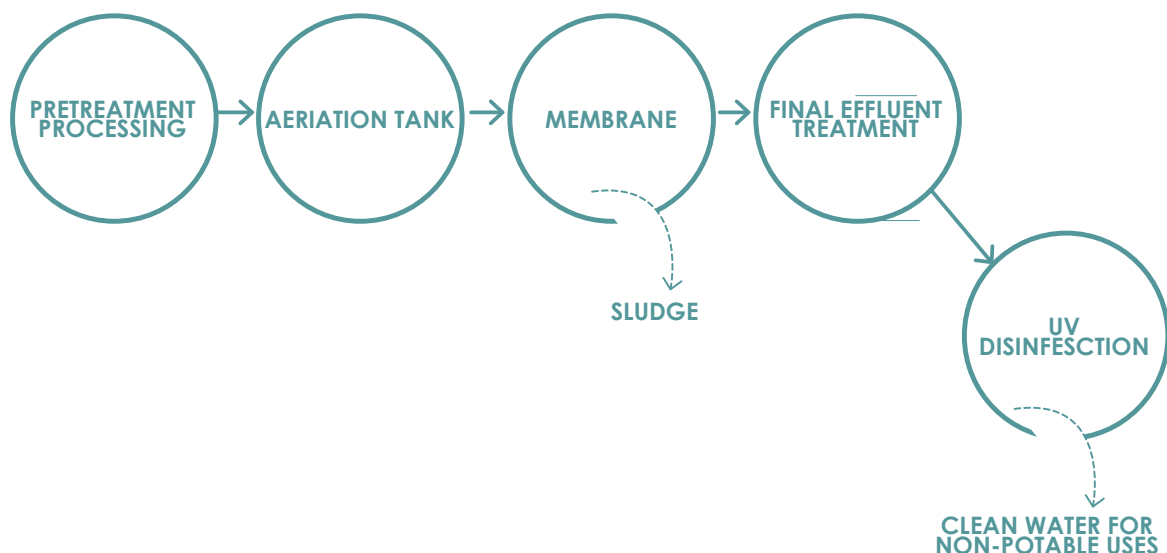
Figure 1-50 In front of an aeration tank (Source: <http://4.bp.blogspot.com/-jumF1VzFdGw/TDSfBgOkel/AAAAAAAAAGA/5NlyhVW6wRc/s1600/5+week+sabbatical+travels+to+Middle+East+and+Scotland+327.jpg>)

LIVING MACHINE



A living machine is a “compact” way to clean waste water through biological and natural processes, imitating the laws of nature without chemical procedures. Within the process both fauna and flora are taking part actively in order to create the right environment where the organic matter is being broken down. The system consists of three phases; the anaerobic septic tank, the closed aerobic reactor and a series of aerated tanks.

MEMBRANE BIO-REACTOR



A membrane bio-reactor is a chemical way of treating water. The system combines a membrane process of filtration or ultrafiltration, as well as a bioreactor where chemical processes take place. It is used largely for wastewater treatment in urban environments, due to its limited space demands. It can also be combined with more natural processes. Effluent can be further treated through UV disinfection.

In the aerobic tanks, plants, fish, bacteria and other organisms exist. These organisms are acting as water-cleaners, or they provide shelter for bacteria to grow and break down the organic matter. The plants that can be found in a living machine can be categorized into four types (Melnik et al., 2004):

- Floating plants, which remove nutrients directly from the water through their root system [Duckweed, Azolla, Water Hyacinth, Water Lettuce, Parrot's Feather]
- Oxygenating plants, which absorb large amounts of CO₂ in order to process photosynthesis, and hence generate oxygen
- Marginal plants, are the ones which roots are submerged into the water and aid with its cleaning, while their foliage stays out of the water [Iris, Taro, Cattails, Cannas, Japanese Umbrella Palm, Papyrus, Primrose Creeper]
- Deep-water plants, which their roots are placed on the bottom of the tank, in order to filter the water substantially through the whole depth of the tank [Water Lily, Lotus]

As far as the fauna is concerned, the types of animals that can be found in a living machine are:

- Scavengers, who consume algae and detritus [snails, tadpoles, frogs]
- Goldfish, which is the most common fish found in a Living Machine because they feed a little algae and consume small quantities of oxygen

The Membrane Bio-Reactor (MBR)

The system includes two phases; the bioreactor and the membrane. The bioreactor hosts an aeration process where aerobic bacteria break down the organic material in an oxygenated environment. The membrane is a module with porosities of 0.035-0.4 microns (μm). (Fitzgerald, 2008) Through the microfiltration or ultrafiltration of the membrane, water gets separated from organic matter and bacteria. (Sutherland, 2010)

These two phases can work on succession; the wastewater passes first from the bioreactor and stays as long as it is necessary for the reaction process to take place, and then it passes through the membrane. Separated sludge from the membrane process might pass again from the bio reactor. There is also the possibility of the two processes to work together; having the membrane submerged into the slurry of the bioreactor, which in that case is separated in different partitions. This type of Membrane Bio Reactor is called submerged or immersed. (Sutherland, 2010)

The benefit of the MBR is that due to the microfiltration, the stages of sludge settlement and sedimentation are eliminated. (Sutherland, 2010) Hence, the MBR can generate water of higher quality and it can do it in a smaller space, whereas sedimentation tanks have great requirements of space. (Fitzgerald, 2008) Moreover, an MBR can treat sewage with much higher solid concentration more efficiently than a conventional activated sludge plant. (Sutherland, 2010) The smaller footprint and the better water quality make MBR an attractive option for decentralized wastewater solutions.

Currently, there are two types of membranes used in an MBR, one developed by Zenon (www.gewater.com/products/equipment/mf_uf_mbr/mbr.jsp) and one by Kubota (www.kubota-membrane.com/). Even though the cost of an MBR is quite high, it is expected to fall as the number of MBRs installed increases and the technology gets more widely applicable. (Sutherland, 2010) (Figure 1-51)



Figure 1-51 Image of membrane of Membrane BioReactor (Source: <http://img3.tradeee.com/up/tianchuang/16188.jpg>)

4.2.3.3 Decentralized wastewater treatment implications

Even though decentralized wastewater systems, can be very beneficial on a district level and act as a backup for centralized systems, there are certain implications that should be taken into consideration. First, there are certain risks that are transferred from the public utility and must be dealt by the individual owners. Those risks are related to the system's liability and potential public health issues. In case of a system's failure and potential natural damage, there are legal implications for the owners. In order to avoid such risks, the systems should be designed for redundancy. (Paladino and Company, 2008) However, oversizing a system can also cause implications, such as the case of the living machine of Oberlin College, where the wastewater input is not enough to keep the system working properly. (Bailey, 2002) From the Oberlin College case study, it is realized that wastewater treatment facilities are better incorporated in residential areas, where the number of users/occupants is mostly constant.

Another major issue of the decentralized systems is health and safety issues that might come up due to unintended reuse or contamination of the system due to improper occupant action. (Paladino and Company, 2008) People should be informed through proper signage wherever reclaimed water is being reused, to notify them that it is for non-potable uses only. In Oregon Health and Science University Center (OHSU), proper signage has been placed even above the toilets and urinals. (Figure 1-52) Moreover, most wastewater treatment systems

cannot process chemical substances and pharmaceutical products. Hence, occupants should be properly informed and educated in order to avoid throwing such substances down the drain. In the case of OHSU Center, there is a handbook, where occupants are provided with all the related information as well as with a phone line that they can contact immediately in the case of an accident. (OHSU, 2006)

Finally, the costs of totally disconnecting from the municipal wastewater services are high for a private owner and sometimes the system might be discouraged. (Melnik et al., 2004) However, as there is always the treatment of the bio-solids (byproducts of the wastewater treatment), the system can still be connected to the municipal system to discharge them and will have decreased costs due to low discharge. Attention should be paid again, in the case of chemical disposal in the systems, the bio-solids are considered bio-hazards. In Omega Center's Eco Machine, they consider the possibility of chemical contamination within the system really high, and they are labeling the bio-solids as biohazards by default, in order to avoid possible infections. (Graziano, 2012)

Several implications can be caused by the fact that a decentralized wastewater system is a long-term investment. First, there must be a long-term ownership in order to secure proper and stable maintenance of the system. However, the system must be designed in a way that proper labeling, as well as operation documentation is available in case of ownership change. (Paladino and Company, 2008) Additionally, the systems should be designed to generate water of much higher quality than the regulations and standards demands. As the standards get higher, such a big investment should be future orientated and able to comply with possible change of policy and standards.

Based on all the above, it is understood that the constant monitoring of the system is an indispensable part of the process. This can be realized through computerized central systems that can be accessed and operated online.



Figure 1-52 Signs in OHSU Center (Source: http://25.media.tumblr.com/tumblr_l4e0w8jikP1qc593no1_500.jpg)



ADAM JOSEPH LEWIS CENTER for ENVIRONMENTAL STUDIES Oberlin College

Year: 2000

Website: <http://new.oberlin.edu/office/environmental-sustainability/index.dot>

Background: The Adam Joseph Lewis Center for Environmental Studies is a two story high building with an atrium and it is a part of the Oberlin College campus in Ohio. The building's design and purpose were based on the College's philosophy; it should be powered by natural sources, recycle wastewater and help build a balanced relationship between the environment and humankind. One of its main objectives was also to use the building as a teaching tool for the students. In addition to applying strategies to minimize energy demands and produce energy on-site in order to become a zero energy building, the building was designed to be adaptable in incorporating any sustainable technologies that may be developed in the future. The Center is being used for classes, meetings, presentations and also sponsors guest lectures. It also accommodates office spaces, a resource center, an auditorium and an atrium. It has also been a point of attraction for thousands of visitors and it has become a center for community events.

System Description: The most important feature of the building is its on-site wastewater treatment system, the "Living Machine", located next to the building. It is both a research laboratory and an educational school. In order to purify the water, the Living Machine uses an integration of mechanical systems, microbes, plants, snails and insects. The system is capable of cleaning 2,000 gallons of wastewater per day and reducing organic substances, nitrogen and phosphorus. The water, after leaving the building, goes to two outside underground



Figure 1-53 In front of an aeration tank (Source: !@#\$%^&)

anaerobic reactors, where the digestion of the waste begins. Afterwards, the water flows to two underground aerobic reactors, where the organic compounds are being further degraded. Then it passes through the Living Machine in three open aerobic reactors with tropical, sub-tropical and native plants that help with the cleaning process. Finally the water flows to the wetland, and after an ultraviolet disinfection is ready to be reused in the building's toilets. The wetland in front of the Living Machine, apart from being a habitat for 70 indigenous plant species and animals, is connected to a 7,500 gallon cistern to keep the filtered water on site. (EERE, 2002)

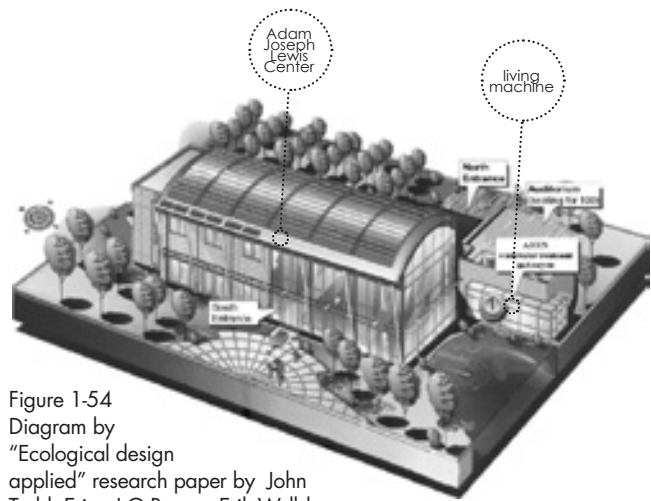


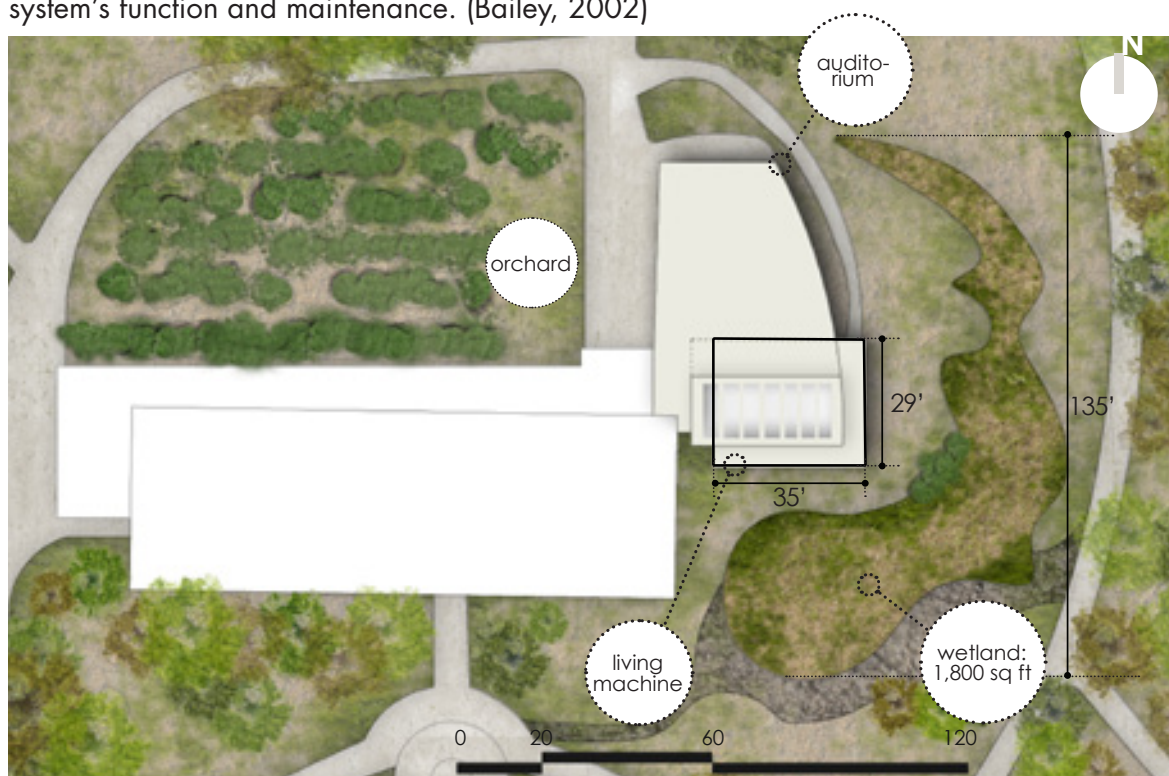
Figure 1-54
Diagram by
"Ecological design
applied" research paper by John
Todd, Erica J.G Brown, Erik Wellsb

Key Dimensions: The building's area is 0.31 acres (13,600 sq ft) and the area of the Living Machine is 0.02 acres (35' x 29'). The area of Wetland is about 0.04 acres (1,800 square feet)

Capacity: The living machine can treat 2,000 gallons of water per day. The collection cistern that is connected to the wetland has a capacity to store 7,500 gallons of water.

Cost of System: The cost of the Living Machine was \$400,000 and the landscape with the wetland: \$84,000 (EERE, 2002)

Implications: The system is oversized for the amount of influent available. As an educational centre, the use of toilets from occupants is unpredictable, which causes problems to the system's function and maintenance. (Bailey, 2002)





OMEGA CENTER FOR SUSTAINABLE LIVING, Rhinebeck, NY

Year: 2010

Website: www.eomega.org

Background: The Omega Center of Sustainable Living is an educational center for environmental practices. It offers the opportunity to students, teachers, architects and many other people in the field to learn about and observe closely environmentally friendly high technology systems, such as geothermal and solar systems and wastewater treatment. In 2005 they decided to substitute their old wastewater septic system with an Eco Machine by John Todd. In that way they could treat their black and grey water through natural processes without the use of chemicals. The Center's new building hosted the Eco Machine and also was built in a way that all energy required by the building and the machine is generated on site. The Center was accredited with LEED Platinum and was the first building to receive the Living Building Challenge accreditation. Working within the idea of a closed loop, the Center is using water in two ways. First, rainwater is collected, purified and used for toilet flushing. Second, the wastewater is being processed by the Eco Machine and sent to recharge the aquifer. (Omega Center, 2012)

System Description: The system treats water naturally with the use of microscopic algae, fungi, bacteria, plants and snails. The water passes through 6 phases. The first is the multiple solid settlement tanks where solids settle and decompose. In the second phase the water



Figure 1-55 Source: <http://c214210.r10.cf3.rackcdn.com/files/projects/25155/images/900:w/Omega1.jpg>



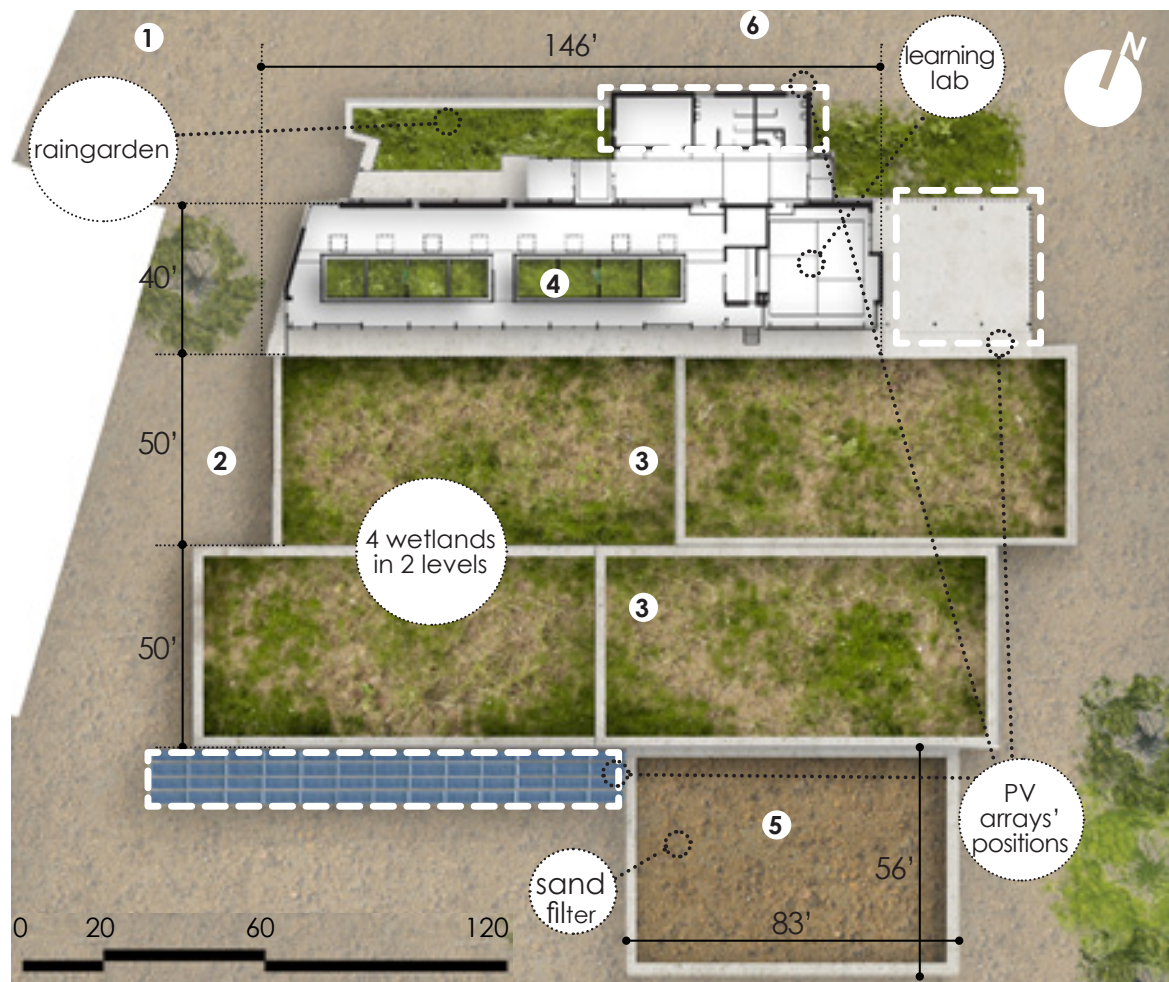
Figure 1-56 Source: <http://ecobeth.com/wp-content/uploads/2012/08/photo341.jpg>

passes through two equalization tanks of 6,000 gallons each that evenly release water to the second phase of anoxic tanks. There are 2 anoxic (or anaerobic) tanks which are set underground and have a capacity of 5,000 gallons each. After that, the water goes to the first 2 constructed wetlands and slowly moves to the lower 2 wetlands. Each wetland is the size of a basketball court (50'x100'), 3 feet deep and filled with gravel. The wastewater is found 2 inches below the gravel and gets cleaned by microorganisms and native plants (cattails and bulrushes). Afterwards, the water moves to the Center in 2 aerated lagoons that are 10 ft deep and contain fungi, algae, snails and plants. The plants are set on floating racks and their roots that reach 5 ft deep are the habitat for the microorganisms. The final phase before the dispersal fields is the recirculating sand filter. There are 2 dispersal fields under the parking lot of the Center. From there the water drips slowly and recharges the aquifer, which is 300 ft beneath the campus. The Center draws its water from the aquifer through deep wells on site, closing the water loop. (Omega Center, 2012)

Key Dimensions: The building's area is 0.14 acres (40'x156') and with the wetlands the system takes up 0.72 acres (31,246 square feet) (International Living Future Institute, 2010)

Capacity: The living machine can treat 52,000 gallons per day. The onsite rainwater cistern has a capacity of 1,800 gallons.

Energy: There are 3 PV arrays which generate 38,994 kWh/yr. The actual annual energy use of the building is 37,190 kWh/yr.





**OREGON HEALTH AND SCIENCE UNIVERSITY CENTER,
Portland**

Year: 2006

Website: www.ohsu.edu

Background: The project team was aiming at LEED Platinum certification, something quite difficult for a project of this scale, and within that context a lot of forward thinking and future oriented systems were included in the agenda. The goals for the water efficiency were set up early in the process to address Portland's comparatively higher water fees along with local system development charges. Based on the precipitation in Portland, the captured rainwater from the building's roof would be approximately 500,000 gallons per year which would not be enough to cover the needs of the 16-story building. Consequently the investment on a wastewater treatment system onsite was decided, and that would also help reduce the strain on the city's overloaded combined sewer system.

The goal set was to achieve 50% or more of code requirement (Energy Policy Act 1992). In order to achieve that, low-flow fixtures were installed in sinks, toilets, showers and urinals. Afterwards, non-potable water needs were defined; toilets and urinals flushing, landscape irrigation and cooling tower, and they were met through rainwater harvesting, the groundwater pumping and onsite wastewater treatment. Only the core toilets are flushed with the recycled water. For safety reasons, the clinic's and examination rooms use municipal potable water. Great focus was given on the separation of the non-potable water piping from



Figure 1-57 Source: http://img.honestbuildings.com/di_image_71046d17-a7ba-8b9d-b23d-bc9ddd448d28.jpg

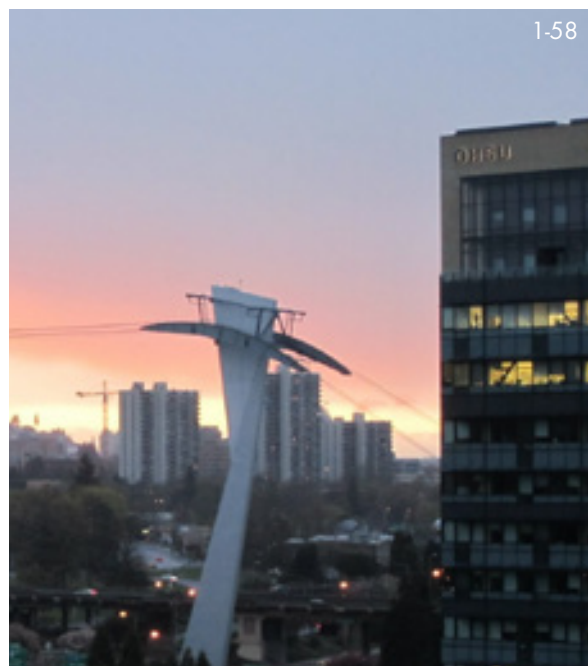


Figure 1-58 Source: <http://4.bp.blogspot.com/-m4wYZzyayMg/Tcl3WYChdZI/AAAAAAAAANU/eG6KUGWdQK4/s1600/tramsunsetapril.JPG>

the potable one, and also signs had to be placed above the toilets to inform the users that the water is not potable. (Interface Engineering, 2005)

System Description: After minimizing the wastewater generation, the project team designed a 100% onsite treatment and reuse system with a Membrane Bio-Reactor (MBR) wastewater treatment technology. The effluents are of very high quality and meet the standards of the State of Oregon Department of Environmental Quality (Paladino and Company, 2008)

The water, as seen in the diagram below, (Figure 1-59) passes through different stages; a pretreatment process, anaerobic digester, oxygenation basin, aerobic digester, and final effluent treatment with UV disinfection. Afterwards, there is a 16,000 gallons tank for storage before the treated water can be reused in the toilets, for irrigation and the cooling tower. From the process, there is a disposal of 1,500 gallons of sludge per week. The system is located in the basement of the building and is also connected to the local sewer system in case of overflow as well as for the periodical sludge disposal. Economically, the wastewater treatment plant is owned, maintained and operated by a third party owner.

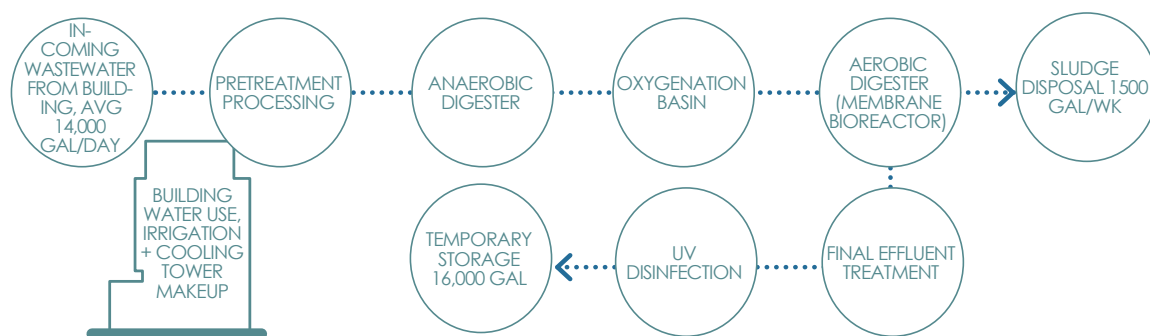


Figure 1-59 Process Diagram (Source: Interface Engineering)

Key Dimensions: The building is 16 stories high (400,000 sq ft). The system is located in the basement, 40 feet below ground. (Ekman, 2011) It takes up 2,600 square feet for the equipment room and an additional 2,000 square feet for the tankage. (Crosman, 2012)

Capacity: The system can treat 30,000 gallons of wastewater per day.

Rainwater Reuse System Details: The building as mentioned above harvests 100% of the rainwater that falls on its roof and stores it in a 22,000 gallons fire-suppression tank.

Other important information: This project focuses on signs and education of the users of the building. The non-potable water piping was carefully differentiated from the potable one, and signs had to be placed above the toilets to inform the users that the water is not potable. Finally, it is strictly prohibited to throw chemicals into the drains of the buildings, due to the fact that the onsite system cannot treat chemical substances and the water is used for landscape irrigation.(OHSU, 2006)

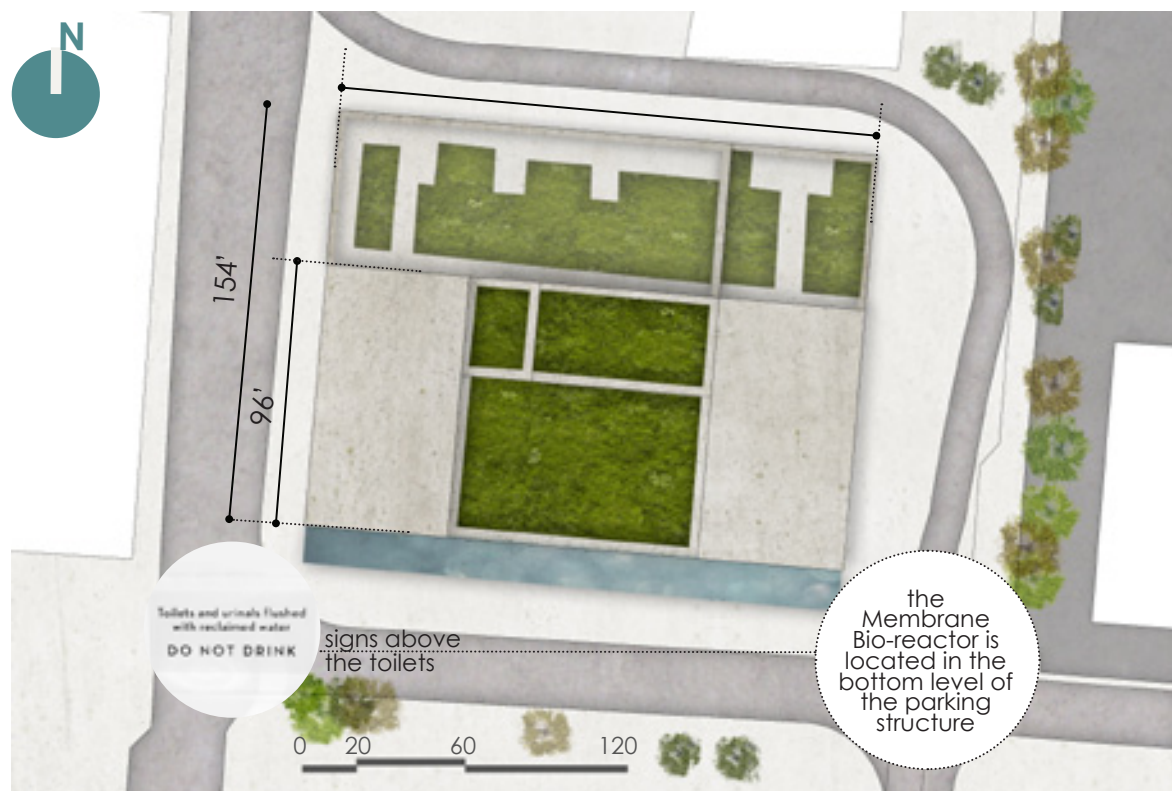
Implications: Originally the design estimated a total building water use of 3.3 million gallons per year (MGY) for potable needs and 4.2 MGY for non-potable purposes. By treating

and reusing wastewater to cover all the non-potable uses onsite, the building would achieve 56% of water savings compared to the baseline building without wastewater treatment. However, based on the post-occupancy evaluation for the period between September 2007 and August 2008 the actual water consumption of the building was 5.7 MGY of potable water and 5.5 MGY of non-potable water. That led to a reduction of the water savings which are actually 49% of the baseline and not 56%. That could be due to tenants' changes of fixtures for maintenance purposes or higher than estimated number of occupants.

Despite the increased water consumption for non-potable uses, it was observed that there was still an abundance of reclaimed and underground water that could not be used. Hence, the excess water was sent to Willamette River. That is due to the fact that a non-potable water pipe which was provided for use of the adjacent building and landscape irrigation was not yet used. (Rdesinski et al., 2009) In conclusion, a system with this capacity could be used to serve non-potable water to more than one building.

Unfortunately, according to the chief engineer of the project, Mark Schnackenberg, the disposal rules have been violated several times by busy technicians and occupants of the laboratories, forcing the system to break down. This, along with other problems that have come up, forced the back-up system to work. Consequently, a penalty of \$0.17/gallon was imposed to the owners by the city of Oregon. (Gragg, 2008)

Another significant observation was that the wastewater system was adding up significantly to the building's energy loads. The bio-reactor has a load of 86 kW and operates approximately for 3,000 hours per year leading to a load of 258,000 kWh annually. (Rdesinski et al., 2009)





DOCKSIDE GREEN, Victoria, Canada

Year: 2008 (first phase)

Website: www.docksidegreen.com

Background: Dockside Green is a mixed-use sustainable community development in Victoria, British Columbia, Canada. The community is a 1.3 million square feet development set up on a former 15-acre industrial site. Dockside Green has set a higher bar for green communities, as it is the first one to achieve LEED Platinum. The development is still in progress and when completed it will include 3 neighborhoods, 26 buildings and 2,500 residents. Water plays an important role throughout the design of the community. With a goal of treating 100% of the community sewage on site and reducing the potable water use by 60%, several design actions have been taken. Low-flow fixtures and water efficient appliances have been installed in all the buildings and are expected to save 39 million gallons of water annually. Moreover, a wastewater treatment plant has been constructed which treats 100% of the sewage. The treated water is used for toilet flushing, landscape irrigation and maintaining the water level of a waterway that passes through the whole development. With all the above actions, water use reduction of 67.5% is achieved in the two constructed buildings; Synergy and Balance.

System Description: First, the water gets screened by two Huber screens and then flows to the equalization tank. From there it passes through the anoxic tanks where the nitrates are



Figure 1-60 Source: <http://civanoneighbors.com/wp-content/uploads/2012/01/Dockside-Reflections1.jpg>



Figure 1-61 Source: <http://blog.emap.com/footprint/files/2009/12/dockside-green-30-sewage-treatment.jpg>

removed and then it goes through the aerobic tanks for ammonia conversion. The final step of the membrane bio reactor is the membrane tank where the membranes filter the water. After that, the water passes through Ultraviolet (UV) disinfection and is ready to be stored and discharged. The treated water is tinted blue and pumped to the buildings through a high pressure system for green roof irrigation and toilet flushing. With a low pressure system, the rest of the water is used to manage and maintain the water level of the main waterway. (EOCP, 2009) If there is an excess of water in the main creek, it naturally overflows over to the Victoria Harbor. In the waterway creek, crayfish were added for further purification and algae removal. However problems were identified as the crayfish population was reduced by the otters from the harbor. (Vancity, 2011) Residents are also being educated in order to avoid throwing chemical substances or harsh cleaning products down the drain. After the water is cleaned, there is a byproduct of biosolids. Biosolids are compressed to bricks and they are used as compost. Potential future use in the biomass gasification plant is taken into consideration. (CSCD, 2009)

Key Dimensions: The wastewater facility is located underground and doesn't affect the aesthetics of the community. (Lima, 2008) It has an area of about 0.06 acres (2,800 sq ft), and only a long façade is visible from the pathway in front of it. (King, 2006) Above the system is a fish pond which is connected to the stream.

Capacity: The system was designed with a maximum flow of 50,000 gpd in the first phase and 100,385 gpd in the second phase. The average flow however reaches 26,417 gpd and the total volume of the plant is 195,487 gal. The average retention time for the water to be treated is 5.5 days. (EOCP, 2011)

Other important information: The environmental benefits of the Dockside Green development are estimated to be 3,400 tonnes of GHG emissions less per year, along with the reduced water consumption. (CSCD, 2009)

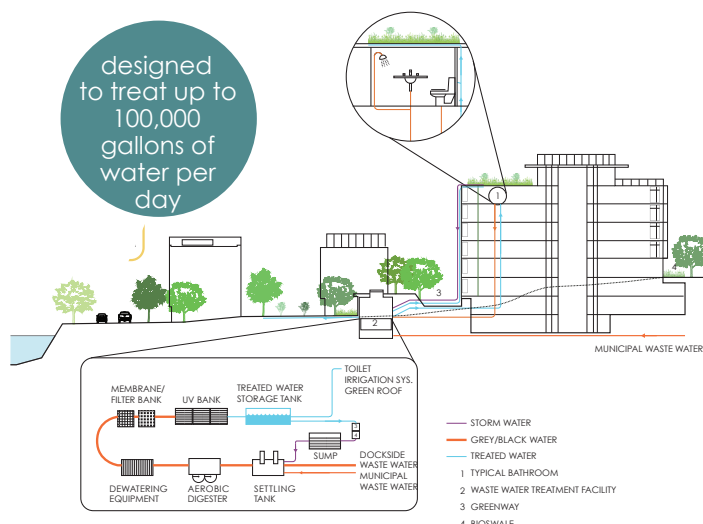
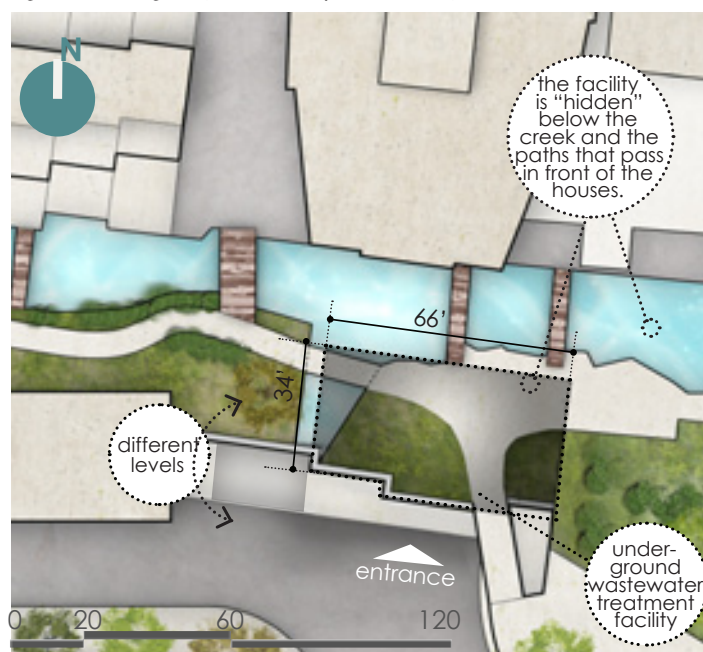


Figure 1-62 Diagram (Source: Busby Perkins+Will)



4.3

ENERGY FROM WASTE



4.3 ENERGY FROM WASTE

Based on our current food system, 27% of the food we produce ends up in landfills. During the natural decomposition of food scrap as well as other organic waste like yard trimming and manure, anaerobic bacteria break down the organic material in the absence of oxygen and produce methane as a byproduct. Methane gas is one of the most significant greenhouse gases, but it can be used as a renewable form of natural gas for cooking and heating. It has a calorific energy of about 1,000 Btu of per cubic foot, (DOE, 2011) and it can be burnt to produce electricity and heat. The system used to capture the biogas is called anaerobic or biogas digester. The yield of biogas per ton of waste can vary between 20 m³ and 800 m³. The yield depends on the quality of the waste used as feedstock and the digester design. (Electrigaz, 2012) Through the anaerobic digestion, sludge is also produced which is rich in nutrients and can be used as a soil fertilizer. Producing biogas is nothing more than capturing the gas produced during the decomposition of the organic matter.



Figure 1-63 Anaerobic digester in Stonyvale Farm in Exeter, Maine (Source: <http://2.bp.blogspot.com/-cmF0hzFw9hk/T9lFoeiVgSI/AAAAAAAAAo0/TU2oE2s5BUc/s1600/Exeter.JPG>)

4.3.1 Benefits of Anaerobic Digestion

The benefits of using the anaerobic digestion to produce biogas are obvious from the process itself. When waste is decomposing, methane and carbon dioxide are produced and released slowly into the air. Both of them are detrimental greenhouse gases that deteriorate the air quality. By using the gas to produce energy, they are prevented from being released into the atmosphere. Moreover, several companies and waste treatment facilities are already flaring the biogas in order to minimize their greenhouse gases production, and all the energy released is being lost. Hence, there is no reason not to capture the heat and electricity produced during the process.

The energy produced during the digestion is significant; a cubic meter of biogas corresponds to 10 kWh of calorific energy. (DOE, 2011) The combustion of the biogas can transform about 1/3 of its initial energy to electricity. (Electrigaz, 2012) The rest of the energy is transformed to heat which can also be captured and used for district heating. Facilities with systems that burn biogas and use only electricity are 20% efficient. Facilities with high-temperature fuel cells can be 50% efficient, and combined with a co-heat generation plant, they can reach up to 80% efficiency. (CAFCP, 2011)

Apart from energy production, anaerobic digestion can lead to further benefits. Fats, oils and grease (FOG) are also potential influents for an anaerobic digester. By diverting them from the sewage systems, possible clogging and overflow of the systems is prevented. (US EPA, 2012b) The sludge produced by the anaerobic digestion can be used as soil fertilizers. In that way the use of chemical substances in agriculture can be reduced. (US DOE, 2011) Consequently, the production of biogas and fertilizer through a natural process can be beneficial and work towards “closing the loop”; the waste of one system becomes the food for another.

Currently, biogas digesters are widely and successfully used in agriculture. There are various farms that have installed manure digesters all across the US; there are 25 in Wisconsin, 21 in New York, 15 in California, 12 in Pennsylvania and 8 in Vermont. (Dairyland Power Cooperative, 2012) The main purpose in the animal agricultural industry for installing an anaerobic digester is their obligation to control odors from massive amounts of daily manure production. Consequently, from a farm proprietor point of view, an anaerobic digester is economically viable if the amount of income from the electricity sales and the savings from purchasing commercial fertilizer meet the cost of maintenance and operation of the system. (Gould, 2012)

Until now, on-farm anaerobic digesters were used mostly in big farms with more than 500 animals. Lately smaller digesters that can treat the manure of just 200 animals are manufactured. One of the first smaller-sized 45 kW digester manufactured by USEMCO, was installed in Peters Farm near Chaseburg in Wisconsin. (BioCycle, 2012) In the future

digesters will be sized ideally based on the available feedstock to be treated. The digester cost was about \$1,000,000 and the purchase was shouldered by UMESCO. The return of investment of an anaerobic digester for a farm depends on several factors; using the heat and part of the electricity on site, selling the electricity to a power company and at which rate, achieving odor and waste control etc. The estimated ROI can vary from 7 to 11 years. (Stockwell, 2012)

Anaerobic digesters can be a successful investment for wastewater treatment plants too. By incorporating food waste and anaerobic digestion in their facilities, wastewater treatment plants benefit by producing part of their energy demands. (US EPA, 2012a) Moreover, if the anaerobic digester is combined with a Combined Heat and Power generation plant (CHP), it is possible to produce 26 kW of electricity and 2.4 million BTU of thermal energy for every million gallons treated per day. The cost of such an action is 1.1 to 8.3 cents per kWh produced. The current cost of electric power varies between 3.9 to over 21 cents per kWh, making such an investment promising for a wastewater treatment facility. (Eastern Research Group, Inc. & Resource Dynamics Corporation, 2011) Finally, municipalities can also profit from such an infrastructure as they are investing in different ways of diverting waste from landfills. (US EPA, 2012a)

4.3.2 Anaerobic Digester

The anaerobic digester is a system that through natural biological process treats waste to produce methane gas (biogas). The biogas, after minimal treatment, can be used as a renewable source of energy. The anaerobic digestion (AD) is a process that takes place when organic matter (waste) is left without oxygen. Methanogens convert organic acids that are created by the fermenting bacteria to methane. (Gould, Charles et al, 2012) The digesting feedstock is called slurry. (Friends of Earth, 2007) The main products of an anaerobic digestion are heat, digestate and gas. The gas contains 60% methane and 40% carbon dioxide (CO₂). It differs from natural gas because it contains significant amount of carbon dioxide, while natural gas is a fossil fuel with more than 70% methane and the rest are hydrocarbons and small amounts of other contaminants. (Cornell Cooperative Extension, 2012)

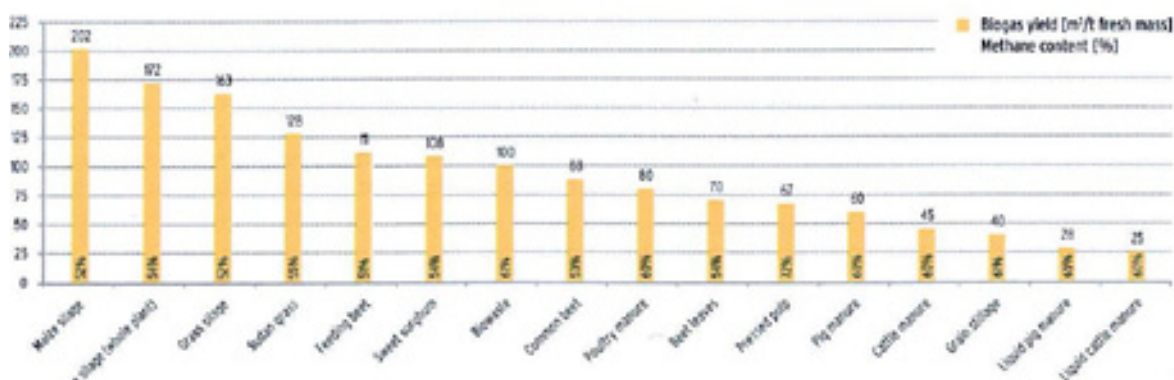


Figure 1-64 Biogas yields by different feedstock (Source: AEBIOM Roadmap to Biogas 2010)

However, biogas can be purified after the digestion and transformed into what is called renewable natural gas or upgraded gas. The digestate is a substrate that is separated to fiber (solid) and filtrate (liquid) and can be used as a fertilizer in agriculture. The amount and quality of products are dependent on the feedstock that is used as input for the anaerobic digester. The feedstock for an anaerobic digestion can be any organic matter that has the potential of producing biogas. Possible feedstock is (Gould, Charles et al, 2012):

- Livestock manures
- Waste feed
- Food-processing wastes
- Slaughterhouse wastes
- Farm mortality
- Corn silage (energy crop)
- Ethanol stillage
- Glycerin from biodiesel production
- Milk house wash water
- Fresh produce wastes
- Industrial wastes
- Food cafeteria wastes
- Sewage sludge

However, it must be mentioned that different type of feedstock can yield different amounts of gas. Both manure and sewage are producing less biogas compared to food scrap for example, because they are pre-digested by the animals. Food waste can be three times more efficient in methane production compared to other bio solids. (US EPA, 2012a) However, food waste is really acidic and attention should be paid on the PH of fermenting mix. In order to achieve an efficient digestion, the PH levels of the fermenting mix should be close to neutral. The methanogens, which exist in non-oxygen environments and produce methane, must be in a PH between 6.8 and 7.2. (Gould, Charles et al, 2012) In order to achieve that and have an energy-dense feedstock, the common practice is to mix high energy waste (food waste) with manure.

There are two types of digestion, the mesophilic and the thermophilic. In the mesophilic digestion, temperatures are kept between 68 - 104° C, while in the thermophilic digestion, temperatures range between 105 - 230° C. Mesophilic digestion does not need extra energy to heat up the fermenting mix. However thermophilic is more efficient as bacteria grow better in warmer environments. In the diagram below (Figure 1-65), the exact process of the anaerobic digester is described. The feedstock enters a mixing pump, and from there into a fermentation tank. The feedstock has to stay in the fermentation tank for approximately 15-30 days, in order for the digestion to happen and produce the methane gas. The fermentation tanks are usually made out of cement or steel, hence they are a costly construction. However, the upper part of the tank, in several cases, has been substituted by cheaper polyethylene fabric. The fabric's flexibility accommodates volumetric change of the tank. (Goldstein,

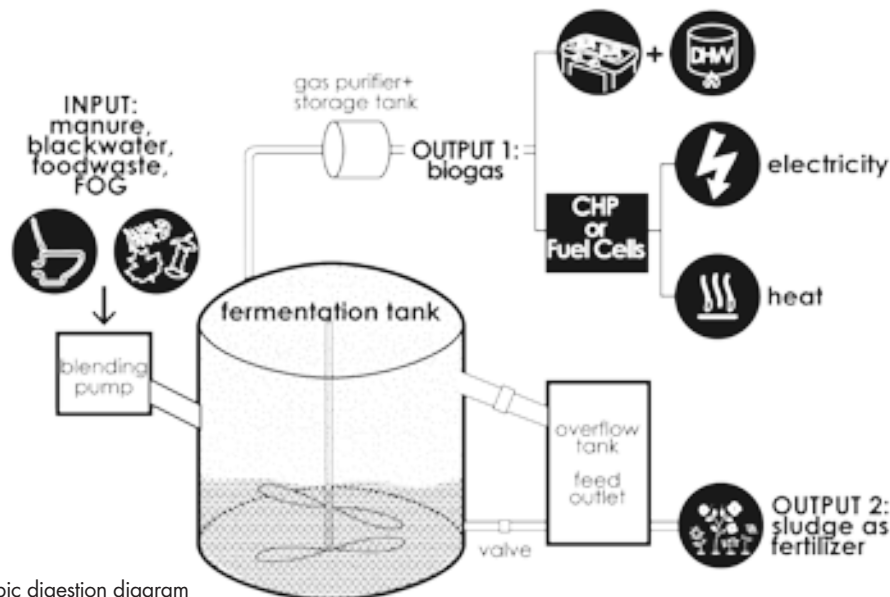


Figure 1-65 Anaerobic digestion diagram

2012) After the fermentation tank the biogas is taken to another tank where it is purified and ready to be used. After this process the biogas is used either directly or sent to a co-heat generation plant where it is burnt to produce electricity along with heat. The second output from the anaerobic digester, the digestate is sent to another tank where it is separated to fiber and filtrate. The fiber can be composted and the filtrate can be used as fertilizer.

4.3.3 Implications through current practices

As mentioned above, digesters are used widely in farms to treat manure and control odor. Even though a private on-site digester can be profitable for a farmer and help with waste and odor management, a larger community digester serving more than one farm or a community, would be more efficient. (Werblow, 2012) Nevertheless, there are implications related to high initial cost of investment, ability to use all the byproducts of the digestion and high transportation costs, which could prevent such attempts from happening easily. These implications are presented below through current practices.

First, an anaerobic digester might not be a profitable investment. For example, in California, in order to prevent frequent black-outs due to increased power demand, the Inland Empire Utility Agency (IEUA) built an anaerobic digester to produce biogas from the manure obtained from 300,000 cows within a 10 mile radius area. From the biogas, the plant produces 1 MW of electricity and 135 tons of fertilizer per day. The heat captured from the process is used for the heating needs of the digester and for other industries in the area as well, such as the desalination plant. Rich Atwater, who is the general manager of the IEUA, claims that even if it is a successful system it is not a profitable one. (Werblow, 2012) That means that it generates a million dollars per year in order for the whole system to cover its operation and maintenance costs as well as it returns the initial investment. However, it is not an investment that will yield further great economic benefits above the operation and maintenance costs and that is the reason why it is not still widely done.

On the other hand, in the Midwest, the hopes of investment on biogas production are

higher based on the energy production of the existing anaerobic digesters in the area. Based on current studies and a feasibility study in 2003, John Reindl, the recycling manager of Dane County, believes that combining the nearby manure of 125,000 cows and a thousand hogs, the sewage system of the second biggest city in Wisconsin with a community digester can only lead to environmental and economic benefits. (Werblow, 2012) The 2003 study showed that having a community digester is more profitable and efficient than having a lot of smaller on-farm digesters. It showed in detail that such an investment would have an initial cost of \$4,400,000, costs of operation and maintenance of \$798,000 and it would have an annual net profit of \$200,000. However, what they realized in this case, is that selling the electricity is not enough to make an investment like this economically viable. The authors of the feasibility report stressed the importance of selling the composted substrate as fertilizers and using the waste heat along with selling electricity. (Werblow, 2012) The actual revenues from such an investment are 60% from the sales of solids for fertilizers, almost 30% from renewable energy and greenhouse gas emission credits and finally about 10-11% is from the value of electricity sold. (Reindl, 2008) Consequently, an anaerobic digester makes economic sense when all the byproducts are taken into consideration.

As highlighted earlier, food waste leads to increased biogas yields compared to manure and sewage. Various attempts are being made towards electric production by biogas through the combination of manure and food waste, such as the Synergy Biogas formed by CH₄ Biogas in Covington, NY and the Cayuga County Digester which was commissioned this March (2012). However, both of them are very new, and complete conclusions cannot yet being made. The preliminary feasibility studies for the Cayuga County case are not encouraging for the wider promotion of such investments, but this is the first phase of the project and the solid-liquid separator is planned but not yet realized. Hence, again there will be no profit from using all the possible products of the procedure; electricity, heat and fertilizers. The potential profits for the Cayuga case are the energy savings from purchased thermal and electrical energy needed for the plant, the sale of excess energy and the food waste tipping fees. (Shelford, Pronto, & Gooch, 2012) The most important point for consideration of this case study was the high costs of transportation. Trucks were purchased in order to bring the manure from the farms to the digester and realize on farm loading/unloading activities.

Consequently, in order for a system like this to work and be economically viable, the distances should be minimized as much as possible. Digesters should be placed near the farms in a radius of 10 miles or less and all the products and byproducts of both the digestion and the electric and heat generation should be used. The proximity reduces the expenses for hauling the feedstock to the plants and hauling out the compost. It also reduces the infrastructure to distribute the thermal energy from the digester. To increase the biogas yields by using food waste; issues of management and collection of food waste from housing units and food businesses should be taken into consideration in the planning for a community digester. Hence the proximity of the biogas digester to the community becomes of great importance.



HAMMARBY SJOSTAD, Stockholm

Year: 1996

Website: www.hammarbysjostad.se

Background: Hammarby Sjöstad is a redevelopment project in a previously industrial waterfront near Stockholm that was planned to provide habitat to the visitors of the Olympics in 2004. Stockholm did not manage to host the Olympics; however the community project continued to make one of the most sustainable communities in the world, with many future oriented ideas. The goal was to create a community twice as efficient compared to a typical Swedish one. (Gaffney, Huang, Maravilla, & Soubotin, 2007) It was planned for 10,000 apartments and 25,000 residents. (Clean Energy awards, 2007) The Hammarby model was tightly focused on waste management and treatment and it was one of the first communities to develop such sophisticated systems for waste sorting. Great emphasis has been stressed on facilitating the residents to separate their organic waste from the rest in order to be easily processed. Organic waste (combustible waste; food waste and paper) is used in a Co-Heat Generation Plant (CHP) to produce electricity and hot water for the buildings. Biogas from the digestion in the wastewater treatment plant is captured and purified. The existing underground wastewater treatment plant in Henriksdal, built in 1941, was modified to capture biogas from the new development's influents.

System Description: The biogas digester is situated next to the wastewater treatment facility in Henriksdal which is within the overall area of Hammarby. It is located only half a mile away from the residential areas and has been operating since 2003. The underground wastewater treatment plant was built in 1941. The sludge from the sedimentation tanks goes



Figure 1-66 Hendriksal (Source: <http://www.cfmoller.com/ingintr/Biogas-facilities-Henriksdals-sewage-works-in-Stockholm-Arkititektfirmaet-C-F-Moeller-img-13875-w530-h714+D.jpg>)

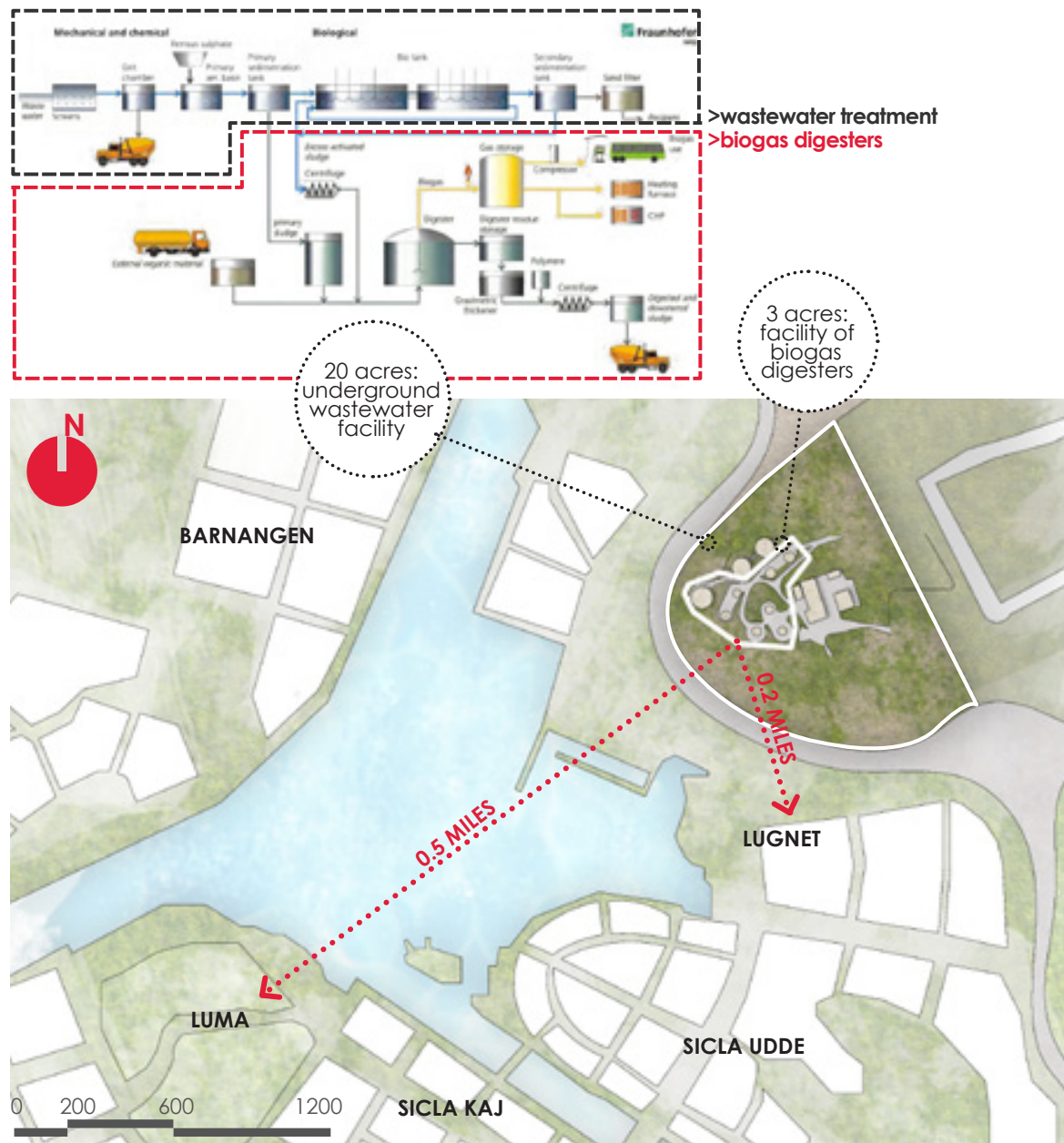


Figure 1-67 Hammarby and Hendriksal area (Source: Bing maps)

into the 7 digesters of the biogas plant. The plant processes several influents; food waste from restaurants, institutional kitchens and market halls and fats. The total volume of the 7 digesters is 13,770 tons (39,000 m³) and the maximum quantity of upgraded biogas produced is 58,000 MWh. (Held, Mathiasson, & Nylander, 2008) The digestion is mesophilic (97 - 98.5 °F) and it needs 19 days for the influents to get treated. However, currently less biogas is produced. Most of it is used as transportation fuel for buses and cars and just 2% is used for residential gas use in 1,000 households. A 1.2 mile pipeline runs from the biogas plant to a bus depot to provide fuel for 140 buses. Moreover biogas is supplied to 11 gas filling stations. (Held et al., 2008)

Key Dimensions: The wastewater treatment facility occupies 20 acres and 3 of them are the biogas facility

Capacity: The system can treat up to 600,000 tons of sewage sludge per year mixed with 25,000 tons of fats and 2,000 tons of food waste. It can produce up to 58,000 MWh of upgraded biogas. (Held et al., 2008)



Waste distribution system: The most innovative infrastructure investment in Hammarby is the waste collection system by Envac. The system is either stationary or mobile. In the stationary system, vacuum pipes transport waste to a reception center or underground storage tanks. Vehicles can receive easily and transport the waste accordingly to landfills or recycling centers from the reception center, located on the outskirts of the city. The pipelines from the inlets to the reception center cannot be more than 2 km (1.3 miles). (Envac AB, 2010) The mobile system is more convenient for smaller neighborhoods. It sends the waste to underground tanks and the waste is pumped into vehicles at strategic docking points.

The system in Hammarby is being used for three types of waste: organic food waste, mixed waste and newspapers. The diameters of the pipelines of such a system are about 500 mm (20 inches). The newspapers created some problems with the piping and after some time were not used for some of the neighborhoods. However, the most important part of a system like this is the separation of food waste and the reduction of waste transportation. Finally, the system can be operated by fewer than four people and it also has a remote access system, which make it easily accessible from whichever part of the world. The sizing of the system depends on the density of the neighborhood. For example the stationary system of the Norra Hammarbyhamnen area, which serves 3000 apartments, has a capacity of 3.1 tons of waste per day and its pipeline is 5500 m (3.4 miles) long. There are 200 inlets and only one type, because it was the first area to be constructed with such a system. (Envac, 2007)

As far as the actual realization and the economics of a project like this are concerned, there are several parameters that need to be taken into consideration. Even though the system may be expensive, it has to be evaluated with a long-term view incorporating life-cycle and environmental costs analyses. This system cannot be evaluated with just a five year perspective, because waste last longer than this. Even though the initial cost might be expensive, there are considerable savings and benefits throughout its function (Envac, 2007):

- Eliminate waste-vehicle movements and minimize transportation
- Reduce CO2 emissions
- Reduce manual labor
- Create clean neighborhoods and advance public health
- Separate organic waste from the rest



Figure 1-68 Envac system (Source: <http://www.solaripedia.com/images/large/3386.jpg>)



THE PLANT, Chicago

Year: 2010

Website: www.plantchicago.com

Background: This system is a holistic approach of producing food, treating waste and generating energy. The plan is to produce plants, tilapia fish, beer and tea in a way that the waste from one of them becomes the raw material and food for the other. As shown on their diagram, the plants will create oxygen for the kombucha tea, and the CO₂ from the kombucha tea production will go back to the plants. The waste water from the fish tanks includes nutrients that feed the plants. From the fish tanks, the water will pass through the plants to get cleaned and filtered. The filtered water go back to the fish, completing the cycle. The extra waste from the plants and fish tanks, as well as waste from the brewery, the food waste from the kitchen and waste from neighboring businesses will go to an anaerobic digester to produce biogas. The digester is planned to have a capacity of 5,000 tons per year in the first phase and 10,000 tons per year on the final phase. The biogas will then be burned in a combined heat and power plant to produce 200 KWh of electricity (A phase) along with heat to be used in the brewery. (McDowell, 2012) Excess heat will go to an absorption chiller for heating and cooling purposes of the building. (The Plant, 2012)

System Description: The biogas digester has a footprint of 80' x 170' (0.31 acres)

How much do they produce: 2 MMBtu/hr of Biogas yields 200 kW of electricity at an efficiency of 29% (A phase, production will be doubled in the B phase) (McDowell, 2012)

How much waste will be treated: 10,000 tons of waste annually in the final phase

Other by-products: The digester will produce 1 ton/day of press-cake for composting and 8 tons/day of liquid soil amendment for fertilizer. The heat energy will be used in the absorption chiller and in the brewery. (McDowell, 2012)

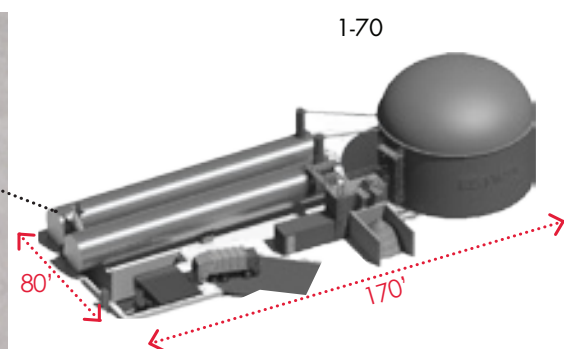
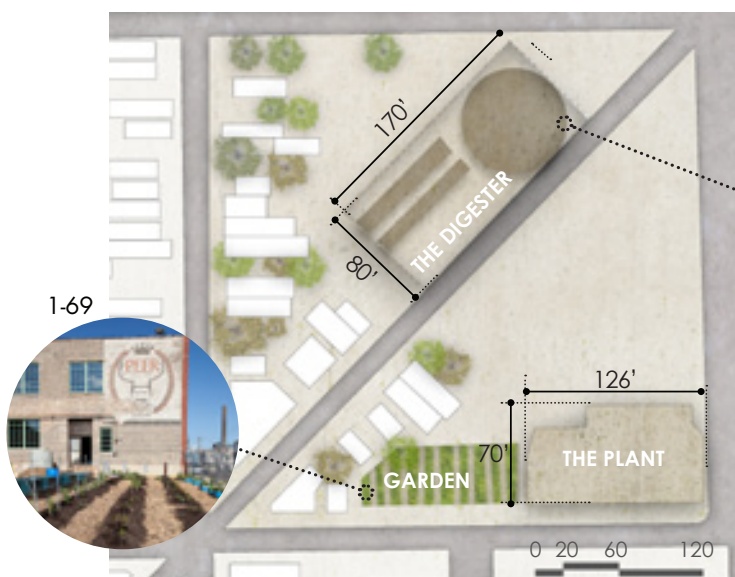


Figure 1-69 Outdoors garden (Source: www.flickr.com/photos/plantchicago/7434969300/in/photostream)

Figure 1-70 The Anaerobic Digester's 3d model (Source: EISENMANN)



AMAGERFORBRAENDING, Copenhagen, Denmark

Year: Construction started in 2010 and will be completed by 2016

Website: www.amfor.dk

Background: The Bjarke Ingels Group (BIG) office has won the architectural competition of designing and constructing the new waste-to-energy factory of Amagerforbraending in an industrial area on the outskirts of Copenhagen. The new plant is going to replace the old one which has been active for the last 40 years to include new technologies and will be the biggest environmental project in Denmark. (Jordana, 2011) Currently the company treats household waste (50%), incinerable waste from recycling stations (10%) and industrial waste (40%) in order to produce electricity and district heating. (Amagerforbraending, 2011) In 2011, the company received 404,000 tons of waste.

Even though, this is not an organic waste treatment facility, the significance of the project is its dual purpose; the waste treatment along with social functionality. Typically, waste treatment plants are introduced in the spatial landscape through the big-box form. BIG's design intends to incorporate functionality to the plant's outer skin and create community outreach. The project's goal was to create an envelope for the plant that is attractive to the residents in order to achieve a triple bottom line agenda. Apart from being an environmentally and economically viable project it should also be socially profitable. In order to achieve that, the roof of the building was repurposed in order to carry a function; that of a ski slope for the



Figure 1-71 Source: www.dac.dk/Images/img/1920x1200M/{27478}/27478/20110601_113350_baggrund.jpg

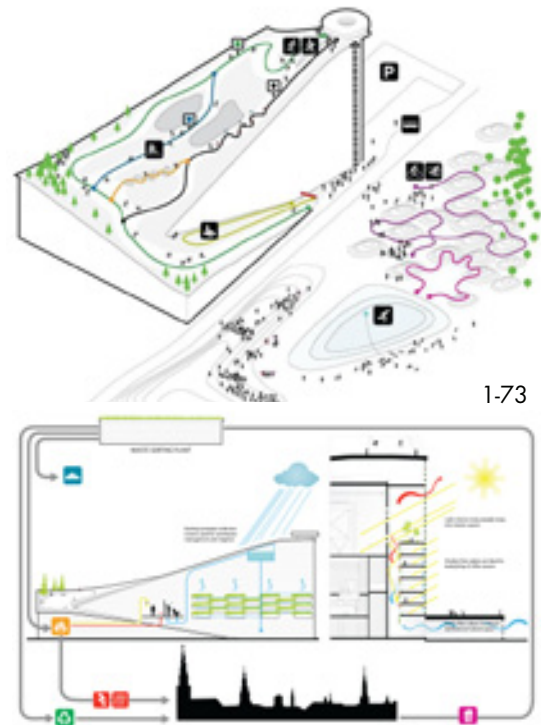
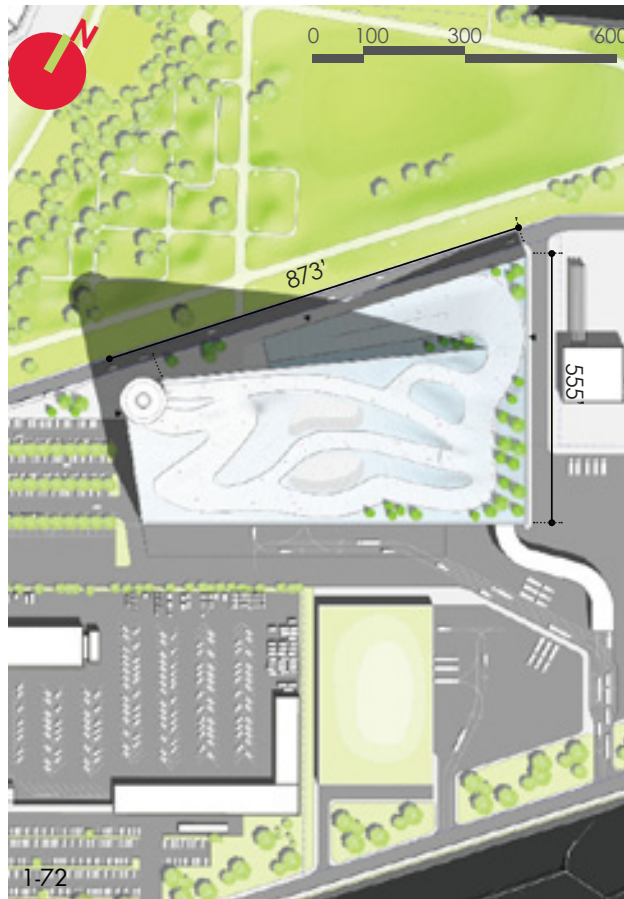


Figure 1-72 Plan by Bjarke Ingels Group (Source: http://buildipedia.com/images/masterformat/Channels/In_Studio/BIGs_Fun_Factory/Drawings/Amager_Waste-to-Energy_BIG_-_Drawing_01.jpg)

Figure 1-73 Diagrams by Bjarke Ingels Group

residents of Copenhagen. The slope is generated by lifting one side of the roof so that the smokestack of the plant gets integrated into the building. (Jordana, 2011) The general site and roof will accommodate spaces for cable skiing, go-carting and rock climbing. Moreover there will be an administrative and visitors center within the building.

System Description: After sorting the waste, part of the waste will end up in the landfill, another part will go for recycling and the rest will be burnt to produce electricity and heat. Both electricity and heat will be used on site and the excess will supply the city of Copenhagen. The plant will have a capacity of treating 550,000 tons of waste per year and supply electricity for 140,000 households. The efficiency of the plant will be increased by 20% compared to the old one, achieving electricity efficiency rate of 27-30%. (Holm, 2011) Moreover, wastewater and stormwater will be treated and used for irrigation of the green façade.

Key Dimensions: The total floor area of the roof is 7.9 acres (32,000 square meters)

Capacity: The new plant will be incinerating about 550,000 tons of waste per year, which equals to 10% of all residual waste produced in the country. The electricity and heat produced will supply 140,000 households. (Holm, 2011)

Other byproducts: 20% of residue waste is left after incineration

Other important information: The project is one of Denmark's biggest environmental investments with a budget of 3.5 billion DKK (\$570,000,000)



MEN1
erlin



2010/01/01
2010/01/01
2010/01/01

2171 Residents:
100% have no access to fresh food
22.3% of low-income
36.6% no vehicle

TOOLKIT

for urban
regenerative
environments

food
water
waste
energy
in + around
the city

5. TOOLKIT for URBAN REGENERATIVE ENVIRONMENTS

The study of the above systems for food production, stormwater management, wastewater treatment and energy from waste reveals numerous opportunities for regenerating the urban context and promotes the idea of closing the loop. Outputs from one system can become the input for another, minimizing the total waste production by supporting the cycles of the natural environment. (Figure 1-74) Nevertheless, these systems are as important, even if applied alone, and it is verified by the quantitative benefits and yields presented through the above case studies. The question is: how designers and people involved in the building industry, become aware of such case studies, their specifications and related benefits, in order to consider applying them in their projects?

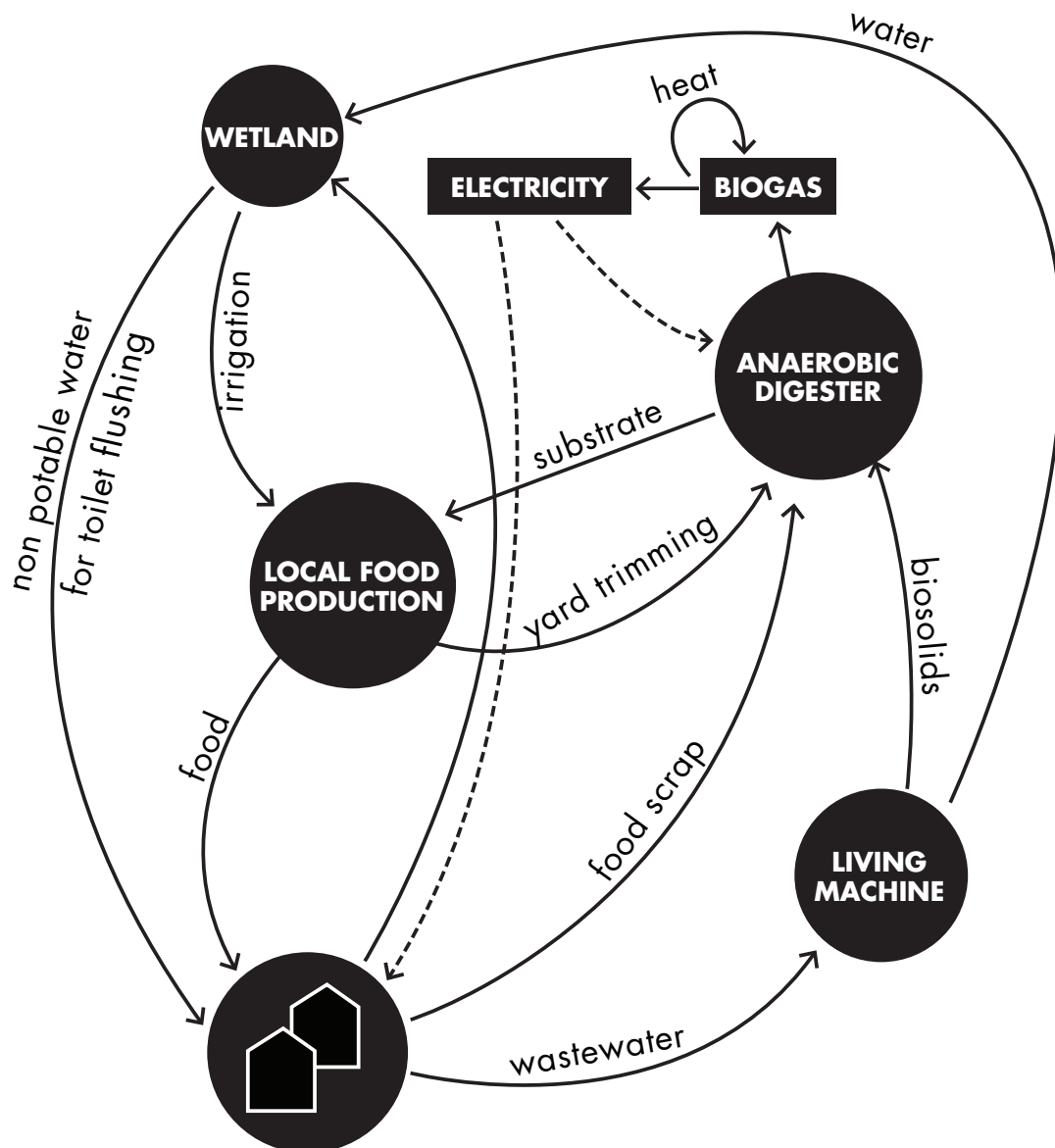


Figure 1-74 Theoretical diagram with the inputs and outputs of the systems working in a close loop

5.1 PURPOSE OF THE TOOLKIT

The purpose of this toolkit is to make designers aware of various innovative and forward-thinking strategies related to food production, stormwater management, wastewater treatment and energy production. The toolkit for urban regenerative environments is a tool for the design team during the preliminary design phase. This toolkit illustrates spatial requirements and quantitative benefits of these strategies with the goal of pushing the team towards a new way of thinking. Considering the toolkit as a “Green Infrastructure for Dummies”, it could actually help the design team during the schematic phases. Due to ongoing technological advances, the intent is not to showcase best practices, but present current practices. Consequently, the toolkit is not meant to be a static best practices book to refer to, but a constantly evolving and updated database.

Additionally, it can become useful in another part of the design process; the charrettes. It is an easy way to showcase several case studies to people from different backgrounds, as both the illustrations and the texts are presented in a simplified manner to be useful to a wider audience. Through the case studies, the toolkit also provides convincing evidence to the clients by correlating the space needed and the potential benefits of the systems being considered.

5.2 TOOLKIT INSTRUCTIONS

The toolkit includes 2 introductory cards, 4 cards with general information about the four system categories; food production, stormwater, wastewater treatment, energy from waste, 19 cards presenting different case studies, a reference card and a CD.

The first two introductory cards present how the toolkit is structured and how it is used. The instruction card gives the necessary information or references to the design team on how to calculate the following data, based on the number of residents of



Figure 1-75 Instructions Card

a certain project:

1. How much fresh fruits and vegetables they consume
2. The runoff volume generated from the area of the project
3. The wastewater produced by the residents
4. How much food waste is produced from the residents

Based on the above data and space availability, the design team can decide which system from the case studies that follow is more appropriate.

On the second introductory card the classification index of the case studies is presented. All the case studies are classified based on:

The system: Food Production, Stormwater, Wastewater Treatment and Energy from Waste	   
Location of Action: Landscape, on Rooftop, on the Façade or Whole Building approach	   
Scale of project: Building Level, Neighborhood Level and District Level	  

For each classification, a key is designed and presented through the index. The above key images are placed on all the case studies cards to highlight the system type, location and scale. On the back of the index card, a case studies' matrix presents the case studies in relation to their scale.

The systems introductory cards are found before the related case studies cards. On the front they introduce the type of system and why it should be incorporated in the urban context. On the back left side (Figure 1-77a), the benefits of each system based on research papers and literature are presented. On the right side (Figure 1-77b) there is a short description of the different current technologies that exist along with explanatory diagrams.

Each case study card has the same structure that helps the user understand the project, its basic information, the system and its requirements. On the top of the front size, there are images of the project along with the title. Next to the title are the three key images that identify the location, scale and type of the system. All the images are numbered and their references can be found on the references card at the end of the toolkit. On the bottom part, there is a paragraph about the background of the project. The back side is dedicated



Figure 1-76 Index + Matrix Card



Figure 1-77 Systems Introductory cards

to the description of the system. On the right are the main information about the system; the system description, its key dimensions, its capacity, how much it yields etc. For all the case studies, there is always a description of the system and key dimensions category, as well as a category for the yield or capacity of the system. Consequently, the spatial demands of each system presented are correlated with its quantitative benefits. To support the written description and fully explain its system, the supporting graphic material is located on the right side. On the top there are diagrams, photos and details, and on the bottom there is the plan of each system presented as a "stamp". The idea of the stamp is to outline fully the system and its key dimensions. The design team could literally recreate those stamps on their development plan and multiply accordingly to calculate the yields.



Figure 1-78 Case Study Card standard layout - Front Side

- a: title
- b: classification keys
- c: images of the project
- d: project's background paragraph

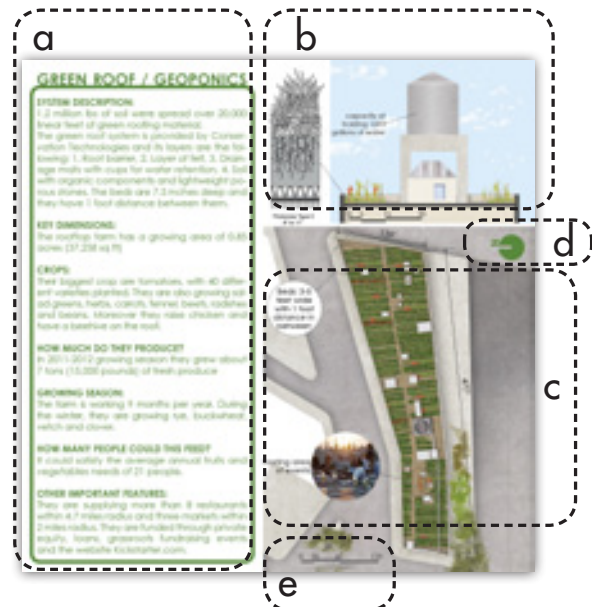


Figure 1-79 Case Study Card standard layout - Back Side

- a: system description (yields/dimensions etc)
- b: supporting diagrams and drawings
- c: stamp (plan)
- d: North arrow
- e: graphic scale

However, as the design process is not being done anymore by hand, a digital version of the case studies "stamps" is provided as an Autocad file(version 2010) in the CD. Hence, the design team can now "copy-paste" the stamps on their project file following the same concept. Moreover, as the scales of each case study and system vary from building to district, it would be impossible to create all the stamps in a certain scale. Nevertheless, a graphic scale and a North arrow indication are provided on each stamp.

Finally, in the following matrix (page 102), all the stamps from the case studies are categorized into 4 rows based on their size. Next to each case study its area and yield is specified in order to be able to co-relate the spatial demands and benefits of each system. In the case of a preliminary study the available space would be estimated and the appropriate system would be chosen.

the stamps matrix

0 10 30
0.005 acres



12

area: 0.005 acres
infiltration rate: 4 in/h



7

area: 0.003 acres
capacity: 320 plants

0 10 30
0.02 - 0.1 acres



14

area:
0.020 acres
capacity:
2,000 gpd



6

area:
0.036 acres
capacity:
1680 plants



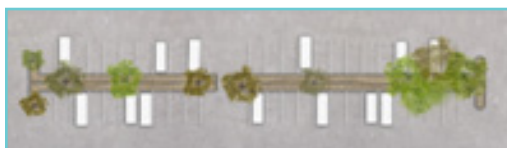
17

area:
0.060 acres
capacity:
100,000 gpd



3

area:
0.140 acres
an. produce:
1.12 tons



11

area:
0.300 acres
infiltration rate:
7 in/h

0 60 180
0.01 - 1.0 acres



16

area:
0.105 acres
capacity:
30,000 gpd



15

area:
0.140 acres
capacity:
52,000 gpd



5

area:
0.850 acres
an. produce:
7 tons



13

area:
0.308 acres
infiltration rate:
7 in/h



19

area:
0.310 acres
annual tratment:
5,000 tons
annual biogas:
5,860 mmBtu



4

area:
0.850 acres
annual produce:
7 tons



1

area:
1.000 acres
annual produce:
3 tons

0 100 300 600
1.0 - 10.0 acres



2

area:
4.000 acres
annual produce:
12 tons



18

area:
3.000 acres
annual treatment:
600,000 tons
annual biogas:
235,438 mmBtu



20

area:
7.900 acres
annual treatment:
550,000 tons

5.3 PROOF OF CONCEPT

5.3.1 The Northern Liberties Neighborhood

In order to test how the toolkit will be used in an actual design process, a design exercise was realized as a proof of concept in the city of Philadelphia. The design was based on the information gathered in the case studies. Based on the US Census Bureau in 2010, Philadelphia has a population of 1,526,006 people and its density is 11,379 people per square mile. Philadelphia was chosen over Pittsburgh because it has double the density of Pittsburgh and still has similar climatic conditions. Philadelphia is the 5th largest city in the US. (US Census Bureau, 2009)

Even though the city consists of an urban dense area, food deserts are found within its limits. According to the United States Department of Agriculture's 'Food Desert Locator,' there are three basic areas currently defined as a food desert (U.S. Department of Agriculture, 2011); one of those was selected as the study example. (Figure 1-80) Although there are several variations of the food desert definition, the USDA uses the Healthy Food Financing Initiative's (HFFI) definition as a "low-income census tract where a substantial number or share of residents has low access to a supermarket or large grocery store" (U.S. Department of Agriculture, 2011). The implications of limited food accessibility in communities, especially areas considered as food deserts, often influence the health and economy of the community and its residents (Wrigley, Warm, Margetts, & Whelen, 2002) (Pothukuchi, 2004).

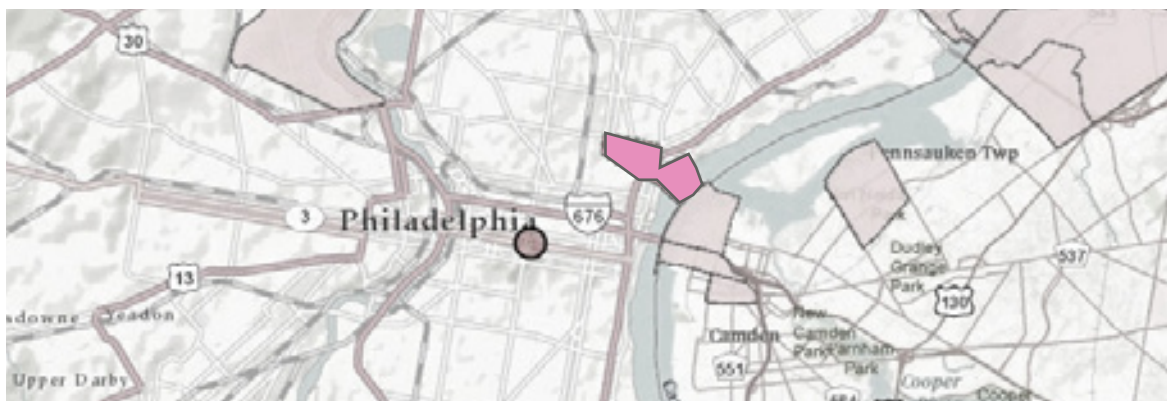


Figure 1-80 Food Desert Locator map (Source: www.ers.usda.gov/data-products/food-desert-locator/go-to-the-locator.aspx)

The selected neighborhood is located in the general area of Northern Liberties and Fishtown. (Figure 1-80/ Highlighted pink area) It has 2171 residents, and all of them are considered to have low access to fresh food. (USDA, 2012a) There are 951 housing units and the total area of the development is 142 acres. Based on the information provided by the food desert locator the following data are provided:

- 22.3% of the population are low-income residents (466 people)
- 20.6% of the population are children in the age of 0-17 years old (447)
- 9.5% of the population are people above the age of 65 (206 people)
- 36.6% of the households (348 households) do not have a vehicle, making the access to fresh food even more difficult

5.3.2 Design Assumptions

The information for the selected neighborhood has been gathered from the Pennsylvania Spatial Data Access (PASDA, 2010), Google Earth, Bing Maps and Food Desert Locator. It must be clarified that this is a conceptual preliminary design approach of how this neighborhood could evolve. In order to implement an actual proposal, further research, field data collection and outreach to the community should be realized. The community's needs and development's demands would actually prioritize the design actions and the systems selected. As a food desert, it is taken as a given that food access would be a priority; however the needs and problems related to water and waste are not known. Assumptions have been made based on the US average for wastewater and waste production of the community.

Moreover, in an actual application the design decisions would be tightly related to the economic factor; available funds and grants. The following design proposal has as a goal to show proof of the toolkit's application and the possibilities of how a neighborhood like this could be developed in a hypothetical scenario where there are no economic restrictions, which is outside the scope of this thesis.

The scenario used for the design is presented through the assumptions made for each criteria; possible food production locations, stormwater demands based on precipitation, amount of wastewater produced from the residents and organic waste produced by the households.

- **Land availability for Food Production**

In 2010, a research was conducted by Sharanbin S. Grewal and Parwinder E. Grewal from Ohio State University to identify the possibilities of cities becoming self-reliant in food. The city of Cleveland was used as a case example and three different scenarios were investigated:

- a. Utilizing 80% of every vacant lot in the area for food production
- b. Utilizing 80% of every vacant lot and 9% of every occupied residential lot for food production
- c. Utilizing 80% of every vacant lot, 9% of every occupied residential lot and 62% of every industrial and commercial building's rooftop in the area for food production

The scenarios were selected based on current policies, laws, area availability, human demands in food and possibilities for crop yields. (Grewal & Grewal, 2011)

Accordingly, for the design proposal in Philadelphia, a scenario should be selected

to identify the viability of growing food in the area. The possible areas for food production in the selected neighborhood are:

1. Vacant lots
2. Backyards of residential buildings
3. Alleys and blocks' interiors
4. Industrial rooftops
5. Commercial rooftops
6. Facades

As a scenario which would utilize 100% of all the above spaces would not be realistic in any case. For this proposal, the third scenario from the Grewal & Grewal research study was loosely followed. However, alleys and the interior spaces of the blocks will not be included in this study. Alleys could provide really good spatial opportunities to create green community spaces, however as they can have limited sunlight availability, it has been decided to exclude them from the study. Due to limited information on the façade areas of the neighborhood, as an option for food production. Finally, the residential lots in the area lack front and backyards. They are tightly placed next to each other with limited free space that could be utilized for food production. [INSERT THE PHOTO WITH THE STREET VIEW] Consequently, the 9% of the residential lots taken into consideration in the study of Cleveland is not considered for the Philadelphia study. Based on the above conditions, the following scenario is considered for food production in the proposal:

- a. 80% of every vacant lot
- b. 62% of every industrial and commercial rooftop

Vacant lots:

The vacant lots in the area are calculated and the total area is 26 acres (1,133,332 square feet). The assumption for the Philadelphia would be that food is grown on 80% of this land; hence a total of 20.8 acres are used for food production. A big undeveloped parcel of 6.5 acres is found in the neighborhood and will be used to create the "Fresh Park", where trees and ornamental plants will be combined with food production. The remaining 14.8 acres of food producing areas will be scattered among the vacant lots in the neighborhood.

The selected case study to be applied in the vacant lots is Added Value Farm. It is estimated that 62.5 tons of fresh fruits and vegetables can be produced in the area. Moreover, 0.2 acres of the park will be used for an orchard, similar to the one in Oberlin (64 trees) with apple and pear trees, and can produce 1.2 tons of fruits. **In total the fresh produce would reach 63.7 tons.**

Industrial and commercial rooftops:

The total area of Industrial rooftops is 8.9 acres (389,154 square feet) and the area of Commercial rooftops is 4.9 acres (212,562 square feet). The use of 62% of all commercial and industrial rooftops leads to 8.5 acres of rooftop used for food production.

Based on the rooftops available, 6 could accommodate a greenhouse as big as Gotham Greens. That would take up 75,240 square feet (1.73 acres) out of the 8.5 acres available for rooftop farming. The remaining 6.77 acres of rooftop, both for economic reasons and space limitations, will be implemented with geponic system similar to the one at Brooklyn Grange.

Using these strategies, the fresh produce from the greenhouses will be 240 tons and 56 tons from the geponic rooftops. **In total 296 tons of fresh fruits and vegetables will be produced per year, only from rooftops.**

Food production from the rooftops and vacant lots could produce 359.2 tons of fresh fruits and vegetables per year. **That could satisfy the annual needs for fruits and vegetables of 1091 people, which is 50% of the residents of the neighborhood.**

- **Stormwater management**

Based on the book of Site Engineering for Landscape Architects by Strom & Natham, there are two methods of calculating the runoff water volume generated in a certain area; the Rational Method and the Modified Rational Method. (Strom & Nathan, 1998) Based on these methods the runoff volume is calculated in relation to the catchment area, the dimensionless coefficient of each type of surface (green roof, asphalt, soil etc.) and the rainfall intensity (iph). The rainfall intensity depends on the storm frequency and the rainfall intensity of the area as well as the size of the drainage area. As the development is 142 acres and contains a lot of different types of surfaces, the process of calculating the runoff volume and rate would require breaking the area into smaller parts, and processing the calculations for each one of them. That would require a detailed and tedious process, which is not part of a preliminary study. Henceforth, calculations like this are not part of the toolkit, whose purpose is to assist an schematic design based on fast estimations. That is why the stormwater calculations were not realized for Philadelphia.

- **Wastewater treatment**

As mentioned above, the neighborhood has 2171 residents and 951 households. (USDA, 2012a) In order to calculate the wastewater produced per day and select the proper system, only the wastewater from permanent residents is calculated and not of visitors or



Figure 1-81 Industrial and Commercial Rooftops in the neighborhood

Figure 1-82 Vacant lots in the neighborhood



- industrial+commercial rooftops
- parking lots
- green spaces
- vacant lots
- buildings

0 100 500

people who work in the area. The calculations for the wastewater are realized based on the Residential Default Fixture Uses of “Green Buildings Operation and Maintenance” (US Green Building Council, 2012) with 1.6 gallons per flushing. Based on those assumptions the residents of the area use the following amount of water:

- $2171 \text{ residents} \times 5 \text{ flushes per day} \times 1.6 \text{ gallons} = 17,368 \text{ gal/day}$
- $2171 \text{ residents} \times 1 \text{ shower per day} \times 8 \text{ minutes} \times 2.5 \text{ gpm} = 43,420 \text{ gal/day}$
- $2171 \text{ residents} \times 5 \text{ faucet uses} \times 1 \text{ minute} \times 2.2 \text{ gpm} = 23,881 \text{ gal/day}$
- $951 \text{ households} \times 4 \text{ uses of sink} \times 1 \text{ minute} \times 2.2 \text{ gpm} = 8,369 \text{ gal/day}$

The total amount of blackwater (toilets) generated per day is 17,368 gallons and the total amount of greywater per day is 75,940 gallons. **That adds up to 93,308 gallons of wastewater per day.**

Based on this calculations, a Membrane Bio-reactor is the best strategy, similar to the Dockside Green case study, which manages to treat 100% of the wastewater generated on site.

- **Organic waste generation**

Based on a study by the Department of Agriculture, in 1995, out of the 178 million tons of food produced 48.2 million ended up in the trash. (Martin, 2008) That equals to 1 pound of food waste per person per day. Based on these facts the annual food waste produced by the residents in selected area would be **396.2 tons.**

The information about the residential Energy Use Intensity (EUI) was acquired from a report produced at Carnegie Mellon University for Multi-Family Buildings after 1960, based on Residential Energy Consumption Survey data (REC S). According to the report, the gas EUI for Northeast Multifamily housing units is 44 MBtus/sqft and the electricity EUI is 28 MBtus/sqft. (Cosgro, Pan, & Reddy, 2012) The average square footage of a multifamily housing unit is 2,086 sq ft. (US EIA, 2009) Based on the above information, the annual residential energy demand for the neighborhood was calculated to be 55,546 MMBtu for gas and 87,287 MMBtu for electricity.

If an anaerobic digester is installed in the neighborhood like the one from The Plant case study, it will be possible to treat the residential food waste of 12 neighborhoods of the same size. The efficiency assumed for the digester is 400 m³ of biogas per 1 ton of waste because the feedstock used is of high quality (food waste). (Electrigaz, 2012) Based on the fact that each cubic meter of biogas has 10 kWh of calorific energy, the produced gas from **the digester will cover 7% of the total residential gas demand of the neighborhood.** (US DOE, 2011)

** The calculations for all the above numbers for food production, wastewater, organic waste production and energy production can be found in the Appendix (pg. 114-117)*

5.3.3 Design and estimated benefits

The estimated quantitative benefits from the design actions based on the above calculations are presented thoroughly in the following table:

	FOOD PRODUCTION Based on the above design solutions it is possible to supply 50% of the residents' needs for fresh fruits and vegetables (1085 residents)
	WASTEWATER RECLAIMED With the implementation of the Membrane Bio-Reactor 100% of the residential wastewater produced gets treated on site
	ORGANIC WASTE TREATED The neighborhood will host the anaerobic digester which will treat the residential food waste of 12 neighborhoods of the same size
	ENERGY GENERATED The anaerobic digester produces annually 5,860 MMBtus of gas which satisfies 7% of the neighborhood's gas demand (66.5 Housing Units)
	STORMWATER Through the proof of concept in Philadelphia it was realized the limitation of the toolkit to address the detailed runoff volume calculations in such a large area.

Figure 1-83 Table with Quantitative benefits of the design actions

From the table above it is obvious there are great opportunities in incorporating decentralized food production, waste treatment and energy production systems in the urban context. The benefits of such actions however lay beyond numbers. Such systems can affect significantly many other aspects of the community; they can provide education, create job opportunities, make the community walkable etc. The quantitative benefits are presented in the next table:

EDUCATION
• Workshops and educational programs are organized in the local farms for students • Informational Center of the digester brings 'human waste to human scale' • Residents are learning how organic waste is digested and how energy is being produced
JOB OPPORTUNITIES
Creation of job opportunities and support of local economy through on site farms and food processing businesses
COMMUNITY
• Creation of green spaces with activities that can bring the community together. • Development realized in phases can regenerate the neighborhood
REDUCING MILES TRAVELLED
Food is becoming accessible in the neighborhood reducing the miles travelled. Moreover the local food production industry can supply other areas of Philadelphia without travelling great distances, as they are within a 5 miles radius
WASTE DIVERSION
Every year 5,000 tons of organic waste is diverted from landfills and about 70,629,334 ft³ of methane is being captured instead of emitted in the air

Figure 1-84 Table with Qualitative benefits of the design actions

MAP WITH DESIGN ACTIONS AND PERSPECTIVE VIEWS OF THE PROPOSALS

vacant lots based on the
Added Value case study

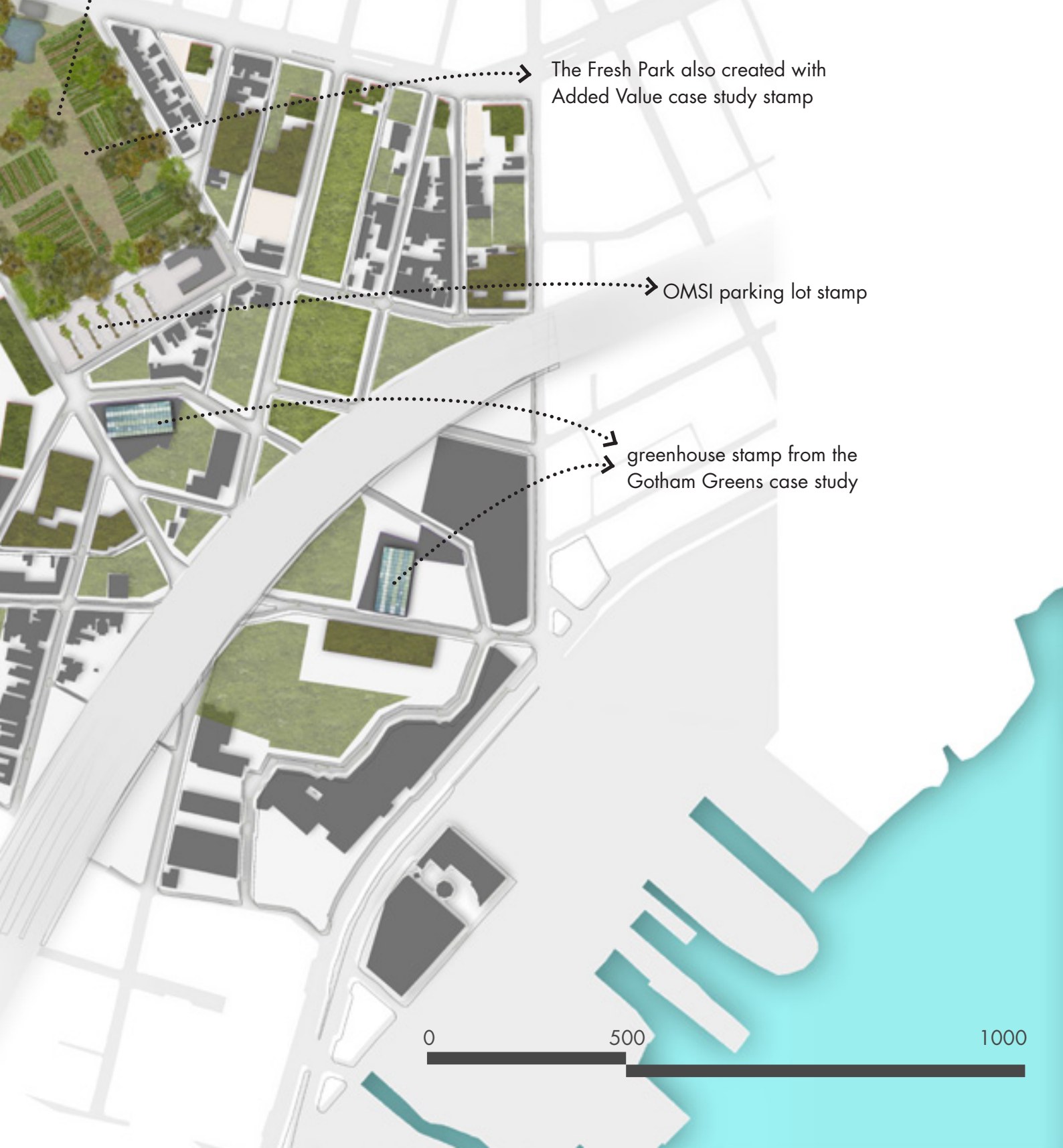
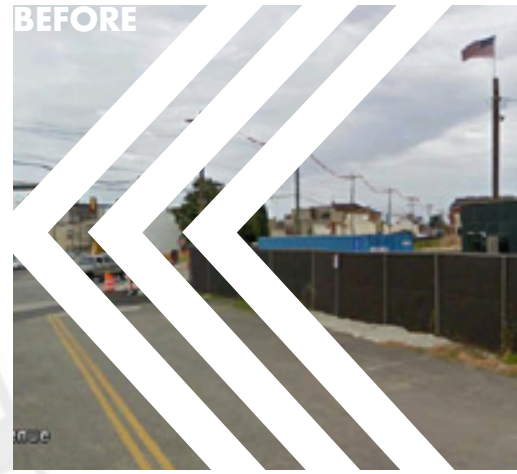
rooftop urban
agriculture based on
the Brooklyn Grange
case study

anaerobic digester stamp
from The Plant case study

BEFORE AFTER



1



The Fresh Park also created with
Added Value case study stamp

OMSI parking lot stamp

greenhouse stamp from the
Gotham Greens case study

0

500

1000

5.4 LIMITATIONS

Through the design exercise in Philadelphia, the toolkit was of great assistance to recreate the systems on the project's plans and estimate the yields of the benefits. It should be stressed though, that the toolkit is not meant to be used for detailed and analytical study. The stamps are a way of initially testing if the spatial constraints allow for such systems to be included in the preliminary study, and if they can, what are their benefits and added value. It should be clear that further study and design research should be done in order to integrate the various systems and apply them to an overall design. The hope is that this toolkit will be a tool for architects, urban designers and planners to incorporate food, water, waste and power generation infrastructures in their projects. It can also be used as an educational tool within architecture schools by introducing students to green infrastructure in an easy-to-understand format.

Through the Philadelphia example, it was identified that the stormwater calculations require a more detailed process and could not be calculated easily with the use of the toolkit. Further research should be realized in order to properly include the stormwater calculation in the toolkit.

5.4.1 Limitations - Policy Support

The toolkit promotes the merge of several infrastructures that serve the city and traditionally are placed out of the city into the urban context. It can provide information on how this merge can be realized based on certain current examples. However, it should be taken into consideration that such practices are not applicable easily everywhere. In order to realize such forward thinking projects, the support from policies and regulations is indispensable.

A live example of that is the city of Portland. The Portland Bureau of Environmental Services has supported the stormwater practices throughout the city. Moreover, it has created a detailed Stormwater Management Manual with practices, details, forms, submittal guides, calculators and city codes to assist the industry embrace those kinds of systems. (Portland Bureau of Environmental Services, 2012) The Appendix A1, A2 and A3 present to the users the city code, policies and drainage rules. It is clear that without the support from the city's policy, Portland would not have the image that has today.

That applies to all of the systems presented above. Health risk regulations can prevent the supply of locally grown produce to be distributed. Regulations might also prevent an anaerobic digester to be built in a close distance from an urban area. City and State policy can help promote the implementation of such practices, otherwise the idea of urban regenerative environments will stay mere imagination.

5.5 FUTURE WORK

From this study, three main areas of future work were identified. First, as mentioned earlier, easy-to-use stormwater calculations should be integrated. An automated stormwater calculation applet within the toolkit can assist runoff volume calculations, to lead the user to the appropriate design solution and system.

The second part of future work is to transform the toolkit to an online database, which is always kept up to date with current projects. Current practices and case studies should be available to everyone who looks for information about green urban infrastructures. As the database start to grow, one more classification should be added to the case studies: the date. As technology advances the user should be able to identify the case studies chronologically and select systems from the most current projects. Apart from the main classifications, more detailed tags on the case studies, will lead the user to the appropriate system through a search engine tool. For example a case study of hydroponic towers will be classified under the system of “food production” but will carry also the tag of “hydroponics”. An example of a similar database used mostly by urban designers is “Holistic City”. (Holistic City, 2012) Holistic City is a database of Housing Projects, Public Spaces and Streets filed based on their main features; shape, size, location etc. Holistic City is mostly a morphological database. The proposed Database for Urban Regenerative Environments will provide all the information and details found on the current toolkit along with the option to download the digital drawings of the system for each project.

Finally, the database should include the financial factor. The following financial and economic data should be included for each case study and system:

- Initial Cost of Investment
- Return of Investment/Payback
- Manufacturers or retailers
- Benefits of systems integration

The financial and economic information will be useful throughout the design process, extending beyond the preliminary phase. The financial analysis will assist the design team in promoting those ideas and making an economic statement to the client.

6. APPENDIX [FOOD, WASTE, WASTEWATER AND ENERGY CALCULATIONS]

FOOD

Annual need of fresh fruits + vegetables per person: 0.33 tons¹

Residents	Annual Need/person (tons)	Total Needs of Neighborhood For Fruits+Vegetables (tons)
2171	0.33	716.43

Spaces of Implementation of Food Production Systems²:

A. 80% of vacant lot in the neighborhood = 20.8 acres

B. 62% of industrial and commercial rooftops in the neighborhood = 8.5 acres

Case Study	Produce/area (tons/acre)	Area (acres)	System's Produce (tons)	Total Produce (tons)
Added Value	3.0	20.8	62.4	
Gotham Greens	148.1	1.6	240.0	
Brooklyn Grange	8.2	6.9	56.7	359.1

Based on the above it is possible to supply 50% of the residents' needs for fresh fruits and vegetables (1085 people)

WASTEWATER

Daily residential wastewater production¹
(Based on default fixture uses)

Source	Times per day	Duration (min)	Gallons per min / flush	Residents	Total Daily (gal)	Total Annual (gal)
Toilets	5	-	2	2,171	17,368	6,339,320
Bathroom sinks	5	1	2	2,171	23,881	8,716,565
Showers	1	8	3	2,171	43,420	15,848,300
	Times per day	Duration (min)	Gallons per min / flush	Housing Units		
Kitchen sinks	4	1	2	951	8,369	3,054,612
					93,038	33,958,797

Wastewater treatment based on different systems²:

A. 80% of vacant lot in the neighborhood = 20.8 acres

B. 62% of industrial and commercial rooftops in the neighborhood = 8.5 acres

Case Study	Gallons treated/day	Gallons treated/year	Percentage of residential wastewater treated (%)
Omega Center	52,000	18,980,000	56%
Dockside MBR	100,385	36,640,525	108%

The selected system is that of a Membrane Bioreactor like the one in Dockside Green and will be treating 100% of the residential wastewater³

Sources

1. http://visualeconomics.creditloan.com/food-consumption-in-america_2010-07-12/

2. Assumption of percentages based on this research paper: www.sciencedirect.com/science/article/pii/S0264275111000692

Sources/Notes/Assumptions

1. <http://www.usgbc.org/ShowFile.aspx?DocumentID=6493>

2. Efficiencies taken from the different case studies

3. There are commercial uses and office buildings in the area, so the 8% excess in capacity is going to be met

6. APPENDIX [FOOD, WASTE, WASTEWATER AND ENERGY CALCULATIONS]

FOOD WASTE

Daily residential food waste production ¹
(Based on default value of 1 daily pound of waste per person)

Residents	Daily Food Waste/ person (tons)	Annual Food Waste/person (tons)	Total Annual Food Waste of Neighborhood (tons)
2,171	0.0005	0.183	396.2

Waste input to Anaerobic Digester ²

System / Case Study	Organic Input Substrate Sources ³	Annual System Feedstock (tons)
The Plant: Anaerobic Digester by EISENMANN	Agriculture, Food Processing Facilities, Restaurant waste, Yard waste and grass clippings, Residential food waste	5,000.0

Percentage of Neighborhood's food waste treated (%) : 1262

That means that the neighborhood will host a facility that will treat the food waste of 10-13 neighborhoods of the same size (≈2,000 residents)

ENERGY FROM WASTE

Annual Energy Demand of the 951 Housing Units of the Neighborhood by End Use ⁴

End Use	Annual EUI (Mbtus/sqft)	Res Floor Area (sq ft)	Annual Energy Consumption/Housing Unit (Mbtu)	Housing Units	Total Annual Residential Energy Consumption of Neighborhood (MMbtu)
Electricity	28.0	2,086	58,408	951	55,546
Gas	44	2,086	91,784	951	87,287
Total	72.0	2,086	150,192	951	142,833

Efficiency of the digester: 400 m³ of biogas produced by 1 ton of waste ⁵
1 m³ of biogas contains 10 kWh of calorific energy ⁶
Plant's efficiency of burning biogas to electricity: 29% ³

Scenario of End Use ⁷	Input/ Annual Tons of Waste	Annual m ³ of biogas produced	Annual Biogas Produced (MWh)	Annual Electricity Produced (MWh) [29% efficiency]	Energy in MMbtus	Percentage of residential Gas needs met (%)	Percentage of residential Electricity needs met (%)
Biogas	5,000.0	2,000,000	20,000		5859.9	7	
Electricity				5,800	1699.4		3

It is possible to satisfy 7% of the neighborhood's needs for Gas. That means satisfy the needs of 66.5 Housing Units.

Sources/Notes/Assumptions

1. http://www.nytimes.com/2008/05/18/weekinreview/18martin.html?_r=4&oref=slogin&pagewanted=all

2. Waste Input needed taken from the case study: The Plant

3. <http://www.slideshare.net/eisenmannusa/sustainability-in-an-urban-environment-through-anaerobic-digestion-12974307>

Sources/Notes/Assumptions

4. Source for EUIs: "Multi-Family Buildings After 1960", Tom Cosgro, Hongfu Pan, Nivedita Papi Reddy, Carnegie Mellon University

Source for average size of Single Family Attached Housing Unit: <http://www.eia.gov/emeu/recs/sqft-measure.html> (Average between 1993+2001: 2,086 sq ft)

5. Digesters can yield between 20 m³ to 800 m³ of biogas from 1 ton of waste. Here due to the high levels of food waste, which are a higher energy feedstock, a 400m³/ton efficiency is assumed. (Source: http://www.electrigaz.com/faq_en.htm)

6. http://www.energysavers.gov/your_workplace/farms_ranches/index.cfm/mytopic=30003

7. It is an either or scenario. In case biogas is used directly or in case all of it is burnt to produce electricity

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