FORDHAMOPOLIS 6.0

Revolutionizing the Built Environment

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Ecology for Designers

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With the guidance and support of Dr. Dickson Despommier

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INTRODUCTION

Purpose

The following city, referred to as Fordhamopolis, aims to provide an opportunity for more sustainable living. Located in the Pacific Northwest of the United States, it tackles multiple environmental crises that especially dominate the industrialized world. Specifically, in the following pages of this design report, Fordhamopolis will break down (1) food production, (2) rainwater harvesting, (3) passive energy capture, and (4) carbon sequestration. While these four pillars are addressed individually, they ultimately function as intertwined systems to best replicate natural ecological relationships and to maximize the city's efficiency.

Fordhamopolis consists of approximately 100,000 residents. Within the city there are 10,000 buildings, 60% of which will be allotted as residencies while the other 40% will be set aside for commercial use, such as for office buildings, entertainment, hospitals, schools, etc. The goal of Fordhamopolis is to revolutionize the built environment by learning from the teachings of nature. Urban areas are typically seen as separate from the natural world, but the mission of Fordhamopolis is to prove that by interweaving the built environment and its processes into the greater fabric of the earth, cities become stronger, safer, and more sustainable.

Instead of further dividing the natural environment from our living spaces, Fordhamopolis strives to cultivate a sense of appreciation for the methods of sustainability and ecological balance that the natural world has already mastered. This is ultimately important as a little more than half of the world's population lives in urban areas, and more will continue to do so over time.[1] The four pillars previously mentioned allow for a holistic approach to the issues that have been to be of greatest threat to urban health, with issues ranging from poor waste management to inefficient transport systems and infectious disease clouding livelihoods.[2] Through each of these lenses, a city design that emphasizes regeneration and collaboration has been constructed. In sum, Fordhamopolis will not only challenge structural and systemic norms of traditional cities but will also foster stronger, more connected and considerate communities that look after one another in the face of climate change and increasing environmental insecurity.

FOOD PRODUCTION

Pitfalls of Traditional Agriculture

Food - one of our most basic necessities - has become a dominating force in our daily lives in ways that we could have never imagined thousands of years ago. In the industrialized world food is commodified, processed, and regulated; food is a product to be advertised and dominated. From the vegetables we buy at the grocery store to the coffees we pick-up on our way to work, what we eat has been globalized and disconnected from its origins. Such a decontextualization has resulted in a failure to recognize the ways that the food we eat impacts communities and livelihoods outside of our own. Furthermore, convenience and efficiency provide a smokescreen for the ways that land and people are displaced for industrial agriculture, employees are poorly treated for their factory farmwork, and small farmers are left behind in this race towards productivity. Therefore, the rapid pace that industrial food production systems have

[1] "Urban Health." *World Health Organization,* https://www.who.int/health-topics/urban-health. Accessed 14 May 2021.
[2] "Urban Health."

acquired as a direct aspect of commodification has simultaneously resulted in a level of consumption that is threatening the stability of our natural environments.[3] With that said, when we consider what it means to live sustainably it is a question that cannot be answered fully unless changes to our current methods of food production are taken into account.

Firstly, while it is important to look at the methods by which we produce food, it is equally necessary to understand the implications that our current agricultural practices have on the people who consume it. “Food deserts” – defined as “areas with low availability or high prices of healthy foods” – remain an issue in the United States.[4] Allcott et al. state that there are two basic facts which provide the backdrop for discussions regarding “food deserts”, one of which goes as follows: “Low-income neighborhoods have more drug and convenience stores and fewer large supermarkets, which offer a wider variety of healthy options,”.[5] With healthy options inconveniently located, low-income communities face a significant public health issue as they are left in a physical state of displacement, limited in their access to basic needs, and compounded by the potential for worsening health and increased inability to afford fresher, more nutritious foods.

That being said, distance is an important factor of food production. With little-to-no farming within urban areas, the transportation of produce from farms outside of the area contributes to carbon emissions within the atmosphere.[6] Another notable contributor to air pollution on the planet is the production of livestock such as cows and pigs. Particularly, past

[3] Cafaro, Philip J., et al. “THE FAT OF THE LAND: LINKING AMERICAN FOOD OVERCONSUMPTION, OBESITY, AND BIODIVERSITY LOSS.” *Journal of Agricultural and Environmental Ethics,* vol. 19, 2006, pp. 541-561. DOI 10.1007/s10806-006-9008-7.
[4] Allcott, Hunt, et al. “Food Deserts and the Causes of Nutritional Inequality.” *Quarterly Journal of Economics*, vol. 134, no. 4, 2019, pp. 1793-1844, doi:10.1093/qje/qjz015.
[5] Allcott, Hunt, et al. pp. 1796.
[6] Despommier, Dr. Dickson. *The Vertical Farm.* Kindle ed., New York, Thomas Dunne Books, 2011.

studies have identified the agricultural sector as directly contributing nearly one-fourth of all atmospheric greenhouse gas emissions.[7] Ayyildiz & Erdal further pinpoint animal production as a catalyst for these emissions across all of the varied income-groups of countries analyzed within their study. This effect was especially attributed to poor pasture management and animal feeding.[8]

Finally, the large amounts of food which are produced often end up going to waste without the proper management protocols that would allow the recycling of organic material and/or the regulation of potential pathogens. Especially in urban areas such as New York City, these problems have yet to be adequately resolved.[9] While it is reasonable to state that as a species, humans have merely adapted to their environment and have taken advantage of their resources, it is unreasonable to believe that these methods cannot change once more and to the benefit of all living organisms.

Looking Ahead

The solutions that are provided in this section of Fordhamopolis can be briefly summarized as follows: the replacement of current industrial livestock production with the use of community farming, an emphasis on vertically farmed aeroponic and hydroponic systems, as well as the use of community pantries and kitchens in combination with compost facilities to minimize waste. As will be discussed, the use of community farming aims to recognize the existence of current ethical modes of livestock production and provide job opportunities to smallholders and local farmers, consequently decreasing the reliance on large-scale unsustainable

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[7] Ayyildiz, Merve. & Erdal, Gulistan. "The relationship between carbon dioxide emission and crop and livestock production indexes: a dynamic common correlated effects approach." *Environmental Science and Pollution Research,* vol. 28, 2021, pp. 597-610, doi:10.1007/s11356-020-10409-8.
[8] Ayyildiz, Merve. & Erdal, Gulistan. pp. 607
[9] Despommier, Dr. Dickson.

production industries such as that of poultry within the United States. This method of adapting current livestock farming hopes to acknowledge that not all individuals are willing to commit to a purely plant-based lifestyle, whether that be for cultural reasons, health-related reasons, etc. The added use of aeroponic and hydroponic systems aims to decrease the amount of water that is utilized relative to traditional soil-based farms, while also making healthy and nutritious foods more accessible to urban communities. An added result of this design is the decrease in land used for agricultural purposes, which would help restore the natural landscape. Waste will be addressed through community pantries/kitchens and compost facilities, in total, creating a "fresh" food culture that is more inclusive and collectivist at its core.

Endo-City Production: Aeroponics, Hydroponics, and Central Grocers

Figure 1. Scissortail Farms in Tulsa, Oklahoma.[10] Inspiration for rooftop gardens and farms.

[10] "Greenhouse Farms: Scissortail Farms." *Tower Farms*, The Juice Plus+ Company, 2021, https://www.towerfarms.com/us/en/possibilities/greenhouse-farming/scissortail-farms. Accessed 12 May 2021.

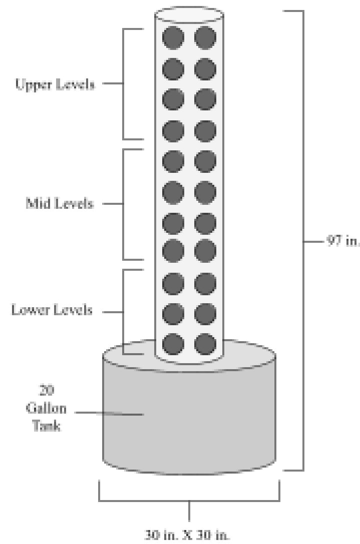

Figure 2. Typical Tower Farm (Front View) as described by The Juice Plus+ Company.[11] Google Draw diagram made by Franchesca Macalintal.

For food production, methods such as aeroponics, hydroponics, and aeroponic towers will be implemented (See *Figures 1 & 2*). The benefits of these systems are that they have longer surging rates, plants receive all the oxygen and carbon dioxide needed, and use 70-95% less water than regular soil-based farming.[12]Aeroponic systems especially have been found to be the efficient system in terms of plant growth and production in comparison to other types of hydroponic cultivation[13], and this is a reason as to why aeroponic systems were chosen as one of our main food production sources.

Its technology is not complicated and is easy to control. As stated by Despommier in *The Vertical Farm*, the nozzle beneath the plants spray a nutrient solution mist onto the roots, using 70% less water than hydroponics when in a closed-loop system[14]. Currently, aeroponic systems

[11] "Have a vertical farming question?." *Tower Farms*, The Juice Plus+ Company, 2021, https://www.towerfarms.com/us/en/faq. Accessed 12 May 2021.
[12] Despommier, Dr. Dickson. *The Vertical Farm.* Kindle ed., New York, Thomas Dunne Books, 2011.
[13] Eldridge, Bethany M. et. al. "Getting to the roots of aeroponic indoor farming." *New Phytologist Foundation,* vol. 228, no. 4, 2020, pp.1183-1192, doi:10.1111/nph.16780.
[14] Despommier, Dr. Dickson.

have been made using plastic, treating any toxic phthalates that might contaminate the nutrient solution.[15] Overall, they are easy to manage and control. Their building, structure and material are not difficult or heavy, allowing easier rearrangement of the systems themselves. They will be placed at the upper levels of the buildings, allowing for easy access, also in coordination with the rooftop gardens and farms. Additionally, the tower vertical farm design allows for more efficient use of space and optimal crop production, which are both important factors for supplying food for a densely populated urban area. While an issue that might arise is not only the contamination from the plastics, but that of parasites and the like, this is easily handled by the use of indoor farming only, within the building and within the greenhouses where the environment can be more easily controlled. The design and layout of the towers will be discussed in detail later in this section.

These systems will focus on growing microgreens, fruits, vegetables, leafy greens, herbs, and rooting crops. Some of these include strawberries, tomatoes, lettuce, potatoes, cherry tomatoes, squash, bell peppers, and kale.[16] With aeroponic and hydroponic indoor farming, crops like strawberries which are meant to be grown seasonally will now be grown more frequently throughout the year, and in general, the crops would produce higher yields.[17] One indoor acre is equivalent to that of 4-6 outdoor acres or more, depending on the crop. For strawberries specifically, one indoor acre is equivalent to 30 outdoor acres.[18] In an efficient vertical farm setting, one acre of a hydroponic system has an ecological footprint that is ten to twenty times

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[15] Despommier, Dr. Dickson. *The Vertical Farm.* Kindle ed., New York, Thomas Dunne Books, 2011.
[16] Eldridge, Bethany M. et. al. "Getting to the roots of aeroponic indoor farming." *New Phytologist Foundation,* vol. 228, no. 4, 2020, pp.1183-1192, doi:10.1111/nph.16780.
[17] "What can you grow in aeroponics?" *LettUs Grow,* LettUs Grow Ltd, 2015-2021, https://www.lettusgrow.com/blog/what-can-you-grow-in-aeroponics. Accessed 12 May 2021.
[18] Despommier, Dickson D. & Ellingsen, Eric. "The Vertical Farm: The sky-scraper as vehicle for a sustainable urban culture." *CTBUH 2008, 8th World Congress,* 2008, pp. 1-8, https://www.researchgate.net/publication/241325575_The_Vertical_Farm_The_sky-scraper_as_vehicle_for_a_sustainable_urban_agriculture.

less than that of a soil-based acre depending on the crop.[19] Overall, it can be said that with vertical farming, especially in aeroponics, less is more.

The other system that we would use is hydroponics, more specifically continuous-flow solution culture. This particular system has the roots of the crops submerged in tanks filled with nutrient solutions, allowing crops to have direct contact with the needed nutrients while getting enough oxygen to optimize plant growth. Its temperature and nutrient concentrations are easy to manage and regulate especially in larger tanks. Within these larger tanks, the plants can be separated, allowing for more growth space and availability of the inclusion of multiple plants.

One of the most efficient designs is the Nutrient Film Technique (NFT) with a circulating irrigation system and a tank that serves like a channel. The NFT system is highly dependent on finding and maintaining the right channel slope, the right flow rate, and the right channel length. In this design, the processor will act as the brain of the control system which will be connected to the power supply unit. The processor will be triggered by the temperature sensor, pH sensor, light-dependent resistor sensor, water level sensor, and electrical conductivity sensor. In other words, all these will help the processor detect temperature, detect the pH of the nutrition liquid in the tank, detect sunshine intensity, detect surface level in the tank and water pipe, and detect the electrical conductivity of the nutrition liquid in the pipe respectively.[20]

The channel pipe is designed to be slightly tilted in order for the nutrient solution to flow past the roots with gravitational force. Usually it is recommended to use channels with a 1:30 or 1:40 ratio slope. Flow rates should be one liter per minute, maximum flow rate could be two

[19] Despommier, Dr. Dickson.
[20] Saputro, Joko S. et al. “Design of Nutrition Automation on Lactuca Sativa NFT Hydroponic Systems.” *Journal of Electrical Electronic Information and Communication Technology*, vol. 2, no. 1, 2020, pp. 14-17, DOI:10.20961/jeeict.2.1.41353.

liters per minute. A flow rate higher or lower than suggested could produce nutritional problems. As for the length of the channels, they should not exceed twelve meters in length. A decline in growth has been noticed when the channels are longer than twelve meters. However, in rapidly growing crops, channels are recommended to be elongated, measuring between ten and fifteen meters. Due to the higher lengths, a decline in growth is possible. To avoid this, another nutrient feed could be placed halfway through the channel having flow rates of one liter per minute through each outlet. One of the biggest concerns with this system is its unsettledness, given that it is easily disturbed by power outages due to ponding or water logging. In slight contrast to the aeroponic system, managing this system with carefulness is important and a bit more tedious.[21] To better manage these hydroponic tanks, they will be situated in the lower levels of the building where supplies delivery and environmental control are more convenient. Overall, not limiting ourselves to one system will give our vertical farms more flexibility, and securing our crops in case of an emergency. Similarly to the aeroponics system, most of the crops grown would be grains, vegetables, fruits, leafy vegetables, condiments, and some medicinal plants.

As our secondary system, all other crops that cannot be grown in the aeroponics or that cannot be produced as efficiently will be grown in the hydroponic system. Some of the more popular crops that can be grown aeroponically can also be grown hydroponically, but in smaller quantities, just to have more yields on hand. For aeroponic grains, a dacron-based clothlike sheet will be used as proposed by Dr. Dickson Despommier, holding the seeds which will later be sprayed for germination.[22] Grains like rice, although they take longer to grow throughout the year, would grow efficiently under a hydroponic or aeroponic system, producing 600 times more

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[21] "Different Methods for Hydroponic Growing." *M&M Hydroponics & Garden Supply,* M&M Hydroponics & Garden Supply, 2016, http://www.mmhydro.com/different-methods-for-hydroponic-growing/.
[22] Despommier, Dr. Dickson. *The Vertical Farm.* Kindle ed., New York, Thomas Dunne Books, 2011.

than the current average global yield in soil-based farming.[23] Considering its importance in consumption and its recent involvement with hydroponic systems, this crop will be grown in both systems.

In accordance with the dietary guidelines for Americans 2020-2025, an average adult person is suggested to consume 2.5 cups of vegetables and 2 cups of fruits per day.[24] If 2.5 cups of vegetables are needed per day, in a 30 day span, a person should consume 75 cups of vegetables. 75 cups of vegetables per 100,000 people (population) would require a total of 7,500,000 vegetables in a month. A hydroponic tank using NFT produces about 150 plants, each plant having about 30 vegetables, meaning each tank will produce a total of 150 vegetables. When dividing the people's monthly consumption by the amount a single tank produces, you get that 50,000 tanks are needed. There are 6,000 residence buildings throughout the city, meaning that each building will require about 8-9 hydroponic tanks to suffice the people's daily vegetable consumption. These same guidelines by the USDA indicate that an average person is recommended to eat 2 cups of fruit per day. Using the same calculations, you will see that 7 hydroponic tanks dedicated to fruit crops would be needed per residential building.

Aeroponic towers will be placed in the rooftops of all residential and commercial buildings, as well as restaurants. These towers will focus on growing leaves, greens, herbs, and flowers. Hydroponic and aeroponic systems will be placed in all residential buildings, however, if any of the residents desire to have an aeroponic tower installed in their own apartment for personal use, they are more than welcomed to purchase one and to take care of it.

[23] Asseng, Senthold et al. "Wheat yield potential in controlled-environmental vertical farms." *PNAS,* vol. 117, no. 32, 2020, pp. 19131-19135, doi:10.1073/pnas.2002655117.
[24] U.S. Department of Agriculture and U.S. Department of Health and Human Services. "Dietary Guidelines for Americans: 2020-2025." *DietaryGuidelines.gov,* 9th ed., 2020, pp. 98, https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf.

Dietary guidelines for the 2020-2025 term as provided by the U.S. Department of Health and Human Services (HHS) and the United States Department of Agriculture (USDA) recommend that the average person – committing to a 2,000 calorie/day diet – should consume 2.5 cups of vegetables per day.[25] According to the Tower Farms website, a single tower which contains 44 plots for a plant produces approximately 6 oz. of leafy green vegetables per month.[26] The HHS and USDA guidelines also indicate that 2 cups of leafy green vegetables is equivalent to 1 cup of the recommended intake. With that information, the following calculations (See *Eq. 1* through *5*) were made to approximate the number of leafy green vegetables that would be potentially required by the farms to sustain the 100,000 person population's vegetable intake on a monthly basis:

Eq. 1 - Calculating the number of leafy green vegetables recommended for one person daily and monthly (approximation).

$$\left(\frac{2.5\ cups\ of\ vegetables}{1\ day}\right)\left(\frac{2\ cups\ of\ leafy\ greens}{1\ cup\ vegetables}\right) = 5\ cups\ of\ leafy\ greens/day$$

$$\frac{5\ cups\ leafy\ greens}{1\ day} * 30\ days = 150\ cups\ of\ leafy\ greens/month$$

Eq. 2 - Calculating the amount of leafy greens needed for the entire population per month, also defined as the city demand.

$$150\ cups\ of\ leafy\ greens/month\ *\ 100,000\ people\ =\ 15,000,000\ cups\ of\ leafy\ greens/month$$

Eq. 3 - Converting cups to dry weight ounces.

$$\left(\frac{15{,}000{,}000\ cups\ of\ leafy\ greens}{1\ month}\right)\left(\frac{8\ ounces\ of\ leafy\ greens}{1\ cup\ of\ leafy\ greens}\right) = 120,000,000\ ounces\ of\ leafy\ greens/month$$

Eq. 4 - Calculating the approximate number of towers needed to fulfill recommended vegetable

[25] U.S. Department of Agriculture and U.S. Department of Health and Human Services. "Dietary Guidelines for Americans: 2020-2025." *DietaryGuidelines.gov,* 9th ed., 2020, pp. 144-145, https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf.
[26] "Have a vertical farming question?." *Tower Farms*, The Juice Plus+ Company, 2021, https://www.towerfarms.com/us/en/faq. Accessed 12 May 2021.

intake per month for the entire population.

$$\left(\frac{6\ ounces\ of\ leafy\ greens}{1\ plant}\right)\left(\frac{44\ plants}{1\ tower}\right) = 264\ ounces\ of\ leafy\ greens/tower$$

$$120,000,000\ ounces\ of\ leafy\ greens/month\ \div 264\ ounces\ of\ leafy\ greens/tower = 454,545.5\ \approx 45$$

Eq. 5 - Determining the number of towers needed per residential building.

$$454,545\ towers\ \div 6,000\ residential\ buildings\ = 75.8\ towers/building\ \approx 75\ towers/building\ *$$

*Rounded down to the nearest whole to maximize rooftop space and account for plants produced by hydroponics systems, concurrently avoiding food waste given varied dietary requirements within a population.

Figure 3 shows a potential rooftop garden design, accounting for the 75 towers that would need to be placed on top. The towers are notably placed within a greenhouse as opposed to being uncovered. This decision was made for a couple of reasons. Firstly, including a cover allows the rainwater harvesting processes to be more efficient, as the aeroponics systems do not require overhead watering but are instead dependent on the water tanks at their base which must have a gallon of water added weekly. The water can easily trickle down the covers of the greenhouse into the rainwater harvesting system to then be distributed as is discussed in the next section. Secondly, adhering to a greenhouse system, although in some ways more complex and expensive, ensures that a controlled environment can be maintained year round as highlighted earlier, thus removing the limitations of relying on the climate outdoors for optimal growth and harvesting. In the top left corner of the diagram, one will find a Harvesting Center/Agricultural Education Facility. It is important that the residents of Fordhamopolis are able to access information on food production, its systems within the city, and how it is distributed. This is key to maintaining a sociopolitical environment that advocates for these processes and embeds them into Fordhamopolis's culture. Centers such as these not only would serve as locations for those cultivating the farms to conduct more the administrative work of harvesting, cleaning, and delivery, but also as open areas for residents to speak to those working with the produce and observe them, creating closer bonds between the community and the food that they consume.

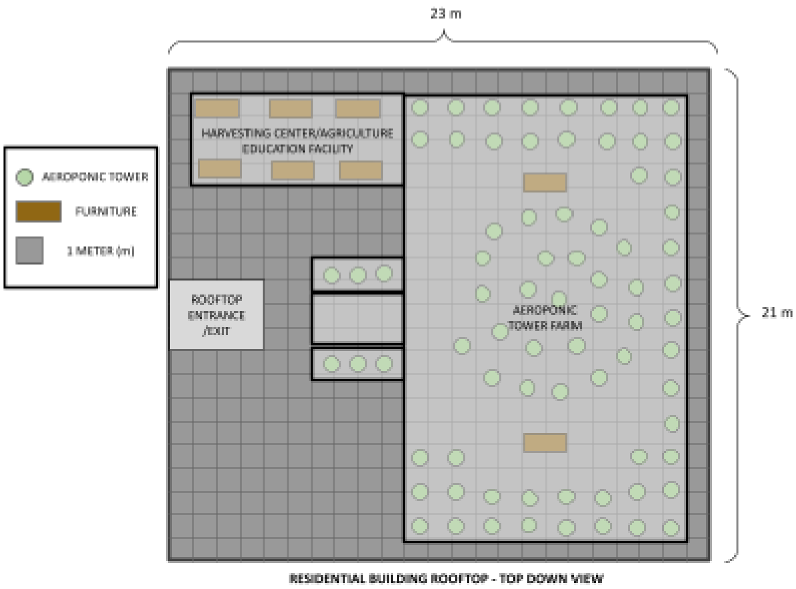

Figure 3. (Left) Diagram of residential building rooftop with aeroponic farm system using Tower Farm water tank base dimensions.[27] Created by Franchesca Macalintal using Google Draw.

The distribution of the produce grown will occur through central grocery stores located throughout the city. While each residential building will have its own indoor farm, both aeroponic or hydroponic, the varied crops and their yields will be made available to all residents of the city. In combination with there being a set price for all produce, this would eliminate the possibility of one grocery store selling more than the next one. This would also address any issues of unequal growth, ensuring that all available produce across the city is utilized as opposed to restricting individuals to their residential building's yields alone. Such restrictions would only hinder proper considerations of the diversity of diets and the varying daily caloric intake recommendations within the city's population. An extra detail of importance is that residents will be able to purchase their own tower farms, if they so choose, and install it in their individual residencies. This provides individuals the opportunity to develop a better

[27] "Have a vertical farming question?." *Tower Farms*, The Juice Plus+ Company, 2021, https://www.towerfarms.com/us/en/faq. Accessed 12 May 2021.

understanding of the agricultural practices while tailoring to their individual needs. It is understandable that this may not be a choice for everyone, which is why the standardization of the central grocery stores is a significant aspect of the distribution process.

All that being said, there are limitations to the structure of these rooftop vertical farms. Dr. Dickson Despommier's proposed design for a vertical farm includes that it is "modest in height, perhaps five stories tall, and maybe 1/8th of a city block in footprint."[28] This design proposal maximizes space and accounts for the space needed for a plant nursery, laboratory and control center. Within Fordhamopolis, however, the design above indicates that the aeroponic system specifically will stray from this design only slightly, still committing to the major themes that Despommier uses to characterize any vertical farm: "(1) capture sunlight and disperse it evenly among the crops, (2) capture passive energy for supplying a reliable source of electricity, (3) employ good barrier design for plant protection, and (4) maximize the amount of space devoted to growing crops."[29] As a rooftop farm, the crops will still capture sunlight, and given that the towers are cylindrical and can be easily moved, even distribution of light may be achieved through rotation of the towers throughout its growth or more practically, the use of reflective material on the floors or lower parts of the walls of the greenhouse to help reflect sunlight onto shaded plants. A less energy-efficient, more common alternative could be to install LED lights within the greenhouses that are divided in circuitry between the East and West sides of the building. This way, farmers could switch the grow lights on for whichever side of plants is shaded throughout the day.[30] To continue, the overhead greenhouse will provide a barrier, and the tower design would help maximize space. Less energy will be required to sustain the crops given

[28] Despommier, Dr. Dickson. *The Vertical Farm.* Kindle ed., New York, Thomas Dunne Books, 2011.
[29] Despommier, Dr. Dickson.
[30] Tunio, Mazhar H. et al. "Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security." *Chilean Journal of Agricultural Research,* vol. 80, no. 1, 2020, pp. 118-132, doi:10.4067/S0718-58392020000100118.

that grow lights would not be necessary for the entire duration of growth as natural sunlight will be provided.

Extra-City Production: Community Farming

While indoor farming will contribute to most of the food production within Fordhamopolis, we feel that it is necessary to understand that residents may not want to fully commit to a vegetarian or vegan diet, or at the very least will require a gradual transition to more plant-based foods. To resolve this, Fordhamopolis grocery stores will work in collaboration with nearby organic, ethical, local farms to supply all dairy products and lean meats. This specific relationship or process is known as community supported agriculture (CSA), wherein community members – in this case the city of Fordhamopolis as a singular body – purchases a share from a participating local farm of choice to receive a certain percentage of yields each season.[31] This accomplishes several tasks in addition to providing a source of meat and dairy products. To begin, by utilizing local farms who are committed to ethical and organic practices we can ensure that the food we are eating is fresh, free of any additives, and raised and harvested in ways that are respectful and mindful of both land and livestock. Farms such as Helios Farm, which is listed in the USDA's CSA Directory, prides itself on its soy-free eggs and meats, lack of agricultural or pharmaceutical chemicals, and what it identifies as "orthomolecular regenerative farming".[32] Specifically, Helios Farms states the following: "Our farm focuses on regenerating fertility of the land and preserving a balanced microbiome in the soil, plants, animals, and farm family,".[33] The farm goes even further to minimize as much waste as possible by delivering their dairy products

[31] The Alternative Farming Systems Information Center (AFSIC) Staff. "Community Supported Agriculture." *U.S. Department of Agriculture: National Agricultural Library,* May 2019, https://www.nal.usda.gov/afsic/community-supported-agriculture. Accessed 12 May 2021.
[32] "Helios Farms." *Helios Farms, LLC.,* 2020, https://www.heliosfarms.com. Accessed 12 May 2021.
[33] "Helios Farms."

and eggs in reusable jars and cartons that farm share owners are asked to return to be recycled and cleaned for future use.

Community farms are also beneficial because they support local farmers. It is important to recognize that there are many farmers who, like Helios Farm, have stronger understandings of their land and livestock and are thus able to implement more sustainable practices than what we have seen by major food industries in the past. Working with these farms through a farm-share program ensures their livelihoods while concurrently avoiding uprooting more land within Fordhamopolis to breed our own livestock. Additionally, given that the farms are local, this ensures that the goods are still relatively fresh. This small distance also helps make the farm-to-table relationship much tighter as residents are once again confronted more frequently with the origins of their foods and how they are acquired. Increased consciousness of these details would hopefully contribute to more mindful dietary habits, particularly ones rooted in greater collectivism and a decrease in excess consumption.

Waste Management: Community Pantries and Compost Facilities

One of our biggest concerns in our city is food waste, which when improperly managed, can lead to sanitation issues and the loss of reusable material. To address this issue, compost facilities will be placed within buildings and at community pantries and kitchens. The compost will later return to the land, potentially used for outdoor crops or recreational park development. People will be allowed to turn in any waste at no cost. Alongside this, a recycling system will also be implemented. There will be a differentiation of organics, inorganic, and plastic. Here, the plastics will be treated and recycled, trash will go hand in hand with inorganic waste, and there will be a section of organics to be able to get direct access to composts.

Community pantries and kitchens will be a;sp available throughout the city. At these small kiosk-like stations, people can drop off any food that is still okay to consume that they no longer wish to hold onto, and drop it off at no cost. Employees working these pantries will evaluate the produce and goods for quality and price them at a cost lower than the standard set price as these produce will be older and likely in smaller quantities. Through this process, if someone wants to pick up any food, they can purchase it at a discounted price. This will give people the option to drop off any food they would not be able to consume before it goes bad, costing them nothing, while still providing for the rest of the community. On the other hand, by not giving out the dropped-off food for free, we avoid members picking up food randomly or without regulation and potentially taking more than they need, essentially avoiding more food waste.

Community pantries are an excellent way to foster a “fresh” food culture that recognizes the needs of all the residents. It brings back the concept of accessibility, specifically to healthy and nutritious foods and aids in challenging the proliferation of food deserts and food inequality. Through community pantries, and in combination with central grocery stores and local farms, residents will be able to see firsthand how their consumption affects the livelihoods of others within Fordhamopolis. In sum, by making fresh food readily available while implementing waste management that can be observed and appreciated by the community throughout the “lifespan” of the produce, issues of displacement of goods from their origins and inclinations to over-consume will be subdued.

RAINWATER HARVESTING

The Current Water Crisis

Many of the world's current environmental crises revolve around water, a renewable yet limited resource. Although water covers 70% of our planet, only 3% of that is freshwater, and a mere fraction of that supply is available for immediate use. This is extremely concerning considering the ever-expanding global population, climate change-related weather pattern shifts, and inefficient water use that further increase the pressure placed on aquatic ecosystems. By 2025, over two thirds of the world's population will face water shortages that will no doubt produce significant economic, political, and environmental consequences[34]. The design of Fordhamopolis seeks to mitigate the burdens on this precious resource through sustainable water management which will not only benefit the local temperate rainforest ecosystem, but will also make the city resilient to climate change disasters and decrease the water supply demand on a global scale.

Receiving over 92 inches of rainwater per year, the coastal Pacific Northwest in which Fordhamopolis resides is not in immediate risk of severe water shortages[35]. However, even cities in freshwater-rich ecosystems contribute to water scarcity through the demand for fresh produce often sourced from regions such as the southwest US where agriculture uses large amounts of water, resulting in severe droughts and water system stress. Agriculture itself also contributes largely to water pollution in the form of toxic runoff created by a combination of poor soil management and nutrient-rich fertilizers and manure[36]. When soil is unable to adequately absorb these materials due to poor quality and erosion, rain causes them to flow into water systems. This process results in water contamination, algae blooms, and dead zones, which can significantly disrupt aquatic ecosystems and those who depend on them for sustenance. Through rainwater

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34 "Water Scarcity." *WWF*, World Wildlife Fund, www.worldwildlife.org/threats/water-scarcity.
35 "Vancouver Climate." *Data.org*, en.climate-data.org/north-america/canada/british-columbia/vancouver-963/.
36 Lindwall, Courtney. "Industrial Agricultural Pollution 101." *NRDC*, 5 Feb. 2020, www.nrdc.org/stories/industrial-agricultural-pollution-101.

harvesting, water recycling, and sourcing the majority of produce from local sources within the city, Fordhamopolis will lighten the demands on water systems on a national scale.

Solutions

Rainwater capturing will be incorporated as a central design feature throughout Fordhamopolis, which will allow the city to maintain self-sufficiency, reduce the burden on local water systems, and develop resilience to climate change. This method of water sourcing provides residents with a dependable source of water throughout the year that can be stored in underground cisterns and disinfected for later use[37]. Rainwater capturing also works to mitigate erosion and pollution around the city. Typically, rainwater collects trash and toxic substances as it runs off city surfaces such as streets and rooftops, and these pollutants end up in local aquatic ecosystems. This problem will be significantly reduced with the implementation of Fordhamopolis's innovative rainwater harvesting system.

The total annual amount of rainwater expected to be collected will provide for almost half of the city's yearly water demand. With an average surface area of 2,500 square feet and accounting for a 20% run-off coefficient, each of the 10,000 buildings in Fordhamopolis will collect an average of 111k gallons per year[38]. As a whole, the city can expect to collect about 1.1 billion gallons of rainwater per year, which will account for almost half of the annual water demand of 2.5 billion gallons based on the average 70 gallons per day water use of US citizens[39]. Additionally, the 2.5 billion gallons annual demand is expected to be significantly reduced

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[37] Kloss, Christopher. "Managing Wet Weather with Green Infrastructure." *EPA*, Dec. 2008, www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_harvesting.pdf.
[38] DTE Staff. "Catch Water Where It Falls: Urban Rainwater Harvesting." *Down To Earth*, 3 July 2018, www.downtoearth.org.in/news/water/catch-water-where-it-falls-urban-rainwater-harvesting-65422.
[39] Kloss, Christopher. "Managing Wet Weather with Green Infrastructure." *EPA*, Dec. 2008, www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_harvesting.pdf.

through the use of vertical farming, sustainable infrastructure, and water recycling within the city.

Figure 4. Diagram of a swale, which uses native plants and grasses to decrease flooding and erosion, stimulate proper drainage, and mimic a natural wetland to filter rainwater and runoff.[40]

Fordhamopolis's rainwater harvesting design will incorporate biomimicry as a central component in order to ensure longevity and minimize its impact on local ecosystems. The model will be based on Vancouver's "Green Rainwater Infrastructure", which mirrors natural processes to safely capture, store, and recycle water. It involves planting large quantities of native plants, trees, and soils to maximize the amount of green space available in the city. Green roofs, rain-friendly streets, swales, rain gardens, and parks allow the city to act as a natural wetland. These features actively improve air and water quality, sustainably manage rainwater, reduce flooding and pollution, and serve as a sanctuary for native wildlife[41]. In this design, rainwater

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[40] "Green Rainwater Infrastructure: Sustainably Managing Our Rainwater." *City of Vancouver*, vancouver.ca/home-property-development/green-infrastructure.aspx.
[41] "Green Rainwater Infrastructure: Sustainably Managing Our Rainwater."

will not only be captured by rooftop systems, but will also be stored in large green areas which will significantly reduce flooding and erosion after regular heavy rainstorms.

Water Recycling

Water recycling is another method that will be employed by Fordhamopolis to ensure that a safe, secure and reliable water supply is provided to the city. Fordhamopolis's wastewater will be treated and reused following existing global water recycling processes, such as Singapore's NEWater initiative[42]. NEWater consists of a process that purifies wastewater in three steps, including ultrafiltration/microfiltration, reverse osmosis and ultraviolet disinfection. The treated water is then placed into reservoirs rather than directly used, as this allows for an environmental buffer as well as an opportunity for microminerals to be reintroduced by contact with reservoir water. A similar wastewater treatment process will be utilized in Fordhamopolis to alleviate dependency on rainwater harvesting and storage as well as increase climate resiliency as wastewater is perpetually being recycled.

Alternative Applications of Rainwater Harvesting and Redirection

While the potential of standalone buildings to harvest rainwater is considerable, there are many other avenues for rainwater capture throughout the city. Climate Tiles, permeable pavement, and methods of fog collection are among the potential methods for additional water redirection, capture or storage. Permeable pavement is a porous surface made up of open pore pavers, concrete, or asphalt with an underlying stone reservoir. Permeable pavement catches precipitation and surface runoff, storing it in the reservoir while slowly allowing it to infiltrate

[42] Lee, Hannah, and Thai Pin Tan. "Singapore's Experience with Reclaimed Water: NEWater." *International Journal of Water Resources Development*, vol. 32, no. 4, 2016, pp. 611–621., doi:10.1080/07900627.2015.1120188.

into the soil below or discharge via a drain tile. Permeable pavement reduces runoff and prevents flooding and erosion in a city environment, as well as reduces the concentration of some pollutants either physically (by trapping it in the pavement or soil), chemically (bacteria and other microbes can break down and utilize some pollutants), or biologically (plants that grow in-between some types of pavers can trap and store pollutants)[43]. Additionally, Climate Tiles are innovative tools that redirect rainwater that exists due to climate change-induced flooding[44].

Figure 5. Pilot stretch of the Climate Tile project in Copenhagen.

The Climate Tile reintroduces the natural water circuit in existing cities through a simple process that manages the rainwater from the roof and sidewalks and ensures that the water runs to the right place for plants or water banks. It can catch and redirect 30% of the projected extra rainwater coming due to climate change and prevents overloads within existing drainage systems. The streets of Fordhamopolis will utilize Climate Tiles to collect and manage water in a

[43] Selbig, William. *Evaluating the Potential Benefits of Permeable Pavement on the Quantity and Quality of Stormwater Runoff*, Upper Midwest Water Science Center, 2018, www.usgs.gov/science/evaluating-potential-benefits-permeable-pavement-quantity-and-quality-stormwater-runoff?qt-science_center_objects=0#qt-science_center_objects.

[44] Baldwin, Eric. "Climate Tile Designed to Catch and Redirect Excess Rainwater From Climate Change." *ArchDaily*, ArchDaily, 20 Sept. 2018, www.archdaily.com/902399/climate-tile-designed-to-catch-and-redirect-excess-rainwater-from-climate-change.

way that contributes to the ecological health and safety of the city. The tiles will improve the quality of life of residents of Fordhamopolis and provide an innovative solution that works with roads, bike paths, urban furniture, town squares, and urban nature.

Fog collection is another form of rainwater collection that Fordhamopolis would find success in, considering the rainy, foggy climate of the Pacific Northwest where the city is located. Fog collection is a unique type of rainwater collection that is utilized all over the world with great success. Traditional fog nets allow water to drip into a container which stores the captured droplets for human use. The notoriously dry city of Lima, Peru, has seen incredible results with fog collection in rural areas, where each net was measured to capture 200-400 litres of fresh water everyday[45]. Recent innovations and projects have brought along the “Fog Harp”[46] that boasts a more efficient and elegant way to collect fog than traditional methods, most of which utilize screen mesh.

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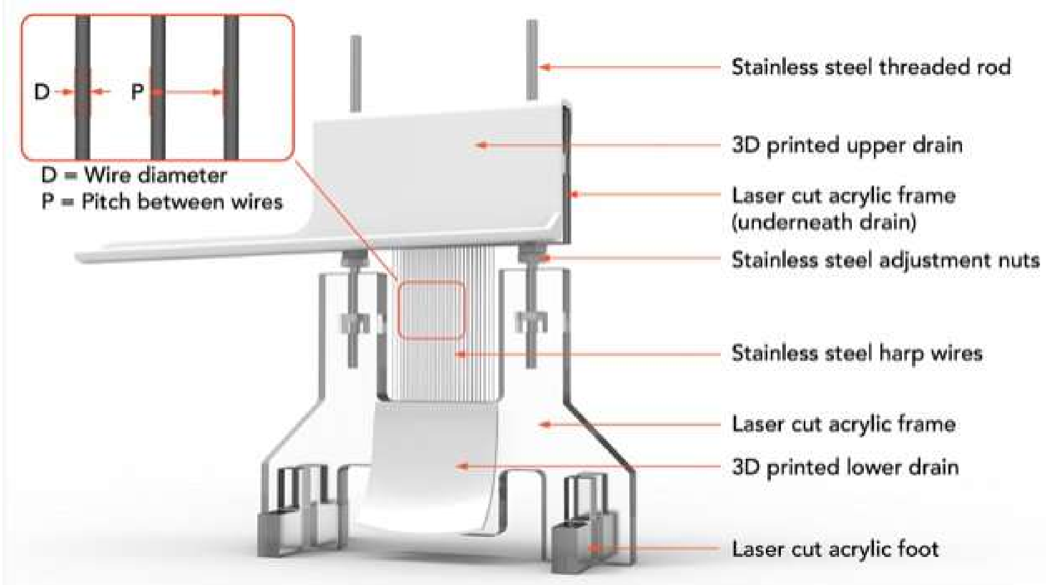
[45] Trevino, Miguel Trancozo. “The Ethereal Art of Fog-Catching.” *BBC Future*, BBC, 23 Feb. 2020, www.bbc.com/future/article/20200221-how-fog-can-solve-water-shortage-from-climate-change-in-peru.
[46] Shi, Weiwei, et al. “Harps Enable Water Harvesting under Light Fog Conditions.” *Advanced Sustainable Systems*, vol. 4, no. 6, 2020, p. 2000040., doi:10.1002/adsu.202000040.



To test the fog harp's design, researchers constructed small-scale models of vertical wire arrays that could be placed inside an environmental chamber with artificial fog. The team discovered that water collection efficiency continued to increase with smaller and smaller wires.

Figure 6. Fog harp design created by an interdisciplinary research team at Virginia Tech to maximize fog capture potential. [47]

Just as many trees rely on fog drip as a water source, Fordhamopolis will employ the most recent fog-catching technology to ensure that clean and safe water is available to the city. Utilizing the technology of the fog harp, Fordhamopolis will create a “Fog Fence” around the city that captures water droplets from atmospheric mist and fog and stores them for use. This fence will surround the outskirts of the city and will continuously capture fog droplets on its wires. These droplets will drip into pipes running along the bottom of the fence, and the water will flow towards the same reservoir that recycled water in the city is placed in. From these

[47] Shi, Weiwei, et al. “Harps Enable Water Harvesting under Light Fog Conditions.”

reservoirs, recycled water and water collected via fog drip will be used to supply the city with water in addition to the supply provided by localized harvested rainwater.

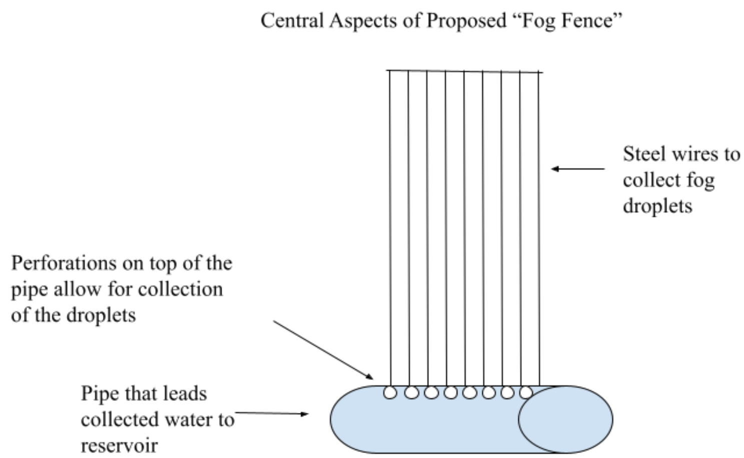


Figure 7. Diagram showing the central features of the Fog Fence that will surround Fordhamopolis. Drawing created by Maya Reddy via Google Draw.

PASSIVE ENERGY CAPTURE

The Shortcomings of Today's Energy Industry

Human populations around the world today rely heavily on the burning of fossil fuels and large-scale power grids, or macrogrids, to generate and transport electricity to consumers. This reliance on burning fossil fuels to produce energy releases large volumes of carbon dioxide into the atmosphere, leading to rapidly rising global temperatures.[48] In 2018, burning fossil fuels for energy contributed about 75% of the United States' total anthropogenic greenhouse gas

[48] "Energy and the Environment Explained: Where Greenhouse Gases Come From." Eia, 2020, www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php#:~:text=In%20 2018%2C%20carbon%20dioxide%20.

emissions.[49] The current use of expansive macrogrids to supply consumers with energy has resulted in numerous blackouts, or widespread power outages, that have led to increased mortality.[50]

Maintaining the energy industry's reliance on fossil fuels and subsequently failing to reduce greenhouse gas emissions to a sustainable level will allow the consequences of climate change, such as coastal flooding, increases in extreme weather, spreading disease, and mass extinctions, to continually threaten the survival of life on this planet.[51] Similarly, continuing to use macrogrids to transport energy will lead to future community blackouts that put communities at risk. In 2017, Hurricane Maria resulted in a power outage throughout Puerto Rico that left the island's residents with no electricity for an extended period of time. On average, households went 84 days without access to electricity, and many who required medical services were not able to receive the care they needed.[52] This contributed to an overall 64% increase in Puerto Rico's mortality rate following Hurricane Maria.[53] In addition, a study investigating the effects of the 2003 New York City blackout on mortality found that nonaccidental mortality increased by 25.3% as a result of the city-wide power outage. [54]

To mitigate the consequences of rapid climate change and the vulnerability of macrogrids to natural disasters, reform in the energy production industry is necessary. Cities, which have the most densely populated landscapes and the highest energy demands, are responsible for most of

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[49] "Energy and the Environment Explained: Where Greenhouse Gases Come From."
[50] Dominianni, Christine, et al. 2018. "Health Impacts of Citywide and Localized Power Outages in New York City." *Environmental Health Perspectives*, 126 (6): 1.
[51] Goel, Anjali, Bhatt, Ranjana. 2012. "Causes and Consequences of Global Warming." *International Journal of Life Sciences Biotechnology and Pharma Research* 1 (1): 29.
[52] Kishore, Nishant, et al. 2018. "Mortality in Puerto Rico after Hurricane Maria." *The New En*gland *Journal of Medicine* 379 (2): 165.
[53] Kishore, Nishant, et al., 162.
[54] Anderson GB, Bell ML. 2012. Lights out: impact of the August 2003 power outage on mortality in New York, NY. Epidemiology 23(2):189.

the world's carbon dioxide emissions. Therefore, reforming energy production in cities can play a substantial role in slowing rapid climate change and laying the groundwork for more reliable electricity transport. As a model for reform in energy production, Fordhamopolis will be detached from large-scale power grid infrastructure and receive energy from a more reliable and sustainable network of local renewable energy resources in conjunction with backup hydrogen fuel, peer-2-peer energy sharing, and energy conserving technologies.

Renewable Energy Sources

Renewable energy is defined as coming from natural sources that are constantly replenished.[55] The manipulation of the natural world to fulfill human desires is nothing new, wind, water, and light, were the ancient standards for power before technologic and economic developments lead to the dirty harnessing of cheap energy. However, as research progresses and the need for renewable energy sources transitions from a possibility to a necessity, renewable energy has become less expensive, more accessible, and more creative. In order for Fordhamopolis to effectively run off a renewable dependent energy system, it must employ the use of renewables that are best fitting to a metropolitan landscape. This will include solar, kinetic, thermoelectric, hydroelectric, and wind power.

Solar energy suits a metropolitan environment. The large, high, buildings provide a plethora of surface area for panels with minimal sunlight obstruction. Fordhamopolis will utilize two forms of solar energy. The first is solar fuel generators that perform artificial photosynthesis, these will be touched on in more detail later on and will contribute to Fordhamopilis' larger

[55] Shinn, Lora. "Renewable Energy: The Clean Facts." *NRDC*, 15 June 2018, www.nrdc.org/stories/renewable-energy-clean-facts#:~:text=your%20own%20home.-,What%20Is%20Renewable%20Energy%3F,depends%20on%20time%20and%20weather.

power network. The second is intelligent solar bio panels, microalgae technology that only harvest energy but additionally cleans the air.[56] The bio panels collect solar energy and carbon dioxide which is used to power algae bioreactors.[57] The algae grows within the clear pio panel and when it exceeds the volume of the panel it is transported to the combustion chamber where it produces heat and electricity through biomass technologies.[58] The system is carbon neutral as the byproduct of the combustion process is collected and recycled as nutrients for the next round of algae generation. This style of solar energy harvesting is cleaner and more cost effective. The production of photovoltaic solar panels typically results in pollution and the creation of non-recyclable/biodegradable materials, the bio panels are created with bioplastics that eliminate production pollutants. While photovoltaic systems are expected to take 15 years to pay back their costs, bio panel systems are expected to take only 5.[59] Fordhamopolis buildings can take advantage of the clear bio panels as windows to produce energy for the building on top of the shared energy system, and sequester carbon.

[56] Steffen, Andrea D. "'Innovator of the Year' Creates Biodegradable Algae Solar Panels That Clean The Air." *Intelligent Living*, 25 Mar. 2021, www.intelligentliving.co/innovator-of-the-year-biodegradable-algae-solar-panels/.
[57] Gieger, Robert. "A Great Solution for Homeowners." *The Verde System*, Grow Energy Inc., 2013, www.growenergy.org/verde/.
[58] Gieger, Robert. "A Great Solution for Homeowners."
[59] Gieger, Robert. "A Great Solution for Homeowners."

Figure 8. Solar powered algae bio-facade “Vivo”, designed by XTU Architects.

The New York Times estimates that in Manhattan there are 2000 windows per square block.[60] With a standard window size of 20 square feet[61], that is a potential 40 000 square footage of window surface that could be integrated with microalgae technology. Verde, a company specializing in microalgae technology, states that “a typical system is capable of producing up to 12 500 kWh/year from 2000 square feet of bioreactors.”[62] That means a city block with 40 000 square footage of window surface can support 20 systems, generating 250 000 kWh/year. That is enough to power 23 homes for a full year based on the estimate that the average american home uses 10 800 kWh/year.[63] Through using Manhattan as an example it is clear that the integration

[60] Pollack, Michael. “Calculating the Number of Windows in Buildings in Manhattan.” *New York Times*, 20 Dec. 2013.
[61] Pollack, Michael. “Calculating the Number of Windows in Buildings in Manhattan.”
[62] Gieger, Robert. “A Great Solution for Homeowners.”
[63] Eisenbach Consulting. “How Much Electricity on Average Do Homes in Your State Use? (Ranked by State).” *Electric Choice*, Eisenbach Consulting, LLC, 2017, www.electricchoice.com/blog.

of microalgae technology is a well fitted renewable energy source for Fordhamopolis, and with an increase in glass based architecture and energy efficient appliances the energy generated will be greater and distributed further.

Movement is one of the most neglected potential energy sources in metropolitan areas. A high density population navigating throughout a city 24 hours a day is a massive and perpetual source of energy. Fordhamopolis will integrate kinetic pavement into its high traffic walkways to harness the energy of commuters. The walkways will be laid with tiles that harness the energy of footsteps through piezoelectric technology. A single footstep is estimated to produce as high as eight watts of power.[64] The tiles are made from recycled rubbers and plastics in a triangular shape that maximizes the energy harvested off of a single foot step.[65] The tiles not only collect energy, but also information. Using just one percent of the energy they harvest, the tiles can transmit traffic density statistics to a central computer to be analyzed.[66] This allows Fordhamopolis to continually assess how much energy at a specific time is being harnessed in any of its kinetic walkways, this information will allow Fordhamopolis to intelligently relay energy from walkways to places that need it at that moment. Furthermore, this information will provide crucial information about commuter habits that Fordhamopolis can use to maximize commuter flow efficiency.

[64] Kemball-Cook, Laurence. "Case Studies." *Pavegen*, Pavegen, 2020, pavegen.com/case-studies-all/.
[65] Kemball-Cook, Laurence. "Case Studies."
[66] Kemball-Cook, Laurence. "Case Studies."

Figure 9. Photo of kinetic tiles from Pavegen.

The New York Times estimates that the average New Yorker takes upwards of 8000 steps a day.[67] As mentioned above, one step can generate eight watts meaning a single New Yorker could potentially generate 64 000 watts of energy in a single day with kinetic pavement. When considering that the population of New York City is 8.4 million, kinetic pavement becomes a realistic substantial energy contributor. Fordhamopolis will use kinetic pavement in high traffic areas. Let us consider the Grand Central Terminal as an example. Grand Central Terminal is 43 million square feet and receives on average 750 000 visitors a day,[68] if that 43 million square feet was converted into kinetic tiles and each of the 750 000 visitors takes at least ten steps then Grand Central Terminal alone could generate 60 000 kW in a single day.

[67] Sweeney, Camille. “City of 10,000 Steps.” *New York Times*, 23 Apr. 2015.
[68] Metro North Railroad. “About.” *Grand Central Terminal*, 5 Nov. 2019, www.grandcentralterminal.com/about/.

High density populations also result in immense quantities of body heat. Inspired by Stockholm's Central Station, which provides energy to an office building off of the body heat of 250 000 daily commuters[69], Fordhamopolis will similarly take advantage of the energy potential of densely populated spaces such as transit terminals, schools, shopping centres, etc. The system uses heat exchanges in central ventilation units to transfer excess body heat into hot water which is then pumped into nearby buildings to provide heat.[70] The current systems are said to reduce a single building's energy consumption from heating by 25%.[71] In principle, if excess body heat could be collected in a concentrated manner it could boil water to power steam generators providing an energy source to be used beyond simple heating purposes. Similar developments in wearable technology suggests that small handheld and wearable devices can be powered by excess body heat so long as the difference in temperature between the body and the outside body is great enough.[72] Fordhamopolis could take advantage of this technology on a larger scale, such as allowing public seating to harness energy off the body heat of anyone in contact. Handrails on stairs and escalators, elevators, high traffic doors, anything that the public comes in contact with can be integrated with body heat harvesting technology. The power output would not be huge, but it would be enough to power small devices which would effectively diminish their reliance on a main power grid.

One adult human body generates between 6000 and 10 000 BTUs of energy in a day[73], that is roughly 1758 to 2931 watts. Using Grand Central Terminal as an example again, assuming

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[69] Yoneda, Yuka. "Swedish Company Harvests Body Heat to Warm Buildings." *Inhabit*, BBC, 13 Jan. 2011, inhabitat.com/swedish-company-harvests-body-heat-to-warm-buildings/.
[70] Hinchey, Xanthe. "Harvesting Energy: Body Heat to Warm Buildings." *BBC News*, BBC, 9 Jan. 2011, www.bbc.com/news/business-12137680.
[71] Hinchey, Xanthe. "Harvesting Energy: Body Heat to Warm Buildings."
[72] Stevens, Matthew. *Human Body Heat as a Source for Thermoelectric Energy Generation*. Stanford University, 27 Nov. 2016, large.stanford.edu/courses/2016/ph240/stevens1/.
[73] Carr, Kevin. "Was the Matrix Even Necessary in 'The Matrix'?" *Film School Rejects*, Reject Media 2018, 8 Jan. 2014, filmschoolrejects.com/was-the-matrix-even-necessary-in-the-matrix-c64070985674/.

that each of the 750 000 daily visitors spends at least one hour in the terminal[74], there is approximately between 54750 and 91500 kW of energy being generated from body heat within the terminal every day. Through integrating technology that harvests body heat into spaces that occupy high density populations Fordhamopolis can supplement its energy reserves.

Fordhamopolis will be focused on harmonizing natural and metropolitan elements to create not only a sustainable city, but a city that compliments the natural world. This ideology should extend into the visual aspect of Fordhamopolis' energy network. Inspired by *The Weather Project* by artist Olafur Eliasson, an art installation that through mist, heat, and lighting, recreates an outdoor environment, Fordhamopolis will fund the creation of artwork which illustrates to the public the nature of the city's renewable energy sources. This will include sculptures that implement solar-microalgae panels into their design and take advantage of their vibrant green hue, walkways that absorb the energy produced by foot traffic and also power an interactive motion sensored light system, and more directly inspired by Eliasson's work, site specific artwork that uses harnessed excess body heat to create indoor environments that mimic the natural world. It is critical that Fordhamopolis environmental initiatives are infrastructural as well as cultural, a sustainable lifestyle is a combination of practice and mindset.

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[74] Metro North Railroad. "About." *Grand Central Terminal*

Figure 10. The Weather Project, Olafur Eliasson

Figure 11. algae powered light, Bionic Chandelier, by Julian Melchiorri.

BACKUP ENERGY SUPPLY IN FORDHAMOPOLIS

Backup Energy Inspired By Nature

A major challenge facing the use of renewable sources to supply energy is the intermittent period in which renewables are unable to produce enough energy to meet energy demand.[75] Photovoltaic solar panels, for instance, experience an intermittent period when the sun has set and its energy is no longer available for capture. Finding inspiration in nature, energy sharing that resembles the cooperation of trees in temperate zone forests are gaining traction as a strategy to improve energy supply stability.[76] In addition, researchers are developing integrated solar fuel generators that undergo artificial photosynthesis to capture sunlight and provide renewable fuel that can be stored long-term and used when the sun is no longer shining.[77]

Sharing to Maintain Stability in Natural and Urban Environments

In temperate zone forests, trees are part of an underground mycorrhizal network. This mycorrhizal network is made up of white fungal threads called mycelium which travel throughout the soil picking up nutrients and water and attaching to tree roots.[78] When tree roots and mycelium attach, they experience a symbiotic, or mutually beneficial, relationship in which tree roots provide fungi with carbon, and fungi provide tree roots with vital nutrients.[79] With the mycorrhizal network in place, trees are linked to each other with mycelium and able to exchange

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[75] Modestino, Miguel, Segalman, Rachel. 2014. *"Artificial Solar Fuel Generators." Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2013 Symposium, National Academies Press*, 97.
[76] Long, Chao, et al. 2018. "Peer-to-Peer Energy Sharing through a Two-Stage Aggregated Battery Control in a Community Microgrid." *Applied Energy*, 226: 262.
[77] Modestino, Miguel, Segalman, Rachel. 2014 *"Artificial Solar Fuel Generators." Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2013 Symposium, National Academies Press,* 97.
[78] Lagomarsino, Valentina. 2019. "Exploring The Underground Network of Trees – The Nervous System of the Forest." *Science in the News*, sitn.hms.harvard.edu/flash/2019/exploring-the-underground-network-of-trees-the-nervous-system-of-the-forest/.
[79] Lagomarsino, Valentina.

nutrients in response to shortages.[80] In addition, trees are able to individually obtain nutrients from mycorrhizal fungi which decentralizes the network and increases its reliability.[81] Thus, it is the combined abilities of trees to supply themselves with nutrition and cooperate with other trees when nutrients are scarce that results in improved resiliency within a temperate zone forest as a whole.

In Fordhamopolis, an energy trading mechanism called peer-to-peer energy trading will be offered to mimic the nutrient-sharing capabilities of trees, achieve greater energy resilience throughout the city, and prevent excess renewable energy from going to waste. Like trees within a forest ecosystem, peer-to-peer energy trading allows resources--in this case energy--to be exchanged without centralized intervention.[82] In other words, buildings that produce energy from renewables are able to sell excess energy they generate directly to other buildings that are facing energy shortages.

The peer-to-peer energy trading system will utilize the excess energy produced by the bio panels that cover Fordhamopolis' buildings, as these panels are widely distributed throughout the city. Moreover, the energy demands of the various buildings equipped with these biopanels differ. A large commercial building or vertical farm, for instance, may require a large abundance of energy while a small residential building only needs a comparatively small amount. Additionally, the energy consumption habits within buildings are inconsistent. The same building may use more energy in the morning and less in the evening whereas another building

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80 Toomey, Diane. 2016. "Exploring How and Why Trees 'Talk' to Each Other." *Yale Environment 360*, Yale School of the Environment, e360.yale.edu/features/exploring_how_and_why_trees_talk_to_each_other.

81 "Mycorrhizae Benefits To Your Trees." *San Antonio Tree Surgeons*, 2015, sanantoniotreesurgeons.com/mycorrhizae-benefits-to-your-trees/#:~:text=The%20root%20system%20can%20absorb,the%20tree%20roots%20as%20needed.

82 Chau, S. C. K., et al. 2019. Peer-to-Peer Energy Sharing: Effective Cost-Sharing Mechanisms and Social Efficiency." *E-Energy - Proceedings of the 10th ACM International Conference on Future Energy Systems*, 215.

may do the opposite. In short, allowing buildings to trade energy would accommodate the unique energy needs of Fordhamopolis' buildings.

To enable peer-to-peer energy trading in Fordhamopolis, transmission lines can be used to establish direct connections between buildings, and excess solar energy produced by a building's bio panels can be stored in batteries (i.e., lithium ion batteries) that provide enough short-term storage for energy trading to take place.[83] Once stored within the battery, an energy representative, or a person appointed to manage a building's energy, can post the excess energy for sale on a secure platform, such as Blockchain, that is visible to buildings in need of additional energy. Blockchain is a database technology that manages and records transactions in a way that is public and verifiable, enabling autonomous energy transactions to take place.[84] Figure 5 provides a simplified visualization of the process of energy transactions via Blockchain database technology. These transactions allow prosumer energy representatives (PERs) to receive payment for the excess energy generated by their buildings and consumer energy representatives (CERs) to enjoy additional electricity in their buildings.

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[83] Long, Chao, et al. 2018. Peer-to-Peer Energy Sharing through a Two-Stage Aggregated Battery Control in a Community Microgrid. *Applied Energy* 226: 264-265.
[84] Dutsch, Gunther, Steineck, Neon. 2017. Use Cases for Blockchain Technology in Energy & Commodity Trading. *PWC*: 5.

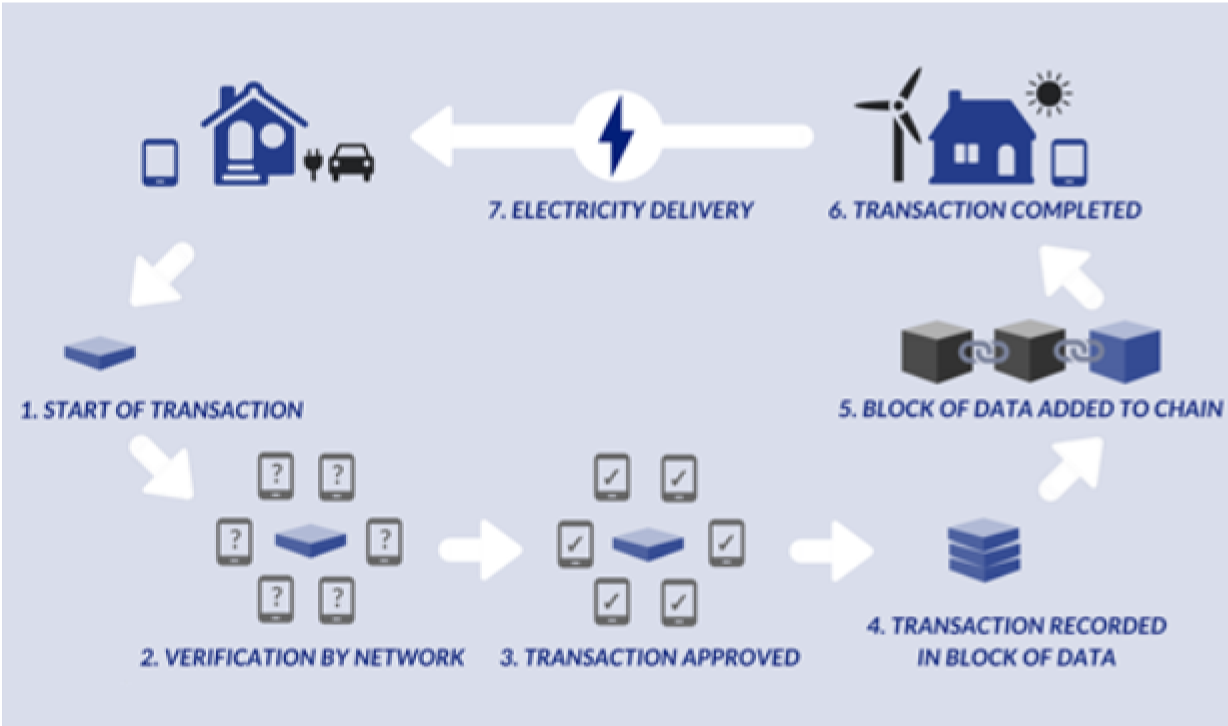

Figure 12. Energy transactions are processed and carried out by Blockchain database technology.[85]

Following energy transactions, the profit from the excess energy is to be distributed by the PERs to residential units within the building in proportion to energy usage per resident within each unit. Moreover, residential units that consumed the least amount of energy per resident will receive the greatest portion of profit while the residential units using the most energy per resident will receive the smallest portion. Conversely, the CERs are to bill residents for the transmission costs from the excess energy purchase in proportion to each residential unit's energy consumption per resident. In this way, the residential unit that used the most energy per resident will pay most of the bill while the residential unit that used the least energy per resident will pay the least. The goal of this financially rewarding and penalizing system is to ultimately motivate

[85] "Blockchain Technology Can Boost Climate Action." *SAMPLES*, 10 Apr. 2019, samples.ccafs.cgiar.org/blockchain-technology-can-boost-climate-action/.

Fordhamopolis residents to conserve energy in order to benefit from the profits of trading excess renewable energy.

Energy Storage Through Artificial Photosynthesis

When the renewable energy provided by bio panels, kinetic energy, body heat, and peer-to-peer energy trading is not enough to meet the energy demands of city buildings, hydrogen fuel can function as an additional backup energy supply that is available for purchase through Blockchain trading platforms. This hydrogen fuel will be generated with a solar fuel generator that biomimics the processes of photosynthetic organisms.

Though photosynthetic organisms are not very efficient at transforming sunlight into fuel--they convert only about 1 percent of sunlight into energy--researchers have studied their photosynthetic capabilities to develop solar fuel generators that produce pure hydrogen fuel through artificial photosynthesis.[86] This hydrogen fuel can be used to generate electricity without releasing any greenhouse gases or pollutants into the atmosphere.[87] Thus, using hydrogen fuel to power Fordhamopolis would reduce the city's overall carbon footprint.

The design of a solar fuel generator is based on a few key qualities of the photosynthetic apparatus of many microalgae and cyanobacteria. When these organisms perform photosynthesis, they use sunlight to split water into hydrogen and oxygen.[88] To prevent hydrogen fuel from spontaneously combusting in the presence of oxygen, these photosynthetic organisms separate the half reactions, or oxidation and reduction reactions, that produce hydrogen and

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[86] Modestino, Miguel, Segalman, Rachel. 2014. *"Artificial Solar Fuel Generators." Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2013 Symposium, National Academies Press*, 97.
[87] "Energy and the Environment Explained: Where Greenhouse Gases Come From." *Eia*, 11 Aug. 2020, www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php#:~:text=In%20 2018%2C%20carbon%20dioxide%20.
[88] Sivaram, Varun. 2018. *Taming the Sun : Innovations to Harness Solar Energy and Power the Planet*. Cambridge, Massachusetts: The MIT Press, 174.

oxygen into two different light-absorbing compartments.[89] These compartments are known as photosystem I (PSI) and photosystem II (PSII). Each of these photosystems contain catalysts that speed up the half reactions, and a membrane between the two photosystems allows charged ions to flow through it, maintaining a balance of charge between the half reactions.[90] During the oxidation half reaction in PSII, water splits into oxygen and hydrogen protons. The resulting oxygen is released into the atmosphere, and the protons travel through the membrane to PSI to participate in subsequent chemical reactions.[91] In microalgae and cyanobacteria, the light energy in PSI can be used to convert carbon dioxide into glucose or reduce hydrogen into H2 gas with an enzyme called hydrogenase.[92] This H2 gas, or pure hydrogen fuel, can be used to generate electricity without releasing carbon dioxide and pollutants into the atmosphere. [93]

Generating Electricity with Hydrogen

To capture sunlight, split water, and produce pure hydrogen fuel, the photosynthetic processes of microalgae and cyanobacteria should be applied to develop integrated solar fuel generators called IPECs.[94] These generators carry out artificial photosynthesis by capturing solar energy and catalytically converting low energy reactants into energy dense fuels.[95] These generators are more efficient than other forms of wired hydrogen production which require energy from renewables to be sent to an electrolyzer that splits water.[96] Moreover, IPECs are able

89 Sivaram, Varun. 2018. *Taming the Sun : Innovations to Harness Solar Energy and Power the Planet*. Cambridge, Massachusetts: The MIT Press, 175.
90 Sivaram, Varun., 175.
91 Sivarum, Varun., 174.
92 Allakhverdiev, S. I., et al. 2010. Photosynthetic Hydrogen Production. *Journal of Photochemistry and Photobiology.* 11(2-3): 103.
93 Modestino, Miguel, Segalman, Rachel. 2014. *"Artificial Solar Fuel Generators." Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2013 Symposium, National Academies Press*, 97.
94 Modestino, Miguel, Segalman, Rachel., 98.
95 Modestino, Miguel, Segalman, Rachel., 98.
96 Sivarum, Varun., 175.

to produce more energy in less space and can operate throughout an entire day whereas the wired electrolyzers can only operate for 25 percent of the day.[97]

To perform artificial photosynthesis, IPECs must incorporate two photoelectrodes to function as photosystems and absorb the light energy required for each of the half reactions to split water.[98] In addition, two catalysts are needed to speed up each half reaction, and a photoelectrochemical cell (PEC) must be present to act as a membrane that envelops the device and separates the half reactions to prevent spontaneous combustion.[99]

Unlike the photosystems in plants, however, the photoelectrodes in PECs should not compete for sunlight from the same part of the sun's spectrum.[100] Instead, one photoelectrode should operate as an anode that absorbs high energy photons and delivers electrons down to the other photoelectrode which functions as a cathode and absorbs lower energy photons.[101] This design would simultaneously optimize the production of oxygen by the anode and pure hydrogen fuel by the cathode. Within a hydrogen fuel cell, the pure hydrogen gas produced by the generator can be combined with oxygen to produce electricity.[102]

Before being converted into electricity, the hydrogen generated by IPECs must be compressed into hydrogen storage tanks. This is because hydrogen has a very low density, so to minimize the space and expenses required for its storage, its density must be increased through compression.[103] Thus, hydrogen-storing compression tanks will be located within the confines of

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[97] Sivaram, Varun. 2018. *Taming the Sun : Innovations to Harness Solar Energy and Power the Planet*. Cambridge, Massachusetts: The MIT Press, 175.
[98] Sivaram, Varun., 176.
[99] Sivarum, Varun., 175.
[100] Sivarum, Varun., 175.
[101] Sivarum, Varun., 175.
[102] "Hydrogen & Fuel Cells." *Renewable Energy World*, 5 Nov. 2021, www.renewableenergyworld.com/types-of-renewable-energy/hydrogen/#gref.
[103] Andersson, J., & Grönkvist, S. 2019. Large-scale storage of hydrogen. *International Journal of Hydrogen Energy*, 44(23), 11902.

Fordhamopolis at a hydrogen power plant. These compression tanks will offer long-term energy storage that can help smooth over fluctuations in energy supply that result from renewable intermittency.[104] When additional electricity is needed to support Fordhamopolis' energy demand, the compressed hydrogen will feed into hydrogen fuel cells that produce electricity.

Hydrogen fuel cells are similar to batteries--which are currently the main providers of energy storage--in that they each generate electricity by transferring electrons between two electrodes (anode and cathode) with an electrolyte, or an ion-conducting material, situated between them.[105] In batteries, electrons are released from the anode material which changes the chemical composition of the anode overtime and interferes with the effectiveness of the battery.[106] Hydrogen fuel cells, however, conduct electrons that have been released from compressed hydrogen. As a result, hydrogen fuel cells are not chemically changed in the process of generating electricity, making them more stable than batteries.[107] Producing electricity with hydrogen fuel cells combines oxygen with pure hydrogen gas and releases water and heat as byproducts.[108] The generated electricity can then be purchased by commercial and residential buildings when renewables are unable to meet the demands of energy loads. Figure 6 illustrates the multi-step process of hydrogen power generation.

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[104] Andersson, J., & Grönkvist, S. 2019. Large-scale storage of hydrogen. International Journal of Hydrogen Energy, 44(23), 11902.
[105] *Hydrogen & Fuel Cells: Science Behind Fuel Cells*, sepuplhs.org/high/hydrogen/hydrogen.html.
[106] *Hydrogen & Fuel Cells: Science Behind Fuel Cells*.
[107] *Hydrogen & Fuel Cells: Science Behind Fuel Cells*.
[108] *Hydrogen & Fuel Cells: Science Behind Fuel Cells*.

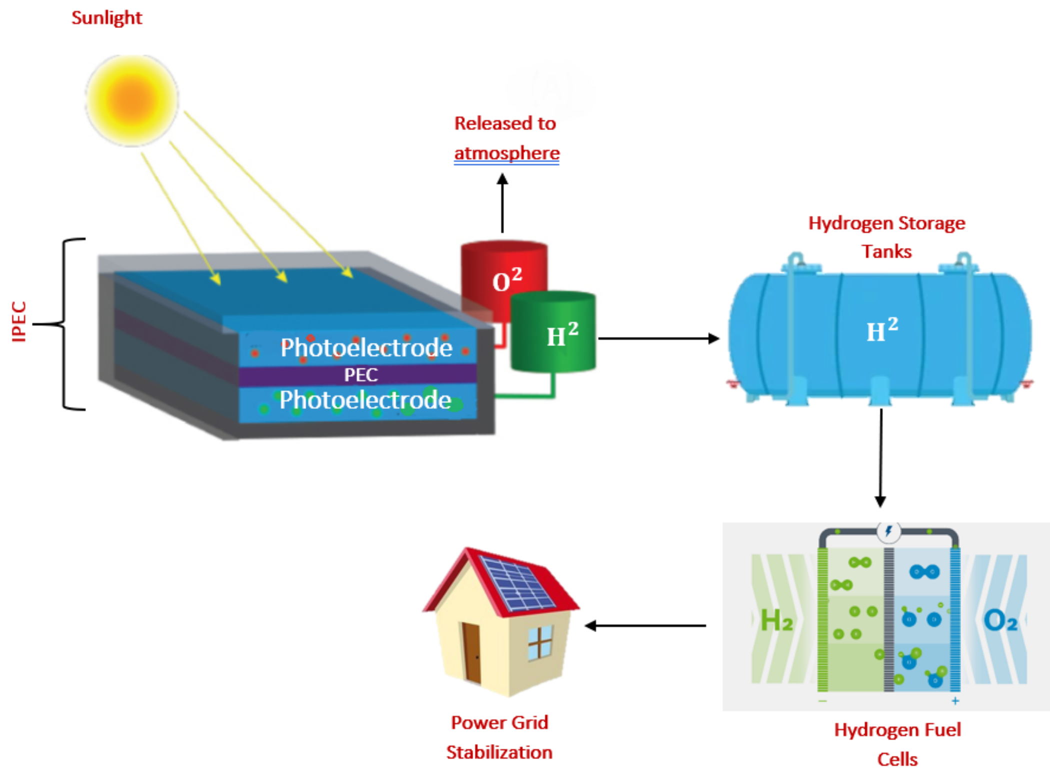

Figure 13. Solar energy is used to generate hydrogen fuel with an IPEC. Hydrogen fuel is stored in tanks until power is needed. The hydrogen then powers fuel cells to generate megawatt-scale power. This provides enough reliable, stable, zero-emission energy to power a building, facility, or regional grid.[109]

Commercialization Hurdles of IPECs

IPECs are not yet commercially available, but recent developments in technology show promise for their future success in providing consumers with energy storage. To achieve commercial success, IPECs must be safe, resilient, and efficient.[110] With regard to safety and resiliency, the membrane that promotes safety by spontaneous combustion must also demonstrate resilience through resistance to acidic and basic solutions produced by the oxygen and hydrogen

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[109] Modestino, Miguel, Segalman, Rachel. 2014. *"Artificial Solar Fuel Generators." Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2013 Symposium, National Academies Press*, 99. See also "Fuel-Cell Stacks: the Recipe for Success in Mass Manufacturing." *BOSCH*, www.bosch.com/stories/fuel-cell-stack/.

[110] Sivaram, Varun. 2018. *Taming the Sun : Innovations to Harness Solar Energy and Power the Planet*. Cambridge, Massachusetts: The MIT Press, 176.

half reactions.[111] Moreover, the membrane material must be resistant to dissolution by acidic solutions and corrosion by basic solutions to keep oxygen and hydrogen products separated and prevent spontaneous combustion.[112] In addition, the membrane must allow charged ions to pass through it to maintain the balance of charge between half reactions.[113] In their search for a sufficient membrane material, researchers at the Joint Center for Artificial Photosynthesis (JCAP) discovered that titanium dioxide, a substance found in sunscreen, can coat photoelectrodes in a thin film and act as a membrane.[114] Titanium dioxide is an ideal candidate for the membrane, as it is resistant to corrosion but still allows for sunlight to be captured and for ions to pass through it.[115]

With regard to efficiency, commercial success depends on how quickly the photelectrodes of the IPEC are able to absorb sunlight and how fast the half reactions can split water.[116] To achieve high efficiency light capture, perovskite/silicon tandem structures have been proposed to function as the photoelectrodes.[117] Together the different bandgaps of perovskite and silicon are able to absorb more of the solar spectrum and convert solar radiation into electricity more efficiently.[118] These breakthroughs in the development of IPECs along with future investment in hydrogen storage research and development make energy generation and storage through artificial photosynthesis a possibility in the futuristic city of Fordhamopolis.

Energy Conservation Technology

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[111] Sivaram, Varun. 2018. *Taming the Sun : Innovations to Harness Solar Energy and Power the Planet*. Cambridge, Massachusetts: The MIT Press, 176.
[112] Sivaram, Varun., 176.
[113] Fesenmaier, Kimm. 2014. “JCAP Stabilizes Common Semiconductors For Solar Fuels Generation.” *California Institute of Technology*, www.caltech.edu/about/news/jcap-stabilizes-common-semiconductors-solar-fuels-generation-42921.
[114] Fesenmaier, Kimm.
[115] Fesenmaier, Kimm.
[116] Sivaram, Varun., 177.
[117] Sivaram, Varun., 178-179.
[118] Sivaram, Varun., 152.

To ensure that the energy generated by renewables is being used to its full potential and not going to waste, Fordhamopolis buildings will incorporate energy-conserving technologies that prevent heat loss, respond to energy use habits, and provide energy efficient geothermal heating.

Buildings without energy-conserving technologies in place are at risk of losing energy through heat loss.[119] This heat loss most often occurs through the roofs, windows, walls, floors, windows gaps and doors of buildings.[120] To mitigate this loss, Fordhamopolis buildings will block heat escape routes with improved insulation in walls, roofs, floors and double glazed window fixtures.[121]

Synchronizing energy use with variations in energy demands throughout the day can prevent energy waste. During Fordhamopolis' warm summer months, for instance, a programmable smart thermostat can be used to allow the temperature of a household to climb a few degrees when its residents are not at home and then reduce the temperature to a more comfortable level in time for their return.[122] Similarly, motion sensor lighting can be leveraged so that energy is only spent to light rooms that are in use.[123]

With the majority of energy going toward heating and cooling in U.S. households, highly efficient geothermal heat pumps--which are capable of using 25% to 50% less energy than convention heating or cooling systems--can play a substantial role in realizing the full potential

[119] "Reducing Heat Transfers – Houses - Conduction, Convection and Radiation - GCSE Physics (Single Science) Revision - BBC Bitesize." *BBC News*, BBC, www.bbc.co.uk/bitesize/guides/zttrd2p/revision/4.
[120] "Reducing Heat Transfers – Houses - Conduction, Convection and Radiation - GCSE Physics (Single Science) Revision - BBC Bitesize."
[121] "Reducing Heat Transfers – Houses - Conduction, Convection and Radiation - GCSE Physics (Single Science) Revision - BBC Bitesize."
[122] D'Aprile, Jason. 2020 "Best Smart Thermostat: Reviews and Buying Advice." *TechHive*, TechHive, www.techhive.com/article/3206565/best-smart-thermostat.html.
[123] "Benefits of Using Motion-Sensor Light Switches." *The Eco Guide*, 25 Oct. 2017, theecoguide.org/benefits-using-motion-sensor-light-switches.

of renewable energy to power Fordhamopolis.[124] With regard to Fordhamopolis' location within the Pacific Northwest, a history of volcanic and seismic activity within the region has resulted in the formation of hotspots within the earth's mantle that make geothermal heat pump installation viable option for heating and cooling buildings.[125] Tapping into these hot spots can provide a limitless supply of geothermal energy that can be used for heating and cooling purposes within Fordhamopolis buildings.[126]

The heating and cooling of buildings with a geothermal heat pump is carried out with a ground loop system that uses a water solution, heat exchanger, and ductwork to heat and cool buildings. The water within this system can be sourced from Fordhamopolis' Fog Fence water harvesting technology that was previously discussed within the water harvesting section of this report. During cold winter months, this water solution absorbs heat from the ground as it circulates through pipes.[127] After being warmed, the water travels into the home so that a water-to-air heat pump can concentrate its thermal energy content.[128] A conventional ductwork system then transfers this concentrated thermal energy to the air, allowing it to circulate throughout the home and provide heating.[129] This process is reversed during the summer months and excess heat from the home is pumped into the ground. [130]

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124 D'Aprile, Jason. See also "Benefits of Geothermal Heat Pump Systems." *CaliforniaGeo*, 2019, www.californiageo.org/benefits-of-geothermal-heat-pump-systems/.
125 Winkel, Carol. 2016. "Tapping Into Geothermal Energy." *Northwest Power and Conservation Council*, www.nwcouncil.org/news/tapping-geothermal-energy.
126 "Geothermal Heating and Cooling." *Taco Comfort Solutions*, www.tacocomfort.com/residential-solutions/geothermal-heating-and-cooling/.
127 "What Is a Geothermal Heat Pump?" *Energy Environmental*, www.energyhomes.org/renewable-technology/howgeoworks.html.
128 "What Is a Geothermal Heat Pump?"
129 "What Is a Geothermal Heat Pump?" *Energy Environmental*, www.energyhomes.org/renewable-technology/howgeoworks.html.
130 "What Is a Geothermal Heat Pump?"

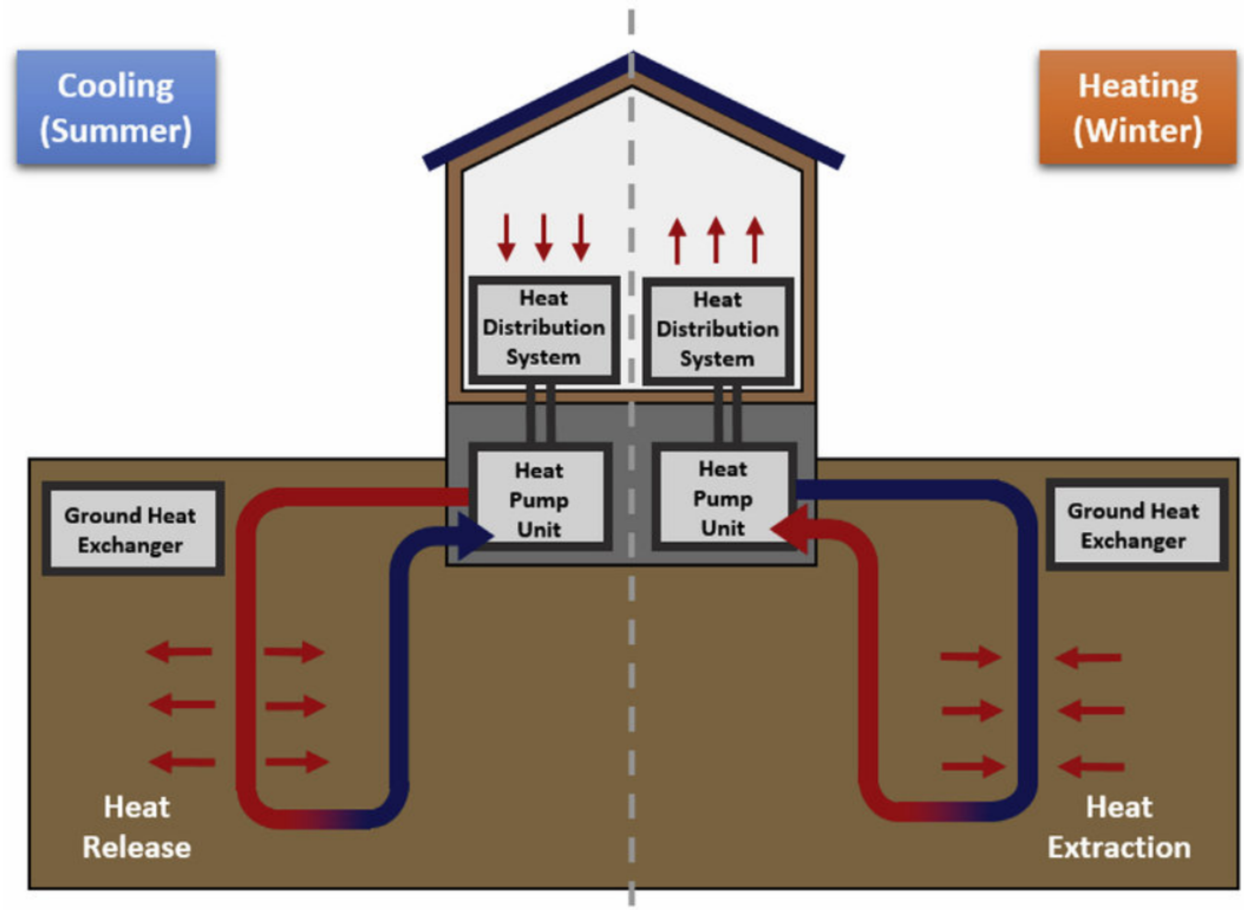

Figure 14. The flow of thermal energy through a geothermal heat pump in the summer is reversed during the winter.[131]

[131] Jeon, Jun-Seo, et al. 2018 "A Modified Mathematical Model for Spiral Coil-Type Horizontal Ground Heat Exchangers." *Energy*, 152: 733.

CARBON SEQUESTRATION

Forest and Timber Product Management

Forests are an important aspect of carbon storage, as it utilizes the natural world as a means to promote sustainability and combat climate change. By using the Pacific Northwest's already existent forests, Fordhamopolis will also focus on allotting land to sustain the planting of a biodiverse forest. Through photosynthesis, trees serve as yet another way to capture carbon, and are able to sequester carbon within its trunks and roots. Pertaining to Oregon and Washington, forests are rather abundant and store 2,100 million metric tons of carbon.[132] However, they have potential to store much more and would be able to capture more carbon if not for wildfires and privately owned timber harvesting land.

There will be extended efforts to preserve and restore all forests surrounding Fordhamopolis, as such forests have been storing carbon for ages and constantly run the risk of deforestation due to human activity. Actively protecting these already existent forests is important to ensuring the carbon stored within them remains stored. Managing the harvesting of all nearby forests and ensuring the avoidance of harvesting whole trees is also necessary. Drawing inspiration from The Forest Stewardship Council, Fordhamopolis will develop a plan for forest management in an effort to effectively preserve all surrounding forests. This plan will include implementing longer rotations such that the trees will have more time to grow before being harvested for wood usage. A study done by the organization Ecotrust and the University of Washington which focused upon FSC forest management techniques within the Pacific Northwest showed that "Carbon storage for these longer rotation scenarios was 18-25% higher in

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[132] Watts, Andrea. "There's Carbon in Them Thar Hills: But How Much? Could Pacific Northwest Forests Store More?" *Science Findings*, www.fs.fed.us/pnw/sciencef/scifi195.pdfSS.

Oregon and 20-26% higher in Washington, averaging 23% more carbon storage than business as usual."[133] By limiting the harvest size as well as having longer harvesting rotations, biodiversity within the forest is preserved and larger amounts of carbon is stored. The reduction of harvesting will result in trees releasing less carbon than they store, greatly cutting down carbon emissions.

It is rather important to analyze the intended products of the timber harvested. Usages of timber will be limited to long-term products, such as residential complexes and buildings, furniture, or other durable long lasting goods. Wood products with short-term usage will be discouraged. Paper will especially be monitored in terms of usage, and no products like paper plates and paper napkins will be used. There will be an emphasis on purchasing permanent goods rather than temporary single-use goods. In a study done by the Center for International Trade in Forest Products in collaboration with the University of Washington, it was found that "...paper products only provide a small climate benefit due to their short lifetime. Out of all products considered, paper has the highest level of emissions associated with its production."[134]

[133] Davies, Brent Vice. "Increasing the Carbon Storage Potential for Pacific Northwest Forests." *Ecotrust*, 7 Aug. 2019, ecotrust.org/tipping-the-balance-to-more-carbon-storage/.
[134] Gangulya, Indroneil, and Francesca Pierobona. "Global Warming Mitigating Role of Working Forests in Washington State." *Amforest*, Feb. 2019, amforest.org/wp-content/uploads/2020/03/Global-Warming-Mitigating-Role-Summary.pdf.

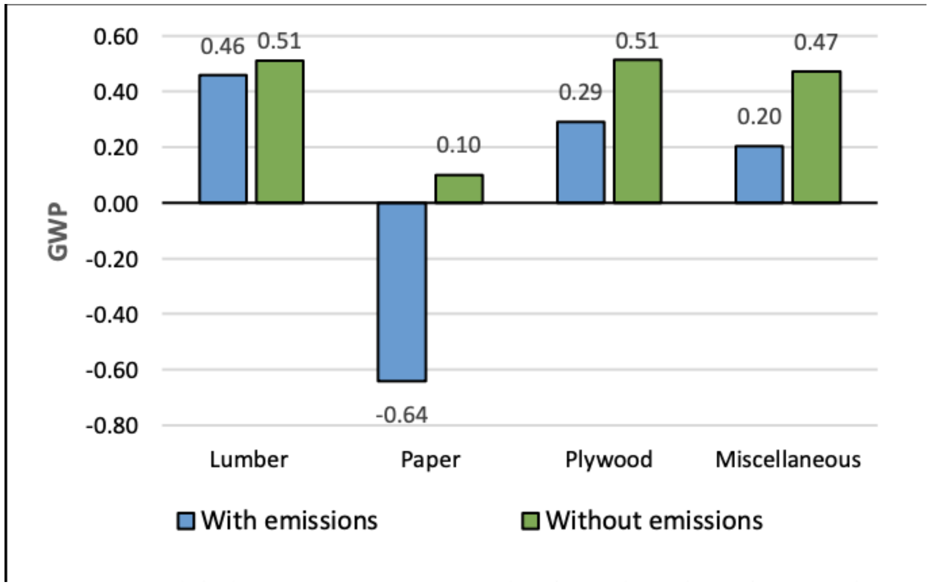

Figure 15. Wood product emissions[135]

Paper is a necessary component of city life, therefore we will focus on using sustainable alternatives. Paper products used recreationally and in the household will be replaced with recycled paper, as recycled paper allows for multiple usages and a reduction in water usage.

Reforestation through New Forests and Urbanized Forestation

Although old forests have more potential to sequester greater amounts of carbon, they also hold the risk of releasing greater amounts of carbon. This is because logging, wildfires, and natural disasters will eventually reduce the number of older trees thus causing large releases of carbon. This unavoidable phenomena can be offset by the planting of trees, thus we intend to dedicate substantial space for the planting of new forests. To maximize carbon storage, we will wait for all newly planted trees to fully mature before harvesting, and such harvesting will be highly selective. There will not only be a plot of land dedicated to planting new forests, but trees

[135] Gangulya, Indroneil, and Francesca Pierobona. "Global Warming Mitigating Role of Working Forests in Washington State." *Amforest*, Feb. 2019, amforest.org/wp-content/uploads/2020/03/Global-Warming-Mitigating-Role-Summary.pdf.

will also be planted within the urban areas of Fordhamopolis, in places that would cause no obstruction to city life. These trees planted within the city absorb carbon, but they would also control water runoff and would promote Fordhamopolis' urban biodiversity. Trees must be planted in a manner that accounts for avoiding obstruction of urban life. Another way we can incorporate forestation within urban areas would be including reforestation in public parks. By doing so, there will be even more land allotted to the planting of new trees, resulting in further reduction of carbon emissions.

Figure 16. Usage of root barriers to plant trees on paved areas[136]

Carbon Storage Through Seagrass

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[136] Trees-Energy-Conservation. "Urban Tree Planting (Part 1): Site Selection." *Trees for Energy Conservation*, 11 Sept. 2019, trees-energy-conservation.extension.org/urban-tree-planting-part-1-site-selection/.

Reforestation and conversation is not only applicable to the forests of Fordhamopolis, but also applicable to preserving and increasing the seagrass that grows in the coastal regions of the city. The Pacific Northwest, a coastal region, has a type of seagrass specific to their coasts known as eelgrass. This form of a coastal wetland provides a carbon sink, one of the most useful methods of carbon storage and sequestration.

Eelgrass ecosystems serve as powerful carbon sinks, as seagrass beds have proven to be more effective at storing carbon than forests. Seagrass itself allows for the burial of carbon and nitrogen within underwater sediments, which allows for filtering polluted runoff and increasing water clarity.[137] If seagrass environments flourish, there is potential for large amounts of blue carbon storage and burial. One acre of seagrass itself can sequester 740 pounds of carbon in a year. However, seagrass only makes up a small portion of the ocean, yet makes up half of the carbon stored in oceanic settings. This shows the potential of incorporating large beds of eelgrass, native to the Pacific Northwest, in Fordhamopolis' coasts.

[137] Gaeckle, Jeff. "Seagrass Restoration: WA - DNR." *WA*, 2021, www.dnr.wa.gov/SeagrassRestoration.

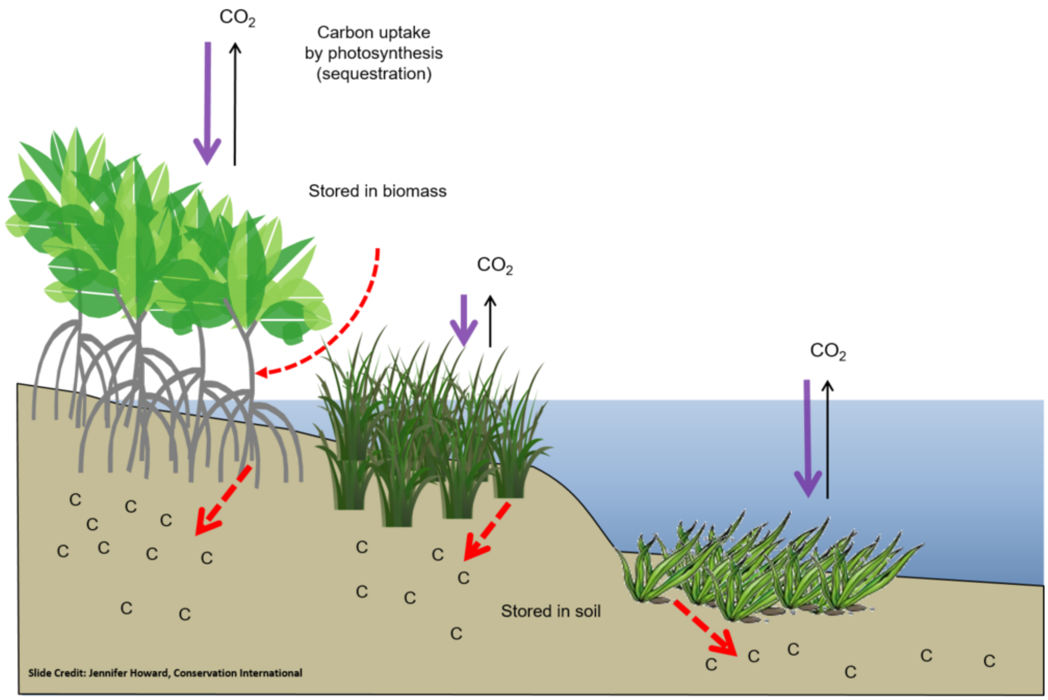

Figure 17. Carbon storage and sequestration through seagrass[138]

Eelgrass' potential for carbon storage is monumental thus efforts to preserve these plants, numbers reduced due to human activity, is pertinent. Seagrass habitats, over the years, have faced alarming rates of destruction, thus their ability to store and sequester carbon is heavily reduced. Unlike seaweed, seagrass allows for replantation due to the production of seeds that can be planted back into seagrass beds. The existing eelgrass of the environment can be revitalized and can have its numbers increased through the planting of large eelgrass meadows near Fordhamopolis' surrounding coasts.

[138] Lutz, M. (2020, November 03). Creature feature: Eelgrass! Retrieved May 14, 2021, from https://www.juniorseadoctors.com/blog/2020/9/29/creature-feature-eelgrass

Incorporation and Production of Graphene

Fordhamopolis will utilize graphene as well as the incorporation of graphene to reduce overall carbon emission as well as improve carbon capture and storage. Graphene is a two-dimensional material made of layered carbon atoms which form a hexagonal lattice. Although being the thinnest material, it serves to be 200 times stronger than steel.[139] Carbon waste can be transformed into graphene, which can then be incorporated into a multitude of appliances, increasing durability.

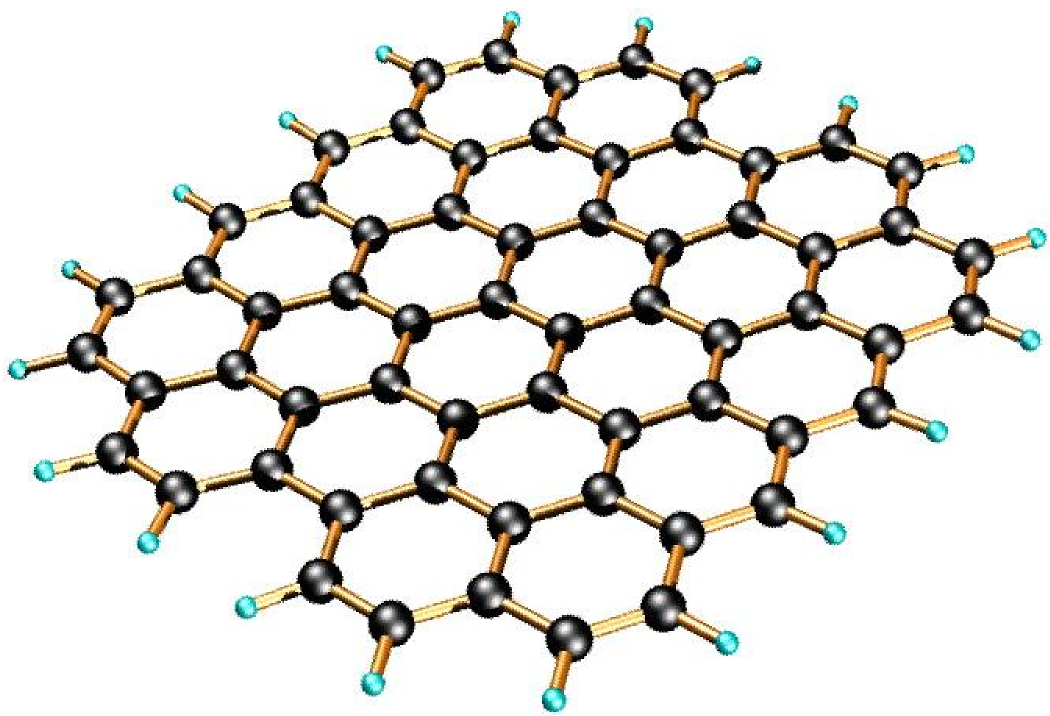

Figure 18. Single Graphene Sheet[140]

Previously, mass production was a large problem regarding the general usage of Graphene. However, researchers at Rice University have found a method to take any carbon

[139] Home. (n.d.). Retrieved May 14, 2021, from https://www.graphene-info.com/graphene-introduction
[140] Ewels, C. (n.d.). Dr Chris Ewels. Retrieved May 14, 2021, from http://www.ewels.info/

containing material and convert it into graphene through a process called “flash graphene”. Chemist James Tour of Rice University stated that “solid carbon-based matter, including mixed plastic waste and rubber tires, can be turned into graphene”[141], through the utilization of the newfound “flash graphene” technique. In terms of mass production, this technique has proved to override all other forms of graphene production, as it is cost efficient and requires less effort than alternate techniques and technologies. Flash Joule Heating is used to produce bulk graphene, and allows for layers of graphene to easily separate, thus allowing graphene to be incorporated into a multitude of other materials.

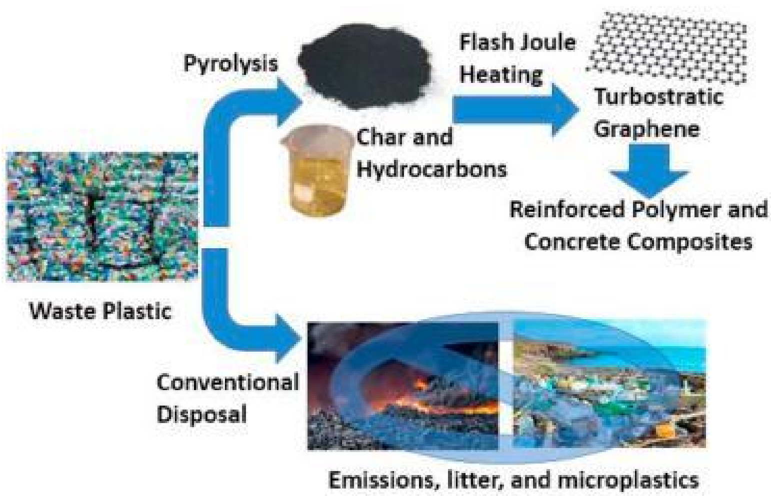

Figure 19. Graphene production through FJH.[142]

Usage of Graphene to Reduce Carbon Emissions

Graphene can be used to make ultra-thin carbon filters, thus the material not only reduces waste composed of carbon, but can also capture carbon more efficiently than alternate forms of carbon capture. Through the utilization of Flash Joule Heating, thin layers of Graphene can be

[141] Rice lab turns trash into valuable graphene in a flash. (n.d.). Retrieved May 14, 2021, from https://news.rice.edu/2020/01/27/rice-lab-turns-trash-into-valuable-graphene-in-a-flash/
[142] Home. (n.d.). Retrieved May 14, 2021, from https://www.graphene-info.com/tags/rice-university

used to form composites of graphene with building materials. This is especially useful, as the incorporation of Graphene with cement offers a large opportunity for a more environmentally friendly usage of cement. Small amounts of graphene within concrete make concrete more durable, thus concrete would be produced at lower levels. This would entail a reduction in carbon emission as well as allow for cheaper production of this widely used building material. Transportation vehicles would incorporate graphene, extremely light yet being 200 times stronger than steel, within the material used, allowing for the vehicle to have a lighter mass and reducing factory usage, thus reducing the overall carbon footprint. All transportation used in Fordhamopolis, including public transportation, will utilize graphene during production to create lighter vehicles in an effort to reduce fuel consumption.

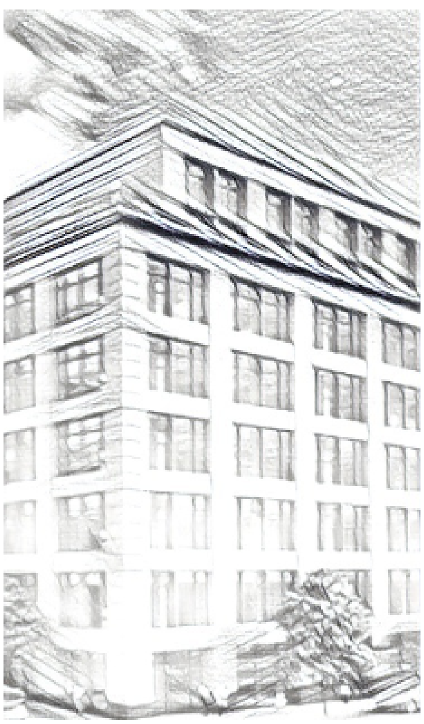

Figure 20. The buildings will have the added benefit of design flexibility when CLT is used, and unique structures will be built as a result.(Left)

CLT was created in Europe in the 1990s and has been becoming increasingly popular since creation in Europe but CLT is not frequently used in the United States. We intend to follow along with Europe's trend for Fordhamopolis' office buildings and healthcare centers. It is an appealing choice for buildings in the northwest due to CLT being fire resistant and has done well during earthquake tests. Utilizing wood correctly could possibly lead us to creating a substantially negative carbon footprint for apartment complexes. It may also be possible to counteract to a certain extent an amount of the heating and cooling energy use. Choosing to have the apartment complexes constructed out of cross-laminated timber will also speed up the amount of time it will take to build the apartment complex as well as it being easier for it to be completed. Factoring in both of these advantages we would be lessening the amount we would have to pay for labor and the costs to transport fuel and on-site energy use will also be decreased. Overall, we are seeking to build a more sustainable environment for people to inhabit and lead healthier lives.

Figure 1 - CLT Conceptual Diagram

Figure 21. Wood construction used together with sustainable forestry can grow the carbon sinks in Fordhamopolis.(Above)

A 2020 study discovered that the carbon storage capacity of buildings is not greatly altered by the kind of wood, type of building, or its size; instead it is affected by the number and the volume of wooden elements that were utilized in the structural and non-structural parts of the building. In order for Fordhamopolis to have carbon-neutral construction we are going to make it a priority to give attention to the amount of wooden elements in our buildings. Our wooden buildings will eject the very least amount of GHG emissions, compared to concrete or steel buildings, throughout their life cycle.

Furthermore, farmers that live on the outskirts of Fordhamopolis will be using conservation tillage to enhance water quality, decrease production expenses, and improve nutrition retention. Soil erosion will be controlled by using no-till and additional conservation tillage practices. By using conservation tillage practices farmers will also have the advantage of [143][144]being able to sequester more carbon than regularly used agricultural tilling practices. Conservation tillage used together with cover crops will substantially expand the soil organic carbon. Using conservation tillage with cover crops will increase infiltration, nutrient retention, and lessen erosion possibility.

Zero-till systems have the added advantage of needing a smaller amount of fossil fuel for machinery passes. Fuel usage in conventional systems in the United Kingdom and also in Germany differs from 0.046-0.053 t C ha-1 yr-1; although for zero-till systems, it is only 0.007-0.029 t C ha-1 yr-1 (0.007 is for direct energy use only; 0.029 includes the embodied energy in herbicides). In contrast with the reductions from decreased carbon loss and increased carbon sequestration in soils, these stand for a little amount of complete reductions totaling more or less seven percent.

Concerning conservation tillage, our farmers can benefit regarding the amount of time they spend working, energy and price of their materials. Tillage and harvest depict the largest amount of fuel consumption in conventional tillage systems.[145] Farmers will use cover crops such as legumes, grasses, and forbs that are planted to supply seasonal soil cover when the soil would usually be uncovered. This occurs prior to the major crop materializing in the spring or following

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[143] Schahczenski, Jeff, and Holly Hill. Agriculture, Climate Change and Carbon Sequestration. (2009)

[144] Robert, Michel. “SOIL CARBON SEQUESTRATION FOR IMPROVED LAND MANAGEMENT.” 2001.on Sequestration.” 2020.

[145]“Carbon Sequestration - Conservation Tillage and Cover Crops.” Carbon Sequestration - Conservation Tillage and Cover Crops | MN Board of Water, Soil Resources, bwsr.state.mn.us/carbon-sequestration-conservation-tillage-and-cover-crops.

fall harvest.

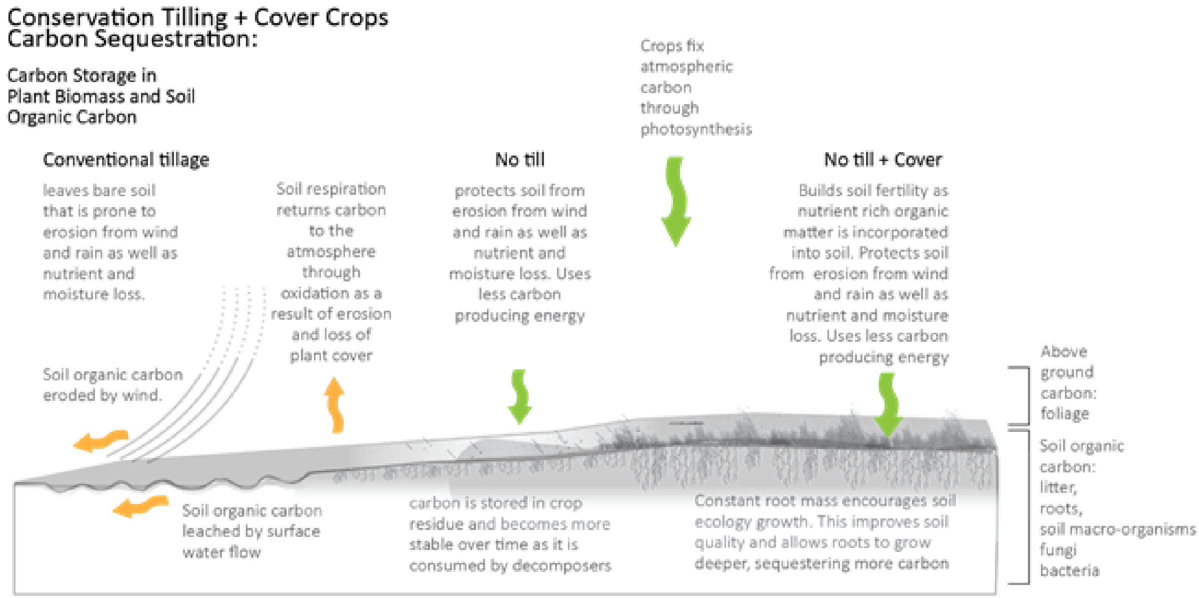

Figure 22. Cover crops sequester carbon by including biomass onto the soil surface and under the ground. (Above)

Cover crops promote advantageous root-zone fungi, bacteria, and invertebrates which play a part in soil carbon and shield it gradually by creating aggregates. Aggregates are beneficial because they grow to a large extent, the soil's robustness and fruitfulness. Farmers will plant towards the end of the summer to permit cover crops to produce a considerable amount of biomass for the duration of fall and a second time in the spring. Winter rye will be the picking of farmers due to it being more immune to decay compared to other cover crops.[146]

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[146] SARE Outreach. "Conservation Tillage Systems in the Southeast Soil Organic Matter and Carb
www.triplepundit.com/story/2016/hidden-carbon-benefits-cross-laminated-timber/27481.
bwsr.state.mn.us/carbon-sequestration-conservation-tillage-and-cover-crops.

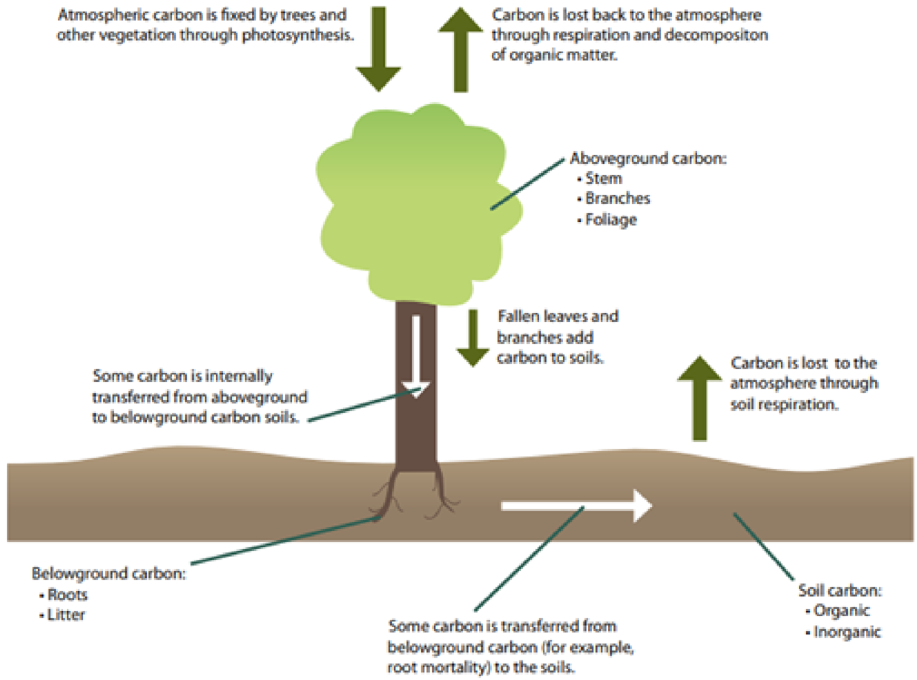

Figure 24. Combining alternating fiber and solid composition makes CLT not only thin and light but also durable. (Above)

For the majority of the 20th century, a large portion of Oregon's economy was commanded by the lumber industry by some means or other. Due to the copious amount of forests in the Pacific Northwest, and specifically, Portland's means of entry to the Willamette River, Portland became a notable timber city and port. Customarily, lumber is manufactured in standardized proportions and is utilized in a multitude of individual ways. Unconventionally, cross laminated timber panels are generally constructed for particular building projects. Building with sustainably harvested wood generates a considerable quantity of evaded greenhouse gas emissions. Fordhamopolis will harvest and produce their own wood resulting in less energy being used compared if steel or concrete were being produced. The carbon emitted to make a ton of concrete is approximately eight times that is emitted when we will manufacture a [147][148]ton of framing lumber. Steel producing emits approximately twenty-one times as much carbon as an equivalent weight of framing lumber.

Table 1–3. Net carbon emissions in producing a tonne of various materials

Material	Net carbon emissions (kg C/t)[a,b]	Near-term net carbon emissions including carbon storage within material (kg C/t)[c,d]
Framing lumber	33	–457
Medium-density fiberboard (virgin fiber)	60	–382
Brick	88	88
Glass	154	154
Recycled steel (100% from scrap)	220	220
Concrete	265	265
Concrete[e]	291	291
Recycled aluminum (100% recycled content)	309	309
Steel (virgin)	694	694
Plastic	2,502	2,502
Aluminum (virgin)	4,532	4,532

[a]Values are based on life-cycle assessment and include gathering and processing of raw materials, primary and secondary processing, and transportation.
[b]Source: EPA (2006).
[c]From Bowyer and others (2008); a carbon content of 49% is assumed for wood.
[d]The carbon stored within wood will eventually be emitted back to the atmosphere at the end of the useful life of the wood product.
[e]Derived based on EPA value for concrete and consideration of additional steps involved in making blocks.

Figure 25. When everything is considered in unison, building with sustainably harvested wood can in effect offset greenhouse gas emissions.(Above)

It is instrumental for lessening the total amount of carbon dioxide within the air that we breathe that is unfortunately a factor in climate change. A life-cycle analysis study of two five-story

[147] "Could Wooden Buildings Be a Solution to Climate Change?" BBC Future, BBC, www.bbc.com/future/article/20190717-climate-change-wooden-architecture-concrete-global-warming.
[148] Salazar, James, and Jamie Meil. "Prospects for Carbon-Neutral Housing: the Influence of Greater Wood Use on the Carbon Footprint of a Single-Family Residence." Journal of Cleaner Production, Elsevier, 1 July 2009, www.sciencedirect.com/science/article/abs/pii/S0959652609002054.

office buildings, the first building was made out of cross laminated timber and the second building was made out of concrete, came to the conclusion that the existence of a CLT building consumed fifteen percent less energy than the existence of a concrete building. The cross laminated timber building had also decreased the operation energy needed by ten percent than the building made out of concrete, mostly because of the insulating advantages of the wood in contrast to concrete. A significant quantity of carbon can be sequestered in forest litter, forest trees, and forest soils. Our harvested wood products will also serve as a significant carbon reservoir, and the wood that we will use in construction sequesters carbon for the existence of our buildings.

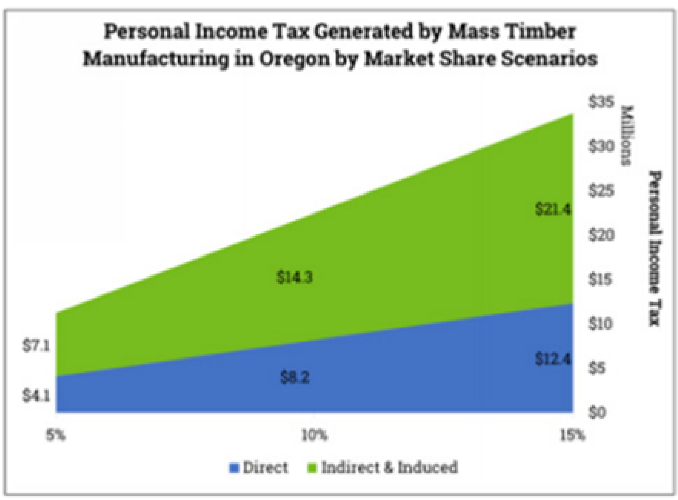

Figure 8 - Income Tax Generated12

[149]While the environmental advantages have repercussions for Fordhamopolis in general, our manufacturers and builders are required to actively support cross laminated timber to make it a normal option as a building material. *Figure 25.* Manufacturers and builders will be mostly engrossed in the time and price associations, and cross laminated timber can positively answer for each one. Panels and walls are premade in the industrial unit and elaborated by using a computer numerical control machine. When a building material is premade it is usually comparable with faster installation on-premises in assembly. The Murray Grove

[149] Salazar, James, and Jamie Meil. "Prospects for Carbon-Neutral Housing: the Influence of Greater Wood Use on the Carbon Footprint of a Single-Family Residence." Journal of Cleaner Production, Elsevier, 1 July 2009, www.sciencedirect.com/science/article/abs/pii/S0959652609002054.

project located in London, United Kingdom has eight stories and has been created by using cross laminated timber over a one-story platform made out of concrete. The building containing eight stories was able to be created within twenty-seven days which is approximately fifty percent of the usual time it takes for a concrete building to be created or possibly even shorter.

Highly developed mass production and logistic corporations will ship the premade panels in the sequence they are going to be installed, which permits the crane to pick them up only one time, and then put the panels in position. An average working party is four or perhaps five workers for this type of service, which is a smaller degree than what is needed to position concrete. Cross laminated timber is additionally approximately seventy-five percent less heavy compared to concrete. Working with lighter timber permits for reduced intensive foundations and more compact cranes on the premises in order to have more construction productivities.

The orthogonal positioning of the layers of wood permits panels to carry in two different directions which is exceedingly comparable to a slab of concrete. The strength-to-weight connection permits for better utilization of cross laminated timber buildings for mid and high-rise applications. Cross laminated timber has the capability to span up to twenty-five feet by growing the number of layers in a panel. Seismically, the cross laminated timber buildings have also functioned competently. The thermal functioning of cross laminated timber structures is amplified because of reduced air leakage from particular links in addition to thermal properties and energy conservation from the wood that was used to create the building.

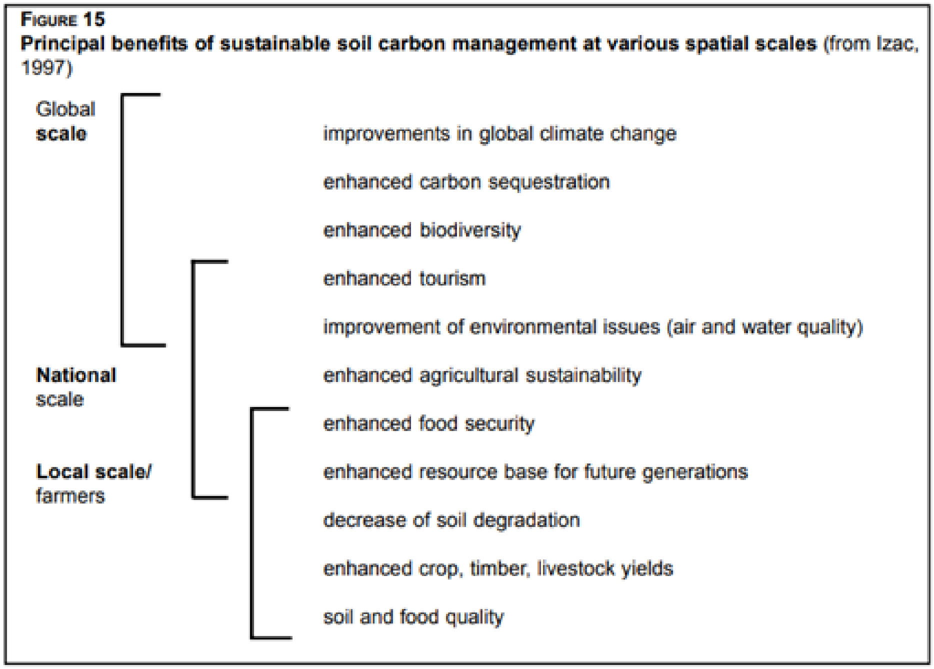

Figure 26. The capabilities of cross laminated timber buildings have been examined purposefully in regards to its structural, seismic, fire and thermal features. (Above)

[150]

DISCUSSION AND CONCLUSIONS

Additional Aspects of the City

I. Governance and policy making

To ensure that these initiatives are able to operate smoothly and successfully, a democratic and egalitarian governing system must be set in place to avoid corruption and gridlock. This system will transfer power to the residents of the city to make decisions on behalf of their communities, their ecosystems, and the planet. This power-sharing governance structure

[150] Ross, Robert J., and Forest Products USDA Forest Service. "Wood Handbook : Wood as an Engineering Material." 2010, doi:10.2737/fpl-gtr-190.

will establish Fordhamopolis as a just and equitable city where residents are guaranteed safe and low-cost resources, and will encourage citizens to become personally invested in the management of their city. Additionally, all citizens will have opportunities to engage in the decision-making process of the city. Frequent town hall meetings and community engagement initiatives will ensure that historically marginalized communities have a say in what happens in their city.

II. Public Works

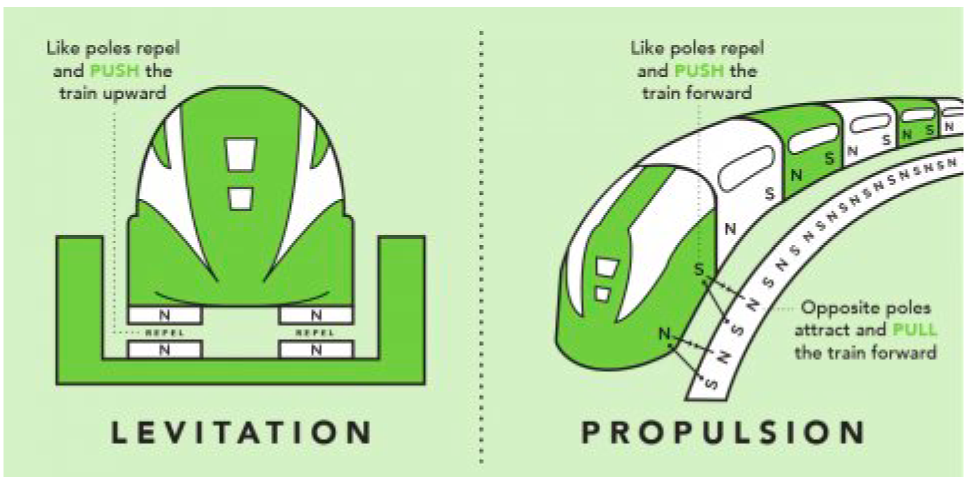

Figure 20. Model of the Maglev train.[151]

Public works, including public transportation, parks, schools and hospitals, within Fordhamopolis will abide by the goals of the four pillars as well as introduce new initiatives to connect the city's residents to each other in a sustainable fashion. Efficient public transportation will be free and accessible to all, thus encouraging residents to minimize their personal ecological footprint. Rather than using traditional subway systems which run on electricity, Fordhamopolis will implement a public transit system based on the design of Maglev trains.

[151] "How Maglev Works." Energy.gov, Department of Energy, 14 June 2016, www.energy.gov/articles/how-maglev-works.

Deriving its name from “magnetic levitation”, high-speed Maglev trains run solely on superconducting magnets, thus significantly decreasing energy consumption. Jesse Powell, the son of the Maglev inventor, describes the efficiency of these trains, stating, “With Maglev, there is no driver. The vehicles have to move where the network sends them. That’s basic physics. So now that we have computer algorithms for routing things very efficiently, we could change the scheduling of the entire network on the fly. It leads to a much more flexible transportation system in the future”. [152] Fordhamopolis will also include proper infrastructure to encourage biking and walking rather than personal vehicles, and will aim to model cities such as Copenhagen and Amsterdam where bicycles significantly outnumber vehicles. Building a cycling culture in Fordhamopolis will not only decrease air and noise pollution, but will also minimize vehicle infrastructure that traditionally creates division within cities.

III. Cultivating a Sustainable Culture

Importantly, Fordhamopolis strives to cultivate a sustainable culture. A sustainable culture is one in which the community members understand the significance of their sustainable practices to their own livelihoods as well as to others. Here, a shift takes place from an anthropocentric perspective of the world to one that recognizes humankind as in tandem with countless other organisms all interacting with and influencing each other. This is firstly accomplished through the physical design of Fordhamopolis, as has been reiterated throughout this paper. The emphasis that Fordhamopolis places on mimicking natural processes – i.e. through fog fences and solar fuel generators – helps the community to see more directly their

[152] “How Maglev Works.” Energy.gov, Department of Energy, 14 June 2016, www.energy.gov/articles/how-maglev-works.

relationship with the environment, challenging early perspectives of humans and nature as two separate entities.

This sort of environmental consciousness will be reiterated through sustainable educational programs, awareness initiatives, and funding of sustainability-focused research. The Harvesting Center is just one example of how these educational programs will be implemented into Fordhamopolis's society. Other avenues include the incorporation of a sustainability-oriented curriculum in the school setting, potentially through a greater emphasis of ecological studies, design, and fieldwork studies. By fieldwork studies, this could mean asking students to spend some time analyzing the structures and functions of their residential buildings, or taking class tours around Fordhamopolis to construct diagrams of the interconnections between the various systems at its foundation. Awareness initiatives might include monthly town hall meetings that address citizen's perceptions of sustainability and function within Fordhamopolis, thus ensuring that city practices are being considerate of the community's needs as well as transparent about the city's actions. They may also include the invitation of leaders from other cities to come and see first-hand the motions and motivations of Fordhamopolis, hopefully inspiring them to construct or make similar adaptations to their own cities.

Sustainable culture, as it advocates for a deeper understanding of one's relationship to other living organisms and the environment as a whole, must then include considerations for communal spaces. Green spaces and any form of protected natural parks, beaches, or coasts are essential for that matter. While rooftop gardens provide a more intimate space for residents to socialize, larger, central spaces are necessary for community members of all buildings to converge and nurture their relationships with one another.

Integration of the four pillars to create a cohesively sustainable city

By implementing these interdisciplinary ideas, Fordhamopolis will be able to address interrelated issues pertaining to resource management and distribution, sustaining natural ecosystems in the face of the changing needs and functions of human society, and mitigating environmental degradation and climate change. These four pillars of sustainability, from food production to carbon storage, are as inseparable from each other as aspects of naturally occuring ecosystems. Food production in the city will require a stable supply of water, for example, which is dependent on the efficiency of rainwater harvesting initiatives as well as safe and sustainable water treatment and recycling practices. These individual pillars are all deeply intertwined and each administer basic needs to the residents of the city while enriching the surrounding environment rather than adding new stressors to an already ailing planet.

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