Implementing The Plant: Chicago's First Vertical Farm

Researching and designing the future of urban food production, industrial reuse, and creative ecology

IPRO 336, Spring 2011

Executive Summary

With interest growing in locally grown, fresh organic produce and balanced, minimally-processed diets among certain markets of the populace, large urban centers are presenting a need for a steady supply source of fresh produce in large quantities. This need can be especially acute in cities located in the northern part of the United States with long winters and short outdoor growing seasons like Chicago, where the winter can last for over half of the year. Indoor growing businesses, such as greenhouses, cannot compete in such climates due to the extreme cold and weak sunlight common in the winter months and the exorbitant costs associated with maintaining a viable growing environment. Moving growing operations inside abandonded or underutilized industrial buildings where the environment can be more easily controlled may prove to be a profitable and workable solution. IPRO 336: The Vertical Farm focused this semester around studying the feasibility of creating a large-scale indoor growing operations, maximizing a building's interoperability, low-emissions ways to power and heat such buildings, and developing open-source control systems for such operations.

The sponsor for this project is John Edel, owner of The Plant, a former meatpacking plant Edel is converting into a small food business incubator and manufacturing facility. Edel has a history of repurposing unused warehouses and creating "green" or sustainable enterprises in these spaces, starting with the Chicago Sustainable Manufacturing Center on Chicago's South Side. Warehouses are good candidates for indoor growing operations since their interiors are mostly empty space with few pre-existing walls and finished spaces and their floors are designed to handle heavy loads for prolonged periods of time. Previous semesters' work has centered around feasibility and space programming studies of a six floor warehouse currently owned by the City of Chicago, located at 39th and Morgan on Chicago's South Side, which Edel hoped to purchase for a mixed-use development of light manufacturing, indoor farming, retail, and food service. However, due to the difficulties in the sale of such a building, a smaller property—a former food manufacturing plant—was purchased at 47th and Loomis, to be developed into a mostly growing-centered facility.

Spring 2011 IPRO 336 students divided into four groups at the outset to study different yet interrelated parts of the concept. The **Indoor Farming Systems** group expanded the first phase of a large-scale experimental aquaponics system built in the Fall of 2010 with the design and construction of germination and fish-breeding systems. The **Computer Controls** team worked with the Indoor Farming Systems team to develop a working interface that would be able to monitor and remotely control the environment within the growing space, while the **Biogas Reactor Test Systems** team designed and built three small-scale biogas reactors to study feedstock mixtures for a large-scale power system. Finally, the **Architectural Concepts** team worked with Edel and SHED Architects to examine ways to include living walls and a rooftop greenhouse into the overall practice of the building. With such large areas covered by each team, sub-groups took on specific foci and tasks within these four main groups, which are explained in greater detail further in the report.

Purpose and Objectives

Indoor Farming Systems

Aquaponics (the combination of recirculating aquaculture and hydroponics) is the practice of growing fish—in IPRO 336's case Nile tilapia—in a closed-loop system where expensive chemical and mechanical filtration is replaced with biological treatment in the form of microbes and plants. Plants float on the surface of a flowing bed where they take up the nutrients created by the fish, meaning that the water returned to the fish is clean and reactivated for them. In past semesters, IPRO teams had investigated the viability of different systems in order to fully take advantage of the energy expended in the lights and water pumping, and a large-scale system was then built to create an experimental center to study the feasibility of expanding operations to large industrial buildings. Since existing research and design parameters are non-existent for this kind of operation, a large part of the effort is intended in creating the necessary knowledge resource to allow other practitioners to fully implement this practice. Looking to expand the work of previous semesters, the Indoor Farming Systems team looked into ways to expand the reach and quality of the feedstock to the growing systems, by designing and building a breeder system for fish and a germination system to grow plants from seedlings.

Computer Control Systems

The Computer Control System has two main functions with regards to the aquaponics system. The first is to allow efficient control and maintenance of the system which reduces energy use and both simplifies and minimizes the labor involved in the system while providing optimal conditions for the growth of The Plants and fish. The second goal of the Control System is to collect operational data from both automatic sources (sensors/actuators) and manual input sources (growth speeds, complex chemical analysis). This operational data will be used to better understand the system and to assist in experimentation and research in both future IPRO courses and The Plant's operational research team. The system can best be described as a distributed real-time embedded system or a Cyber-Physical System (CPS).

During the previous IPRO (Spring 2010) the control system went from an idea to a fully functional prototype. The prototype was operational in controlling the previous iteration of the aquaponic system built in our sponsor's previous building to its shutdown upon completion of the current system. The Control System consists of a central server which connects to a micro-control 'Arduino' board. Once configured the Arduino is capable of controlling the light cycles and air/water temperatures without communication to the server. The server may also issue requests to the Arduino to receive information about the current state of the environment. Work has been done over the summer and previous semester through an independent study to design a control system which is generalized and scalable. The next iteration of the control system will provide a platform with three main functionalities:

1. A network communication system which allows the server to communicate with Arduinos and Arduinos to communicate with each other. JSON-RPC, a Remote Procedure Call specification, has been chosen for implementation. This will allow communication to be much more flexible than with the previously used hard coded binary protocol.
2. A generalized transducer framework for the Arduino to allow for quick a uniform integration of new sensors and actuators into the platform.
3. A configuration interface, specified in JSON-RPC to allow the server to tell the Arduino which transducers it is connected to. This will allow the continued use of simple and inexpensive analog transducers and will allow configuration of the system from a central location.

Using this platform we will build the functionality for the control of the aquaponics system while also allowing the flexibility to build control systems for other processes within The Plant such as the anaerobic digester and the Combined Heat and Power system.

Biogas Reactor Test Systems

Growing indoors requires a lot of energy on a continuous basis. Growing lights and water pumps require continual electrical supply and heat and humidity management. In addition, our sponsor has expressed a strong desire to make the building as power and waste neutral, with a goal for net-zero energy operations. Part of achieving this goal involves the sourcing of a new way to both supply electricity to the building at a lower-than-utility rate and to supply the necessary heat for all of the building's operations. Over the past year, different possible energy sources have been investigated to supply a combined heat-and-power system, with the most viable option being a biogas-fed turbine. In order to better understand the possible outcomes of the biogas and to understand the process for a full-scale system, three bench test units were designed with a standalone gas-cleaning apparatus. The goals set out at the beginning of the semester were:

1. Understand the basic pitfalls of the anaerobic digestor system, and develop firm, experimentally-derived numbers to properly size the full-scale biogas production facility.
2. Explore different experimental / operational systems to clean, store, and deliver biogas to the combined heat & power system.
3. Establish relationships with possible feedstock suppliers.

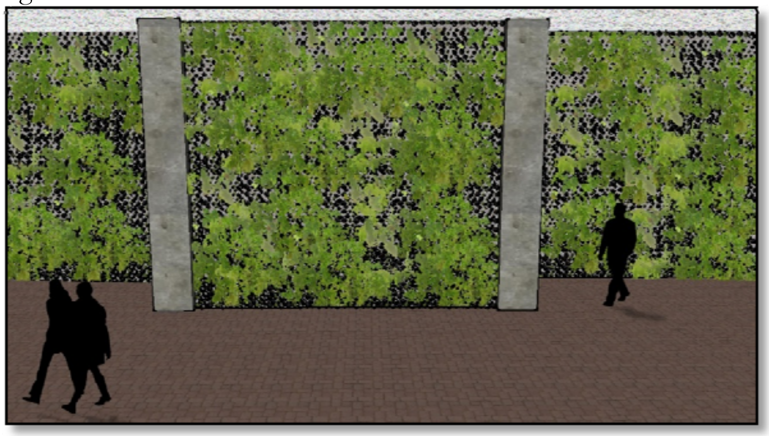
The Biogas Reactor Test Systems team faced several challenges, the first being that none of the students had been exposed to the regular operation of such a digestor, and a marked dearth of published literature on the subject reflecting our necessary goal. Anaerobic digestion is primarily used as a solution to reduce the amount of landfilled waste for certain operations confronted with a single, large source of feedstock. Wastewater treatment facilities, dairy farms, food processing facilities all use these systems to reduce the bulk and mass of their solids, but use a single-source, thereby any biogas harvesting is ancillary to the goal, whereas The Plant is looking to import waste to get the best biogas output. Therefore, reliable research does not exist on the ideal feedstock or even operational side of digesters, so this team is looking for better ways to accomplish this goal.

Architectural Concepts

As part of the integration of the concepts embodied in the operations of The Plant, Edel encouraged the Architectural Concepts Team to concentrate on two areas – the main entrance and lobby with a living wall made from recycled materials and integrated aquaponics systems; and a rooftop greenhouse that will act as a three-season growing space and space of respite for all occupants.

The team began its research into the Living Wall design with investigations into currently available systems that allow this kind of presentation, and extending into different crops that would be ideal for a vertical growing system. By working with different concepts for the look and "feel" of this entrance, the team developed a space layout that brought together the need for a wheelchair accessible ramp, a main entrance with reception and receiving areas, and a dramatic focal point that embodies the philosophy of The Plant. Figure 1 shows an example of a conceptual living wall.

Figure 1



The second area under the group's purview was the design of a rooftop green house. The vertical farm encourages ecological and sustainable approaches within the walls of the building, and the vertical living wall embodies The Plant at the entrance. With a rooftop greenhouse growing space, excess heat and exhaust air can be pushed through additional revenue-producing square footage to integrate all of the building's operations and ensure net-zero energy use. A thorough research of the most effective materials for the construction of the green house was undertaken, and necessary environmental controls and conditions were also outlined, with a special emphasis on reusing materials that might already be within the existing building.

Organization and Approach

Overall Course

With four distinct groups operating and researching seemingly disparate topics, an important part of the overall course was concentrated on maintaining focus and maximizing the integrative aspects of all the teams. Initially, the class met on the IIT campus to go over the initial concepts and designs, highlighting interactions and allowing everyone input on design reviews. The second half of the course was then spent working on the implementation of the designs at The Plant during the regularly scheduling class and other times. Some students' assignments tended to spill over into different groups as the semester's work progressed and their opportunities, interests, and labor demands changed, leading to an adaptive approach to labor and responsibilities. Most of the work approach has been outlined in the previous section, and so does not need to be reiterated here.

Indoor Farming Systems

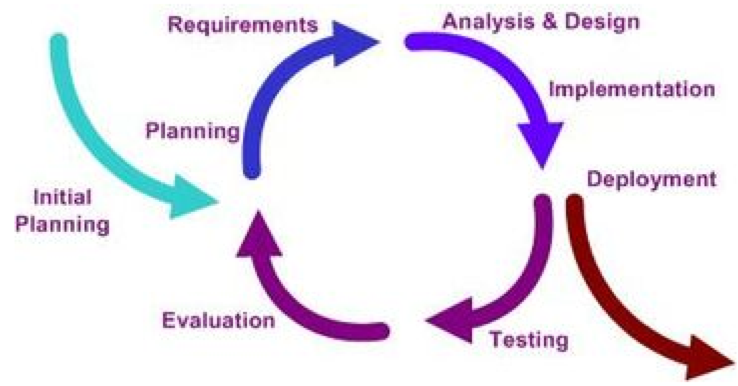
Iterative design reviews and development led to the balance of work taking place at The Plant, where constructability and practical considerations were achieved with constant and informal consultations to the applicability of different systems. For example, ensuring the structural stability and maintainability of the germination system and the fish breeding system were confronted as time went on.

Computer Controls

By using an open-source computer language and microprocessing control board to manage the different variables in the working farm, the computer controls team built a working prototype computer system for the initial aquaponics prototype housed in the Chicago Sustainable Manufacturing Center. With the construction of the larger system at The Plant, a new, more muscular system was developed that allowed for the greater application of different sensors and operations parameters. Using market-available sensors and control boards and building a product, the computer controls team developed protocols to monitor and control the lighting, temperature, and humidity of the prototype room, and to do this remotely from a desktop computer via an Internet connection.

The team employed an iteration based software engineering approach to identify and correct problems, as best described in Figure 2.

Figure 2. Iteration-Based Problem-Solving Approach



Biogas Reactor Test System

Since none of the Biogas Reactor Test team had experience in the design or construction of such a system, the iterative approach was once again employed, where designs were developed and then refined through first the theoretical design stages to eventual final implementation. The gas-cleaning system was copied from a laboratory system used in the Chemical Engineering department, with and faculty in the Environmental Engineering department helped find biologically active sludge to prime the pumps of the digester. The use of the Chemical Engineering department's mass spectrometer was also pledged to identify and grade the quality of the outgoing gas.

Architectural Concepts

With the goals and concepts described in the previous section, the Architectural Concepts team divided into two groups to focus on both the entranceway and the rooftop greenhouse simultaneously. With a registered architectural firm volunteering many services for The Plant in terms of maintaining drawings and code compliance, the entranceway/lobby sub-team worked closely with SHED Studio architects to work out the best manner of integrating designs into the building. As is common in the conceptual development process iterative meetings with the sponsor and architects helped refine the designs and basic analysis.

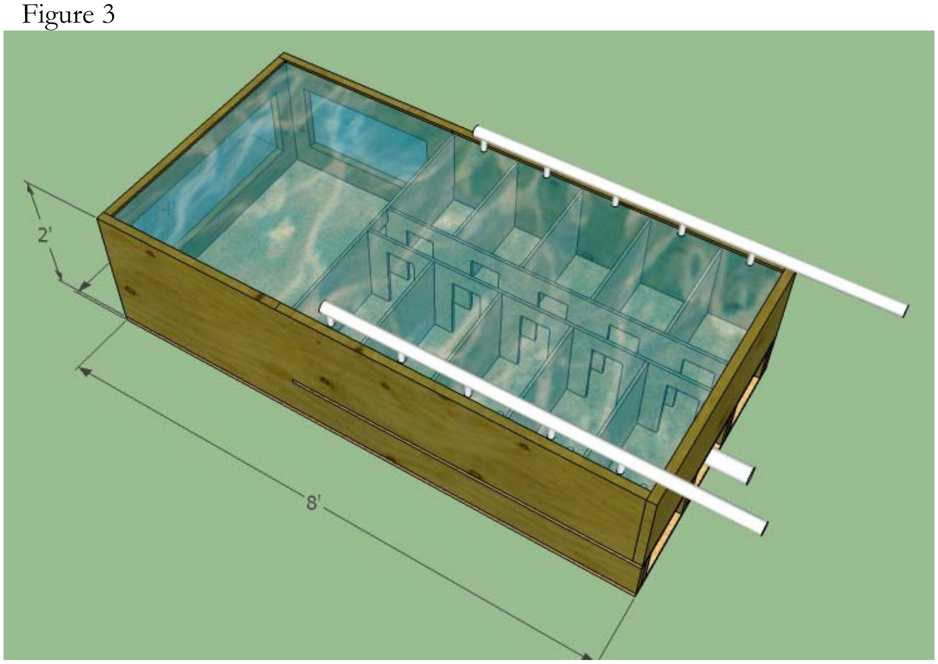
For the rooftop greenhouse, a sub-team composed of architects and civil engineers worked together to work out the best approaches for a low-cost, energy efficient design. Structural, thermal, and operational concerns were routinely considered to come up with the final design, the results of which are visible in later sections.

Analysis and Findings

Indoor Farming Systems

The designs developed for the germination and fish breeding systems have been installed in The Plant and are nearing operational completion. The systems as completed are designed to offer minimal maintenance, maximize material and operational efficiency, and provide seamless operations to the working Plant employees. Figure 3 is a rendering of the breeder system, which provides a stress-free environment for the brood colony of fish to live and move about without having to leave the water – a traumatic experience which can lead to the loss of hatchlings and disrupt the overall production system. The breeding colony lives in the large tank along the end, and then batches of fish fry are hatched and grown to a sufficient size in each of the smaller sections before being moved to the production systems. As far as the group can tell, this is the first tank of its kind, and solves the unique problem of the fish losing their babies during the hatching process.

Figure 3



The germination system uses water from each of the large production systems to feed densely-packed seedlings in a closed environment to maximize the operations of the large system. Seedlings need little light and a high-humidity environment to grow best, and so do not need the intense light provided on the large system's grow bed. By providing the large system with larger plants at the outset, better production can be ensured and the nutrient balance can be maintained within the system.

Computer Controls

The Plant's system has a working prototype which includes basic sensors and basic control. These basic sensors and controls include: air and water temperature, light intensity, heating and cooling, lights

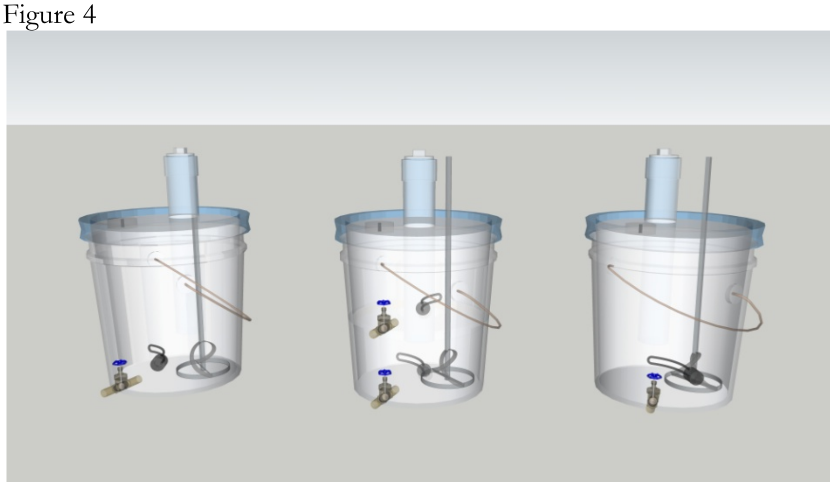
Further research on implementing includes: PH levels in water, CO_2 levels, O_2 levels, nitrates, nutrients, water levels, ammonia, automatic fish feeding.

Our system uses a main computer as a server for storing and hosting information, and as the backbone for the farm. In each "room", designated by a plant type and/or physical barrier, there is a separate embedded control system that communicates directly with the server. If the server were to fail, these embedded systems remain unharmed and continue to operate independently.

Biogas Reactor Test System

Continual design revisions and liquid-tightness issues prevented the digesters to be completely operational by the end of the semester; however, the final design of what's affectionately called "Bench Test 1.0" will be ready soon, with full experimental data being produced starting in mid-June 2011. As stated above, these systems were continually revised, and Figure 4 shows the current design of the digesters.

Figure 4



The picture above shows the three buckets, with feeding tube, heating elements, mixing stick, and drains installed.

The overall goal of these systems is their continual operation, extending well into the operational life of the full-scale operation to test and refine feedstock quantities and to test new feedstock mixes when opportunities arise.

Architectural Concepts

Figures 5-6 show the final results for the entranceway (including the living wall).

Figure 5 – Perspective of entrance ramp for The Plant.

Figure 6 – Another perspective of the entrance way.

As can be seen from the above renderings, the design of the entranceway includes both pathways to bring visitors into the building, and quiet spots for looking at the different practices ongoing within the building – farming, brewing, and cooking.

The rooftop greenhouse as shown in the following two figures takes advantage of the solar angles incident on The Plant year round to provide sunlight to rows of vegetation inside the superstructure of steel and polycarbonate. Polycarbonate sheeting is a translucent plastic sheeting made from several layers of plastics with pockets of air in between them. As opposed to glass, polycarbonate is lighter, has a better thermal and impact resistance, and allows for simpler connections to a structural skeleton without need for highly skilled glaziers to install. In addition, it is more sustainably manufactured and can be found in the area easily for a good price. The line of Polycarbonates recommended for The Plant is a 16mm triple-wall material, with a diffused 78% light transmission and thermal resistance more than double that of glass of equivalent thickness. Figures 7 & 8 show the final design optimized for The Plant's location and operations.

Figure 7 – A view of The Plant's roof from the Southwest

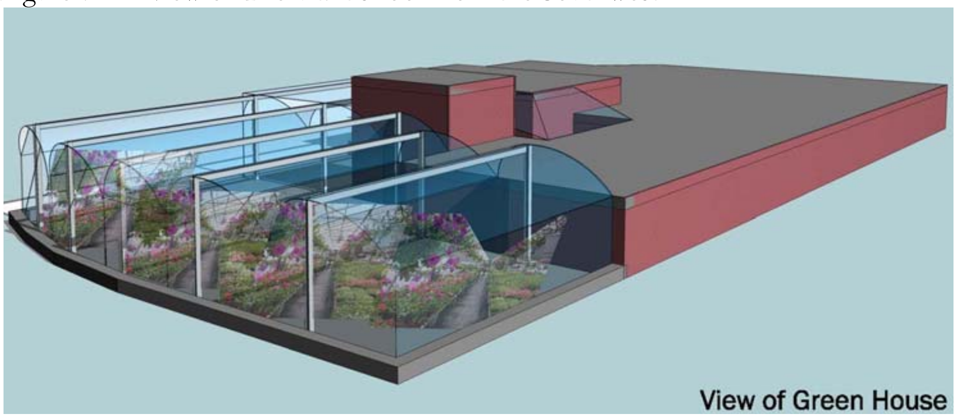
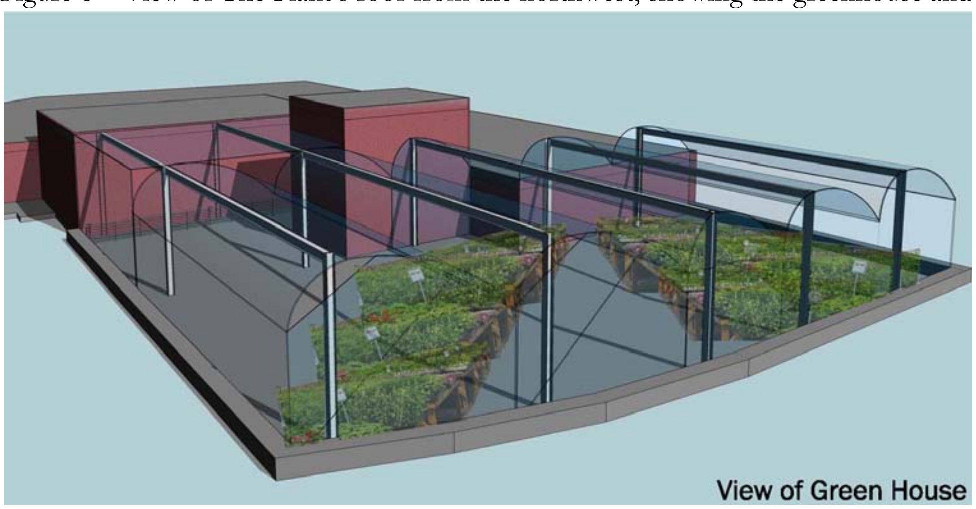


Figure 8 – View of The Plant's roof from the northwest, showing the greenhouse and structure.



Thermal modeling of such a rooftop greenhouse system is not simple, nor are parameters established for this kind of construction. While rooftop greenhouses are common around the world, their maintenance and operations are not integrated into the building, but are commonly added as afterthoughts, with any benefits/challenges being ancillary to the gardening benefits. However, by working from fundamental concepts, the greenhouse sub-team determined that the peak heat demand for the space to be approximately 145,000 Btu/hr, or approximately 6.5% of the total heat demand of The Plant. By pulling excess heat from the rest of the building into the greenhouse, most of this can be maintained with minimal primary generation. An individual report by the greenhouse team is attached to this report in the Appendix.

Conclusions and Recommendations

Indoor Farming Systems

Since The Plant—and its farming operation—will continue to operate after the IPRO is over, the concepts and systems designed and built during the semester will be continually refined and developed for future work. Fully operational completion of the breeder system and germination systems are anticipated by mid June 2011, with a continual refinement of the germination systems to come with the completion of additional large-scale aquaponics systems.

Computer Controls

A computer control system is a plausible solution to maintain and improve a full scale vertical farm. The research and development completed during this semester concluded the best locations for analysis, and began the collection of data to use in a learning environment to better understand the dynamics of the living systems. Future work can be completed by further IPROs and extensive PhD research conducted by IIT's Computer Science department, and some of the future steps the process will undergo will be to implement more sensors into the systems, expand and develop more sensor libraries for better and more accurate analysis and control.

Biogas Reactor Test System

With operational completion anticipated by mid-June 2011, the Biogas Reactor Test System will provide controllable and accurate modeling of the different feedstocks available to The Plant's operators as opportunities present themselves. Future work can include the invitation of a capstone IPRO from the Chemical Engineering department for the analysis and improvement of both the design and operations of the digester, and effective mix control parameters for the large-scale system.

Architectural Concepts

Further exploration is needed into the machinations and inner workings of the Living Wall system, and how it can be better integrated into the systems of the building. The rooftop greenhouse, with its high winter heat demands and ventilation rates, can act as a biological chiller tower, absorbing all of the excess heat from the building during both the summer and winter.

Appendix

Team Members

Academic Major or affiliations are included in [brackets]

Industry Sponsors
John Edel [The Plant]

Faculty Advisor
Blake Davis [Industrial Technology & Management]

Indoor Farming Systems
Philip Speroff [Computer Engineering]
Angela Skaar [Psychology]
Michael Schmidt [Computer Engineering]
Joel Plunkett [Electrical Engineering]
William Mocny [Chemical Engineering]
Frank Lockom [Computer Science]
Katarzyna Handzel [Architecture]

Computer Controls
Philip Speroff [Computer Engineering]
Michael Schmidt [Computer Engineering]
Frank Lockom [Computer Science]

Biogas Reactor Test System
Yao Xiao [Architectural Engineering]
Carlos Viramontes [Architectural Engineering]
Nic Sansone [Chemical Engineering]
Joseph Millham [Architectural Engineering]
Laurel Chavez [Architectural Engineering]

Architectural Concepts Team
Mariana Palau [Architecture]
Raluca Ostasz [Architecture]
Andrew Liu [Architecture]
Kaycee Kenney [Architecture]
Joseph Hallak [Civil Engineering]
Ioana Bugnar [Civil Engineering]

Project Team Budget

Indoor Farming Systems	
Basecamp upgrade(more projects,file sharing) $24/month x 4 month	$92
Broodstock MossambicaxHornorum	$200
Recirculating Aquaculture M.B. Timmons and J.M. Ebeling	$90
XXXServer(I emailed you the full parts list)	$450
XXXCisco SR224G 24+2gb switch	$150
Arduino UNO+Ethernet Shield $65×5	$325
PAR light sensor LI-190SZ Quantum Sensor	$370
XXXThere is some flexability with the testing kits:	
XXXLaMotte hydroponic 9/4 param test kit	$467/240
XXXLaMotte 9/6 param aquaculture test kit $209/174	
Cameras	
TRENDnet TV-IP110 Internet Camera Server $79.99 × 4	$320.00
One for each fish tank for IPRO day	
TRENDnet TV-IP410 Pan/Tilt Internet Camera Server	$159.99
WIFI Arduino setup	
WIFI Shield $55.00 × 2	$110.00
Arduino Accessories	
Arduino ScrewShield ($10.00 × 10)	$100.00
Arduino 5V Relay Omron G5LA $9.00 x 5	$45.00
Arduino Sensor Shield V5.0 $15.00 × 5	$75.00
Arduino Connection Cables $2.00 x 20 = $40.00	
Humidity Sensor $23.00 × 4	$92.00
Digital Temperature Sensor $5.00 x 20	$100.00
Additional Sensors	
PH, DO, CO2	$300
Anaerobic Digestor Stuff:	
PVC Piping, Fittings	$150
Plastic Buckets	$20
Heat Tape, Insulation	$50
Mass Scale	$50
Volumetric Flasks, Lab Glassware	$30
Commercial-Grade Large Food Processor, Surplus/Used	$150
Total	$450