LIFE SUPPORT

Designed by Team Food On Deck

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1 Problem Formulation

1.1 Introduction

Contained in Section 1 are the objective statement and a Black Box Model. The Black Box Model, shown in Figure 1-1, depicts the state of the Wetland Project before and after the application of our design.

In the summer of 2014, an island-based ecosystem and mobile habitat, also known as WetLand will be launched on the Delaware River in Philadelphia, Pennsylvania. Founded by Mary Mattingly, an artist based in New York City, WetLand will promote art, community, sustainable living, and environmental technology. The Wetland barge will provide a short-term home for artists and a venue for educational events. One of the goals of WetLand is to serve as a model for interdependent living and self-sufficiency. WetLand will achieve this goal by growing food on the barge; using solar power; and gathering, purifying, and storing water on site (WetLand Project Proposal).

Team Food On Deck (Rebecca Denny, Heidi Otten, Joseph Trejo, and Gavin Zirkel) has been commissioned by Mary Mattingly to design a component for the WetLand barge.

1.2 Objective

The objective of Team Food on Deck is to design an edible railing for WetLand. The purpose of the railing is to provide a safe perimeter for the barge that also provides a place to grow food. The edible railing will be sturdy, weather-resistant, and act as a self-sustainable food source model.

Figure 1-1: This Black Box Model shows the state of WetLand before and after the application of the edible railing.

2 Problem Analysis and Literature Review

2.1 Introduction
Section 2 outlines the objective as described in the objective statement in Section 1.2. This section outlines the specifications, considerations, criteria, and constraints for the design, and provides details on the different aspects of the project in a literature review.

2.2 Problem Analysis

2.2.1 Introduction
The Problem Analysis consists of the specifications, considerations, criteria, and constraints regarding the design of the edible railing. This section also addresses the usage and production volume of the final railing design.

2.2.2 Specifications
Specifications are the basic requirements of the railing. They are as follows:

- The railing will provide 25 to 30% of the daily food intake for three people per day.
- The railing will include plants that will survive in the Delaware River Basin.
- The railing and/or planters will utilize materials from the Humboldt County waste stream.
- The railing will serve to protect people from falling while maneuvering around the deck, as well as prevent them from falling overboard.
- The railing must not exceed 1 foot in width.

2.2.3 Considerations
Considerations are important aspects of the WetLand project that were inferred from the specifications, criteria, and general knowledge of the project. The considerations for the WetLand project are as follows:

- The barge will be accessible to the public.
- Three to five people may be living on the barge at one time.
- The client and the people who will be living on the barge are artists.
- The barge will be used as an educational tool.
- The barge is within the legal constraints of federal and Pennsylvania state laws.
- The barge will be outside, on the water, year-round.

2.2.4 Criteria and Constraints
The criteria and constraints for designing the edible railing were established through communication with the client and are listed in Table 2-1. These criteria and constraints are used as measurable goals throughout the project and to gauge the success of the project once complete.

Table 2-1: Each design criteria for the edible railing also has a constraint.

Criteria	Constraints
Durability	The railing must last at least three months.
Plant Locality	Plant varieties must be available and be able to survive in Philadelphia.
Cost	The model of the railing must cost no more than $400 and the entire railing on the WetLand barge must cost no more than $2000.
Environmental Justice	Building materials for the model must come from the Humboldt County, CA waste stream. For the railing on the WetLand barge, building materials should either come from the Humboldt County, CA waste stream or be available in the Philadelphia, PA waste stream.
Safety	The railing must be built to CFR specifications and waste stream materials used to grow plants must be soil safe.
Produce Production	The railing must provide at least 25 to 30% of the food for three people per day.
Ease of Maintenance	The railing must not require more than 30 minutes per person per day for maintenance.
Water Conservation	The plants on the railing must use the least amount of water possible.
Aesthetically Pleasing	The design must mix organic and synthetic material.
Ease of Replication	The design must be simple enough to be replicated by a high school graduate.
Educational Value	The processes and ideas demonstrated by the design must be able to be understood by a fourth grader.

2.2.5 Usage

The edible railing, which will be installed around the perimeter of WetLand, is both a safety measure to ensure no one falls off the barge and a source of food for the inhabitants of the barge. The railing has to last at least of three months throughout the summer beginning either in June or September. Some of the plants on the railing will grow food that can be picked daily. Others will be harvested periodically at intervals to be determined by a planting schedule.

2.2.6 Production Volume

One 8-foot prototype of edible railing will be designed and produced. A 1-inch steel conduit railing will be built on the barge. Some of the design components will be prepared locally and shipped to Philadelphia with detailed instructions for assembly. Any design components not prepared locally and shipped to Philadelphia will be arranged to be collected in Philadelphia. The 8-foot prototype will be replicated fifteen times on the barge.

2.3 Literature Review

2.3.1 Introduction

The literature review provides an in-depth summary of all research done to develop an optimal solution for an edible railing. Included in the literature review are client criteria, Philadelphia climate data, edible plants native to Philadelphia, edible plants that may grow in brackish water, general growing requirements for edible plants, types of growing systems, types of vertical growing structures, and legal railing requirements.

2.3.2 Client Information

Mary Mattingly is the founder of the WetLand project. Current partners of the project are Fringe Arts and Creative Time. The launch date for WetLand has not yet been determined. WetLand may launch June 1, 2014 or September 1, 2014, depending on whether the launch coincides with Philly Fringe's September festival or if the project participates in a water event at the Seaport Pier in June.

2.3.2.1 Dimensions

The barge is 50 feet long and 20 feet wide, therefore the railing will cover a 140-foot perimeter. The railing will not cover the entire perimeter of the barge, as gaps in the railing will allow for a gangway and water entrances. The railing is made of 1-inch, square steel conduit. The edible railing design is allotted up to 1 foot of space within the perimeter of the barge.

2.3.2.2 Number of People

There will be two to five people living on WetLand. During events, fifty to seventy people will be on the barge at one time.

2.3.2.3 Requests

The client has requested a railing for the barge that provides safety as well as food. The client would like the railing to grow enough food to provide for ten people. If possible, the client would like lights on the railing and corner planters that houses plants that use water directly from the river.

2.3.3 Philadelphia, Pennsylvania Climate

2.3.3.1 Temperature

Philadelphia has a warm temperate climate with hot summers and rainfall in every month of the year. January is the coldest month, with temperatures sometimes dipping below freezing. July is the hottest month in Philadelphia. Table 2-2 shows average monthly temperatures; average high and low temperatures; the number of days per month with temperatures above 90 degrees Fahrenheit; and the number of days per month with temperatures below freezing[1]

[1] Freezing is measured to be 32 degrees below Fahrenheit.

Table 2-2: Philadelphia's average temperatures are lowest in January and highest in July. (Climate Zone 2003).

Philadelphia Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg. Temperature	30.4	33.0	42.4	52.4	62.9	71.8	76.7	75.5	68.2	56.4	46.4	35.8	54.3
Avg. Max Temperature	37.9	41.0	51.6	62.6	73.1	81.7	86.1	84.6	77.6	66.3	55.1	43.4	63.4
Avg. Min Temperature	22.8	24.8	33.2	42.1	52.7	61.8	67.2	66.3	58.7	46.4	37.6	28.1	45.1
Days with Max Temp of 90 F or Higher	0.0	0.0	0.0	< 0.5	1.0	5.0	9.0	6.0	2.0	0.0	0.0	0.0	23.0
Days with Min Temp Below Freezing	25.0	22.0	14.0	2.0	< 0.5	0.0	0.0	0.0	0.0	1.0	8.0	20.0	93.0

2.3.3.2 Precipitation

Philadelphia gets precipitation in every month of the year, either in the form of rainfall or snow. The largest amount of rainfall occurs in July (an average of 4.3 inches), and February receives the most snowfall (an average of 6.6 inches) as is shown in Table 2-3.

Table 2-3: In Philadelphia, the greatest amount of rainfall occurs in July the most snowfall occurs in January. (Climate Zone 2003).

Philadelphia Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation (inches)	3.2	2.8	3.5	3.6	3.8	3.7	4.3	3.8	3.4	2.6	3.3	3.4	41.4
Days with Precipitation 0.01 inch or More	11.0	9.0	11.0	11.0	11.0	10.0	9.0	9.0	8.0	8.0	9.0	10.0	117
Monthly Snowfall (inches)	6.0	6.6	3.6	0.3	< 0.05	< 0.05	0.0	0.0	0.0	0.0	0.7	3.2	20.4

2.3.3.3 Other Weather Indicators

Philadelphia's average relative humidity is greater than 50% every month of the year. Most days of the year are sunny or partly sunny. The average annual wind speed is 9.5 mph. Table 2-4 shows average wind speed, number of clear days, partly cloudy days, cloudy days, percent of possible sunshine, and average relative humidity for each month of the year as well as annual averages.

Table 2-4: Philadelphia's average wind speed, number of clear and cloudy days, and average relative humidity are shown below. (Climate Zone 2003).

Other Philadelphia Weather Indicators	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Wind Speed	10.3	10.9	11.3	10.8	9.5	8.8	8.2	8.0	8.3	8.8	9.6	10.0	9.5
Clear Days	7.0	7.0	8.0	7.0	6.0	7.0	7.0	8.0	10.0	11.0	7.0	7.0	93.0
Partly Cloudy Days	8.0	7.0	8.0	9.0	11.0	11.0	12.0	11.0	9.0	9.0	9.0	8.0	112
Cloudy Days	16.0	14.0	15.0	14.0	14.0	12.0	12.0	11.0	11.0	12.0	14.0	15.0	160
Percent of Possible Sunshine	49.0	53.0	55.0	56.0	57.0	62.0	61.0	62.0	59.0	60.0	52.0	49.0	56.0
Avg. Relative Humidity	56.0	65.5	63.5	62.0	62.0	65.0	66.0	67.5	68.5	69.5	66.0	65.0	67.5

2.3.3.4 Hardiness Zone

The USDA Plant Hardiness Zone Map is the standard by which gardeners and growers can determine which plants are most likely to thrive in a location (Prism Climate Group 2012). The map is based on the average annual minimum winter temperature, divided into 10-degree Fahrenheit zones (Prism Climate Group 2012). Figure 2-1 shows a close-up view of the hardiness zone map for Philadelphia and surrounding areas.

Figure 2-1: Philadelphia lies in USDA Plant Hardiness Zone 7b (Prism Climate Group 2012).

2.3.4 Edible Plants Native to Philadelphia

An edible plant is a plant that is safe for human consumption. There is a vast diversity of plants that are edible. The following sections will outline requirements and conditions needed for several plants that are both edible and native to Pennsylvania.

2.3.3.1 Highbush Blueberry

Figure 2-2: Highbush Blueberry (Fine Gardening 2013).

Figure 2-2 shows a Highbush Blueberry plant. This species of blueberry, also known as *Vaccinium corymbosum*, is a tall blueberry shrub that can grow anywhere between 6 and 12 feet (Iconserve Pennsylvania 2011). This plant prefers coarse, medium, or fine acidic soils between a pH of 4.7 to 7.5 with minimal moisture (Iconserve Pennsylvania 2011). The Highbush Blueberry has high tolerance to salinity levels, has little tolerance for drought, and requires an annual precipitation of approximately 32 inches (Iconserve Pennsylvania 2011). This plant requires full sun and can tolerate partial sun but cannot tolerate full shade (Iconserve Pennsylvania 2011). Highbush Blueberry can handle temperatures as low as -33 degrees Fahrenheit (Iconserve Pennsylvania 2011). These plants require 6 to 10 feet of spacing per plant (Fine Gardening 2013).

2.3.3.2 Wild geranium

Figure 2-3: Wild geranium (Hilty 2013).

Figure 2-3 shows a wild geranium plant. Wild geranium, or *Geranium maculatum*, is an herbal perennial plant that can grow between 1 and 2 feet tall (Iconserve Pennsylvania 2011). A perennial plant is a plant that has a lifespan of less than two years. This plant requires moist soil that is rich, loamy, and full of organic material. The soil needs to be acidic with a pH less than 6.8 (Hilty 2013). Wild geranium needs at least 18 to 24 inches of space between each plant (Easywildflowers 2013). This plant needs a temperature range between 50 and 80 degrees Fahrenheit (Wiley 2013). Geranium prefers partial sun but can tolerate full sun (Hilty 2013). The plant can be used as tea to counter diarrhea, sore throat, inflamed gums, and mouth ulcers (University of Texas 2013).

2.3.3.3 Sneezeweed

Figure 2-4: Sneezeweed (Better Homes and Gardens 2013)

A sneezeweed plant is shown in Figure 2-4. *Helenium autumnale*, more commonly known as sneezeweed, is an herbal perennial that grows 2 to 6 feet tall (Iconserve Pennsylvania 2011). Soil requirements are a pH between 4.0-7.5 and a depth over 6 inches (USDA). This plant has low tolerance for both salinity and drought and requires an annual rainfall between 10 and 60 inches. Sneezeweed cannot handle temperatures below -43 degrees Fahrenheit and does not tolerate shade. This plant requires a spacing of 1 to 2 feet per plant (Better Homes and Gardens 2013).

2.3.3.4 Wild Bergamot

Figure 2-5: Wild Bergamot (Hilty 2013).

Wild Bergamot is shown in Figure 2-5. Wild bergamot, or *Monarda fistulosa*, is an herbal perennial that can grow 2 to 5 feet tall (Iconserve Pennsylvania 2011). This plant requires soil that is high in moisture, has a medium or fine texture, a depth of over 4 inches, and a neutral pH of 6-8 (USDA). This plant has no tolerance to drought or salinity and needs an annual rain fall of 20 to 60 inches. Bergamot needs a temperature higher than -32 degrees Fahrenheit to survive and thrives in either partial or full sun (Garden 2013). Wild Bergamot can catch powdery mildew disease and can be invasive in a garden (Garden 2013).

2.3.3.5 Serviceberry

Figure 2-6: Serviceberry (USDA).

Figure 2-6 shows a serviceberry plant. Serviceberry, or *Amelanchier arborea*, is a fruit tree capable of reaching heights of 20 to 30 feet and as the name implies, produces edible berries (Iconserve Pennslyvania 2011). Serviceberry requires moist soil with a medium to coarse texture and a pH between 4.8 and 7.5 (USDA). This plant has low tolerance for drought and salinity. Serviceberry survives in temperatures greater than -47 degrees Fahrenheit and requires medium water usage. Under ideal conditions, this fruit tree has a medium fruit production. This tree tolerates full sun and full shade (University of Texas 2013).

2.3.3.6 Wild Plum

Figure 2-7: Wild Plum fruiting (Hilty 2013).

A wild plum plant is shown in Figure 2-7. Wild plum, or *Prunus Americana* can grow 15 to 30 feet tall (Iconserve Pennsylvania 2011). This tree can survive in temperatures greater than -38 degrees Fahrenheit and requires soil that has a medium to coarse texture and is over two feet deep (USDA). This tree has low tolerance to salinity and requires an annual rainfall of 16 to 40 inches. The soil needs to have a pH range of 6.8 to 7.2 and requires medium water use (University of Texas 2013). Everything but the skin and flesh of the plum fruit is toxic if consumed such as the leaves, roots, stems, etc. (Wildflower 2013).

2.3.3.7 Elderberry

Figure 2-8: Elderberry (USDA).

An Elderberry plant is shown in Figure 2-8. Elderberry, or *Sambucus Canadensis*, is a berry shrub that grows black edible berries and can grow from 5 to 15 feet tall (Iconserve Pennsylvania 2011). This berry plant requires medium water use and an annual rainfall of 34 to 60 inches. Elderberry has moderate tolerance for drought and no tolerance to salinity. This plant also cannot tolerate temperatures below -28 degrees Fahrenheit (USDA). Elderberry prefers rich moist soil that is slightly acidic and prefers partial shade (University of Texas 2013). There are small levels of toxicity in the leaves, stems, roots, and unripe berries if consumed (University of Texas 2013).

2.3.3.8 Joe-Pye-Weed (Trumpet Weed)

Figure 2-9: Trumpet Weed (Connecticut Botanical Society 2013).

Trumpet weed is shown in Figure 2-9. *Eupatorium fistulosum*, trumpet weed, or Joe-pye-weed is a perennial herbal plant that can be grown between 3 to 10 feet tall (Iconserve Pennsylvannia 2011). Trumpet weed prefers moist soils containing lime and can endure full sun or partial shade (University of Texas 2013). This plant is known as a weed in some places due to its aggressive growing behavior (Beaulieu 2013).

2.3.3.9 Wild Boneset

Figure 2-10: Wild Boneset (Hilty 2013).

Wild boneset is shown in Figure 2-10. *Eupatorium perfoliatum,* or wild boneset, is a perennial herbal that can grow 1 to 5 feet tall (Iconserve Pennsylvania 2011). This plant can thrive in either full sun or shade and requires moist soil that consists of sand, clay, and moderate amounts of organic material (University of Texas 2013, North Creek Nurseries 2013, Hilty 2013). This plant is flood tolerant, but cannot exist as an aquatic plant (Hilty 2013). Boneset can be made into tea to treat cough, cold, and constipation (University of Texas 2013). In large doses this plant can act as a laxative (Debbie 2008).

2.3.5 Edible Plants That May Grow in Brackish Water

The water in the Delaware River is brackish[2], thus plants that are salt-tolerant must be considered. A study from the US Department of Agriculture (1999) gives an overview of edible plants that are salt sensitive and those that are only moderately salt sensitive. Other edible plants not in this study have also been known to thrive in brackish water.

2.3.5.1 Edible Plants That Thrive in Brackish Water

2.3.5.1.1 Cherry Tomatoes

Cherry tomatoes have been grown by Israeli scientists in a mixture of freshwater and brackish water. In the Negev desert, the scientists found that the cherry tomatoes grown using this mixture were among the sweetest-tasting in the world. This difference in taste was attributed to the tomato plants striving to balance the high osmotic pressure[3] of the brackish water by boosting their production of sugar (Hayden 2007). Tomatoes grown by watering with a salt-water solution have been known to ripen faster and produce smaller fruits (Mizrahi 1981).

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[2] Having more salt than freshwater and less salt than ocean water.

[3] The pressure exerted by the flow of fresh water through a semipermeable membrane to mix with salt water.

2.3.5.1.2 Celery
Wild celery is classified as salt thriving (Shannon, Grieve 1999). Cultivated celery was derived from wild stock which grew naturally in brackish marshes, near tidal waters, and near the sea in Sweden, Algeria, Egypt, and Abyssinia (Shannon et al 1999).

2.3.5.1.3 Cattails
Cattails grow naturally in full sun areas in lakes, streams, rivers, canals, and in brackish water (Wilderness Survival 2001). The cattail is a unique wild food source as almost every part of the plant can be harvested for food (Plaisted 2006). Figure 2-11 shows the different parts of the cattail. The young tender shoots are edible raw or cooked. The rhizome[4] is often very tough, but is a rich source of starch. To harvest the starch the rhizome must be pounded. Once the starch is removed it can be used as flour. The pollen is also a source of starch and protein (Plaisted 2006). When the cattail is still green, the immature flower head can be boiled and be eaten like corn on the cob (Wilderness Survival 2001).

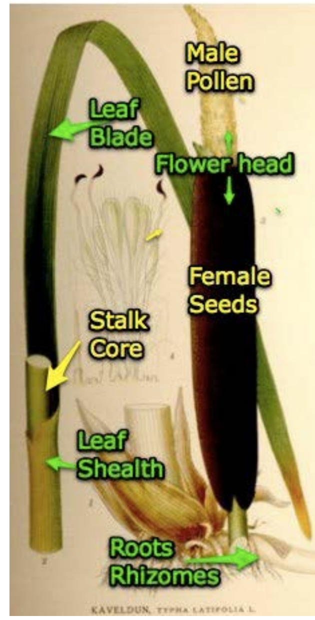

Figure 2-11: Most parts of the cattail plant are edible (Hole In The Fence).

2.3.6 Basic Plant Requirements
All plants have four basic requirements for growing: nutrients, sunlight, water, and space.

2.3.6.1 Nutrient Requirements
The most essential nutrients plants need to grow are nitrogen (N), phosphorus (P), and potassium (K). Nitrogen plays a key role in the plant's production of chlorophyll[5] and in the plant's production of protein. If the plant does not receive enough nitrogen, the leaves may be pale green or yellow, and the plant will not develop to full size. Plants need phosphorus in order to produce high quantities of vegetables. Phosphorus is one of the main components in the process that supplies energy to the plant. Plants need potassium to help regulate their water content and expansion (The Ohio State University 2011).

In addition to nitrogen, phosphorus, and potassium, plants also need calcium (Ca), magnesium (Mg), and sulfur (S). These nutrients are necessary for plant production, but are needed by plants at lower levels than nitrogen, phosphorus, and potassium. Calcium is used in the plant to reduce physical damage as well as disease. The plant's growth is supported by both magnesium and sulfur (The Ohio State University 2011).

There are several micronutrients that plants need that affects the growth of the plant through photosynthesis[6]. These nutrients include iron (Fe), boron (B), zinc (Zn), and molybdenum (Mo) (The Ohio State University 2011).

[4] Underground part of the cattail stem.
[5] The green pigment that is responsible for photosynthesis.
[6] The conversion of sunlight and water into sugar.

In soil, the nutrients that plants need are decomposed from organic and inorganic materials into inorganic elements. The elements adhere to soil particles and are released into the soil solution to then be absorbed by the plants (Dunn). In a hydroponic nutrient solution, the nutrients are mixed in their elemental form with water and then that nutrient solution is supplied to the plant's roots directly (Dunn). Section 2.3.6.4 discusses hydroponic nutrient solutions more thoroughly.

2.3.6.2 Sunlight Requirements

The sunlight requirements for plants vary depending on the species of plant being grown. The amount of sunlight a plant will tolerate can be divided into three broad categories: full sun, partial sun, and full shade. Full sun is defined as 6 to 8 hours of direct sunlight per day. Partial sun is defined as short periods of direct sunlight or dappled sunlight that can be caused by an overhanging tree. Full shade is defined as very little to no sunlight (Grafman 2013).

2.3.6.3 Water Requirements

The water requirements for plants are highly variable based on the type of plant being grown. A general guideline for watering vegetable plants is 1 inch of water per week. During the hot summer months, the recommendation is to give 0.5 inches of extra water per week for every 10 degrees the average temperature is above 60 degrees Fahrenheit (Bonnie Plants 2013). Since Philadelphia's average temperature for June is 71.8 degrees Fahrenheit, plants should receive approximately 1.5 inches of water per week. In July and August, when average temperatures are 76.7 degrees Fahrenheit and 75.5 degrees Fahrenheit, plants should receive approximately 1.5 to 2 inches of water per week, respectively.

2.3.6.4 Space Requirements

The space requirements for plants vary depending on the species of plant being grown. In general, most plants can tolerate a small growing space, although they would prefer more space. Table 6-1, found in Appendix C, shows the space requirements for several plant species.

2.3.7 Growing Systems

The following sections provide a brief overview of the most common types of systems used to grow edible plants.

2.3.7.1 Traditional Soil System

Growing plants in soil is the most traditional method of gardening. The requirements of a soil growing system are a soil medium, a space or container to hold the soil medium, and water.

2.3.7.2 Hydroponic Systems

Hydroponics is the practice of growing plants without soil (Fedunak 1997). Instead of a soil medium, the plants are grown in liquid medium. Hydroponics has grown in popularity around the world because these systems can use space efficiently and can be used in urban areas where land to grow plants is not available (Midmore). The elimination of the need for a soil medium allows plants to be grown where soil may not be suitable for growing plants (Grafman 2013). Hydroponics is most commonly practiced indoors or in greenhouses, but can be successfully done outdoors (Jensen).

An advantage of all hydroponic systems is that the growing environment greatly reduces the likelihood of spreading plant disease and infection that is commonly found in soil (Spinoff 2006). Plants will also grow differently in hydroponic systems compared to other growing systems. While seedlings roots are forming, they do not stretch or wilt. Transplanting seedlings from a hydroponics system is easier than from other types of growing systems because the risk of transplant shock is diminished (Spinoff 2006).

There are several types of hydroponic systems. These include wick, water culture, ebb and flow (flood and drain), drip (recovery or non-recovery), N.F.T. (Nutrient Film Technique), and aeroponic systems (University of Florida).

2.3.7.2.1 Wick

Wick systems are passive systems, or in other words use no moving parts. Figure 2-12 shows the parts needed for a wick system, which include: a reservoir to hold the liquid nutrient solution; an air pump and an air stone to aerate[7] the liquid; a grow tray with growing medium; and a wick to deliver the liquid to the grow tray. The most popular types of growing mediums in this type of system are perlite, vermiculite, Pro-Mix, and coconut fiber. This type of system is not suitable for larger plants, as they may need larger amounts of water than the wick(s) can supply (University of Florida).

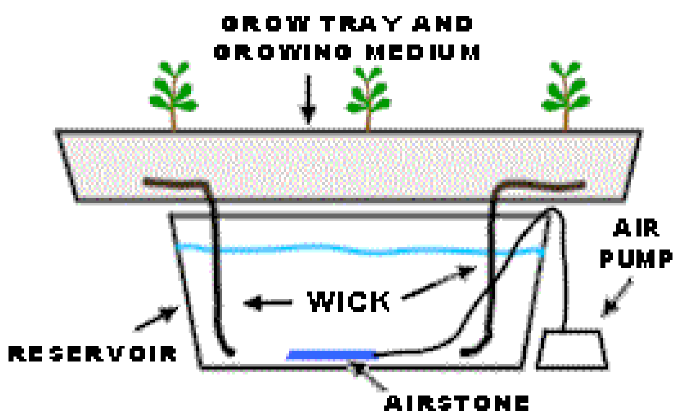

Figure 2-12: This generalized hydroponic wick system utilizes two wicks to absorb nutrient solution and deliver it to plants (University of Florida).

2.3.7.2.2 Water Culture

A water culture system is an active system, in that the system requires the use of moving parts. As Figure 2-13 shows, a water culture system consists of a reservoir to hold the nutrient solution; an air pump and air stone to aerate the solution; and a floating platform that holds the plants. In this system the plants are floating directly in the liquid nutrient solution. This type of system is best for plants that need a lot of water, such as leaf

[7] Aeration is the mixing of oxygen into a substrate, in this case a liquid.

lettuce. Like the wick system, the water culture system is not suitable for large plants and also does not work well with long-term plants (University of Florida).

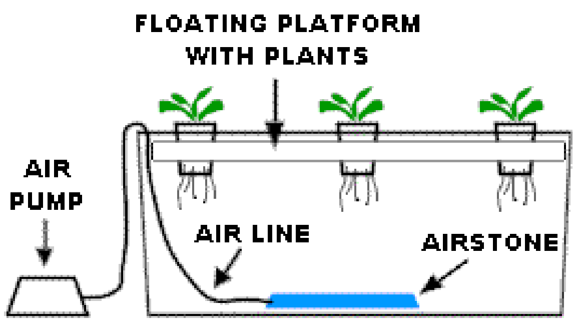

Figure 2-13: In a water culture hydroponic system plants float directly in the liquid nutrient solution (University of Florida).

2.3.7.2.3 Ebb and Flow

As Figure 2-14 shows, an ebb and flow system consists of a growing tray with a drain and an overflow wall; a reservoir to hold the liquid nutrient solution; and a pump to move water from the reservoir to the grow tray. Most commonly the pump is connected to a timer that is set to go off several times a day. The frequency of the pumping depends on the size and type of plants; temperature and humidity of either the outside atmosphere or the indoor atmosphere; and the type of growing medium. When the timer turns the pump on, the liquid is pumped into the grow tray; when the timer shuts off the pump, the liquid flows back into the reservoir (University of Florida).

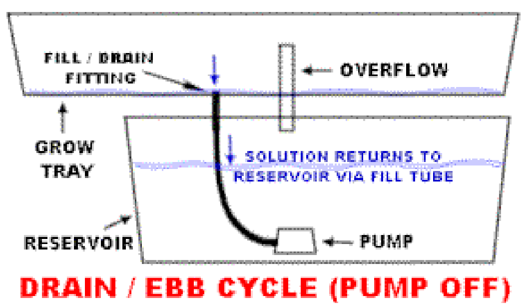

Figure 2-14: This ebb and flow hydroponics system shows water flowing from the grow tray to the reservoir, when the pump is off (University of Florida).

2.3.7.2.4 Drip

There are two types of drip systems. The first is a recovery drip system where the unused liquid nutrient solution is collected back into the reservoir for future use. The other type of drip system is a non-recovery drip system, in which the excess liquid is not collected. Both systems consist of the same components: a reservoir for holding the liquid nutrient solution; an air pump and air stone to aerate the liquid; a pump hooked up to drip lines to feed the liquid solution to the plants; and a grow tray to hold the plants and growing medium. In a recovery system the bottom of the grow tray will have a pipe connected to the reservoir, as Figure 2-15 shows. The pump that delivers the solution to the plants via the drip lines is usually hooked up to a timer. One disadvantage of the recovery system is that the recycling of excess solution can cause large shifts in the pH and nutrient strength levels in the liquid solution (University of Florida).

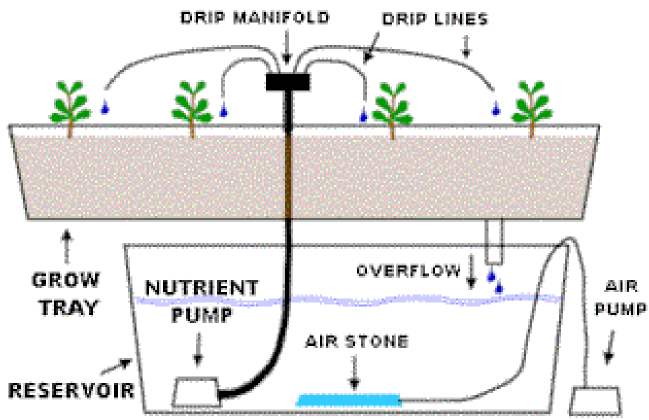

Figure 2-15: In a hydroponic recovery drip system unused liquid nutrient solution is collected back into the reservoir for future use (University of Florida).

2.3.7.2.5 N.F.T.

N.F.T. (Nutrient Film Technology) systems consist of a reservoir for holding the liquid solution; a grow tray; an air pump and air stone; and a water pump. This type of system provides a constant flow of the nutrient solution to the exposed roots of the plants in the growing tray. This allows for the elimination of a timer system. The growing tray is usually built at an angle so that gravity will causes the liquid to flow across all the plants' roots and finally to a pipe that feeds the water back into the reservoir. Figure 2-16 shows the typical set up of an N.F.T. system (University of Florida).

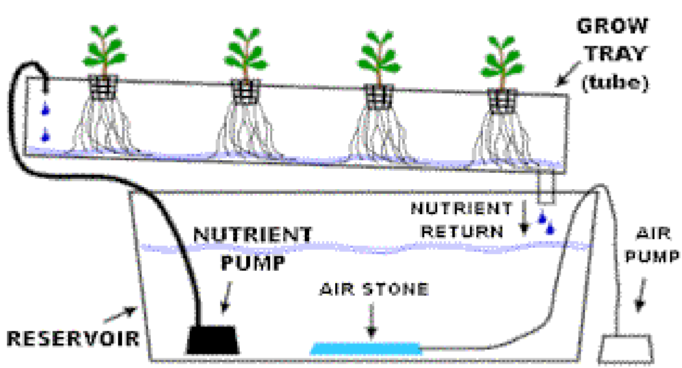

Figure 2-16: This N.F.T. system shows the grow tray built at an angle to allow for the use of gravity (University of Florida).

2.3.7.2.6 Aeroponic

Aeroponic systems spray a liquid nutrient solution onto the roots of the plants that are suspended in a closed chamber (Hayden). Figure 2-17 shows a typical set-up of an aeroponics system. This system includes a chamber that holds the liquid solution, suspends the plants in the air, has a pump, and mist nozzles to spray the plant roots with the solution (University of Florida).

One of the advantages of aeroponics is that a minimal amount of water is needed for this system compared to other hydroponic systems, and traditional soil systems (Ziegler 2005). Water usage can be reduced by 98% when using an aeroponics system compared to different growing systems. Fertilizer usage can be reduced by 60% and pesticide usage by 100 percent (Spinoff 2006).

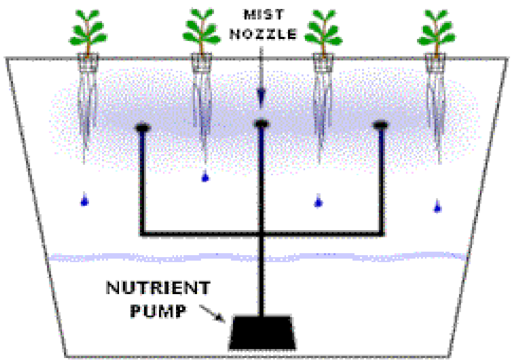

Figure 2-17: An aeroponic system uses a minimal amount of water (University of Florida).

2.3.7.3 Hydroponic Growing Mediums
Several different types of growing mediums can be used in hydroponic systems. These include sand, gravel, perlite, and rockwool.

Perlite is commonly found in most potting soil mixes and is used to improve the aeration of the soil. Due to this, roots formed in perlite are much stronger than those formed in water. Perlite is a naturally occurring volcanic glass that expands to about thirteen times its original volume when heated to 1600 degrees Fahrenheit (Naeve 2004).

Rockwool is basalt rock that is ground-up, heated, and then spun into threads, which makes wool. This procedure makes rockwool very light and allows the wool to hold water while still retaining sufficient air space (Dunn).

2.3.7.4 Hydroponic Nutrient Solutions
Since the plants in a hydroponic system are grown in liquid instead of soil, the important nutrients the plants need to grow must be supplied through the liquid. Thus, one of the most important aspects of a hydroponics system is the liquid nutrient solution (Midmore). There are retail stores all over the world that supply hydroponic nutrient solutions.

Hydroponic nutrient solutions most commonly consist of water and different concentrations of the major elements and micronutrients plants need. Table 2-5 lists these elements and the normal concentration range found in most nutrient solutions (Dunn).

Table 2-5: Most hydroponic solutions contain the following nutrients in the following concentrations (Dunn).

Element	*Concentration Range mg/L, ppm*
Major Elements	
Nitrogen (N)	100 to 200
Phosphorus (P)	30 to 15
Potassium (K)	100 to 200
Calcium (Ca)	200 to 300
Magnesium (Mg)	30 to 80
Sulfur (S)	70 to 150
Micronutrients	
Boron (B)	0.03
Chlorine (Cl)	-
Copper (Cu)	0.01 to 0.10
Iron (Fe)	2 to 12
Manganese (Mn)	0.5 to 2.0
Molybdenum (Mo)	0.05
Zinc (Zn)	0.05 to 0.50

To determine whether a nutrient solution contains the correct amount of nutrients, pH, and electrical conductivity (EC) can be tested. pH is a measure of the acidity of the solution and controls the availability of mineral nutrients, and EC is an estimate of the nutrient content. The recommendation is that the pH be between 5.0 and 6.0 for hydroponic systems, and the EC level should be between 1.5 to 3 dS/m (Dunn).

There are several techniques for managing the nutrient solution in a hydroponics system. The first technique is to have the addition of water, pH levels, and electrical conductivity control to be automatic in the tank. The second method is to have the addition of water be automatic to the tank, but the electric conductivity and pH be manually checked and adjusted. To make the pH more acidic[8] a dilute sulfuric acid solution is added; to make the pH more basic[9] a dilute sodium hydroxide solution is added. The third method is to allow the solution in the tank to run down to a certain level, and then add, by hand, a pre-made solution. For this technique the pH and electrical conductivity must be checked after the addition of the batch solution (Dunn).

2.3.8 Vertical Growing Structures

The following sections provide a brief overview of the types of structures that plants can be grown in vertically. For the majority of these systems, any type of growing system can be used.

[8] An acidic solution is one that has a pH less than 7.0.
[9] A basic solution is one that has a pH greater than 7.0.

2.3.8.1 Trellising/Walls

Trellising is a vertical growing technique that allows vining plants to grow upwards (Grafman 2013). In some circumstances growing non-trellising plants in a vertical manner is desirable. When this is the case, a structure that can be mounted to the wall must be built. This structure either contains a series of soft pockets created from a felt like material or be constructed of a hard material, such as plastic, and divided into cells as Figure 2-18 shows. An individual plant is grown in each pocket or cell and the whole module is hung vertically on a wall (Hightowner 2013).

Figure 2-18: This vertical wall planting structure is made of plastic (Hightowner 2013).

2.3.8.2 Tumbling

Tumbling refers to planting in hanging containers. This vertical growing structure is well suited for plants that like to let their leaves sprawl, such as tomatoes and strawberries (Grafman 2013). Shown in Figure 2-20, a reused plastic water bottle can make a suitable hanging container. By hanging the bottles in succession, an irrigation system can be installed and by using a pump and timer the whole system requires little maintenance in the form of watering (De Decker 2010). Another type of hanging container structure is the use of fabric pockets, as Figure 2-19 shows (Freeman 2009).

Figure 2-19: A vertical cloth shoe holder can be converted into a garden (Freeman 2009).

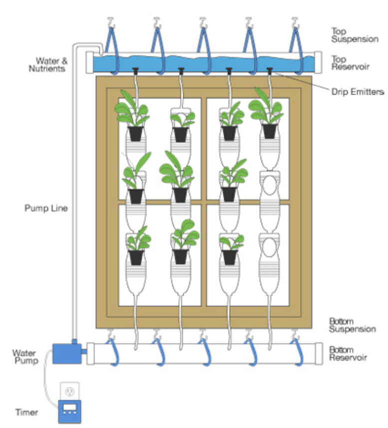

Figure 2-20: Plastic bottles can be used to make a vertical plastic water bottle soil system (De Decker 2010).

2.3.8.3 Terracing

Terracing is the vertical growing structure that includes stacking containers, usually boxes or tubes, on top of one another (Grafman 2013). This stacking can be accomplished in several ways including making a stair like structure, attaching the containers to a wall or other structure, and hanging the containers above one another as Figures 2-21 and 2-22 show. Terracing works well when space is limited and a high volume of plants is desired. Gravity can be utilized in a terraced structure for the irrigation system to eliminate the use of a pump.

Figure 2-22: A hydroponics system using tube structures suspended is from the ceiling (Levene 2012).

Figure 2-21: These strawberries are growing in vertically suspended PVC pipe (Lynne 2013).

2.3.9 Legal Railing Requirements

Legal requirements for the structural integrity and sizing of the deck rails on a barge are listed in Title 46 §177.900 of the Code of Federal Regulations (CFR)[10]. This document is can be found in Appendix B.

[10] A set of laws enforced by the federal government of the United States.

3 Search for Alternative Solutions

3.1 Introduction

Section 3 discusses the brainstorming process and the possible solutions for the edible railing in detail. To develop alternative solutions that meet the criteria, specifications, and constraints for the edible railing, Team Food On Deck had two brainstorming sessions that resulted in eight potential solutions.

3.2 Brainstorming

Two brainstorming sessions were conducted that focused on meeting the criteria, specifications, and considerations outlined in Section 2. During the first session, Team Food On Deck focused on listing different growing systems, vertical structures, and building materials. The second session focused on combining different growing systems, vertical structures, and materials to make eight alternative designs. In the second session ideas were eliminated from the first session that did not meet the criteria, specifications, and considerations of the edible railing. Notes from both sessions can be found in Appendix D.

3.3 Alternative Solutions

During the brainstorming sessions, eight alternative designs for the edible railing were developed. During the second brainstorming session all growing systems other than a soil system were eliminated, and thus all alternative solution designs are based on soil growing systems. The eight alternative design solutions are:

1. Plastic Bottle Vertical Railing
2. Pipe Railing
3. Yogurt Container Railing
4. Pallet Railing
5. Lattice Railing
6. Planter Box Railing
7. Tire Railing
8. Hanging Container Railing

All of the alternative design solutions can be attached to a 1-inch steel conduit railing. The base railing consists of vertical rail posts spaced every 8 feet, bolted into metal plated L brackets attached to the barge. Four horizontal crossbars are spaced 1 foot apart connecting each vertical post. Each of the vertical posts is 40 inches tall. All of the following alternative designs are for one 8-foot section of the railing and can be replicated throughout the entirety of the railing.

3.3.1 Alternative Solution 1: Plastic Bottle Vertical Railing

The Plastic Bottle Vertical Railing utilizes plastic bottles to house the plants. Figure 3-1 shows how the plastic bottles are connected to the base railing structure.

Each vertical column of water bottles has a “feeder” bottle (labeled A in Figure 3-1) at the top of the column and a “collection” bottle (labeled B in Figure 3-1) at the bottom of the column. The bottom of the feeder bottle is removed and a hole is in the cap. The neck of the feeder bottle is inserted into a hole in the bottom of the next bottle. The bottles in the middle section of the column are all attached by inserting the cap of the above bottle into a hole in the bottle below. All caps have holes to allow the water to flow from one bottle to the next. The “collection” bottle is positioned upright connecting the above bottle’s opening to the “collection” bottle’s opening, to allow any excess water to be collected. Each bottle in the middle section of the column has two large holes cut into their sides. Soil is filled to the bottom of these side holes. This allows one to two plants to be placed in each bottle within the middle section.

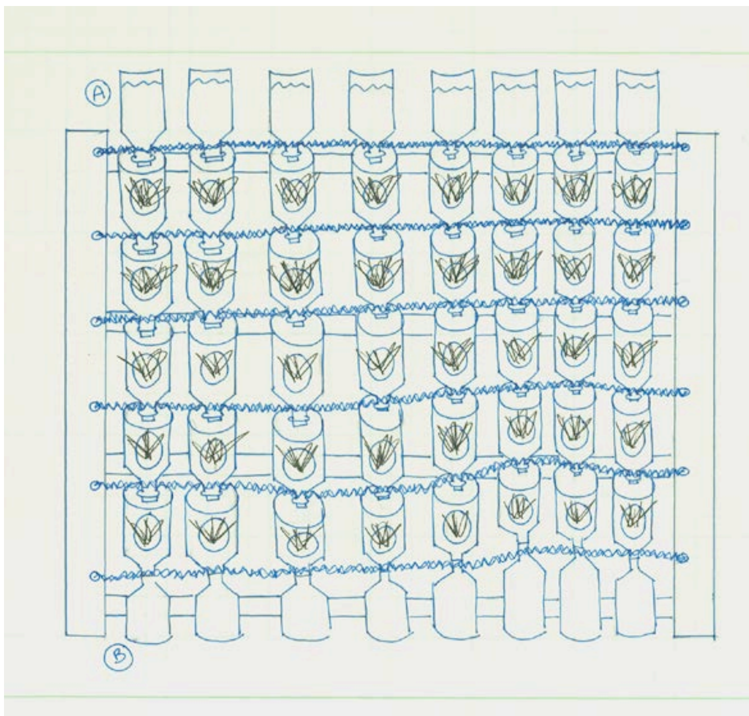

Figure 3-1: The Plastic Bottle Vertical Railing is made of recycled plastic bottles (Otten).

When the “feeder” bottle is filled with water the water drips from the hole in the cap into the bottle below. The water flows by gravity from one bottle to the next, until any water not absorbed by the plant’s roots is collected in the “collection” bottle at the bottom of the column. The water in the “collection” bottle can then be re-poured into the “feeder” bottle to recycle the water. The soil placed in each bottle in the middle section must be porous enough to allow water to filter through easily.

The selection of the plants that will be held in this type of structure is very important. Because of the way water is fed through the structure, very water tolerant plants must be planted at the top of the columns, and plants that need little water should be planted at the bottom of the columns.

The "feeder" bottle is attached to the top bar of the main railing structure at the neck to allow the bottle to be filled easily. All of the bottles in the middle section of the column are attached either to the vertical posts or the adjacent bottle columns by using wire. These connections help support the structure during high winds and when the barge sways. The "collection" bottle is attached to the bottom bar of the railing structure at the neck to allow easy removal of the bottle.

The Plastic Bottle Vertical Railing is designed to last at least three months. The cost of the Plastic Bottle Railing is relatively low because all the plastic bottles are collected from the local waste stream. Because of the small size of the bottles, this design will only allow for smaller plants to be grown in each bottle, but a large quantity of bottles will allow many small plants to be grown. The Plastic Bottle Vertical Railing has a moderate maintenance requirement. The "feeder" bottles must be filled once a day, either manually or by turning on and off an irrigation hose. Plastic bottles can be found in high quantities in almost any densely populated area; thus, this design can be easily replicated.

3.3.2 Alternative Solution 2: Pipe Railing

The Pipe Railing is constructed from large diameter pipes that house the plants. The pipes have several holes cut out from the top or one large hole cut from the top. The entire pipe is filled with soil and plants are placed within the holes cut in the pipe, as Figure 3-2 shows. Drip irrigation hoses run from the posts along the pipe to each hole. The pipe can be made from any reused material such as, old PVC pipe or yogurt containers cut and arranged to form a pipe.

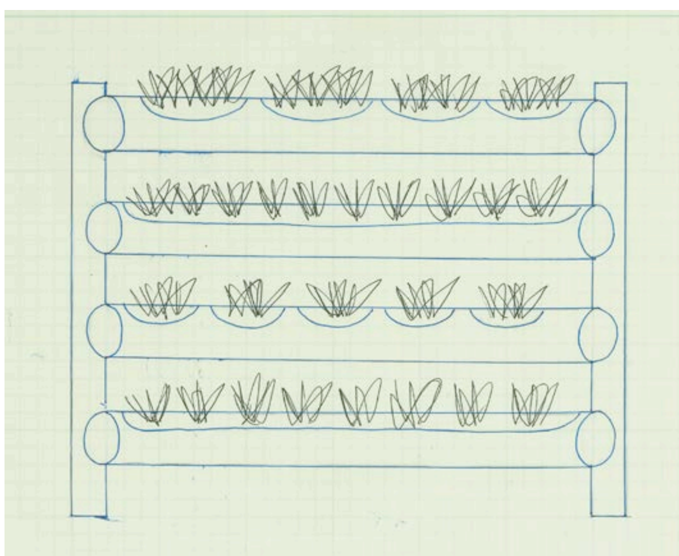

Figure 3-2: PVC pipes or yogurt containers can be used for the Pipe Railing (Otten).

Depending on the materials used for the pipes, this design can either be low cost or high cost. New PVC pipe is very expensive. Ideally a material from the local waste stream would be used, such as old yogurt containers. The large depth and length of the pipe allows for larger plants to be grown, which may result in a high produce production. The maintenance of the Pipe Railing is relatively low. Once a day the drip irrigation needs to be turned on and off, and the produce must be harvested. This design will meet the client's criteria for a design that looks "futuristic" by utilizing pipes. This is a relatively simple design that can be easily replicated throughout the other sections of the barge.

3.3.3 Alternative Solution 3: Yogurt Containers Railing

The Yogurt Containers Railing is constructed using 1-inch by 6-inch by 8-foot wood boards attached to the vertical posts of the base railing structure. One 8-foot section of railing includes four 1-inch by 6-inch by 8-foot cross boards. The cross boards are cut in half and attached to the posts using metal L-shaped brackets. Each cross board has twelve holes cut out in order to hold the 24-ounce yogurt containers. The yogurt containers fit into each hole with the top rim of each container resting on the board. Each 8-foot section of railing can hold 48 plants total, as shown in Figure 3-3.

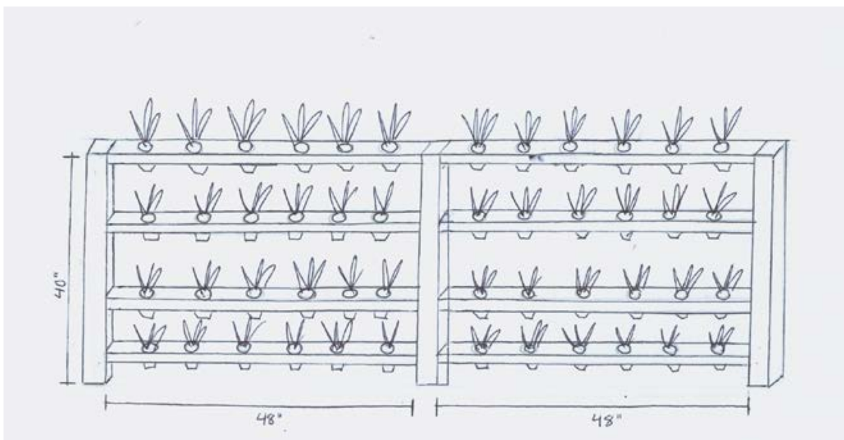

Figure 3-3: The Yogurt Container Railing can hold 48 plants per 8-foot section (Denny).

The recycled containers are free and the cross boards can be inexpensive depending on the type of wood. Repurposed boards from the local waste stream or new boards could be used. The size of the yogurt containers would allow plants to grow a moderate amount of food. Larger containers, set in wider boards could also be used to grow larger plants. This design addresses the client's request for a futuristic design as the Yogurt Container Railing shows the paradox of growing food in would-be trash. The railing and the produce within the containers are easily accessible for maintenance. This design requires low maintenance, requiring only hand-watering and occasional weeding.

3.3.4 Alternative Solution 4: Pallet Railing

The Pallet Railing is constructed using recycled wooden pallets. Discarded pallets are abundant in the waste stream and are available in many different sizes. A common size is 48 inches by 40 inches. This size is used in the grocery, auto, printing, and chemical industries (PalnetUSA 2012). The example shown in Figure 3-4 combines three 48 inches by 40 inches pallets to construct a 10-foot section of railing. However, a combination of various sized pallets can be used to construct an 8-foot section of railing.

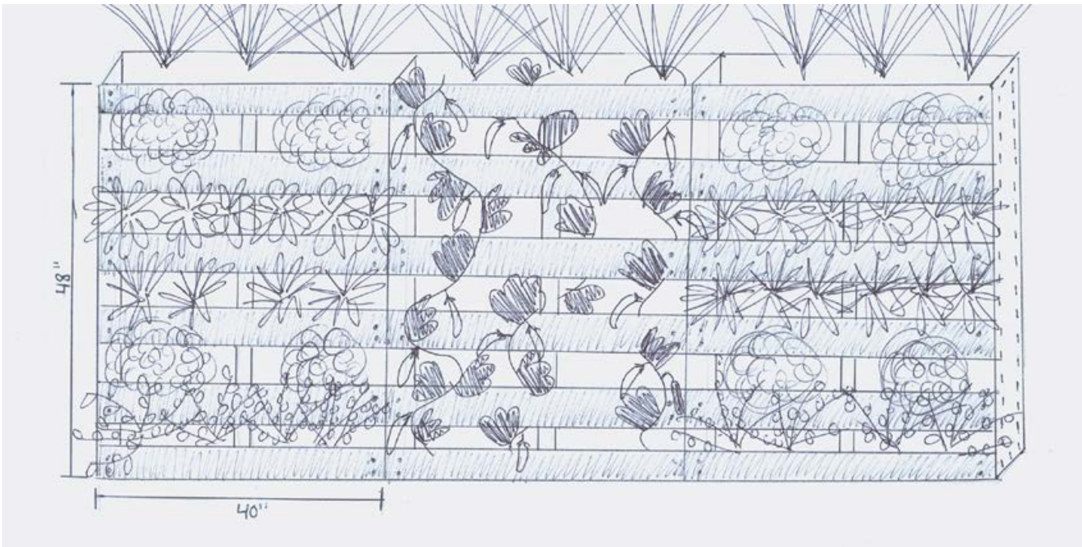

Figure 3-4: The Pallet Railing can house a combination of plants, including vining plants (Denny).

All wooden pallets are fumigated[11] prior to being used for industry purposes (PalnetUSA 2012). They are either heat treated to 56 degrees Celsius for 30 minutes or fumigated with methyl bromide (PalnetUSA 2012). Growing food within pallets that have been treated with methyl bromide is unsafe (Richardson, 2011). Pallets used in this design have been heat treated, which is indicated by the "HT" stamp on the wood (PalnetUSA 2012).

The pallet railing is built by attaching a double layer of landscaping fabric to the back, bottom, and sides of the pallet using a staple gun (Richardson, 2011). The top and front are left open so plants can grow out from the top as well as between the planks in the front. With the pallet lying flat (fabric side down), potting soil is poured in, between the slats, and packed tightly. Approximately 4 cubic feet of soil is used in each 48 inch by 40 inch pallet. Finally, plants are planted between the slats and at the top. The recommendation is to keep the pallet flat for two weeks to allow the plants' roots to take hold of the soil before standing the pallet upright (Richardson 2011).

The Pallet Railing is durable because the design is a solid structure made from a product that is intended to hold heavy loads. Assembled, the Pallet Railing meets the requirements for safety as outlined in the CFR. Although the pallets are free, found in the local waste stream, the amount of soil required to fill them could be expensive, depending on the type of soil used. A moderate amount of food can be grown in the Pallet Railing and it can serve as a vertical support for vining/climbing plants. The plants are easily accessible for maintenance, although a tear in the fabric backing may be difficult to repair from the other side.

[11] Fumigation is the process of disinfecting or treating wood to get rid of insects.

3.3.5 Alternative Solution 5: Lattice Railing

The Lattice Railing is composed of a frame with a cross wire pattern and a garden bed at the bottom. The raised garden bed is 8 inches tall, 1 foot wide, and 8 feet across and is filled with soil and contains the plants. Figure 3-2 shows that between each post there are overlapping wires that span the entire distance between the posts with spacing of 2 inches between each wire producing 2 inch by 2 inch open squares. The horizontal wires are tied and tightened to hooks that are screwed into the posts and the vertical wires are tied around the top-most and bottom-most horizontal wires.

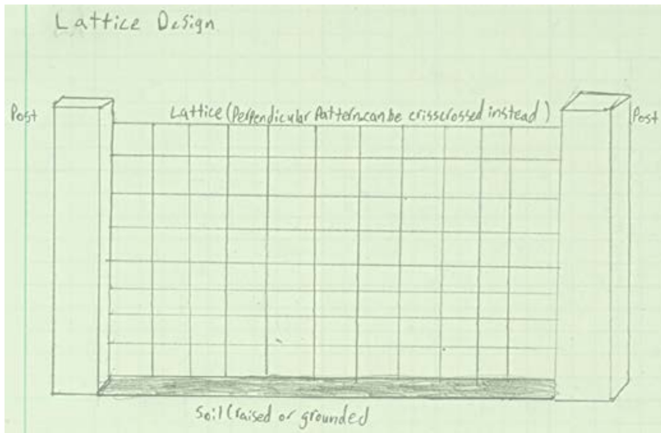

Figure 3-2: The Lattice Railing consists of a criss-cross pattern of wires (Trejo).

The wiring design is lightweight and low-maintenance. The Lattice Railing is inexpensive because only wire, wood for the garden bed, and soil are required. This design will be easy to replicate with instructions. The Lattice Railing is a durable structure; however, durability will decrease as the size and weight of the plants increase. This design is only intended to accommodate vining plants with shallow roots such as cucumbers, beans, and peas. The Lattice Railing is not suitable for plants with deep roots such as carrots or potatoes.

Often the plants would naturally grow up the lattice and spread but sometimes the plants need to be trained or weaved through the lattice or trimmed as not to overwhelm the trellis with their growing weight (Ellis-Christensen).

3.3.6 Alternative Solution 6: Planter Box Railing

Planter boxes are boxes or crates used specifically for growing plants. The Planter Box Railing uses wooden boxes that are eight feet across, 8 inches tall and 1 foot wide. The bottom box sits on the floor of the barge, wedged between the vertical posts of the railing. The other two planters are also wedged between the posts as well as screwed in place and sit on top of the railing’s crossbars as Figure 3-3 shows. These boxes are then filled with soil and plants.

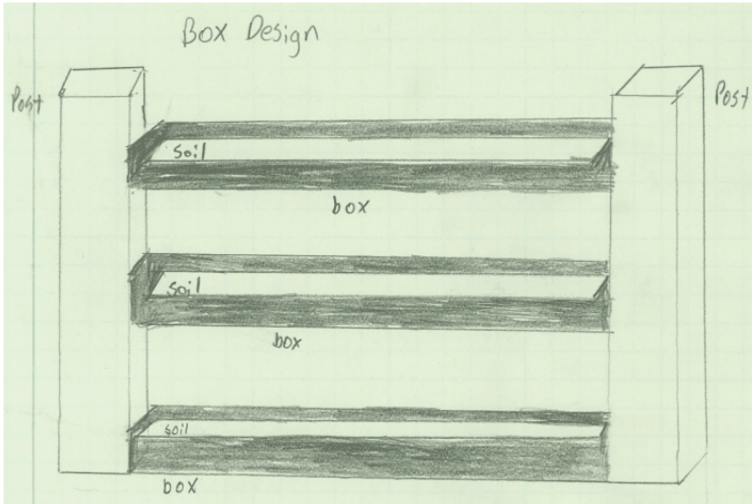

Figure 3-3: This Planter Box Railing is made of wooden boxes (Trejo).

This is a low-maintenance structure, only water and proper caring for the plants is required. Planter boxes can be relatively cheap, made exclusively of wooden planks that can be easily obtained. The durability of the Planter Box Railing will be strong if the boxes are properly built and placed correctly.

3.3.7 Alternative Solution 7: Tire Railing

The Tire Railing is constructed with used tires mounted onto the crossbars of the base railing. The tires are sourced from the Humboldt County waste stream and act as an educational example of repurposing waste materials. The tires shown in Figure 3-5 are filled with soil and hold either one plant that requires relatively larger root space such as a potato plant, or several smaller plants. The tire planters are constructed of various sized cuts of used tire, for both functional and aesthetic purposes.

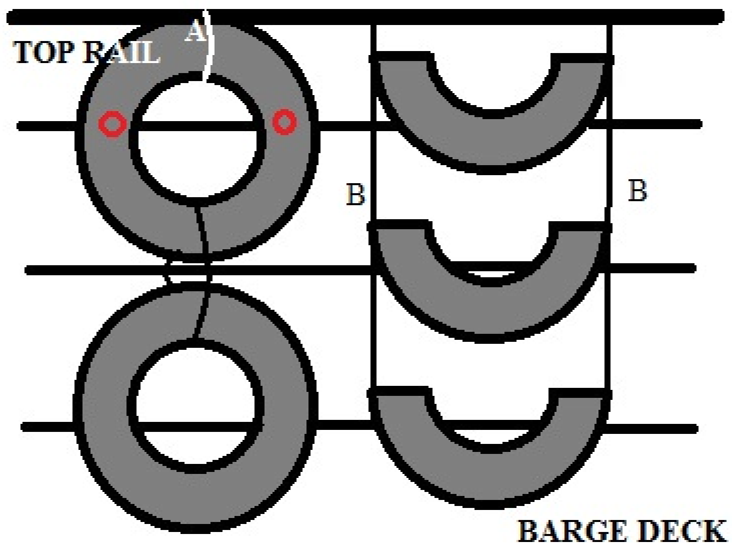

Figure 3-5: This is one possible layout for the Tire Railing (Zirkel).

The tire planters are attached in a hanging manner with a rope loop to the metal crossbars as marked in white with the letter “A” in Figure 3-5. Smaller sections are hung in a ladder form by rope as marked in black with the letter “B.” For stability, holes are punched in the backs of the tires at the height of each crossbar, as the red circle in Figure 3-5 show. These punched holes are threaded with rope and tied to the metal railing.

3.3.8 Alternative Solution 8: Hanging Container Railing

In the Hanging Container Railing, the base metal railing is the support structure for chains of suspended plastic containers, which act as planters. The plastic containers are sourced from the Humboldt County waste stream and are of several colors and sizes. This variety allows for plants of different root-depth requirements and for aesthetically pleasing layout options involving color patterns. The aesthetics enhance the educational experience of the edible railings by adding a visually engaging example of repurposed waste stream materials.

The railing shown in Figure 3-6 is constructed with vertical chains of plastic containers linked together with thin cable or polymer line such as thick fishing line. A boom arm is anchored to the top crossbar of the railing as seen with the label “A” in Figure 3-6. This boom arm acts as a hanger protruding inward towards the deck of the barge. Different sized containers are paired with plants of coinciding root space requirements. The chain of plastic containers spans the entire height of the railing and is anchored to the deck of the barge as seen with the label “B” in Figure 3-6. This bottom anchor prevents any swinging motion from wind or swaying barge movement. There are 5 to 8 container chains per 8-foot section of railing, depending on container widths.

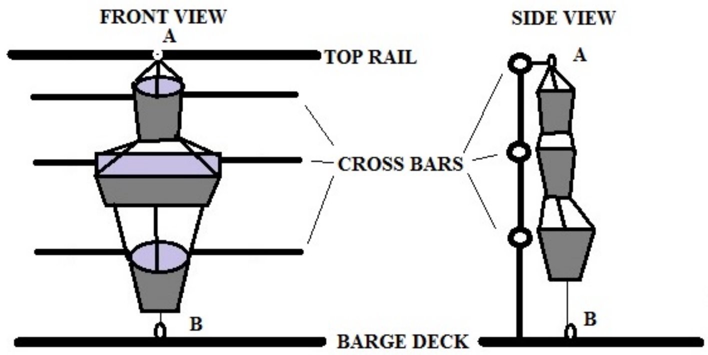

Figure 3-6: The hanging containers on the Hanging Container Railing are suspended by chains (Zirkel).

4 Decision Phase

4.1 Introduction

Section 4 is a description of the process by which a final solution was chosen. This section relates the alternative solutions from Section 3 to the criteria from Section 2.

4.2 Criteria Definition

To judge the alternative solutions described in Section 3, the following criteria from Section 2 were used. The criteria are defined as follows:

- **Durability:** The amount of time the edible railing can endure natural elements as well as human use before the railing must be fixed or rebuilt.
- **Plant Locality:** The distance from the railings location in Philadelphia to the place of availability of each plant.
- **Cost:** The total amount of money, labor, and time required to construct and maintain the edible railing.
- **Environmental Justice:** The amount of reused and repurposed materials used to build the railing.
- **Safety**: The ability of the railing to keep patrons from falling off the side of the barge, the railings ability to meet code requirements, and the railings ability to be used safely by all ages of the public.
- **Produce Production:** The amount of edible material that is available for consumption from the railing.
- **Ease of Maintenance:** The ability of a high school graduate to maintain the edible railing, including daily maintenance and repairs, if needed.
- **Level of Water Conservation:** The amount of water that can be saved through plant selection and railing design.
- **Aesthetically Pleasing:** The edible railing fulfilling the client’s request for a futuristic design.
- **Ease of Replication:** The ability of a high school graduate to be able to reconstruct the railing’s design through the use of instructions.
- **Educational Value:** The railing’s ability to visually convey what materials and plants are used to build the railing and how they work together.

4.3 Solutions

Eight alternative solutions are being evaluated in the decision phase. Specific design details for each solution are provided in Section 3. These alternative solutions are:

- Vertical Plastic Bottle Railing
- Pipe Railing
- Yogurt Container Railing
- Pallet Railing
- Lattice Railing

- Planter Box Railing
- Tire Railing
- Hanging Container Railing

4.4 Decision Process

Team Food On Deck used the Delphi Matrix shown in Table 4-1 to make our final design decision. First, the criteria that were the most critical to the success of the final design were selected. Team Food On Deck gave each criterion a score between one and ten, ten being the highest. Then, individually, each team member evaluated each alternative solution in terms of how well they met each of the criteria. Each alternative solution was scored, in terms of each criterion, on a scale of one to fifty, fifty being the highest. The individual scores were averaged and then multiplied each by the previously determined weight of each criterion to obtain a total for each criterion. The totals for each criterion were summed to give the overall total for each alternative solution.

Table 4- 1: This Delphi Matrix was used to determine a final solution.

Criteria	Team Weights (0-10)	Alternative Solutions (0-50)							
		'ertical Plastic Bottle Railin	Pipe Railing	'ogurt Container Railin	Pallet Railing	Lattice Railing	Planter Box Railing	Tire Railing	Hanging Container Railing
Durability	9	38 / 342	48.25 / 434.25	43.75 / 393.75	44.5 / 400.5	39 / 351	44 / 396	47 / 423	37.5 / 337.5
Plant Locality	6	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300
Cost	8	47.75 / 382	8.75 / 70	42.5 / 340	22.5 / 180	36.25 / 290	35 / 280	41.25 / 330	40 / 320
Environmental Justice	7	48.75 / 341.25	3.75 / 26.25	45 / 315	22.5 / 157.5	19.5 / 136.5	27 / 189	49.5 / 346.5	32 / 224
Safety	10	50 / 500	50 / 500	50 / 500	50 / 500	50 / 500	50 / 500	50 / 500	50 / 500
Produce Production	9	36.25 / 326.25	45 / 405	42 / 378	43.75 / 393.75	35.75 / 321.75	45 / 405	43.25 / 389.25	42 / 378
Ease of Maintenance	6	43.25 / 259.5	39.5 / 237	46.75 / 280.5	28.75 / 172.5	38.75 / 232.5	43 / 258	44.5 / 267	41.25 / 247.5
Level of Water Conservat	5	48.25 / 241.25	37.5 / 187.5	41.75 / 208.75	28.75 / 143.75	41.25 / 206.25	32.5 / 162.5	40.5 / 202.5	39.25 / 196.25
Aesthetically Pleasing	4	47.5 / 190	50 / 200	45.75 / 183	32.5 / 130	32.5 / 130	28.75 / 115	46.25 / 185	43.25 / 173
Ease of Replication	9	41.25 / 371.25	35 / 315	45 / 405	36.25 / 326.25	35 / 315	45 / 405	42.5 / 382.5	41.75 / 375.75
Educational Value	4	50 / 200	43.75 / 175	47.5 / 190	43.75 / 175	47.5 / 190	46.25 / 185	48.75 / 195	46.25 / 185
	Total	3453.5	2850	3494	2879.25	2973	3195.5	3520.75	3052

4.5 Final Decision Justification

By using the Delphi Matrix, the top three designs that matched the criteria were selected. These solutions in order from first to third are the Tire Railing, the Vertical Water Bottle Railing, and the Yogurt Containers Railing. The team decided to construct a railing that incorporates all three of these designs. After discussing the need for a structure that would allow vining/climbing plants, the team decided to use the Lattice Railing instead of the Yogurt Containers Railing. Team Food on Deck decided to incorporate elements from the Tire Railing, the Vertical Water Bottle Railing, and the Lattice Railing.

Team Food On Deck had concerns about the possibility of toxic chemicals leaching from tires into the soil, causing the plants to be unsafe for consumption. Not finding any conclusive research addressing these concerns, Team Food On Deck decided that tires would not be used in the final design.

In the process of collecting plastic bottles Team Food On Deck discovered plastic water bottles are not abundant in the waste stream of Humboldt County. Therefore a search for more abundant waste stream materials to use in the edible railing design was conducted. Plastic plant nutrient solution containers were found to be abundant both in Humboldt County and Philadelphia. Thus, these plastic plant nutrient solution containers were used in the final edible railing design. A lattice structure using the plastic plant nutrient solution containers as a base was incorporated into the final design.

5 Specification of Solution

5.1 Introduction

Section 5 contains the specifications and details for one 8-foot section of the edible railing structure. When applied to the barge, this 8-foot template will be repeated in fifteen sections to cover the 140-foot perimeter. This section includes a description of the solution, materials, costs, implementation instructions, and prototype performance. The solution description section includes detailed descriptions of the railing structure, the growing containers, the trellis, and the irrigation system. The cost analysis section covers material costs, hourly cost, and maintenance cost to build and maintain the edible railing. The implementation instructions explain how to reconstruct the railing as well as how to use and maintain the railing. The product performance section describes the final designs' ability to meet the specified criteria.

5.2 Solution Description

The edible railing, as depicted in Figure 5-1, is a self-supporting structure that functions as protection from the side of the barge, as well as a source of food. The name of the final design is Life Support. The railing structure is composed of four main components: the base railing, the planters, the trellis, and the irrigation system.

Figure 5-1: Life Support is an 8-foot section prototype of the final edible railing design.

5.2.1 Railing

The base railing structure, without any attachments, includes two posts and four crossbars, as shown in Figure 5-2. The posts are vertical, square 1-inch steel conduit that are spaced 8 feet apart and are 40 inches tall. The crossbars are welded to the posts and the posts are bolted to the barge using metal plated L-brackets. The crossbars are made of 1-inch, square, steel conduit that span 8 feet between each post. Each crossbar is spaced 10 inches apart and the bottom crossbar is 6 inches from the floor of the barge.

Figure 5-2: This 8-foot section of the railing is the base for Life Support.

5.2.2 Planters

The containers used to hold the plants and soil are recycled plant nutrient containers that were donated, as seen in Figure 5-3. Two container sizes were utilized for the railing. The small containers are 8 inches long, 6.25 inches wide and 7.4 inches tall. These containers are used to house the smaller plants. Nine small containers are used in one 8 foot section with four attached on the top crossbar, three on the second crossbar, and two on the third and fourth crossbars. The small containers are arranged in a checkered pattern, spaced 8 inches from each other to provide each plant space for growing. The big containers are 12.25 inches long, 8 inches wide and 13.75 inches tall. Four big containers are used in each 8 foot section, two used as the base for the trellis and two used for larger plants.

Figure 5-3: This small plastic nutrient solution container is attached to the top crossbar of the railing.

Four holes are drilled into the back of each container. Two zip ties are threaded through these holes to attach the containers to the crossbars of the railing. A hole is drilled into each side of each container irrigation system to run through. Two small holes are drilled into the front of the bottom of each container to allow for water drainage.

5.2.3 Trellis

The trellis is made up of two separate pieces of repurposed fence that are 12 inches wide and 40 inches tall, as seen in Figure 5-4. Each trellis is attached to the back of the inside of one of the two big containers. From the containers the trellis extends to the top of the railing where it is attached with a series of zip ties to each of the three top crossbars. The whole trellis structure will span 2 feet of the railing's length. The trellis provides support for vining plants.

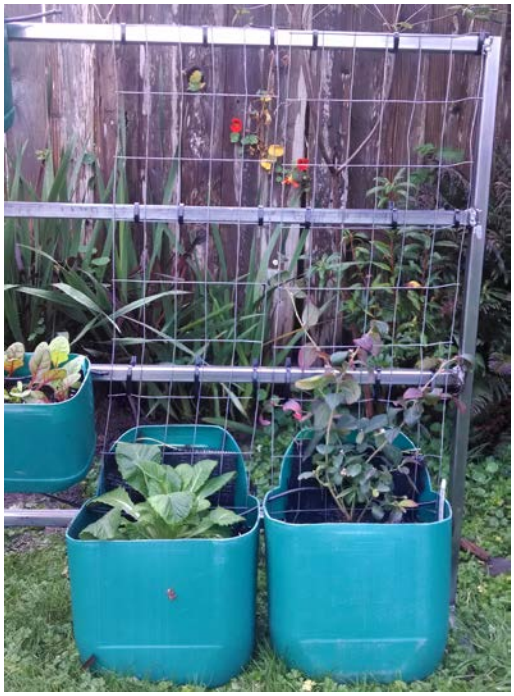

Figure 5-4: The trellis is attached to the railing.

5.2.4 Irrigation System

A gravity-fed drip irrigation system is used on the railing to provide water to the plants in each 8-foot section of the railing. The irrigation system is made up of a reservoir tank, a large ball valve, a series of thread and tubing converters, 0.5 and 0.25-inch tubing, four small ball valves, and 0.25-inch T's. On top of the left post is an elevated steel conduit cage that houses the reservoir tank, as seen in Figure 5-5. The tank is a 5 gallon recycled plant nutrient container. The container is placed so the opening is facedown. There is a 2-inch by 2-inch, square hole cut from the top of the container to allow the container to be filled. Figure 5-5 shows a hose thread-to-pipe thread converter connects the reservoir to the large ball valve. The large ball valve allows the whole 8-foot section to be turned on and off. Connected to the large ball valve is a pipe thread to 0.5-inch tubing converter that connects 0.5-inch tubing to the ball valve; this 0.5-inch tubing extends down the vertical post. At the two top crossbars a 0.5-inch T connector is used to connect 0.5-inch tubing horizontally across the crossbars. At the third crossbar a 90-degree connector is used instead of a T connector. Each horizontal 0.5-inch tubing line has a small ball valve that allows each row to be turned on and off individually. From the small ball valve a 0.5-inch tube-to-pipe thread converter and 0.25-inch thread-to-tube converter is needed to allow 0.25-inch tubing to extend through each container across each crossbar. At each container a 0.25-inch T is inserted into the tubing; these T's allow water to flow from the tubing into the containers. At the end of each 0.25-inch tubing there is a 0.25-inch plug.

Figure 5-5: The reservoir tank dispenses water to the main 1/2 inch tubing line of the irrigation system.

5.2.5 Soil System

Each container contains a soil system that is comprised of a weed mat, volcanic rock, coconut fiber, and Fox Farm Soil and Fertilizer Company's patented Ocean Forest Potting Soil mix (Fox Farm Potting Mix). The weed mat is placed at the bottom of each container to prevent soil from leaking through the drainage holes. In each large container, weed mat is also places at the back of the inside of the container to prevent soil from leaking through the zip tie holes. A 1-inch layer of volcanic rock is placed on top of the weed mat to provide water drainage and root aeration. On top of the volcanic rock layer is a mixture of Fox Farm Potting Mix and coconut fiber. The Fox Farm Potting Mix provides the plants with the necessary nutrients and the coconut fiber will help the soil retain water.

5.2.6 Plant Recommendations

Eleven specific plants have been selected for planting in the Life Support railing. These plants were chosen based on their ability to grow well in containers as well as the volume of food they produce (Miller Farms Nursery, personal communication, November 15, 2013). Team Food On Deck has recommended varieties of each plant that are suitable for growing in containers, however, the client is advised to purchase varieties that are grown locally in Philadelphia. The varieties that will be locally available to the client are not known until the local farmers announce what they have for sale for the Spring 2014 season (Greens Grow Farms Philadelphia, personal communication, October 30, 2013).

Life Support is designed to grow beans, peas, and cucumbers in the containers with the trellis; peppers, potatoes, and tomatoes in the larger containers; and radishes, carrots, lettuce, spinach, and strawberries in the smaller containers.

5.2.6.1 Recommended Varieties

Team Food On Deck has recommended the following plant varieties for growing in containers:

5.2.6.1.1 Beans

- Bush beans: Blue Lake 274, Bush Kentucky Wonder, and Derby (University of Illinois Extension 2013).
- Pole beans: Blue Lake, Kentucky Blue, and Kentucky Wonder (University of Illinois Extension 2013).

5.2.6.1.2 Cucumbers

- Long green slicing (compact plant): Bushcrop, Fanfare, and Salad Bush (University of Illinois Extension 2013).
- Pickling: Bush Pickle, and Carolina (University of Illinois Extension 2013).

5.2.6.1.3 Peas

- Early: Daybreak, Spring (University of Illinois Extension 2013).
- Main Season: Sparkle, Little Marvel, Green Aarow, Wando (University of Illinois Extension 2013).
- Sugar: Snowbird, Dwarf Gray Sugar, Snowflake (University of Illinois Extension 2013).

5.2.6.1.4 Lettuce

- Green Leaf: Black-seeded Simpson, Grand Rapids, and Oak Leaf (University of Illinois Extension 2013).
- Red Leaf: Red Fire, Red Sails, and Ruby (University of Illinois Extension 2013).
- Cos or Romain: Cimmaron, Green Towers, and Paris Island (University of Illinois Extension 2013).
- Heading: Great Lakes, Ithaca, and Iceburg (University of Illinois Extension 2013).

5.2.6.1.5 Peppers

- Hybrid Bell: Bell Boy, Lady Bell, Purple Belle, and Chocolate Bell (University of Illinois Extension 2013).
- Sweet Frying or Salad Type: Gypsy, Sweet Banana (University of Illinois Extension 2013).
- Hot Peppers: Cayenne, Jalepeno, Red Chili (University of Illinois Extension 2013).

5.2.6.1.6 Carrots

- Small, Round: Orbit, Thumbelina (University of Illinois Extension 2013).
- Baby: Baby Spike, Little Finer, Minicor, Short n' Sweet (University of Illinois Extension 2013).

5.2.6.1.7 Spinach

- Crinkled Leaf: Bloomsdale Long Standing, Winter Bloomsdale (University of Illinois Extension 2013).
- Hybrid Savoy: Indian Summer, Melody, Tyee, Vienna (University of Illinois Extension 2013).
- Plain-Leaf: Giant Noble (University of Illinois Extension 2013).
- Plain-Leaf Hybrid: Olympia (University of Illinois Extension 2013).

5.2.6.1.8 Radishes

- Spring: Burpee White, Champion, Cherry Belle, Cherry Queen, Early Scarlett Globe, Easter Egg, Fuego, Plum Purple, Snow Belle (University of Illinois Extension 2013).
- Spring or Summer: French Breakfast, Icicle (University of Illinois Extension 2013).
- Winter: China Rose, Chinese White, Round Black Spanish (University of Illinois Extension 2013).

5.2.6.1.9 Strawberries

- Early: Earliglow, Sweet Charlie, Wendy (Strawberryplants 2013).
- Early Midseason: Darselect, Honeoye (Strawberryplants 2013).
- Midseason: Allstar, Chandler, L'Amour (Strawberryplants 2013).
- Late Midseason: Jewel (Strawberryplants 2013).
- Day Neutral: Albion, Evie 2, Seascape, Tribute, Tristar (Strawberryplants 2013).

5.2.6.1.10 Tomatoes

- Small-Fruited/Salad: Super Sweet 100, Sweet Million, Yellow Pear, Large Red Cherry, Mountain Belle (University of Illinois Extension 2013).
- Dwarf/Container: Tiny Tim, Cherry Gold, Red Robin, Yellow Canary, Pixie Hybrid II, Patir Hybrid, Small Fry, Husky Red Hybrid, Husky Gold Hybrid, Husky Pink Hybrid (University of Illinois Extension 2013).

5.2.6.1.11 Potatoes

- Early: Irish Cobbler, Norland, Yukon Gold (University of Illinois Extension 2013).
- Midseason: Red Pontiac, Viking (University of Illinois Extension 2013).
- Late: Katahdin, Kennebec (University of Illinois Extension 2013).

5.2.6.2 Planting Schedule

A planting schedule has been provided for the client. This schedule is a very general guideline for planting the recommended plants (Veggie Harvest 2013). If the residents of the barge decide to use transplants, rather than planting from seeds, the planting dates should be delayed approximately two weeks (Miller Farms Nursery, personal communication, November 15, 2013). Ultimately, planting dates will vary depending on the weather in Philadelphia in 2014 and which plants and varieties the residents of the barge choose. The full planting schedule can be found in Appendix E and online at the Appropedia page: http://www.appropedia.org/WETLAND_Humboldt_LifeSupport.

5.3 Cost Analysis

Cost Analysis covers the costs of materials, design, and maintenance of Life Support.

5.3.1 Material Cost

Table 5-1 provides a list of materials and costs for each section of the railing. Included are materials, quantities, and cost for one 8-foot section of Life Support and for all 15 sections of Life Support.

Table 5-1: The quantity and cost of materials used to build Life Support are calculated for each 8-foot section as well as for the entire 140-foot railing.

Section	Material	Quantity Per 8-foot Section	Quantity for Whole Railing	Price per Quantity	Price per 8-foot Section	Price for Whole Railing
Planters	Small Plastic Nutrient Containers	9	135	Donated	$0.00	$0.00
	Large Plastic Nutrient Containers	4	60	Donated	$0.00	$0.00
	Zip Ties	36	540	$15/100 Zip Ties	$15.00	$120.00
	Sandpaper	1	15	$5/3 pack	$5.00	$5.00
	Trellis	2 feet	30 feet	Donated	$0.00	$0.00
Irrigation System	1/2'' Hose	3.7 feet	55.5 feet	$0.13/1 Foot	$0.48	$7.22
	1/4'' Hose	18.8 feet	282 feet	$0.07/100 Feet	$1.32	$19.74
	1/2'' 90 Degree Connector	1	15	$1/1 Piece	$1.00	$20.00
	1/2'' T-Connector	2	30	$1/1 Piece	$2.00	$40.00
	Large Ball Valve	1	15	$4/1 Piece	$4.00	$80.00
	Hose Thread to Pipe Thread Converter	1	15	$0.90/1 Piece	$0.90	$18.00
	Valve to Bottle Connector	1	15	$0.80/1 Piece	$0.80	$16.00
	Small Ball Valve	3	45	$2.60/1 Piece	$7.80	$156.00
	1/2'' Connector with Thread	3	45	$2.00/1 Piece	$6.00	$120.00
	1/4'' Converter with Thread	3	45	$0.10/1 Piece	$0.30	$6.00
	1/4'' T Connectors	13	195	$0.10/1 Piece	$1.30	$26.00
	1/4'' End Plugs	3	45	$0.10/1 Piece	$0.30	$6.00
	Large Plastic Nutrient Container	1	15	Donated	$0.00	$0.00
Soil System	Weed Mat	7.5 feet^2	112.5 feet^2	$40/150 feet^2	$2.00	$40.00
	Volcanic Rock	14 inches	210 inches	Donated	$0.00	$0.00
	Coconut Fiber	1.5 feet^3	22.5 feet^3	Donated	$0.00	$0.00
	Potting Soil	1.5 feet^3	22.5 feet^3	$13/15 feet^3	$13.00	$260.00
Total					**$61.20**	**$939.96**

5.3.2 Design Cost

The design cost measured in hours, shown in Figure 5-6, displays the hours spent on each step of the design process. The estimated time to replicate one 8-foot section of Life Support is 8 hours for 4 people. This is based on the time Team Food On Deck projects that a high school graduate could replicate one 8 foot section using detailed instructions.

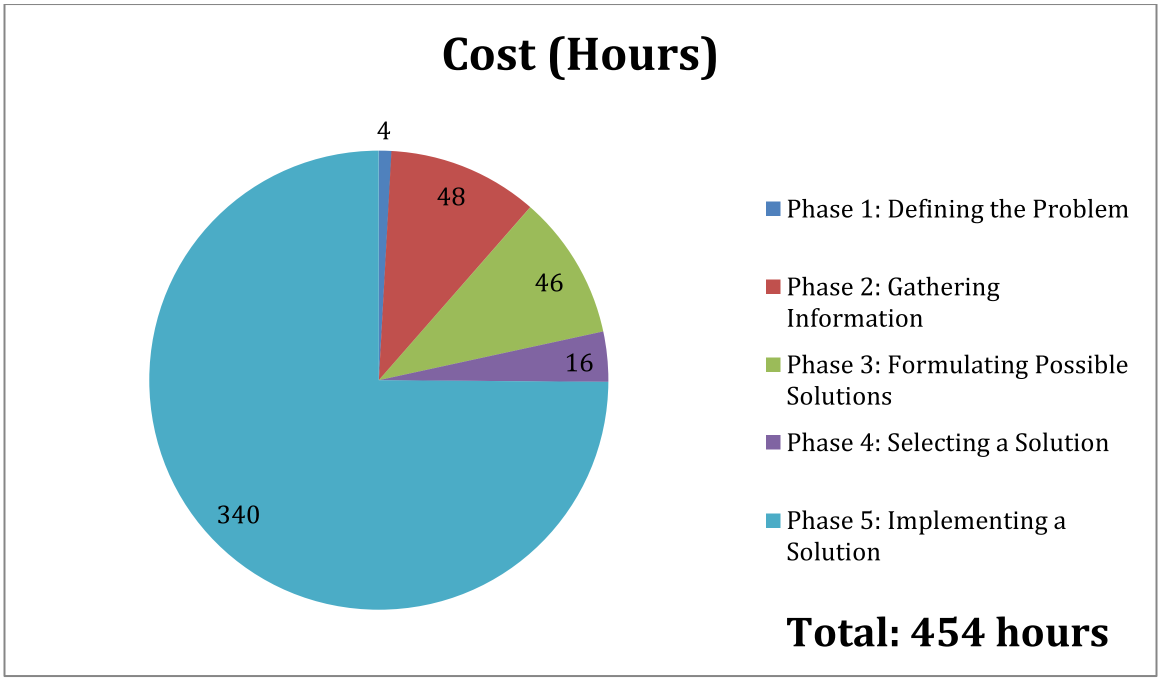

Figure 5-6: Team Food On Deck spent 454 hours designing Life Support.

5.3.3 Maintenance Cost

The maintenance of Life Support involves caring for the plants and checking that various components of the attachments are working properly. At least three people living on the barge are responsible for the maintenance of Life Support. Table 5-2 lists the tasks to be performed to maintain Life Support, the frequency these tasks should be performed, and the cost in minutes to perform these tasks. The total time spent on maintenance per month is estimated to be 7 hours per person. The total time spent on maintenance per week is estimated to be 1 hour and 45 minutes per person. Full descriptions of the maintenance tasks can be found in Appendix F.

Table 5-2: The tasks, predicted frequency, and predicted cost in minutes for the maintenance of Life Support.

Task	Frequency	Cost (minutes)
Water plants	Once per day	20
Check that each plant is getting watered	Twice per week	15
Check that all zip ties are as tight as possible	Once per week	15
Remove any weeds and dead foliage from containers	Once per week	15
Harvest produce	Once per day	10
Replace any missing soil in the containers	Once per month	30

5.4 Implementation Instructions

Complete, detailed instructions for the replication of Life Support can be found in Appendix F. Instructions can also be found, online, at the Appropedia page: http://www.appropedia.org/WETLAND_Humboldt_LifeSupport.

5.5 Prototype Performance

Life Support was displayed outdoors for a period of two weeks and was watered in the technique described in the Appendix F. The plants in the containers are growing and are anticipated to yield food as planned. All of the zip ties are tight and the containers have remained stable. All components of the irrigation system have operated properly.

Crop yields are highly variable, dependent upon the variety of plant selected, growing conditions, and the amount of maintenance each plant receives. For the recommended varieties of plants, estimated crop yield over the summer growing season, per plant, is as follows:

- Carrots: 6 to10 carrots
- Radishes: 6 to12 radishes
- Lettuce: 0.5 pounds to1 pound
- Spinach: 0.5 pounds to1 pound
- Potatoes:1.5 pounds
- Tomatoes: 0.75 pounds to 2 pounds
- Peppers: 0.5 pounds
- Beans: 0.3 pounds to 0.5 pounds
- Peas: 0.3 pounds to 0.5 pounds (Bonnie Plants 2013)
- Cucumbers: 10-15 cucumbers (Yardener 2013)
- Strawberries: 0.5 pounds to 1 pound (Strawberryplants 2013)

Appendix A: References

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Appendix B: CFR Regulations

CFR Regulations

Title 46 §177.900

(a) Except as otherwise provided in this section, rails or equivalent protection must be installed near the periphery of all decks of a vessel accessible to passengers or crew. Equivalent protection may include lifelines, wire rope, chains, and bulwarks, which provide strength and support equivalent to fixed rails. Deck rails must include a top rail with the minimum height required by this section, and lower courses or equivalent protection as required by this section.

(b) Deck rails must be designed and constructed to withstand a point load of 91 kilograms (200 pounds) applied at any point in any direction, and a uniform load of 74 kilograms per meter (50 pounds per foot) applied to the top rail in any direction. The point and uniform loads do not need to be applied simultaneously.

(c) Where space limitations make deck rails impractical for areas designed for crew use only, such as at narrow catwalks in way of deckhouse sides, hand grabs may be substituted.

(d) The height of top rails required by paragraph (a) of this section must be as follows:

   (1) Rails on passenger decks of a ferry or a vessel engaged in excursion trips, including but not limited to sightseeing trips, dinner and party cruises, and overnight cruises, must be at least 1,000 millimeters (39.5 inches) high.

   (2) Rails on a vessel subject to the 1966 International Convention on Load Lines must be at least 1,000 millimeters (39.5 inches) high.

   (3) All other rails must be at least 910 millimeters (36 inches) high.

   (4) While engaged in big game angling, the minimum rail height may be reduced to not less than 760 millimeters (30 inches) in way of a person using specialized angling techniques or equipment, such as when using a pedestal mounted fixed fighting chair on a low freeboard vessel, if it can be shown that a higher rail would interfere with the fishing operation and the lower rail would not significantly reduce safety. A rail complying with the requirements of paragraphs (d)(1), (2), or (3) of this section as applicable must be installed when big game angling is not being conducted.

(e) Where the principal business of the vessel requires the discharge of persons or cargo in a seaway, such as on pilot boats and dive boats, the cognizant OCMI may accept alternatives to the rails required in paragraphs (d)(1), (2), and (3) of this section for those areas of a deck where passengers or cargo are discharged and for which removable rails, lifelines, or chains would hinder discharge operations.

(f) A sailing vessel, an open boat, or any other vessel not specifically covered elsewhere in this section, must have rails of a minimum height or equivalent protection as considered necessary by the cognizant OCMI, based on the vessel's operation, route, and seating arrangement.

(g) Rail courses or the equivalent must be installed between a top rail required by paragraph (a) of this section, and the deck so that no open space exists that is more than 305 millimeters (12 inches) high except:

  (1) On passenger decks of a ferry or of a vessel on an excursion trip the following must be installed:

    (i) Bulwarks;

    (ii) Chain link fencing or wire mesh that has openings of not more than 4 inches
    in diameter; or

    (iii) Bars, slats, rail courses, or an equivalent spaced at intervals of not more than 100 millimeters (4 inches).

  (2) On a vessel subject to the 1966 International Convention on Load Lines, rail courses, or an equivalent, must be installed so that there is not an open space higher than 230 millimeters (9 inches) from the deck to the first rail course or equivalent.

(h) Rails must be permanently installed except that the following rails may be removable;

  (1) Rails in way of embarkation stations and boarding locations;

  (2) Rails over 760 millimeters (30 inches) high in way of fishing seats addressed by paragraph (d)(4) of this section; and

  (3) Rails on a vessel when the service of the vessel is routinely changed, as determined by the cognizant OCMI, and the required top rail height varies depending on the service of the vessel at a particular time.

Appendix C: Plant Requirements

Table A-1: General requirements for plants (Pears, University of Illinois Extension 2013, Gardeners 2013, Miller Farms Nursery, personal communication, 2013, The American Horticultural Society 1980, Shannon, Grieve 1999).

Plant	Seed to Harvest	Sunlight Requirements	Season	Ideal pH Range	Space Requirements	Salt Sensitivity
Beans, string	7-13 weeks	Full sun	Warm	6.5-7.5	Needs trellis	
Beets	7-13 weeks	Partial sun	Cool	6.5-7.5	Needs space for deep roots	Tolerant
Broccoli	11-14 weeks	Partial sun	Warm	6.5-7.5	Large plants	Moderately sensitive
Peas	11-14 weeks	Full sun	Cool	6-6.8	Needs trellis	
Brussels Sprouts	20 weeks	Full sun	Cool	6.5-8		Moderately sensitive
Cabbage	20 weeks	Full sun	Spring, summer, and winter varieties	6-8	Moderate amount of space required	Moderately sensitive
Cauliflower	16-40 weeks	Full sun	Cool	6.5-8	Large plants	Moderately tolerant
Carrot	9-20 weeks	Shade	Cool	6.5-7.5	Root depth depends on variety (small to moderate)	Sensitive
Celery	11-16 weeks	Partial sun	Warm	6.5-7.5	Needs deep container	Tolerant
Swiss Chard	8-12 weeks	Partial sun	Warm	6.5-7.5	Needs little space	Tolerant
Chives	12-16 weeks	Full sun		6.1-7.8	Needs little space but will spread	Sensitive
Collards			Warm		Large plants	

Cucumber	12 weeks	Full sun	Warm	5.5-7	Needs trellis	
Dandelion						
Endive	7-13 weeks	Partial sun	Cool	5.5-7.5	Deep root space required	
Fennel	10-15 weeks	Full sun	Cool	5.5-7.5		Sensitive
Garlic	16-36 weeks	Full sun	Cool	6-7.5	Needs little space	Sensitive
Tomatoes	7-12 weeks	Full sun	Warm	5.5-7	Moderate to large plants depending on variety	
Kale	7 weeks	Partial sun	Cool	6.5-7.5	Large plants	
Leeks	16-20 weeks	Full sun	Cool	6.5-7.5	Needs little space	Sensitive
Kohlrabi	5-9 weeks	Partial sun	Year-round	6-7	Needs little space	Moderately sensitive
Lettuce	4-14 weeks	Partial sun	Cool	6-7	Needs little space	Widely varies depending on variety
Okra	50-65 days	Full sun	Warm	6.5-8.5	Needs little space	
Onion	20-24 weeks	Full sun	Cool	6-7	Needs little to moderate space depending on variety	Sensitive
Parsley	6 weeks	Partial sun		6-7	Needs little space	
Parsnips	16 weeks	Shade	Cool	6.5-8	Deep root space required	Sensitive
Peppers	20-28 weeks	Full sun	Warm	6-6.5	Moderate space required	
Potatoes	13-20 weeks	Shade	Warm	5-6	Moderate to deep root space required	Moderately tolerant
Radishes	4 weeks	Partial sun	Cool	6.5-7.5	Needs little space	Sensitive

Spinach	5-10 weeks	Partial sun	Warm	6.5-7.5	Needs little space	Tolerant
Sweet Potatoes	90-110 days	Full sun	Warm	6.2-6.8	Needs deep root space	Sensitive
Turnips	60-85 days	Partial sun	Cool	6-6.5	Needs space for deep roots	Moderately sensitive

Appendix D: Brainstorming

Brainstorming Notes

Two brainstorming sessions were conducted by Team Food On Deck to develop alternative solutions for the edible railing design. Figure 6-1 shows the written material developed during the first brainstorming session. Figure 6-2 displays the written material developed during the second brainstorming session.

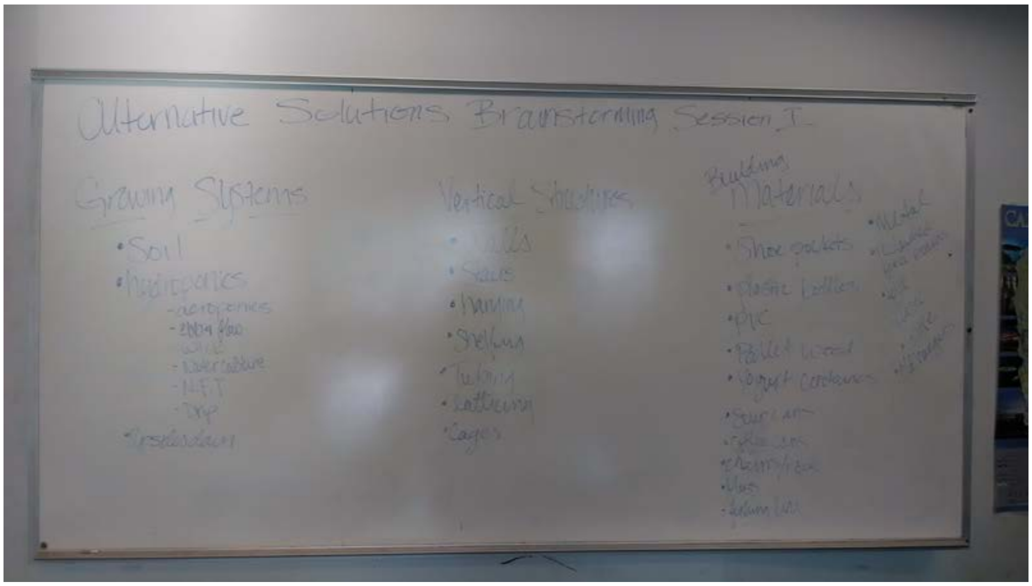


Figure D-1: Alternative Solutions Brainstorming Session 1.

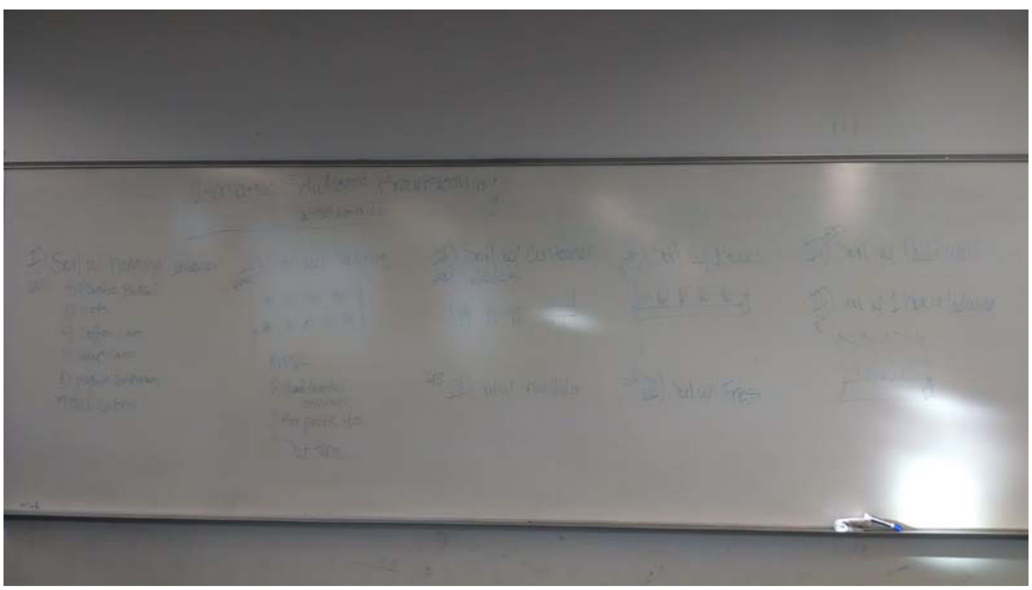


Figure D-2: Alternative Solutions Brainstorming Session 2.

Appendix E: Planting Schedule

Planting Schedule

Several plant species are recommended to be planted in Life Support. A general planting schedule for these plants is in included in Figures E-1 through E-7.

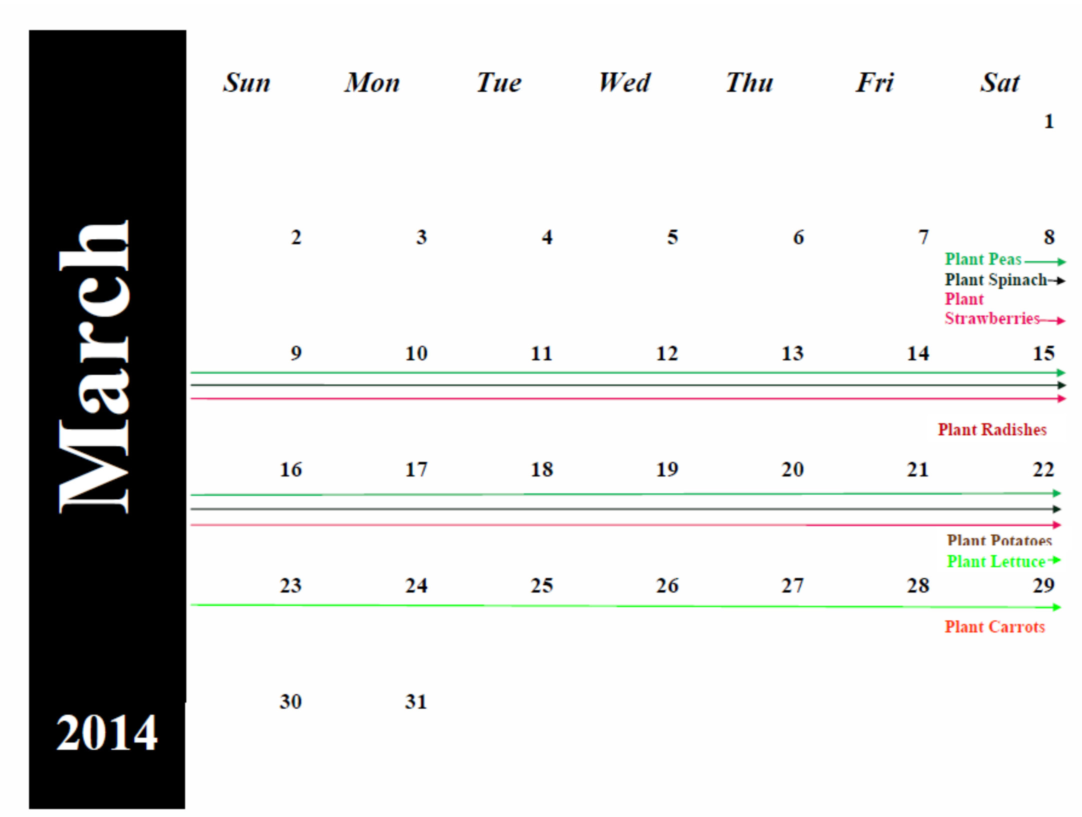


Figure E-1: Recommended planting schedule for Life Support for March 2014 (Veggie Harvest 2013).

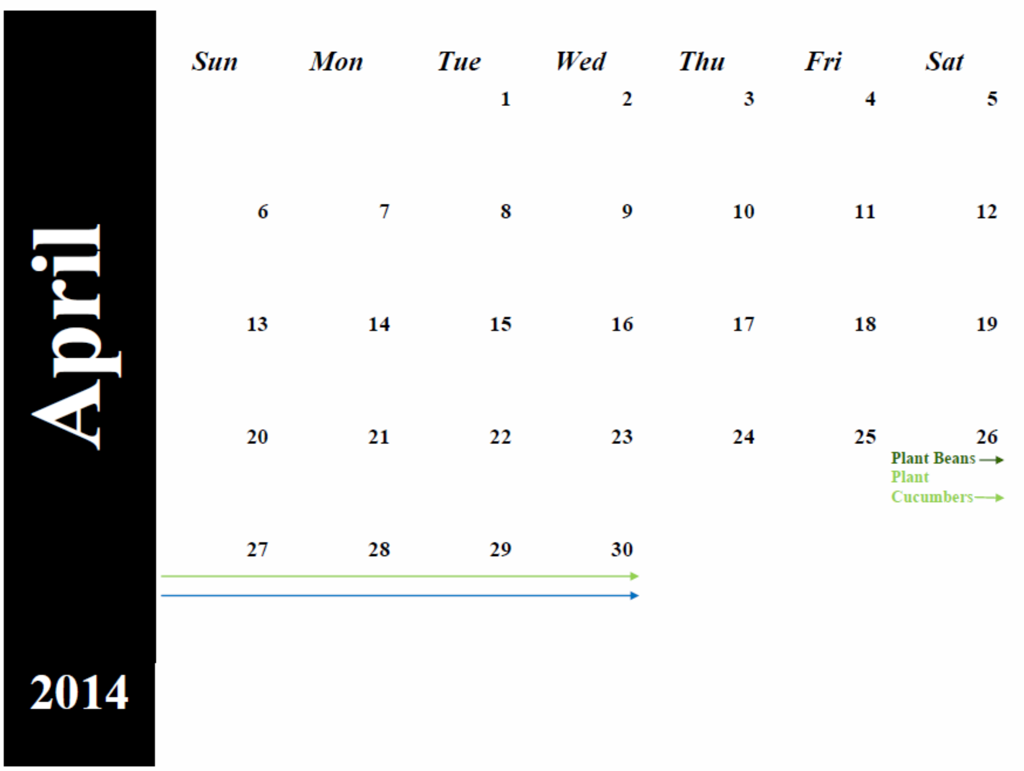


Figure E-2: Recommended planting schedule for Life Support for April 2014 (Veggie Harvest 2013).

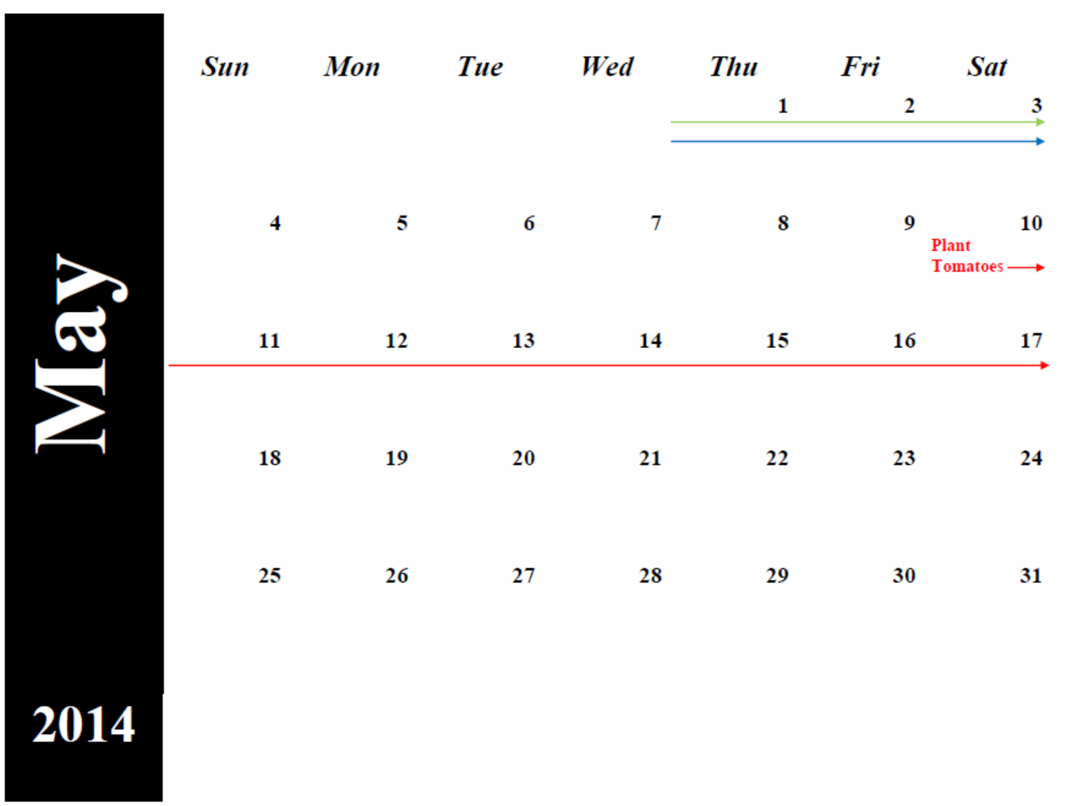


Figure E-3: Recommended planting schedule for Life Support for May 2014 (Veggie Harvest 2013).

June

2014

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

Figure E-4: Recommended planting schedule for Life Support for June 2014 (Veggie Harvest 2013).

July

2014

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

Figure E-5: Recommended planting schedule for Life Support for July 2014 (Veggie Harvest 2013).

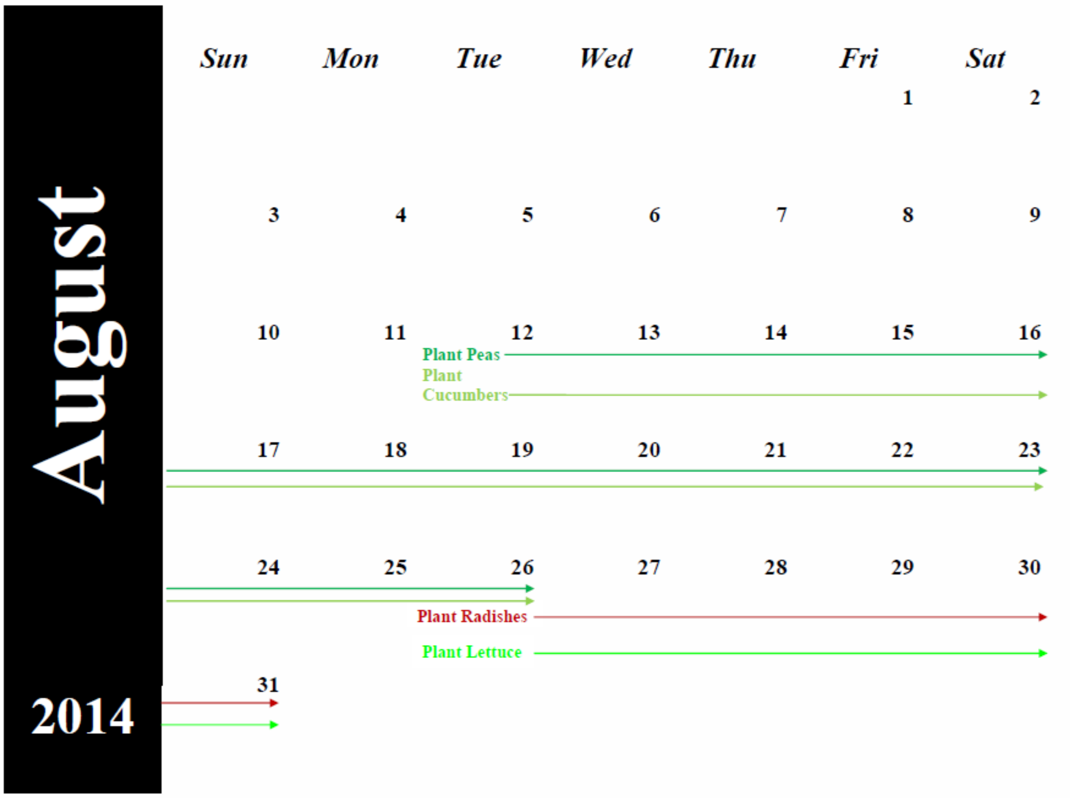


Figure E-6: Recommended planting schedule for Life Support for August 2014 (Veggie Harvest 2013).

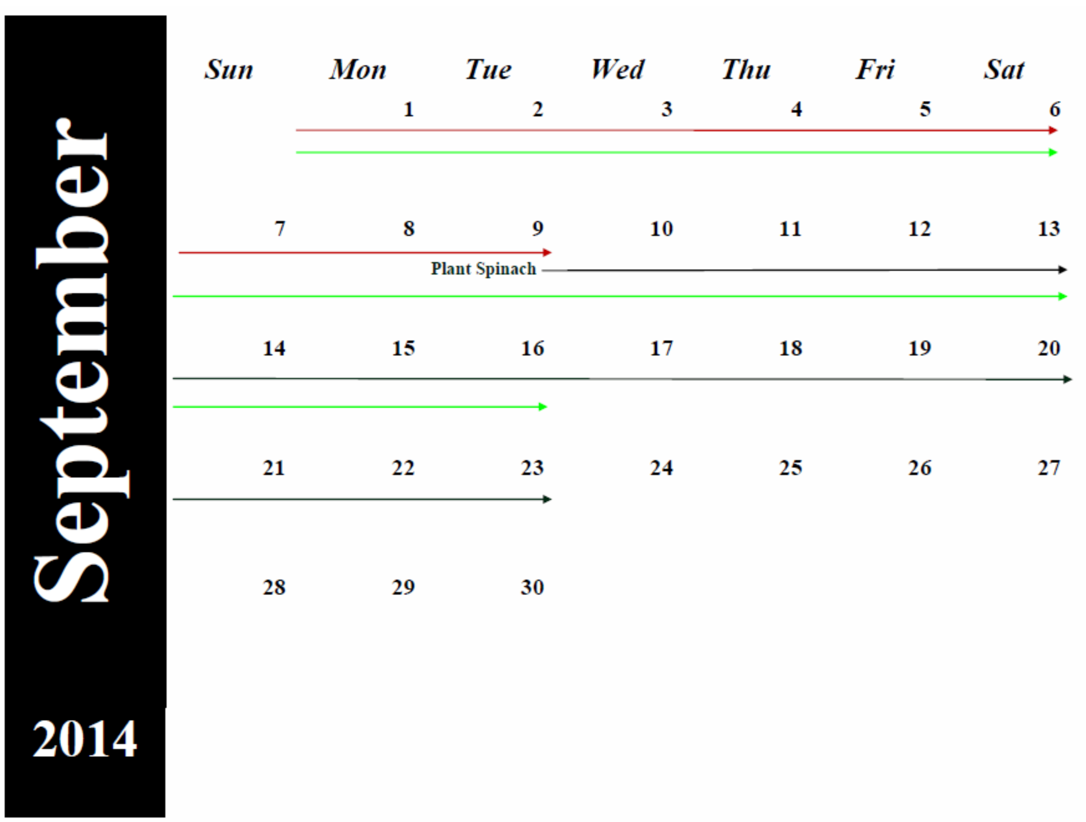


Figure E-7: Recommended planting schedule for Life Support for September 2014 (Veggie Harvest 2013).

Appendix F: Materials, Replication, and Maintenance

Materials Specifications

The following sections provide lists of the materials needed to build one 8-foot section of Life Support.

Plastic Containers and Trellis

Replication of one 8-foot section of the plastic container and trellis portions of Life Support requires the quantities of materials listed in Table F-1.

Table F-1: A list, description, and quantity needed of the plastic nutrient solution containers and trellis to replicate on 8-foot section of Life Support.

Picture	Description	Quantity Needed per 8-Foot Section
	Small plastic nutrient containers; 7 by 12 by 8 inches.	9
	Large plastic nutrient containers; 13 by 12 by 8 inches.	5, 2 for larger plants, 2 for the base of the trellis, and 1 for the water reservoir.
	Wire Fencing	2 pieces, 40 inches tall, 12 inches wide
	Zip Ties	44
	Sand Paper	1 pack

Soil

Table F-2 shows materials that are needed to replicate one 8-foot section of the soil portion of Life Support.

Table F-2: A list of soil materials needed for one 8-foot section of Life Support, including pictures, descriptions, and quantities of all materials.

Picture	Description	Quantity Needed per 8-Foot Section
	Weed Mat	7.5 Square Feet
	Volcanic Rock	13 Inches
	Fox Farm's Ocean Forest Potting Soil	1, 1.5 cubic foot bag
	Coconut Fiber	1 , 1.5 cubic foot bag

Plants

Each of the three sizes of plastic containers on Life Support can house different plant species. Table F-3 provides the quantities of each plant species that can be planted into each size of container for using both seeds and transplants.

Table F-3: a list of the plant species that can be planted in each size of plastic container on Life Support (Miller Farms Nursery, personal communication, 2013).

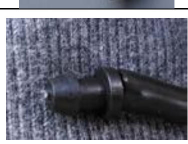
Type of Container	Plant	If using seeds, quantity per container	If using transplants, quantity per container
Small	Lettuce	6-8	n/a
	Spinach	6-8	n/a
	Strawberries	n/a	1
	Radishes	10-12	n/a
	Carrots	10-12	n/a
Large	Potatoes	4 pieces	n/a
	Peppers	n/a	1
	Tomatoes	n/a	1
Trellis	Beans	6	2-3
	Peas	6	2-3
	Cucumbers	6	n/a

Irrigation System

To replicate the irrigation system portion of Life Support, the materials and quantities listed in Table F-4 are required.

Table F-4: A list of the materials needs to replicate the irrigation system on one 8-foot section of Life Support.

Picture	Description	Quantity Needed per 8-Foot Section
	0.5 Inch Tubing	3 feet, 7 inches
	0.25 Inch Tubing	18 feet, 8 inches
	0.5 Inch 90 Degree Connector	1

	0.5 Inch T Connector	2
	Large Ball Valve with Hose Thread to Pipe Thread Converter and Valve to Pipe Thread Converter	1
	Small Ball Valve	3
	½ Inch Connector with Tread	4
	0.25 Inch Converter with Thread	3
	0.25 Inch T Connectors	13
	0.25 Inch End Plugs	3

Replication Instructions

The following sections provide detail instructions on the process of replicating Life Support. Figure F-1 shows one 8-foot section of Life Support and the dimensions of all the component pieces.

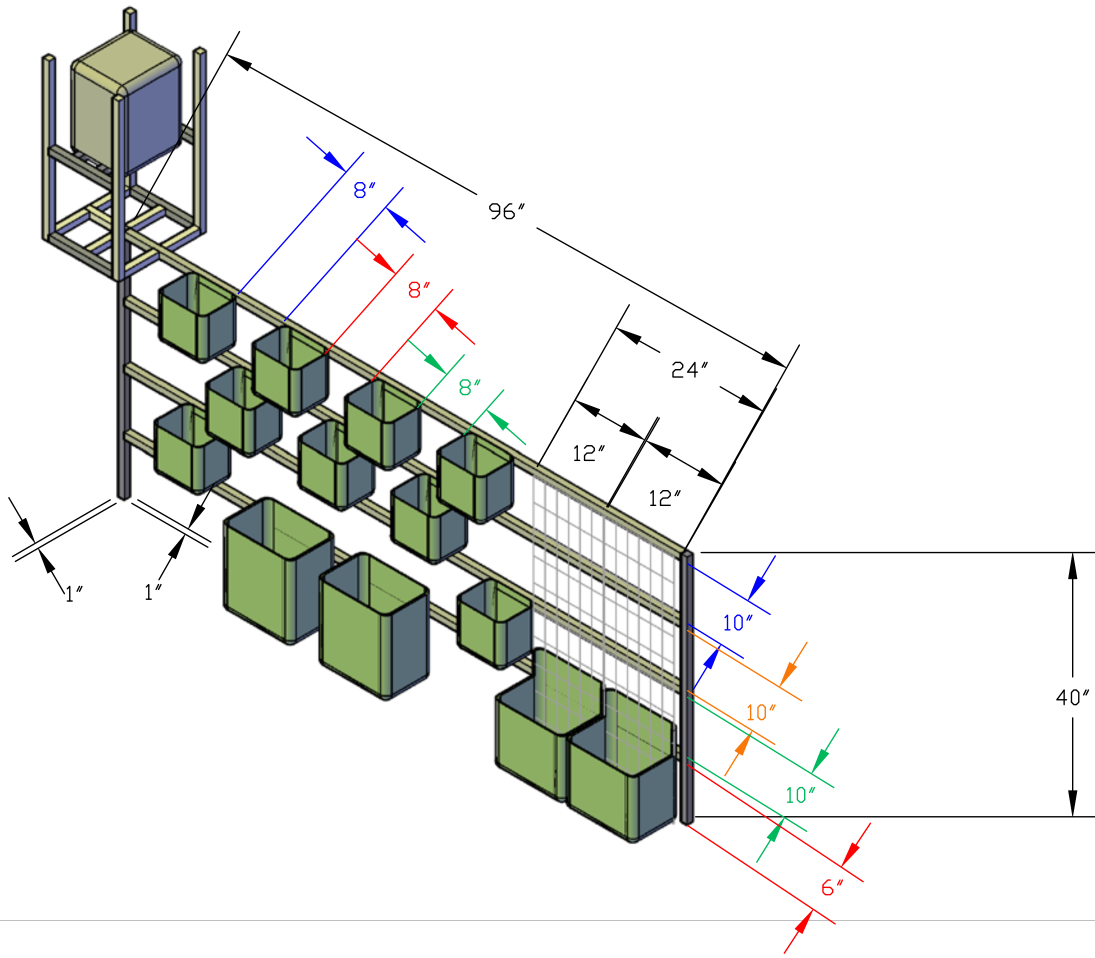


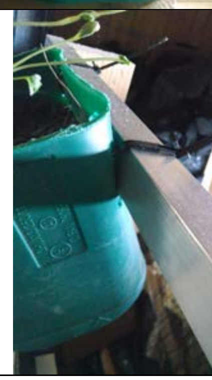
Figure F-1: The dimensions of one 8-foot section of Life Support (Trejo).

Small Plastic Containers

Table F-5 provides step-by-step instructions to assemble the small plastic nutrient containers to the metal railing.

Table F-5: Step-by-step instruction to assemble and attach the small plastic nutrient containers to one 8 foot section of metal railing.

Step	Description	Picture
1	Cut the tops off all containers approximately 7.5 inches from the bottom of the container.	
2	Thoroughly clean the inside and outside of the containers. Remove any labels.	
3	Use sand paper to smooth the rough edge where the top was cut off.	
4	Drill 4 holes in the back of the containers. The 2 top holes should be 1-inch from the top and 1-inch from the side. The bottom holes should be 1 inch below the top holes. A 0.25 inch drill bit should be used for these holes.	
5	Drill 2 holes in either side of the container 1-inch from the top of the container and 1-inch from the backside of the container. A 0.25 inch drill bit should be used for these holes.	

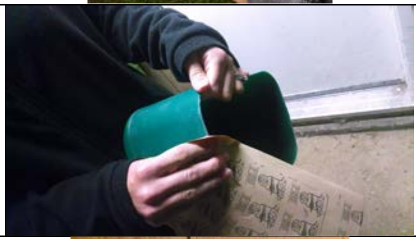
6	Drill 2 holes in the front bottom of the containers, approximately 1 inch from the front and 3 inches from the side. A 0.25 inch drill bit should be used for these holes.	
7	Thread 2 zip ties through the holes in the back of the containers.	
8	Attach the containers to the railing by wrapping the zip ties around the metal crossbars. Space the containers according the Figure 2-10. Make sure to tighten the zip ties as tight as possible.	

Large Plastic Containers

Table F-6 provides step-by-step instructions to assemble the large plastic nutrient solution containers to an 8-foot section of metal railing.

Table F-6: Step-by-step instructions to assemble the large plastic nutrient containers to an 8 foot section of metal railing.

Step	Description	Picture
1	Cut the tops off all containers approximately 14 inches from the bottom of the container.	

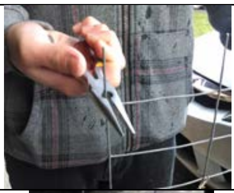
2	Thoroughly clean the inside and outside of the containers. Remove any labels.	
3	Use sand paper to smooth the rough edge where the top was cut off.	
4	Drill four holes in the back of the containers. The two top holes should be 7 inches from the bottom and 1.5 inches from the side. The bottom holes should be 1 inch below the top holes. A 0.25 inch drill bit should be used for these holes.	
5	Drill two holes in either side of the container 1 inch from the top of the container and 1 inch from the backside of the container. A 0.25 inch drill bit should be used for these holes.	
6	Drill two holes in the front bottom of the containers, approximately 1 inch from the front and 3 inches from the side. A 0.25 inch drill bit should be used for these holes.	

7	Thread two zip ties through the holes in the back of the containers.	
8	Attach the containers to the railing by wrapping the zip ties around the metal crossbars. Space the containers according the Figure 6-10. Make sure to tighten the zip ties as tight as possible.	

Trellis

Table F-7 provides step-by-step instructions to assemble the trellis to an 8-foot section of metal railing.

Table F-7: Step-by-step instruction to assemble the trellis to an 8 foot section of metal railing.

Step	Description	Picture
1	Cut the wire fencing into two 12 by 36 inch sections	
3	Place each trellis section into the large containers.	
4	Attach each trellis to the railing by wrapping zip ties around the wire and crossbar. Each trellis should be attached to the top three crossbars in three places.	

Soil

Table F-8 provides step-by-step instructions to assemble the soil inside each plastic nutrient container.

Table F-8: Step-by-step instructions to assemble the soil inside of each plastic nutrient container.

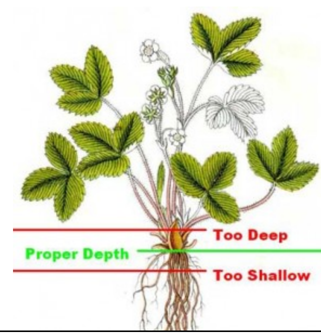
Step	Description	Picture
1	Cut the weed mat into nine 7.5 by 8.5 inch pieces and eight 9 by 12 inch pieces.	
2	Place 7.5 by 8.5 inch pieces of weed mat into the bottom of each of the small containers.	
3	Place 9 by 12 inch pieces of weed mat into the bottom and back of each large container.	
6	Place approximately 1 inch of volcanic rock on top of the weed mat inside of each container.	
7	In a large bucket or other container, mix the bag of Fox Farm's Ocean Forest Potting Soil with the bag of coconut fiber.	

8	Fill each container up to 1 inch of the top with the soil mixture.	

5.5.1 Plants

Table F-9 provides step-by-step instructions on how to plant each of the recommended edible plant species and in which container.

Table F-9: Step-by-step instructions to plant each of the recommended plant species.

Plant	Container Type	If using seeds	If using transplants
Lettuce	small	Plant seeds ¼ to ½ inch deep	n/a
Spinach	small	Plant seeds ½ inch deep	n/a
Strawberries	small	n/a	Plant deep enough to cover the roots with soil and so the bottom of the “crown” is level with the top of the soil as shown 
Radishes	small	Plant seeds ¼ to ½ inch deep	n/a
Carrots	small	Plant seeds ¼ to ½ inch deep	n/a
Potatoes	large	Plant potato pieces 1 to 3 inches deep	n/a
Peppers	large	Plant seeds ¼ to ½ inch deep	Plant deep enough so the top of the root ball is level with the top of the soil
Tomatoes	large	Plant seeds ¼ to ½ inch deep	Place in the soil covering the roots and

			stem up to the first set of leaves
Beans	trellis	Plant seeds 1 inch deep	Plant just deep enough to cover the roots with soil
Peas	trellis	Plant seeds 1 to 1½ inches deep	Plant just deep enough to cover the roots with soil
Cucumbers	trellis	Plant seeds ½ to 1 inch deep	Plant just deep enough to cover the roots with soil

Reservoir Cage

Table F-10 provides step-by-step instructions to assemble the reservoir cage to an 8-foot section of metal railing.

Table F-10: Step by step instructions to assemble the reservoir cage.

Step	Description
1	Cut the following lengths of 1-inch square steel conduit: <u>Label</u> <u>Length (in)</u> <u>Amount</u> A 27 4 B 11 4 C 13 6 D 6 6
2	Weld each section together as shown in the images below.
3	Align the 1-inch space at the base of the water reservoir cage with the top crossbar of the barge railing and weld together.

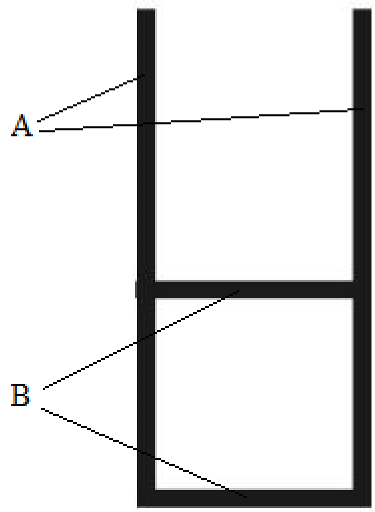


Figure F-2: Front view (Zirkel).

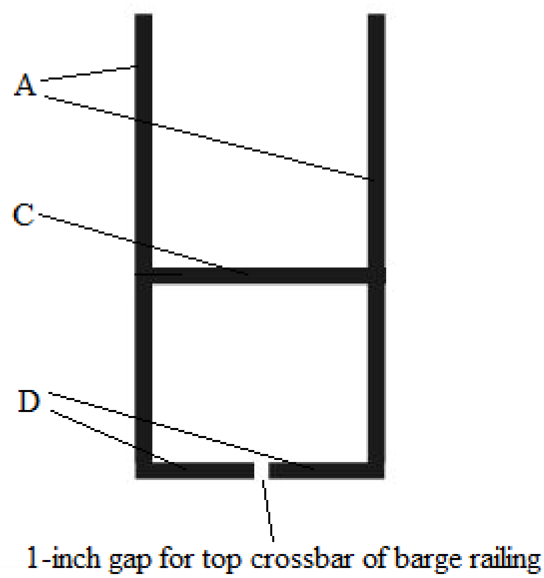


Figure F-32: Side angled view (Zirkel).

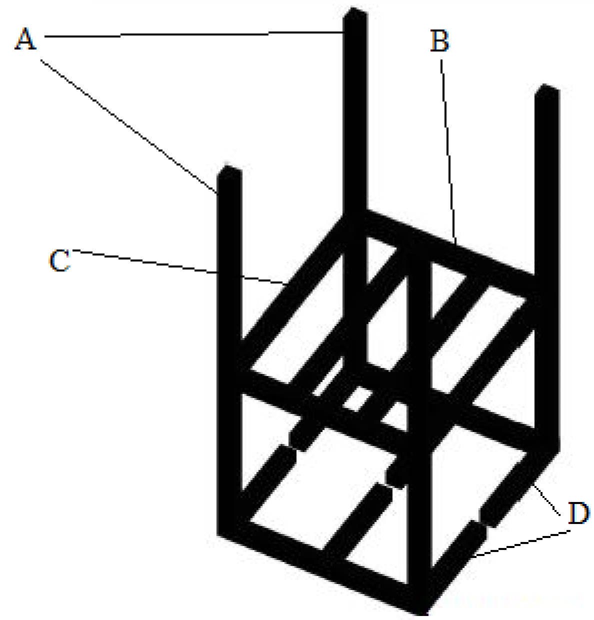


Figure F-4: Top angled view (Zirkel).

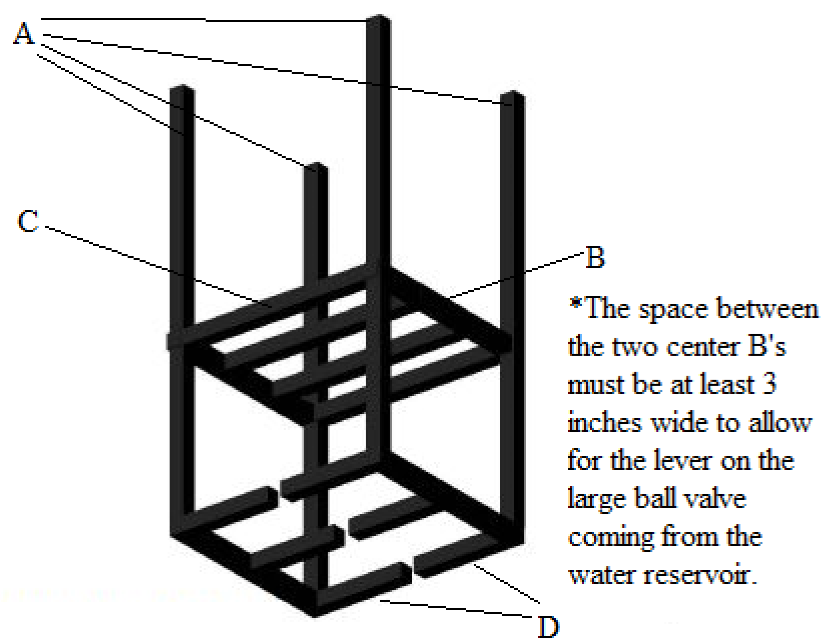


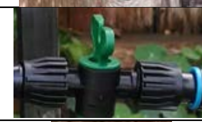
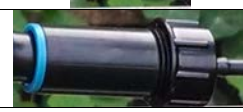
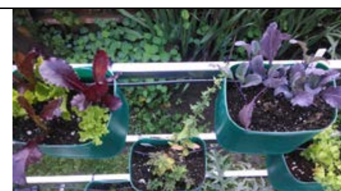
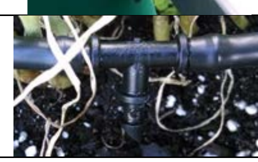
Figure F-5: Bottom angled view (Zirkel).

Irrigation System

Table F-11 provides step-by-step instructions to assemble the irrigation system to an 8 foot section of metal railing.

Table F-11: Step-by-step instructions to assemble the irrigation system to an 8 foot section of metal railing.

Step	Description	Picture
1	Connect the large ball valve with attached hose thread to pipe thread converter and valve to pipe thread converter	
2	Connect the 0.5-inch connector with thread and 0.5-inch cap with thread converter to the hose thread to pipe thread converter.	
3	Attach 3.25 inches of 0.5- inch tubing to the cap converter.	
4	Attach a 0.5-inch T connector to the 0.5-inch tubing.	
5	Attach 10 inches of 0.5-inch tubing to the bottom half of the first T connector.	

6	Attach 3.5 inches of 0.5-inch tubing to the horizontal part of the T connector.	
7	Attach one of the small ball valves to the 3.5 inches of 0.5-inch tubing.	
8	Attach 3.5 inches of the 0.5-inch tubing to the other side of the small ball valve.	
9	Attach the 0.5-inch connector with thread to the 0.5-inch tubing.	
10	Attach the 0.25-inch converter with thread to the threaded end of the 0.5-inch connector.	
11	Attach the indicated length of 0.25-inch tubing to the 0.25-inch converter. Top row: 65 inches Middle row: 75 inches Bottom row: 96 inches	
12	Thread the 0.25-inch tubing through the side holes of each container.	
13	Attach a 0.25-inch end plug to the end of the 0.25-inch tubing.	
14	In the center of each container cut the 0.25-inch tubing and attach a 0.25-inch T connecter.	

15	Attach the second 0.5-inch T connector to the 10 inches of 0.5-inch tubing that is attached to the first 0.5-inch T connector.	
16	Repeat steps 6-14	
17	Attach 10 inches of 0.5-inch tubing to the bottom of the second 0.5-inch T connector.	
18	Attach the 0.5-inch 90 degree to the 10 inch of 0.5-inch tubing.	
19	Attach 3.5 inches of 0.5-inch tubing to the horizontal end of the 90 degree connector.	
20	Repeat steps 6-14.	

Maintenance Guidelines
The following sections provide guidelines for maintaining Life Support.

Containers
Once per week, check that the zip ties connecting the containers to the railing are as tight as possible.

Irrigation System
The amount of water Life Support should receive is highly variable. The variables controlling the amount of water that should be supplied to each plant are climate conditions, season, type of plant, and location. Therefore the following guideline is a general recommendation for irrigating Life Support.

Once every other day, fill each reservoir. Before filling make sure the big ball valve and all three small ball valves are turned off (the tab is perpendicular to the pipe). Once the reservoir is filled, open the main ball valve. Open the first small ball valve. Leave this first valve open for approximately 3 minutes. After approximately 3 minutes, close the first small ball valve and open the second small ball valve. Leave the second valve open for approximately 3 minutes. After approximately 3 minutes close the second small ball valve and open the third small ball valve. Leave the third valve open for approximately 3 minutes. After approximately 3 minutes close the large ball valve. After approximately 3 minutes close the third small ball valve. Closing the large ball valve first allows any water stored in the tubing to drain out through the third line.

Check each container to make sure water is draining from each 0.25 inch T connector.

Plants

Once per week, or more often as necessary, remove any weeds and dead foliage from the containers.

Once per day, check each plant for ripe produce.