***biostack:*** *Agriculture's future*
***James Dyson Award***

# Viability Study


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# Needs Identification

## 1. Mission Statement

**Name**
The name given to the product should be something representative of its purpose and the image we want to project. Those are the reasons we decided to name our hydroponic system as ***biostack***, which joins the word bio (representing the ecological side of the product) and stack (showcasing the modular hydroponic system).

**Product Description**
***biostack*** refers to a rethinking of the successfully proven method of cultivation: hydroponics, and its automation to further ease agriculture.

The system consists of three different modules that, together, are adapted to the needs of our clients. The base module is the control module which contains all the computational elements that allow monitoring and responding to changes in temperature, humidity or light of the crop. These modules are programmed according to the type of crop they monitor so customers can have as many crops as they have controller modules.

The second type of module is the extension or cultivation module, which only contains spaces for production and its sensors for monitoring. When an extension module is stacked on a control module these two types of modules are interconnected so that the control module receives relevant information from the crop modules stacked on top of it and determines the actions necessary to maintain the optimal parameters according to the type of crop.

Finally, we have an optional module that will make the crop even more environmentally friendly by having a solar panel that collects enough energy so that the entire infrastructure works without connection to the electricity grid.

**Value Proposal**
Every year, worldwide, 12 million hectares are lost and our country is severely affected by the deterioration of its soil. SEMARNAT estimated in 2002 that more than 45% of the Mexican territory was deteriorated, with the main cause being chemical deterioration due to the use of fertilizers, inadequate irrigation and other activities related to agriculture that are included as "loss of fertility". Ultimately, this causes 300 thousand people to emigrate from infertile lands each year just in Mexico.

For this reason, we seek to reimagine how our food is grown, in addition to seeing the way in which we could help communities whose lands deteriorate year after year. After an analysis of the problem and the agents involved, ***biostack: the future of agriculture*** emerged. ***biostack*** is an economical and user-friendly solution that allows anyone to grow different vegetables and legumes in very little space and without the need for hectares of fertile land.

For its part, automation is related to our architecture of value. It is based on the control technology of each of the hydroponic modules to regulate the conditions of each crop (such as temperature or humidity). This allows for the improvement of crop production and reduction of maintenance that modules require.

**Product Objectives**

The objective of ***biostack*** is to ensure opportunities and a nutritious diet for the growing world population without the problems that traditional farming presents.

There are many benefits of this type of crop; first, the control you have over them allows you to avoid diseases or pests and above all, a reduction in water use of more than 90% compared to a traditional crop. Likewise, the nutrients are absorbed in a more homogeneous way since they reach the roots of the plants directly, achieving more nutritious crops of the same quality throughout.

In terms of community benefits, this system allows the generation of a profitable source of income for those who grow the products if they are handled as sales, or as a source of nutritious food. In addition, being able to grow different legumes and vegetables such as chard, lettuce, tomatoes, strawberries, coriander, among many others, could considerably improve the quality of the diet of the population of said community since legumes contain a high protein level and can create an alternative to consumption of meat.

**Primary Market**

The primary market will focus on communities relying on agriculture that suffer from land degradation in their crops and financial strain. However, the main customer will be governments and non-profit organisations that aid rural development. Thanks to the implementation of a hydroponic growing system, they should not depend directly on the quality of the soil, in addition to having a positive effect financially, their health and their quality of life.

**Secondary Market**

Rural communities will also be able to buy biostack modules directly to benefit from the advances in hydroponics and control systems.

**Other Possible Markets**

biostack will also offer its modules for sale to users in urban areas in order to generate additional income that will allow us to continue with product development. These users could include restaurants, supermarkets and users that wish to grow a portion of their own food.

**Restrictions**

Because it is a product that will be used in the agricultural sector, it must have the corresponding authorizations in the public and private sectors to be able to go into the market.

Similarly, because electronic components are used, the corresponding specifications and standards must be met depending on the country in which it is located. For example, NOM-063-SCFI-2001 for safety requirements in electrical products in Mexico and the ISO 9001 standard to ensure product quality internationally. [1, 2]

**Assumptions**

The resulting product will be constructed with both recycled and recyclable materials. This product arose from the need to improve a common situation for millions of people around the world in a sustainable way. With this in mind the product will not have a high level of integration and will favor modularity for scalability and maintenance purposes. The product must have a long life cycle, this can be achieved with a durable construction and/or with easy repairability.

**Stakeholders (internal and external)**

The investors involved in the development and commercialization of this product are of two types:

Internal: those who will be involved in the development of the product, in addition to the investors granting the necessary capital to achieve it and its subsequent introduction to the market, who will receive dividends as the product is stabilized in the market.

External: personnel in the agriculture sector, public and private, who will recommend the product and retailers and wholesalers who will allow the sale of the product in the market and who will be awarded a percentage of the sale price as profit.

## 2. Gather Raw Data

Raw data was gathered by interviewing two experts and analyzing similar products in their use environments. One of the people interviewed was a chemist with an inorganic specialization with experience in the environment and education, while the other has worked in government projects related with food distribution and information systems for several years. Products analysed ranged from simple recycled hydroponic systems to advanced concepts and prototypes that did not reach production in the past years.

Because of the nature of the product and it being directed mainly to government social programs, the need for a focus group was deemed as not necessary with advice from the professor.

The first interview was made to Adrián Fernández Reyes, an expert in sustainability with several works on the subject. The principal questions posed to him were in relation to the feasibility of the project and the ways it could be improved in terms of sustainability, the environment and the social factor of biostack. He gave us real world insights that the product could work and be successful in the agricultural market.

The first point treated with Adrian was scalability of the product, as he said the lifetime cycle and types of materials should be a main priority. Also, he made a point that one of the problems that could be targeted is the reduction of nitrogen and phosphorus levels in the atmosphere, as well as carbon dioxide, but studies should be done to confirm this hypothesis.

One of the ideas he gave that we hadn't considered was the esthetics of the product, as he noted that a good looking product would be more attractive to customers than a raw-built product, even with the same materials.

The last idea given by Adrian was the after-care and maintenance of the product and how it would be handled, and how we should prioritize making it user-friendly.

The second  interviewed person was Martha Jarquín who is an advisor to the information and monitoring system of the supply center (Central de Abastos de la Ciudad de México). The interviewee shared with us the information about the mechanism in the central supply, as well as that of the food residue. Likewise, she shared an explanation of the food that can be produced during a year and the scarcity that can be associated with it.

There are currently no similar products in the market, but there have been projects in hydroponics and automation that have worked on big scales. The best example is Aerofarms, an indoor vertical farming based on precision and productivity with minimal environmental impact. They have raised over $140 million dollars since their establishment in 2004, proving the possibility of the success of the product on a bigger scale.

## 3. Interpret Raw Data

For the process of product development we identified the need to:

- The product has a big variety of crops available
- The product has automatic control
- The product is not extremely expensive
- The product is sustainable
- The product functions in areas with no electrical power
- The product is made of recyclable/reusable materials
- The product has little maintenance requirements
- The product has easy maintenance
- The product measures and displays water measurements
- The product optimizes the water usage
- The product has measurable water usage
- The product is designed modularly
- The product has the capacity to resize
- The product is good pricing
- The product can be used as a harvest replacement
- The product is user friendly
- The product can be used inside
- The product is scalable
- The product can adapt itself to the varying needs of a crop's life cycle
- The product is durable
- The product can resist a few hits
- The product has the ability to isolate/quarantine crops
- The product has good structure for crops
- The product can have different crops with different needs
- The product monitors the products easily.
- The product reduces crop losses
- The product makes it easy for agriculturists to cultivate common crops
- The product can have different crops in the same space
- The product produces crops with nutritional value
- It requires less than five tools to install
- The product is portable
- The product adapts to accept genetically enhanced crops
- The product is a cheap system that can be bought by agriculturists (at most ¾ the price of the competitors)
- The product allows to modify control parameters
- The product can be used in tight spaces (1 m x 0.5 m)

- The product is weather independent
- The product has its own power-source
- The product can accept the use of additional vitamins
- The product is easy to transport in trucks
- The product reduces crops waste
- The product helps have better quality
- The product can control the crops parameters over the time easily
- The product can be used inside or outside
- The product requires less than 5 tools for maintenance
- The product has the capability of planning a specific number of crops
- The product reduces the possibility of plagues without using pesticides
- The product regulates the nutrients of each crop by a control element
- The product controls the pH level of the water
- The product lasts more than 5 years
- The product has replaceable parts for longer life
- The product functions without additional vitamins for the crops
- The product can adapt to users' space requirements

# 4. Organize the Needs

## Primary needs

- The product has a big variety of crops available.
- The product has automatic control.
- The product functions in areas with no electrical power.
- The product is not extremely expensive.
- The product has good pricing.
- The product has little maintenance requirements.
- The product is sustainable.
- The product is made of recyclable/reusable materials.
- The product reduces crop waste.
- The product has easy maintenance.
- The product is designed for modularity.
- The product can be used as a harvest replacement.
- The product is user friendly.
- The product can be used inside.
- The product is scalable.
- The product is durable.
- The product is portable.
- The product can resist a few hits.
- The product has replaceable parts for longer life.
- The product can be used inside or outside.
- The product has the ability to isolate/quarantine crops.
- The product helps have better quality.

- The product has good structure for crops.
- The product can have different crops with different needs.
- The product can have different crops in the same space.
- The product can adapt to accept genetically enhanced crops.
- The product is weather independent.
- The product monitors the products easily.
- The product reduces crop losses.
- The product makes it easy for agriculturists to cultivate  common crops.
- The product functions without additional vitamins for the crops.
- The product can adapt to users' space requirements

## Secondary needs

- The product measures and displays water utilised
- The product optimizes the water usage
- The product controls the pH level of the water
- The product has measurable water usage
- The product has the capacity to resize
- The product allows to modify control parameters
- The product can be used in tight spaces (1 m x 0.5 m)
- The product requires less than 5 tools for maintenance
- The product lasts more than 5 years
- The product is easy to transport in trucks
- The product has the capability of planning a specific number of crops
- The product can adapt itself to the varying needs of a crop's life cycle
- The product produces crops with nutritional value
- The product requires less than five tools to install
- The product is a cheap system that can be bought by agriculturists (at most ¾ the price of the competitors)
- The product has its own power-source It can accept the use of additional vitamins
- The product can control the crops parameters over the time easily
- The product reduces the possibility of plagues without using pesticides
- The product regulates the nutrients of each crop by a control element

## Grouped needs

**1. The product can grow different crops**

- The product has a big variety of crops available.
- The product can have different crops with different needs.
- The product can adapt to accept genetically enhanced crops.
- The product can be used as a harvest replacement.

**2. The product can grow multiple crops simultaneously**

- The product can have different crops with different needs.

- The product can have different crops in the same space.

**3. The product can improve crop quality**
- The product has the ability to isolate/quarantine crops.
- The product helps have better quality.
- The product has good structure for crops.
- The product reduces crop losses.
- The product helps to have better quality.
- The product produces crops with nutritional value
- The product can accept the use of additional vitamins
- The product reduces the possibility of plagues without using pesticides

**4. The product requires little manual intervention**
- The product has automatic control.
- The product has little maintenance requirements.
- The product has easy maintenance.
- The product monitors the products easily.
- The product controls the pH level of the water
- The product requires less than 5 tools for maintenance
- The product regulates the nutrients of each crop by a control element
- The product can adapt itself to the varying needs of a crop's life cycle
- The product requires less than five tools to install
- The product can control the crops parameters over the time easily

**5. The product can operate without a power grid available**
- The product functions in areas with no electrical power.
- The product has its own power-source

**6. The product is sustainable**
- The product is made of recycled/reusable materials.
- The product reduces crop waste.
- The product reduces the possibility of plagues without using pesticides

**7. The product is affordable**
- The product is not extremely expensive.
- The product has good pricing.
- The product is a cheap system that can be bought by agriculturists (at most ¾ the price of the competitors)

**8. The product can operate during any season of the year**
- The product is weather independent.
- The product can adapt itself to the varying needs of a crop's life cycle

**9. The product has a durable construction**

- The product can resist a few hits.
- The product has a good structure for crops.

**10. The product is user friendly**

- The product makes it easy for agriculturists to cultivate common crops.
- The product allows to modify control parameters
- The product measures and displays water utilised
- The product can control the crops parameters over the time easily

**11. The product is portable**

- The product can be used inside or outside.
- The product can be used inside.
- The product has the capacity to resize
- The product can be used in tight spaces (1 m x 0.5 m)
- The product is easy to transport in trucks

**12. The product is scalable**

- The product is designed for modularity.
- The product can adapt to users' space requirements
- The product can be used in tight spaces (1 m x 0.5 m)
- The product has the capability of planning a specific number of crops

**13. The product has a long life-cycle**

- The product has replaceable parts for longer life.
- The product is durable.
- The product lasts more than 5 years

**14. The product generates little waste**

- The product reduces crop waste.
- The product reduces the possibility of plagues without using pesticides

**15. The product uses resources efficiently**

- The product reduces crop waste.
- The product functions without additional vitamins for the crops.
- The product optimizes the water usage
- The product can accept the use of additional vitamins

## 5. Establish Importance

We developed a survey to define the priority of the needs that people have about hydroponic crops. Next, the data will be displayed in an orderly manner according to the survey we carried out around 35 people.

| Necessity | Importance |
|---|---|
| The product has a durable construction | 4.04 |
| The product can improve crop quality | 3.93 |
| The product is sustainable | 3.93 |
| The product generates little waste | 3.85 |
| The product is affordable | 3.81 |
| The product is user friendly | 3.81 |
| The product can grow different crops | 3.77 |
| The product can grow multiple crops simultaneously | 3.74 |
| The product has a long life-cycle | 3.70 |
| The product requires little manual intervention | 3.63 |
| The product can operate during any season of the year | 3.63 |
| The product uses resources efficiently | 3.55 |
| The product is scalable | 3.52 |
| The product can operate without a power grid available | 3.41 |
| The product is portable | 3.04 |

## 6. Reflect on the Process

***biostack*** is a project the team has been working on for around 8 months, and the thought process about it has evolved around many different changing factors, such as purpose, sustainability, structure and benefits.

This process has been very good for the product development process as we have identified new needs for the product and found out problems we had not considered. The interviews we had with experts allowed us to verify the feasibility of the product in the real world market, and gave us insights as to how it could be directed in it.

Finally, a collateral effect that we observe is that ***biostack*** can help reduce food waste in the future, since these are sometimes rejected by buyers due to their maturity. We can think ahead in the project to reduce waste and be able to convert the non-required product into food for the needy people.

# Definition of Specifications

## 1. Prioritized Necessities Table

From the previous document presented we developed a survey to define the priority of the needs that people have about hydroponic crops. The data is displayed in an orderly manner according to the survey we carried out to around 35 people.

| | **Necessity** | **Importance** |
|---|---|---|
| 1 | The product has a durable construction | 4.04 |
| 2 | The product can improve crop quality | 3.93 |
| 3 | The product is sustainable | 3.93 |
| 4 | The product generates little waste | 3.85 |
| 5 | The product is affordable | 3.81 |
| 6 | The product is user friendly | 3.81 |
| 7 | The product can grow different crops | 3.77 |
| 8 | The product can grow multiple crops simultaneously | 3.74 |
| 9 | The product has a long life-cycle | 3.70 |
| 10 | The product requires little manual intervention | 3.63 |
| 11 | The product can operate during any season of the year | 3.63 |
| 12 | The product uses resources efficiently | 3.55 |
| 13 | The product is scalable | 3.52 |
| 14 | The product can operate without a power grid available | 3.41 |

| | | |
|---|---|---|
| 15 | The product is portable | 3.0 |

## 2. Specifications

In the first place, metrics and units should be specified.

| # | Necessities covered | Metric | Importance | Units |
|---|---|---|---|---|
| 1 | 1, 6 | Special tools required for maintenance | 4.04 | list |
| 2 | 1, 6 | Number of steps to disassemble/assemble for maintenance | 4.04 | list |
| 3 | 1, 9 | Product life time | 4.04 | cycles of use |
| 4 | 1, 11 | Environment test duration until part degradation | 4.04 | hours |
| 5 | 2 | Number of harvested vegetables | 3.93 | units per cycle |
| 6 | 3 | Energy auto sufficiency | 3.93 | hours |
| 7 | 3, 4 | Amount of garbage generated | 3.93 | kg/month |
| 8 | 3, 4, 12 | Water required per crop | 3.93 | litres/week |
| 9 | 3, 12 | Industrial Standard Tests | 3.93 | list |
| 10 | 5 | Complete system price | 3.81 | $(MXN) |
| 11 | 5 | Unit manufacturing cost | 3.81 | $(MXN) |
| 12 | 6 | Required time to prepare crop | 3.81 | minutes |
| 13 | 6, 7, 10 | Number of steps required to change between crops | 3.81 | Number of clicks |
| 14 | 7, 8 | Crop cycle length until harvest | 3.77 | months |
| 15 | 8 | Number of different crops allowed simultaneously | 3.70 | List |
| 16 | 9 | Crop cycles to failure | 3.74 | cycles |

| | | | | |
|---|---|---|---|---|
| 17 | 10 | Installation time | 3.63 | minutes |
| 18 | 10 | Steps required for initial assembly and installation | 3.63 | List |
| 19 | 11 | Flexibility in seasons | 3.63 | List |
| 20 | 12, 14 | Solar module energy capacity | 3.55 | kW/hr |
| 21 | 13 | Maximum quantity of modules | 3.52 | List |
| 22 | 13, 15 | Crop module size | 3.04 | cm |

## 3. Orthogonality and universality verification

Inspecting the orthogonality of the specifications in the table above, three relevant pairs were identified. Metrics 1 and 2 are not considered orthogonal, as they both relate to exactly the same needs and there is an important correlation between the amount of time it takes for maintenance and the number of tools required for it. However, it was decided to leave both specifications since time is an important variable for the user and the number of tools is also related to the complexity of the maintenance (its relation to the need is added accordingly).

Something similar is identified with metrics 17 and 18, since initially it is considered that both are related only to need 10, when in reality it can be considered that 18 also measures complexity and is related to need 6. Also, specification 17 is highly dependent on the user and, thus, is eliminated. Finally, the Metrics 10 and 11 are not orthogonal and only the final price is preserved as a metric.

When verifying universality, it is identified that specification 21 is not universal, since it depends directly on the modular design of the product under consideration. Therefore, that specification is removed.

The specification table reflecting these changes is shown below.

| # | Necessities covered | Metric | Importance | Units |
|---|---|---|---|---|
| 1 | 1, 6, 10 | Special tools required for maintenance | 4.04 | list |

| | | | | |
|---|---|---|---|---|
| 2 | 1, 6 | Number of steps to disassemble/assemble for maintenance | 4.04 | list |
| 3 | 1, 9 | Product life time | 4.04 | cycles of use |
| 4 | 1, 11 | Environment test duration until part degradation | 4.04 | hours |
| 5 | 2 | Number of harvested vegetables | 3.93 | units per cycle |
| 6 | 3 | Energy auto sufficiency | 3.93 | hours |
| 7 | 3, 4 | Amount of garbage generated | 3.93 | kg/month |
| 8 | 3, 4, 12 | Water required per crop | 3.93 | litres/week |
| 9 | 3, 12 | Industrial Standard Tests | 3.93 | list |
| 10 | 5 | Complete system price | 3.81 | $(MXN) |
| 11 | 6 | Required time to prepare crop | 3.81 | minutes |
| 12 | 6, 7, 10 | Number of steps required to change between crops | 3.81 | Number of clicks |
| 13 | 7, 8 | Crop cycle length until harvest | 3.77 | months |
| 14 | 8 | Number of different crops allowed simultaneously | 3.70 | List |
| 15 | 9 | Crop cycles to failure | 3.74 | cycles |
| 16 | 6, 10 | Steps required for initial assembly and installation | 3.63 | List |
| 17 | 11 | Flexibility in seasons | 3.63 | List |
| 18 | 12, 14 | Solar module energy capacity | 3.55 | kW/hr |
| 19 | 13, 15 | Crop module size | 3.04 | cm |

# 4. Needs to specification matching

| # | Needs \ Metrics | 1 Special tools required for maintenance | 2 Time to dissassemble/assemble for maintenance | 3 Product life time | 4 Environment test duration until part degradation | 5 Number of harvested vegetables | 6 Energy auto sufficiency | 7 Amount of garbage generated | 8 Water required per week per crop | 9 Industrial Standard Tests | 10 Complete system price | 11 Unit manufacturing cost | 12 Time a task requires (usability) | 13 Number of steps required to change between crops | 14 Crops cycle until harvest | 15 Number of different crops allowed simultaneously | 16 Crop cycles to failure | 17 Direct manual intervention | 18 Flexibility in seasons | 19 Solar module energy capacity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | The product has a durable construction | X | X | X | X | | | | | | | | | | | | | | | |
| 2 | The product can improve crop quality | | | | | X | | | | | | | | | | | | | | |
| 3 | The product is sustainable | | | | | | X | X | X | X | | | | | | | | | | |
| 4 | The product generates little waste | | | | | | | X | X | | | | | | | | | | | |
| 5 | The product is affordable | | | | | | | | | | X | | | | | | | | | |
| 6 | The product is user friendly | X | X | | | | | | | | | X | X | | | | | | | |
| 7 | The product can grow different crops | | | | | | | | | | | | X | X | | | | | | |
| 8 | The product can grow multiple crops simultaneously | | | | | | | | | | | | | X | X | | | | | |
| 9 | The product has a long life-cycle | | | X | | | | | | | | | | | | X | | | | |
| 10 | The product requires little manual intervention | X | | | | | | | | | | | X | | | | X | | | |
| 11 | The product can operate during any season of the year | | | | X | | | | | | | | | | | | | X | | |
| 12 | The product uses resources efficiently | | | | | | | | X | X | | | | | | | | | X | |
| 13 | The product is scalable | | | | | | | | | | | | | | | | | | | X |
| 14 | The product can operate without a power grid available | | | | | | | | | | | | | | | | | | X | |
| 15 | The product is portable | | | | | | | | | | | | | | | | | | | X |

# 5. Selection of competitors to guide product design

There are no products similar to *biostack* in the market, although there are plenty of successful companies that specialize in hydroponic crops and systems. The competitors chosen are as follows:

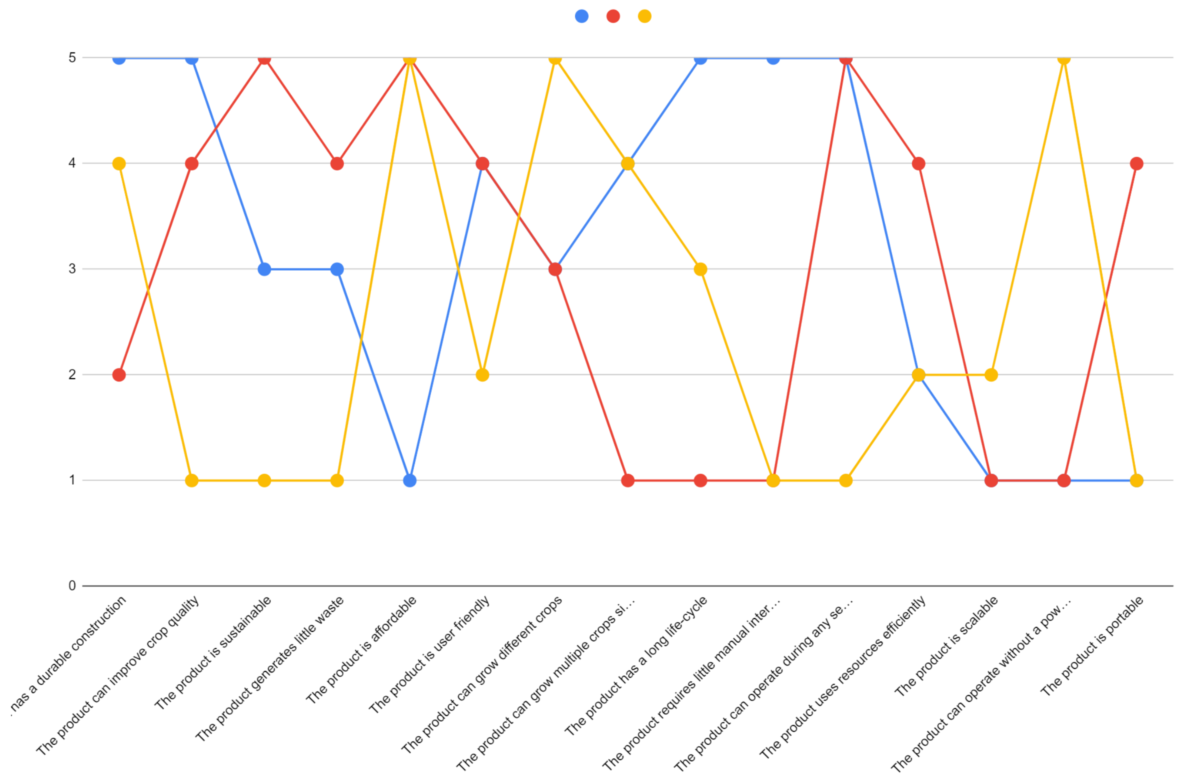
| Competitor ID | Name | Color assigned at the graphs |
|---|---|---|
| C1 | H2HYDROPONICS | Blue |
| C2 | Cultivarte | Red |
| C3 | Tierra | Yellow |

# 6. Qualitative benchmark

According to the information recovered for each competitor, the following table shows the qualitative benchmark for the necessities.

| **Necessity** | **C1** | **C2** | **C3** |
|---|---|---|---|
| The product has a durable construction | 5 | 2 | 4 |
| The product can improve crop quality | 5 | 4 | 1 |
| The product is sustainable | 3 | 5 | 1 |
| The product generates little waste | 3 | 4 | 1 |
| The product is affordable | 1 | 5 | 5 |
| The product is user friendly | 4 | 4 | 2 |
| The product can grow different crops | 3 | 3 | 5 |
| The product can grow multiple crops simultaneously | 4 | 1 | 4 |
| The product has a long life-cycle | 5 | 1 | 3 |
| The product requires little manual intervention | 5 | 1 | 1 |
| The product can operate during any season of the year | 5 | 5 | 1 |
| The product uses resources efficiently | 2 | 4 | 2 |
| The product is scalable | 1 | 1 | 2 |
| The product can operate without a power grid available | 1 | 1 | 5 |
| The product is portable | 1 | 4 | 1 |
| **Total score** | **48** | **45** | **38** |

With this qualitative benchmark as a table, we can reproduce the information with a graphic view in order to visualize the possible zones that our product will consider within its development.




As it is demonstrated by this data, there is a wide variety of hydroponic systems and each of them offers different benefits and attends to different needs and, therefore, different paths can be followed.

# 7. Qualitative product planning

Planning related to the qualitative aspect for biostack is based on the previous benchmark. Considering each necessities' importance, we decided to go beyond the competitors in those necessities where our market ranked as the five-most important, to fulfill just as good as the best competitor the middle important necessities and to fulfill as the mean competitor those marked as the less important.

This information is shown at the next table, where each necessity is shown with its respective importance, the maximum and minimum values that the competitors reached and the high and low levels, called marginal value (MV) and planned satisfaction rate (PSR), designated for biostack by the product design and development team.

| Necessity | Importance | Max | Min | MV | PSR |
|---|---|---|---|---|---|
| The product has a durable construction | 4.04 | 5 | 2 | 5 | 5 |
| The product can improve crop quality | 3.93 | 5 | 1 | 5 | 5 |
| The product is sustainable | 3.93 | 5 | 1 | 5 | 5 |

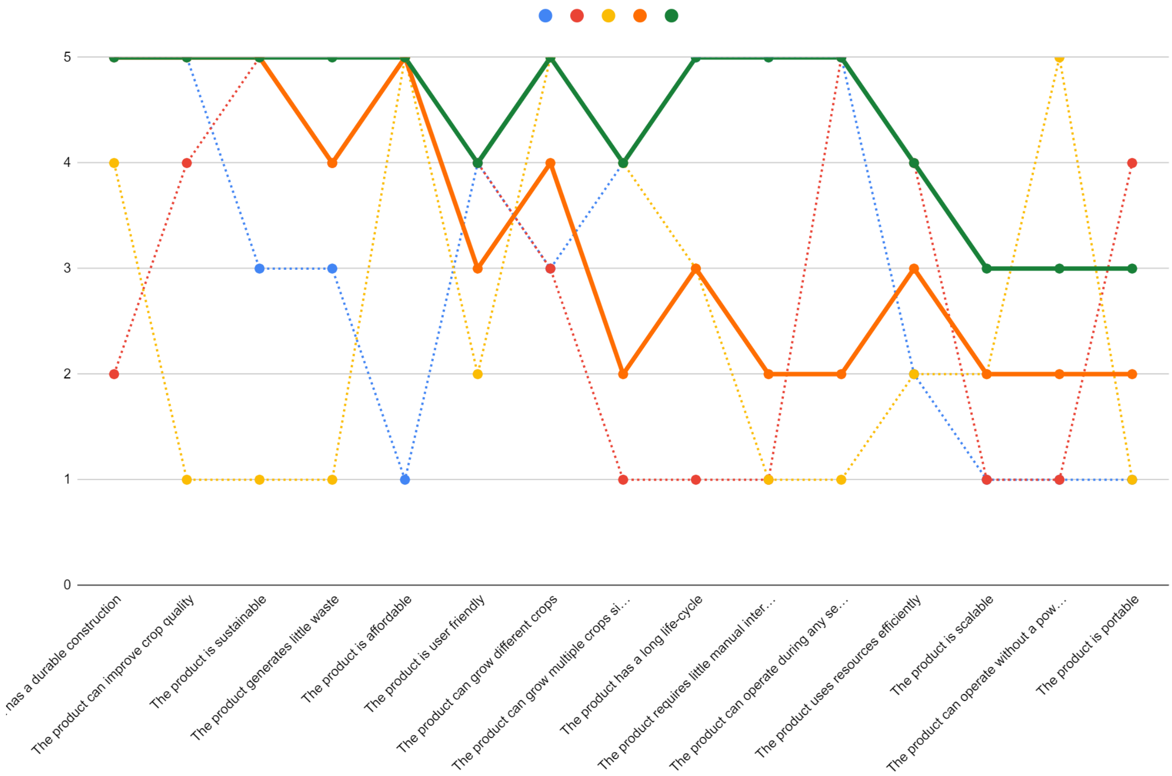
| | | | | | |
|---|---|---|---|---|---|
| The product generates little waste | 3.85 | 4 | 1 | 4 | 5 |
| The product is affordable | 3.81 | 5 | 1 | 5 | 5 |
| The product is user friendly | 3.81 | 4 | 2 | 3 | 4 |
| The product can grow different crops | 3.77 | 5 | 3 | 4 | 5 |
| The product can grow multiple crops simultaneously | 3.74 | 4 | 1 | 2 | 4 |
| The product has a long life-cycle | 3.70 | 5 | 1 | 3 | 5 |
| The product requires little manual intervention | 3.63 | 5 | 1 | 2 | 5 |
| The product can operate during any season of the year | 3.63 | 5 | 1 | 2 | 5 |
| The product uses resources efficiently | 3.55 | 4 | 2 | 3 | 4 |
| The product is scalable | 3.52 | 2 | 1 | 2 | 3 |
| The product can operate without a power grid available | 3.41 | 5 | 1 | 2 | 3 |
| The product is portable | 3.04 | 4 | 1 | 2 | 3 |

Notice that these values will only be able to be compared with the competition if we also consider the relative importance of each necessity, obtained by multiplying the importance of the necessity times qualitative value. This information is resumed at the next table, whose content shows that the marginal values option is at least slightly better than the best competitor of the market.

| **Necessity** | **1** | **2** | **3** | **MV** | **PSR** |
|---|---|---|---|---|---|
| The product has a durable construction | 20.2 | 08.08 | 16.16 | 20.2 | 20.2 |
| The product can improve crop quality | 19.65 | 15.72 | 3.93 | 19.65 | 19.65 |
| The product is sustainable | 11.79 | 19.65 | 3.93 | 19.65 | 19.65 |
| The product generates little waste | 11.55 | 15.4 | 3.85 | 15.4 | 19.25 |
| The product is affordable | 3.81 | 19.05 | 19.05 | 19.05 | 19.05 |
| The product is user friendly | 15.24 | 15.24 | 7.62 | 11.43 | 15.24 |
| The product can grow different crops | 11.31 | 11.31 | 18.85 | 15.08 | 18.85 |
| The product can grow multiple crops simultaneously | 14.96 | 3.74 | 14.96 | 7.48 | 14.96 |
| The product has a long life-cycle | 18.5 | 3.7 | 11.1 | 11.1 | 18.5 |
| The product requires little manual intervention | 18.15 | 3.63 | 3.63 | 7.26 | 18.15 |

| | | | | | |
|---|---|---|---|---|---|
| The product can operate during any season of the year | 18.15 | 18.15 | 3.63 | 7.26 | 18.15 |
| The product uses resources efficiently | 7.1 | 14.2 | 7.1 | 10.65 | 14.2 |
| The product is scalable | 3.52 | 3.52 | 07.04 | 07.04 | 10.56 |
| The product can operate without a power grid available | 3.41 | 3.41 | 17.05 | 6.82 | 10.23 |
| The product is portable | 03.04 | 12.16 | 03.04 | 06.08 | 9.12 |
| **Total relative importance accomplished** | **180.38** | **166.96** | **140.94** | **184.15** | **245.76** |

With these values in mind, the high (PSR) and low (MV) limits for each necessity are marking the qualitative product planning. These limits are shown with green and orange lines at the following graph.



# 8. Quantitative benchmark

According to the information recovered for each competitor, the following table shows the qualitative benchmark for the metrics.

| Metric | Units | C1 | C2 | C3* |
|---|---|---|---|---|
| Special tools required for maintenance | list | Technician sent by the company | NA | Vast amount, highly depends on location |
| Time to disassemble/assemble for maintenance | days | 28 | NA | 0 |
| Product life time | years | 8 | 15 | 50> |
| Environment test duration until part degradation | hours | NA | NA | 10,000> |
| Number of harvested vegetables | units per cycle | 20 | 1 - 3 | 100> |
| Energy auto sufficiency | hours | 0 | 0 | 0 |
| Amount of garbage generated | kg/month | 10 | .5 | 50 |
| Water required per crop | litres/week | 50-5,000 | 4 (12 per cycle of 2 months) | 1.2-2.5 |
| Industrial Standard Tests | list | No | No | No |
| Complete system price | $(MXN) | $416,669 | $3,163 | $236 |
| Required time to prepare crop | minutes | 1,140 | 30 | 1,440 |
| Number of steps required to change between crops | Number of clicks | NA | NA | NA |
| Crop cycle length until | months | 2 | 3 | 3-4 |

| | | | | |
|---|---|---|---|---|
| harvest | | | | |
| Number of different crops allowed simultaneously | List | 1 | 3 | 1 |
| Crop cycles to failure | cycles | 100> | 110> | 100> |
| Steps required for initial assembly and installation | List | Add water, PVC tubes, material and seeds | Add water and seeds | 0 |
| Flexibility in seasons | List | spring summer autumn winter | spring summer autumn winter | spring summer autumn |
| Solar module energy capacity | kW/hr | 0 | 0 | 0 |
| Crop module size | cm | NA | NA | NA |

*based on a tomato harvest in a 1.6m$^2$ space of land in rural Mexico

## 9. Quantitative planning

Planning related to the quantitative aspect for biostack is based on the previous benchmark. Considering each metrics' importance, we decided to fulfill the minimum requirements for the correspondent marginal values and PSR. This information is shown at the next table.

| Metric | Units | 1 | 2 | 3 | MV | PSR |
|---|---|---|---|---|---|---|
| Special tools required for maintenance | list | Technician sent by the company | NA | Vast amount, highly depends on location | > technician | Allen (mm) |
| Time to disassemble/assemble for maintenance | days | 28 | NA | 0 | 0 | 1 |
| Product life time | years | 8 | 15 | 50> | 8 | 50> |
| Environment | hours | 150 | 200 | 10,000> | 200 | 500 |

| | | | | | | |
|---|---|---|---|---|---|---|
| test duration until part degradation | | | | | | |
| Number of harvested vegetables | units per cycle | 20 | 1 - 3 | 100> | 1 | 100> |
| Energy auto sufficiency | hours | 0 | 0 | 0 | 0 | 100 |
| Amount of garbage generated | kg/month | 10 | .5 | 50 | >10 | 5 |
| Water required per crop | litres/week | 50-5,000 | 4 (12 per cycle of 2 months) | 1.2-2.5 | 1.2 | 10 |
| Industrial Standard Tests | Binary | No | No | No | None | Yes |
| Complete system price | $(MXN) | $416,669 | $3,163 | $236 | $236 | $7,000 |
| Required time to prepare crop | minutes | 1,140 | 30 | 1,440 | 30 | 150 |
| Number of steps required to change between crops | Number of clicks | NA | NA | NA | 10 | 5 |
| Crop cycle length until harvest | months | 2 | 3 | 3-4 | 3 | 2 |
| Number of different crops allowed simultaneously | List | 1 | 3 | 1 | 1 | 100> |
| Crop cycles to failure | cycles | 100> | 110> | 100> | 110> | 150> |
| Steps required for initial | List | Add water, PVC tubes, material | Add water and seeds | 0 | Add water, PVC tubes, | Add seeds |

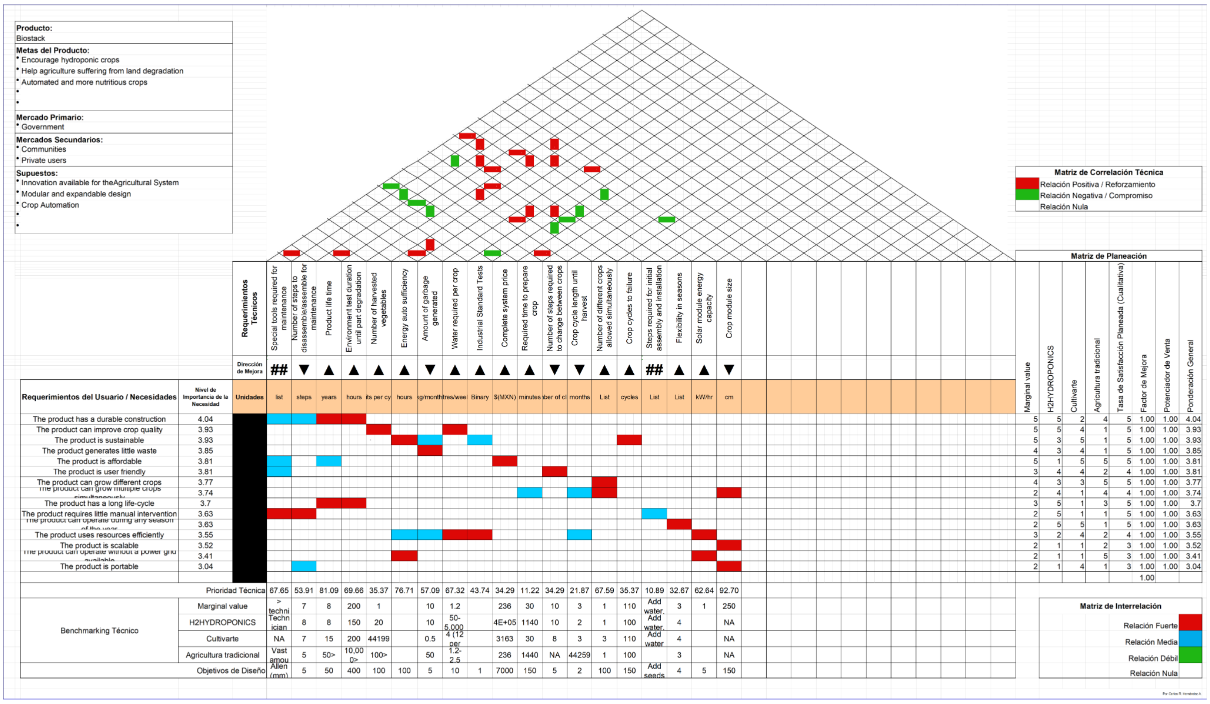
| | | | | | | |
|---|---|---|---|---|---|---|
| assembly and installation | | and seeds | | | material and seeds | and water |
| Flexibility in seasons | List | spring summer autumn winter | spring summer autumn winter | spring summer autumn | spring summer autumn | spring summer autumn winter |
| Solar module energy capacity | kW/hr | 0 | 0 | 0 | 1 | 5 |
| Crop module size | cm | NA | NA | NA | 250 | 150 |

According to what was presented in the previous section, the ideal values for *biostack* are in the following table.

| **Metric** | **Units** | **Values** |
|---|---|---|
| Special tools required for maintenance | list | Allen (mm) |
| Time to disassemble/assemble for maintenance | days | 1 |
| Product life time | years | 50> |
| Environment test duration until part degradation | hours | 500 |
| Number of harvested vegetables | units per cycle | 100> |
| Energy auto sufficiency | hours | 100> |
| Amount of garbage generated | kg/month | 5 |
| Water required per crop | litres/week | 10 |
| Industrial Standard Tests | Binary | Yes |
| Complete system price | $(MXN) | $7,000 |
| Required time to prepare crop | minutes | 150 |
| Number of steps required to change between crops | Number of clicks | 5 |

| | | |
|---|---|---|
| Crop cycle length until harvest | months | 2 |
| Number of different crops allowed simultaneously | List | 100> |
| Crop cycles to failure | cycles | 150> |
| Steps required for initial assembly and installation | List | Add water, PVC tubes, material and seeds |
| Flexibility in seasons | List | spring summer autumn winter |
| Solar module energy capacity | kW/hr | 5 |
| Crop module size | cm | 150 |

With all the previous information, the House of Quality (HoQ) for biostack was designed as the following image shows us. For more details, please consult the corresponding Excel which contains this HoQ.

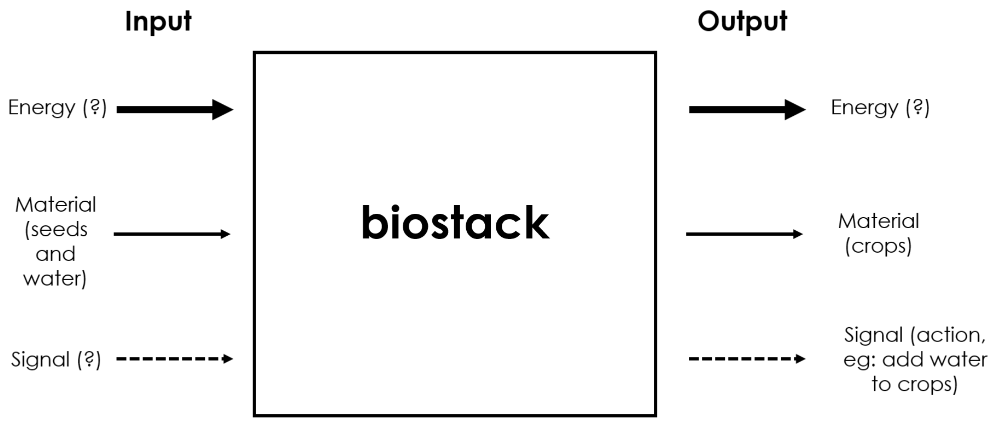


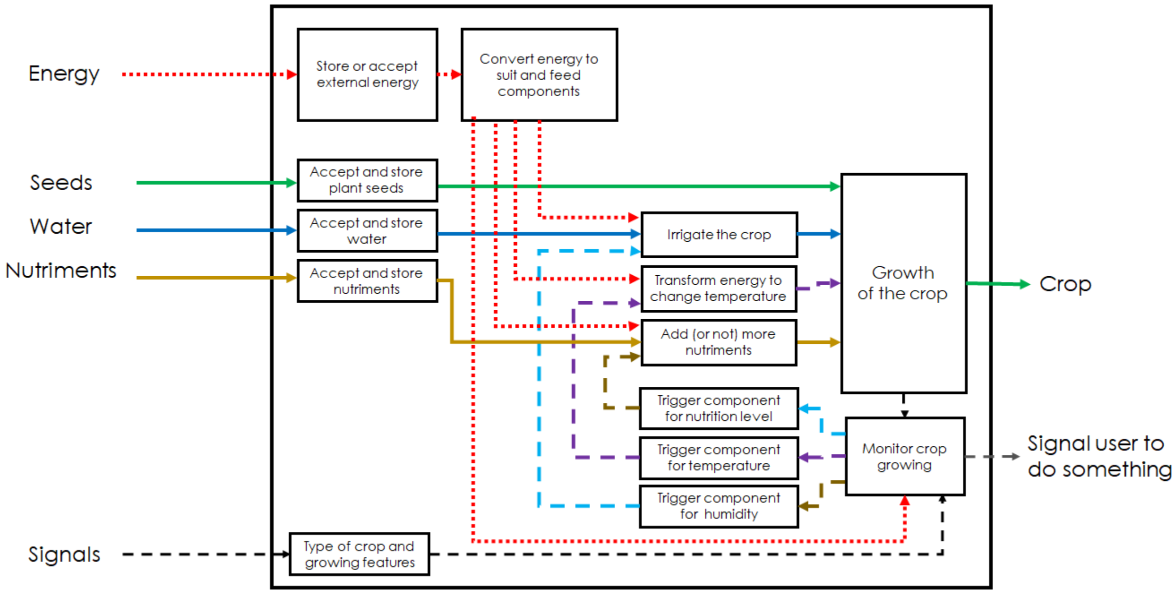
# Generation and Selection of Concepts

# Generation

## 1. Functional Decomposition

Given the initial inputs (energy, material and signal) our product, biostack, would have to give a crop as the output. They were determined this way as to simplify the idea generation process and determine the functional decomposition diagrams.



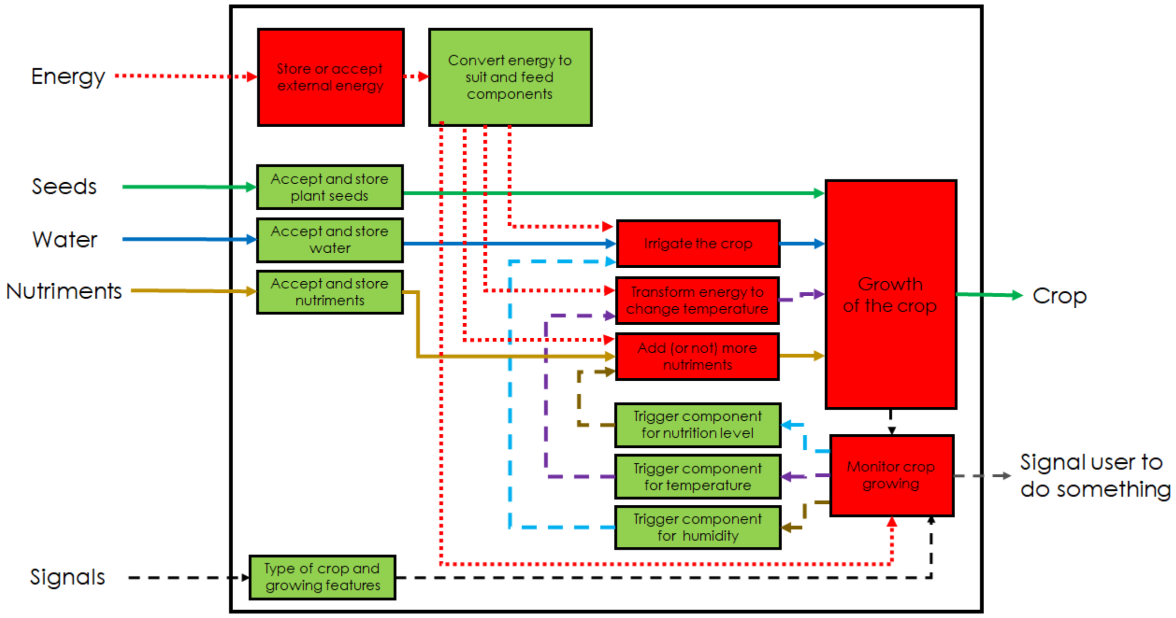



# 2. Critical Sub-processes

The critical sub-processes are:

- Store or accept external energy
- Irrigate the crop
- Add (or not) more nutriments
- Growth of the crop
- Monitor crop growing

These processes were defined as critical because the main value and differentiator of our product is the automation of the crop growth. The selected processes are the ones on which the control and automation rely on. The rest of the sub-processes do not affect the core of the product and there are simple solutions available on the market.




Critical sub-problem

Non-critical sub-problem

# 3. External and Internal Search

## External

### Patents

| Patent | Link |
|---|---|
| Aerator to ensure oxygen sufficiency: SHENZHEN EVERGREEN LANDSCAPE CO LTD. (n.d.). Automatic change hydroponics planting system. [Online]. | https://worldwide.espacenet.com/patent/search/family/058983151/publication/CN206227267U?q=automated%20hydroponics%20 |

| | |
|---|---|
| Aerator to ensure oxygen sufficiency: POSTDOCTORAL SCIENTIFIC RESEARCH WORKSTATION & GUANGZHOU NANSHA INFORMATION TECH PARK CO LTD. (n.d.). Automatic plant water culture device capable of realizing precise micro-bubble aeration. [Online]. | https://worldwide.espacenet.com/patent/search/family/071528954/publication/CN211020421U?q=automated%20hydroponics%20 |
| Controlled hydroponics apparatus for growing feed for livestock: AVOCET INFINITE PLC. (n.d.). HYDROPONICS APPARATUS AND METHOD. [Online]. | https://worldwide.espacenet.com/patent/search/family/058159569/publication/WO2018099609A1?q=automated%20hydroponics%20 |
| Electronic automation device of growing seedlings: XI HAO. (n.d.). Electronic automation device of growing seedlings. [Online]. | https://worldwide.espacenet.com/patent/search/family/063282783/publication/CN207783891U?q=automated%20hydroponics%20 |

There are two patents found corresponding to aerators that ensure crops have sufficient oxygen and prevent crop death. Because the patents are registered under the European Union, but not globally, their designs could be used directly without the need to pay royalty fees.

**Experts and papers**

After talking to different experts we realized that there are different types of hydroponic cultives: Deep Flow Technique (DTF) and Nutrient Film Technique (NFT) are the most common and the ones we will be using for this project.

| **Nutrient Film Technique** | **Deep Flow Technique** |
|---|---|
| • Has a channel where the water with nutrients is.<br>• The water has to circulate.<br>• The crop sits in a small opening.<br>• Channels are positioned in an angle. | • The crop is situated in a high nutrient solution<br>• It is similar to the *Chinampas*' principle |

## Internal

Internal search was done to define available components and designs, based on the team's knowledge and expertise. It was based directly on the critical sub processes defined earlier, as a simple way to brainstorm how *biostack* will function and what it will eventually become.

The first collage was for the Store or accept energy su process, in which several ways of power sources are presented. In spite of the fact that some of the options are not physically possible, like wind or coal power, the idea of a direct wall outlet and a solar panel became very attractive in this process.

The first collage was for the Store or accept energy su process, in which several ways of power sources are presented. In spite of the fact that some of the options are not physically possible, like wind or coal power, the idea of a direct wall outlet and a solar panel became very attractive in this process. We also add ideas like electric power, lithium energy and coal.

## Store or accept energy

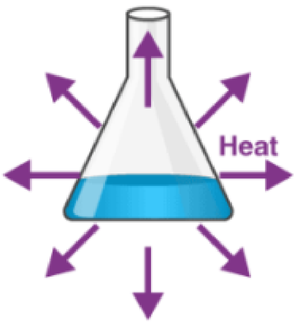
- Fossil fuel storage.
- Mechanical. Spring. Compressed air energy storage (CAES) ...
- Electrical, electromagnetic. Capacitor. ...
- Biological. Glycogen. ...
- Electrochemical (Battery Energy Storage System, BESS) Flow battery. ...
- Thermal. Brick storage heater. ...
- **Chemical**. Biofuels.

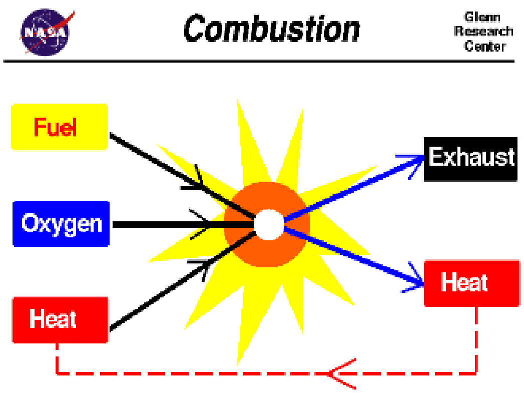

For the Irrigation of Crops there were several components that we believed would fit the design well and would function correctly, such as valves, pumps, electrovalves and motors. This would allow for an efficient use of water in the system and do not waste it also.

## Irrigate Crops

Plants need different temperatures and lighting to ensure that they grow healthy, this is the reason why several options were presented to fit this need, like exothermic reactions, combustion, resistors, UV lighting and incandescent light bulbs.

## Transform energy to change temperature



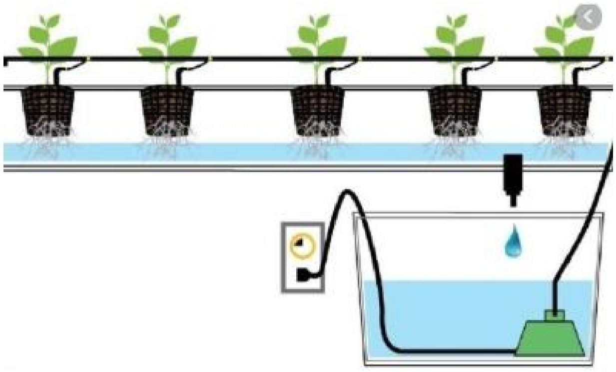




In hydroponics, control of nutrients is available depending on the form it's done, so as in irrigation, the ways to control it after a sensor reading would be through pneumatic and mechanical pumps, valves, motors.

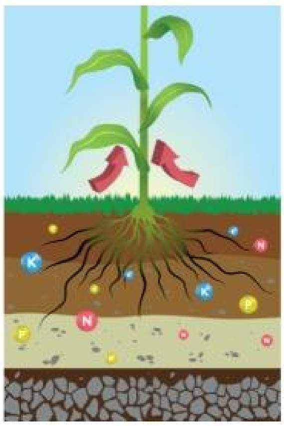
## Add (or not) more nutriments

Because crops need to be monitored to ensure the quality is the best, the team thought about the several ways this can be done, with sensors, pH meters and expertise.

## Monitor crop growth







As the quality of a crop should be monitored, it should also be the case with it's growth, determining substrates, water levels, lighting, fertilizers, etc. We also want to monitor the change of fluids, take in consideration the calibration of the equipment if needed.

## Growth of the crop

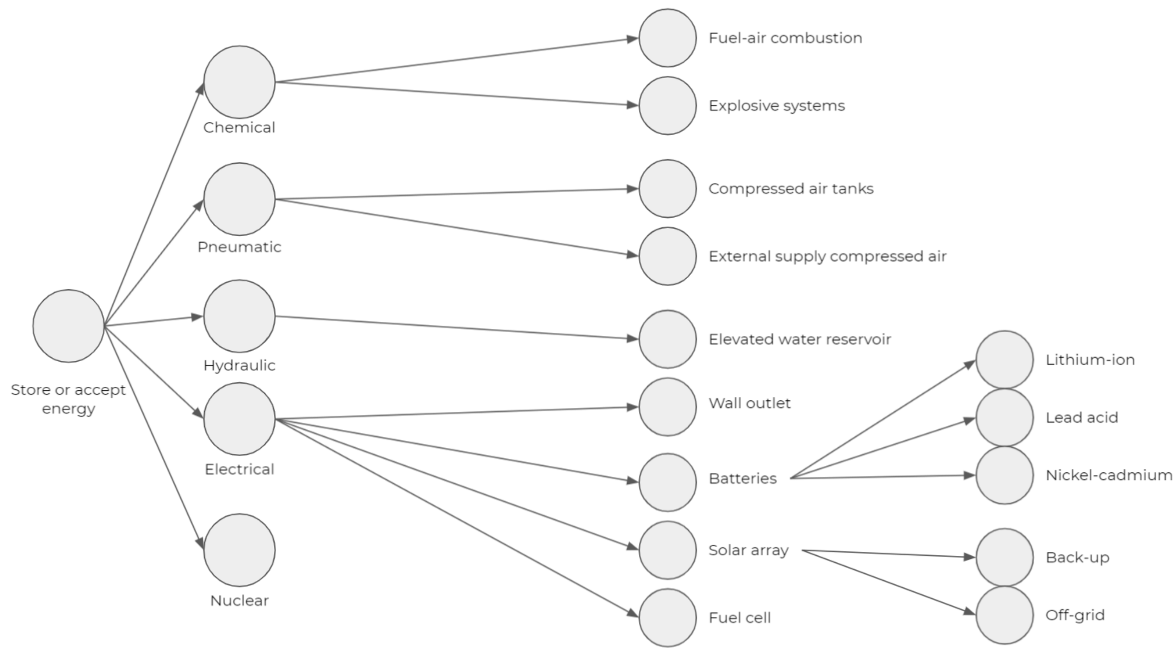
Change fluids

Calibrate equipment

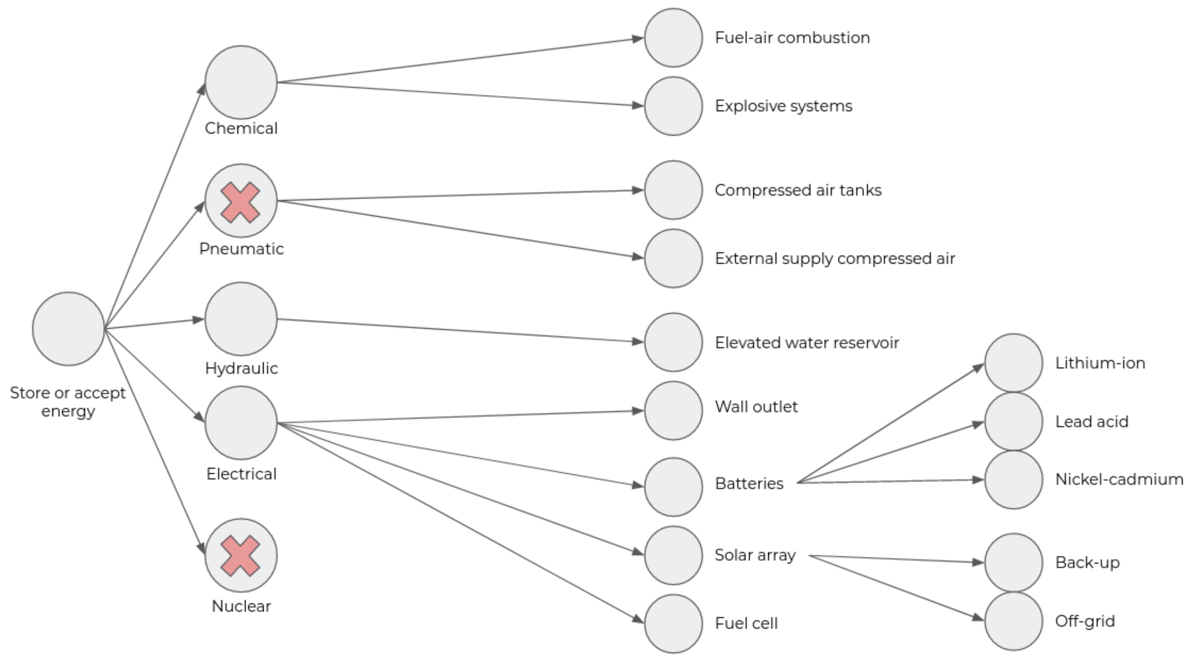
Find a solution to replace the nutrients that plants require from soil

# 4. Classification Trees

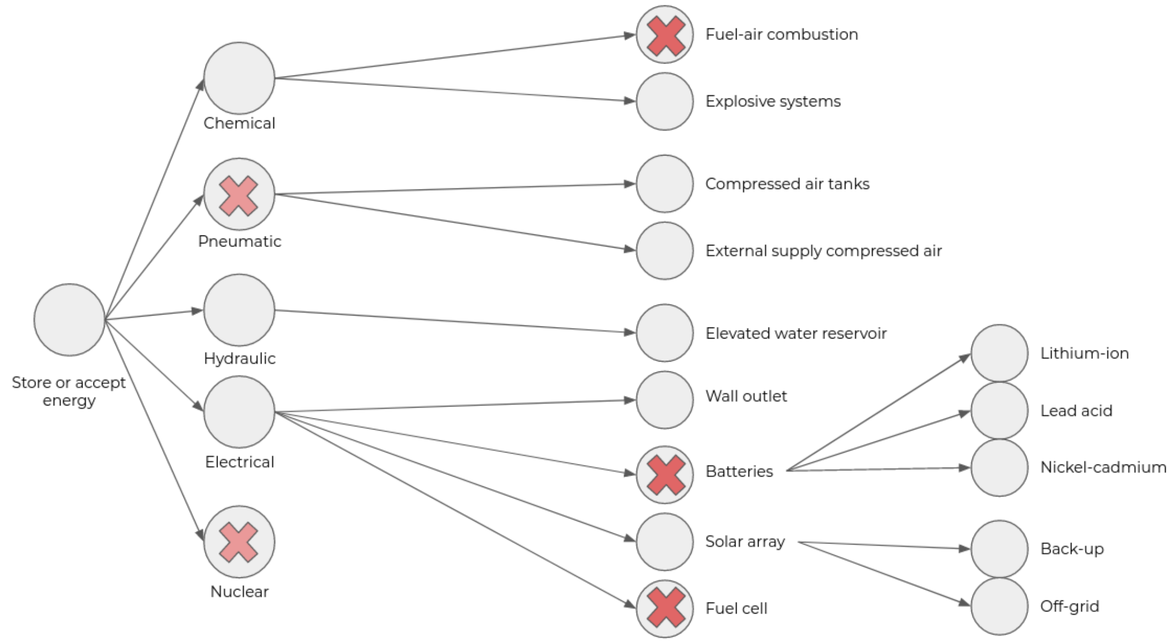
### Store or accept energy



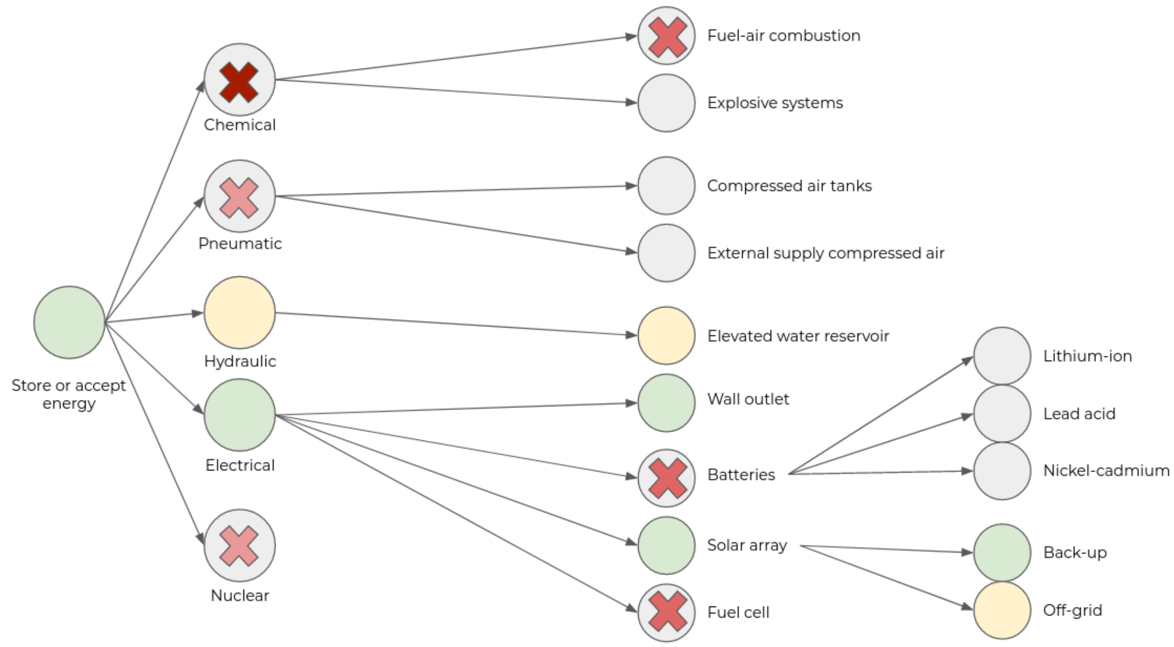

Pneumatic and nuclear energy were the first types of energy to be pruned due to being high maintenance and having a higher price. We also consider that nuclear energy systems are not suitable due to their scale and requirements.




We then pruned the *fuel-air combustion* branch from the chemical energy and the *batteries* and *fuel cell* branches from the electrical energy because we believe that they aren't viable in this application.

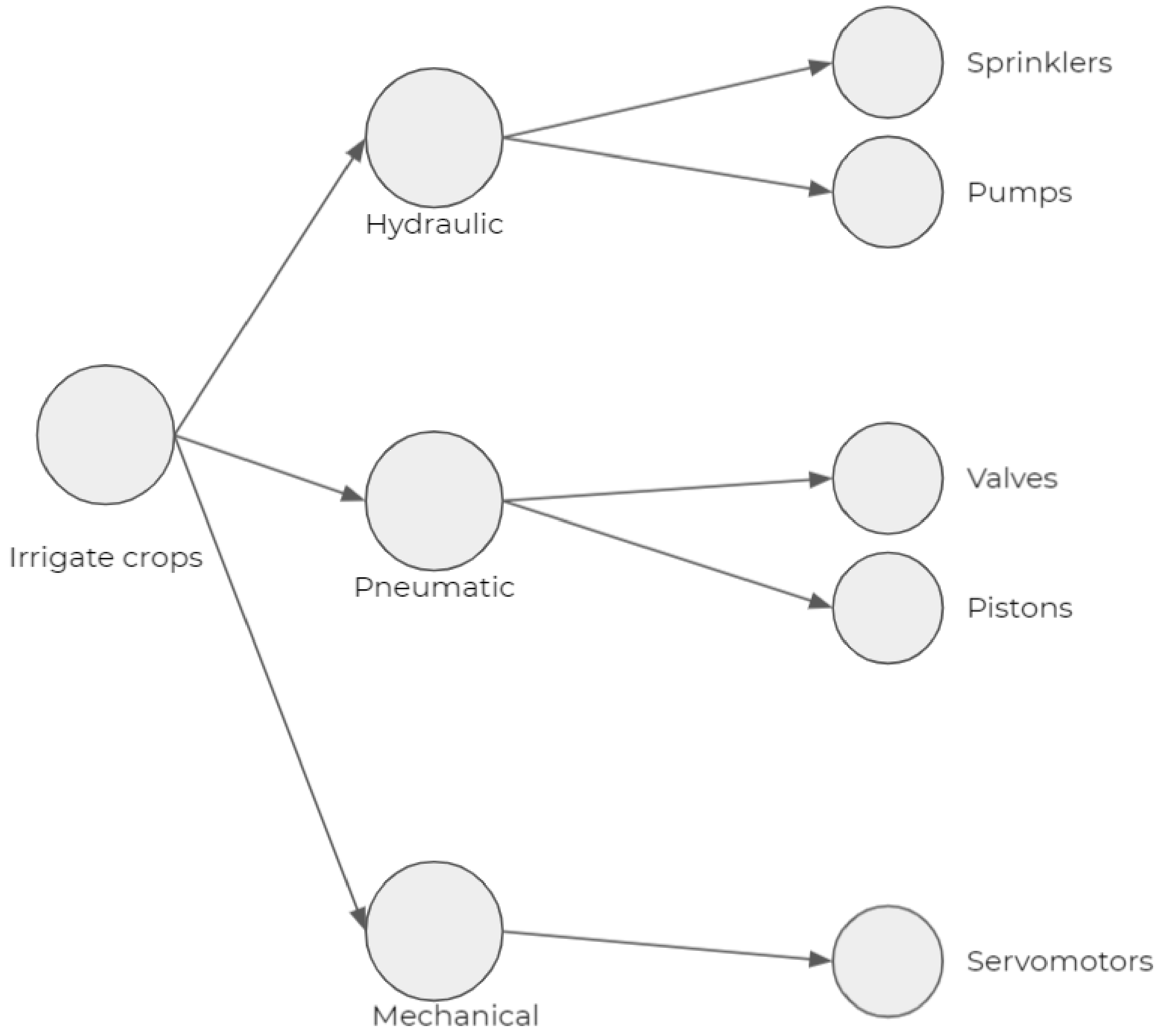



In the last pruning we decided that we are going to have two different options for *storing and accepting energy*, wall outlet and an off-grid solar array. Both options are electrical since it is the most convenient. Chemical energy systems are usually not environmentally friendly, which is an important part of the expected perception of our product, thus the corresponding branch was pruned.

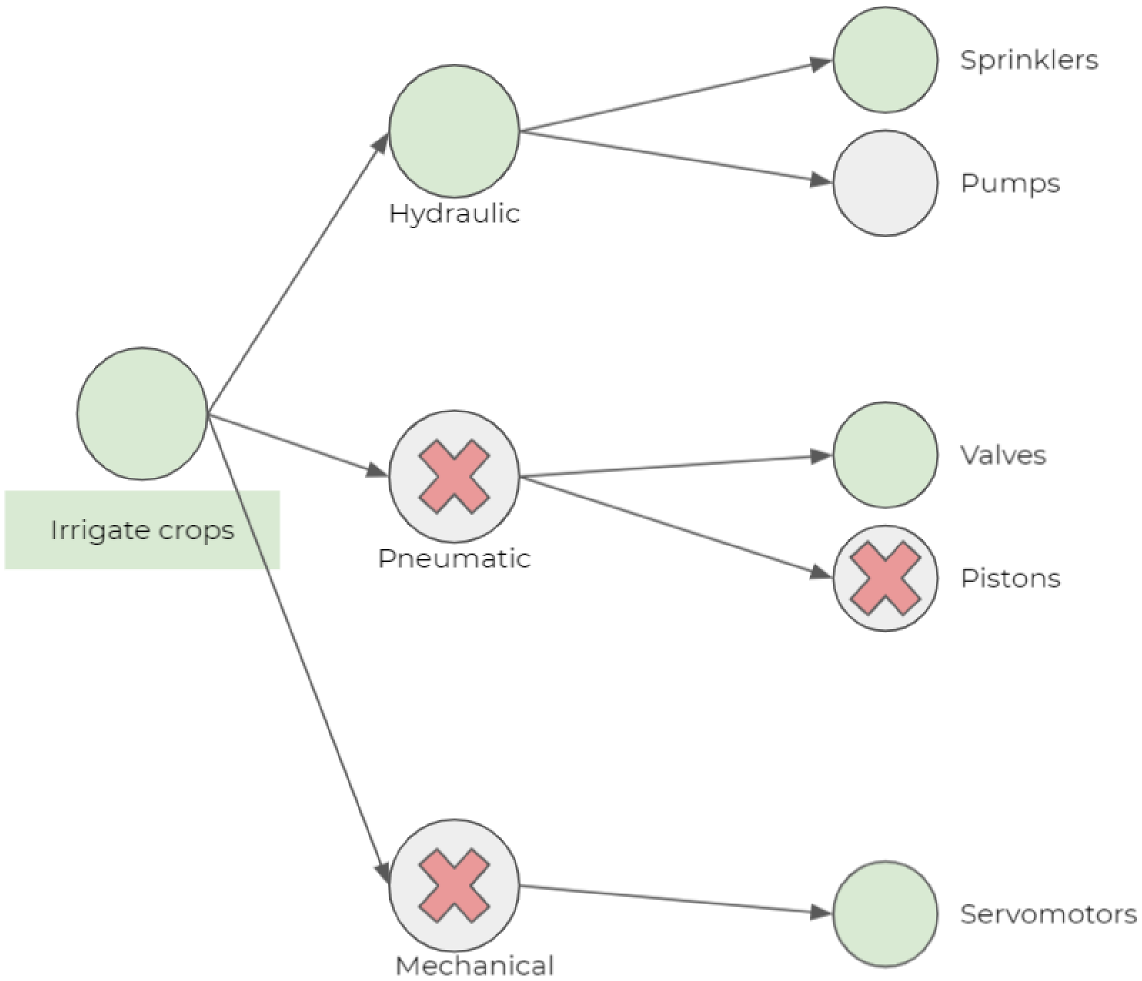



The electrical energy systems were selected as the preferred concepts for our product because of their practicality and ease of implementation. However, the hydraulic systems were not pruned as the elevated water reservoir concept could be included in the product to eliminate the need of water pumps.

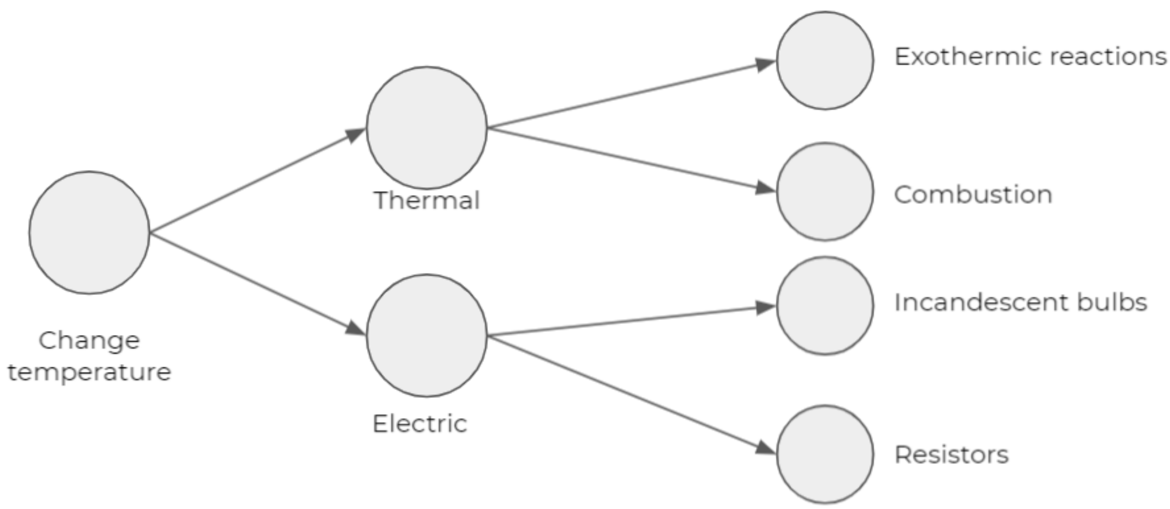
**Irrigate crops**



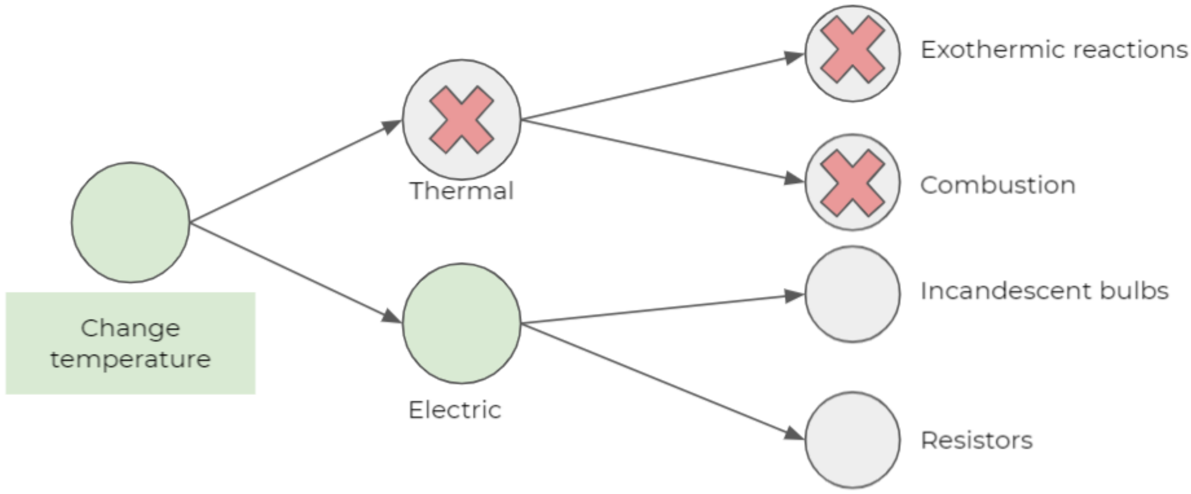

While considering the different concepts for the crop irrigation process we discarded the pneumatic processes altogether, since they were discarded as a viable option for the energy acceptance in the previous section. Finally, hydraulic methods were selected as the more appropriate approach, given that the irrigation process already deals with fluids. The sprinkler concept was selected as the preferred concept, as it is more common among existing products. However, the pump concept was not discarded altogether.



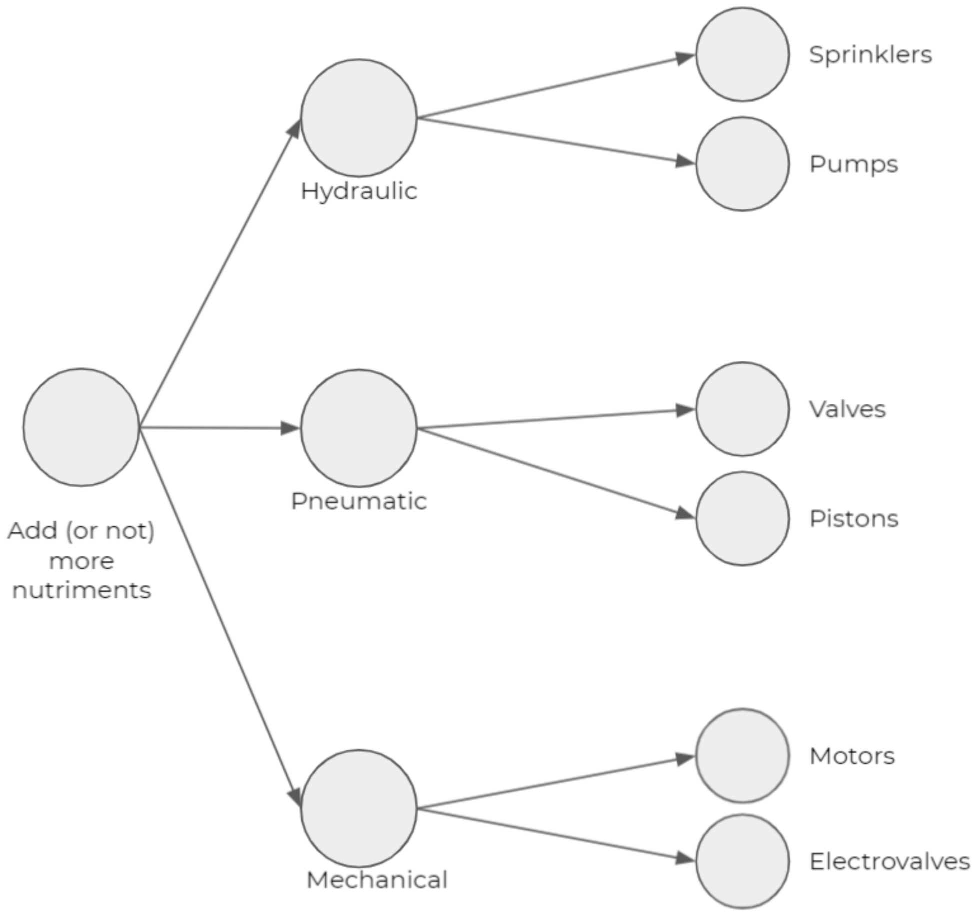

**Change temperature**



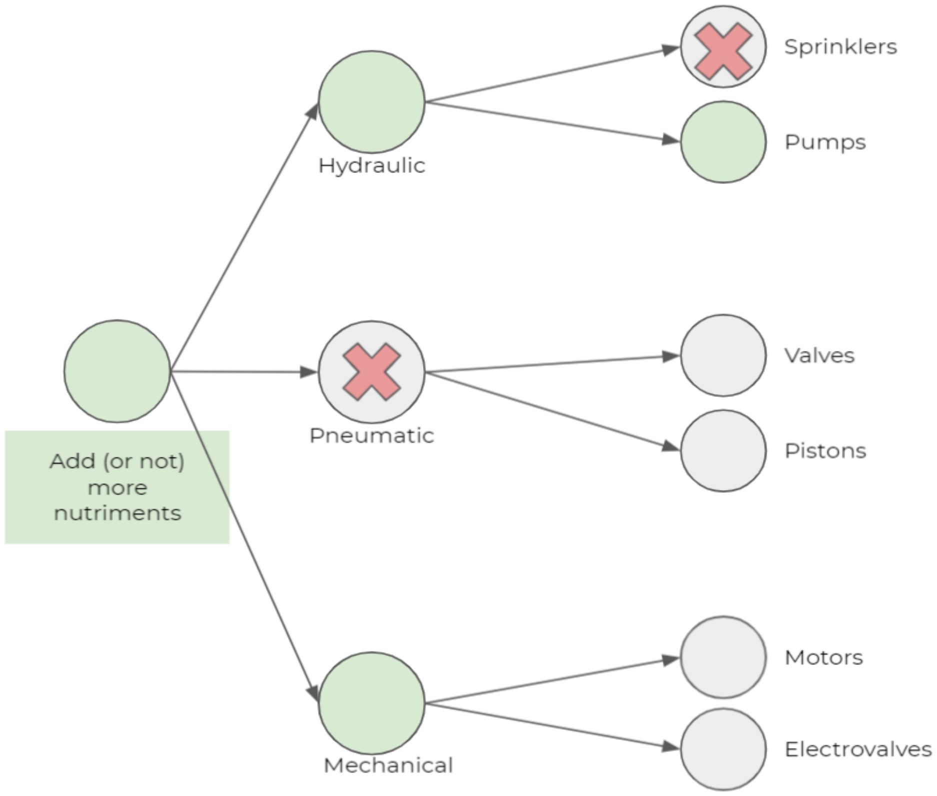

For the temperature control process two possible approaches were identified: thermal or electric. After discussing the concepts available under the thermal branch it was decided that it should be pruned. Exothermic reactions can be dangerous and more difficult to control for fine adjustments. The same could be said about concepts relying on combustions, plus they are not suitable for indoor use and are not environmentally friendly.



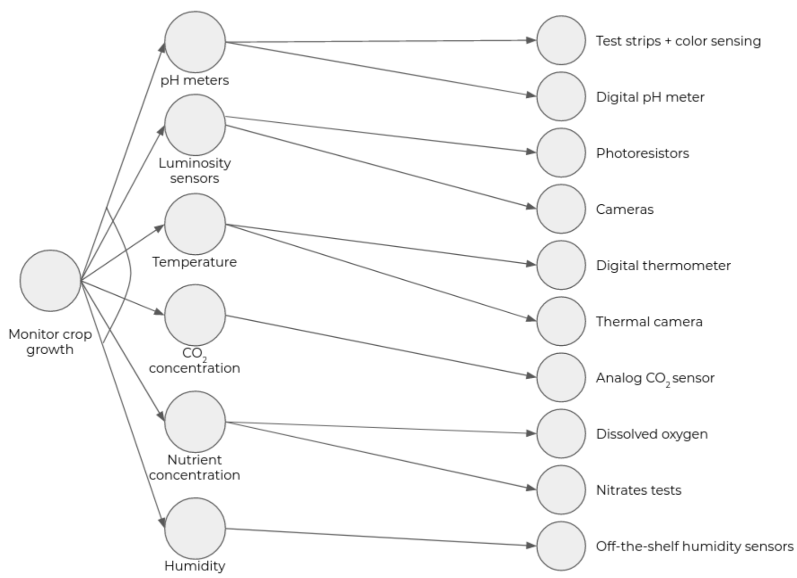

**Add nutrients**




When it comes to adding or limiting the concentration of nutrients and other parameters of interest, the approaches considered are similar to the ones shown in the irrigation section since both deal with fluids. However, the sprinkler concept was pruned as these can become clogged when small solids pass through. This could be a problem if the nutrients added do not dissolve entirely before reaching the sprinklers. Then, the pneumatic concepts were pruned for the same reason discussed in the irrigation section.

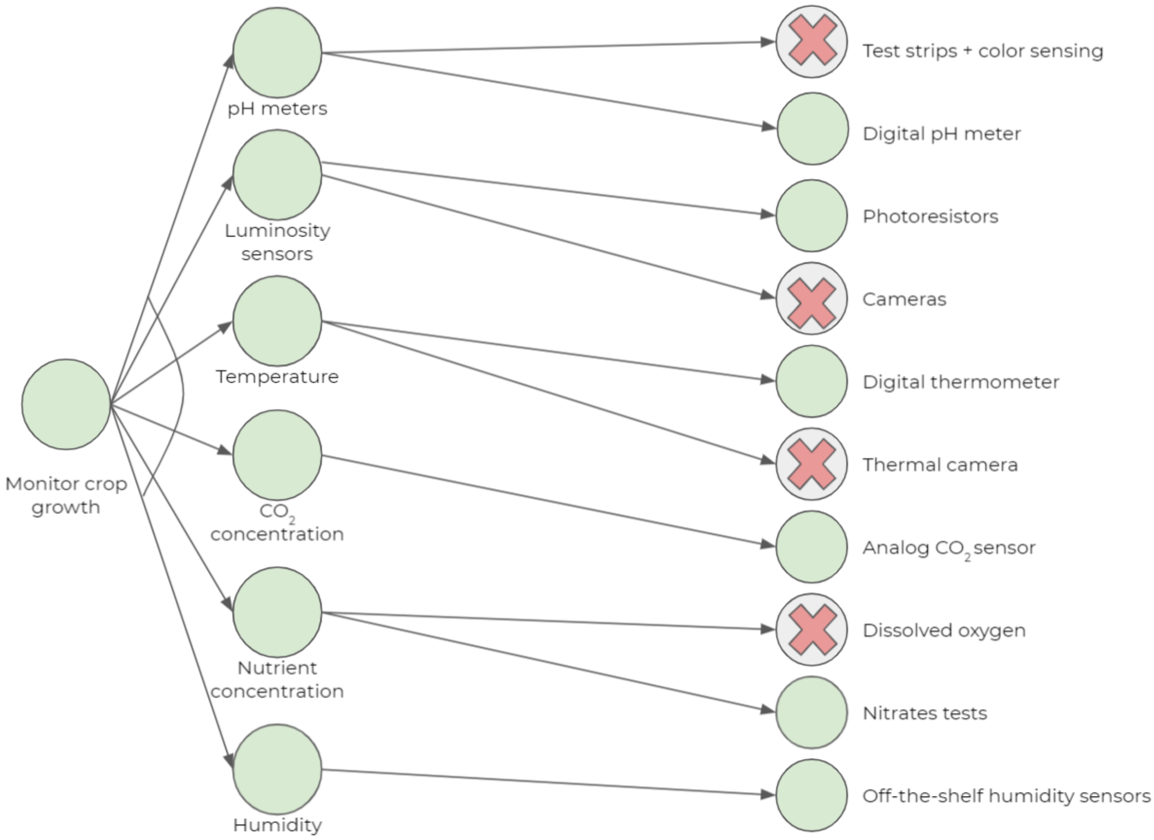



**Monitor crop growth**

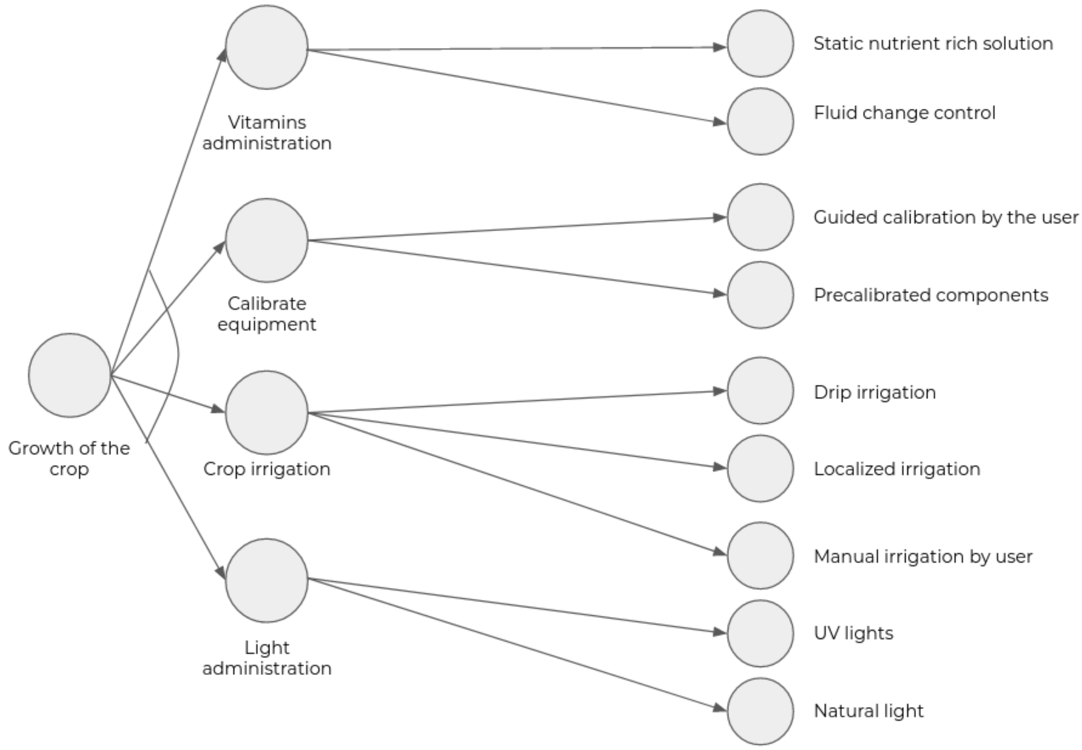



Since every child of the root node needs to be fulfilled we could only crop on a second level. Therefore, we decided to choose the most viable alternative for the system to be as automatized as possible while maintaining a reasonable production cost.

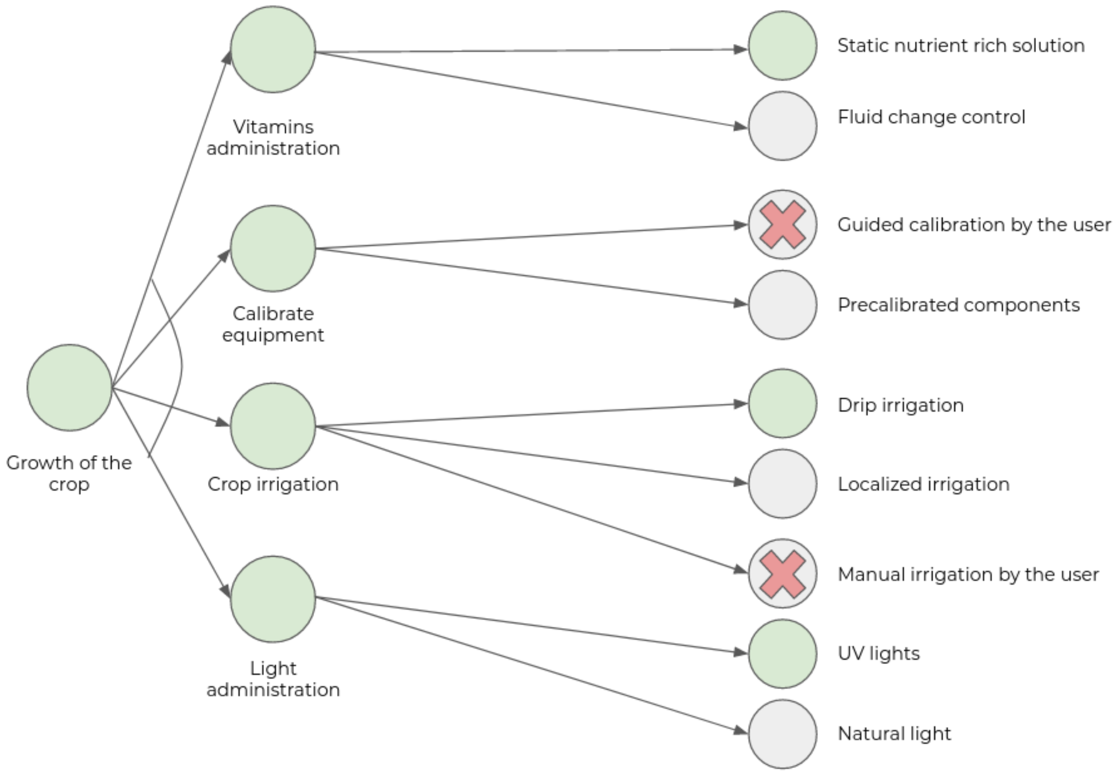
The digital pH meter was selected as the preferred concept for the pH monitoring requirement, since it can provide a continuous measurement which will be useful for the control processes. Thus, test strips were discarded and considered a less viable solution. For the luminosity sensing requirement the photoresistors were considered a more cost effective and sufficient solution, the camera array technique was pruned. Under the temperature reading branch the thermal camera was pruned as it is a more expensive option and is only suitable for temperature readings on solid objects. For nutrient concentration measurements the nitrate tests were considered more relevant in this case. Although dissolved oxygen in a water source is necessary for plant growth, we assume that commonly available water sources fulfill this requirement. Finally, humidity sensing can be done with cheap off-the-shelf components.



**Growth of the crop**




Like in the previous section, all of the child nodes of the crop growth process have to be fulfilled in order to achieve the objectives. The vitamin administration can be accomplished by either a static nutrient solution or a fluid change control, but the former is the preferred method as it is thought to be more efficient. For equipment calibration it was decided that user calibration is not appropriate, as we intend to create a more user friendly product than the competition. For the same reason the manual irrigation by the user concept was eliminated from the rest of the process. Both drip and localized irrigation concepts can be compatible with automatized control, but the former was selected as the preferred method as it could be cheaper. Finally, light administration could be accomplished with artificial lightning (UV lights) or with natural lighting, but UV lights can provide more control over the growth process and was therefore selected as the preferred concept. However, natural lighting was not discarded, as it could prove to be a more cost effective solution under certain situations.




## 5. Combination Tables

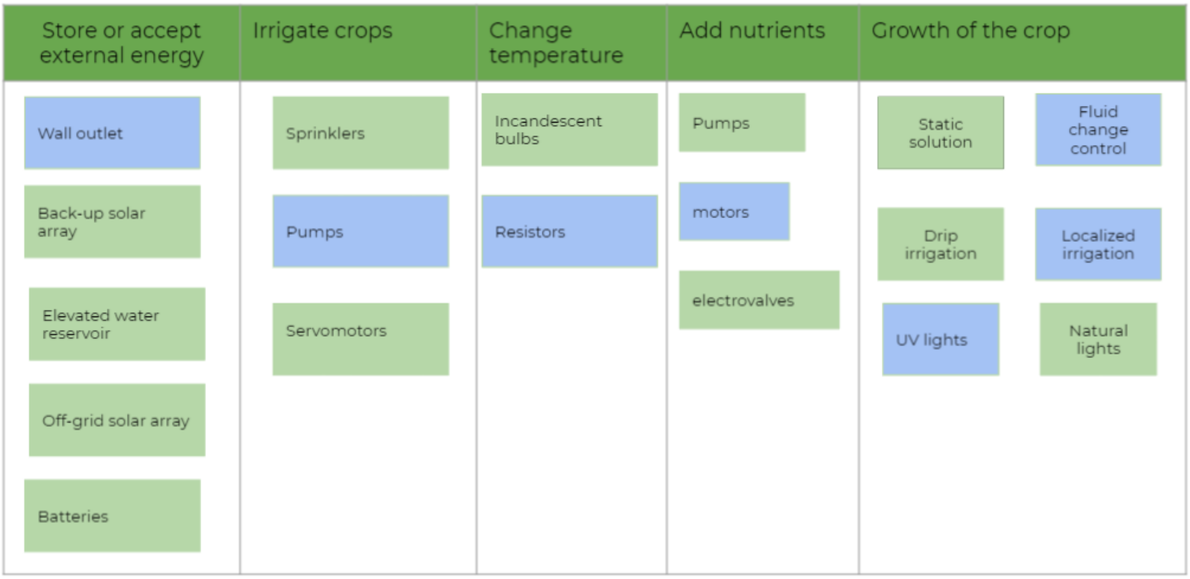
The combination tables for 15 different concepts are presented below. Each column of a table represents one of the five critical subproblems presented in the functional diagram, and show all the possible solutions identified in the previous sections. The selected concepts for each combination table are highlighted in blue. When more than one box is highlighted it indicates that the selected solutions are implemented to complement each other. For example, under the Store or Accept External Energy both the wall outlet and batteries could be selected and the batteries could act as a backup system if there is a power outage.

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop | |
|---|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution | Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation | Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights | Natural lights |
| Off-grid solar array | | | | | |
| Batteries | | | | | |

**1**

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop | |
|---|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution | Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation | Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights | Natural lights |
| Off-grid solar array | | | | | |
| Batteries | | | | | |

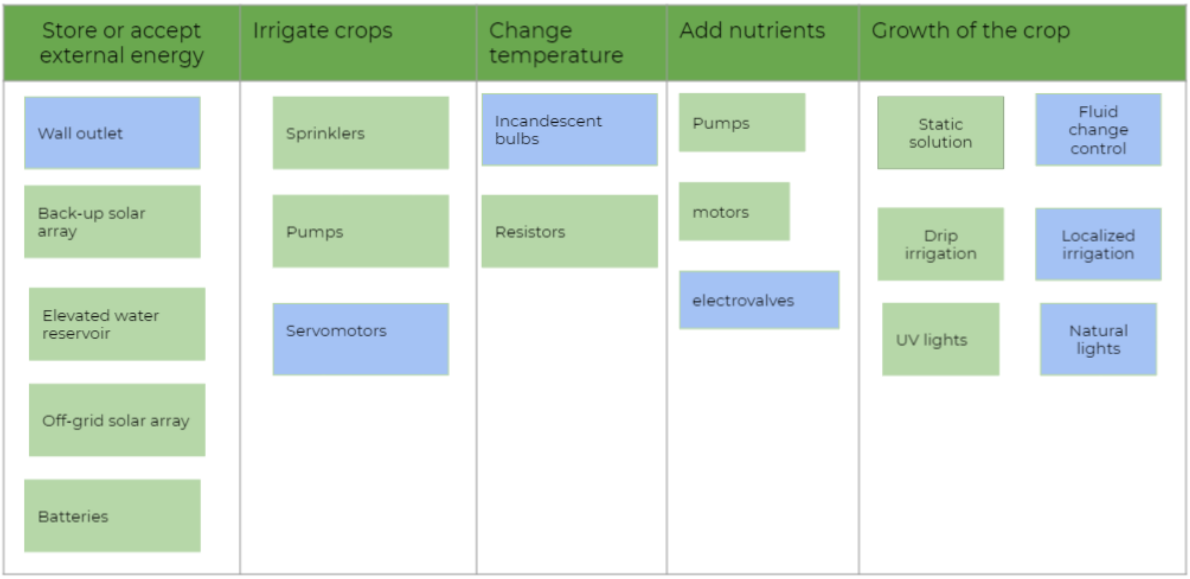
**2**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

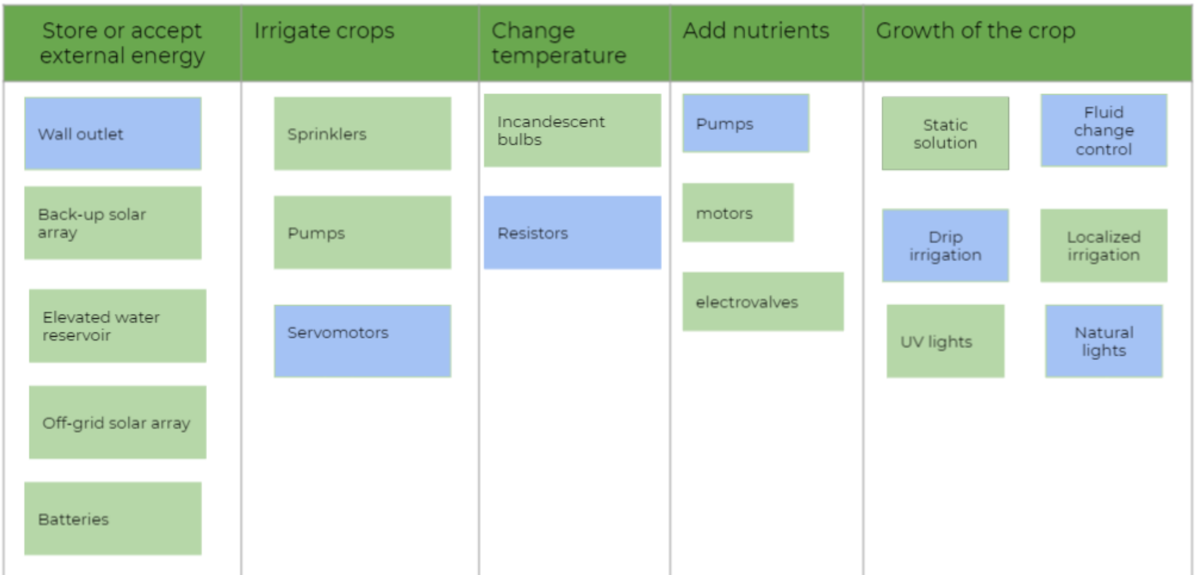
**3**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**4**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**5**


Store or accept external energy
Irrigate crops
Change temperature
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Growth of the crop
Wall outlet
Back-up solar array
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Off-grid solar array
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Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**6**

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop | |
|---|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution | Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation | Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights | Natural lights |
| Off-grid solar array | | | | | |
| Batteries | | | | | |

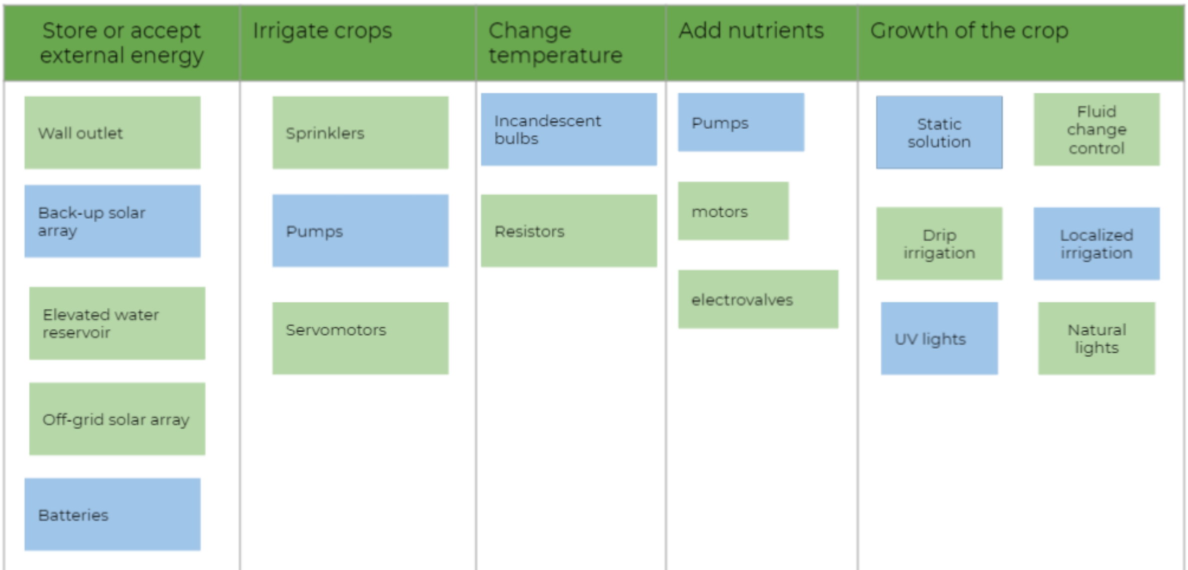
**7**

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop | |
|---|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution | Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation | Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights | Natural lights |
| Off-grid solar array | | | | | |
| Batteries | | | | | |

**8**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**9**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
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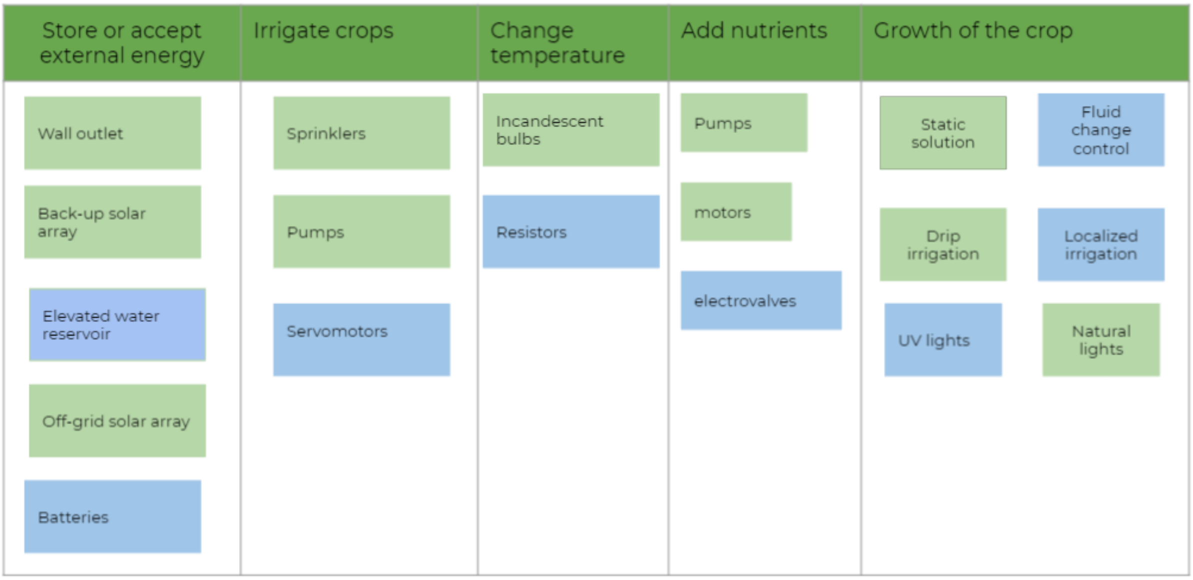
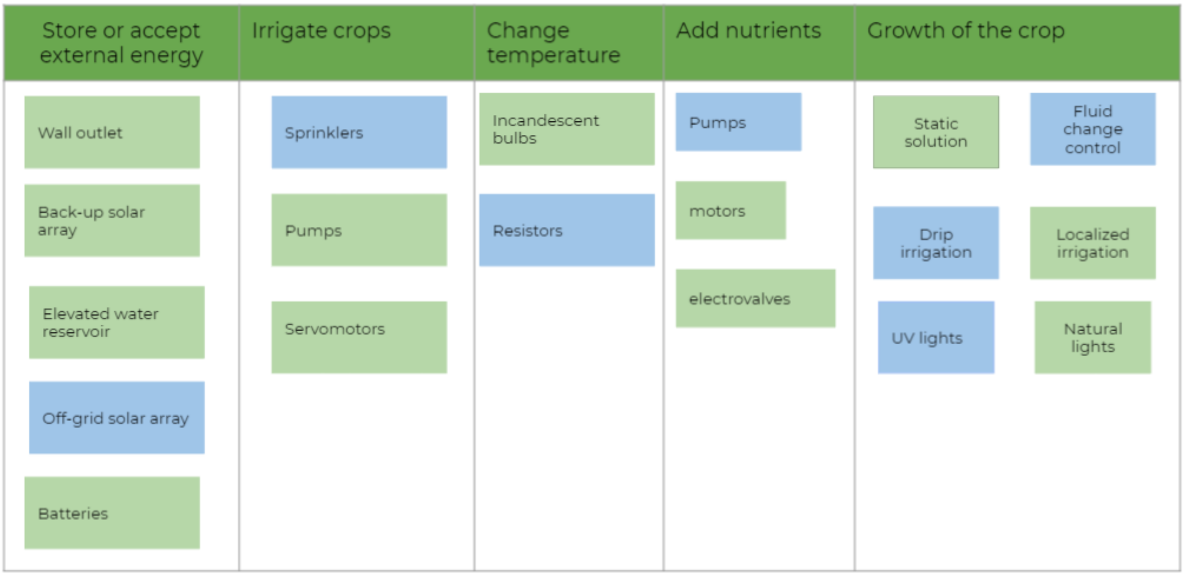
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**10**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**11**


Store or accept external energy
Irrigate crops
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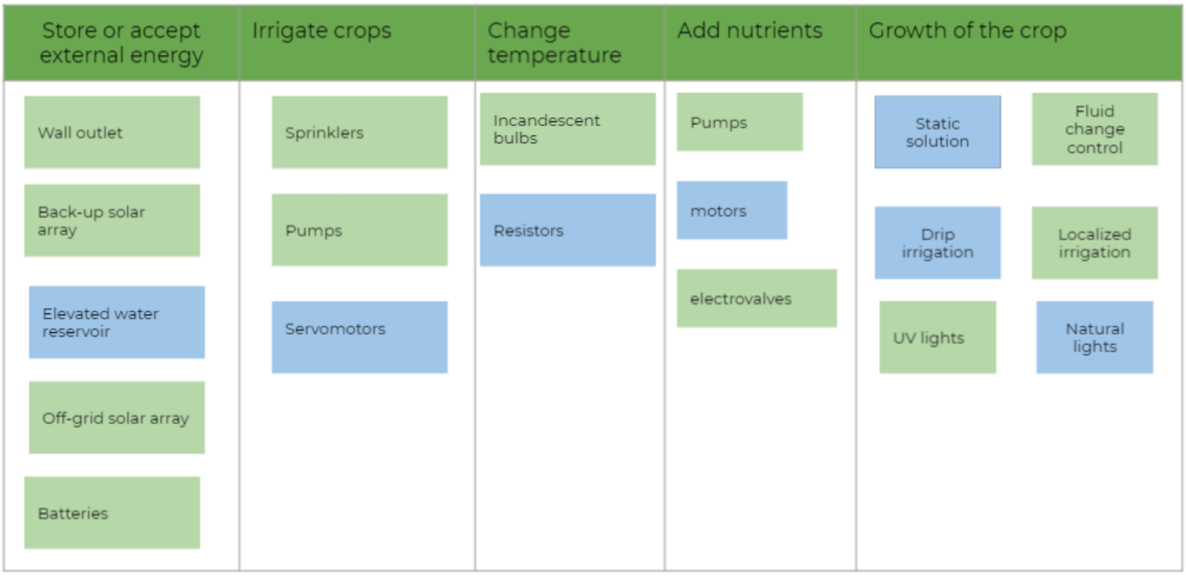
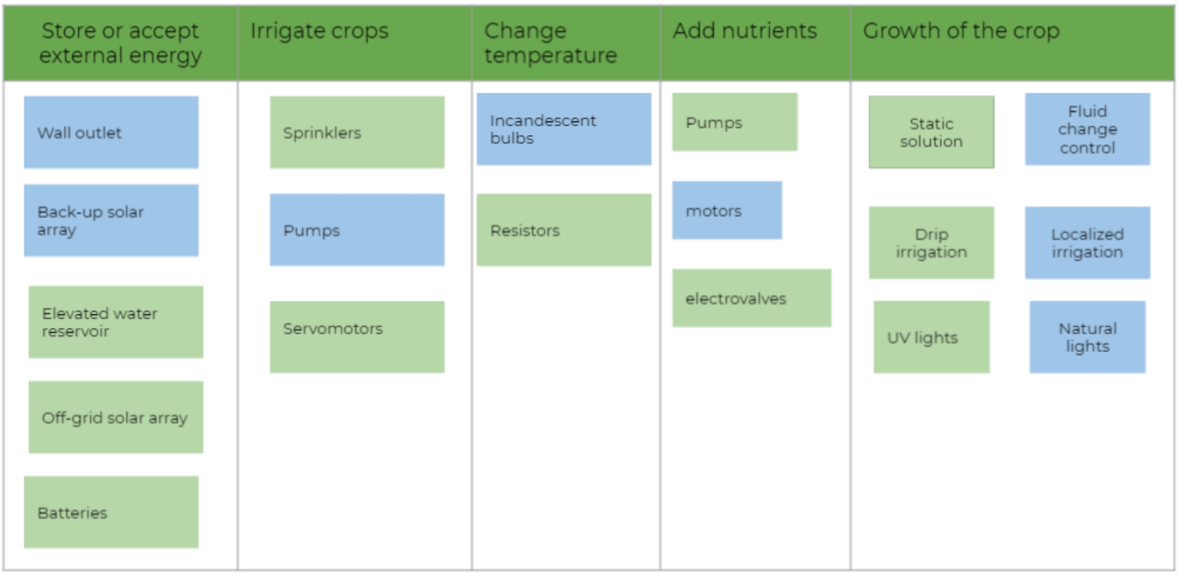
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**12**



Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights


**13**



Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
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Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights


**14**

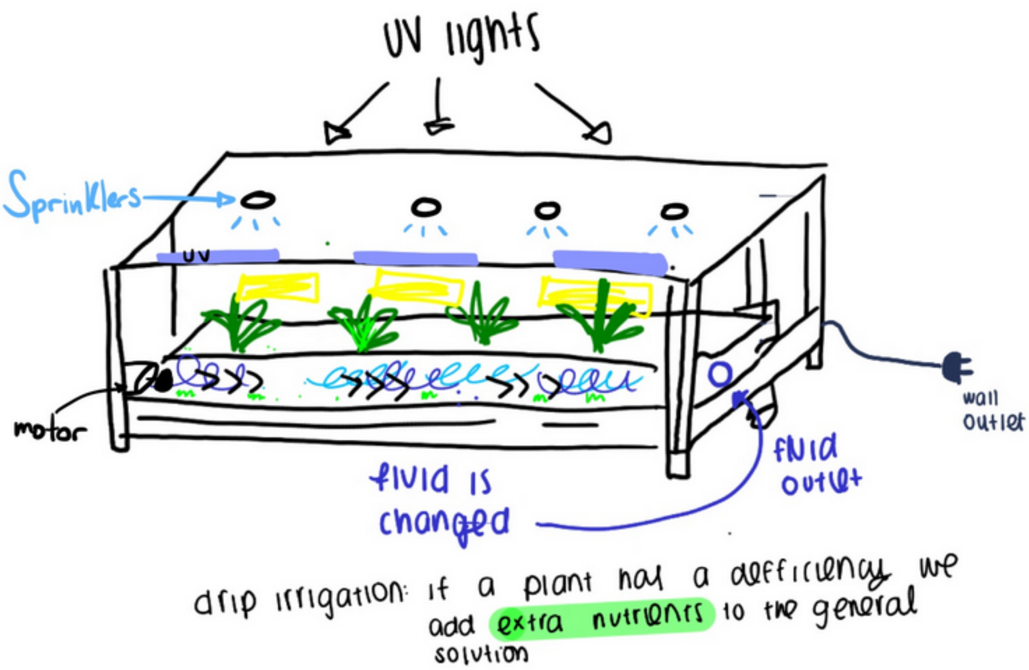
| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop |
|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution |
| Back-up solar array | Pumps | Resistors | motors | Fluid change control |
| Elevated water reservoir | Servomotors | | electrovalves | Drip irrigation |
| Off-grid solar array | | | | Localized irrigation |
| Batteries | | | | UV lights |
| | | | | Natural lights |

**15**

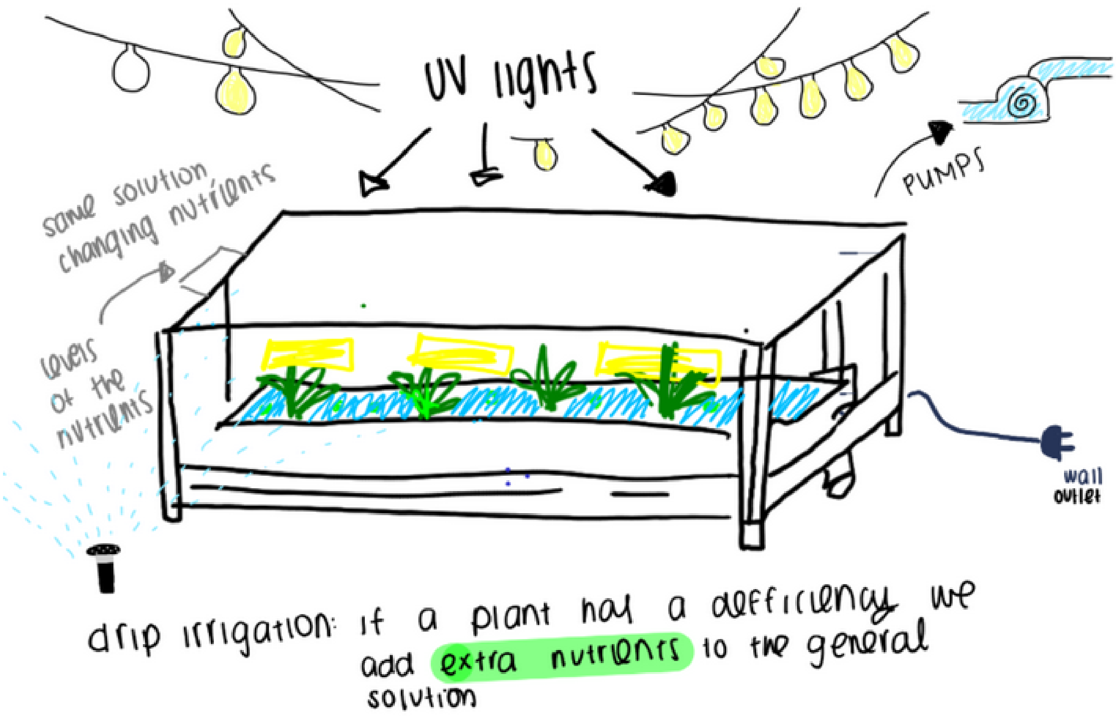
# 6. Concepts

Sketches for all possible combinations were created, but only the ones that the team considered most relevant are included below in order not to saturate the document. The rest of the concepts are visually similar to the ones presented and therefore only a description indicating key features is presented.

1. It is based on drip irrigation using motors and sprinklers for water control, with UV lights and incandescent bulbs for temperature control and growth of the crop. Its power source is directly from a wall outlet, and based on fluid change control.

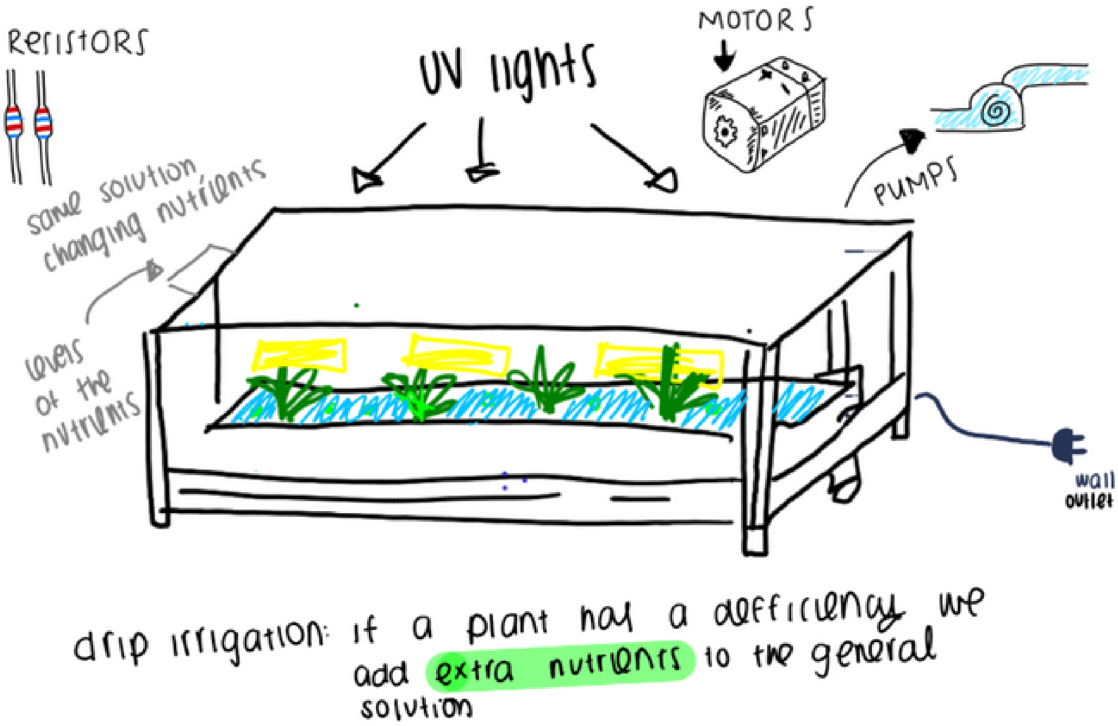



2. It is based on drip irrigation using pumps and sprinklers for water control, with UV lights and incandescent bulbs for temperature control and growth of the crop. Its power source is directly from a wall outlet, and based on fluid change control.

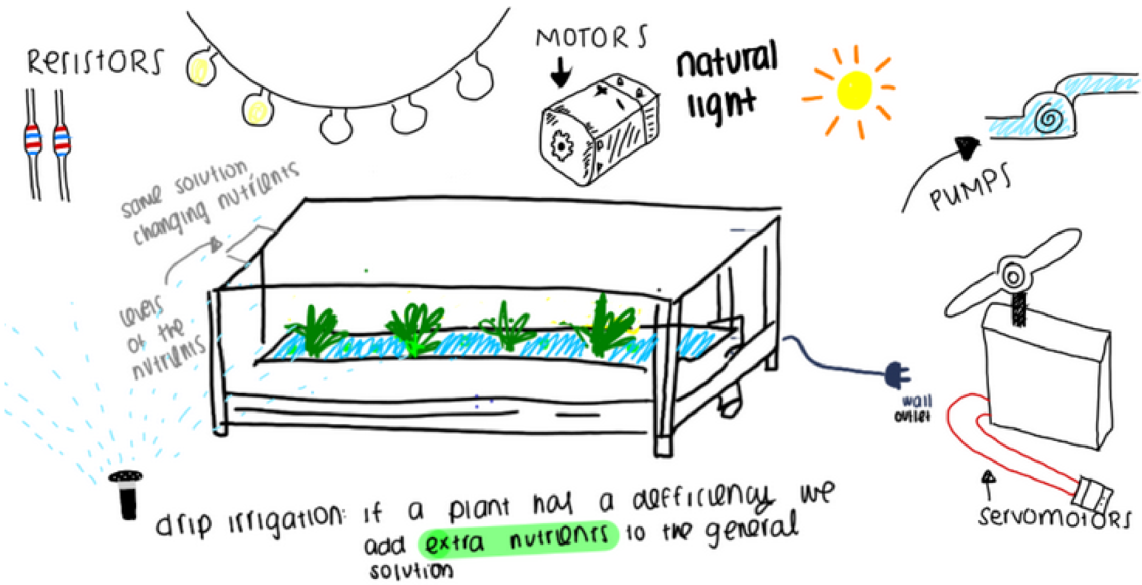



3. Some UV-lights and a drip irrigation system. The water is highly nutritious

and is the same for the crop's lifecycle. We will also use a drip irrigation method for the crops and use pumps, motors and resistors.

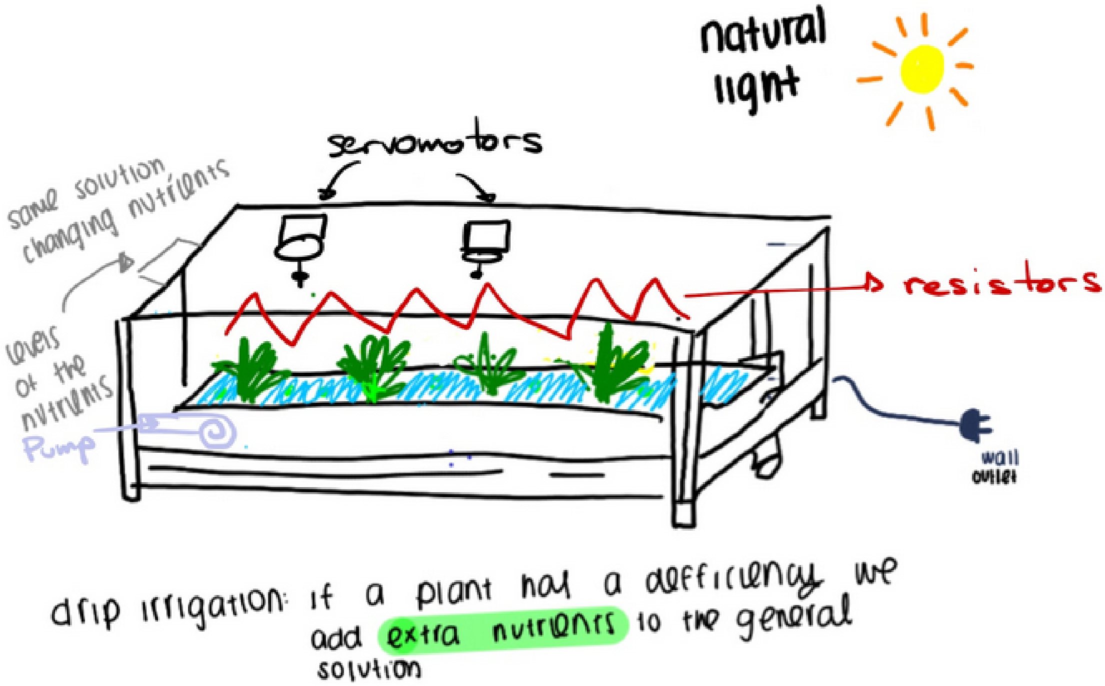



4. It is based on drip irrigation using motors and servo motors for water control, and incandescent lights for temperature control, Using electrovalves to distribute nutrients. Its power source is directly from a wall outlet, and based on fluid change control, natural lighting and localized irrigation.

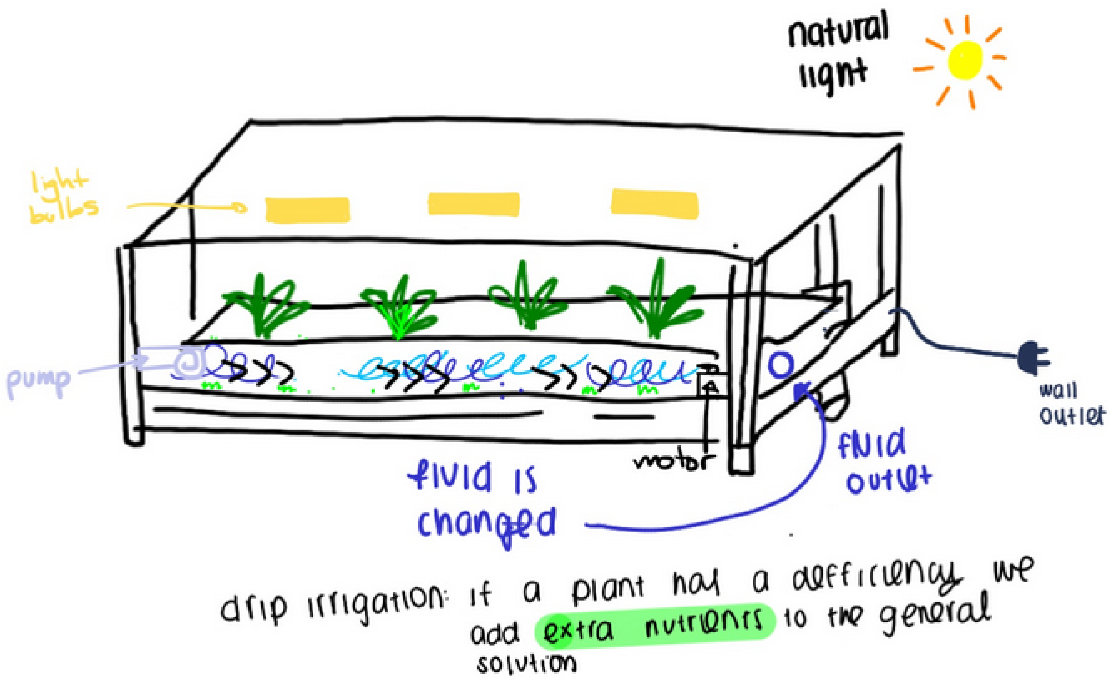



5. It is based on drip irrigation using servo motors and pumps for water control and nutrient distribution, with natural light and resistors for

temperature control and growth of the crop. Its power source is directly from a wall outlet, and based on fluid change control.

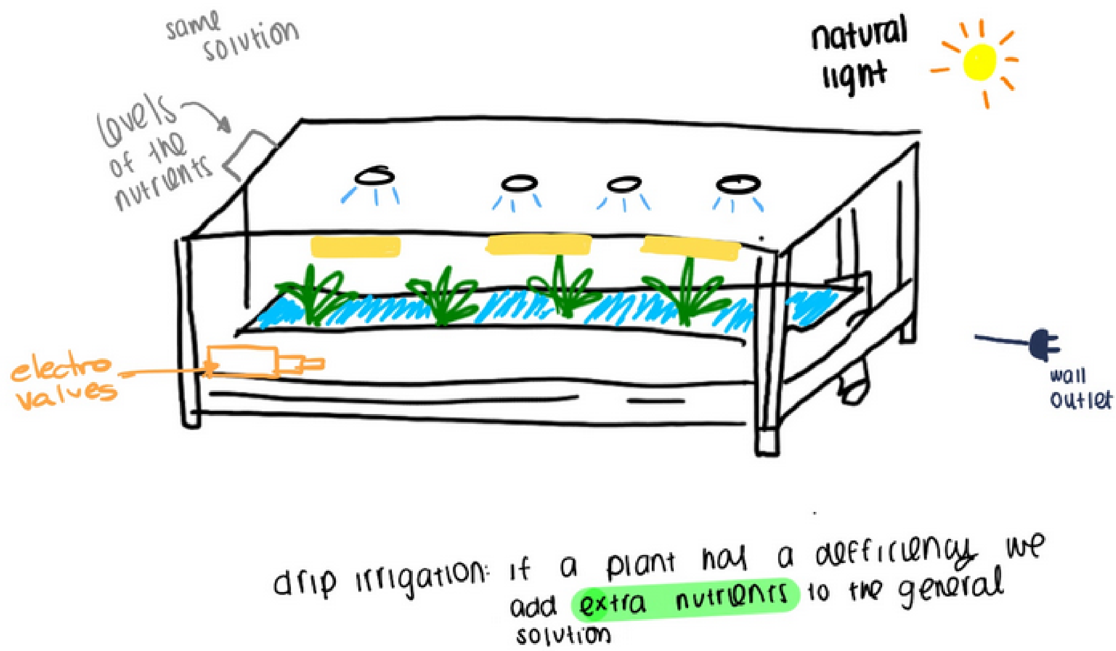



6. It is based on drip irrigation using motors and pumps for water control, and incandescent bulbs for temperature control, Using motors to distribute nutrients. Its power source is directly from a wall outlet, and based on static solution, natural lighting and localized irrigation.

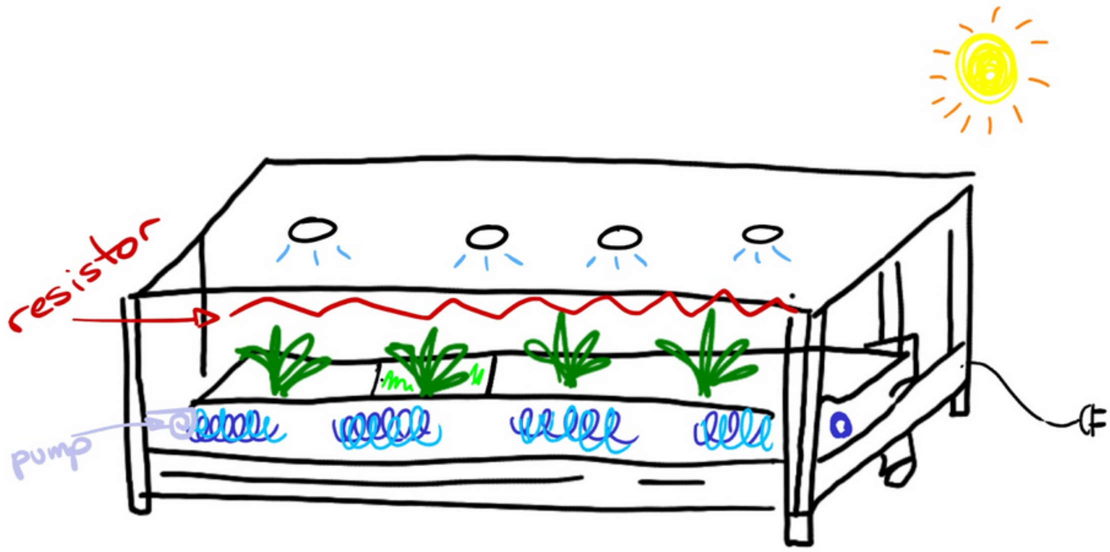



7. Drip irrigation, same solution (highly nutritious), natural light and wall

outlet. We will be using electrovalves for the nutrients and sprinklers for the crop's irrigation.




8. A system that uses natural light for the crop's growth. The energy is a wall outlet and we have a fluid change control. Resistors are the way of controlling the temperature and we have pumps for the crop's irrigation. However, if needed, we have localized irrigation.




9. Large solar panels and batteries, use sprinklers and water pumps and motors to add nutrients in predetermined portions. It uses totally artificial light and is a static solution without individual control.
10. Low capacity solar with auxiliary batteries. It does everything in the day and only monitors at night with the charge of the batteries, but does not make adjustments until the panels come back to power. Water and

nutrients can be underneath and are added with pumps when required, but it is a static solution and individual irrigation. The light is artificial during the day and low intensity at night.

11. It uses AA, 9V or similar batteries, it has very low energy consumption. The water and nutrients are above the crops so that they fall by gravity and valves are opened or closed for them to pass. The user must be constantly adding the water or it must be received from an external source.
12. This is one that works with an off-grid solar array. Use sprinklers for individual irrigation of plants, and pumps to add nutrients from a tank that is below the crops. Use resistors to change the temperature. It has a controlled solution, drip irrigation, and UV light.
13. This is one that works with a water tank and without batteries. It uses servo motors for individual irrigation of plants, and motors to add nutrients from a tank that is below the crops. Use resistors to change the temperature. It has a static solution, drip irrigation, and natural light.
14. This is one that works with an electrical outlet but not batteries. It uses pumps for individual irrigation of the plants, and motors to add the nutrients from a tank that is under the crops. Use incandescent bulbs to change the temperature. It has a controlled solution, localized irrigation and natural light.
15. It has a raised water tank but no batteries. It uses servo motors for individual irrigation of plants, and solenoid valves to add nutrients from a tank that is below the crops. Use resistors to change the temperature. It has a static solution, localized irrigation and UV light.

# Selection

## 1. Concept Filtering

Initial concept filtering was done by comparing every concept against the product created by the competitor H2HYDROPONICS. If the corresponding concept was considered to satisfy a need better a ‘+’ symbol is inserted in the selection table, if the concept performs worse than the competition then a ‘-’ is assigned. If the product is similar or the comparison is inapplicable a ‘0’ is inserted. At the end of the process ‘+’ are added and ‘-’ are subtracted. The best 6 concepts are selected for the following stages of the selection process.

| **id** | **Selection Criteria** |
|---|---|
| 1 | The product has a durable construction |
| 2 | The product can improve crop quality |
| 3 | The product is sustainable |

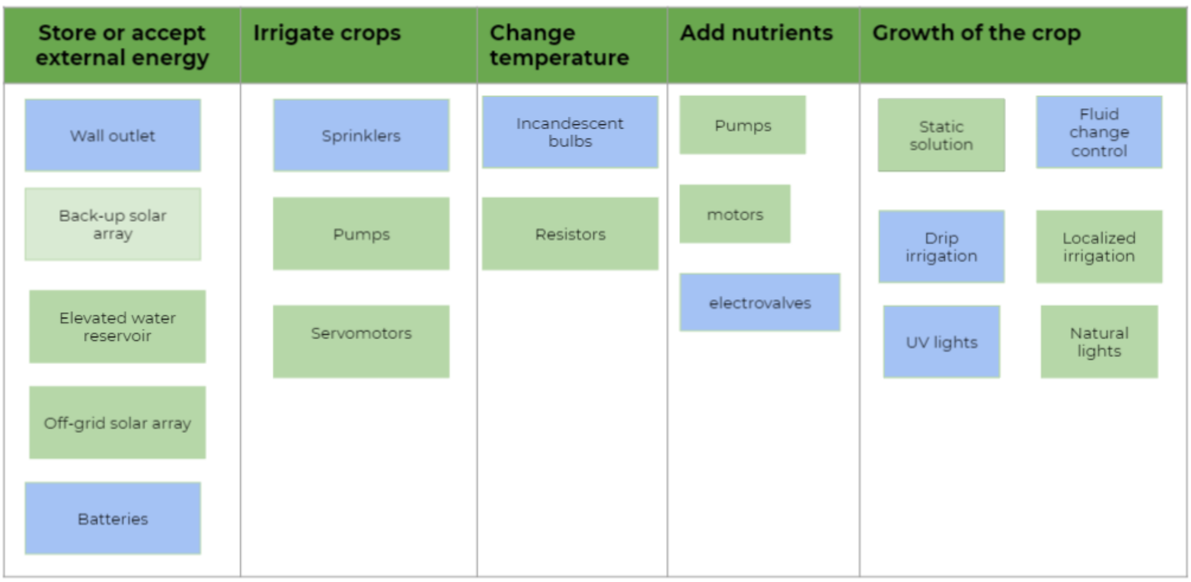
| | |
|---|---|
| 4 | The product generates little waste |
| 5 | The product is affordable |
| 6 | The product is user friendly |
| 7 | The product can grow different crops |
| 8 | The product can grow multiple crops simultaneously |
| 9 | The product has a long life-cycle |
| 10 | The product requires little manual intervention |
| 11 | The product can operate during any season of the year |
| 12 | The product uses resources efficiently |
| 13 | The product is scalable |
| 14 | The product can operate without a power grid available |
| 15 | The product is portable |

| **id** | **c1** | **c2** | **c3** | **c4** | **c5** | **c6** | **c7** | **c8** | **c9** | **c10** | **c11** | **c12** | **c13** | **c14** | **c15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2** | + | + | + | + | + | + | + | + | + | - | - | + | - | + | - |
| **3** | - | - | - | - | - | - | - | - | + | + | - | - | + | - | + |
| **4** | + | - | + | + | + | + | + | - | + | - | - | + | + | + | + |
| **5** | + | - | + | + | + | + | + | + | - | + | + | - | + | + | + |
| **6** | 0 | 0 | - | - | - | 0 | 0 | - | 0 | - | - | 0 | 0 | - | - |
| **7** | + | + | + | + | + | + | + | + | + | + | - | + | + | + | + |
| **8** | + | + | + | + | + | + | + | + | + | - | - | + | + | + | + |
| **9** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **10** | + | + | - | - | + | - | + | - | + | + | - | + | - | + | + |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **12** | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| **13** | + | + | + | + | + | + | + | + | + | - | - | - | + | + | + |

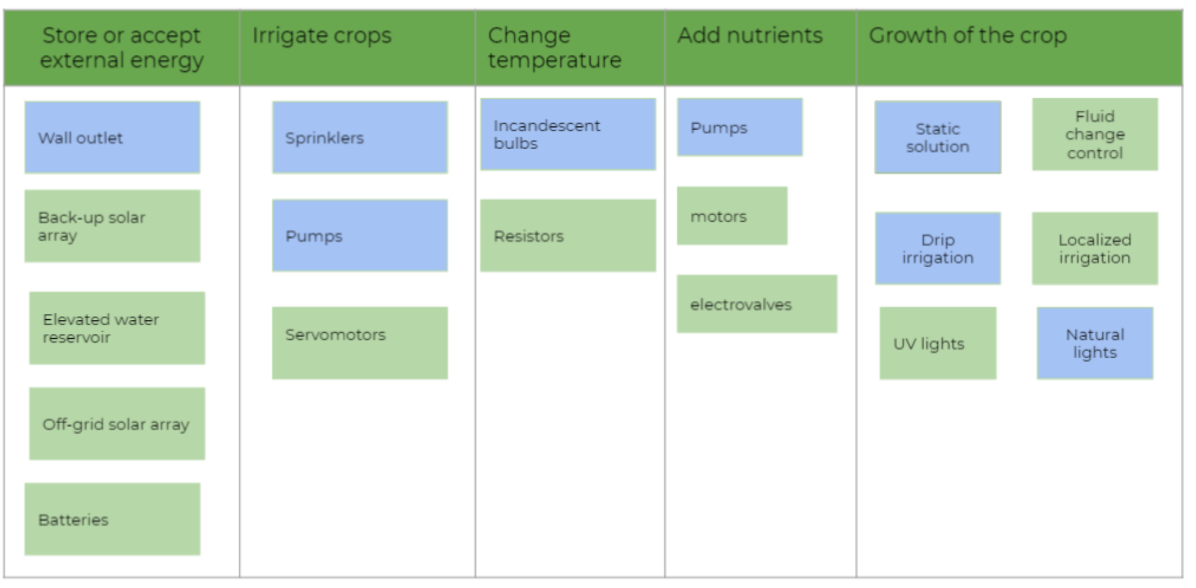
| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **14** | - | - | - | - | - | - | - | - | + | + | + | + | + | + | + |
| **15** | + | + | + | + | + | + | + | + | - | - | + | - | + | + | + |
| **+** | 9 | 7 | 8 | 8 | 9 | 8 | 9 | 7 | 9 | 6 | 4 | 7 | 9 | 10 | 10 |
| **0** | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 3 | 3 | 4 | 4 | 3 | 3 |
| **-** | 2 | 2 | 4 | 4 | 4 | 3 | 3 | 2 | 5 | 2 | 6 | 8 | 4 | 2 | 2 |
| **NET** | 7 | 3 | 4 | 4 | 6 | 5 | 7 | 2 | 7 | 0 | -4 | 3 | 7 | 8 | 8 |
| **Rank** | 3 | 11 | 9 | 9 | 7 | 8 | 3 | 13 | 3 | 14 | 15 | 11 | 3 | 1 | 1 |
| **Continue?** | Y | N | N | N | N | N | Y | N | Y | N | N | N | Y | Y | Y |

## 2. Concept Combination and Improvement

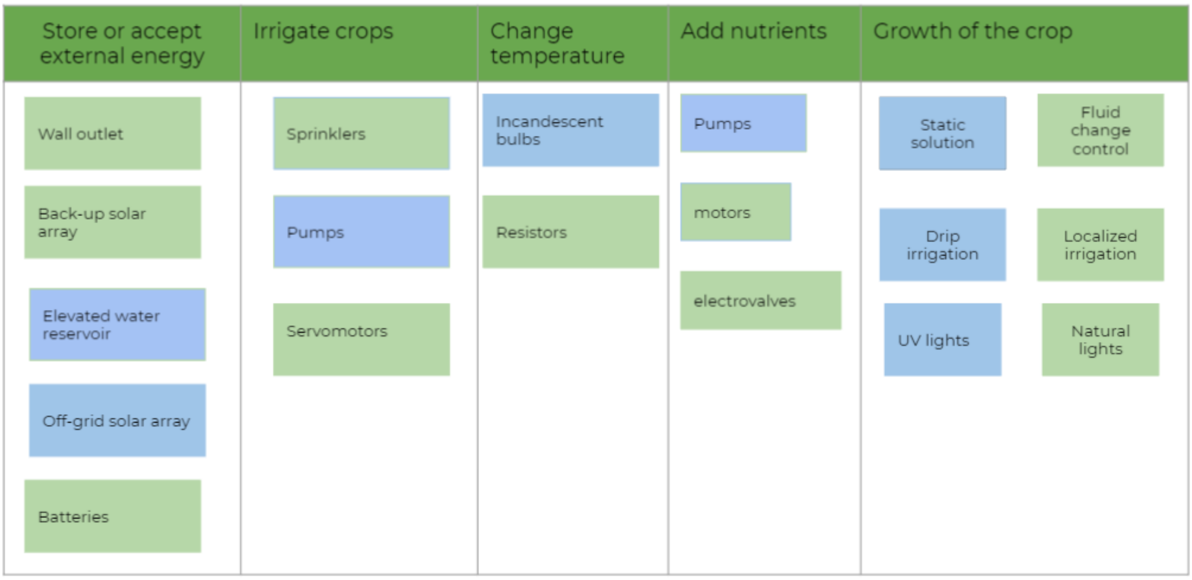
Once concepts 1, 7, 9, 13, 14 and 15 were selected for recombination and improvement the following combination tables were created. Recombination was done by creating pairs of promising concepts and interchanging one or two characteristics between them. This was done iteratively until all concepts were considered and analysed. This process resulted in 12 improved combination tables and associated concepts. Sketches in this section are also omitted to avoid saturation, since the visual representations are similar to the ones already included in previous sections.




**1**


Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
Wall outlet
Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

**2**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Servomotors
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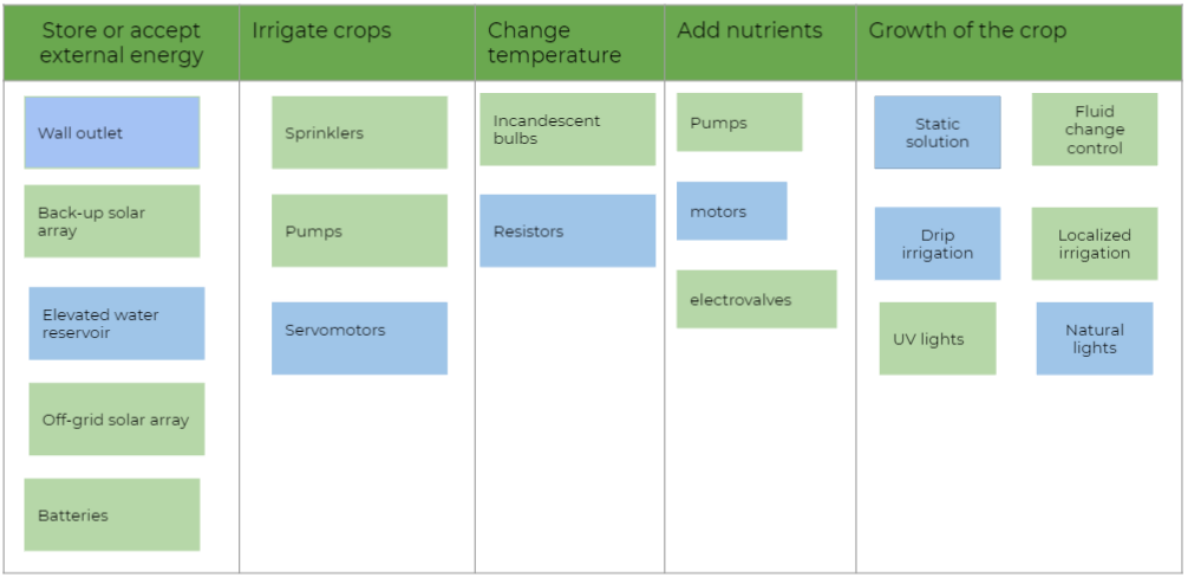
**3**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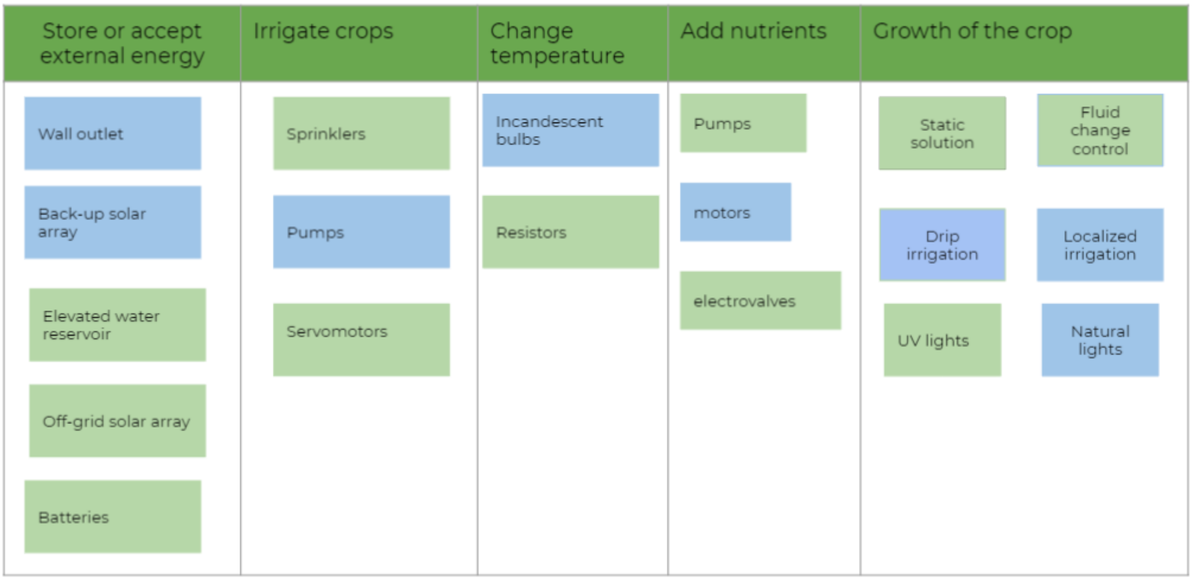
**4**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Pumps
Servomotors
Incandescent bulbs
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Pumps
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights

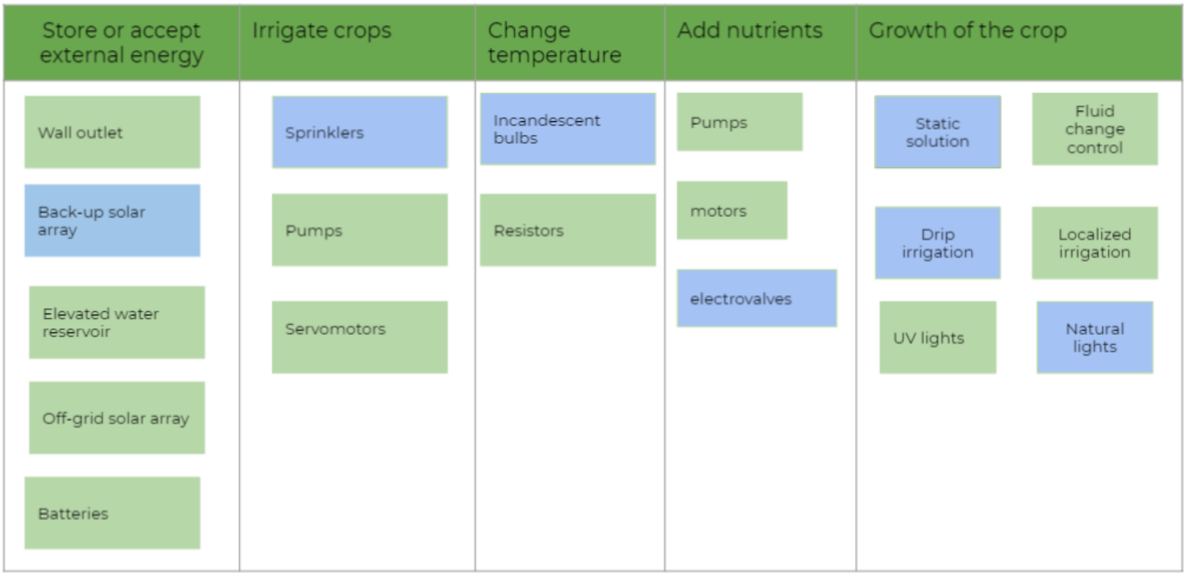
**5**

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop |
|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution; Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation; Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights; Natural lights |
| Off-grid solar array | | | | |
| Batteries | | | | |

**6**

| **Store or accept external energy** | **Irrigate crops** | **Change temperature** | **Add nutrients** | **Growth of the crop** |
|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution; Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation; Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights; Natural lights |
| Off-grid solar array | | | | |
| Batteries | | | | |

**7**



Store or accept external energy
Irrigate crops
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Growth of the crop
Wall outlet
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electrovalves
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Drip irrigation
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UV lights
Natural lights


**8**

Store or accept external energy
Irrigate crops
Change temperature
Add nutrients
Growth of the crop
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Back-up solar array
Elevated water reservoir
Off-grid solar array
Batteries
Sprinklers
Pumps
Servomotors
Incandescent bulbs
Resistors
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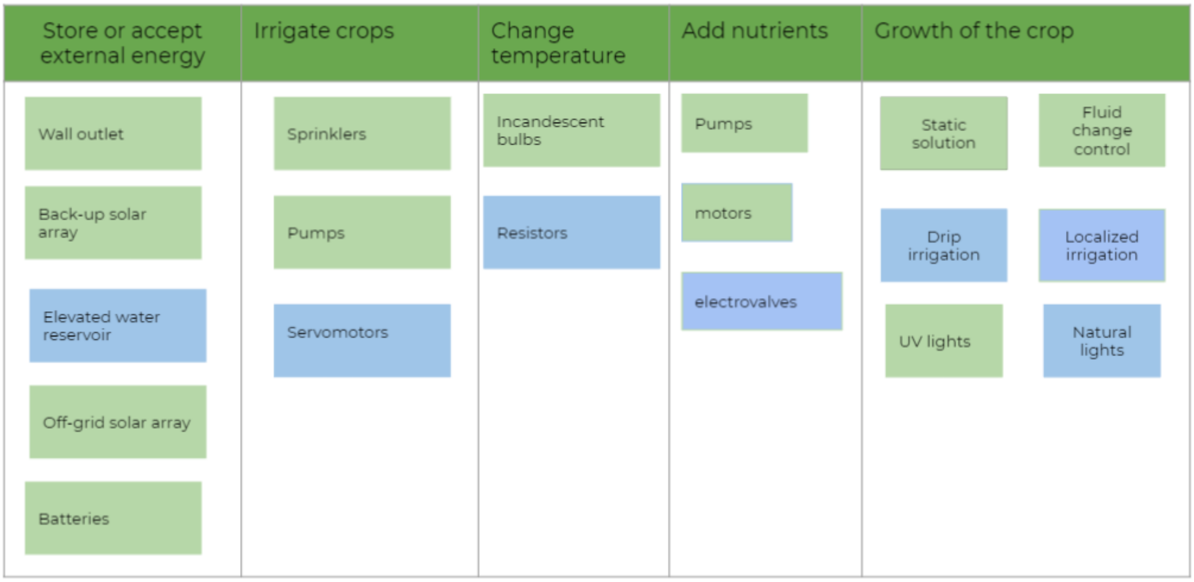
motors
electrovalves
Static solution
Fluid change control
Drip irrigation
Localized irrigation
UV lights
Natural lights


**9**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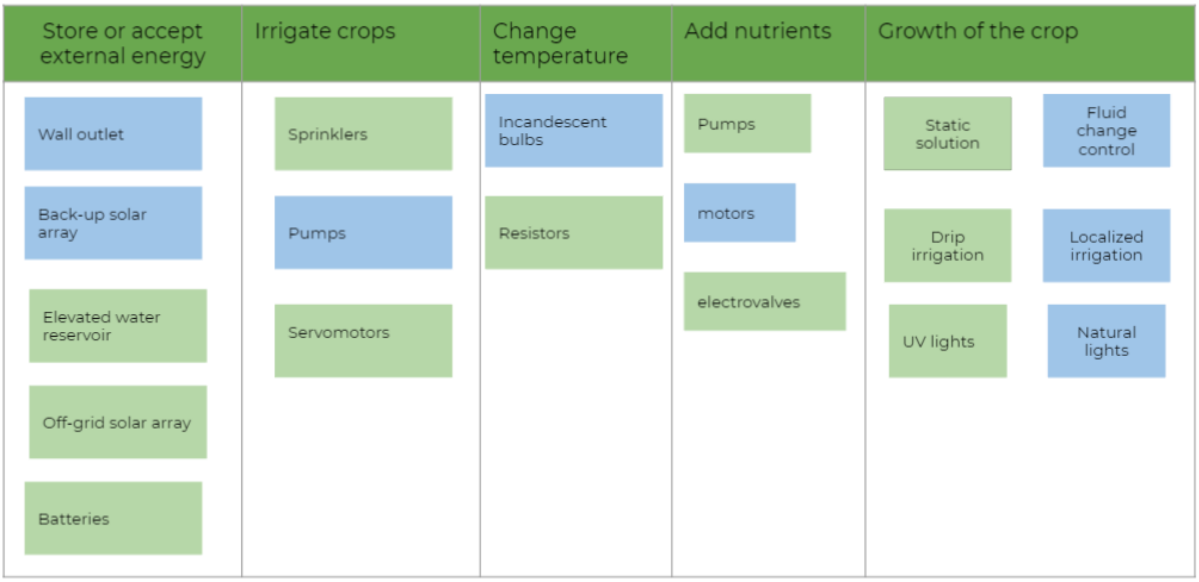
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**11**

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop | |
|---|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution | Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation | Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights | Natural lights |
| Off-grid solar array | | | | | |
| Batteries | | | | | |

**12**

# 3. New Filtering

The process described for the initial filtering is then applied to the newly obtained concepts, which after recombination are expected to improve their overall performance.Thus, only 4 concepts get selected for the scoring stage of the selection process.

| id | Selection Criteria |
|---|---|
| 1 | The product has a durable construction |
| 2 | The product can improve crop quality |
| 3 | The product is sustainable |
| 4 | The product generates little waste |
| 5 | The product is affordable |
| 6 | The product is user friendly |
| 7 | The product can grow different crops |
| 8 | The product can grow multiple crops simultaneously |
| 9 | The product has a long life-cycle |
| 10 | The product requires little manual intervention |
| 11 | The product can operate during any season of the year |

| | |
|---|---|
| 12 | The product uses resources efficiently |
| 13 | The product is scalable |
| 14 | The product can operate without a power grid available |
| 15 | The product is portable |

| id | c1 | c2 | c3 | c4 | c5 | c6 | c7 | c8 | c9 | c10 | c11 | c12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2** | + | + | + | + | + | + | + | - | - | + | + | + |
| **3** | + | - | + | + | + | + | - | + | + | + | + | + |
| **4** | + | - | - | + | + | + | 0 | 0 | 0 | + | + | - |
| **5** | - | + | - | + | - | + | - | - | + | - | + | - |
| **6** | + | + | + | + | + | + | + | + | + | - | + | - |
| **7** | + | + | + | + | + | + | + | + | + | + | + | + |
| **8** | + | + | + | + | + | + | + | + | + | + | + | + |
| **9** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **10** | + | - | + | + | + | + | + | + | - | - | + | - |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **12** | - | + | - | - | + | + | + | - | - | + | + | - |
| **13** | + | + | + | + | + | + | + | + | + | + | + | + |
| **14** | + | - | + | + | + | + | - | + | + | + | + | + |
| **15** | + | + | - | + | + | + | + | + | + | + | + | + |
| **+** | 10 | 8 | 8 | 11 | 11 | 12 | 8 | 8 | 8 | 9 | 12 | 7 |
| **0** | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 |
| **-** | 2 | 4 | 4 | 2 | 1 | 0 | 3 | 3 | 3 | 5 | 0 | 8 |
| **NET** | 8 | 4 | 4 | 9 | 10 | 12 | 5 | 5 | 5 | 4 | 12 | -1 |
| **Rank** | 5 | 9 | 9 | 4 | 3 | 1 | 6 | 6 | 6 | 9 | 1 | 12 |

| Continue? | N | N | N | Y | Y | Y | N | N | N | N | Y | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

# 4. Concept Scoring

Keeping the competitor H2HYDROPONICS's product as a reference the selected improved concepts were compared with more detail in a scale of 1-5:

1. The given concept does not fulfill the need at all,
2. The concept barely satisfies the need,
3. The concept performs just as well as the reference,
4. The concept performs better than the reference,
5. The concept completely satisfies the need.

Using the relative importance of the needs calculated in the HoQ presented in the E2. Definition of specifications these scores were weighed and then added, the selected concepts is the one that obtains the best overall weighted score.

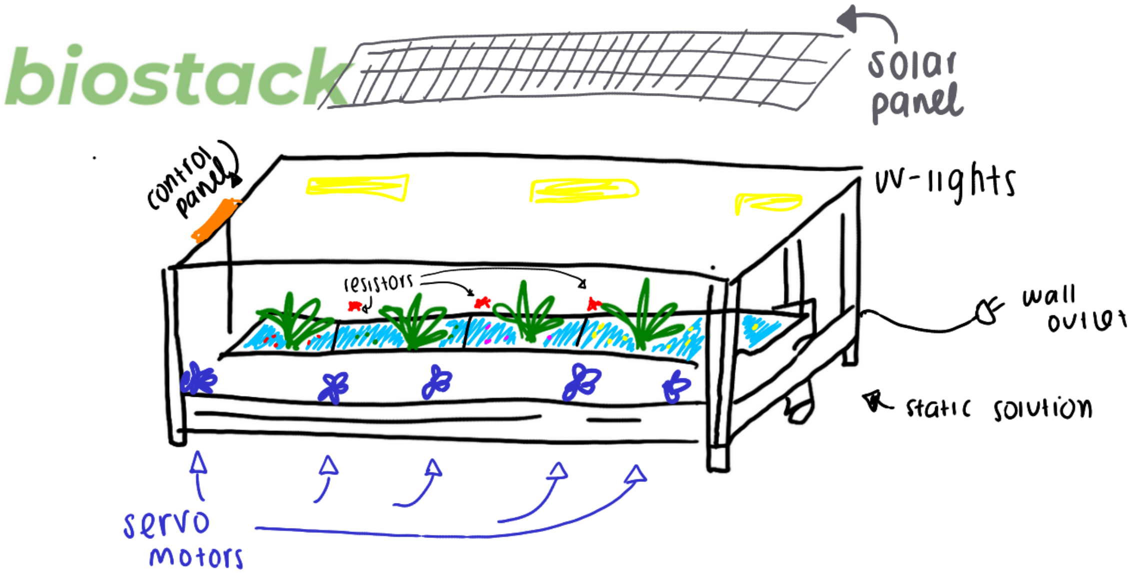
| id | Weight | c4 | | c5 | | c6 | | c11 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Rating | W.Score | Rating | W.Score | Rating | W.Score | Rating | W.Score |
| 1 | 4.04 | 3 | 12.12 | 3 | 12.12 | 3 | 12.12 | 3 | 12.12 |
| 2 | 3.93 | 4 | 15.72 | 4 | 15.72 | 5 | 19.65 | 5 | 19.65 |
| 3 | 3.93 | 5 | 19.65 | 4 | 15.72 | 5 | 19.65 | 4 | 15.72 |
| 4 | 3.85 | 5 | 19.25 | 4 | 15.4 | 5 | 19.25 | 5 | 19.25 |
| 5 | 3.81 | 5 | 19.05 | 2 | 7.62 | 4 | 15.24 | 5 | 19.05 |
| 6 | 3.81 | 5 | 19.05 | 4 | 15.24 | 5 | 19.05 | 4 | 15.24 |
| 7 | 3.77 | 5 | 18.85 | 4 | 15.08 | 5 | 18.85 | 4 | 15.08 |
| 8 | 3.74 | 4 | 14.96 | 4 | 14.96 | 5 | 18.7 | 5 | 18.7 |
| 9 | 3.7 | 3 | 11.1 | 3 | 11.1 | 3 | 11.1 | 3 | 11.1 |
| 10 | 3.63 | 5 | 18.15 | 5 | 18.15 | 4 | 14.52 | 5 | 18.15 |
| 11 | 3.63 | 3 | 10.89 | 3 | 10.89 | 3 | 10.89 | 3 | 10.89 |
| 12 | 3.55 | 1 | 3.55 | 4 | 14.2 | 5 | 17.75 | 5 | 17.75 |
| 13 | 3.52 | 5 | 17.6 | 4 | 14.08 | 5 | 17.6 | 4 | 14.08 |
| 14 | 3.41 | 5 | 17.05 | 4 | 13.64 | 4 | 13.64 | 5 | 17.05 |
| 15 | 3.04 | 5 | 15.2 | 4 | 12.16 | 5 | 15.2 | 4 | 12.16 |
| Total score | | 232.19 | | 206.08 | | 243.21 | | 235.99 | |
| Rating | | 3 | | 4 | | 1 | | 2 | |
| Continue? | | NO | | NO | | YES | | NO | |

# 5. Selected Concept Presentation

The selected concept would be the combined concept number **6**. This would mean the systems storage or acceptance of external energy supply would be based on a direct wall outlet with a back-up solar array. The back-up solar array concept includes a small battery pack that stores both the generated energy and recharges whenever electricity from a wall outlet is available. This would allow for portability and operation without a power grid under certain scenarios and for limited periods of time.

In terms of crop growth, it would be based on localized irrigation and a static solution, this allows simultaneous growth of multiple different crops if desired or several crops of the same plant. Temperature control is going to be controlled through resistors, nutrient control is accomplished thanks to electrovalves and UV lights to ensure crops get sufficient lighting.

As stated in the initial concept of the product, the system will have a control panel that will allow the user to choose the crop and its respective settings, meaning there will be complete control over the crop, from sowing to harvest.



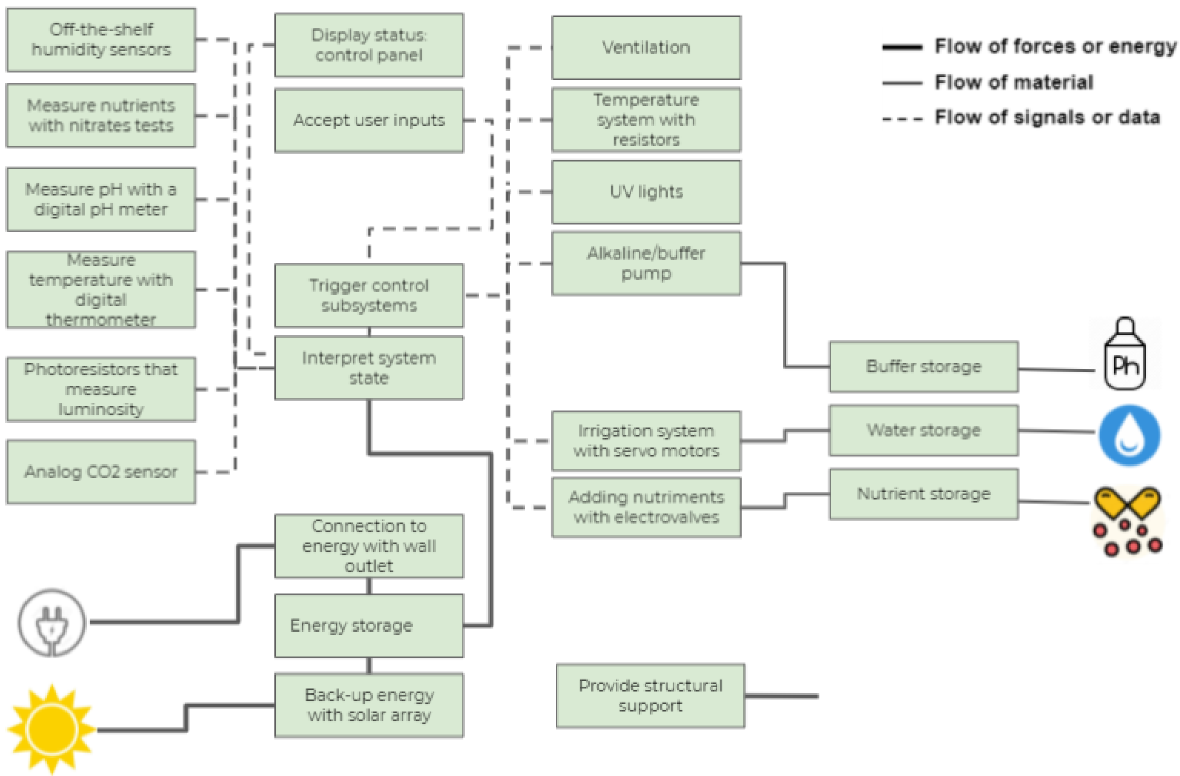

| Store or accept external energy | Irrigate crops | Change temperature | Add nutrients | Growth of the crop | |
|---|---|---|---|---|---|
| Wall outlet | Sprinklers | Incandescent bulbs | Pumps | Static solution | Fluid change control |
| Back-up solar array | Pumps | Resistors | motors | Drip irrigation | Localized irrigation |
| Elevated water reservoir | Servomotors | | electrovalves | UV lights | Natural lights |
| Off-grid solar array | | | | | |
| Batteries | | | | | |

# Concept Architecture Development

## 1. Functional Diagram

For the functional diagram we considered the expected components that the selected concept would have. First, all the required sensors and tests were defined along with an interpretation of the data to understand the state of the crops. This interpreted information is displayed in order to communicate with the user. With this information the user may wish to specify manual overrides or adjust parameters, so a functional element for this was defined.

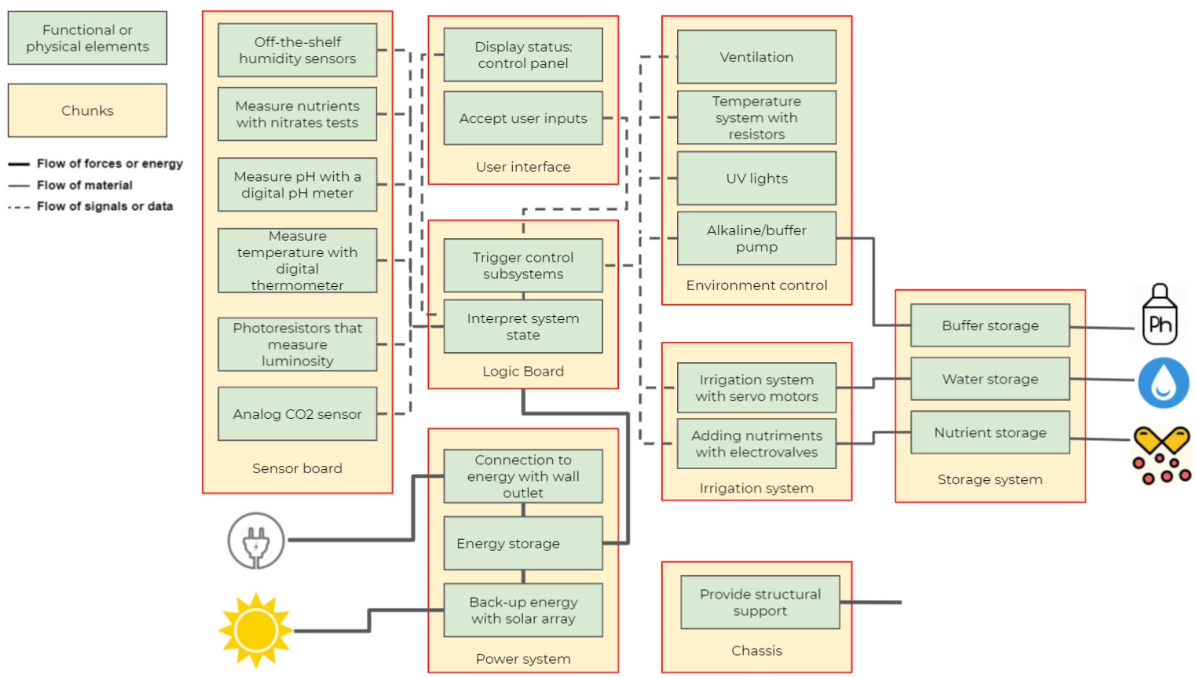
Once the state is interpreted and user inputs are accepted the system can trigger actions to maintain a desired state. These actions are then executed by the different actuators defined in the selected concept. For the irrigation, nutrient and pH control storages for the materials are required. Finally, energy can be accepted either through a wall outlet or by a solar array, and then stored in batteries.



## 2. Chunk Definition

The functional and physical elements defined in the previous section were grouped in the following chunks.

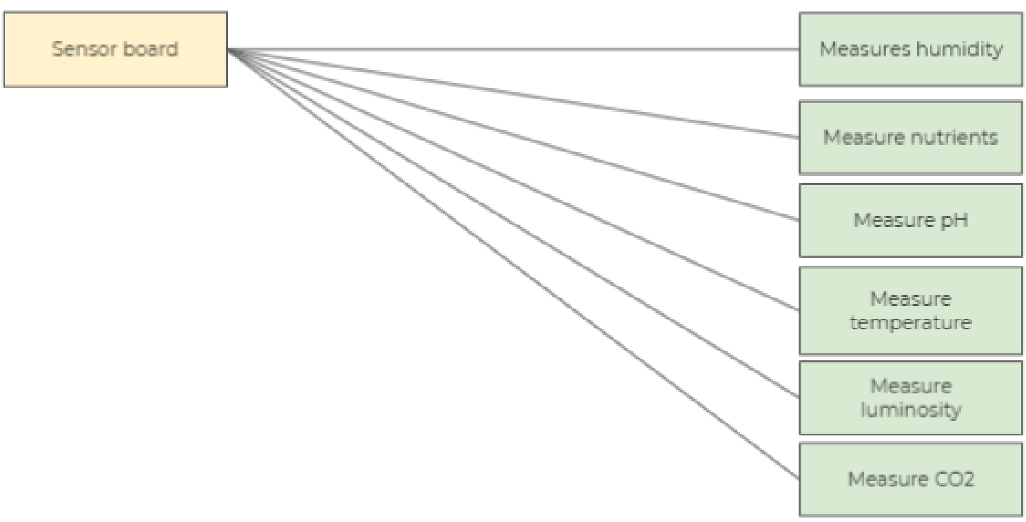
- Sensor board, including all the sensing devices required by the concept.
  - Humidity sensor
  - Nutrients tests
  - pH meter
  - Thermometer
  - Photoresistors
  - $CO_2$ sensor
- Logic board, which includes the interpretation of data and the identification of required actions to maintain the desired state or to alter the current state.
  - Interpret system state
  - Trigger control subsystems
- User interface, which is used to display relevant information to the user and to accept external inputs.
  - Display status control panel
  - Accept user inputs
- Power system, which includes the acceptance and storage of external energy.
  - Connection to energy with wall outlet
  - Energy storage
  - Back-up energy with solar array
- Environment control, this includes all actuators related to the control of the crop environment.
  - Ventilation
  - Temperature control with resistors
  - UV lights
  - Alkaline/buffer pump
- Irrigation system, which groups the required elements to provide water and nutrients to a crop.
  - Irrigation system with servo motors
  - Adding nutrients with electrovalves
- Chassis, including all construction elements that will provide structural support.
- Storage system, which includes three different storage spaces for the required materials.
  - Buffer solution storage
  - Water storage
  - Nutrient storage

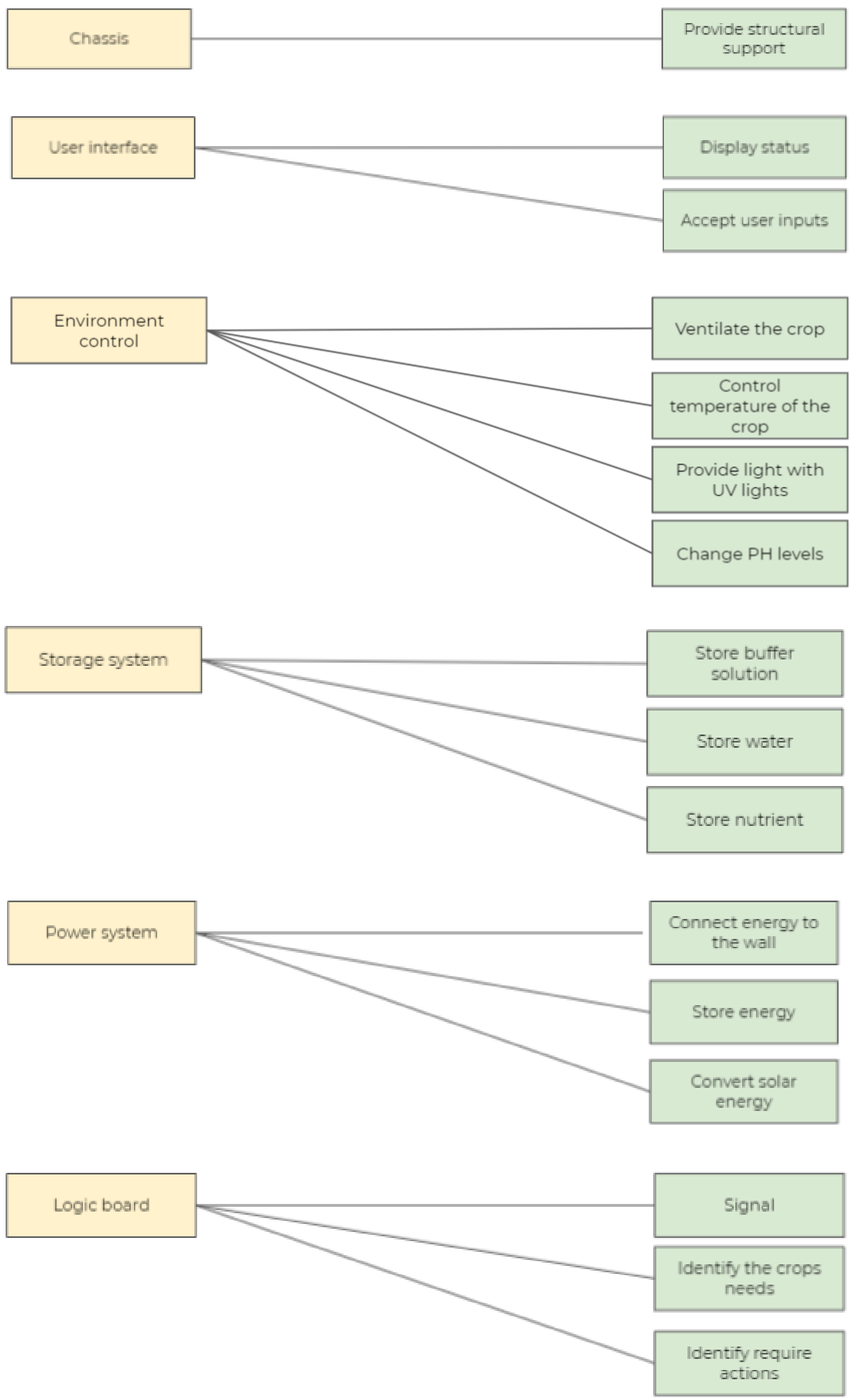



# 3. Integration Levels

The modular design elected was made so that every chunk would be easily detached for easy maintenance and repair. Each chunk has its own set of functions, specific to its definition, and that makes it easy to understand the whole system.

The integration levels are constructed according to the chunk definitions presented in the previous section, and shown below:

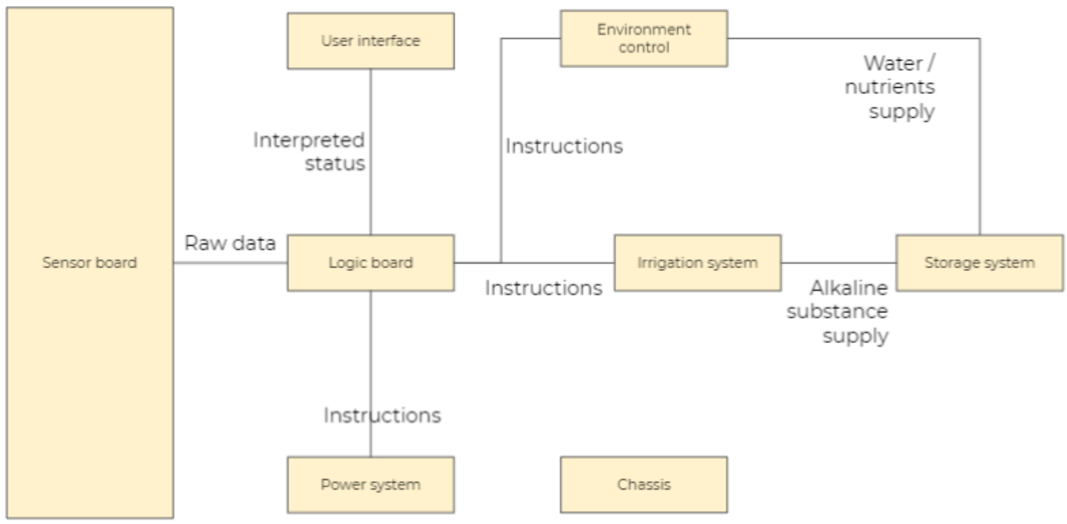



Chassis
Provide structural support
User interface
Display status
Accept user inputs
Environment control
Ventilate the crop
Control temperature of the crop
Provide light with UV lights
Change PH levels
Storage system
Store buffer solution
Store water
Store nutrient
Power system
Connect energy to the wall
Store energy
Convert solar energy
Logic board
Signal
Identify the crops needs
Identify require actions

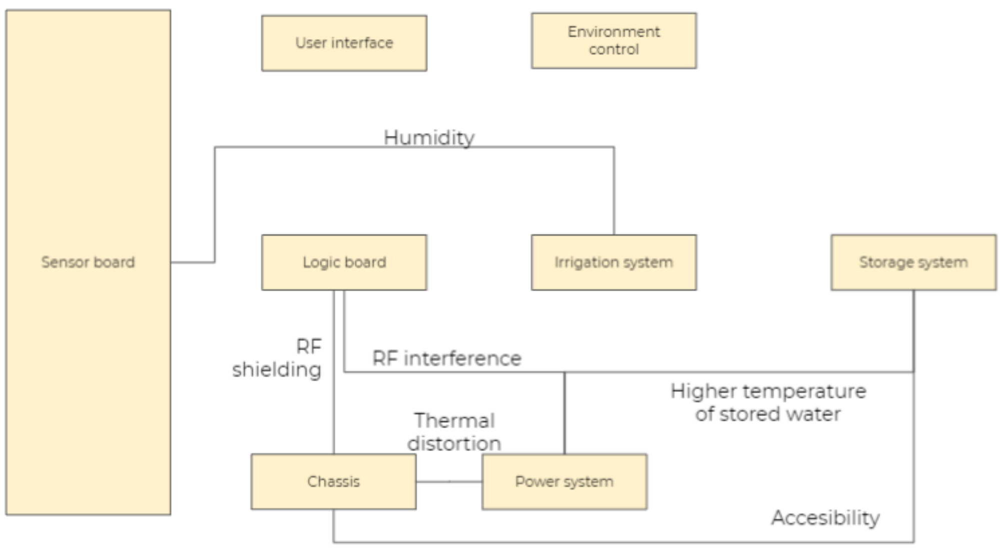
# 4. Planned and Incidental Analysis of Interactions

The planned interactions were defined following the functional diagram and chunk definitions. However, the interactions between components were analysed more carefully in order to specify which interactions are expected to occur. For the incidental interactions the geometric distribution diagram was considered and possible interactions between the chunk were identified, both desirable and undesirable.

**Planned interactions**




**Incidental interactions**



# 5. Commonality and Differentiation

| Chunks | Number of Types | Government | Communities | Private Users |
|---|---|---|---|---|
| Sensor board | 1 | Generic Sensor Board | Generic Sensor Board | Generic Sensor Board |
| Chassis | 3 | biostack: Gamma version | biostack: Beta version | biostack: Alfa version |
| User interface | 2 | Basic GUI | Basic GUI | Deluxe GUI |
| Irrigation system | 1 | biostack IS | biostack IS | biostack IS |
| Environment Control | 1 | Dragon control solutions | Dragon control solutions | Dragon control solutions |
| Storage system | 1 | Generic storage | Generic storage | Generic storage |
| Power system | 2 | Solar Connectivity<br>Home Connectivity | Solar Connectivity<br>Home Connectivity | Home Connectivity |
| Logic board | 1 | biostack core | biostack core | biostack core |

Considering that we have a primary market (government and communities) that has different needs than the secondary market (private users), we decided to have some different modules for each client.

**Chassis:** the difference between the versions is the material used for each chassis, this will mostly be in aesthetics and durability. The different versions we have are:

- *biostack: Gamma version*
- *biostack: Beta version*
- *biostack: Alfa version*

**User interface:** the main difference between the interfaces are that we have a basic one with buttons and a deluxe one that has a touch screen. The options consist of:

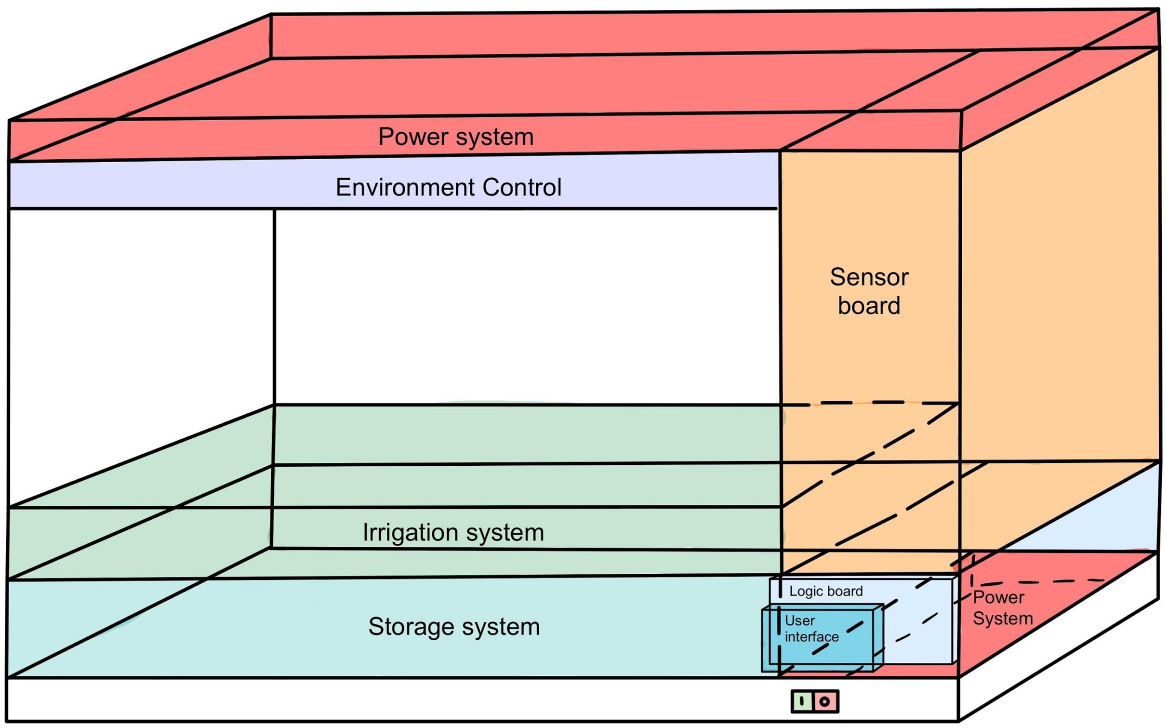
- *Basic GUI*
- *Deluxe GUI*

**Power system:** for the power system we have two options:

- *Solar connectivity*
- *Home connectivity*

## 6. Geometric Distribution Diagram

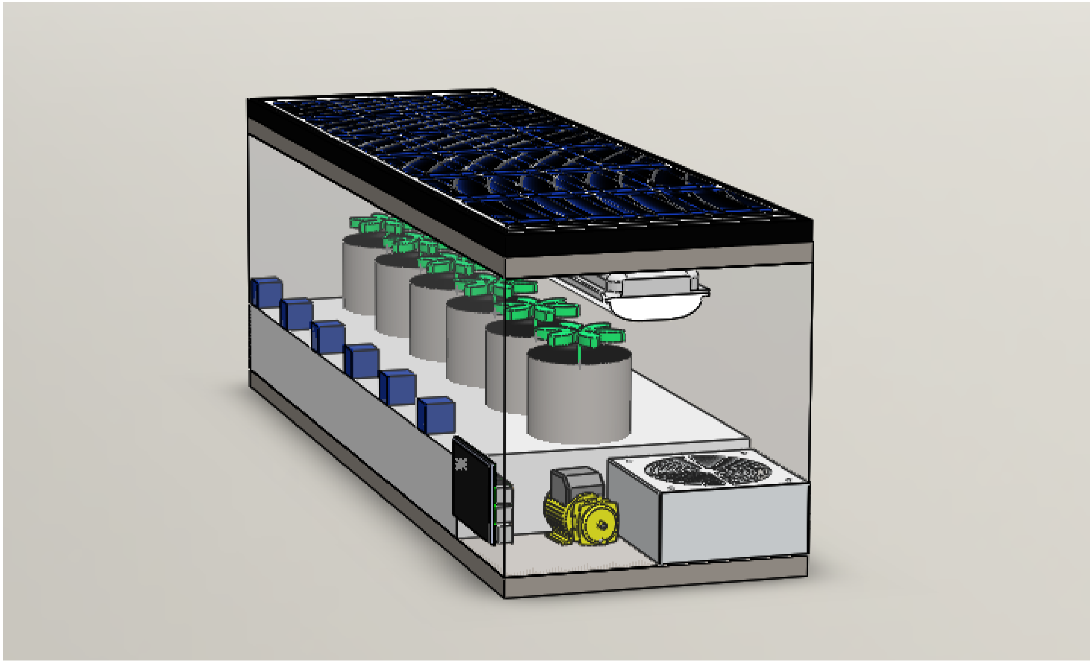
In order to establish a way to visualize the correspondent chunks of biostack, a geometric distribution diagram was made. Each chunk was positioned within the biostack product in order to reduce the distance that both energy and materials need to travel and reduce the possibility of undesired incidental interactions.



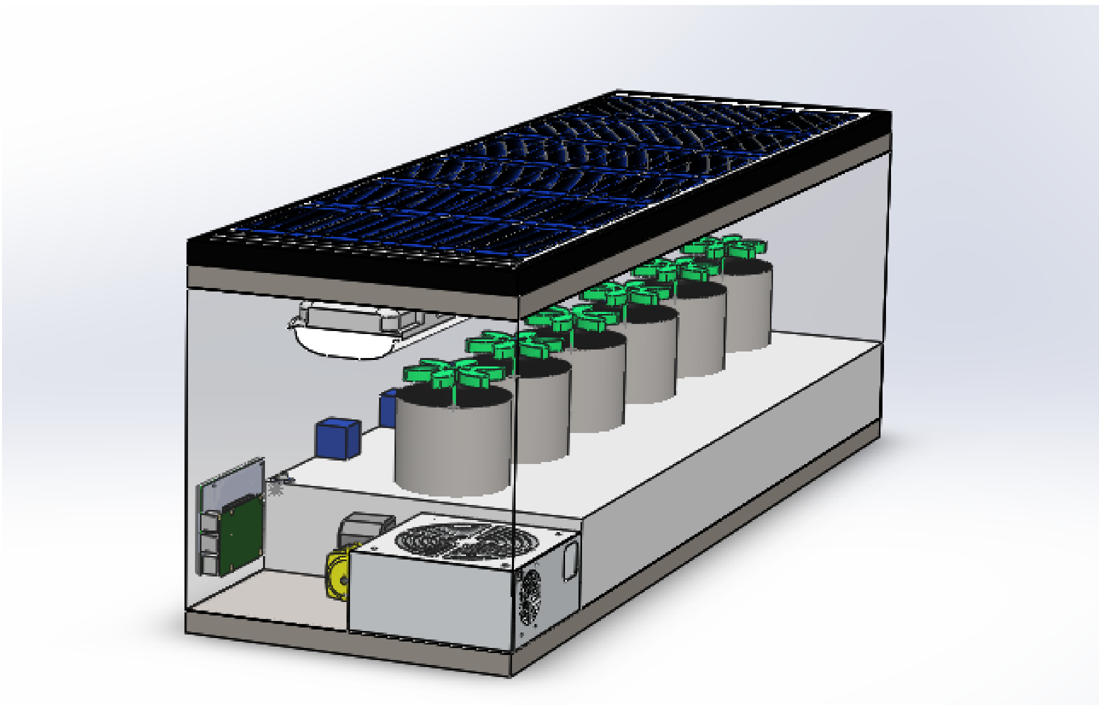
# Virtual Prototype

For visualization of the resulting prototype, a virtual design was built using SolidWorks, which allowed for inclusion of CAD versions of components that will actually be used for the construction of *biostack*.

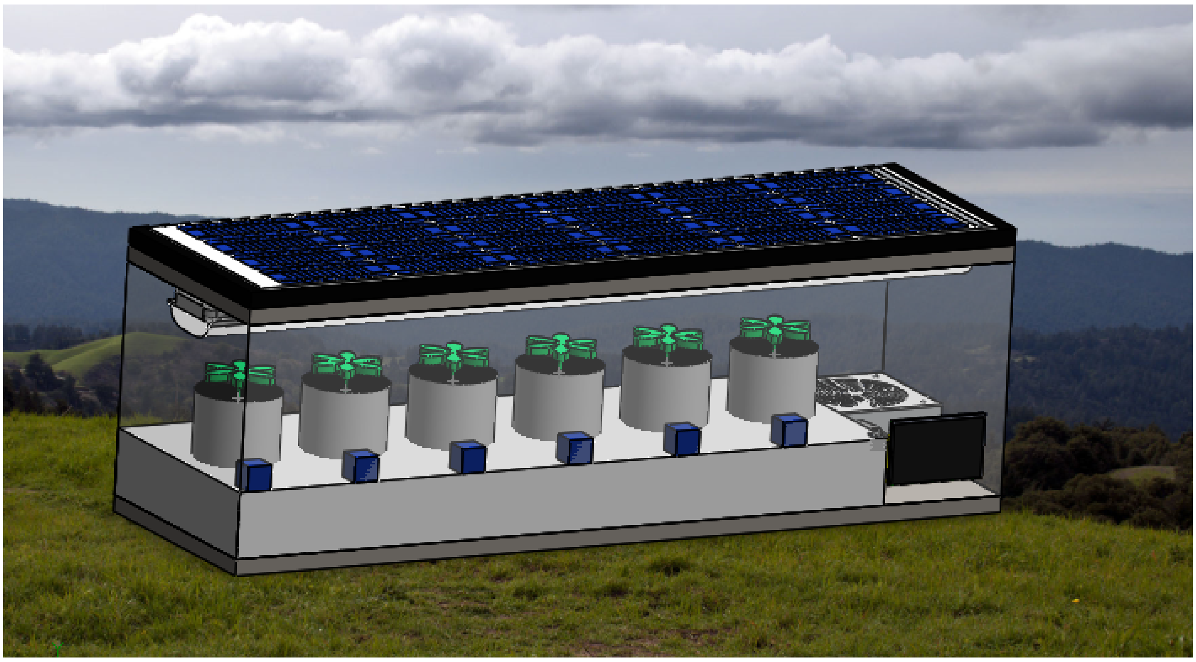
**Render 1**



**Render 2**



**Render 3**



**Render 4**

**Render 5**