SOLARPUNK CONFERENCE '23

Seeding Tomorrow: Sustainable Hydroponics and Open-Source Technology Blueprints

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1. Introduction

As humanity grapples with the multifaceted challenges of the 21st century, the impetus to innovate in the realm of agriculture (among others) has never been more pressing. This paper explores the various facets, and methodologies, of sustainable hydroponic practices, and the ongoing Oikosol project that intertwines sustainability, open-source technology, and decentralization.

2. Why Hydroponics?

Hydroponics, while not entirely new, has garnered increasing attention in recent years as a viable alternative to traditional farming. Hydroponics is generally defined as the soilless cultivation of plants by providing a nutrient-rich liquid solution. But what are its advantages?

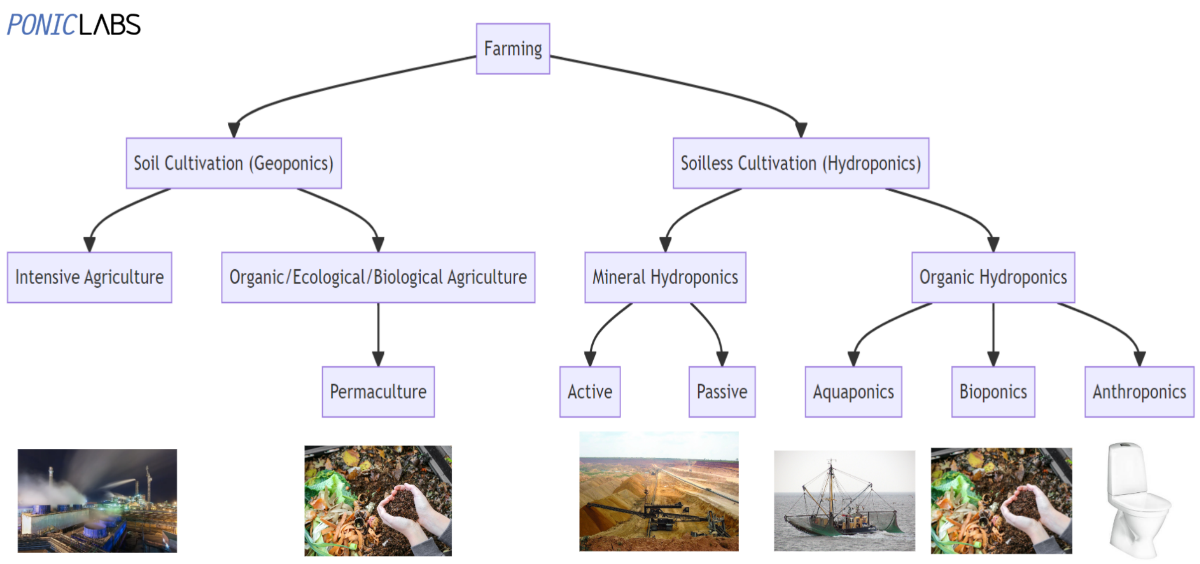
First, the system's inherent design emphasizes the reuse of water, leading to minimal wastage. This not only ensures a consistent supply of water to the plants but also addresses global concerns about water usage.

Additionally, the plants typically experience faster growth, as the nutrients are more readily available in soluble form and ready for uptake by their roots. The use of mineral solutions in particular, as well as indoor growing with artificial light, allows for more control over the time spent in each of the plant’s stages (e.g: vegetative vs flowering). A hydroponic farmer can therefore achieve higher yields, as the plant does not need to spend as much energy to expand its root growth to reach all the necessary micronutrients, and the farmer can more easily maximize space through vertical systems which are typically lighter in weight than the equivalent soil-based vertical farms.

There are also labor savings, as many of the processes are automated (such as water recirculation, water aeration, nutrient dosing, light cycles) and fewer pests to handle, as a lack of soil prevents potential pests from fully developing during their life cycle. Finally, there are also fewer (if any) weeds, and no tillage or heavy machinery to operate as a result.

3. Overview of growing techniques

Over the years, researchers, farmers, and enthusiasts have devised various methods to optimize plant growth and productivity, tailored to specific conditions and objectives.



A general overview of different soil-based and soilless cultivation techniques.

Soil Cultivation can be divided in two main categories: Intensive Agriculture and Organic/Ecological/Biological Agriculture. Intensive Agriculture is by far the most practiced method due to its high yields (at the expense of soil health). It relies on the Haber-Bosch process, where nitrogen is extracted from the atmosphere, alongside a separate extraction of non-renewable minerals from the Earth, to create a balanced and highly optimized artificial fertilizer.

In stark contrast, the traditional methods of agriculture such as organic/ecological/biological agriculture, where Permaculture also falls in, rely on synergies between organisms, building soil health, avoiding industrial pesticides, and/or recycling food waste and/or organic waste as the source of nutrients. All this results in methods that may produce less yields in the short-term compared to intensive agriculture, but are more sustainable in the long-term as they are not depleting the essential resource which is topsoil, and actively prevent its erosion and pollution.

Soilless cultivation, on the other hand, can be divided into two main categories: Mineral Hydroponics and Organic Hydroponics. Mineral hydroponics relies on extracting non-renewable minerals from the Earth and creating nutrient solutions out of them. Mineral hydroponics is also the most common and practiced type of soilless cultivation, with the earliest experiments dating back as early as the 17th and 19th centuries, with more scientific interest in the 1940s, and a popular renaissance in the 1970s.

Within mineral hydroponics, we can further divide it into two sub-categories: Active Mineral Hydroponics and Passive Mineral Hydroponics, with the key difference being whether or not there is energy used to actively recirculate and aerate the nutrient solution (through the use of water and air pumps).

Within organic hydroponics, we can further divide it into into three sub-categories: Aquaponics, Bioponics, and Anthroponics. Aquaponics is the combination of recirculatory aquaculture systems with hydroponics, where typically fish are fed with fish feed from marine environments, and their excretions are converted via beneficial bacteria to plant-available nutrients, which are absorbed in the hydroponic component, returning cleaner water to the aquaculture component. Bioponics and Anthroponics follow a similar concept, except relying only on the beneficial bacteria and hydroponic component. In the case of bioponics, typically organic or food waste is converted to plant-available nutrients, and in the case of anthroponics, typically human waste, like urine, is converted to plant-available nutrients.

4. Active Mineral Hydroponics

As the name suggests, the term "active" signifies the continuous movement and circulation of the nutrient-rich solution, ensuring plants receive a steady supply of essential minerals and environmental conditions for optimal growth.

The defining features include:

- Recirculation: This ensures that plants have uninterrupted access to nutrients, while also promoting water conservation through reuse.
- Aeration: With plants' roots submerged in water, maintaining adequate oxygen levels becomes paramount. Active systems often employ air pumps with air stones to introduce dissolved oxygen, preventing root rot and to ensure that roots can efficiently absorb nutrients.
- System Design: The design of active hydroponic systems can vary, from deep water culture setups where plants float atop the nutrient solution, to nutrient film techniques where a thin film of nutrient solution flows over the roots, to ebb and flow media beds, where the roots are flooded with water then drained in a consistent way, usually with the help of siphons or timers.

A "window garden" design. Photographs taken in Lund, Sweden by the author in 2015.

The appeal of active mineral hydroponics lies in its precision and control. Growers can closely monitor and adjust nutrient concentrations, pH levels, and oxygenation, allowing for fine-tuning of the growing environment. Growing indoors, they also gain more control over lighting, temperature, humidity, and pest management. This method, while more resource-intensive than other hydroponic techniques, offers a high degree of reliability and predictability, making it a preferred choice for many commercial operations and enthusiasts seeking consistent yields and quality.

5. Passive Mineral Hydroponics

Passive Mineral Hydroponics emphasizes simplicity and reduced intervention, initially born from a desire to reduce energy and labor.

A passive system growing a variety of plants vertically. Photographs taken in Lund & Malmö, Sweden by the author throughout 2019-2023.

Unlike its active counterparts, which rely on continuous recirculation and aeration mechanisms, the full nutrient solution, rich in essential minerals, is prepared and provided to plants without the need for active circulation or external aeration. The plants, in turn, absorb these nutrients at their own pace.

A hallmark technique within this category is the Kratky method. Developed and refined by Dr. B.A. Kratky, it essentially allows plants to grow in a static nutrient solution, with no pumps, no electricity, and minimal monitoring. As the plants grow, they consume the nutrient solution, and the decreasing water level provides increasing amounts of moist-rich air to the root zone, ensuring they do not become oxygen-deprived.

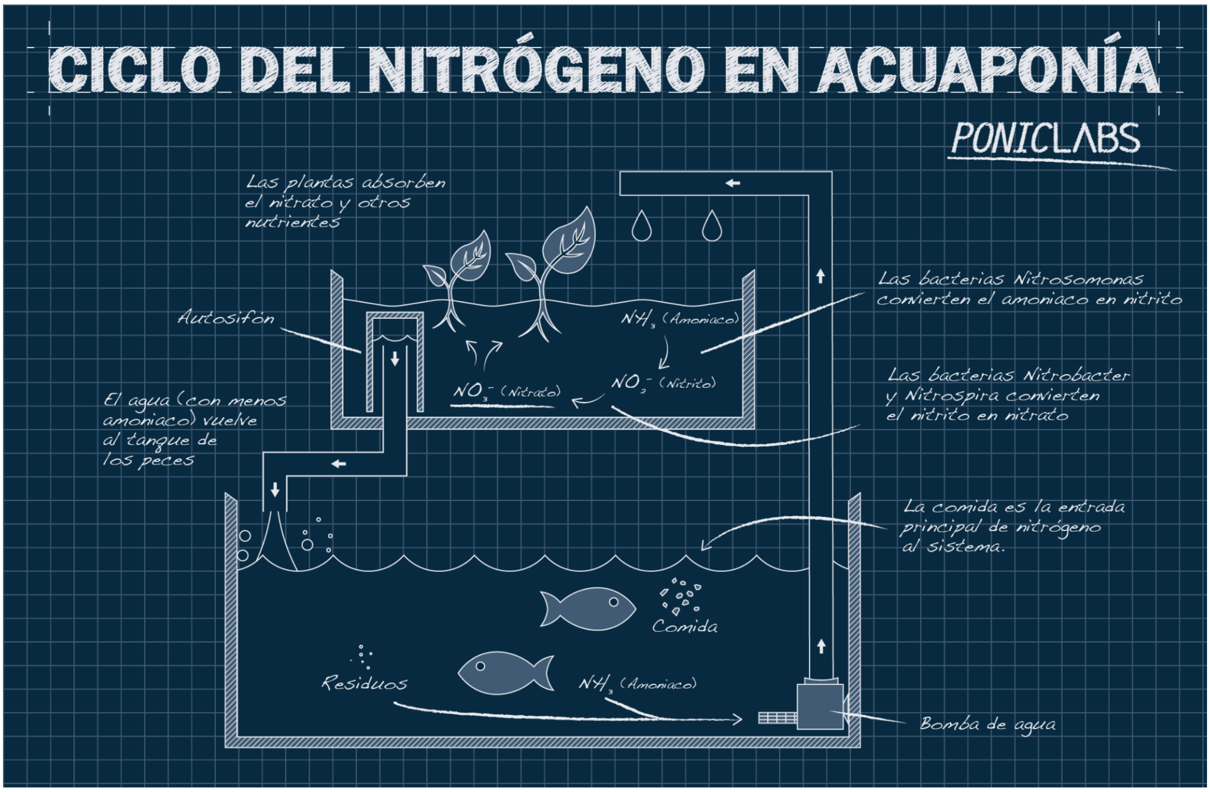
The allure of passive mineral hydroponics lies in its accessibility. Its low-tech nature makes it an attractive option for regions with limited access to electricity or advanced equipment.

Exemplifying the low-tech nature of passive hydroponics. Photographs taken in Lund & Malmö, Sweden by the author throughout 2015-2023.

However, despite less energy used in the operation of these hydroponic cultivations, the problem persists that the nutrient source itself, the mineral fertilizer, is highly unsustainable and extractive.

6. Aquaponics

Aquaponics aims to couple hydroponics and aquaculture into a unified, and more sustainable, recirculatory constructed ecosystem. This method uses the waste produced by aquatic organisms as a nutrient source for plants through the aid of beneficial bacteria, plants which in turn purify the water for the aquatic organisms.

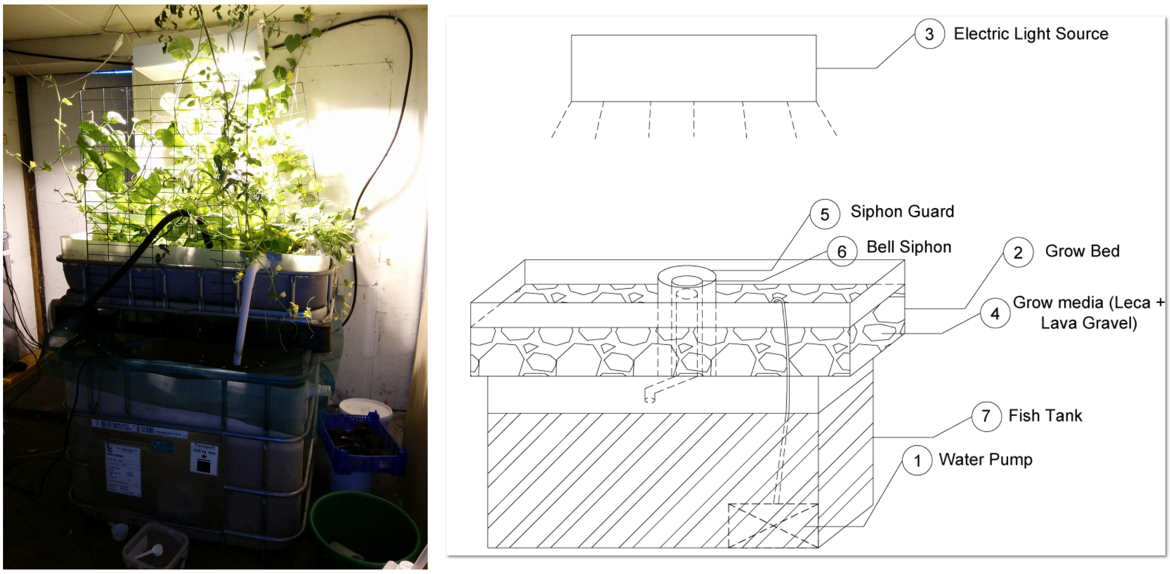


A Spanish illustration of the main components of an aquaponic system and the nitrogen cycle. Image featured from the Aquaponics course by Poniclabs.

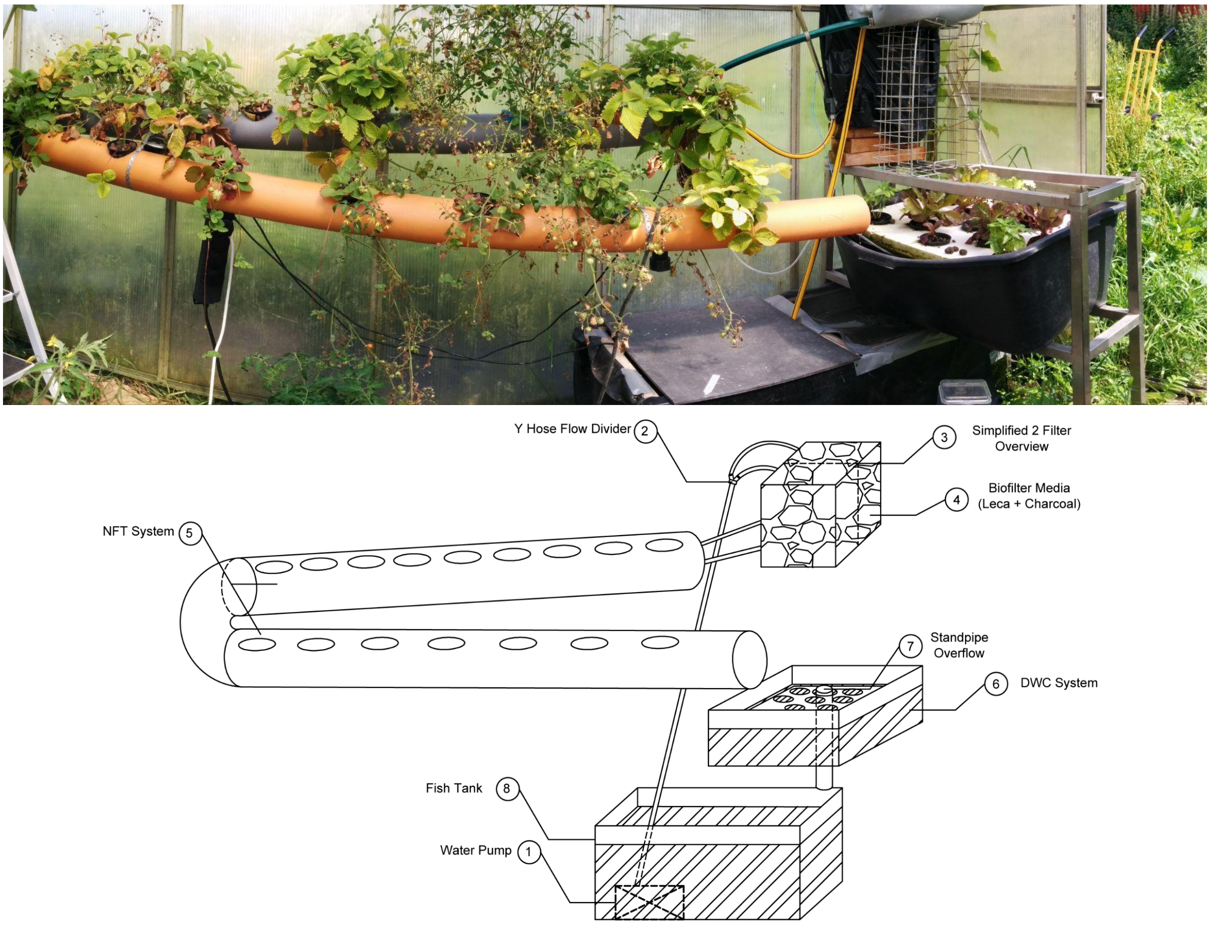
Key components of an aquaponic system include:

- Aquatic Organisms: Commonly, fish are the primary aquatic residents in these systems, though other organisms like prawns or snails can also be incorporated.
- Biofilter: Crucial for converting ammonia from animal waste into nitrates, which act as nutrients for the plants. This conversion, facilitated by beneficial nitrifying aerobic bacteria, ensures the water remains non-toxic for the aquatic inhabitants.
- Hydroponic Component: Here, plants grow, absorbing the nitrates and other nutrients from the water, essentially purifying it before it is recirculated back to the aquatic environment.

The beauty of aquaponics lies in its closed-loop nature (though decoupled systems are also possible and sometimes desirable). Water is continuously recycled, leading to significant conservation compared to traditional farming methods. Moreover, since the nutrients are derived from animal waste, there's little need for additional fertilizers, making the system organic and sustainable.



An indoor aquaponics system, and its diagram, as featured in the MSc thesis: "[Aquaponics and its potential aquaculture wastewater treatment and human urine treatment]" (Sánchez, 2014).



A greenhouse aquaponics system, and its diagram, as featured in the MSc thesis: "[Aquaponics and its potential aquaculture wastewater treatment and human urine treatment]" (Sánchez, 2014).

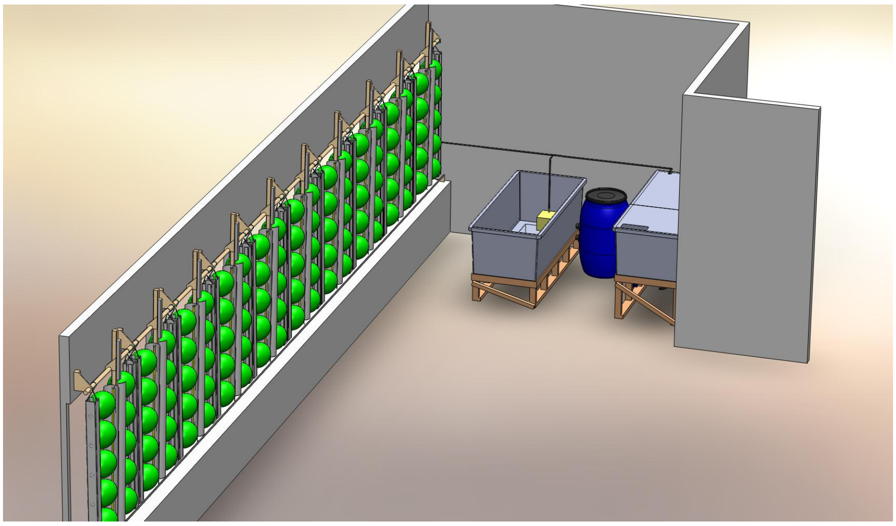
Challenges do exist, such as maintaining a balance between the nutrient production (from animals via their feed) and nutrient absorption (by plants). Yet, with careful monitoring and management, these systems can yield bountiful harvests of both crops and aquatic animals.

An indoor small aquaponic system. Photographs taken in Lund, Sweden by the author throughout 2014-2015.

The remaining challenge in terms of sustainability, however, comes in the source of the nutrient inputs. Unlike mineral hydroponics, where they are mined from the Earth, here the nutrients originally come from the fish feed, which is almost exclusively extracted from marine environments, thus contributing to overfishing and the depletion of marine populations. While alternative land-based feeds are being explored within the recirculatory aquaculture industry, so far they have not been able to fully replace marine sources of feed. Additionally, aquaponic systems must always rely on active water movement and water aeration due to the metabolic requirements of its aquatic animals. As a result, aquaponics is limited in its degree of sustainability.

7. Commercial Aquaponics

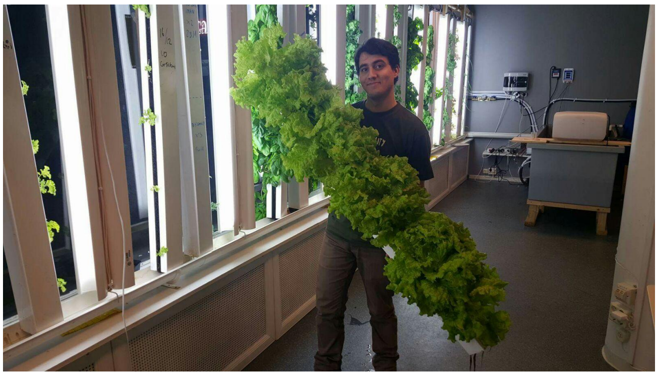
The author has also had the privilege to be directly and heavily involved in the design, dimensioning, building, and operation of Sweden's first CSA (Community Supported Agriculture) Vertical Indoor Aquaponics System pilot project, which operated in Malmö, Sweden between 2015-2019. The project was made possible by direct financing and support as well as collaboration between Sten K Johnsons Stiftelse, the city of Malmö, and the NGO Hemmaodlat and its members.



Early 2015 3D-schematic of the overall design done by Hemmaodlat, and a picture of the window-facing office space where the pilot was located, taken by the author in Malmö, Sweden in 2016.

This pilot, with a total of 20 vertical towers (each supporting up to six plants) and a combined water volume of ~1.8 m^3 to support 30 tilapia, allowed the cultivation of a substantial amount of produce within a small office space.

Two pictures inside of the CSA Aquaponics pilot, taken by Hemmaodlat members in Malmö, Sweden throughout 2015-2019.




Two pictures featuring the author holding towers with lettuce, taken by a Hemmaodlat member in Malmö, Sweden throughout 2015-2019.

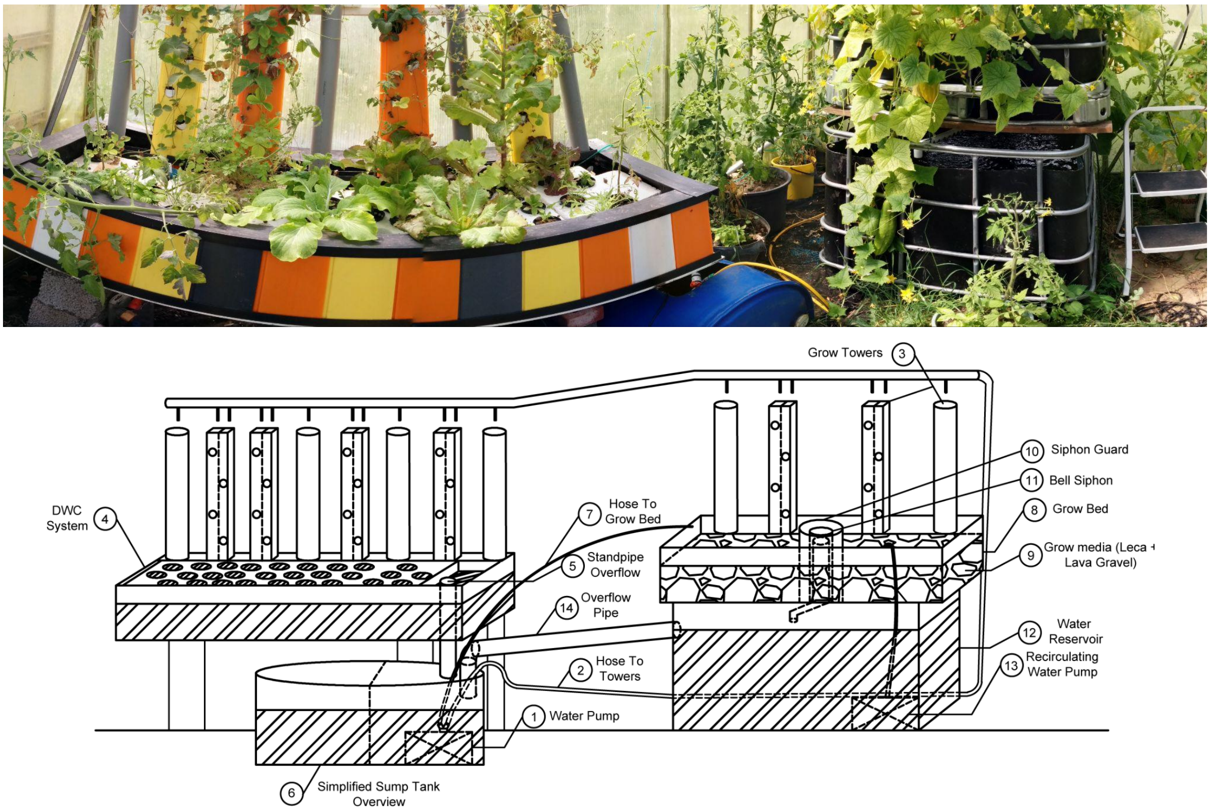
The pilot was operated as a Community-Supported Agriculture (CSA) system, with a capacity to support up to 10 customers, but in practice supporting 4-5 regular customers. The most commonly grown crops included: Lettuce, chard, pak choy, basil, oregano, sage, parsley, coriander, cabbage, spinach, and chives. Each week, each customer would receive a bag with: one full head of lettuce, one full chard, a bundle of basil or other herbs, and one extra plant, for an approximate cost of ~200 SEK/week.

Pictures of the harvested crops and customer bundle, taken by Hemmaodlat members in Malmö, Sweden in 2016.

Ultimately, the pilot showcased the ability to grow food in an indoor urban setting in a cold climate, and with minimal oversight (operational tasks were done twice or thrice a week). A video with more details of this project can be viewed [here](#).

8. Anthroponics

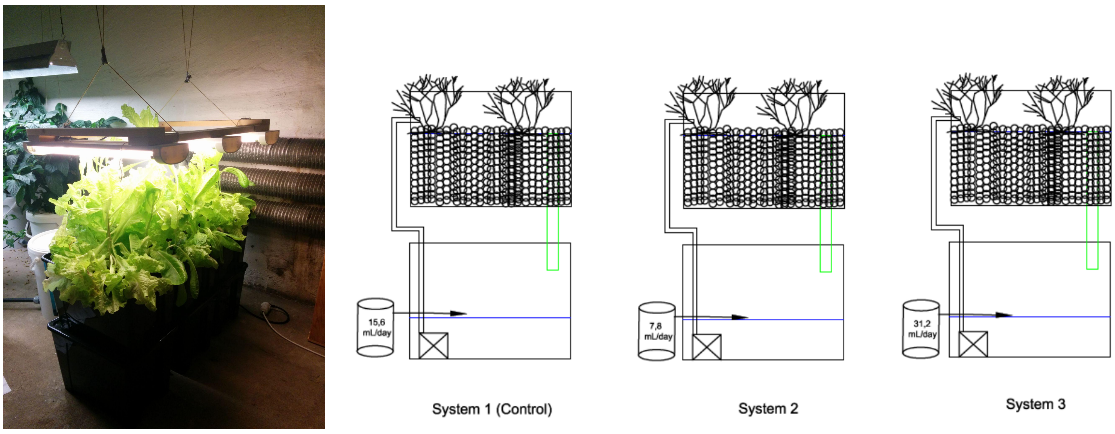
At its core, Anthroponics utilizes human waste, such as urine, as a primary source of nutrients for plants, after suitable processing and treatment to ensure safety. In terms of design and principles, it is similar to aquaponics, except that it skips the aquatic animals, instead focusing solely on the relationship between beneficial bacteria and plants.



A greenhouse anthroponics system, and its diagram. Images as featured in the MSc thesis: "[Aquaponics and its potential aquaculture wastewater treatment and human urine treatment](#)" (Sánchez, 2014).

Key features of anthroponics include:

- Resource Efficiency: By recycling human waste, anthroponics reduces the dependency on commercial fertilizers, making it both more sustainable and cost-effective.
- Safety Protocols: Given its unconventional nutrient source, safety is paramount in anthroponics. The urine undergoes a treatment process to eliminate harmful pathogens before being introduced to the system.
- Closed-loop System: Similar to other hydroponic methods, anthroponics operates as a closed-loop system, conserving water and nutrients, while continuously recycling and reusing them.
- Sustainability: Beyond its agricultural benefits, anthroponics offers a solution to the challenge of waste management, transforming what's often seen as a waste product into a valuable resource for food production.



Three indoor anthroponics systems cultivating lettuce, and their diagrams. Images as featured in the Technical Report: "[Lactuca Sativa production in an anthroponics system](#)" (Sánchez, 2015).

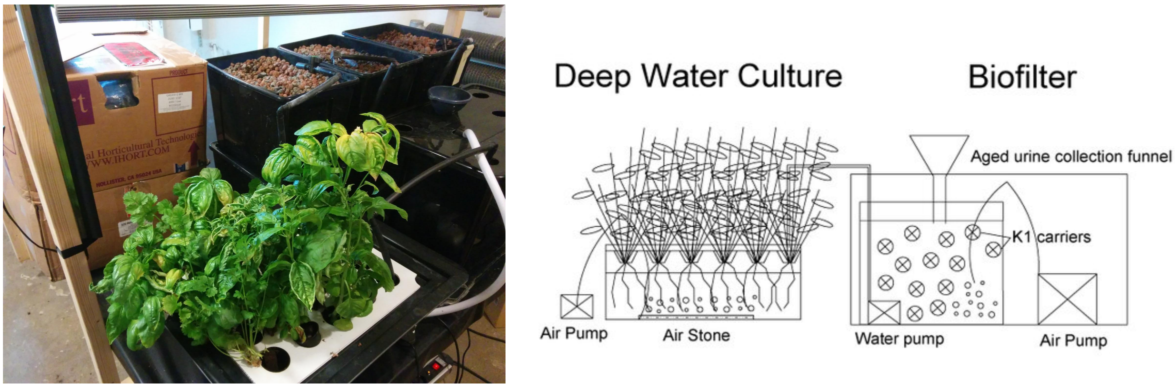
As with other hydroponic techniques, the systems can vary in their design and can be optimized to use less energy.

An indoor anthroponics system cultivating leafy greens. Photos taken by the author in Malmö, Sweden throughout 2017-2019.

Close-up of the NFT anthroponics system's MBBR (left) and the airlift system out of the MBBR for inspection (right).Photos taken by the author in Malmö, Sweden in 2017.

9. Decoupled Anthroponics

Decoupled Anthroponics is practically equal to conventional anthroponics, except that there is no constant recirculation of water, and instead the biofilter component (hosting the beneficial bacteria) is physically separate from the hydroponic component.



An indoor anthroponics system cultivating herbs, and its diagram. Images as featured in the Technical Report: "Ocimum basilicum and Coriandrum sativum cultivation in a decoupled anthroponics system" (Sánchez, 2016).

While there is no constant recirculating water, in practice the energy use is likely higher due to the need for two air pumps running continuously (though this could likely be optimized further). This was an important proof-of-concept to showcase that anthroponics cultivation (a type of organic hydroponics) could be performed in a deep-water culture technique.

10. Bioponics

Bioponics emphasizes the utilization of organic inputs and living organisms to nourish plants. This method transcends the traditional use of mineral-based nutrient solutions, focusing instead on using a thriving microbial ecosystem that facilitates nutrient absorption by plants.

An indoor bioponics system cultivating leafy greens, with the nutrient source being vermicompost leachates. Photos taken by the author in Malmö, Sweden in 2018.

Key aspects of bioponics include:

- Organic Nutrient Sources: Bioponics relies on organic materials, such as compost teas or liquid composts, or vermicompost leachates (to name a few), to provide plants with the essential nutrients they require for growth.
- Microbial Activity: Central to bioponics is the role of beneficial microbes. These microorganisms break down organic matter (either before adding to the system or during operation), converting it into a form that plants can readily absorb.
- Natural Ecosystem: Mimicking natural soil environments, bioponic systems can foster a diverse community of microorganisms, ensuring a balanced and self-regulating nutrient cycle.
- Sustainability: By harnessing nature's processes and eliminating the need for synthetic fertilizers, bioponics aligns closely with sustainable and organic farming principles.

An indoor bioponics system cultivating basil with the nutrient source being dried vermicompost powder. Image as featured in the Technical Report: "Cultivating Ocimum basilicum in a hydroponics deep-water culture (DWC) system using dried vermicompost powder as the nutrient source" (Sánchez, 2019).

Interestingly, it was found that drying vermicompost soil and then crushing it to a dry powder could also be used as a source of nutrients in a deep-water culture setting, whether the resulting nutrient solution was aerated or not.

Two indoor bioponics systems cultivating radishes with the nutrient source being dried vermicompost powder. Photos taken by the author in Limhamn, Sweden, in 2020. [Video]

An indoor bioponics system cultivating leafy greens and herbs with the nutrient source being green waste biogas slurry supernatant after centrifugation. Image as featured in the Technical Report: "Using green waste biogas slurry as nutrient source for a NFT hydroponics system combined with an MBBR" (Sánchez, 2022).

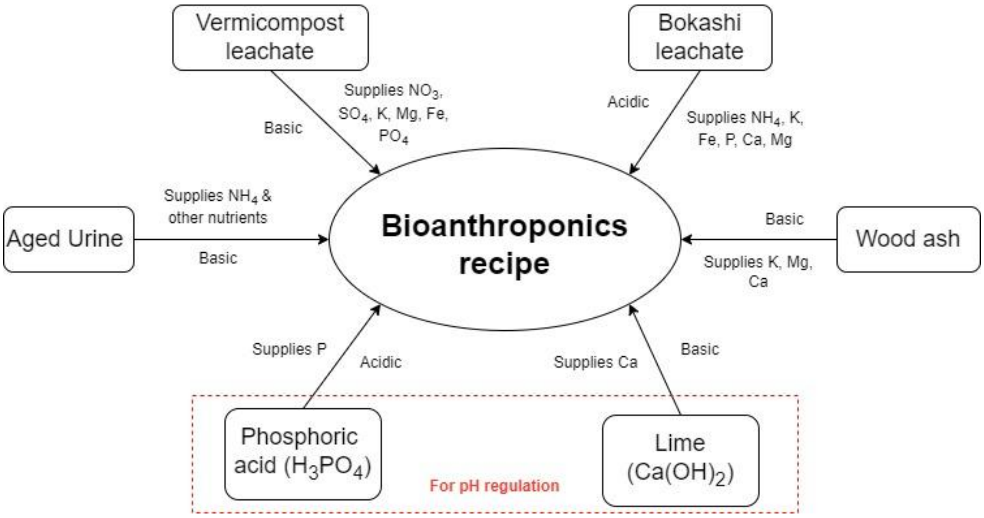
Bioponics bridges the gap between traditional soil-based organic farming and hydroponics, offering a method that is both technologically advanced and ecologically harmonious, flexible in its nutrient sources, and focusing on recycling nutrients from waste sources rather than extracting them.

11. Bioanthroponics

"Bioanthroponics" theorizes the intersection of bioponics and anthroponics, attempting a holistic method that integrates organic inputs and human-derived nutrients into a singular, sustainable system, providing a full range of necessary macronutrients and micronutrients.

Two indoor and passive "bioanthroponics" systems cultivating basil, with the right system using the Media Bed based technique,and the left system using Dr. B.A. Kratky's "pot-in-pot-in-tray" technique to reduce media amount, with the nutrient source being a mix of different organic outputs. Photo taken by the author in Lund, Sweden, in 2022.

As different nutrient deficiencies had been observed in some types of anthroponic and bioponic systems alike, it was theorized that combining both in a biofilter with beneficial bacteria and aeration, and correcting the resulting nutrient solution for pH, would achieve a more balanced organic nutrient solution for hydroponic use.



Crude diagram explaining the different inputs of the trialed "bioanthroponics" recipe

12. OikoSol Project

The Oikosol Project, initiated in 2014, aimed to create free downloadable instructions for anyone to build "DIY-style" technologies in the realm of energy production, food cultivation, water capture and filtration, wastewater treatment and reuse, and transportation.

OikoSol

Current OikoSol logo, created by the author in 2016.

Mission Statement:

We believe in the development of affordable decentralized sustainable technologies, to enable ourselves and other interested individuals worldwide to gain more control and independence in their manufacturing power, their energy source, their food and water source and in their waste and wastewater treatment.

Such control and independence is necessary as we believe in the right to self-sufficiency, regardless of its consequences to existing power structures and distribution networks. We believe that only when every individual has fulfilled their basic physical needs can they be free to peacefully cooperate with others from a position of equal power. We aim to create a repository of knowledge of localized sustainable technology, where everyone is welcome to spread, debate, criticize and improve on sustainable home technologies of the OikoSol repository.

The end-goal will be to provide free DIY instructions that allow for most individuals or families, living in houses or apartments, to become as much energy, food & water, waste and transport independent as possible. The technologies in the instructions should be as conducive to life overall as possible, as well as affordable for all individuals globally.

How OikoSol technology links together

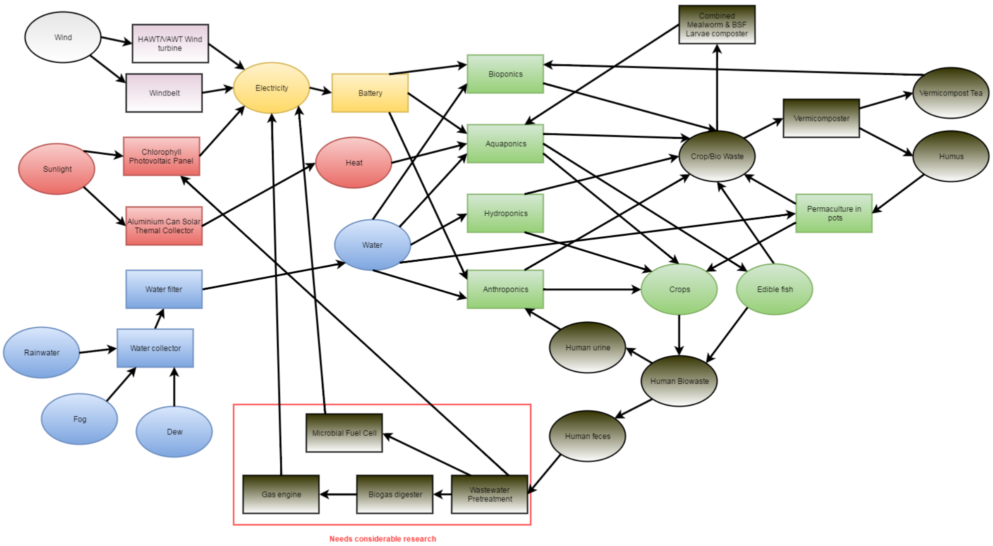
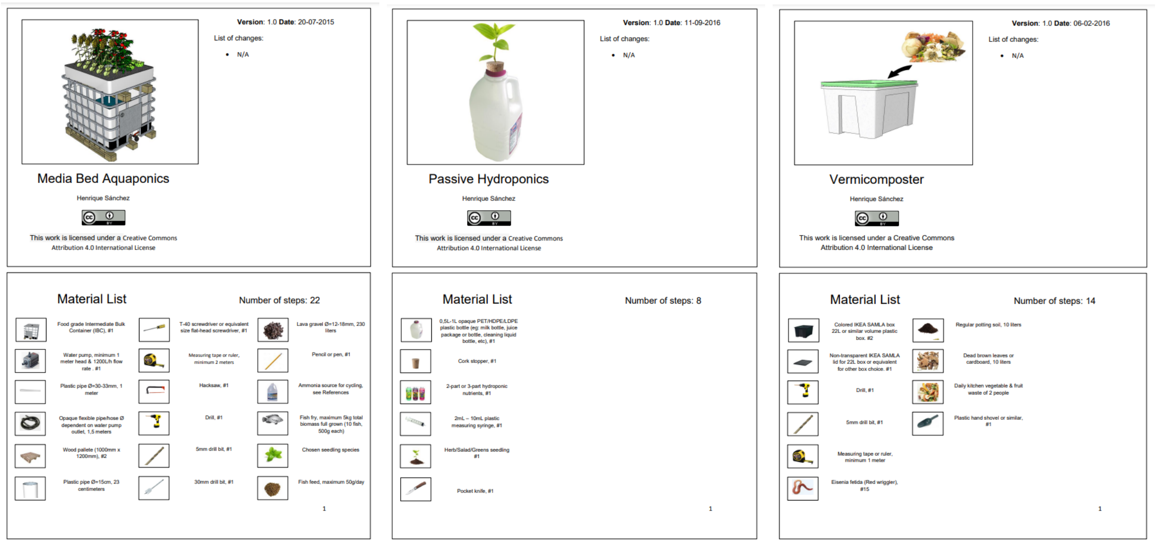


Diagram envisioning different potential technologies to be developed as instructions and how they connect with each other, created by the author in 2017.

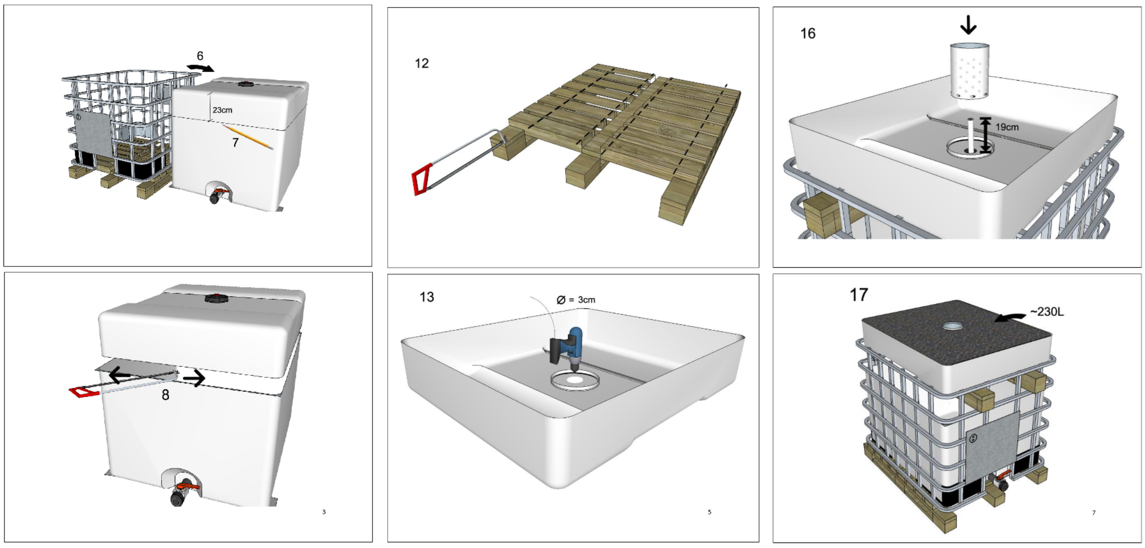
The main target categories (Food, Energy, Water, Waste, Transport) were selected to achieve self-sufficiency. From then, the idea was to create a platform for community discussion, where members can collaborate on researching the potential technologies, their development, and finally write the instructions and iterate on them, with complete transparency at each step, and sharing all the material generated.

Central to the goal was the focus on low-tech solutions, working with the limitations of existing common materials or even waste, in order to create affordable and approachable technologies that would be appropriate for the setting and the goals. These technologies could be rain-harvesting systems, air-heaters made from cans, homemade wind turbines, to name a few.

The instructions themselves needed to be simple to understand, visually explanatory, and with little text so as to make it easy to translate and iterate on. The first page features a render of the design, the version of the instruction (and a list of changes if this version is an iteration), the date of publishing, the author, the Creative Commons License disclaimer, and a material list followed by the number of steps. In the last page, there is a section of known issues to be fixed in future iterations, and a reference list for further understanding of the technology.

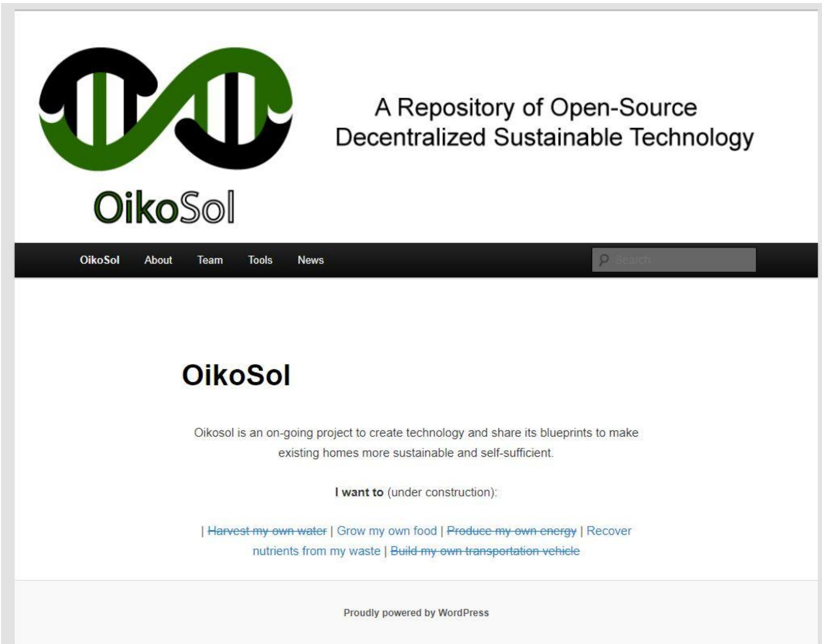


First page of three OikoSol's instructions: [Media Bed Aquaponics]() (2015), [Passive Hydroponics]() (2016), and [Vermicomposter]() (2016).

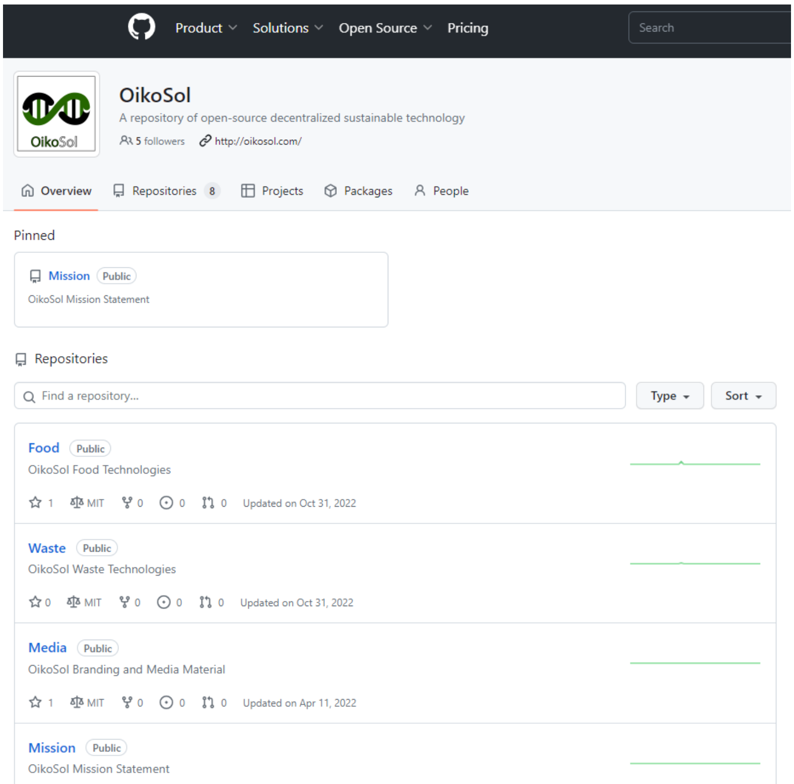


Example of the step-by-step image guides within the [Media Bed Aquaponics]() (2015) instruction.

Initially the project had a goal of a simple website and homepage to navigate its contents. However, after a cybersecurity attack in 2018, the goal shifted to first producing the material and host it publicly on GitHub before focusing on a user-friendly interface.



Original homepage of the OikoSol website, before being attacked and taken down by a botnet in 2018.



Present hosting of the OikoSol content and the domain "oikosol.com"

Currently, the main hub of discussion is in the official Discord page, open for anybody to join and contribute.

QR-code and link to access the ongoing OikoSol discord: https://discord.gg/zZhRvzXgpx