Fogponics in the Loop: Developing and Testing a Nutrient Delivery System for Bioregenerative Lunar Agriculture

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Who am I?

Siert Hamers

BSc. Mechanical Engineering - TU Delft
MSc. Space Engineering - TU Delft
➜ MSc. Thesis - German Aerospace Center (DLR)

Interests

Mechanical Engineering
Plants
Solving Practical Problems

What will I discuss?

-**Nutrient Delivery Systems**

Where are we now?

-**Fogponics**

Definition, the advantages, the technology

-**My Contribution**

The prototype and preliminary results

-**Outlook**

Next steps and future research directions

Nutrient Delivery Systems

Where are we now?

Less Terrestrial Applications

Nutrient delivery systems in lunar agriculture

EDEN ISS

- Lessons learned and new requirements obtained
- To transform into

EDEN LUNA

- A fully integrated analog test facility
- Collaboration DLR & ESA
- Deployment at LUNA analogue facility Cologne

LAM-GTD

- Lunar Agricultural Module - Ground Test Demonstrator
- A full scale, high fidelity, analog test facility of a lunar greenhouse with reduced airpressure (0.7 bar)

Current Nutrient Delivery System

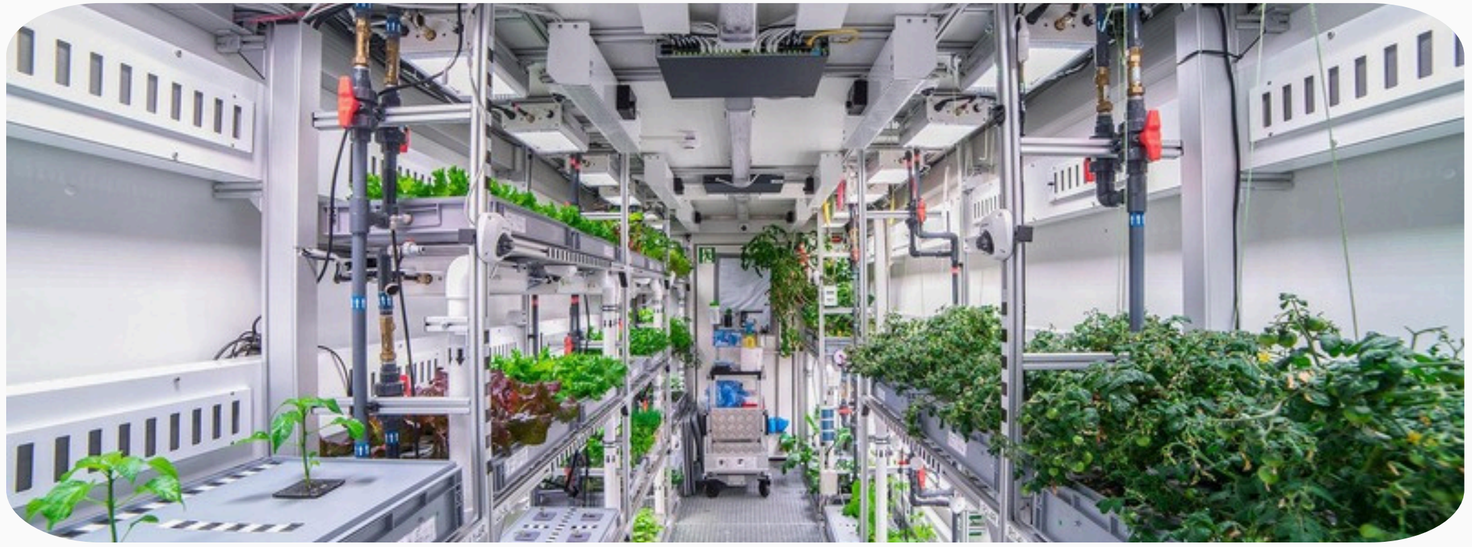


Figure: Image of EDEN- ISS FEG. 40 trays for plant cultivation. Infrastructure for lighting, air management and nutrient delivery.

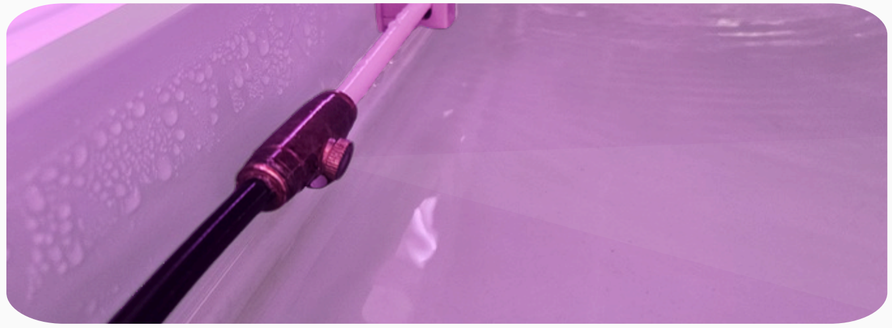


Figure: A *spray nozzle in an aeroponic system.*

Current Nutrient Delivery System

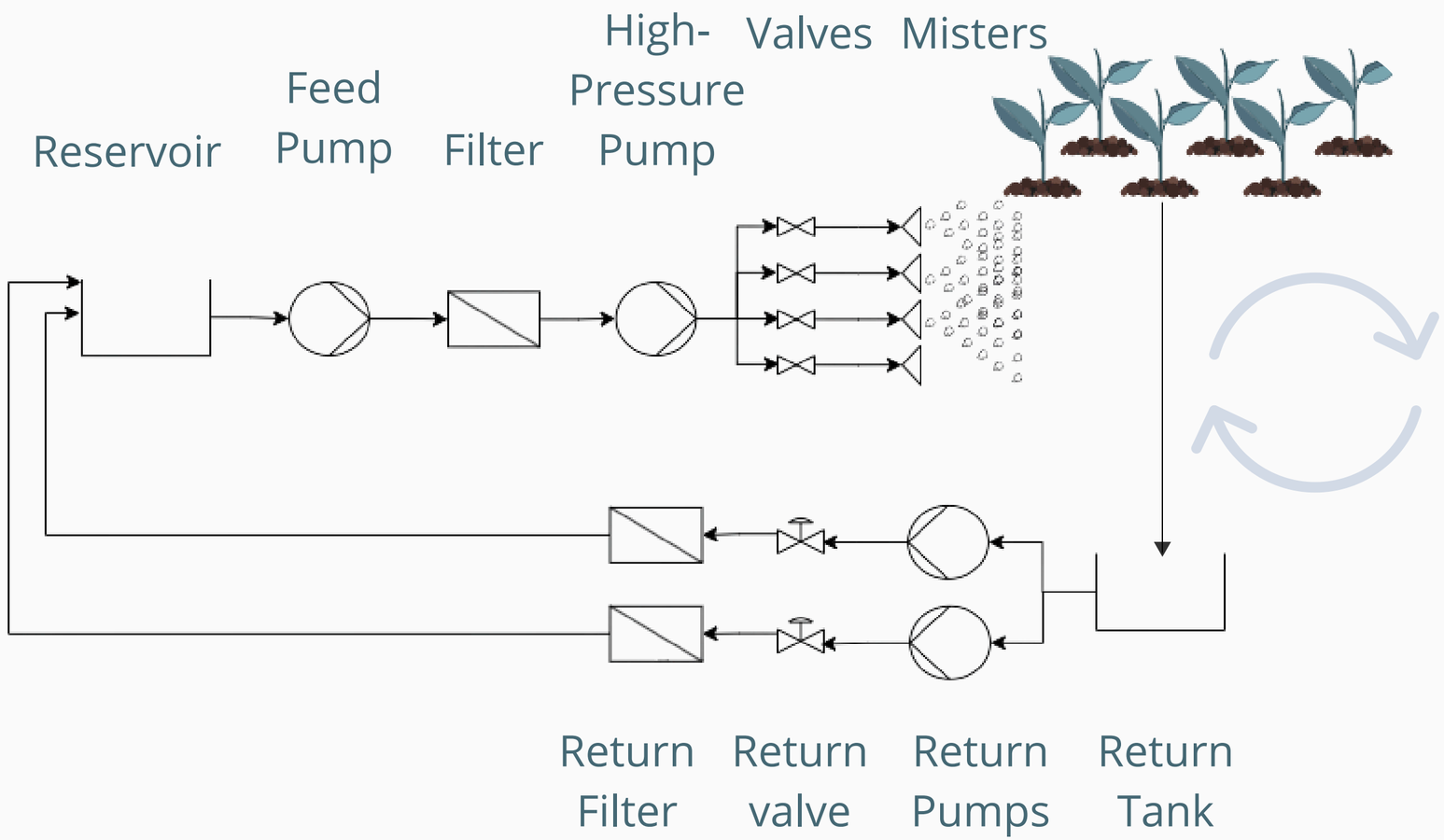


Figure: *Nutrient delivery process in the EDEN facility where excess nutrient solution is recycled.*

Challenges in the Current Nutrient Delivery System

- **High-pressure pumps**
  - Prone to leaks and breakdown → adds system complexity
  - High energy demand
- **Biofilm formation**
  - Nutrient-rich recycled water fosters microbial growth inside tubing and nutrient reservoir
  - Biofilm causes faulty sensor readouts & damages equipment
  - Requires intensive cleaning every ~8 weeks → high crew time
- **Cross-contamination risk**
  - Recycling spreads pathogens between plants
  - Sterilization helps (UV, Ozone,H_2O_2), but risk remains
- **Clogging of nozzles**
  - Caused by solid particles, salts, or biofilm buildup
  - Leads to failures in irrigation and extra maintenance

“How can fogponics be validated as a viable nutrient delivery system, and can its behavior be predicted in lunar greenhouses?”

Fogponics

Definition, the advantages, the technology

What is fogponics?

“Fogponics is a type of aeroponics where plant roots are supplied with nutrients in the form of a fine mist created at ultrasonic frequencies.”

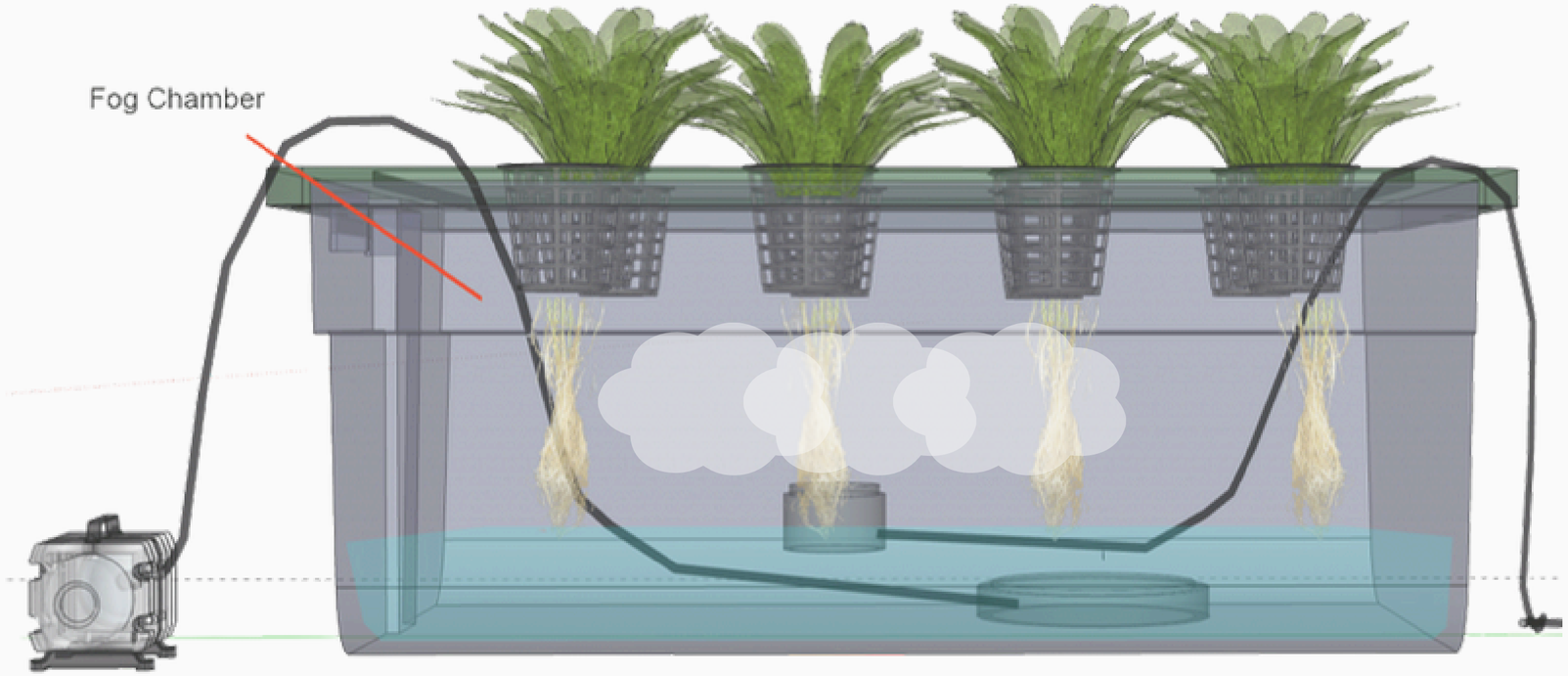
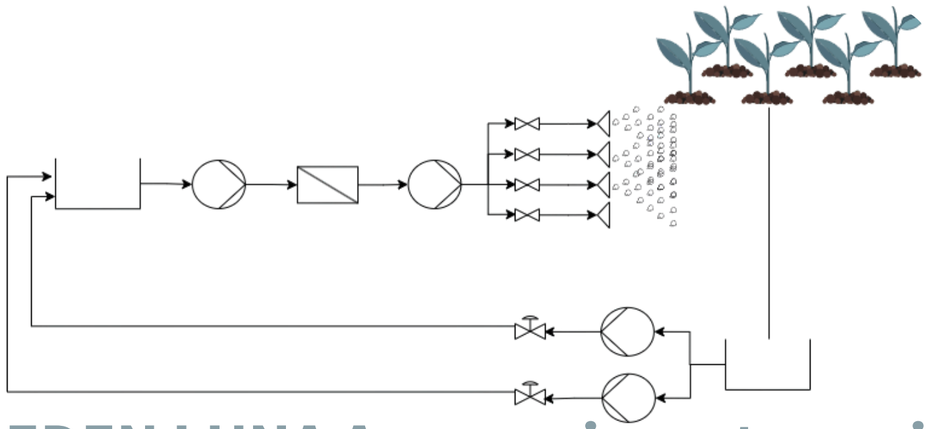


Figure: Schematic drawing of an example of a fogponic nutrient delivery system (NDS). Where a mister creates fog and an aerator provides oxygen to the nutrient solution.

Advantages of fogponics



EDEN LUNA Aeroponic system with nutrient recycling

From Circular to Linear

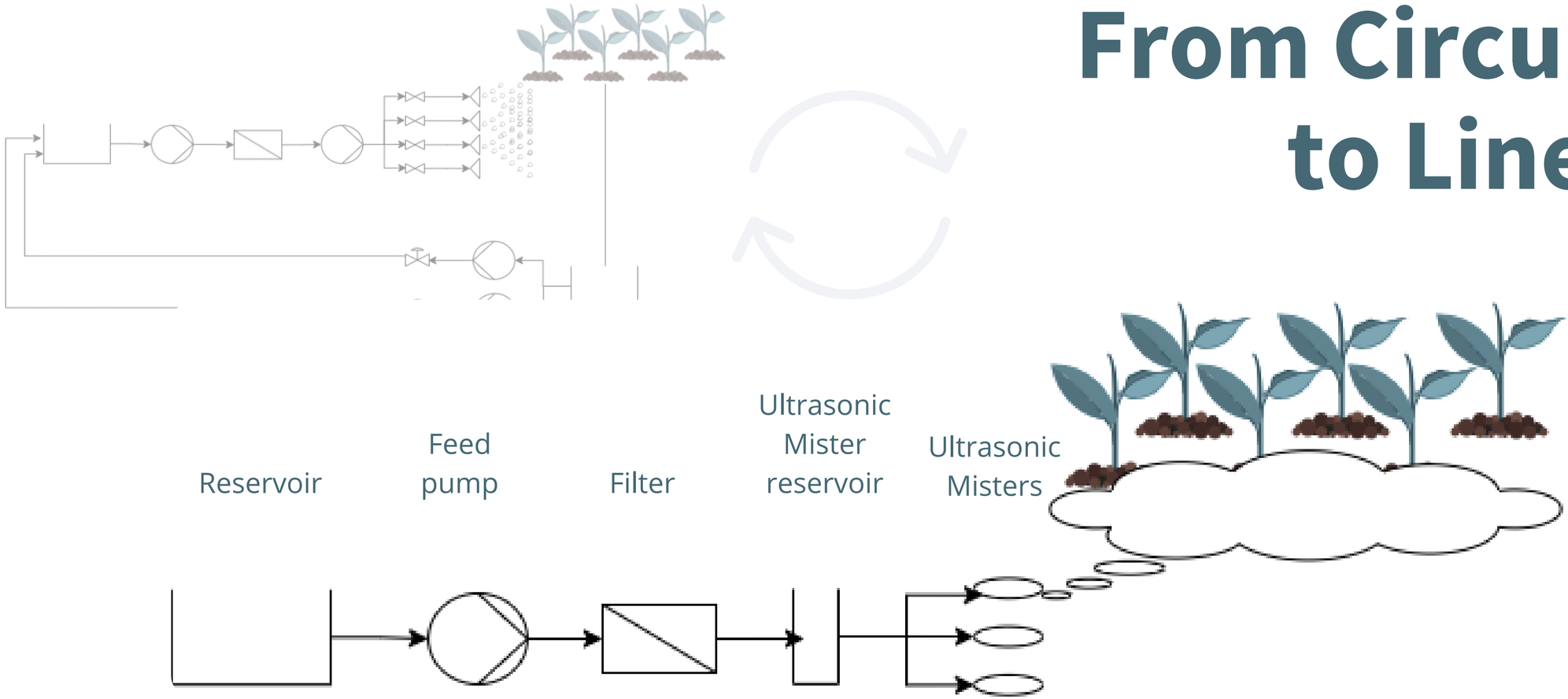


Figure: *Nutrient delivery process by fogponics. Nutrient supply from reservoir to end tray where the excess water is internally recycled back to the misters.*

Expected Advantages of Fogponics

Mass

EDEN LUNA NDS - Fogponics NDS

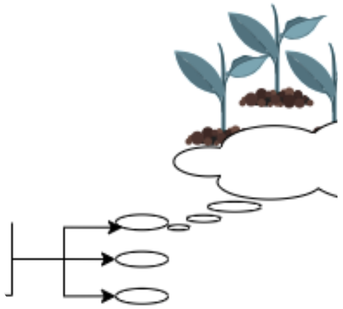
303.93 kg ⟶ **204.4 kg**

Power

EDEN LUNA NDS - Fogponics NDS

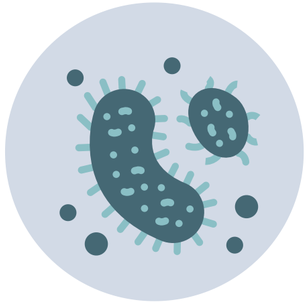
882 W ⟶ **248 W**

Expected Advantages of Fogponics



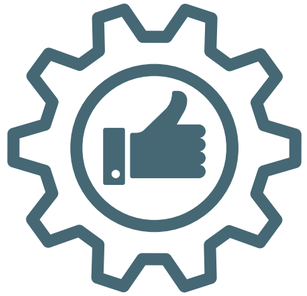
Less Complexity, less mass

No need for high-pressure pumps, tubing, valves, nozzles and drain.



Reduced Biofilm

Potentially no need for sterilisation due to the one way stream of nutrients.



Resource efficient

Potentially less energy, less crew time for maintenance.

Fogponics technologies

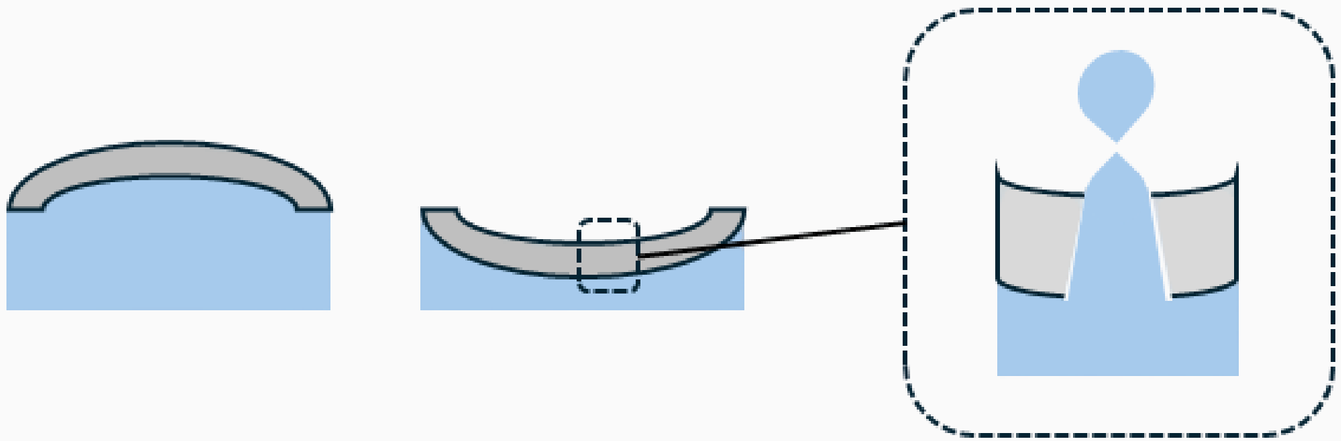
(1) Submerged Ultrasonic Atomizers (MHz range)

(2) Vibrating Horn Atomizers (kHz range)

(3) Vibrating Mesh Atomizers (kHz range)

Vibrating Mesh Atomizers

An energy effective way of atomization



Working Principle

My Contribution

The objective, the prototype and preliminary results

Challenges in Validating Fogponics as a Viable Option

Optimal droplet size

Droplet size in the range of 20 to 50 um.

Stable nutrient solution parameters

Measure pH, EC and Temperature with a higher frequency over the full growth cycle

Implementation in a larger system

Compare the performance metrics to the conventional aeroponics system

Prototype Design

A technical drawing of the implementation with the prototype as experimental setup.

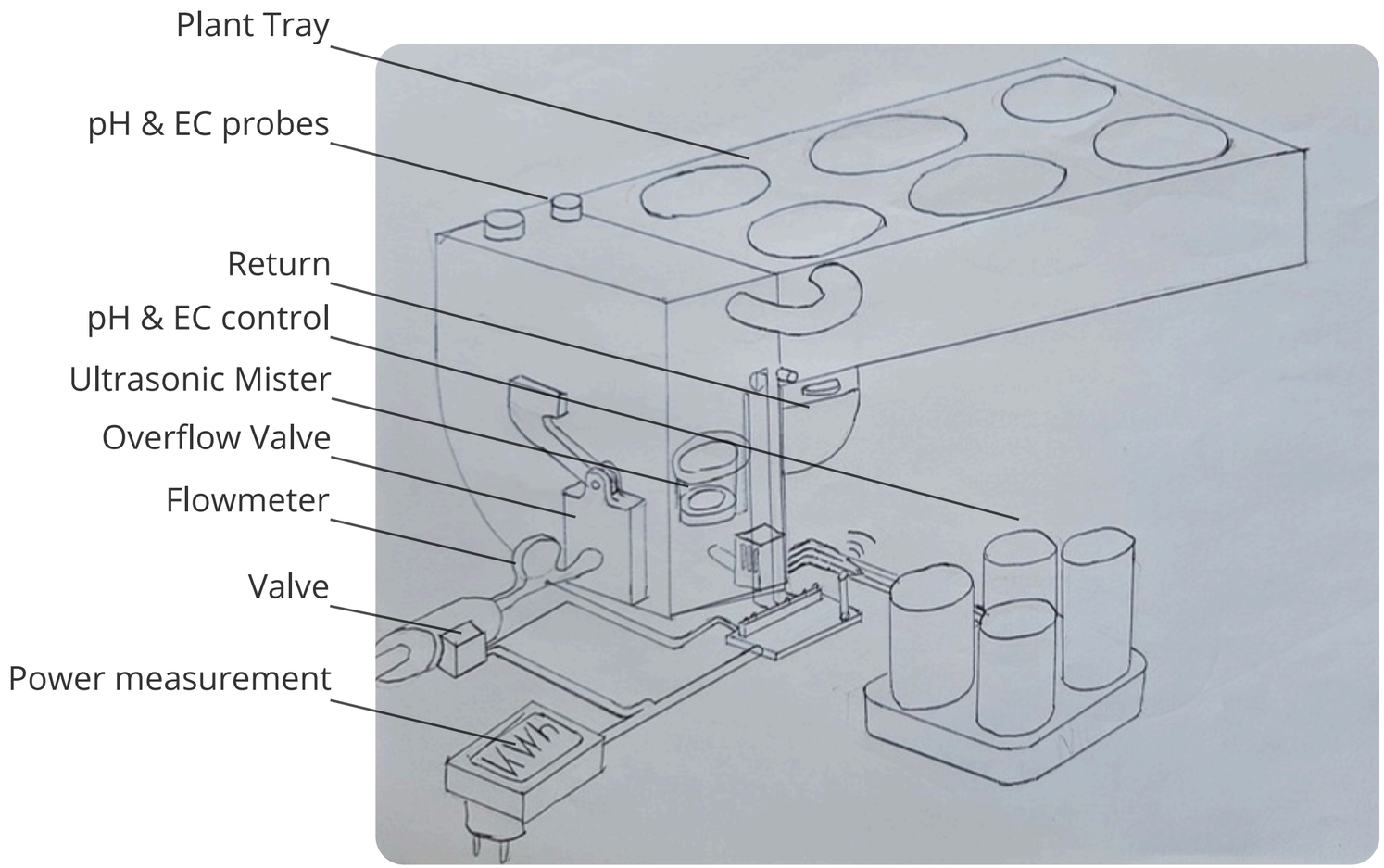
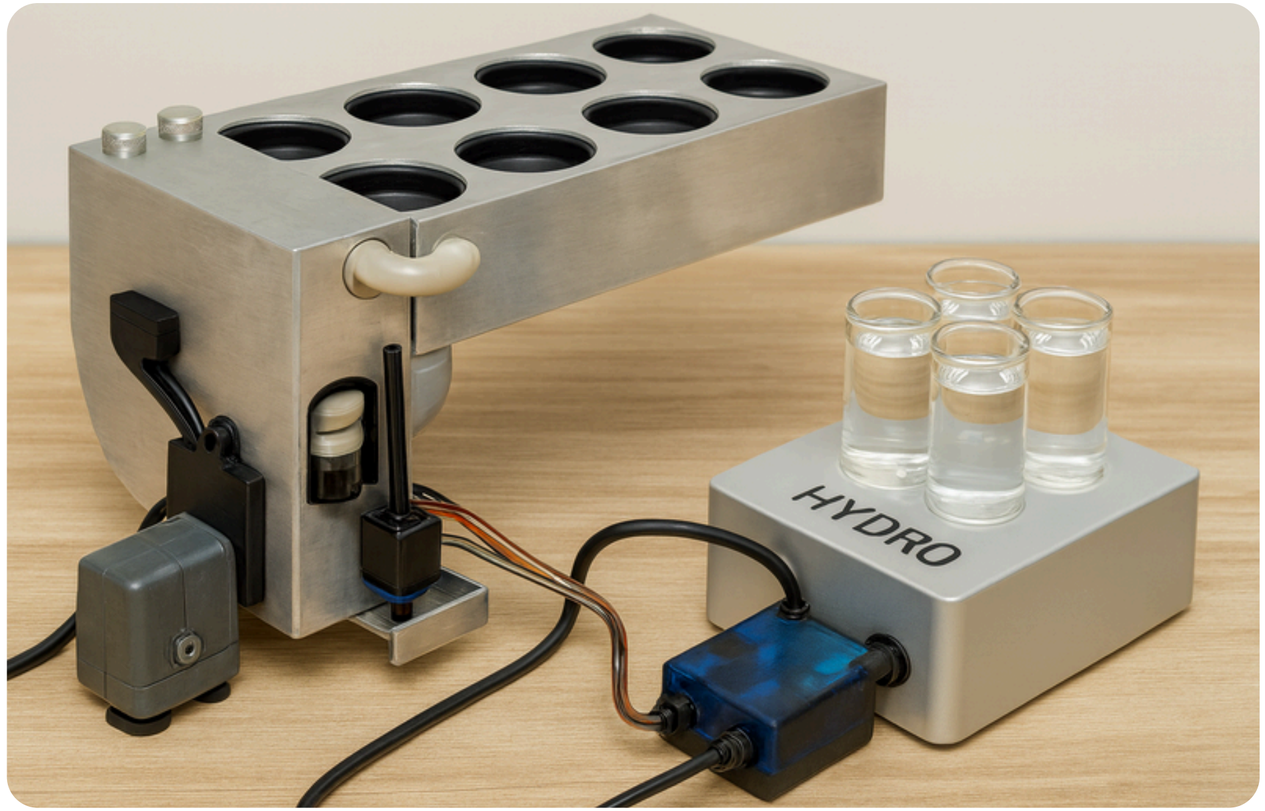


Figure: Prototype design fogponics system.

Interpretation by chatGPT of the drawing



Prototype Testing

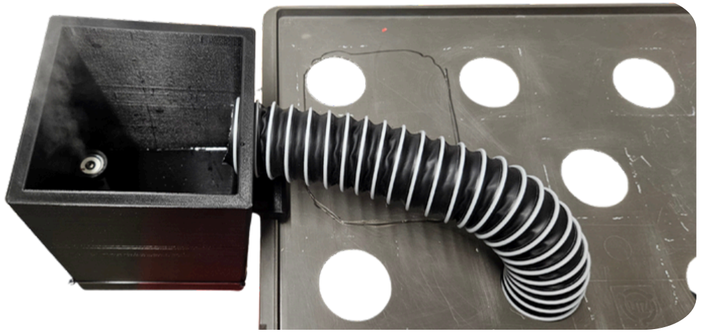


Figure: First prototype top view. Reservoir with fog producing module and supply tube to the plant tray.

Figure: Side view First prototype. Reservoir with space for pH and EC probes in the lid. Full view of the plant growth tray

Prototype Development

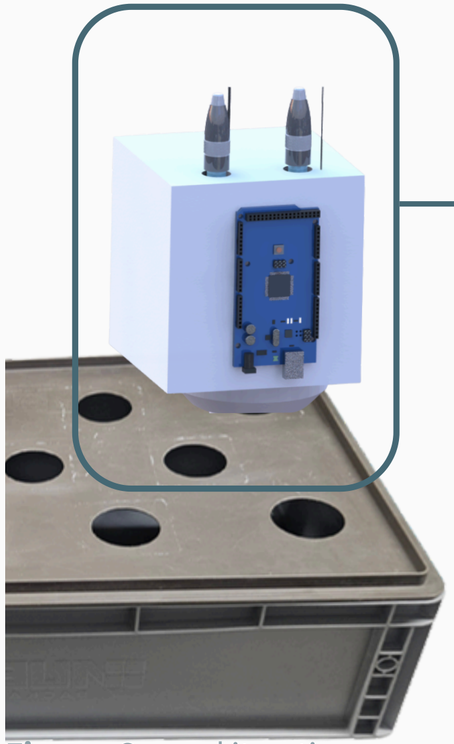


Figure: Second iteration prototype fogponics system implementation in growth tray.

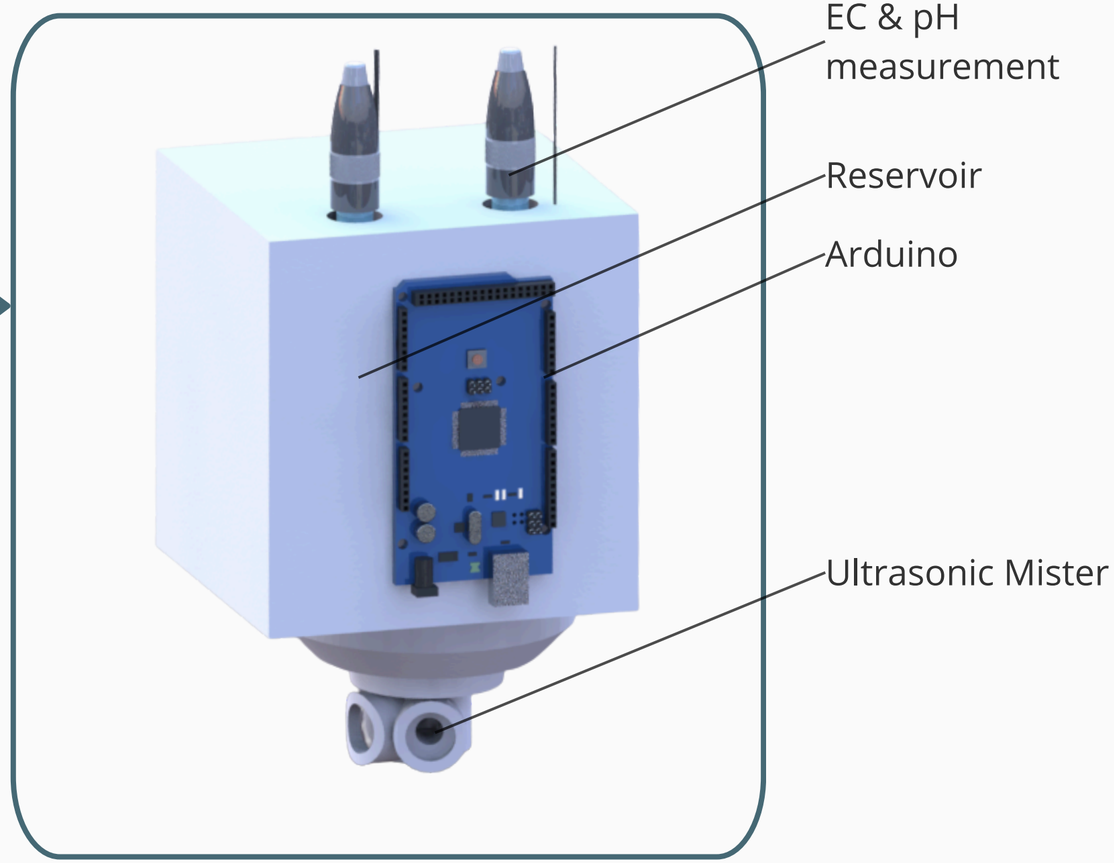


Figure: Second iteration prototype fogponics system.

Flow rate Measurement Experiment

- 4 different atomizers
- 5 minutes on by arduino count
- Measure vaporization
- How quickly does the tray fill up?

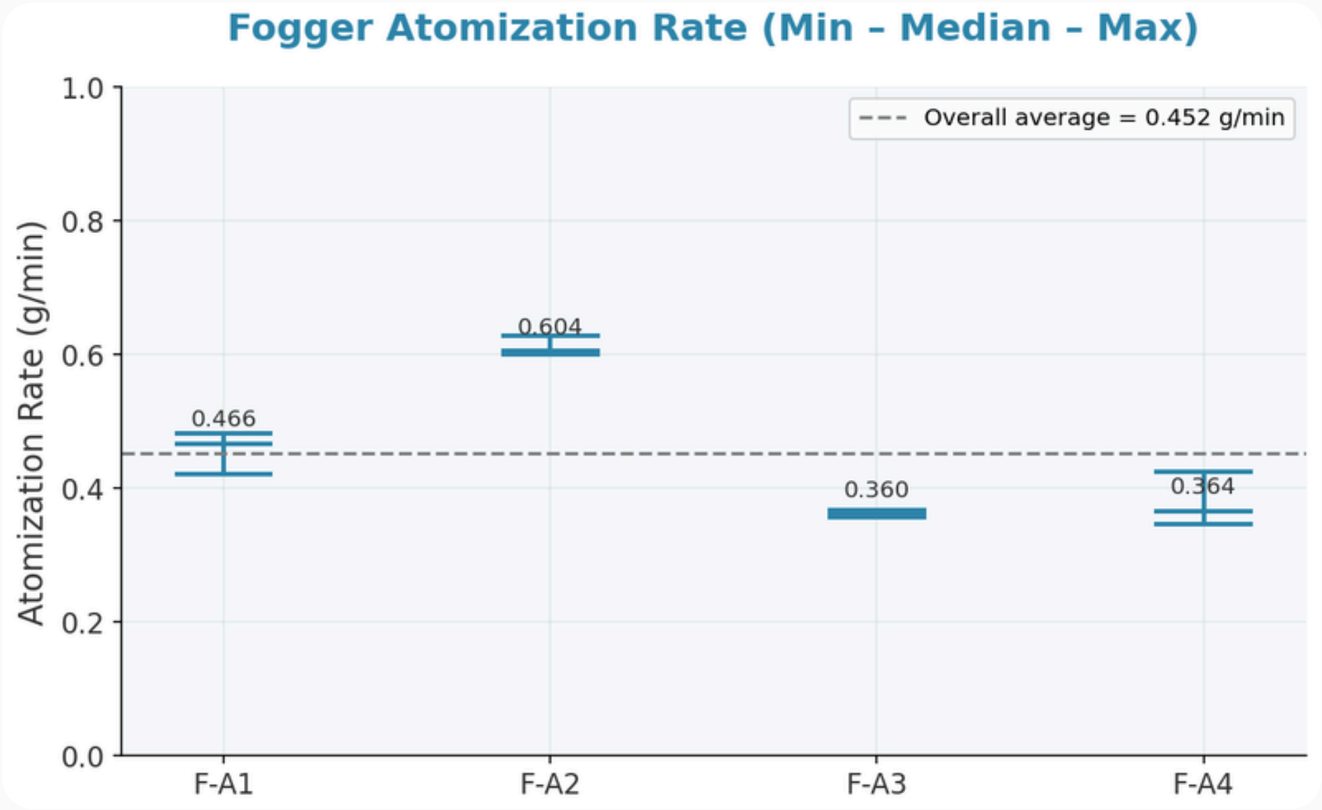


Figure: Plot of flow rate measurement of 4 different fogger with regular tap water.

pH Development over time

- Measurement of pure nutrient solution *without* atomizer. Measured over 10 days.

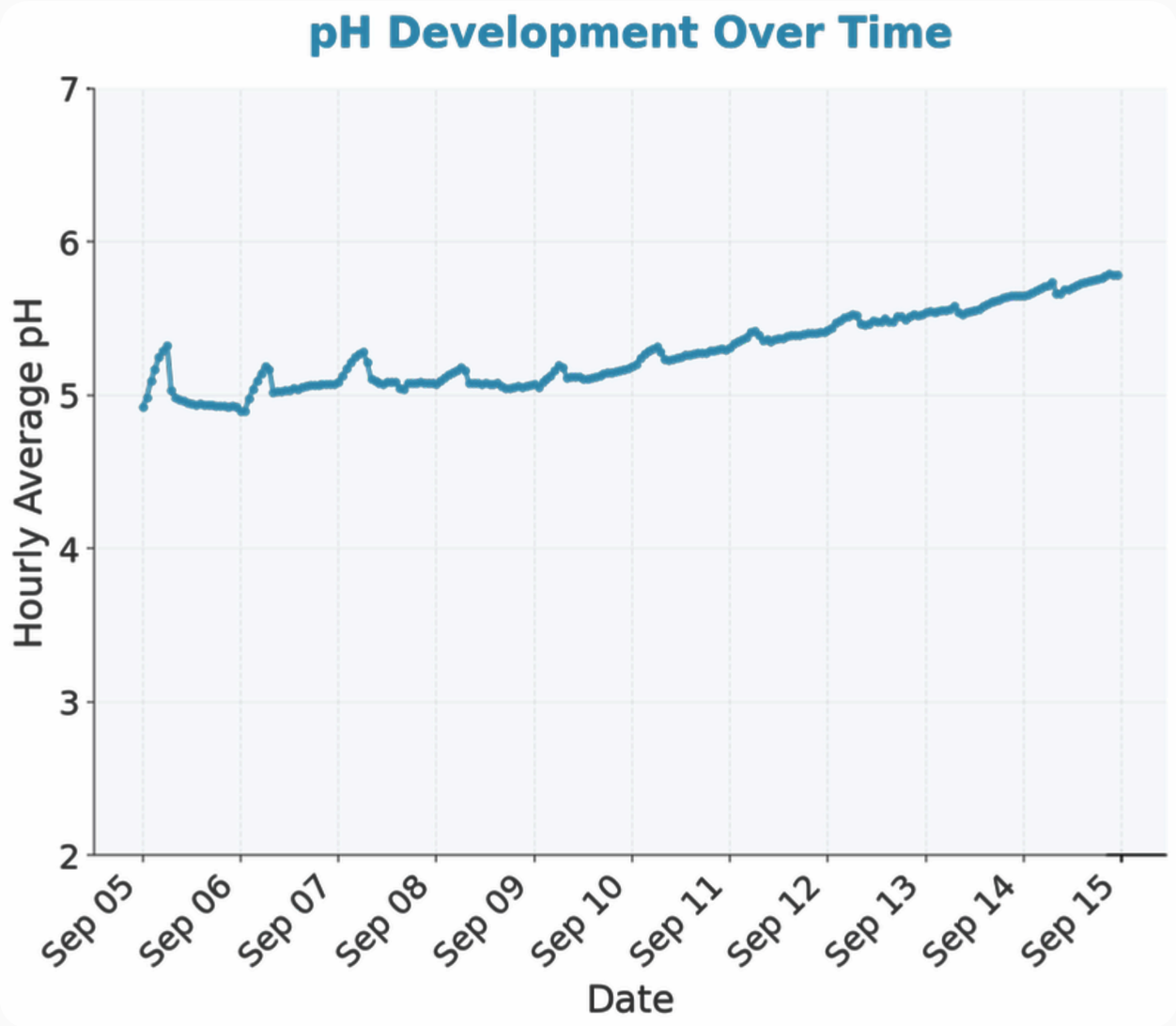
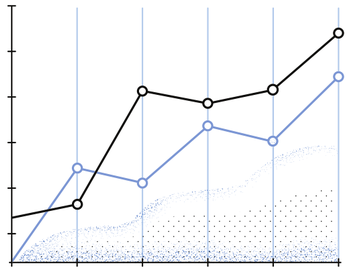


Figure: pH measurement of nutrient solution. Shown increase over 10 days.

Outlook

Next steps and future research directions

Next steps in Validating Fogponics as a Viable NDS



Measure pH, EC and temperature

Confirm the cause of pH and EC drift in fogponic systems

Full growth experiment with lettuce

Collect data: Water use, power draw, yield, pH, EC.

Behavior prediction on the moon

Predict fog production and behavior on on the moon.

Proposed research directions

01

Model roots as filter and determine droplet capture efficiency

02

Narrow down optimal droplet size range per crop

03

Full scale system implementation

04

Lunar Gravity Simulation

Thank you for listening

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MSc Space Engineering

For more questions, feel free to reach out.

Sources:

- **Figure page 11: https://growwithoutsoil.com/fogponics-method-build/**
- **Figure page 21: https://chatgpt.com/**

Mass Breakdown

Nutrient Supply Infrastructure

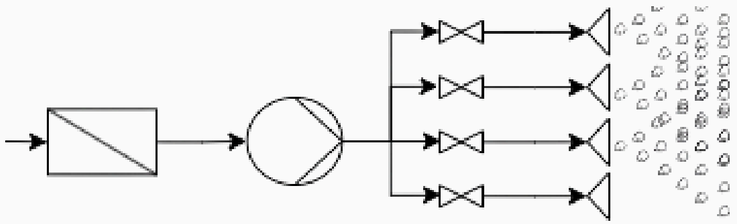

Table : Mass breakdown between EDEN-LUNA (white column) and fogponics (grey column) NDS components [kg].

Category	EDEN LUNA		Fogponics	
	Qty	Total Mass [kg]	Qty	Total Mass [kg]
Misters	**160**	**8**	**120**	**6**
Pump (high pressure)	**4**	**31.6**	**2***	**0.6**
Pressure sensor	**8**	**1.6**	**0**	**0**
Vents	4	2	4	2
Manual valves	40	38.6	40	38.6
Plant trays & tops	40	110	40	110
Tubing*	236	45.4	236	45.4
Level switch	4	0.8	4	0.8
Total	**-**	**238,0 kg**	**-**	**203.4 kg**

sources:
(1)Internal document: LUNA_NDS_Components_List_.xlsx

Mass Breakdown

Nutrient Return Infrastructure

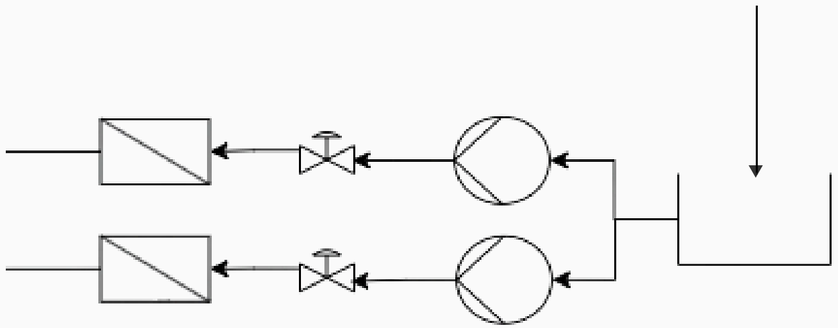

Table : Mass breakdown between EDEN-LUNA (white column) and fogponics (grey column) NDS components [kg].

	EDEN LUNA		Fogponics	
Category	**Qty**	**Total Mass [kg]**	**Qty**	**Total Mass [kg]**
Return pump	**4**	**0.6**	**0**	**0**
Level sensor	**4**	**0.8**	**0**	**0**
Manual valves return	**8**	**31.68**	**0**	**0**
Tubing return	**20**	**9.4**	**0**	**0**
Filter	**2**	**0.5**	**0**	**0**
Return Pump	**2**	**6.4**	**0**	**0**
Waste water tank	**1**	**20**	**0**	**0**
Total	**-**	**70.43 kg**	**-**	**0 kg**

sources:
(1)Internal document: LUNA_NDS_Components_List_.xlsx

Power Breakdown

Nutrient Supply Infrastructure

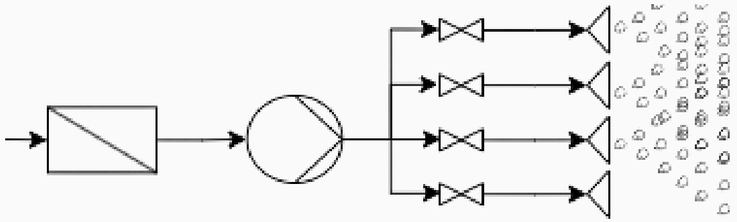

Table : Power breakdown between EDEN-LUNA (white column) and fogponics (grey column) NDS components [W].

Category	EDEN LUNA		Fogponics	
	Qty	Max power [W]	Qty	Max power [W]
Misters	**160**	**0**	**120**	**240**
Pump (high pressure)	**4**	**680**	**0**	**0**
Pressure sensor	8	8	0	0
Vents	4	0	4	0
Manual valves	40	0	40	0
Plant trays & tops	40	0	40	0
Tubing*	236	0	236	0
Level switch	4	0	4	0
Total	**-**	**688 W**		**240 W**

sources:
(1)Internal document: LUNA_NDS_Components_List_.xlsx

Power Breakdown

Nutrient Return Infrastructure

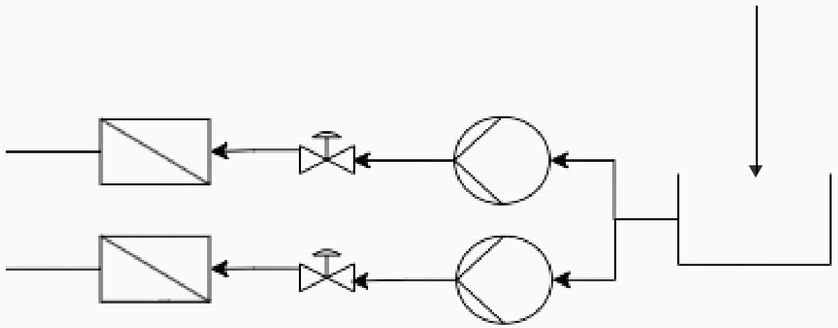

Table : Power breakdown between EDEN-LUNA (white column) and fogponics (grey column) NDS components [W].

	EDEN LUNA		Fogponics	
Category	**Qty**	**Max power [W]**	**Qty**	**Max power [W]**
Return pump	**4**	**144**	**0**	**0**
Return Pump	**2**	**100**	**0**	**0**
Level sensor	4	0	0	0
Manual valves return	8	0	0	0
Tubing return	20	0	0	0
Filter	2	0	0	0
Waste water tank	1	0	0	0
Total	**-**	**244 W**	**-**	**0 W**

sources:
(1)Internal document: LUNA_NDS_Components_List_.xlsx