Next-Gen Aeroponics

This whitepaper aims to review what we know about aeroponics, and introduces the new capabilities of precision irrigation.

Baltic Freya

AEROPONICS:
THE NEXT GENERATION

WHITEPAPER

BALTIC FREYA, 2022

Baltic Freya is an agtech developer focusing on aeroponic precision irrigation technologies. The company has developed highly scalable aerosol generators, enabling increased productivity and reduced resource use for the Controlled Environment Agriculture sector.

Abstract

Aeroponics is the process of growing plants in air, with subcategories that include high pressure, low pressure, and fogponics, which loosely describe the particle size of irrigation water misted on the plant root system. Aeroponics is both the most efficient and most complex irrigation technique used in Controlled Environment Agriculture (CEA).

Aeroponics outperforms all other forms of hydroponic and drip-fed irrigation systems, including by total yield, harvests per year, and product quality. Precise irrigation control available in aeroponics increases total root surface area; maximizing oxygen available to the roots, and increasing water and nutrient uptake. As a result, **aeroponic cultivation can boost total salable biomass yields over 50% - while using 2-3 times less water and fertilizer**. Crops grown in aeroponics develop significantly more phenols, vitamins, anti-oxidants and have even been observed to expand the diversification of withanolides isolated from Physalis coztomatl — a class of compounds exhibiting selective cytotoxicity against cancer cells.

In this White Paper, Baltic Freya introduces a breakthrough in aeroponic technology — the Solid-State Aeroponics e-Nozzles. The Solid-State Aeroponics e-Nozzles eliminates the labor, capital, and expertise barriers to using aeroponics at scale. Free from the requirement of pressurized systems and extensive technical skills and labor, this new aeroponic technology is designed to retrofit into existing infrastructure. Further, this new technology expands what was previously believed to be possible in aeroponics, expanding opportunities for businesses and operating models within aquaponic/organic aeroponics, aeroponic greenhouse structures, global research licensing, and off-planet applications.

Who we are

Baltic Freya, UAB develops agricultural technologies with a focus on aerosol applications in Controlled Environment Agriculture (CEA). Based in Lithuania, the company comprises plant scientists and engineers working to increase plant productivity and reduce resource consumption of CEA operations.

Since 2018, the team has been researching aerosol generation, management, and applications to plant roots and foliage. In 2022, Baltic Freya introduced the first ever Solid-State aeroponic irrigation system, discussed in detail below.

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1. Introduction

The Controlled Environment Agriculture (CEA) industry is under pressure to increase productivity as demand grows rapidly for fresh, local produce. In the context of increasing energy prices and pressure to conserve resources, precision irrigation technology enabling aeroponic cultivation can help boost productivity while reducing water and fertilizer use at the same time.

There are two forces at the center of the CEA industry – (1) the plant (biology), and (2) the industrialized environmental control (engineering).

Regardless of plant type (e.g. lettuce or cannabis), understanding plant biology and environmental requirements is crucial to maximizing productivity and product quality, while facilitating the understanding of lighting, temperature, nutrients, and processes used at a farm. Innovation in environmental control and process automation technologies drive down energy and labor costs, thereby increasing unit economics and the portfolio of profitable crops.

One area currently lacking innovation is precision irrigation. **Irrigation serves three core functions – water, nutrient, and root oxygen delivery**. Hydroponics, the most widely practiced technique, partially or fully submerges plant roots in a nutrient solution, severely restricting root oxygenation due to the limited oxygen solubility in water (up to 20 parts per million). Because the small amounts of dissolved oxygen in the nutrient solution are quickly absorbed by the roots, farm operators must continuously re-oxygenate the water, resulting in additional capital and operational expense. Without continuous re-oxygenation, lower yields will result.

1.1 What is aeroponics?

Aeroponic irrigation – intermittently spraying plant roots with aerosolized nutrient liquid – is the most economically effective irrigation technique delivering 10-60% higher salable biomass yields over 10-30% shorter crop cycles with 50-300% times less water and fertilizer compared to hydroponics. Furthermore, crops grown in aeroponics have increased antioxidants, vitamins and other value drivers which increase downstream marketability. Aeroponic irrigation utilizes plant roots' ability to effectively oxygenate from the air (21% O_2); for reference, oxygen solubility in water

+10-60%	-10-30%	-50-300%
yield gains	shorter crop cycle	less water

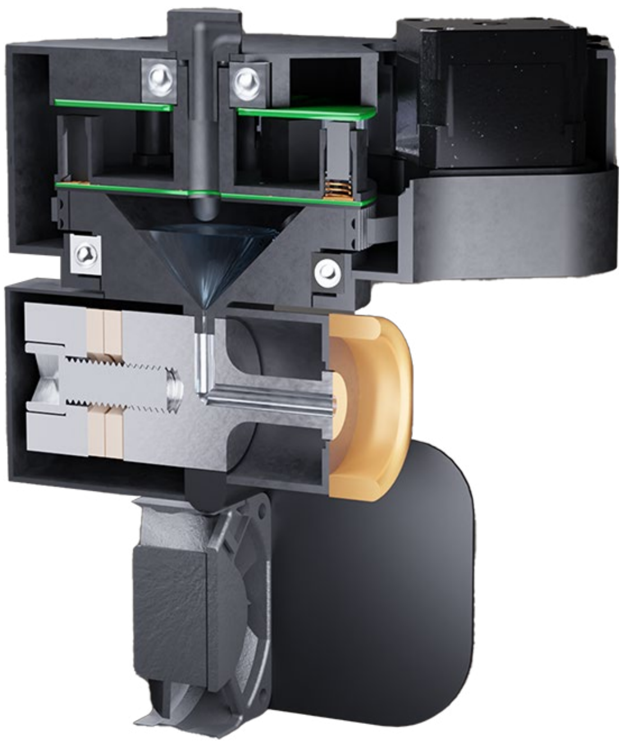
(hydroponics) is up to 20 ppm (0.002%) in the best scenarios. The abundance of oxygen in aeroponics drives plant metabolism, increasing biomass development and root surface area, which then increases the effective oxygen and nutrient absorption area, creating an effective and productive cycle.

In spite of the significant benefits of aeroponic cultivation, this technique is rarely utilized in CEA due to the limitations of available technologies. These limitations include very high maintenance costs resulting from clogging and related tasks (filter replacements, cleaning), the rigid and unscalable aeroponic technologies, and the high degree of technical skill and experience required to operate such complex infrastructures.

For commercial growers, the operating costs often negate the benefits, which makes simple hydroponic installations a more economical choice.

1.2. New technology brief

Baltic Freya started their R&D in 2018 looking for ways to simplify aeroponic irrigation, culminating in 2022 with a product innovation: a highly durable, uncloggable ultrasonic aerosol generation system ("e-nozzles") capable of outperforming any other irrigation method by both yield and OPEX. Most importantly, the e-nozzles work via drip lines (no pressure required) and offer near- zero maintenance.



While the initial e-nozzles were created for retrofitting existing infrastructures, Baltic Freya is close to introducing full greenhouse and indoor cultivation systems.

The technology is further introduced in the final chapter of this whitepaper.

2. Environment control

Controlled Environment Agriculture (CEA) enables growers to exert greater control over environmental factors. From the most basic protection against wind and cold, to the most advanced phenotypic expression manipulations, environmental control will have a major impact on productivity and produce quality.

Environmental factors and their changes trigger biological responses in all biological organisms.

Plants are mostly stationary organisms that have evolved by responding to environmental factors such as weather, climate, pests, soil composition, herbivores and other factors. Plants have endured these selection pressures through successful mutations to their biological processes, thus ensuring survival.

Environmental factors also affect plant gene expression. Expression of different genes alter the phenotypic outcomes of plant characteristics, including color, yield, taste, smell, and biomass. In other words, the same genotype grown in different conditions will produce different outcomes.

Field agricultural practices are designed to treat and manipulate crops to achieve stable yields and quality in different climates, but full plant biological potential is rarely achieved or expressed.

Controlled Environment Agriculture, on the other hand, aims to maximize biological potential by placing crops in environments designed to exploit their biological adaptations. Predictable phenotypic outcomes can be achieved repeatedly by creating clean and/or controlled environments and manipulating factors such as lighting spectrum, photoperiod, CO_2 concentration, irrigation intervals,

Baltic Freya has been independently conducting aeroponic research and product development since 2018, achieving yield improvements over hydroponics of 54% per cycle, while using 2-3x less water and fertilizer.

Credit: Baltic Freya.

nutrients, temperature and other growth-dependent variables.

Plants farmed in controlled environments are treated as bioreactors that are managed through environmental variable control. The more controllable factors, the easier it is to express the desired plant qualities. To understand the impact of different environmental settings at industrial scale, the same genotype is often grown in different conditions. The resulting yield, taste, flavor, color and other plant data is processed by expert plant scientists and artificial intelligence to perform multivariable analysis to predict outcomes and create “growing recipes” for desired phenotypic expressions.

Arguably, the most important environmental factors regarding plant qualities manipulation relate to lighting and irrigation/fertigation methods.

While LED lighting developers, such as Samsung and OSRAM, have introduced breakthrough innovations in efficiency and spectrum, root zone management—oxygenation and fertigation—have only experienced incremental improvement and sporadic attention by specialist suppliers in the industry.

2.1. Root zone oxygenation

Root zone oxygenation is an underutilized value driver in most CEA operations.

It is well established that plant roots absorb and utilize oxygen. The positive effect of oxygen was first seen in field agriculture, where compacted soil was observed to produce lower yields compared to loose, well-aerated soil. This has led to innovations in field agricultural practices and equipment, e.g., tractor tires that reduce soil compaction. When it comes to CEA, proper root zone oxygenation is rarely achieved due to the aforementioned limitations of the underlying processes and technologies.

Increased oxygen availability to the roots enhances yield, crop health, and product quality. **Oxygenation boosts the plant’s metabolic activity and induces the release of additional energy as ATP** (adenosine triphosphate, universal cell energy currency). Increased root oxygenation has also been proven to increase plant resilience, stress resistance, nutrient and water uptake as well as reduce the formation and spread of root disease.

Maximized yield

Aeroponically grown crops in hydroponic infrastructure can fail to account for the extra growth. This picture is an example of overspill - lettuce grew larger than expected, which caused the overspilled leaves exit the active lighting area. In this case, the issue was solved by changing the growbox lids.

Credit: Baltic Freya.

2.2. Hydroponics limits root oxygenation

In typical CEA practice, careful consideration is given to avoid "overwatering", which submerges the roots in water and displaces oxygen (DO) in the root zone creating hypoxic root conditions. In drip-fed hydroponics that utilize fibrous media, e.g. rockwool or coco coir, a natural limit is reached quickly for irrigation, a limit beyond which excess water will starve the plants of oxygen. In deep water culture (DWC) systems, liquid or aerated oxygen is supplemented continuously to maintain acceptable levels of dissolved oxygen in the root zone, with the natural limit being the physical property of water to dissolve oxygen at a given temperature and pressure.

Most indoor farms operate at a temperature range between 20° C and 25° C (68° F – 77° F), which limits the DO concentration in the nutrient liquid to approximately 20 ppm. Dissolved oxygen is rapidly absorbed and needs to be replenished - popular DO management techniques include disk aerators in liquid reservoirs, high flow rate mixing (agitation), air stones, Venturi systems, plasma treatment, and chemical additives. New oxygenation technologies are emerging – including a novel nanobubble technology promising to maintain DO at 25 ppm – but these numbers are still too low to maximize plant performance.

2.3. Aeroponics unlocks plant potential

Aeroponic irrigation works in a different way - instead of submerging plant roots or using drip-fed growing media, plant roots are suspended in air with the nutrient solution delivered to the roots through aerosol droplets. Ideally, for most indoor crops, the aerosol droplet diameter is between 10μm and 50μm, depending on the plant and desired outcome.

The natural limit of dissolved oxygen (DO) in hydroponics is not a concern for aeroponics.

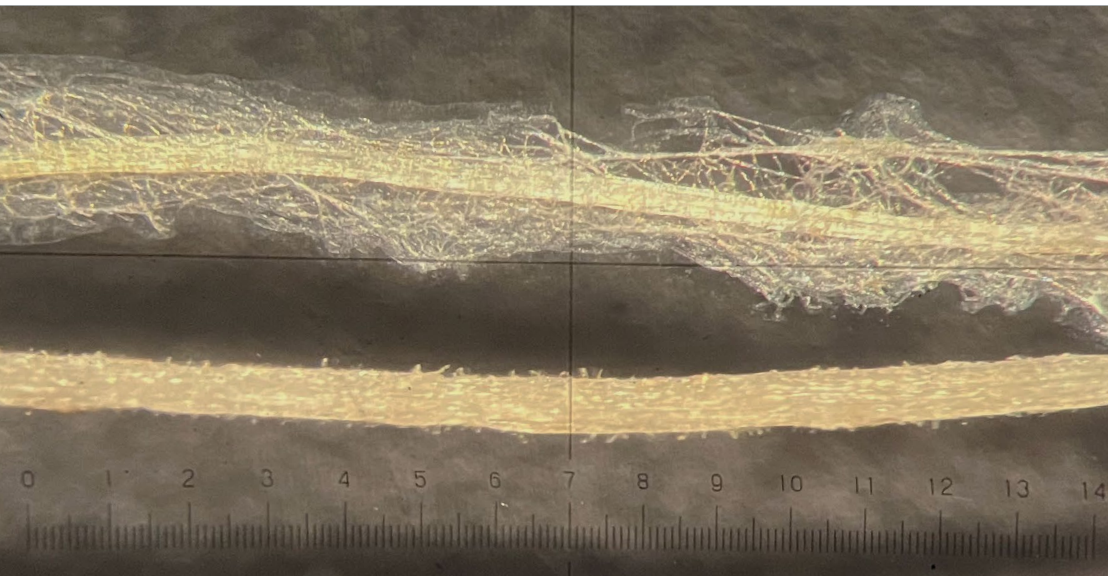
Whereas hydroponic systems struggle to maintain DO concentration of 20 ppm, the oxygen available via air is 21% (210,000 ppm). Therefore, roots grown in aeroponics have access to all the oxygen required to develop to their full potential. Operationally this is even more significant, because it means additional effort and expense is not required to oxygenate the nutrient liquid.

Aerosolized nutrient solution is sprayed in intervals. For example, a trusted lettuce protocol is 1:11, meaning the aerosolized nutrient solution can be sprayed for 30 seconds every 330 seconds. During the 6 minute interval, the aerosolized nutrient solution is captured by tiny root hairs and is rapidly absorbed by the roots, leaving extra time for oxygen respiration.

Because oxygen concentration in the ambient environment is always around 21% (~210,000 ppm), plant roots are exposed to significantly more oxygen than in hydroponic systems, maximizing plant metabolic potential. The boosted plant metabolism results in higher total yields, increased number of harvests and improved produce quality, when compared to hydroponic or substrate-based approaches. In addition, due to the nature of aerosol delivery, it is possible to introduce a precise volume of water and nutrients. This results in predictable and repeatable outcomes, including plant weight and biochemical profiles, which results in less water and nutrient waste, and increases efficiencies and cost savings.

Further, when comparing root development between hydroponics and aeroponics, aeroponic roots develop unencumbered by growing media. Utilizing small droplet diameters, aeroponics dramatically increase root surface area compared to DWC or drip-fed media systems (see image below). Increased root surface area increases the potential for nutrient and oxygen uptake, and therefore increased metabolic activity. Furthermore, a high combined surface area of aerosol droplets enhances the nutrition effectiveness, resulting in increased mineral accumulation.

Despite the benefits of aerosol, working with aerosol has traditionally been much more demanding than any other method due to two core reasons: (1) the high threshold for grower expertise required to set up and manage the infrastructure, and (2) the limitations of available aerosol generation and management technologies.



Aeroponic vs Hydroponic roots

Roots grown in aeroponics (upper sample) develop significantly more surface area than hydroponic roots (lower sample), which increases water and nutrient uptake, oxygenation, and helps unlock the plant's full metabolic potential.

Credit: Baltic Freya.

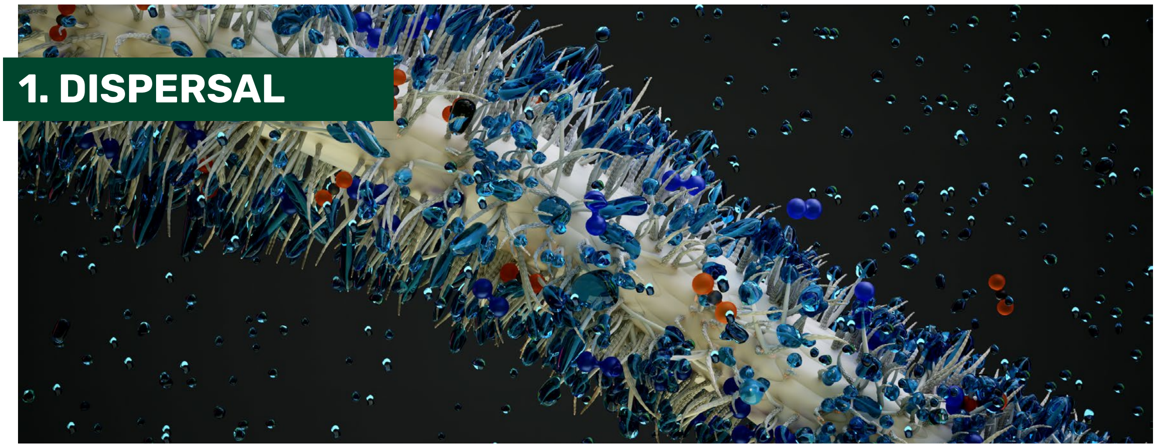
3. Working with Aeroponics

There are several key factors that require management when working with aerosol irrigation, including the mean droplet diameter of the produced aerosol, irrigation intervals, and aerosol distribution in the rhizosphere (root zone).

3.1. Stages of aeroponic irrigation

Before diving into the details, it is helpful to understand the key stages of the aeroponic process.

1. DISPERSAL



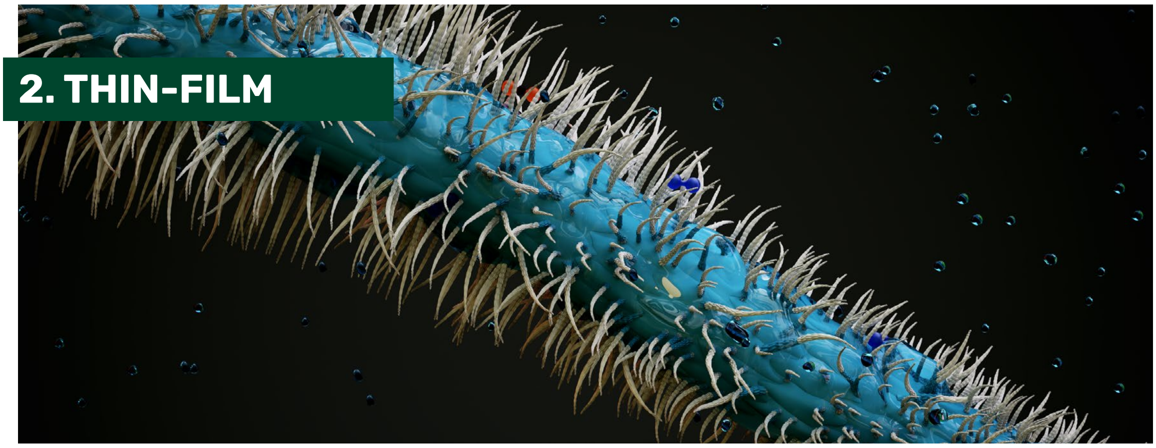
The aeroponic cycle begins with aerosol dispersal into the root zone:

1. Plant roots hang in air and the root surface is actively exchanging gases.
2. The nutrient solution is dispersed/sprayed as aerosol in tiny droplets, ideally between 10μm and 50μm diameter droplets.
3. Aerosol dispersal time depends on the crop's biology – for example, aeroponic lettuce cultivation is efficient at the interval of 1:11, which can be delivered via 30 seconds of spray time followed by 330 seconds of absorption and respiration before the next spray period.
4. Once aerosol is dispersed, tiny root hairs (15-17μm in diameter) capture the droplets. If the droplets are too small or too large, the crop will not utilize growth potential and underperform.

The function of root hairs in plant biology is to increase the surface area over which the plant can absorb water and nutrients.

Optimal droplet diameter and spraying time depends on the crop's biology, and is part of our core intellectual property ("Grow recipe").

2. THIN-FILM



The second stage in the process is Thin-Film Formation:

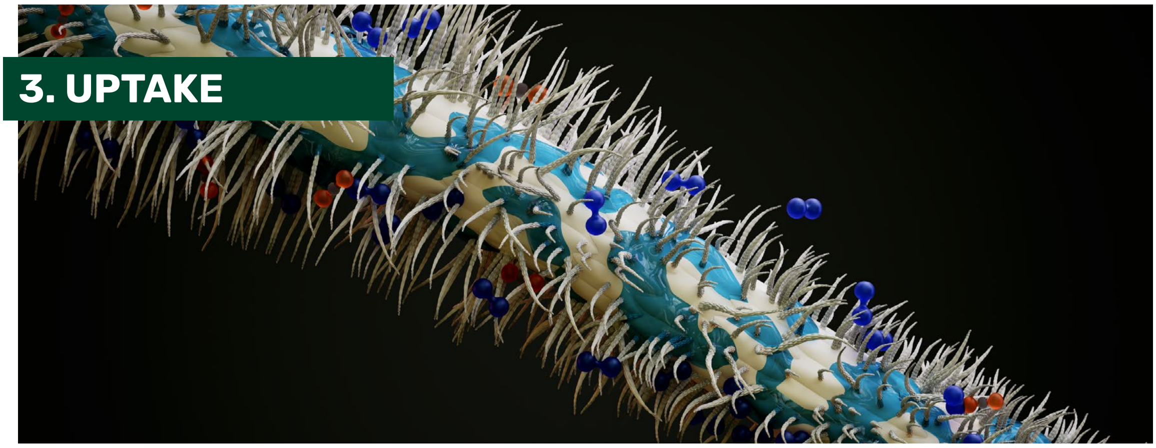
1. The spraying is stopped, but tiny droplets remain suspended in the high-humidity environment for some time.

2. The root hair cells will have captured aerosol to form a thin film of nutrient solution on the root surface, thereby providing enough water and nutrition until the next spray period.

3. Gas exchange is reduced due to the root surface coverage with the nutrient solution.

Droplet size diameter has a major impact on the success of thin-film formation, and impacts the development of the robust root hair growth seen in aeroponics.

3. UPTAKE



As the Thin-Films forms, the roots begin to Uptake the nutrient solution:

1. The thin film is absorbed by the root surface relatively quickly. The rest of the ambient aerosol will have descended by now.

2. Once the root surface is bare again, it restarts gas exchange. This is a core value driver as optimal oxygenation before the next spray period helps the crop increase its metabolism, and therefore increases yield and growth speed.

Irrigation intervals have a major impact on the success of metabolic potential maximization.

4. OXYGENATION

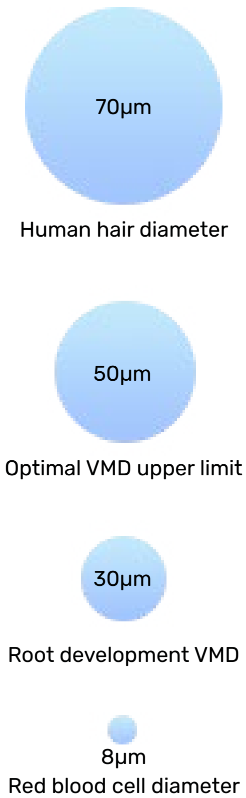
The key value driver of aeroponics is sufficient oxygenation:

1. Plant roots efficiently take up oxygen from the air. Correctly timed intervals will maximize oxygenation and boost plant metabolism, increasing root surface area and root hair density. Rapid oxygenation ends when dispersal begins again.

Oxygenation is a key value driver in aeroponics. Increased respiration boosts metabolism, resulting in faster growth and higher yields.

3.1. The factors of aeroponics

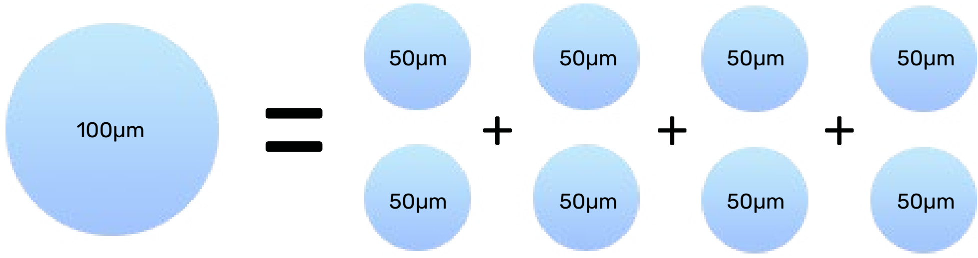
3.1.1. Key Factor: Droplet diameters



Aerosol droplet variable mean diameter (VMD) has a major impact on the plant's ability to capture and absorb the aerosolized nutrient solution

The tiny root hair cells, which are utilized for aerosol sorption, are 15-17µm in diameter. If the droplet VMD is 10µm or less, droplets are less likely to adhere to the surface due to the high surface tension, which over time induces secondary root development to form a dense mesh of thin roots to be able to capture more aerosol. If the VMD is over 50µm, droplets can have too much volume and mass causing suboptimal sorption and nutrition. Droplet VMD between 10-50µm are optimal for most crops, but the most effective diameters will be determined, among other things, by root hair density. Advanced phenotype manipulation techniques adjust the droplet VMD during different stages of the diel cycle as well as different states of the overall plant lifecycle.

Pressure-based systems can produce the required VMD through fixed orifice nozzles, but high pressure pumps, expansion tanks and extensive plumbing is required to produce the required diameters. Fogger-based systems cannot produce droplets larger than 5-10µm, which may only work well for microgreens and other short-vegetation plants.



THE RULE OF EIGHT

“The Rule of Eight”: a 100µm diameter droplet has the same volume as eight 50µm diameter droplets. A droplet with 500µm diameter would have the same volume as 125,000 10µm diameter droplets.

3.1.2. Spray intervals

Aerosol application intervals determine root oxygenation and other important metabolic factors. Such factors are determined by genotype and the available droplet VMD. Some researchers have suggested ideal times for different crops (Table 1). However, such guidelines need to be tested and adjusted to account for the droplet diameter. Additionally, the potential for changes in droplet diameter over time must be evaluated, a capability not previously feasible prior to Baltic Freya’s work.

For example, a system producing 50µm VMD aerosol droplets can cover a much higher surface area than a system producing 100µm over the same time. Therefore, larger droplet sizes may also require more spray time for the same crop. Each genotype will respond to intervals in unique ways – optimal interval duration and frequency for required phenotypic expression is determined by the grower’s recipe.

PLANTS	SPRAY INTERVAL	SOURCE
Tomatoes	60s ON - 5min OFF	Osvald et al. (2001)
Cucumber	7s ON - 10min OFF	Peterson & Krueger (1988)
Lettuce	1.5min ON - 5min OFF	Kacjan-Marsic & Osvald (2002)
Saffron	1min ON - 1min OFF	Souret & Weathers (2000)
Burdocks	30sec ON - 60sec OFF	Pagliarulo & Hayden (2000)
Anthurium	15sec ON - 15min OFF	Fascella & Zizzo (2007)
Acacia	40sec ON - 30sec OFF	Weber et al. (2007)
Peas	3sec ON - 10min OFF	Rao et al. (1995)
Onion	7sec ON - 90sec OFF	Jarstfer et al. (1998)
C. speciosa	2sec ON - 2min OFF	Kumari et al. (2016)

Table 1. Examples of tested effective aeroponic spray intervals for different crops.

AEROSOL DISTRIBUTION

Aeroponically grown plants develop significantly larger roots. Baltic Freya's growboxes are 1 m^2 and hold 30 lettuce plants. For sufficient distribution, we use a single **R1+ 360** rotating e-Nozzle. For context, 9 high pressure nozzles would be required in a comparable high-pressure setup.

Credit: Baltic Freya.

3.1.3. Aerosol distribution in the rootzone

Aerosol distribution in the root zone is a key factor determining yield and quality consistency. Droplet travel and suspension can be impacted by a myriad of factors, including the relative humidity (rH) of the rhizosphere, droplet diameter and mass, irrigation infrastructure installation, electrostatic charge, root architecture, and plant distribution.

Pressure-based systems deal with distribution issues by installing several nozzles in the root zone, which can cause problems, including increased maintenance and oversaturation. Additional airflow for increased aerosol distribution is often required, but can cause positive pressure issues in the root zone resulting in aerosol leaks.

Fogger-based systems also address the aerosol distribution issue by deploying a large number of fogging units. Foggers require frequent cleaning to function properly.

Even when equipment runs without issue, the high energy use and excess heat alters the nutrient solution (e.g., pH) and may require additional cooling. Fogger-based systems are also extremely limited by the range of droplet diameters produced.

Some growers choose to combine foggers with DWC hydroponics, but any perceived productivity gains will be impacted by the increased capital and operating expenses.

3.2. Limitations of aeroponics

Comparing different aeroponic technologies is useful in understanding the differences in technological impact, but helps to understand the capital and operational expense accompanying each approach. Different aerosol methods result in different droplet VMD, irrigation intervals and aerosol distribution. In other words, the core problem of aeroponic cultivation is that there is no stable and standardized aerosol generation and deliveryplatform, and the knowledge, skills and time developed to tend to these systems are often non-transferrable.

Nonetheless, we provide a brief overview of the key limitations of the currently available and utilized aeroponic irrigation technologies in CEA.

3.2.1. Technological limitations

Existing implementations of aeroponics include pressure-based systems and piezoceramic foggers.

Pressure systems produce aerosol by forcing water through a narrow orifice - this nozzle orifice clogs easily from any internal obstructions (e.g. scale, salt precipitation), or due to external calcification. Fine mesh filters are used to prevent internal clogging. However, filters are also problematic due to the constant upkeep, cleaning and replacement, resulting in increased operating costs. Filters, at best, slow down clogging instead of preventing it.

Furthermore, external nozzle blockage can occur due to orifice calcification. Clogged nozzles quickly result in plant wilting and, in mere hours, dead crops.

Fogger-based systems also limit oxygenation and crop potential. Foggers produce droplet diameters that are too small for most commercially-valuable crops. Furthermore, foggers inherently produce heat, altering the ionization constant of the nutrient solution, which can require additional cooling installation.

3.2.2. Operational limitations

Pressure-based systems are complicated to set up and require high upfront investment. Specialized equipment is costly and limited in operational scale due to the nature of pressure systems. To limit the need for pressure-pumping systems, equipment providers often settle on lower pressure systems, which clog less but produce large droplets and can limit plant potential. **For comparison, a specialized low pressure system can produce around 6 cannabis harvests per year, whereas a system achieving 50µm droplets and below will be able to deliver 8 harvests for an experienced grower.**

Maintenance costs are high and operational scale is limited by built-in inefficiencies and higher cost margins. By the time clogged nozzle detection occurs, it is too late. Crops will have already begun to wilt. Nozzle repairs then expose roots to light, which is suboptimal. During room flip times, nozzles often calcify, which requires additional cleaning labor.

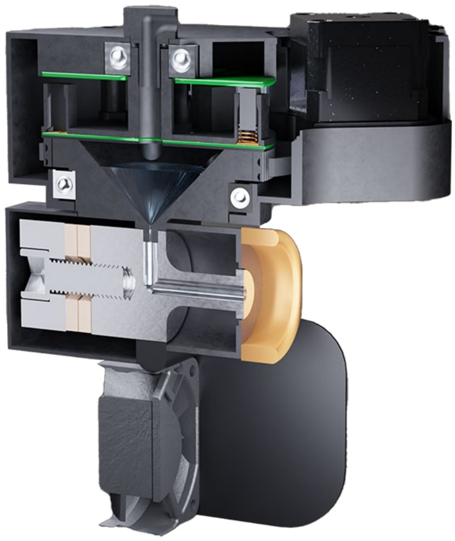
3.2.3. Research & Knowledge Transfer

Aeroponic research has only begun to scratch the surface of phenotypic manipulation, but results are often non-transferrable because aeroponic systems are not standardized.

Most of the required aeroponic droplet diameters are between 10µm and 50µm. With very few exceptions, this VMD range can only be using pressure-based systems. However, research results often cannot be replicated at scale because a commercial scale installation may not perform in the exact same way as the small scale laboratory installation. Research is further limited by clogging, because large particles cannot be tested (e.g., organic material recirculation or salinity stressing). Furthermore, the disruptive impact of high-pressure installations (often >100 PSI) while testing the effects of various bacteria can rupture the membranes of cells and kill the bacteria. Experiments often fail entirely due to clogging, further limiting research and high quality data.

4. Next-Generation Aeroponics

For the first time ever, aeroponic irrigation is simpler and easier than hydroponics. Combining acoustic technology, precision-machined titanium and artificial intelligence, Baltic Freya builds smart, uncloggable and highly tunable aeroponic nozzles and systems for controlled environment cultivation.



BREAKTHROUGH INNOVATION

The Baltic Freya NEBULA series aeroponic e-nozzle systems require no pressure pumps and few technical skills, thereby eliminating any previous barriers to aeroponic cultivation.

Moreover, each nozzle is a smart IoT device – you can remotely adjust droplet diameters and irrigation intervals, and even observe operating data.

ZERO PSI

Forget about pressure systems and unlock your operational scale. E-Nozzles generate aerosol through efficient ultrasonic vibration. **No pressure is required.**

NO CLOGGING

E-nozzles can disperse solid particles, including organics, aquaponic water and even sand, offering a near-zero maintenance setup and full recirculation.

SMART

Each nozzle is a connected device, enabling tracking live operating status, built-in contingency protocols and nozzle-level control of intervals and droplet diameters.

ADJUSTABLE VMD

E-Nozzles enable droplet diameter manipulation - by adjusting the ultrasonic frequency, dispersed aerosol VMD can be changed remotely.

N1 E-NOZZLE

NEBULA N1 Aeroponic e-Nozzle is a highly universal aeroponics solution offering easy installation in DIY and Commercial infrastructure.

Features:

- Uncloggable aeroponic e-Nozzle
- Electronic management unit for settings adjustment
- No pressure pumping systems required
- Near-zero maintenance
- Max. dispersal - 21 LPH / ~0.09 GPM
- Max. power at non-stop usage - up to 40W/H

Available dispersal shapes:

- 30° Narrow spray
- 120° Cone spray

R1+ 360 E-NOZZLE

NEBULA R1+ AirFlow 360° Aeroponic e-Nozzle is an advanced solution for hydroponic conversions. The additional airflow feature, delivered by an IP69K-rated fan helps distribute aerosol further without causing positive pressure issues.

Features:

- Built-in IP 69K Fan
- Uncloggable aeroponic e-Nozzle
- Electronic management unit for settings adjustment
- No pressure pumping systems required
- Near-zero maintenance
- Max. dispersal - 27 LPH / ~0.12 GPM
- Max. power at non-stop usage - up to 50W/hour

Dispersal diameter: up to 220 cm (7.22').

	BALTIC FREYA AEROPONICS	PRESSURE-BASED AEROPONICS	FOGGERS-BASED FOGPONICS	HYDROPONICS & DERIVATIVES
MAINTENANCE & ISSUES	**LOWEST**	HIGHEST - CLOGGING, FILTER REPLACEMENTS, PART COUNT, PRESSURE INFRASTRUCTURE	HIGH – CLEANING, REPLACING RUPTURED MEMBRANES, HEATING & PH INSTABILITY, INEFFICIENT	MEDIUM/LOW – MASSIVE INFRASTRUCTURE, HIGHEST VOLUME OF WATER
WATER & FERTILIZER USE	**LOW**	LOW	LOW	HIGH
DROPLET DIAMETERS	**ADJUSTABLE** **10μM - 100μM**	CAN BE ADJUSTED MANUALLY LOW PRESSURE SYSTEMS (+60μM) ARE SUBOPTIMAL HIGH PRESSURE SYSTEMS (30μM – 50μM) CAN BE OPTIMAL	NON-ADJUSTABLE SUBOPTIMAL FOR MOST CROPS DRY FOG (<5μM)	-
PERIPHERY	**ELECTRONIC CONTROLLER** **DRIP LINE**	HIGH PRESSURE PUMPS FILTERS EXPANSION TANKS EXTENSIVE PLUMBING REVERSE OSMOSIS	COOLING	OXYGENATION
ENERGY USE	**LOW**	HIGH	HIGH	MEDIUM
SETUP / CONTROL	**EASY /** **CONTROL EACH NOZZLE REMOTELY**	COMPLEX / HIGH	EASY / LIMITED	CAN BE EASY / HIGH
SMART FEATURES	**REMOTE CONTROL** **PREDICTIVE MAINTENANCE** **CONTINGENCY PROTOCOLS** **SUPERIOR DATA** **ELECTROSTATIC CHARGE**	-	-	-

GREENHOUSE & INDOOR SYSTEMS

Baltic Freya is currently engaged in complete systems development, including aeroponic A-Frames for greenhouses, organic aeroponic cannabis growtech and fodder systems. For pre-market testing or co-development opportunities, ***please contact Lukas Bartusevicius, CCO at lukas@balticfreya.com.***

4.1. Solid-State Aeroponics

We define an evolution of aeroponics we term “Solid-State Aeroponics”. Whereas “Solid-state” has applied to electronics with the replacement of vacuum tubes and moving parts with transistors, here, Solid-State Aeroponics is differentiated with the removal of mechanically pressurized systems, forced-pressure nozzles, and any other mechanical input that is consumed by the process.

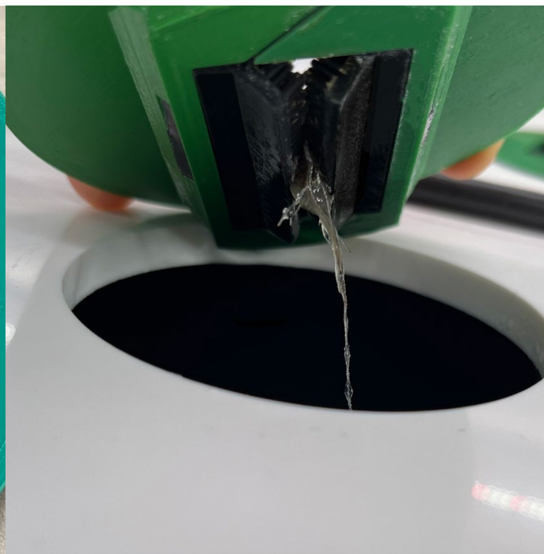
Solid-State Aeroponics defines an evolution in hydroponic and aeroponic cultivation which seeks to eliminate not just pressurized mechanical pumping systems (which consume excess power), but also all other physical consumables and disposable inputs such as high pressure or drip nozzles, disposable growing media such as rockwool, peat, coir, or other fibrous media, and other physical materials that may be consumed during the process.

By definition, Solid-State Aeroponics should require no turnover in the mechanical, non-biological, components of the growing system, and instead only have turnover in water, fertilizer, and plant matter.

Brief introduction - video

R1+ 360 e-Nozzle - video

N1 Coned e-Nozzle - video



SOLID-STATE SUBSTRATE

Silicone substrate, as developed by KAPPA AgTech, is currently being tested in Baltic Freya’s ***Rhodiola Rosea*** in-vitro explant rooting research. The silicone inserts are inert, reusable, enable USDA-Organic certification, and are very easily washed before returning to circulation.

Credit: KAPPA AgTech, Baltic Freya.

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