# Socio-economic benefits from ESA Technology Transfers (Pilot)

## Case Study 1

SEMiLLA: From waste to resource

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# **Cities as Spaceships:** The circular resource economy

**Already today, cities consume 75% of the natural resources, produce 50% of the global waste, and emit 60-80% of the greenhouse gases (GHG).[1] By 2050, two thirds of the population will live in cities around the world.[2]**

As cities embrace the circular economy model in an effort to be more sustainable, space technology applied to these terrestrial challenges can aid cities by providing resilient circular solutions, and delivering significant socio-economic benefits.

**Resource circularity could be a game-changing technology in helping to tackle these growing environmental challenges.** The application of circular systems in cities can also bring about a number of social and economic benefits, including sustainable water supply, increased and healthier food production, and greener cities.

## 'Necessity is the mother of invention'

On the International Space Station (ISS), orbiting 400km above the Earth, resources such as water, food and oxygen, are extremely precious. **Even with ongoing technological innovation reducing the cost of launch significantly, commercial services currently deliver cargo to the ISS at a cost of $25,000/kg.**[3] For this reason, a closed-loop life support system that recycles waste into water and oxygen has been a fundamental aspect of life onboard the ISS for over twenty years.

**MELiSSA** (Micro-Ecological Life Support System Alternative) is a European project running for more than 30 years within the **European Space Agency (ESA)**, bringing many research institutes and organisations together to develop circular life support systems for the ISS and beyond. Through MELiSSA, organic and ceramic membranes were developed to filter astronauts' wastewater, removing unwanted compounds, including nitrates. Furthermore, the project has been successful in using micro-organisms to process the waste to grow plants and food. Whilst work continues to increase the system efficiency towards 100% (a self-sustainable ecosystem that does not require resupply) for post-ISS habitats beyond Earth orbit, attention in recent years has turned to exploring how this technology can be adopted to benefit life on Earth. Many areas and aspects of life on Earth would greatly benefit from the ability to turn waste into resources, in turn enhancing our ability to meet global environmental and sustainability goals.

## Space technology brought down to Earth ...

**SEMiLLA IPStar** (referred henceforth as SEMiLLA) is a MELiSSA technology transfer partner charged to test MELiSSA technologies for terrestrial applications and show that the impact goes beyond that of space applications. SEMiLLA applies MELiSSA technologies to Earth-based needs, including water treatment, waste management and recycling. SEMiLLA hope to provide an integrated waste management system to support the lifestyle of city inhabitants.

[1] Market and Markets (2017). *Vertical Farming Market by Growth Mechanism, Structure, Offering, Crop Type, and Geography - Global Forecast to 2022.*
[2] United Nations (2018). 'Around 2.5 billion more people will be living in cities by 2050, projects new UN report'. Available at: https://www.un.org/development/desa/en/news/population/2018-world-urbanization-prospects.html
[3] Jones, H.W. (NASA Ames Research Center) (2018). 'The Recent Large Reduction in Space Launch Cost', *48th International Conference on Environmental Systems*. 2018 prices, unadjusted. Available at: https://ntrs.nasa.gov/citations/20200001093

## ... helping Amsterdam become fully circular by 2050

Municipal wastewater is a great resource for nutrients and water reuse. This project, led by SEMiLLA and facilitated by ESA, aims to use MELiSSA technology to recover nutrients and clean wastewater for use in vertical farming. ESA are helping to tackle urban waste and food production challenges by helping leverage the photoheterotrophic compartment (C-II) of the MELiSSA loop, responsible for the elimination of the terminal products of the liquefying compartment of the system, for use as an urban waste solution for the Municipality of Amsterdam.

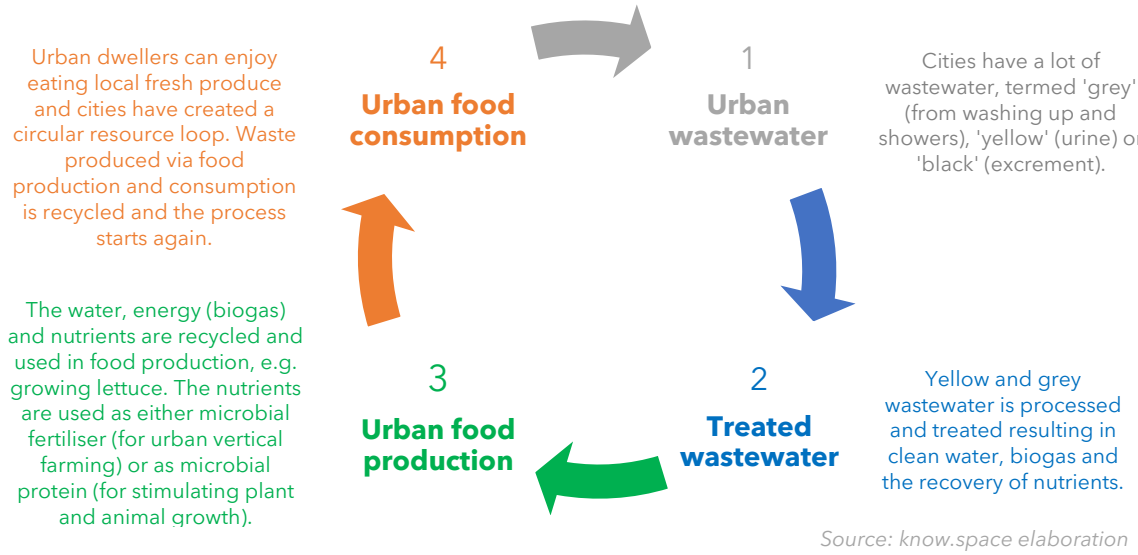
The Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute) is working with SEMiLLA on this project. The AMS Institute help provide solutions to the complex problems faced in cities, by facilitating the integration of scientific, technological, and commercial capabilities and connecting academic, political and entrepreneurial minds. Amsterdam's living labs initiative provides a testbed for developing new solutions, including **SEMiLLA's IPStar Circular System at the recently opened Marineterrein lab, which helps the city of Amsterdam quickly adopt new technologies to enable the city to reach the goal of becoming a fully circular city by 2050.**[4]

## Turning waste into resource

SEMiLLA identified a number of potential applications for using MELiSSA technology for Earth applications from an initial feasibility study. Purple Phototrophic Bacteria (PPB) was chosen for development as Proof of Concept. In nature, PPB proliferate in anaerobic lagoon and ponds and many other stagnant water environments. PPB was chosen because of their peculiar biomass composition, typically rich in protein and other chemical compounds such as carotenoids and quinones. The project successfully demonstrated the use of the PPB raceway reactor (used for in the cultivation of algae) for purple bacteria cultivation on brewery and municipal yellow wastewater (urine).

The project to date has focused on two key areas: **nutrient recovery** and **water treatment**, using the C-II MELiSSA technology **to help cities transition to a circular economy**, developed by SEMiLLA through the Proof of Concept (PoC) process.

*Overview of the SEMiLLA wastewater treatment process*




*Source: know.space elaboration*

The project implemented a local modular biological wastewater treatment system to maximise the recovery of value in water and nutrients by the means of a raceway reactor system. In this project the reactor was fed with a mixture of brewery wastewater and urine. The brewery wastewater was used as the main carbon source for microbial growth, with urine used as the main nitrogen source.

[4] City of Amsterdam (undated website). *Policy: Circular economy*. Available at: https://www.amsterdam.nl/en/policy/sustainability/circular-economy/


Image: GROWx

# Enabling SEMiLLA to develop circular systems for Earth

There are a number of socio-economic benefits that have already been realised in the initial stages of the technology development, with promise of many larger, global benefits to come as the SEMiLLA IPStar Circular System is scaled and becomes available to a wide range of users, from cities and utilities companies responsible for waste management, to buildings and companies seeking to reduce waste and lower energy costs.

## *Improved technology*

As the SEMiLLA system develops, the direct link from MELiSSA (space) to SEMiLLA (Earth) starts to become a two-way feedback loop as the innovation development of SEMiLLA informs MELiSSA and thereby improves ESA's closed-loop life support system for space. This feedback loop provides potential for future technology transfer between space and earth applications as the SEMiLLA technology matures.

## *Cost effectiveness*

**SEMiLLA have developed a new, open point, PPB raceway reactor,** providing a solution that is on average **ten times cheaper than existing closed photobioreactors reactors.**

SEMiLLA adopt the same process as MELiSSA in using a natural conversion from waste to nutrients (not dependent on mechanical filtering) using microbes which act as a filter to purify specific elements within their cell. Existing reactors on the market isolate oxygen from the wastewater system and are thus very expensive to purchase and operate due to the complexities of separating oxygen from the system. Closed point reactors use anoxic conditions and have higher CAPEX and OPEX costs. As result, existing reactors present a cost-ineffective solution for small scale terrestrial circular systems, that simply cannot justify the high costs associated with in-space activities.

The new reactor, tuned and developed with the support of ESA, grows purple bacteria in an open point system for industrial microalgae cultivation, which is more cost-effective than existing reactors on the market. Adopting ESA's MELiSSA technology, SEMiLLA, with the help of the University of Antwerp, have developed a new, open point, PPB raceway reactor, providing a solution that is on average 10 times cheaper than existing closed photobioreactors reactors.

## *New economic activity*

There is a great opportunity for SEMiLLA to create a new product and commercial service that can be provided on the market to a global userbase. The raceway reactor is being developed to be sold as a standalone unit and the near-term goal is to develop a fully-fledged wastewater and nutrient recovery system, provided as a service.

There are very few commercial businesses that are validated in the market for nutrient recovery and water treatment, all in one. There are companies piloting systems, academic endeavours and R&D initiatives, including Cinderela which aims to recover nutrients from urine through distillation. The technology is a non-biological system, and it can be an alternative to the technical solution from the MELiSSA project, however, the SEMiLLA biological raceway reactor is different in the way it handles waste and the commercial viability is assumed higher due to lower energy needed to operate the system. In addition, the Cinderela project is an academic endeavour with less ambition to create a viable commercial offering. The partners in the project are also partners of SEMiLLA, which provides prospects for collaboration instead of competition.

Another project that is piloting in Amsterdam is the SEMiLLA Sanitation, which is a spin-off of SEMiLLA IPStar. Similar to the Cinderela project, distillation is used for nutrient recovery from urine collected from public urinals. This is again not a competitor but actually a gateway to including a higher range of solutions for wastewater treatment and nutrient recovery to be used in Amsterdam. The collaboration with the municipality can help bring the PPB reactor to the market faster.

### *New market segments*

Development of a software tool to go with the new reactor makes it easier to implement for new and varied users. The software enables ongoing monitoring and the ability to adapt the reactor to specific requirements of the user and their typical waste stream. This is a critical step forward, as the waste stream of a brewery is different from an office building, and therefore the reactor can be more easily adopted by a wide range of users. Crucially the system does not interfere with existing wastewater systems, which is crucial for future implementation in cities at scale, such as in Amsterdam.

Whilst the reactor system is currently being tested and deployed for two specific applications, wastewater treatment and nutrient recovery, with support of specific partners, the system can be applied to new applications, such as applying the purple photoheterotrophic bacteria to cholesterol, and can benefit a wide range of users including: agri-food, life sciences, research institutes, municipalities, and building complexes.

### *User profiles*

The wastewater from **Marineterrein**, as with almost all the households in Amsterdam, is discarded to the central municipal wastewater line, ending up at the water treatment plant. This does not represent an acute problem now, however as the city is growing rapidly the present infrastructure will not be sufficient to treat all wastewater in the future. It is also a missed opportunity not to harness the waste into value by recovering nutrients such as nitrogen and phosphorus and cleaning the water in the meantime. These resources could then be used for plant production, whether as greenery on site or via local food production.

**Waternet** are a semi-public company that deals with wastewater in the city of Amsterdam. The existing wastewater system is large and centralised however they want to shift to a decentralised waste system to help cope with the challenge of excess (over capacity) sewage. Sewage systems today act as fertigation systems but Waternet are interested in taking this a step further by recovering nutrients from wastewater and putting these resources back into the city. Waternet stem to benefit from alternative solutions for water treatment and circular solutions for water management.

## Sustainable urban food production

### *Reused waste*

**80%-90% of wastewater can be recovered as irrigation water for food production – on average 2kg of vegetables per person per day.**[5] Framed alternatively, each 1 tonne of organic waste can produce 30kg of salad.[6]

With many competing solutions for treating organic waste and wastewater, SEMiLLA's distinguishing feature is that it is an end-to-end solution – an integrative approach undertaking both nutrient recovery and water treatment in one process – which is novel in the market and has proven to be attractive for a number of applications and users. The system can be installed as an

[5] Giurgiu, R.M. (2020). 'From waste to resource; closing the loops in the urban water, energy and food nexus – Amsterdam case study. SEMiLLA IPStar. *Current and Future Ways to Closed Life Support Systems, MELiSSA Conference.* Available at: https://en.calameo.com/read/00645362566fd8522cc5c
[6] GROWx. www.growx.co/technology

'on the spot circular loop' and thereby does not require extensive engineering to make it fit for purpose. Waste usually has to leave big cities, whereas this biological, decentralised system creates a local solution to dealing with urban wastewater, enabling waste management within cities.

There are huge economic benefits of zero waste of water, $CO_2$, nutrients, and energy. **"Overall, for every dollar spent on food, society pays two dollars in health, environmental, and economic costs. Half these costs totalling $5.7 trillion each year globally are due to the way food is produced".**[7]

*User profiles*

GROWX Circularity is essential for making vertical farming a cost-effective reality and SEMiLLA can play a role in increasing the closed-loop potential by recovering nutrients from the wastewater treatment to be used in crop production. **GROWx** is a Vertical Farm that operates in the city, with the ambition to be more mindful about resources used in order to improve its' sustainability. GROWx are aiming to become the first 100% sustainable vertical farm in the world, with energy, $CO_2$, water, and nutrients all derived from organic waste and are working with SEMiLLA to create an integrated nutrient loop, turning organic waste into tasty, healthy, and fresh salads, sold at affordable market rates. GROWx are planning to expand to 100 farms around the world in the coming years.

The circular vertical farm uses organic waste streams from the city (supermarkets, restaurants, farms) as inputs in a biodigester for producing biogas and/or $CO_2$ as inputs for the vertical farm. The waste stream of this process would be potential input to the purple bacteria reactor and thus recovering important nutrients as biomass that could be used as fertiliser in the farm. Water and energy are the main recycled inputs, but the synthetic fertiliser has also a significant impact for the environment and economy of the farm.

La Trappe TRAPPIST The **La Trappe Abbey** brewery in the Netherlands produces almost a million cubic meters of wastewater each year. Thanks to the new recycling techniques this water is no longer being sent to a municipal processing plant but is used to irrigate the monks' land and clean beer bottles. MELiSSA are helping make their beer-brewing process more sustainable. The system recovers water and purifies it using membranes. An added benefit is that the system also reduces the brewery's electricity use.

## *Improved product*

Purple bacteria can be classed as a 'super bacteria' which deliver a very high quality microbial fertiliser and thereby high quality food products. Biomass fertiliser features 50-70% protein per gram (dry weight) and contains amino acids. For farmers and fisheries, using the microbial proteins from wastewater is able to improve the food sold, providing healthier food to customers.

Currently, the nutrient recovery process results in mixed fertiliser where nutrients are not separated. In the near future with further developments to the SEMiLLA IPStar Circular System, the hope is to be able to filter out and clean specific nutrients which can be inputted directly into plants, creating a fully closed-loop system.

The nutrients recovered can also be used as a microbial protein, rather than fertiliser, and used by farms and fisheries to stimulate animal growth. Microbial proteins, recovered from the system, have been shown to enhance shrimp and salmon production. Moving forwards, developing the waste proteins as biostimulants to trigger hormones that increase the wellbeing of plants offers huge potential for the agricultural industry.

[7] Ellen MacArthur Foundation (2019). *Cities and Circular Economy for Food*.

### *Increased competitiveness*

The biomass fertiliser and microbial proteins are highly nutritious, in some instances removing the need to buy nutrients and thereby cutting costs. It is hoped that the fertiliser produced from the wastewater will become price-competitive with conventional fertiliser product sold on the market in the near future—creating a new source of revenue for vertical farms. There is a need for policy change to make the bacteria fertiliser competitive, as conventional fertilisers are highly subsidised.

### *Summary of benefits of the new reactor for users*

| Users | Benefits |
|---|---|
| **Municipalities** | • Lower operational costs<br>• Resilient systems circularity<br>• Circular solutions from waste to resource to food |
| **Water boards** | • Decentralised modular innovation in water treatment & wastewater recovery systems |
| **Vertical farmers** | • Water reuse<br>• Recycle nutrient solution<br>• Fertiliser supply<br>• Substrate with fertiliser<br>• Increased market value from new organic products (organic fertiliser)<br>• Safe nutrients, free of contamination<br>• Safe operation with biomass |
| **Breweries** | • Water reuse (low OPEX)<br>• Wastewater discharge (fee for discharge level)<br>• Decrease $CO_2$ footprint<br>• Sell by-products for recovering costs<br>• Fully automated systems (limited human intervention)<br>• Higher circularity improves sustainability branding |

## Providing a range of health and social benefits

### *Healthier living*

Cities will become better places to live with the transition to a circular economy, with benefits ranging from cleaner streets, better air and water quality, and reduced risk of foodborne diseases.

### *Better food for customers*

With moving food production to the urban areas, closer to the majority of the population, the reduction in time to transport the food means that consumers can eat fresh food and take comfort knowing it was produced locally. Recent research suggests that purple bacteria can be beneficial in food as it has lower cholesterol properties. Regenerative and local sourcing can improve the taste, shelf-life, and micronutrient content of food.

### *Addressing food production challenges*

**GROWx** can produce **1 tonne of salad per 1m² per year**.

Vertical farms make better use of space than traditional farms. For example, GROWx currently have 35 layers of farm built up, with potential to double this in the coming years. This helps address food production challenges of feeding a growing global population; an increasing number of which are moving into urban areas.

The feasibility study for the GreenTower in Amsterdam estimated the waste from the building could **create an output of 276 to 575 kg of dried biomass per year**. This quantity controlled for the 100% nitrogen requirement would **result in 377 to 785 tons of lettuce produced per year**.[8]

[8] Giurgiu, R. (2021). *Piloting a raceway reactor for the PNSB cultivation on domestic wastestreams for recovery of nutrients and water treatment as resources for food production.*

# Protecting the environment

## *Reduced emissions*

Recycling waste helps to simultaneously solve energy and climate challenges. Circular vertical farms are carbon-negative as they take $CO_2$ out of the air to feed plants. The process of recycling wastewater leads to a sustainable power source as energy comes from the anaerobic digestion of waste in the form of biogas – the GROWx circular system uses much less energy compared to a traditional vertical farm because of this process.

The metropolitan area of Amsterdam currently imports 3.9 million tonnes of biomass. Replacing some of the imported mass with recovered biomass from waste would result in **an estimated reduction of 600,000 tonnes of $CO_2$ – 3% of the total $CO_2$ emissions of the city.**

Transitioning to circular food economies globally could result in a 4.3 billion tonne reduction in equivalent $CO_2$ emissions, comparable to taking 1 billion cars off the road permanently.[9] It is estimated that a circular economy for food catalysed by cities could save 290,000 lives otherwise lost to outdoor air pollution per year by 2050.[10]

A collaboration between **FABRIC, Circular Economy** and **TNO** estimates a direct **value creation from the project of €30 million, with a $CO_2$ emissions reduction of 300 kilo-tonnes[11].**

## *More environmentally-friendly source of fish feed*

Much of the fishing industry uses ocean feed to provide fish with the nutrients for growth. The process of gathering this feed however is typically highly damaging to ocean ecosystems, with trawlers often damaging the ocean bed and releasing carbon. Using microbial protein with purple bacteria provides an environmentally friendly source of feed and reduces the reliance on non-ecologically friendly feed sources. A recent study[12] from Dr. Abbas Alloul of the University of Antwerp (a SEMiLLA project partner) showed that microbial protein with purple bacteria is successful at boosting the growth of shrimp. Other uses for the feed are being explored but there is hope that this approach can also be used to reduce our reliance on other non-environmentally friendly activities, such as soy-bean production.

# Delivering real economic benefits

The Ellen MacArthur Foundation estimates **an economic benefit for the city of Amsterdam of €600 million.**

The Ellen MacArthur Foundation estimates an economic benefit for the city of Amsterdam of €600 million, from the reduction in food waste and recovering nitrogen and phosphorus from food by products, calculated using metrics on job creation, resources used, cost savings with wastewater treatment.[13]

## *Reduced waste*

The Amsterdam Circular Roadmap estimates that high-quality recycling of organic residual streams, over a period of the next 5-7 years, can result in **an added economic value for the municipality of €150 million per year**.

[9] Ellen MacArthur Foundation (2019). *Cities and Circular Economy for Food*.
[10] Ellen MacArthur Foundation (2019). *Cities and Circular Economy for Food*.
[11] FABRIC, Circle Economy, and TNO (2016). *Circular Amsterdam - A vision and action agenda for the city and metropolitan area*.
[12] A. Alloul et al. (2020). *Purple bacteria as added-value protein ingredient in shrimp feed: Penaeus vannamei growth performance, and tolerance against Vibrio and ammonia stress*.
[13] Ellen MacArthur Foundation (2019). *Cities and Circular Economy for Food*.

Currently, 97% of household organic waste is burned for energy recovery and only 3% is recycled for other purposes. Through edible food redistribution efforts, cities can keep valuable food from going to landfill and address food security issues. The Amsterdam Circular Roadmap estimates that high-quality recycling of organic residual streams, over a period of the next 5-7 years, can result in an added economic value for the municipality of 150 million euro per year. Of that total, 42 million euros (28%) is owed to nutrient recovery, the separation of organic waste results in proteins that can be used in animal feed, for biogas, and for the chemicals sector.[14]

### *Job creation*

The Amsterdam Circular Roadmap estimates **the creation of over 1,200 jobs in the city of Amsterdam**

The Amsterdam Circular Roadmap estimates that the high-quality recycling of organic residual streams, over a period of the next 5-7 years, will lead to the creation of over 1,200 jobs in the city of Amsterdam, on top of 10,000 new jobs in the agricultural sector stemming from the processing of the waste. With the expectation of SEMiLLA to grow into a fully-fledged spin off, there will be a requirement in the coming years for a number of jobs, including software engineers and operators of the system. If objectives are reached, there will be significant job creation – for instance SEMiLLA may develop their own production facilities.

### *Cheaper food*

The reduction in energy intensity as a result of using biogas dramatically lowers the cost of vertical farming and enables produce to be supplied at competitive market rates.

### *Security of supply*

Europe is a net-importer of proteins for animal and plant feed. Developing a closed loop nutrients recovery system with the extraction of microbial proteins creates a supply that makes Europe less economically reliant on imports from South America and other geographies.

In delivering these benefits, the SEMiLLA project directly contributes to **five** of the **United Nations Sustainable Development Goals (SDGs)**:


**Zero Hunger**


**Clean Water and Sanitation**


**Sustainable Cities and Communities**


**Responsible Consumption and Production**


**Climate Action**

[14] City of Amsterdam (undated website). *Policy: Circular economy*. Available at: https://www.amsterdam.nl/en/policy/sustainability/circular-economy/

## Would these benefits have been realised without ESA?

**ESA**, through its Technology Transfer Programme, supported SEMiLLA in the technology and technical aspects of the system, but also with the commercial aspects. SEMiLLA rely on the know-how and IP from MELiSSA, provided through ESA. **The role of ESA is seen as an essential part of the project**, as the space aspect is what defines SEMiLLA and provides a unique selling point; a factor that has helped SEMiLLA attract project partners (such as AMS and GrowX) and develop the technology. The opportunity of funding and support through ESA's development process (feasibility → proof of concept → demonstrator) , with a focus on developing the business case and conducting an impact analysis, was very attractive to SEMiLLA and is acknowledged as a key component in the success to date in developing the technology and system.

"With **ESA's Technology Transfer Programme**, **SEMiLLA can assess the feasibility of the MELiSSA technologies portfolio with direct potential end-users**. The proof of concept is a short-term intense innovation project that validates the study and lays the path for a large-scale demonstrator, thus **bringing the systems closer to market maturity**. ESA's support allows SEMiLLA to optimize the MELiSSA technologies and the business models for terrestrial applications and **creates an ecosystem of public-private partners**. These consortiums work together through the entire value chain from waste to value with the ultimate goal to close the loops and increase sustainability where everybody wins."

*Radu Giurgiu, SEMiLLA*

## ... with further development and benefits to come

At this stage, with the Proof of Concept complete and providing promising results for nutrient recovery of purple bacteria, further work is needed to test the scalability and further applications of the SEMiLLA IPStar Circular System. In particular, there is strong evidence for using the nutrients recovered as biostimulants to improve plant growth. The low TRL (level 4) of the technologies and unanswered questions are holding the technology back from direct commercialisation (for now). Therefore, further research and development is planned to integrate the system at full scale will help demonstrate the system for deployment in cities and thus lead to sales opportunities. The project to date has shown great promise and whilst the total impact is uncertain, there is much promise and optimism that SEMiLLA and others, with the support of ESA, have made a significant breakthrough that will help address several global challenges in the years to come.