

Socio-economic benefits from ESA Technology Transfers

A report for **eesa**



CASE STUDY: WASTEWATER RECYCLING (URIDIS)

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No such thing as a waste product: using space technology to recycle urine

Humans require large volumes of oxygen, water and food to survive in space. Currently, these vital resources are delivered to astronauts on the HYDROHM International Space Station (ISS) in Low Earth Orbit (LEO) by expensive resupply missions. Yet in the future, with ambitions for humans to return to the Moon and reach Mars, it will be vital to create a closed-loop, circular life support system aboard spacecraft, recycling waste products into oxygen, EOOS LAUFEN water and food. The MELiSSA project has been researching this loop for over 30 years, aiming to develop a system for long-term space travel that eawag decreases the amount of resources required on board the spacecraft to maintain a crew.



BILL& MELINDA MELiSSA (Micro-Ecological Life GATES foundation Support System Alternative) is a gent: European project led by the European Space Agency (ESA), bringing 50 research institutes and organisations together to develop circular life support systems for the ISS and beyond.

One crucial waste product to recycle is urine. Urine is an important source of water and nutrients, yet is challenging to recycle as it rapidly degrades, and so requires fast stabilisation. Existing chemical solutions can be used to recycle urine, but the heavy mass of chemicals and bulky equipment needed presents a challenge for the use of this existing technology in space, where resources, weight and capacity are limited.

Under the PhD programme of the MELiSSA Foundation (POMP), the URIDIS concept was developed at Ghent University between 2016-2020. Ghent University holds a patent on the technology, with ESA holding rights to the space application for the MELiSSA project. URIDIS is an innovative technology using electrochemical urine alkalinisation to stabilise the urine using electricity, so that valuable nutrients can be extracted. As an add-on to URIDIS (currently being investigated within the MELiSSA project), a concentrated nutrient solution, which can be used as a fertiliser, and biomass, which can be used as a fertiliser, feed or food ingredient, can also be created from the stabilised urine.

Space technology brought down to Earth ...

Scientists at the University of Ghent recognised the potential for terrestrial applications of the URIDIS technology, founding Hydrohm in 2020. Toilet systems have received remarkably little innovation in recent years, yet account for over 70% of water consumption in non-residential buildings, with the average dual flush toilet using 4-6 litres of water and old-style systems using more than double that at 13 litres of water¹. Furthermore, hygiene is a major issue in public toilets; combating pathogen spread and unwelcome odours requires regular cleaning, a costly process. URIDIS has the potential to overcome both of these problems.



Hydrohm is using technology and expertise developed at the University of Ghent for the MELiSSA project to develop sustainable, hygienic toilet systems for use on Earth.

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¹ Waterwise, n.d. Save Water. Available at: <u>https://www.waterwise.org.uk/save-water/</u>

LAUFEN

Hydrohm have partnered with Laufen, a Swiss bathroom specialist that are leaders in sustainable bathroom design. The firm manufactures a source-separating toilet that is capable of diverting urine away from other waste, without necessitating changes in user behaviour. Since urine contains 50-80% of the

nutrients in wastewater, yet accounts for only 1% of the volume of wastewater², it is important to divert urine from wastewater at the first stage.

Laufen's source-separating toilets have been key to designing a user-friendly, sustainable system. The toilet builds on a design patented by Viennese design company EOOS and the Swiss water research institute, EAWAG, using surface tension to divert the urine down a hidden channel. The toilet then flushes as normal, with minimal flush water going down the urine channel. The idea was developed as part of the Bill and Melinda Gates Foundation's Reinvent the Toilet Challenge, which aims to spur the invention of new technologies to provide safe sanitation to everyone.



Image: Laufen

Hydrohm uses the patented URIDIS technology, combined with a self-cleaning toilet system new for the terrestrial application:



Image: Hydrohm

The urine is processed using the space heritage technology, which uses a urine buffer and a URIDIS electric cell to separate the nutrients (phosphorus, nitrogen and salt) from the water. As an

² Lam, L.; Kurisu, K.; Hanaki, K. Comparative Environmental Impacts of Source-Separation Systems for Domestic Wastewater Management in Rural China. J. Cleaner Prod. 2015, 104, 185–198; Lundin, M.; Bengtsson, M.; Molander, S. Life Cycle Assessment of Wastewater Systems: Influence of System Boundaries and Scale on Calculated Environmental Loads. Environ. Sci. Technol. 2000, 34, 180–186; Maurer, M.; Pronk, W.; Larsen, T. A. Treatment Processes for Source-Separated Urine. Water Res. 2006, 40, 3151–3166

add-on, valuable nutrients can be used for fertiliser, as in space. In addition, **the salts from the urine are used to make disinfecting flush water, which helps keep toilets hygienic**, adding significant value to the terrestrial application.

Providing a 'Place to Pee'

In summer 2021, Hydrohm trialled their technology in Ghent's Blaarmeersen Park, with the support of the City of Ghent, Laufen and water company, Farys. The 'Place to Pee' installation featured a mobile toilet block containing 2 urinals and 3 source-separating toilets from Laufen. Hydrohm successfully treated the urine of over 3,500 visitors and received positive feedback on the Laufen source-separating toilet and disinfecting flush water. In the short term, Hydrohm hope to see their system used in similar settings, for example public toilets



Image: Hydrohm

and portable toilets for events, before eventually selling the system to sustainable developments, to be incorporated within the infrastructure of public, non-residential buildings with high toilet usage.

Potential for significant socio-economic benefits

Whilst Hydrohm is looking for full commercial deployment within 2022, with the aim to install for early movers in 2023/2024, there are some initial socio-economic benefits beginning to emerge, with an indication that larger, wide-reaching impacts will materialise through its successful commercialisation, including for the businesses involved, for the European industrial landscape, and for broader society and the environment.

Creating a new spin-off company within the European industrial landscape

Commercial opportunities

The potential for commercialisation of the urine-recycling space technology motivated the creation of Ghent University spin-off, Hydrohm, and is now a near-term goal for the company.

After a successful trial of their technology last summer, **Hydrohm are looking for their first commercial customers** willing to implement the URIDIS system. The firm is preparing for **deployment in 2022, with installation for early movers from 2023-24**. With ESA's help, Hydrohm are confident that they have created a product that is not only sustainable, but also offers strong commercial opportunities through the addition of the disinfecting flush water systems, which reduce maintenance and cleaning costs, as well as the potential for additional nutrient recovery for fertilisers. Hydrohm's business model involves selling the system to commercial users, then providing continued maintenance after installation.

Furthermore, the URIDIS technology has broadened the commercial opportunities to bathroom specialists Laufen, who will benefit directly from sales in partnership with Hydrohm, as well as the increased interest and awareness in sustainable toilets generated by ongoing demonstrations of their technologies working together in a combined solution. In the future, Laufen hope that the source-separating technology can become a feature across their collections, in part aided by this partnership.

A targeted **5% market share** in Dutch and Belgian **public toilets** by 2027 by Hydrohm, equivalent to **450 toilets per year**

Job creation and skills development

The creation of Hydrohm has created **employment opportunities** within the Belgian employment landscape, introducing a new company within the industry, along with a novel technological concept.

Additionally, developing the project has **expanded the skillsets within the company**, shifting from an academic perspective on the technology at the University of Ghent, towards a commercialised product, whilst broadening the required technical skillsets, for example regarding the knowledge of control systems.

Furthermore, the company has developed expertise in the wider context of safe, sustainable toilet systems and the requirements of end users. Ongoing demonstrators and discussions held with potential customers such as local governments have allowed for **knowledge sharing** from the company to other actors who can develop knowledge about the importance of water recycling and the benefits arising from yellow water recycling specifically.

New partnerships

User profile



The City of Ghent funded the 'Place to Pee' demonstrator project in Ghent's Blaarmeersen Park, after Hydrohm successfully bid for grant funding.

Ghent has ambitions to become a technology and circular economy hub and is working towards this ambition through its Cleantech Cluster, a joint project between the City of Ghent, North Sea Port, University of Ghent, Province East-Flanders, Development Agency East-Flanders and Clean Flanders. As part of this ambition, the city has funded many circular economy projects, since 2012.

The 'Place to Pee' project helped the city to promote cleantech and the circular economy, through the prominent infographics on the toilet system installation and a feature in the city magazine. Moreover, the project was well-suited to the city's strategic vision and, ultimately, it is hoped that projects such as this will promote the city as an attractive place to live and work.

The City of Ghent remain in contact with Hydrohm and see potential for future collaboration, for example, the provision of portable toilet systems for summer festivals. If Hydrohm wishes to supply toilet systems to the city on a permanent basis, they would have to apply to the facilities department in a bid to become the default supplier, when an opportunity next arises.

Over the last two years, Hydrohm has forged several exciting partnerships. As mentioned, Hydrohm and Laufen's products are highly compatible and the partnership with Laufen has been crucial for the technology behind the separation of the yellow water, as well as providing a simple product that can be used easily by end users.

Moreover, the partnership has enabled Hydrohm to connect with hotels and developers open to sustainable solutions, with whom Laufen had existing relationships, whilst Hydrohm has opened a channel of communication between Laufen and municipal government actors, thereby **creating opportunities for both firms**.

Hydrohm have also partnered with a manufacturer to produce their URIDIS system, as well as having a close relationship with Ghent University and the City of Ghent.

Offering a sustainable and hygienic solution

A cost-effective sustainable solution

By targeting buildings with high toilet usage (over 1,000 visits a day), Hydrohm are in a unique position to offer a product which is **not only sustainable**, **but also cost effective** for customers. The system is appropriate for any building or event with sufficient scale to make the system cost-effective, e.g., office blocks, public toilets, temporary toilet blocks for festivals, etc. Hydrohm's own analysis shows that for high-usage buildings, over a number of years the URIDIS system has the potential to be as low cost as a classic toilet system, whilst bringing additional sustainability benefits.

For example, use of this system can help customers to **promote a sustainable brand image**, with a clearly visible example of their commitment to the environment, yet is cheaper than other sustainable solutions, requiring only electricity rather than the purchase of chemicals. Commercial users further benefit from **reduced cleaning and maintenance costs**, as the toilet system uses disinfecting flush water to clean itself with every flush rather than requiring a person to carry out the cleaning.

Hydrohm hope that in the future, sustainable buildings certification criteria will be broadened to include sustainable toilet systems such as URIDIS. These types of certifications can increase the value of a building, thus potentially making URIDIS a more attractive investment for building owners.

Cost payback of just 7 years, based on 1,000 toilet visits a day (realistic for many public buildings) and even lower with greater toilet usage

Small space requirements

The closet-sized URIDIS system is **highly compact** in comparison to other sustainable solutions, due to its space origins. To process the urine of 1,000 toilet visits a day requires just 2.5m² floor space for the urine buffer tank, disinfectant storage tank and technology closet. In addition, it does not require the use of chemicals to treat the urine, so commercial users save the space that would have been required to store chemicals. This makes the URIDIS system a practical addition to buildings in comparison to alternative sustainable solutions, as well as enabling portable toilet solutions.

Improved user experience

Hydrohm's URIDIS system provides disinfecting flush water created within the system using salts extracted from urine to clean toilets as they flush. This means that **the system is more hygienic than a classic toilet system, killing potentially dangerous pathogens**. This is especially important for public toilets, which are in high use by potentially hundreds of different people a day.

URIDIS could also help to remove the characteristic public toilet odour. One reason why toilets may smell is that urea, a nitrogen-rich compound present in urine, produces odorous ammonia gas when combined with water. By diverting the urine at the source, quickly stabilising it and extracting useful nutrients, Hydrohm's **URIDIS technology helps combat unpleasant toilet odours**.

Furthermore, disinfecting flush water keeps the toilet bowl clean, eliminating microbial activity and consequent smells with every flush.

Supporting the environment through water and energy savings

Water savings

Up to 60% water savings made possible

In space, there is a vital need to recycle water, and in the framework of the MELiSSA project, URIDIS was developed with the intention of creating a closed-loop system, where all waste products are recycled. Hydrohm's terrestrial technology builds on the space application and provides water savings of up to 60% relative to the average toilet.

Water is relatively cheap to buy, so water savings have little private commercial benefit, yet the external benefit is significant. Drought and water shortages are global problems, set to only become more pressing as climate change worsens, and drought has affected Belgium and the Netherlands in recent years³.

Energy savings

By recycling flush water, Hydrohm's system not only reduces water usage, but also reduces wastewater and consequent pressure on wastewater treatment systems.

Most toilet wastewater is transported via sewage pipe networks to centralised treatment plants, where wastewater undergoes an energy-intensive process using microbes to clean the sewage. This process is inefficient since urine accounts for less than 1% of domestic wastewater flow, yet comprises 80% of total nitrogen, 50% of total phosphorus and 65% of potassium⁴. By separating urine and other wastewater components at source, Hydrohm's technology has the potential to be far more energy efficient than current systems.

Though data for specific energy savings from the URIDIS system are not yet available, a recent study⁵ found that urine diversion technologies (such as source separating toilets) had better environmental performance than a normal toilet system, producing 29-47% less greenhouse gas emissions and consuming 26-41% less energy.

Supporting the wider environment

The production of **nitrogen fertiliser accounts for 1.2% of global energy use**, whilst humans produce enough urine to replace around a quarter of nitrogen and phosphorous fertilisers.

A vital component of the MELiSSA project is food production. Recycling water is key to growing food, but for a closed-loop system, it would also be necessary to recycle the valuable nutrients in

⁵ Hilton, S. P., Keoleian, G. A., Daigger, G. T., Zhou, B. & Love, N. G. *Environ. Sci. Technol.* 55, 593-603 (2021)



³ Europe Now, 2018 Water Stress and Pollution in Belgium: The Internationalization and Regionalization of a Policy Problem.<u>https://www.europenowjournal.org/2018/12/10/water-stress-and-pollution-in-belgium-the-internationalization-and-regionalization-of-a-policy-problem/</u>

International Groundwater Resources Assessment Centre, n.d. *Drought in the Netherlands and its impact on groundwater resources* <u>https://www.un-igrac.org/stories/drought-netherlands-and-its-impact-groundwater-</u>

resources#:~:text=Nevertheless%2C%20probably%20the%20most%20pressing.and%20soil%20as%20a%20result. ⁴ Ledezma, P., Jermakka, J., Keller, J., Freguia, S., 2017. Recovering nitrogen as a solid without chemical dosing: bioelectroconcentration for recovery of nutrients from urine. Environ. Sci. Technol. Lett. 4, 119-124. https://doi.org/10.1021/acs. estlett.7b00024.

our urine. As an add-on to the URIDIS technology, the MELiSSA project is investigating the potential to remove phosphorous and nitrogen to use as fertiliser.

Such nutrient recovery has enormous potential environmental benefit since **fertiliser production** is crucial to our food supplies, yet highly polluting. Production of nitrogen fertiliser is dependent on natural gas and responsible for around 1.2% of global energy use and subsequent greenhouse gas emissions⁶. Meanwhile, globally humans produce enough urine to replace around a quarter of current nitrogen and phosphorus fertilisers⁷, if this urine were collected and recycled. As such, though the nutrients recovered from a single toilet may be small, in the aggregate technologies such as URIDIS, combined with nutrient recovery, have the potential to drastically reduce our emissions.

In addition, by recovering urine at source, the **URIDIS technology can ensure that these nutrients do not flow into water bodies and cause eutrophication**. Eutrophication is where there is excessive growth of plants and algae due to photosynthesis (often caused by excess nutrients) and is threat to freshwater and coastal ecosystems globally. A recent study found that urine diversion technologies, similar to Hydrohm's product, had 25-64% lower eutrophication potential than normal toilet systems⁸. Therefore, recycling the nutrients in urine is beneficial to the environment in a number of ways.

Furthermore, the terrestrial application developed by Hydrohm recycles the salts in urine to create disinfecting flush water on site. By disinfecting the flush water in this way, users need not clean toilets so regularly, saving on potentially harmful chemical cleaners, such as bleach.

Offering a flexible solution to complement, or avoid huge interconnected, wastewater systems

Providing flexible support to ageing infrastructure

Wastewater systems in developed countries are typically over 50 years old and approaching end of life, at the same time as urban populations are growing, becoming increasingly dense, and legislation on wastewater treatment is becoming progressively more stringent to protect water bodies from eutrophication⁹. This is creating an **increasingly urgent need to transform how we treat our waste**.

Yet, wastewater systems require significant investment, intended to last 50 years or more, which creates a danger of 'locking into' a technology today, only to find it is outdated in 10-20 years as newer technologies become available. Experts in the field argue¹⁰ that this creates a vital role for distributed solutions such as urine diversion, which can be implemented stepwise, offering **a more flexible solution**.

Hydrohm's technology would allow councils or local governments to reduce the strain on current infrastructure, without requiring a radical (and expensive) reimaging of existing systems and all the while reducing greenhouse gas emissions.

¹⁰ Freguia, S., Sharma, K., Benichou, O., Mulliss, M., Shon, H.K. Journal of Hazardous Materials. 415 (2021)



⁶ Dawson, C. J.; Hilton, J. Fertiliser Availability in a Resource-Limited World: Production and Recycling of Nitrogen and Phosphorus. *Food Policy* 2011, 36, S14–S22; Wood, S.; Cowie, A. *A Review of Greenhouse Gas Emissions for Fertiliser Production*; Cooperative Research Centre for Greenhouse Accounting, 2004; Vol. 38, pp 1–20. ⁷ (2020). 7. Simha, P. et al. Sci. Total Environ. 765, 144438 (2021).

 ⁶ Hilton, S. P., Keoleian, G. A., Daigger, G. T., Zhou, B. & Love, N. G. Environ. Sci. Technol. 55, 593-603 (2021)
⁹ Manning, L.J., Graham, D.W., Hall, J.W., 2016. Wastewater systems assessment. The Future of National Infrastructure: A System-of-Systems Approach. https://doi.org/10.1017/CBO9781107588745.008

Strong potential impact in developing countries

Though Hydrohm is currently focussed on incorporating its system into existing sewage infrastructure in Belgium and the Netherlands, there are also potential benefits from a more radical reimagining of sewage systems, in which technologies such as URIDIS could play key roles. This approach may be particularly well suited to applications in developing countries, helping us to reach the United Nation's Sustainable Development Goals, which include clean water and sanitation for all (Goal 6).



URIDIS is a localised solution. Urine treatment is performed on site and can be done anywhere, requiring only electricity, water (can be rainwater), connection to a sewer and separate urine and flush water piping. This is **potentially ideal for developing country applications**, where many people today are not connected to centralised sewer systems and may be in remote areas, and so more localised solutions are suitable. Experts in the field argue that the future of sewage lies in more localised solutions, where waste is treated on-site, rather than huge inter-connected, city-wide wastewater treatment plants¹¹. Such a solution could allow countries to bypass the substantial cost of largescale sewage infrastructure entirely.

57% of the world's population is not connected to centralised sewer systems.

Secondly, Hydrohm's technology has the potential to save up to 60% of the water used by a classic toilet system. This is potentially **invaluable in locations where water is scarce**, a problem particularly apparent in the developing world and only getting worse. Globally, 2.3 billion people live in water stressed countries¹² and 73% of those affected by water scarcity live in Asia¹³.

Thirdly, unlike other localised wastewater recycling systems, the URIDIS technology uses electricity to treat the urine, not requiring the purchase and storage of bulky chemicals. This is perfect for remote locations where electricity can be generated on site (e.g. solar power), but acquiring and transporting bulky chemicals would present a challenge.

Lastly, the recovery of valuable nutrients to use as fertiliser could free farmers from reliance on purchasing expensive fertilisers from elsewhere, benefitting local agriculture.

Would these benefits have been realised without ESA?



ESA have played a pivotal role in Hydrohm since its conception, with the URIDIS technology being created as part of the ESA project, MELiSSA. Furthermore, one of the company founders worked on the technology as part of her PhD at Ghent University, under the POMP1 PhD programme of the

MELISSA Foundation, supported by ESA. As such, the underlying science and technology is derived from ESA-funded research. Once Hydrohm was created as a spin-off, ESA continued to provide strong support, funding a proof-of-concept study from June 2020-2021. After the success of this project, Hydrohm received follow-up funding to complete a demonstration activity from April 2022-2023.

¹¹ Ward, C. *Nature*. 602 (2022)

¹² UN Water, 2021. Summary Progress Update 2021: SDG 6 – water and sanitation for all. Available at:

https://www.unwater.org/publications/summary-progress-update-2021-sdg-6-water-and-sanitation-for-all/

¹³ Burek, P., Satoh, Y., Fischer, G., Kahil, M.T., Scherzer, A., Tramberend, S., Nava, L.F., Wada, Y., et al. (2016). Water Futures and Solution - Fast Track Initiative (Final Report). IIASA Working Paper. IIASA, Laxenburg, Austria: WP-16-006. Available at: http://pure.iiasa.ac.at/id/eprint/13008/

'**ESA's role has been crucial for the company**. A lot of the basic research and development, which are high risk for investors, were done for ESA and through ESA. Since many of the benefits from URIDIS are external and around sustainability, it is difficult to start a company without any institutional support, such as the connection with ESA.'

Pieter Naert, Hydrohm

... with further development and benefits to come

Having tested their technology in Ghent last summer, Hydrohm know that their system can stabilise urine and produce a disinfectant solution. Starting in April 2022, Hydrohm are beginning ESAfunded demonstration activities, further testing the technology, **optimising the design and assessing the longer-term functioning of the system**. Hydrohm are raising awareness of the product and are in conversation with target customers, with the **ambition to get the product to market in 2022**, with the first installations in 2023-2024.

They will initially focus on public toilet systems and portable toilet systems for events, given the shorter timelines involved, before working with public and private agents to incorporate the URIDIS system in new sustainable buildings. This is a longer-term ambition given the timescales involved from designing a large building to finishing construction. Initially Hydrohm will focus on the Belgian and Dutch markets, given the importance of geographical proximity for maintenance, but there are **ambitions to grow the company internationally,** working with local partners for maintenance work. Hydrohm aspire for their technology to be standard place in any building with the necessary scale to accommodate it.