ETM Case study 2: Renewable resources for a circular economy

Waste and wastewater systems were initially designed and implemented to protect humans and the environment from pollutants. Nowadays, circularity is an additional design criterion for systems that convey materials in our society. This new criterion implies that, after use, materials should remain available for societal reuse and that there should be minimal value destruction. This striving for circularity is driven amongst others, by the rising awareness that natural resources cannot endlessly be drained from the earth without jeopardizing planetary health, regardless of the timing of specific scarcity threats. Both societal and ecosystem stability are depending on establishing a circular economy. Phosphorous is an element for which scarcity and related geopolitical issues are widely known, but exhaustion of other elements, such as copper and zinc, is also a threat. Furthermore, circular material cycling can prevent environmental impacts often associated with the current linear material use.

We evaluate the options to restore the cycling of resources (water, carbon, nutrients, minerals), especially their recovery from waste streams, by combining microbiology and physical-chemical processes.

An important waste stream in our society is domestic wastewater. Current wastewater collection and treatment systems were primarily designed to protect humans and the environment from potential harmful effects of sewage. They were not primarily aimed, and are not well suited, for the recovery of the valuable resources sewage contains. Organic matter in wastewaters is often removed via the activity of aerobic microorganisms, resulting in carbon release to the air in the form of CO_2. The forced aeration taking place at the treatment plants consumes large amounts of energy, whereas the organic matter itself is a potential source of energy. Additionally, the nitrogen and phosphorous are traditionally regarded as pollutants and not as resources - a vice not a virtue. A lot of effort is spent on removing these compounds from sewage, whereby the nitrogen is released as N_2 to the air. At the same time society is producing artificial N-fertiliser from the air through the energy-intensive Haber-Bosch process. Municipal wastewaters also contain the other nutrient elements present in human excreta like potassium, magnesium, selenium, boron, etc. Last but not least, sewage contains the most essential resource for all life on earth: water.

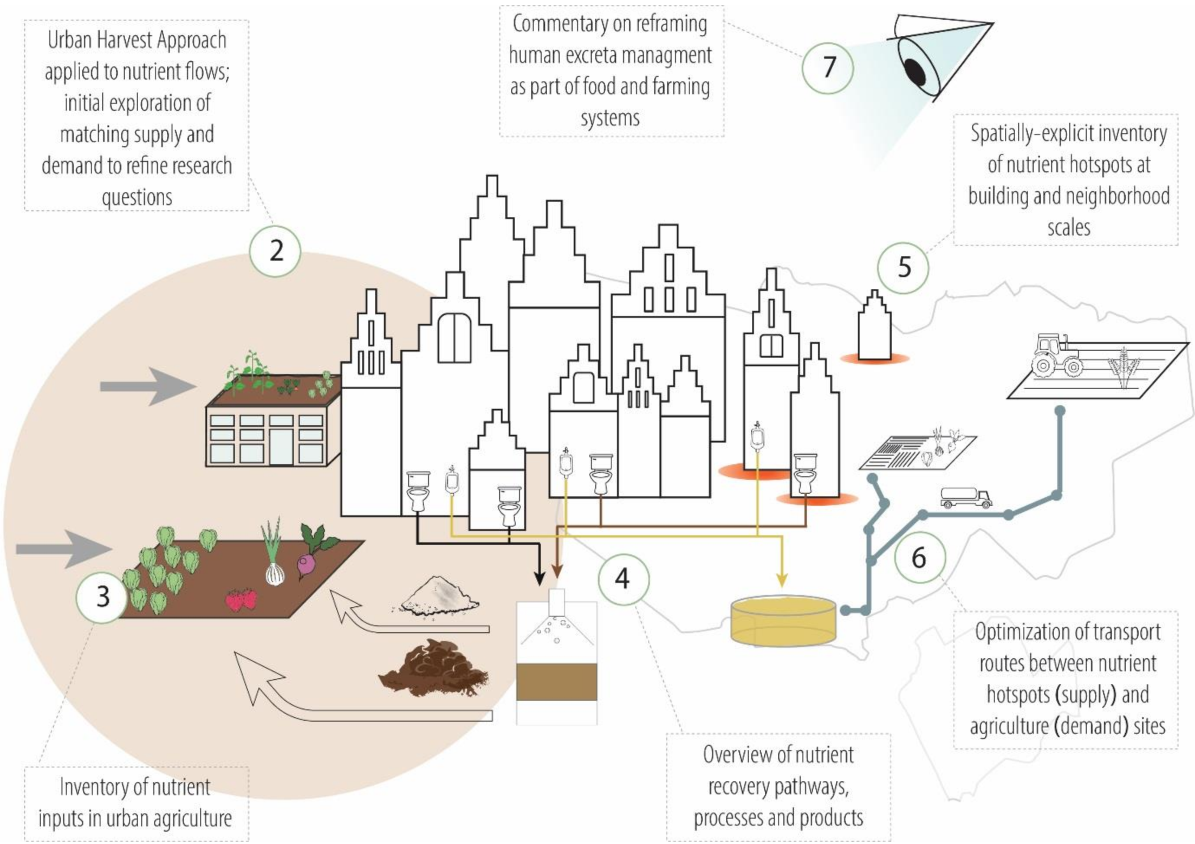

Figure 1: Overview of new sanitation concepts connected to agriculture

Since about 20 years, we work on new concepts with circularity as a prime design criterion besides environmental and hygienic safety. This has led to various new overall sewage system concepts, with the common characteristic that dilution of resources is prevented as much as possible by separating human excreta (black water), which carry the bulk of organic matter and nutrients, from dilute grey water originating from the remainder of household activities such as showering and laundry (Figure 1). In the Netherlands, this concept is known as Novel Sanitation. In these systems, industrial wastewaters are also separately managed. Separation at source has the added advantage that excreta – containing the nutrients originating from food - are not mixed with pollutants from other streams, such as personal care products, industrial heavy metals, flame retardants and microplastics. Thus, the challenges to make micropollutant-free nutrient products from the concentrated flow of excreta, containing the nutrients originating from food, are fewer. Compared to sewage, blackwater flows are at least 10 times smaller. Recovery of resources from this concentrated flow is much more efficient, as well as the removal of unwanted compounds such as the mentioned micropollutants. In a new breakthrough concept developed by us, highly concentrated blackwater is digested at high temperature to simultaneously produce biogas and inactivate pathogens, a step toward reuse of the resulting stream as an organic fertiliser product. The high temperature anaerobic digestion is currently being further developed and demonstrated in the framework of Horizon 2020 project Run4Life in which we are a partner.

In Europe, Novel Sanitation systems are currently implemented in new residential areas of up to 2000 inhabitants. At these sites state-of-the-art and innovative technological solutions are integrated, aiming at integrated optimal resource recovery while ensuring human and environmental safety. Countries with executed and planned projects include Canada, Sweden, Germany, Belgium and the Netherlands. Figure 2 shows the four demonstration sites of the Run4Life project. In this project Novel Sanitation is demonstrated at full scale, showing that the concept is mature.

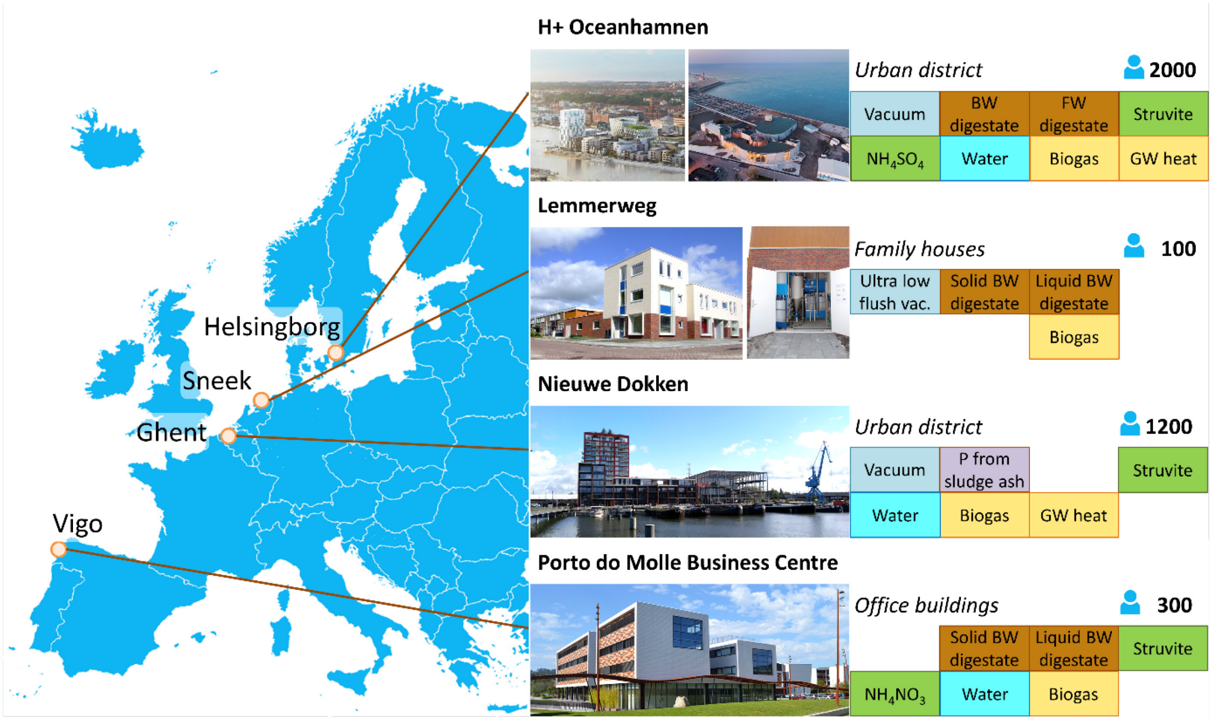

Figure 2: Overview of the four demonstration sites of the Horizon 2020 project Run4Life and the resources recovered at each site (www.run4life-project.eu).

The realization of a circular economy also entails finding alternative sources for a wide range of carbon-based chemicals that currently originate from fossil sources or environment-degrading agricultures such as palm oil industries. Microbial chain elongation is an alternative method developed by us to produce 'oily' carbon-based chemicals. It can be employed to recycle organic waste streams and to sequester CO_2 to form products such as isobutyric acid, n-caproic acid and n-hexanol. More recalcitrant wastes can also be valorised by introducing a gasification step – a high-temperature process that transforms any type of carbon material into syngas, a mixture of CO, H_2 and CO_2. Syngas can further be fermented to several products, including n-caproic acid and n-hexanol. Further development of these technologies facilitates a sustainable transition towards a more circular economy. Microbial chain elongation fermentation from organic waste streams is currently undergoing its first full-scale implementation at a demonstration factory in Amsterdam by ChainCraft B.V., an ETM spin-off company.

More stringent legislation on both wastewater discharge and waste storing facilities and an increasing scarcity of resources leading to higher metal prices creates a need for improved metal removal and recovery technologies. The clusters sulphur reducing technology is applied in the Dominican republic to recover copper. In order to extend the potential of this technology, we are currently studying the biological reduction of sulphur by extremophilic microorganisms, growing at low pH and high temperature. Microorganisms that reduce sulphate and elemental sulphur to produce sulphide are promising for solving circularity challenges in several industries such as viscose production, tanneries, and the mining and metallurgical industries. Sulphide precipitates heavy metals, which can thereby be separated from the liquid and recovered. Such a microbial process is for instance successfully applied at the zinc smelter plant of Nyrstar (Budel-Dorplein, the Netherlands) to avoid zinc pollution and minimise zinc losses.

Figure 3: Left: the zinc factory in Budel, the Netherlands where metal recovery has been implemented. Right: the shore of the Rio Tinto in Spain, where gold, silver, copper and other metals have been mined for centuries. The river's red colour is due to the high amounts of dissolved metals and its high acidity (pH=2).

The possibilities for biorecovery concepts to contribute to recovery of resources, upgrade of materials, production of chemicals, protection of water sources, reduction of energy and use of chemicals are as diverse as the bacteria that are employed in such processes (Figure 3). The possibilities nature has to offer are abundant and have far from dried up. As previous results have demonstrated, biorecovery concepts we created have now developed into full-scale technological solutions, and others will be realised in the future.