



## From Waste to Resource Recycling Sewage Sludge Ash into Phosphate-rich Plant Fertilizer

How the phosphorus contained in sewage sludge can be used to improve the closing of the phosphorus cycle.



### Motivation

Phosphorus is an essential fertilizer in the agricultural production but is limited, regionally concentrated, and mined under harmful conditions. It has been on the EU's critical raw materials list since 2014 due to its importance and high import dependency. Around 90 % of phosphorus in wastewater is retained in sewage sludge – nearly 7,000 tons yearly in Austria and 8,000 tons in the Czech Republic.

Sewage sludge use differs in the Czech Republic, agriculture remains dominant, whereas Austria incinerates most sludge, with Vienna using mono-incineration. By 2033, Austria will mandate, beside onsite solutions, the incineration for larger wastewater treatment plants, requiring 80% phosphorus recovery from the ash. The Czech Republic plans stricter laws limiting agricultural use, pushing for alternative sludge disposal, with thermal utilization as the primary option.

Recovery of phosphorous from sewage sludge ash is challenging due to the co-pollution with heavy metals. In addition, the use of industrial acids for leaching and consequent precipitation renders it an economically and environmentally challenging process. In PHOS4PLANT, alternative ways for incinerating sewage sludge, leaching, and precipitating phosphorous are explored that could represent an environmentally friendly alternative to obtain high quality fertilizer based on biological processes.

### The current state of research in Work Package 3

#### *Bioelectrochemical Phosphorus Recovery in the Form of Struvite*

Following the leaching of phosphorus from sewage sludge ash using biogenic sulfuric acid, the dissolved phosphorus is subsequently recovered through precipitation as struvite. Struvite (ammonium magnesium phosphate) is a valuable recycled fertilizer and represents an important pathway for sustainable phosphorus recovery.

Precipitation occurs under alkaline conditions at a pH of approximately 8–10 and is typically achieved through the addition of bases such as sodium hydroxide. In this project, a bioelectrochemical system for struvite formation is investigated as an alternative to conventional chemical precipitation (see Figure 1). The system consists of a bioanode and a cathode separated by a membrane. At the bioanode, a mixed microbial culture derived from sewage sludge is enriched. This culture has been analyzed and characterized using molecular biology techniques by Masaryk University (MU). The microorganisms are continuously supplied with synthetic wastewater as a substrate, enabling them to degrade the contained organic compounds to  $\text{CO}_2$ . During this process, electrons are released and transferred to the cathode via an external circuit. At the cathode, water is reduced to hydrogen ( $\text{H}_2$ ) and hydroxide ions ( $\text{OH}^-$ ). The generation of hydroxide ions increases the pH in the cathode compartment, thereby establishing the alkaline conditions required for struvite precipitation. Under these conditions, ammonium ( $\text{NH}_4^+$ ), magnesium ( $\text{Mg}^{2+}$ ), and phosphate ( $\text{PO}_4^{3-}$ ) ions dissolved in the electrolyte react to form struvite. The resulting crystals either deposit on the cathode surface (see Figure 1) or form within the bulk solution.

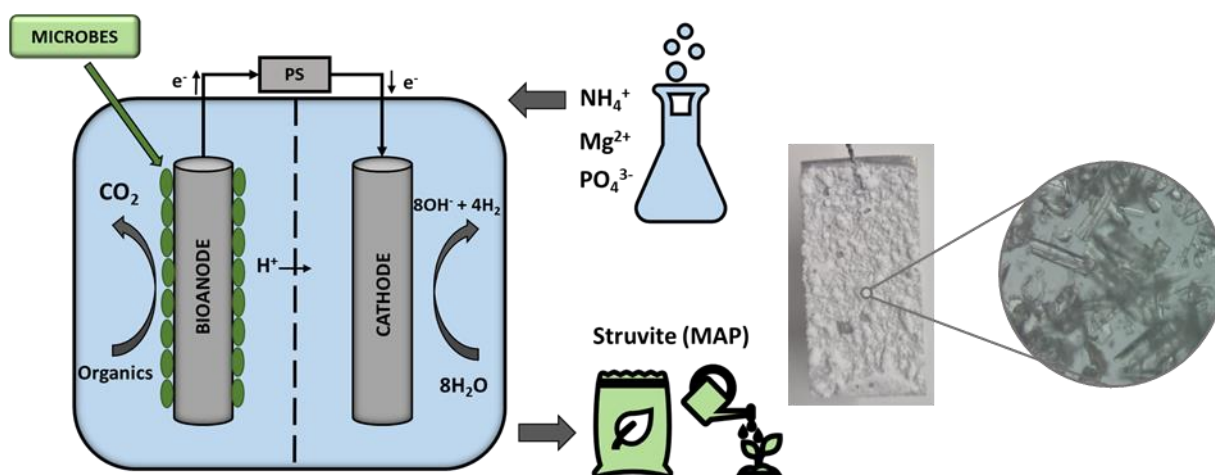


Figure 1: Schematic representation of the bioelectrochemical system and struvite formation at the cathode, including a microscopic image of the precipitate.

The precipitated struvite is subsequently separated by filtration, and its analytical characterization is carried out using X-ray diffraction (XRD) at MU. To evaluate the recovery efficiencies of phosphorus, magnesium, and ammonium, the catholyte is analyzed after struvite removal for residual ion concentrations using photometric methods. In addition, inductively coupled plasma mass spectrometry (ICP-MS) analyses are conducted at MU to accurately determine the phosphorus recovery rate.

The bioelectrochemical system enables the necessary increase in pH without the addition of external bases, thereby enhancing the resource efficiency and overall sustainability of the process.

Initial experiments were conducted using a synthetic leachate solution containing the ions required for struvite formation. The molar ratios of phosphorus, magnesium, and ammonium were systematically varied to optimize phosphorus recovery. In addition, different membrane types were evaluated to investigate their influence on system performance.

Using the synthetic leachate, phosphorus recovery efficiencies of over 90% have already been achieved. Preliminary X-ray diffraction (XRD) analyses confirm the formation of struvite alongside other phosphate-containing phases.

In the next phase of the study, real leachates obtained from phosphorus extraction using biogenic sulfuric acid will be applied in the bioelectrochemical system to assess process performance under more realistic conditions.

### *Laying the Groundwork:*

#### *Data Requirements for Life Cycle Assessment and Life Cycle Costing*

Another activity of PHOS4PLANT aims to rigorously evaluate the environmental performance and economic viability of the project's innovative phosphorus recovery technologies. What is a Life Cycle Assessment — and why does it matter here? A Life Cycle Assessment (LCA) is a standardised method (ISO 14044) for quantifying the environmental impacts of a product or process from cradle to grave — from raw material extraction all the way to disposal. Rather than looking at a single emissions chimney or energy meter, LCA paints the full picture. Alongside the environmental analysis, a Life Cycle Costing (LCC) assessment captures the full economic costs across the same system boundary.

Together, these tools allow PHOS4PLANT to answer a key question: is the new bio-based phosphorus fertilizer genuinely better — environmentally and economically — than conventional alternatives? Three process chains are being compared:

- V1 – PHOS4PLANT fertilizer: sewage sludge incineration (rotary kiln) → carbonation → bio-based leaching (plus conventional leaching as a benchmark) → precipitation
- V2 – Conventional waste-based fertilizer: incineration (fluidized bed) → chemical leaching (HCl or H<sub>2</sub>SO<sub>4</sub>) → precipitation
- V3 – Fossil-based fertilizer: conventional production from primary mineral resources

The team developed a comprehensive data collection framework — a set of structured, user-friendly Excel survey forms and an accompanying guidance document — enabling all project partners to record the material and energy flows of their processes in a consistent, LCA-compatible format. The forms cover inputs (energy sources such as electricity, heat, natural gas, and operating materials including reagents like Na<sub>2</sub>CO<sub>3</sub>, CaO, HCl, and H<sub>2</sub>SO<sub>4</sub>), direct air and water emissions (e.g. lead, cadmium, arsenic), fertilizer outputs, and associated costs per unit.

How will environmental performance be measured? The LCA calculation framework, already under development in the preliminary spreadsheet model, is structured around well-established impact categories from the CML methodology. The two most prominent are Climate Change (measured as kg CO<sub>2</sub>-equivalent, capturing greenhouse gas contributions) and Acidification Potential (kg SO<sub>2</sub>-equivalent, relevant for acid-leaching steps central to PHOS4PLANT). Additional categories include eutrophication, human toxicity, and cumulative energy demand. Complementing the environmental indicators, production costs are tracked in parallel for each process group — covering energy, operating materials, emissions treatment, and fertilizer credits — enabling a direct cost comparison across variants. As next steps data collection will run in parallel with ongoing process optimisation in the laboratory, feeding into the full LCA and LCC analysis planned for project Year 3.

## Dissemination activities

Rebeka Frühholz (K1-MET) and Jiri Kucera (Masaryk University) will present their latest research at the International Biohydrometallurgy Symposium in Orléans (28–30 September 2026), a major international conference in the field of biohydrometallurgy. Rebeka will focus on the optimization of bacterial sulfur oxidation, a process that ultimately results in sulfuric acid production, while Jiri will present recent findings on the role of a novel rhodanese in sulfur trafficking during this process.

Brno University of Technology (BUT) hosted a dissemination event in the form of a workshop titled “Phosphorus and Beyond: Circular Approaches in Waste Management.” The event took place on-site at the Faculty of Mechanical Engineering on 26 November 2025. A hybrid format was chosen to enable broader participation. Dissemination activities were further supported by the launch of a dedicated project webpage on the Institute of Process Engineering’s website. To date, three newsletters and additional updates have been published there, providing comprehensive information about the project. Project key ideas were also promoted through an article in the Czech technical journal „Technický týdeník“. The article, titled “From Waste to Resource: Phosphorus from Sewage Sludge as a Path to a Circular Economy,” appeared in issue 03/2026 on 10 March 2026.

In parallel, BUT, in collaboration with project partners, has initiated work on a manuscript intended for submission to an impact-factor journal. The working title, “A Pilot-Scale Preparation of Pre-Treated Sewage Sludge Ash for Phosphorus Reclamation”, reflects its focus on the thermal treatment of sludge ash, including the assessment of heavy metal mobility and emission measurements.

BOKU University participated in a stakeholder workshop organized by BUT. Furthermore, the project was presented twice at University level in front of students and people of interest. This April, a workshop is organized by BOKU University to discuss project activities with stakeholders. The project will also be presented in a public event called Long Night of Research which is the largest science communication event in Austria.

## Involved partners



K1-MET GmbH has proven expertise in the further development of processes for the treatment of residues and recycling materials with the aim of recovering valuable materials and closing material cycles. The tasks of K1-MET are, therefore, the recovery of phosphorus from sewage sludge ashes by non-contact bioleaching or with acids and the subsequent production of the phosphate-rich plant fertilizer. This is combined with the removal of impurities, such as metals, from the sewage sludge ashes. K1-MET is the lead partner in this project.



Masaryk University (MU) is the second-largest university in the Czech Republic. The Department of Biochemistry, the Department of Chemistry, and the Department of Geological Sciences are involved in the project. The team has many years of experience in the field of acidophilic microorganisms, molecular mechanisms of plant-microorganism interactions, structure-function analysis of microbial communities, mineral analysis, and trace element analysis.



A team from the Department of Thermal Processes and Gas Cleaning which is a part of the Institute of Process Engineering of Brno University of Technology (BUT) is involved in the project. This team has extensive experience in the field of thermal processes and emission treatment. They are responsible for the production of sewage sludge ash in the project. The institute possesses a drum dryer and a rotary kiln necessary for pilot-scale experiments. In addition, analytical infrastructure is available to measure fuel and waste properties and to analyze flue gas emissions.



The Institute of Waste Management and Circularity (ABF-BOKU) is focused on the safe disposal and recycling of waste in order to reduce the amount of waste and to save resources in primary production. Its tasks in the project are the pre-treatment of the highly alkaline ashes, which hinder the biological leaching of the material, the bioleaching of sewage sludge ashes, and the identification of acidophilic bacteria from sewage sludge. In addition, the entire process chain will be evaluated using LCA.



Co-funded by the  
European Union



PHOS4PLANT



EUROPEAN UNION

The project PHOS4PLANT (ATCZ00043) is co-funded by the European Regional Development Fund (programme Interreg Austria – Czechia 2021 – 2027).

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