**Subject strapline:**
**NUTRIENT RECOVERY**

**Title:**
# Closing the Phosphorus Cycle

**Standfirst:**
Phosphorus (P) recovery is as important for closing the P cycle as its discovery 350 years ago was for food production. A new analysis highlights costs and benefits of creating value from the wastes generated by our food systems and modern lifestyles.

**Author name**
Paul J. A. Withers
Lancaster Environment Centre
Lancaster University
Lancaster, UK LA1 4YQ
p.j.withers@lancaster.ac.uk

Phosphorus is one of the critical natural resources required to grow food, but its inefficient use across the whole food system—from production to processing to consumption and waste generation—is harming our ecosystems beyond acceptable limits and threatening future global food security[1,2]. People have preferred using 'clean' P processed from finite phosphate rock deposits rather than recycling the 'dirty' P in bioresources left behind by modern crop and animal production systems and food consumption. However, this leads to an 'open' P cycle that is wasteful and leaky and is causing long-term environmental damage. Tonini at al. in this issue, consider a more innovative solution which is to recover P from these 'dirty' and dissipated bioresources into more acceptable products that can help close the P cycle and make food-production systems more sustainable.

In 1669, Hennig Brandt first recovered phosphorus from human urine. Since its discovery and subsequent recognition of its value as a plant nutrient in the 1840s, phosphorus has played a key role in ensuring food production keeps pace with an expanding population[3]. Following its first application as bone and guano dust in the 19 century, agriculture and food industries have come to rely on the highly soluble inorganic P compounds (fertilisers, feeds and food additives) processed from phosphate rock. Exploitable reserves of phosphate rock are held in only a few countries, so geopolitical or market disruptions could threaten food security in regions that rely solely on P imports[2]. In addition to resource-continuity concerns, agronomic and wider food-chain inefficiencies in P use linked to agricultural intensification, urbanisation and the globalisation of food supply chains have led to widespread unbalanced dissipation and accumulation of P in the landscape and endemic and costly phosphorus pollution of inland and coastal waters[4,5]. As food systems must adapt and transform to help slow down climate change and reverse ecosystem decline, P use must also become more efficient and sustainable.

A re-emerging concept for achieving more P-sustainable food systems is the development of circular (bio)-economies that reduce reliance on P imports mined from phosphate rock by recovering and reusing P already in the food system[6]. A number of the secondary bioresources produced by food production and consumption are potentially reusable, notably sewage sludge, livestock manures, food-waste composts, and food-processing residues. Yet the drawbacks of these bioresources often make them less acceptable to producers and retailers given uncertainties over their nutrient availability in different environments; their bulky nature, which makes them difficult and costly to transport; and the presence of potentially harmful substances, such as pathogens, metals, and other contaminants, which may pose a longer-term or uncertain safety risk to ecosystems and human health. Critically, many of these bioresources are produced in too great a volume for balanced recycling on farms at practical rates of application, especially in highly populated animal-dense regions[7].

Advanced recovery technologies provide the opportunity to recover P from these biogenic materials in more concentrated, consistent and 'safe' forms for more balanced redistribution and to substitute effectively for rock-processed P[8]. These technologies are typically based on precipitation, acidulation and thermochemical processes in the presence or absence of oxygen, but their economic and environmental justification must be justified. The paper by Tonini et al in this issue addresses the current uncertainty. Using a comprehensive life-cycle analysis, the authors examined the health and environmental impacts and net costs of six different P recovery technologies (representing sewage sludge, meat and bone meal and livestock manure feedstocks) that are either already operational, or have high market potential in Europe. They calculated the net impacts and costs of recovering 1 kg of bioavailable P with those of spreading on land an equivalent unit of the bioresource feedstock and producing the same amount of P from phosphate rock. The analysis considered all material handling stages and the major societal impacts in regions with high or low population and animal densities. They found that the internal production costs of P recovery were outweighed by the external impact costs of the environmental emissions (metals, particulate matter, greenhouse gases and nutrients) caused by current P mining and bioresource management. Overall, they concluded that it was more beneficial to society to use recovered P, especially in highly populated regions with high P demand where the health and environmental impacts were more negative.

Realising P recovery is an important step in developing circular economies for sustainable and resilient food production. Although the technologies are in their infancy, the authors suggest that recovered P products might substitute 17-31% of the rock phosphate-based P fertilisers used in Europe by 2030. Recent revisions of EU fertiliser regulations should boost the potential markets for these products. Some recovery options will be more attractive to certain sectors than others, and some regional analysis may be necessary to prioritise technology options and market potential according to the feedstock available. The industry will also require evidence that recovered P products are effective substitutes, but recent research results are encouraging[9]. Although Tonini et al examined recovery of concentrated P fertilisers, exciting opportunities also exist for future recovery of biopolymers that can be used in a wider range of industries[10]. Perhaps most importantly, Tonini et al's analysis will help foster the innovation and redesign of food systems required to make P recovery technologies more commonplace. Hennig Brandt would likely smile to think P recovery is again part of the solution to ensuring future food security for all!

## References


1. Campbell, B. M. et al. *Ecol. Soc.* **22**(4), 8 (2017).
2. Cordell, D. & White, S. *Annu. Rev. Environ. Resour.* **39**, 161–88 (2014).
3. Ashley, K. *Chemosphere* **84**, 737-746 (2011).
4. Yan , Z. et al. *Ecol. Lett.* **19**, 1237-1246 (2016).
5. Withers, P. J. A. et al. *Ambio* https://doi.org/10.1007/s13280-019-01255-1 (2019).
6. Jurgilevich, A. et al. *Sustainability* **8**(1), 69 (2016).
7. Senthikumar, K. et al. *Nutr. Cycl. Agroecosys.* **92**, 145-159 (2012).
8. Schoumans, O. F. et al. *Ambio* **44**, S180-192 (2015).
9. Huygens, D. & Saveyn, H. G. M. *Agron. Sustain. Dev.* **38** (2018).
10. Jarvie, H. P. et al. *J. Environ. Qual.* **48**, 1145-1155 (2019).


A phosphorus (P) recovery plant in the Netherlands uses an innovative stripping process to remove P from pig manure into a high-grade phosphate salt for re-use in the fertiliser industry. The process also recovers nitrogen and a residue for use as a soil conditioner. The plant treats about 100,000 tonnes of pig manure each year in an intensive farming region where water pollution due to the oversupply of P in livestock manure is a major problem.  Photo courtesy of Green Mineral Centre Groot Zevert Digestion (Beltrum, The Netherlands).