A National Framework for Establishing a Circular Economy for Phosphorus

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Executive Summary: Phosphate rock (PR) is a finite and limited resource from which phosphorus (P) is mined for use in fertilizer. Approximately 40% of P applied as fertilizer is lost to erosion, and nutrient pollution and eutrophication caused by run-off from excess P in agriculture is a pervasive environmental issue. As agricultural demand for P fertilizers increases, existing reserves of PR are depleted and alternate sources need to be considered. To ensure a sustained supply of P without destabilizing global food security, there is an urgent need to implement feasible policy and technology options. Establishing a circular economy where P is recovered from existing nutrient-rich waste streams and reused as fertilizers is a viable solution to the dual problem of nutrient pollution and availability. This policy memo offers the Environmental Protection Agency (EPA) and US Congress guidance to prioritize phosphorus policies by: (1) establishing a Federal Advisory Committee on a circular economy for P; (2) increasing Congressional funding of P-recovery research, (3) issuing a national ban on certain phosphate-bearing products, and (4) deregulating struvite from the 40 CFR Part 503 Biosolids Rule. We recommend implementation of a synergistic combination of the proposed policy options to accelerate transition to a circular P-economy.

I. Introduction

Phosphorus (P) is an essential nutrient for plant growth and food production and is fundamental to all living things (Sutton et al. 2013). Most of the P used in fertilizers and industrial products comes from phosphate rock (PR), a finite and mineable resource found in the earth's crust. Currently, the global PR reserve is estimated to be ~70 million tons (USGS 2021), and annual consumption of P is projected to increase to 49 million tons by 2024 from 47 million tons in 2020 (USGS 2021). As a result, mineable P from PR is estimated to deplete within the next ~80 years (Cordell and White 2011; MIT 2016). Increasing fertilizer production and the resulting stress on existing PR reserves has increased the cost of PR by tenfold in the last decade (Alewell et al. 2020; Amundson et al. 2015), and the prospect of a PR shortage threatens global food security because PR is the primary source of P for fertilizer production.

In addition to depleting finite stores of PR, excessive manufacture and use of P compounds negatively affects the environment. In US waters, P arises from various point and non-point sources (NPS) like wastewater treatment plants (WWTPs), industries, agricultural runoff, concentrated animal feeding operations (CAFOs), urban stormwater, and combined sewer overflows.

Mining of PR endangers landscapes and disrupts ecological balance, causing widespread damage to land that serves as valuable habitat to endemic plant and animal species (Center for Biological Diversity 2021). For instance, over 100,000 acres of land in Florida have been mined for PR causing widespread contamination through radioactive waste leakage and water pollution which threaten Florida's groundwater resources (Center for Biological Diversity 2021). Furthermore, current P management in farming systems is modeled on an open P-cycle. In this system, natural recycling of P is prevented by excessive anthropogenic input and waste and most P applied in agriculture is not utilized, with only 15-20% of the P in PR reaching the food consumed globally (Sutton et al. 2013). Underutilized P accumulates in soil and ~ 39.5% of P is lost through erosion and run-off (Lun et al. 2018), exacerbating eutrophication, triggering harmful algal blooms (HABs) and creating hypoxic dead zones in water bodies (CRS 2020; US EPA 2021) (Carpenter et al. 1998; Szymańska et al. 2020). The economic cost of eutrophication in the US was estimated to be over $2.2 billion annually in 2008 (Dodds et al. 2008) and is expected to be much higher today.

Because there are no substitutes for P in agriculture, the need to establish alternate sources to meet agricultural demands for phosphate will become ever more pressing. In 1979, a report to the US Congress submitted by the Comptroller General of the US called for action on long-term P security in the US. Specifically, the report recommended an assessment and review of the US's existing phosphate reserves, future availability, and legislative interventions to ensure continued supply (USGAO 1979; Jacobs et al. 2017). Despite this report, no governmental action was taken nor policies implemented to ensure sustained supply of P in the future. The finite nature of PR reserves and negative environmental impacts associated with improper P management can have disastrous consequences globally. Sustainable management of P must focus on managing existing reserves efficiently, decreasing application of P fertilizers, and closing phosphate loops to reduce environmental impacts on aquatic systems and biodiversity (Carpenter and Bennett 2011, Olde Venterink 2011).

II. Current phosphorus policy and key challenges

Current nutrient management in the US is under the jurisdiction of the Environmental Protection Agency (EPA) as mandated by the Clean Water Act (CWA 1972). However, the CWA largely focuses on regulating point-source discharges into navigable waterways and exempts non-point source (NPS) discharge such as farm run-off. The EPA is heavily reliant on individual States in addressing and establishing P limits through state water quality standards and numeric nutrient criteria under the CWA. Currently, most US states are not compliant with EPA's nutrient criteria (US EPA 2016).

Alleviating environmental stress caused by P pollution requires changing global patterns of fertilizer production and consumption. One solution to impending P scarcity lies in establishing a circular economy that focuses on recapturing, recycling, and efficiently reusing P. A circular economy enables the conservation of a material's value within the economic system for a longer duration (European Commission 2020) and serves to mitigate P demand by extending the life cycle of environmentally extracted raw materials (Gaustad et al. 2018). Successful transition to a circular economy for P (P-economy) could be initiated by reducing environmental losses and utilizing wastes from various sources such as agricultural, mining, and industrial sectors (El Wali et al. 2021; Geissler et al. 2020). Wastewater recovered P product is called struvite and is generated by engineered precipitation (NEBRA 2017) with the goal of being used as a fertilizer. Additional steps to create a circular P-economy include creating niche markets for recovered P fertilizers (Nättorp et al. 2019), improving recovery technologies (Egle et al. 2016), increasing recovered P production capacities (Jedelhauser and Binder 2018), and updating the legal limitations in P-recovery processes (Barquet et al. 2020).

The challenges of designing and implementing a circular P-economy are multifold and barriers to adoption of a national and global strategy ensuring P sustainability are technological, socioeconomic, political, and institutional (Sarvajayakesavalu et al. 2018). These challenges are exacerbated by the fact that different stakeholders are in charge of implementing different parts of the system. In the US, recovering P from nutrient-rich sources (e.g. municipal wastewater) falls under the jurisdiction of states, and is usually managed by agricultural mandates, contaminant criteria, and directives. Deployment of P recovery technologies occurs at the municipal level in wastewater treatment plants and are the water boards' responsibility. State and federal governments are responsible for developing legislation on P-recovery and the fertilizer companies are responsible for introducing and obtaining certifications of the recovered P on the fertilizer market (De Boer et al. 2018). All three stakeholders have other vested economic interests which will hinder transition to a circular P-economy model. For example, the fertilizer and agricultural market in the US is industry-controlled and driven by the consumerist model, where more is better, and has proven extremely hard to change. State governments often consider updating existing infrastructure to be burdensome, citing lack of funding, labor shortages, and technology limitations (Bunce et al. 2018). Without a federal directive, a federally mandated universal nutrient management plan, and additional funding, states will have no incentive or interest in upgrading water treatment facilities and agricultural operations to recover P from waste streams.

In contrast to the US, European countries have made progress concerning P-recovery and reuse of wastewater recovered fertilizer in the last decade. For example, Germany and Switzerland mandated P-recovery for wastewater treatment plants (De Boer et al. 2018). Through the efforts of engaged stakeholder groups like the European Sustainable Phosphorus Platform (ESPP), the European Union has transitioned to integrating resource recovery within the fabric of sustainable environmental policy. The ESPP has helped bring together various experts in accelerating policy developments at the industrial, academic, political, and legislative level. Legislation concerning recovery of phosphorus and resultant products has not yet been developed in the US and achieving policy progress competitive with the European Union will require collaboration among numerous government and industry stakeholders (Sarvajayakesavalu et al. 2018).

III. Policy Options

The objective of this policy memo is to recommend policies to the EPA and appropriation guidance to the US Congress for establishing P recovery and recycling principles from agricultural and domestic wastewater. We outline multiple policy options to encourage a transition to a circular P-economy and to strengthen acceptance of recovered P fertilizers in the agricultural industry.

i. Option 1: Establish a Federal Advisory Committee on a circular economy for phosphorus

The EPA could establish a Federal Advisory Committee on Phosphate (FACP) using guidelines established by the Federal Advisory Committee Act. The FACP would consist of multiple stakeholders representing the federal and state governments, academia, industry, members from additional stakeholder groups, and other specialized groups with expertise in establishing a circular economy for P (e.g., Arizona State University n.d). The FACP would be tasked with assessing current nutrient recovery potential as well as establishing a framework and an executable timeline to transition to a circular economy for P-recovery.

Advantages

The FACP would facilitate collaboration among multiple stakeholders and the public as well as generate new policy alternatives.

Disadvantages

Establishing an FACP is a time-consuming, bureaucratic, and laborious process. Conflict among stakeholders, especially those governed by different interests can delay implementation of the FACP's recommendations. The fertilizer industry wields strong influence through their lobbying efforts which can further delay implementation at the local level.

ii. Option 2: Increase Congressional funding towards research and development of deployable nutrient recovery technologies

Congress should allocate funds through the annual appropriations process to federal agencies like EPA, NSF, USDA and USGS to increase research and innovation in P recovery technologies to prevent P discharge to the environment. Currently EPA, NSF, USDA, and USGS fund research on P-removal technologies on a small scale. The development and deployment of scalable technologies has been slow and is practically non-existent and increased funding from federal agencies would ensure more research grants are available for innovation through fundamental science, engineering, and technological advancements.

Advantages

Financial support will accelerate research in scalable technologies to recover P from nutrient-rich sources.

Disadvantages

Federal budget increases and allocations occur through the annual appropriations process, and at the discretion of Congress. Unless properly justified and lobbied, Congress might not allocate appropriate funds to support increased research funding.

iii. Option 3: Development of supplementary guidelines

The EPA should amend the 40 CFR Part 503 Biosolids Rule to deregulate struvite and issue a country-wide ban on phosphate-bearing household laundry detergents, soaps, and cleaners. Although the EPA currently considers exemptions for struvite on a case-by-case basis (EPA 1994), the EPA could deregulate this class of solid products entirely once it meets an established quality criterion. Currently, a ban on household cleaners with phosphate exists in 17 states. The EPA should rescind the registration of products that contain P to reduce nutrient pollution and register environmentally friendly alternatives to these products.

Advantages

Deregulating struvite will help alleviate concerns about the potential adverse impact of land application and increase its acceptance in the US marketplace. Bans on household products with phosphate will reduce capital and operating costs of wastewater treatment plants and improve water quality in small and medium-scale water bodies currently impaired by phosphate pollution. This ban can be implemented immediately without waiting for formulation and innovation of new products as phosphate-free household products are currently sold in US markets. Moreover, the introduction of a phosphate ban would be a market-driver for new phosphate-free products (Barquet et al. 2020).

Disadvantages

Pushback from large industry groups and lobbying firms may influence state and federal politicians, water boards, and wastewater treatment operators hindering implementation of directives. Struvite is a relatively new fertilizer and despite having gained some recognition in the last two decades it is still unknown to large fertilizer companies and potential end users. This lack of recognition can delay acceptance for use on a larger scale (de Vries et al. 2017).

iv. Option 4: Inaction

The cost of inaction is scarcity of P and increased environmental pollution. From this, the global price of P fertilizer will likely increase, and the US may become excessively reliant on imports of P fertilizers from other countries.

IV. Policy Recommendations

We recommend implementation of a synergistic combination of the proposed policy options as the most sustainable long-term solution to establishing a circular P-economy. Although an improvement over the current P policy scenario, individually implementing each recommended policy will be only a small step towards a circular P-economy while cumulatively they stand to make a much larger impact. Moreover, the timeline for implementation of individual policies vary widely. For instance, the ban on household products with phosphate and guidelines to deregulate struvite from the Biosolids Rule can be implemented immediately and will start reducing P loads in water bodies. Establishing the FACP and increasing Congressional funding of research consist of multiple intermediary steps and will take longer to implement. Collectively, these recommendations work towards creating a supportive platform for stakeholders to adopt practices that transition the current linear P cycle in the US towards circularity.

These changes address implementable solutions, political obstacles, and promote economic sustainability. It is likely that changes will be met with resistance and receive pushback by politicians and industry-focused groups. A successful transition will need to focus on strong collaboration between farmers, industry, and all relevant stakeholders in the P-economy space. Forward-thinking nutrient recovery policies will improve overall P sustainability and accelerate regulatory development pertaining to management of P in municipal wastes, farming, agricultural, and industrial waste.

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