Creating a circular economy for phosphorus fertilizers

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The decades-old concept of the circular economy has become a standard way to frame solutions to environmental problems that stem from linear value chains, that is, value chains that begin with the extraction of a natural resource and end with its disposal. In theory, by keeping materials in play, we prevent them from becoming pollutants, minimize the amount of environmental damage inflicted by extraction, and reduce the acreage required for landfilling waste. This thinking has found purchase in the field of nutrient management through programmes and initiatives such as the US EPA's Nutrient Recycling Challenge and the Ellen MacArthur Foundation's Urban Biocycles Initiative.

Currently, the phosphorus value chain might be described as semi-circular. While hard numbers on phosphorus reuse are difficult to obtain, it is certainly true that most mined phosphorus -perhaps more than 80% is not reused, and we know most of the phosphorus used is mined. The great majority of the phosphorus we use in the food system, doesn't make it into our food but is instead landfilled or 'lost' to the environment along the way. It may accumulate in soils, sediments, and unharvested biomass, and it may pollute our waterways, causing algal blooms that can produce toxins and ultimately suffocate the life in aquatic ecosystems. A 2008 report suggested that nearly a quarter of a million square kilometres of dead zones had arisen in marine coastal areas, roughly the size of the UK's land mass. This year's summer dead zone in the Gulf of Mexico alone is predicted to reach the size of New Jersey, perhaps the largest yet, with major consequences for Gulf fisheries. Such impacts lead naturally to asking how we can reduce phosphorus pollution through more efficient use and recycling.

Formulations

How would a more sustainable economy for phosphorus look? On the demand side, we need to become more efficient at every node of the value chain. This includes such measures as improving the extraction efficiency from phosphate rock,

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Ostara,Chicago - The world's largest nutrient recovery facility has the capacity to produce over 10,000 tons of sustainable fertilizer per year

formulating fertilizers that facilitate optimal phosphorus application, applying phosphorus fertilizers more precisely to crops, formulating more efficient animal feeds, reducing food waste, and breeding and otherwise engineering crops and animals, ethics permitting, for more efficient phosphorus metabolism. As consumers, we can also adopt less phosphorus-intensive diets by reducing our meat consumption.

On the supply side, we need more closed-loop recycling. This means we need to capture and sustainably reuse both non-point-source emissions, especially from cities and farms (difficult), and from point-sources, such as wastewater treatment plants and certain animal feeding operations. We also need to increase our sustainable reuse of animal, human, biomass, and food wastes. This is a multi-dimensional challenge for groups such as our Sustainable Phosphorus Alliance, one that requires developing a collective understanding of sustainable reuse, innovating and propagating technologies and best practices, designing supportive regulatory and market frameworks, and allaying sometimes-misguided public concerns about the safety of recycling wastes.

Drivers and change agents

A 700% spike in the price of phosphate rock in 2008 made it appear that the driver to affect such sweeping changes was in place. With supplies constricted and prices skyrocketing, incentives for efficient use and recycling ran high. Prices have largely settled since, and with the reassessment of Moroccan reserves, improved technologies for removing contaminants and extracting phosphorus from low-grade rock, and a more sober assessment of other supplies, including igneous rock, the prospect of 'peak phosphorus' is nowhere on the horizon (see Fertilizer Focus, May/June 2017). While prices remain elevated compared with pre-spike levels and the threat posed by the combination of geographically stratified reserves and geopolitical uncertainty still looms, major change has not been stimulated.

Nevertheless, drivers for a more sustainable phosphorus economy do exist. One is waste management. Animal feeding operations and wastewater treatment plants produce large quantities of residual materials in search of a home. A time-honored practice has been to apply them to farmlands for nutrient recycling. However, large distances often separate the waste generators from potential sites of land application, a problem exacerbated by a growing geographical disconnect between

Animal waste being pumped into a manure lagoon in North Carolina.
Photo courtesy of USDA NRCS

Minimal volumes of Crystal Green produced at the wastewater plant are stored before shipment

(Above) Crystal Green is a high-purity, renewable, slow-release fertilizer suitable for use in agricultural and horticultural applications; (Top) Manure granules created in the FEECO Innovation Center

livestock and cropping operations. Livestock and human wastes, which are mostly water, tend to be heavy and expensive to transport over long distances. Thus, there can be an incentive to over-apply recycled fertilizer locally, which can lead to harmful nutrient runoff, or to landfill wastes, which can be expensive and removes phosphorus from the nutrient cycle entirely. Meanwhile, low-income economies often struggle with phosphorus scarcity.

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One supply-side solution to local nutrient surpluses has been the Dutch decision to subsidize the slaughter of many tens of thousands of cows over the next few years. Less draconian measures include the state of Maryland's subsidization of chicken litter transport to the tune of upwards of USD1mn/yr. Some companies see a business opportunity here. FEECO International, for example, develops granulation equipment to dry and granulate these products, offering the twin benefits of lightening product loads for transport and providing better moisture and nutrient control for on-field application. Their equipment is in use at one of the largest dairies in the US, Fair Oaks Farms, where treated manure is granulated and further processed into fertilizers marketed by Midwestern BioAg under the TerraNu brand.

Waste recovery

Waste management is also an issue for feedlots that wish to intensify operations but find themselves constrained by regulations, such as state-enacted limits on the size of the treatment lagoons that they operate. In addition, recent court rulings in the US (e.g. Community Association for Restoration of the Environment v. Cow Palace) have threatened regulation of dairy waste as a solid waste - and potentially a hazardous waste - under the Resource Conservation

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and Recovery Act. This has inspired better nutrient management and recovery operations on farm. In one manifestation, the dairy industry has launched Newtrient, LLC, to help vet nutrient management solutions for dairies.

Another form of waste - food waste - puts substantial pressure on the budgets of municipalities and food companies. Over a third of food produced for humans is lost or wasted, according to the UN's Food and Agricultural Organization, and with that, its embodied phosphorus is lost, not to mention the phosphorus that was crop-applied but not assimilated. In high-income economies, that waste mostly occurs during food consumption, leading to a municipal solid waste disposal problem. Though separation and recovery of these wastes still occurs at low rates, many cities, such as San Francisco, Vancouver, and New York, now compost or anaerobically digest wastes for potential reuse.

Another major driver of phosphorus sustainability in the US is the Clean Water Act. To the dissatisfaction of many an environmentalist, it largely exempts from regulation 'non-point-source' emissions, such as farm runoff, but it does effectively regulate point-source emissions into navigable waterways. This has led to strict regulation of wastewater treatment plants. Elsewhere, in Germany, a sludge ordinance will soon require phosphorus recovery, or at least sludge incineration, for all large sewage works. Such point-source restrictions buttress the business cases of a number of companies that sell equipment to recover phosphorus from wastewater, including Ostara Nutrient Recovery Technologies and Renewable Nutrients. Ostara even packages and sells recovered phosphorus, in the form of struvite, as a slow-release, 5-28-0 fertilizer branded CrystalGreen. Capturing the phosphorus reduces point-source loads, and the slow-release fertilizer produced can reduce the non-point-source loads of farmlands. This is a step in the right direction, but only a couple of dozen of treatment plants (out of tens of thousands, at least) operate Ostara systems. Clearly, the growth potential is enormous.

> *"The low cost of virgin phosphate rock undermines the case for its recovery and reuse*

Farmers drive change too. Many farmers are concerned with their phosphorus footprints, not only because phosphate fertilizers have a cost, but also because farms rely upon healthy waterways for irrigation. As a result, voluntary programmes such as the 4R programme for nutrient stewardship, through which the fertilizer industry helps promulgate best practices for fertilizer application, have become popular, as have advances in precision agriculture. State nutrient management plans often prod farmers to adopt such strategies to reduce their phosphorus pollution and even set limits on which farms can apply phosphorus fertilizers.

Regulations on phosphorus will likely increase, on farm and off. Many locales in the US and Canada suffering from phosphorus pollution from urban run-off now institute phosphorus fertilizer bans of one form or another that prohibit homeowners, for example, from applying phosphorus-containing fertilizers to their lawns. Look for more regulations as stories of massive algal blooms and dead zones mount. Ultimately, the industries involved must decide if they would prefer a potentially unwieldy regulatory approach or if they would rather preempt regulations by working collaboratively with concerned stakeholders on these issues.

Beyond regulation, consumer demand for more sustainable products has fueled corporate supply-chain sustainability efforts that could, arguably, do more for reducing phosphorus emissions than direct government efforts. For example, Field to Market provides a Fieldprint Calculator that gauges the sustainability of on-farm practices, including those related to phosphorus management. Food companies and major retailers, including Walmart, increasingly turn to such programmes to drive their suppliers to produce food more sustainably in response to consumer pressure. Almost unconsciously, consumers could drive phosphorus sustainability in this way.

The road ahead

Ultimately, the low cost of virgin phosphate rock undermines the case for its recovery and reuse. It is tempting, then, to suggest price controls or taxes to drive more efficient use and reuse. Here we need to proceed with caution because when the price of phosphorus increases, vulnerable populations may go hungry. While too much phosphorus is a problem in some locales, too little phosphorus has dire consequences in others. Nonetheless, such discussions are ongoing, and projects such as the POLFREE and DYNAMIX projects in the EU have modelled such market interventions.

Another form of support for a circular economy for phosphorus could come in the form of a strategic phosphorus reserve, akin to the strategic petroleum reserve that the US instituted in 1975 to buffer another critical commodity against supply shocks. We can live without petroleum but not without phosphorus. Nations might do well to create stockpiles for lean times and, in doing so, drive the preservation of another vital resource: freshwater. A requirement that some percentage of this strategic reserve come from recovered phosphorus could help support a recovery market, while topping the rest of the stockpile with virgin phosphorus would provide additional revenue to the mining industry, offering a win-win scenario for industry.

Ostara's Pearl technology transforms nutrient-rich wastewater from an Edmonton wastewater treatment plant into sustainable fertilizer; *Photo courtesy of Black & Veatch*

Transformative change could also follow the development of large-scale water quality trading markets akin to the cap-and-trade programmes developed in the US around nitrogen oxide and sulphur dioxide emissions. Cap-and-trade programmes limit aggregate releases of pollutants and allow pollution generators to purchase rights to pollute from those who generate credits by implementing pollution control measures. In the water quality context, a farmer might plant buffer strips that prevent run-off to a waterway, thereby generating credits that a wastewater treatment plant could purchase to comply with its regulatory phosphorus limits, and do so at a great cost savings. In the US and Canada, scores of water quality trading programmes have sprung up around individual watersheds over the past few decades, but these markets are far from robust. In theory, markets could be buttressed by permitting trades among multiple watersheds, but creating such markets appears to be more challenging than establishing their air quality analogs for both technical and regulatory reasons. Still, there is enough activity in this arena to kindle hopes for greater phosphorus use efficiency and perhaps a large-scale recovery market.

These ideas are all fairly speculative at this point. In the interim, one way to valorize phosphorus recovery is to bundle it with co-benefits. For example, animal feeding operations can install suites of unit operations, including anaerobic digesters and nutrient recovery modules, that recover not only phosphorus but also other products such as biogas, nitrogen, carbon, and materials for animal bedding. Combined with tax incentives for nutrient recovery and renewable energy credits, such systems can begin to pencil out and can offer more intangible benefits, such as improved public relations. The economic case would improve if we developed ways to assign adequate value to ecosystem services that have obvious economic value. What is clean water worth to its drinkers, to recreational and industrial users, to property values, to fisheries and to conservationists?

Recycling is an opportunity

Finally, to realize a circular economy for phosphorus, the mining and fertilizer industries will need to assume more producer responsibility for their products. OCP has been pivotal in supporting our efforts in the Sustainable Phosphorus Alliance and recognizes its stewardship role with respect to phosphorus. If we are to build a more sustainable phosphorus economy, more companies from these industries need to adopt such a penchant for stewardship. Substantial efforts will likely cause some pain. That said, we would like to build a positive case for these industries to integrate recycled phosphorus into their supply chains, as has been done with other recycled commodities, such as plastic and aluminum.

When the UN's Environment Programme studied drivers of the recycling of metals, it concluded that recycling "rates tend to reflect [either] the degree to which materials are used in large amounts in easily recoverable applications…or where high value is present." Think aluminum in the former case and platinum in the latter. Phosphorus is not like platinum because of its low value. However, it could be like aluminum: Large amounts are certainly recoverable and reusable, just not economically in the current context. Making recovery and reuse more cost-effective through technological innovation, through the development of large-scale markets for recovered products, and through incentives and regulations might prompt companies operating upstream in the phosphorus supply chain to view recycling as an opportunity.

If we can achieve this and continue to develop and adopt technologies and practices that improve phosphorus use efficiency, we can create a sustainable phosphorus economy and protect our water resources. ■