Closing the Loop on Phosphorus

About half of humanity now lives in urban environments and this is increasing rapidly. To make cities more sustainable, source separation of materials and recycling must become standard practice. The principle nutrients – nitrogen, phosphorus and potassium – recycle in nature, but human intervention has created a linear, non-recycling, open-ended system.

The impending phosphorus crisis

Phosphorus is a nutrient essential to all living organisms, and thus, it is essential in food production for humans. Although it is the eleventh most abundant element on earth, phosphorus never occurs in its pure form and is always bonded with other elements forming other compounds, such as phosphate rock. More importantly, much of the phosphorus in soil is not available to plants, thus requiring nutrient additions to produce crops. This non-renewable resource is being mined at an increasing rate to meet the demand for artificial fertilizers so heavily relied on in agriculture. In all, chemical fertilizers account for 80% of phosphates used globally, with the other 20% divided between detergents, animal feed and special applications (such as fire retardants).

More than 30 countries produce phosphate rock for commercial purposes, with the top 12 countries supplying 91% of all phosphorus. China, Morocco and the United States alone currently produce almost two-thirds of global phosphate. In addition, China's reserves are estimated to account for 36% of the world total and Morocco for 31% (see Figure 2). Due to the finite nature of phosphorus resources, Morocco and Western Sahara have been engaged in a border conflict since 1975 as a result of the reserves in the contested territory.

Estimates on the remaining amount of phosphorus vary, as do projections about how long it will take to deplete the irreplaceable resource entirely. Figures range from 60-130 years (Steen, 1998) and 60-90 years (Tiessen, 1995), at current market prices with diverse assumptions about the rate of production and demand, but all sources agree that continued phosphorus production will decline in quality and increase in cost. The relatively inexpensive phosphorus we use today will likely cease to exist within 50 years (see Figure 1).

It imperative that we begin recycling phosphorus and returning it to the soil to decrease the need for mined phosphorus as artificial fertilizer. Within a half century, the severity of this crisis will result in increasing food prices, food shortages and geopolitical rifts.

The science of phosphorus

The elemental state of phosphorus is highly bondable, meaning it readily combines with several other elements, which is why it is predominantly found in phosphate form. As such, phosphorus molecules bond with soil molecules and are not available for plant use until the soil is saturated, or there are no longer any soil particles for the phosphorus to bond with. The result has been a great demand for artificial fertilizers to boost nutrient content in less fertile soil.

The contradictory nature of phosphorus

Essential for life on earth, yet destructive in excess quantities in an aquatic environment, phosphorus is one of Mother Nature's paradoxes. Eutrophication is the enrichment of freshwater and marine systems with nutrients, particularly nitrogen and phosphorus. In freshwater systems, phosphorus is normally limited, so when excessive amounts are released from agricultural runoff and municipal sewage sources it causes serious water quality problems. Algal blooms result and alter aquatic ecosystems eliminating species of fish and vegetation by clouding the surface of the water and decreasing oxygen levels in deeper waters and sediment. Eutrophication has been a serious environmental concern in much of the developed world for the past 30 years, and is now a global concern.

The process to extract phosphorus is particularly damaging, as strip-mining is the most common method of extraction. The by-products of the processing of phosphorus include radioactive gypsum, commonly stored in "stacks" in the United States,

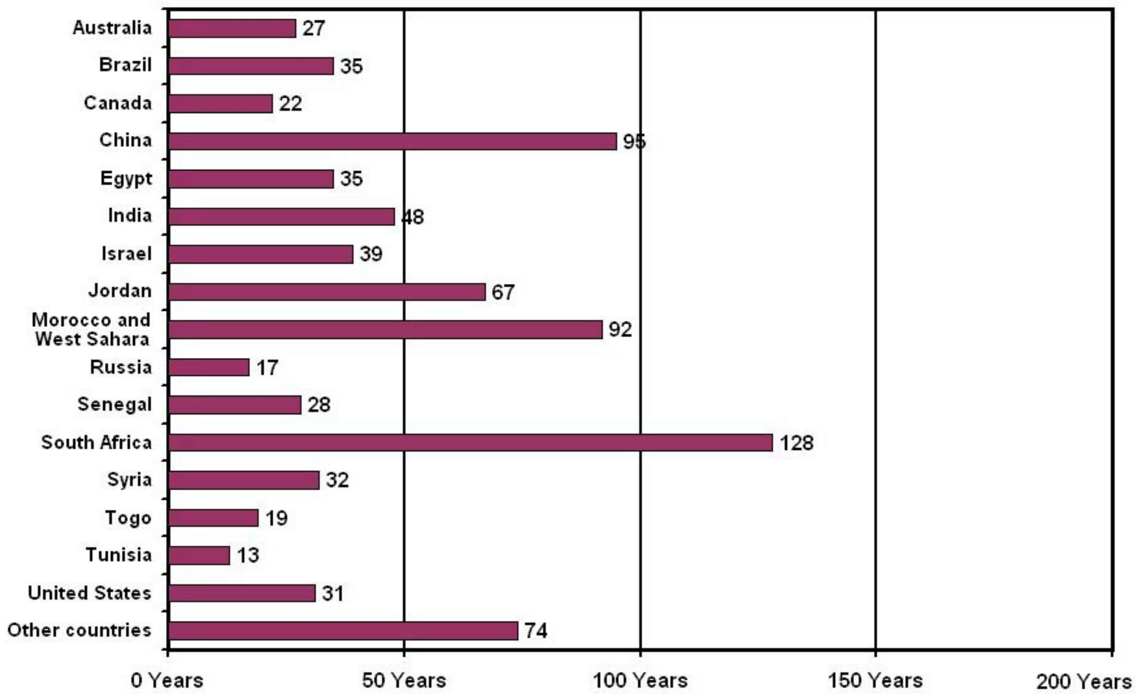

Figure 1. Phosphate rock – years of extraction remaining based on current reserves from 2005 using a 2% yearly increase (Source: USGS)

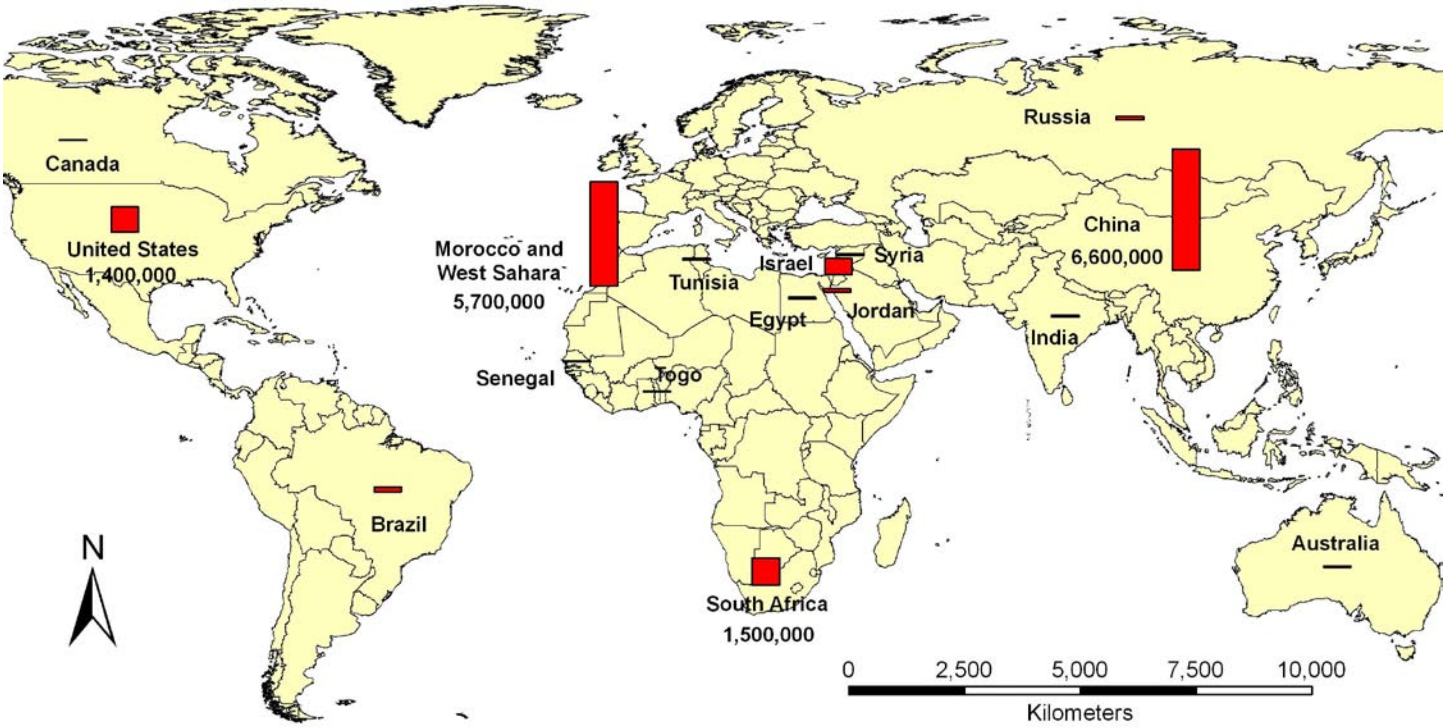

Figure 2. Phosphate rock – worldwide reserve estimates (thousands of metric tons) Source: USGS

and air pollution that includes fluorides. Furthermore, phosphorus deposits are often contaminated by arsenic or cadmium, which can be concentrated during processing and there is a subsequent build-up of these toxic substances in agricultural soils.

The ecological sanitation solution

Given that the vast majority of phosphorus is used in artificial fertilizers, it is logical that this is the area where more efficient use of the nutrient will result in preserving the resource.

Most of the phosphorus consumed by animals and humans is excreted. By safely recovering the nutrients found in human excreta through ecological sanitation, it is possible to reduce the depletion of phosphorus reserves. Recycling of phosphorus from sewage sludge is, however, very costly, and alternative systems are needed. Ecosan offers a holistic system whereby human excreta is made hygienic and creates a valuable and effective organic fertilizer that recycles nitrogen, phosphorus, potassium and other nutrients contained in urine and faeces back into the environment, instead of groundwater and waterways. Urine diversion and recycling would provide immediate advantages because most of the nutrients excreted are in this fraction. If urine is recovered at source, the nutrient load to sewage treatment plants will be significantly reduced, possibly even eliminating the need for tertiary treatment. This, plus recycling organic material from households to farm soil, would further alleviate the need for additional nutrients.

Only a small part of the world actually is served with water-based flush systems (about 1.1 billion people, of which only about 30% provide health and environmental safety). The rest (some 5.3 billion) either have no sanitation (about 2.6 billion) or pit latrines. The advantages in upgrading these systems to ecosan would be cost-effective in terms of improving health, environmental quality and recycling of nutrients.

Need for global recovery of phosphorus

Between 1950 and 2000, about 1 billion metric tonnes of P has been mined (Gumbo et al, 2002). During this period, about 800 million metric tonnes of fertilizer P were applied to the Earth's croplands. This has increased the standing stock of P in the upper 10 centimetres of soil in the world's croplands to roughly 1,300 million metric tonnes, an increase of 30%. Close to a quarter of the mined P (250 Mt) since 1950 has found its way into the aquatic environment (oceans and fresh water lakes) or buried in sanitary landfills or sinks. For 1990, the amount of phosphate discharged into oceans was double the amount of phosphate applied as fertilizer (Tiessen, 1995).

Of the next billion tonnes of P we mine between 2000 and 2050, a significant percentage of phosphorus can be recovered by using sustainable agriculture and sanitation. This should be a priority for the global policy agenda.

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