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Securing a Sustainable Phosphorus Future for Australia

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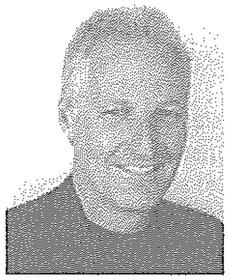
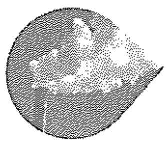


Australia has developed its agricultural export industry on the foundation of importing phosphorus from Nauru, and more recently through substituting domestic production for at least half of all demand for fertiliser. Decreasing ore grades for phosphate rock, increasing concerns about the negative impact of run-off from soils, and the likelihood of future price increases all mean that a rethink is needed of the future of phosphorus in Australia, and globally. The current path for phosphorus use in the world, and in Australia is not sustainable, due to the significant levels of inefficiency, to the certainty of peak phosphorus in the coming decades and the vulnerability to potentially volatile markets. Moving towards a sustainable phosphorus future can be achieved by reducing our dependence on imported and domestic rock, by diversifying phosphorus sources through investing in renewable phosphorus fertilisers, increasing the efficiency of use throughout the system (not just in agriculture) and maximising recovery and reuse of phosphorus. These measures will also have positive environmental impacts by reducing water pollution, water demand, waste disposal to landfill and to energy consumption. Achieving such a scenario will require substantial changes to the currently fragmented institutional arrangements surrounding the food system. For example, developing new partnerships and policies between the wastewater and fertiliser sectors. Further science and research is urgently required due to the limited knowledge of the stocks and flows and the historical lack of attention to this crucial issue. New knowledge regarding baseline phosphorus flows is required, in addition to seeking the most cost-effective and energy-efficient means to reduce phosphorus demand and increase recovery. There is a need to build capacity within government, industry and the research community to develop frameworks for dealing with the issue.



Phosphorus: Life's Bottleneck

Phosphorus is one of the most important elements for humanity, because it underpins our ability to produce food. Phosphorus, together with nitrogen and potassium, is an essential element for all living organisms – including plants, animals, bacteria and is a key ingredient in fertilisers. There is no substitute for phosphorus in crop growth. Feeding a world of nine billion people by 2050 is predicted to require at least a doubling of crop yields, which means agricultural fields will need to expand or intensify, either way requiring more fertilisers, including phosphorus (FAO 2006). However the world's main source of phosphorus – phosphate rock – is a non-renewable resource that is becoming increasingly scarce. Global phosphorus scarcity is likely to threaten the world's ability to meet growing food demand without changes to the current phosphorus use trajectory (Cordell 2010).

Australia is a net food producing country with an agricultural system increasingly dependent on imported phosphate. While Australia has some of the world's most naturally phosphorus deficient soils, we have simultaneously invested in heavily phosphorus demanding export industries, like beef, sheep and wheat. Also, phosphorus reaching waterways from agricultural run-off and sewage effluent is the main cause of the growth of algal blooms.

Historically, most of the world's farmers relied on natural soil phosphorus to grow crops (with local additions of manures and human excreta). However increased soil degradation and food shortages in the 17th and 18th centuries (particularly in Europe) led to a search for external sources of phosphorus fertilisers to boost crop yields, including phosphate rock and guano (Emsley 2000). Phosphate rock was seen as a cheap and infinite source of phosphorus and it became widely used in favour of organic sources. The widespread use of guano and phosphate rock contributed to increased global crop yields and saving billions from starvation over the past half century. Today, humanity is effectively dependent on mined phosphate rock to maintain high crop yields.

While the importance of phosphorus in boosting crop yields is today well established, there is very little discussion, research and policy that addresses long-term availability and accessibility of phosphorus for global food production.

Peak Phosphorus: A New Global Challenge for Food Security

Like oil, phosphate rock is a non-renewable resource and the supply of high-grade reserves are becoming increasingly scarce while demand for phosphorus is expected to increase in the long term. The element phosphorus is not in itself 'running out' or finite – there will always be the same number of phosphorus molecules circulating the earth. Indeed, phosphorus is the 11th most abundant element in the earth's upper crust. However the amount available to humans for productive use in food production is orders of magnitude smaller, due to physical, energetic, economic, geopolitical, biological and other constraints (Cordell 2010).

The world's remaining phosphate reserves are more difficult to access, are contaminated with more heavy metals (eg Cd, U) and contain lower concentrations of phosphorus (P_2O_5 form) (Prud'Homme 2010). Current reserves are expected to be depleted in 50–100 years (Runge-Metzger 1995; Steen 1998). However, as with oil, the important point is not when 100 per cent of the reserve is depleted, but when the production rate reaches a peak, based on the finite nature of non-renewable resources (Hubbert 1949). The production of phosphate rock will eventually reach a peak due to the economic constraints of accessing more difficult and lower quality layers. Based on current estimates of reserves, and demand growth, peak phosphorus is estimated to occur around 2035 (Figure 1). Whilst the data reliability is disputed and hence the exact timeline of the peak may vary, the underlying problem remains the same. A fundamental notion behind peak theory is that as production of a critical mineral resource shifts from mining the 'cheap and easy' resource, to 'difficult and complex' layers (Giurco et al. 2010) growing and unchecked demand will outstrip the economically available production at some point, despite advances in technology and efficiency. There are currently no alternatives on the market today that could replace the large demand for phosphate rock at any significant scale (Cordell et al. 2009a).

The unprecedented 800 per cent price spike of phosphate rock and other fertiliser commodities in 2008 resulted in increased interest and investment in exploration of new phosphate rock deposits and commissioning of new mines, most notably in Saudi Arabia, Australia and seafloor sediments off the coast of Namibia (Jasinski 2009; Drummond 2010; Jung 2010). While these may increase the overall tonnages of world phosphate rock reserves in the coming years, the quality and accessibility of these reserves are markedly lower than current reserves. Important here is that mining lower grade phosphate rock resources, or phosphate found on continental shelves will involve substantial environmental and economic costs due to difficultly of physical accessibility and/or increased processing resources and costs. That is, extracting the same nutrient value from rock will increasingly require more inputs of energy, raw materials and costs, while resulting in increased volumes of waste and pollution.

There are substantial environmental concerns associated with the mining and use of phosphorus

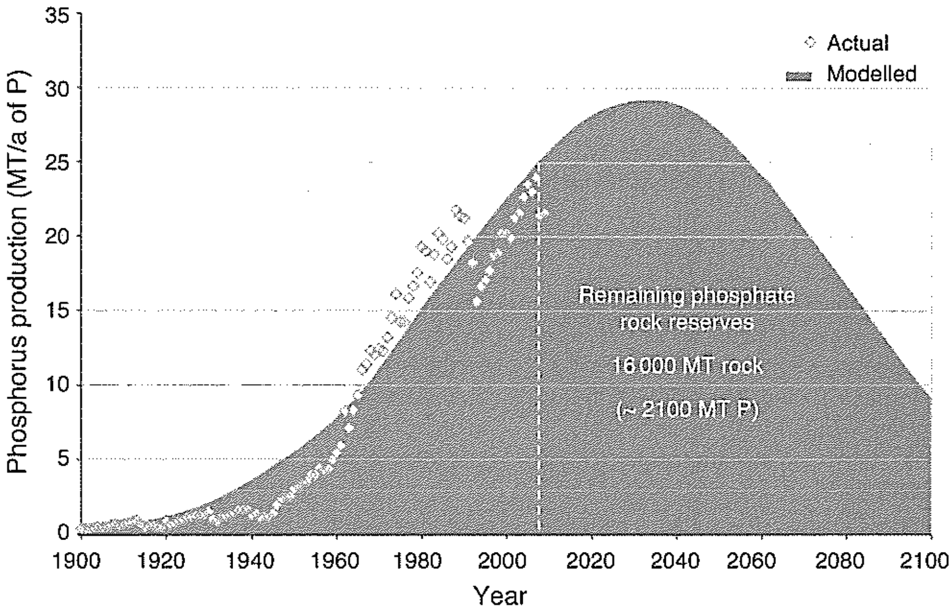


Figure 1: Peak phosphorus: global production of phosphate rock reserves is estimated to peak in 2033 at 29 million tonnes of P/yr (equivalent to approximately 220 million tonnes of phosphate rock) while demand will continue to increase.

Source: Cordell et al. (2009a).

in the global food system. These range from the risk of transferring naturally present radionuclides of uranium and thorium from phosphate rock to agricultural soils; to the generation of a radioactive by-product phosphogypsum during phosphoric acid production which must be stockpiled (USGS 1999); to the life cycle energy associated with transporting 30 million tonnes of phosphate annually from distant mine to the farmgate[1]; and finally to the widespread pollution of waterways from phosphorus run-off.

The availability of phosphorus is also constrained by a scarcity of *management*. That is, phosphorus is also scarce due to inefficient management throughout the food production and consumption system. For example, while the global population consumes around three million tonnes of elemental phosphorus in the food we eat, we mine approximately five times this amount (14.9 Mt/a of P) in phosphate rock specifically for food production (Cordell et al. 2009a). Phosphorus is lost during mining and processing, transport, fertiliser application, food processing and retail, food preparation and consumption. While there has been a general awareness of the large losses occurring at the farm related to phosphorus pollution due to erosion and run-off from fields to waterways, there has been less awareness of losses that occur after the field, with around 50 per cent lost from the global food system after harvest. Substantial amounts of food and organic material are wasted (containing approximately 1.2 Mt/a of P) during food processing, retailing (eg supermarkets, restaurants) and consumption (eg in households).

Economic phosphorus scarcity also occurs when phosphorus users – mainly farmers – cannot access phosphorus fertilisers, usually due to a lack of purchasing power or an inability to access credit. The current demand for phosphorus only represents those users who have the capital enabling them to procure phosphate rock or fertilisers. In order to maximise crop yields globally to feed nine billion mouths by 2050, there will need to be a boost in soil fertility, particularly in areas with phosphorus-deficient

1 For example, phosphate fertilisers applied to Australian agricultural soils may have started as rock in Western Sahara's Boucraa mine, transported to the Moroccan controlled port of Laayoune Plage via the world's longest conveyor belt, shipped to the US for processing into MAP or DAP fertilisers, and subsequently shipped to ports in Australia, then overland to the end user.

soils and a high rate of food insecurity like sub-Saharan Africa. Many of the unprecedented 1.02 billion hungry people today are smallholder farmers (IAASTD 2008; FAO 2009). This means ensuring farmer access to phosphorus is critical to both maximising agricultural productivity, securing farmer livelihoods and feeding the global population (Cordell 2010).

Geopolitical scarcity can further restrict the availability of phosphorus resources in the short or long term. For example, while all farmers need access to phosphorus, 85 per cent of the world's remaining phosphate rock reserves are controlled by five countries, mainly Morocco and China (Jasinski 2010). In 2008 China imposed a 135 per cent export tariff to secure domestic supply for food production (*Fertilizer Week* 2008); a move which essentially halted exports from the region overnight. The US is expected to deplete its own high-grade reserves in the coming decades and increasingly imports rock phosphate from Morocco. Morocco controls the largest high quality phosphate rock reserves in the world (36 per cent of the world's remaining reserves) (Jasinski 2010). However this includes control of Western Sahara's extensive reserves, a territory Morocco occupies in defiance of UN resolutions (Corell 2002). While the ownership is disputed and human rights violations continue, trading with Moroccan authorities for Western Sahara's phosphate rock raises serious ethical and security concerns. Importing phosphate rock via Morocco has been boycotted by several Scandinavian firms (Corell 2002; Hagen 2008).

Finally, *institutional* scarcity is also inhibiting the productive use of phosphorus by humans. That is, there is a lack of effective policies and actors explicitly governing global phosphorus resources to ensure availability and accessibility of phosphorus for food security, both in the short and long term (Cordell 2010). There is also a concerning lack of available, reliable and consistent data on global phosphorus resources and consumption patterns. For example, most primary phosphate rock data is produced and owned by individual mining and fertiliser companies and is often not publicly available for commercial reasons. Further, the assumptions behind phosphate data that is publically available (namely US Geological Survey mineral statistics) are often not disclosed or consistent because they rely on reporting by individual governments or companies.[2] As a result, farmers, policy-makers and scientists are unable to make informed judgements about the future availability and security of a resource critical for crop growth, livelihoods and national food security (Cordell 2010).

The lack of effective global governance is compounded by a lack of stakeholder consensus on the issues and fragmentation of institutional arrangements. While phosphorus is relevant to numerous different sectors (for example, a 'commodity' in the mining sector, a 'pollutant' in the water and wastewater sector) phosphorus *scarcity* is currently not a priority within any sector, and hence long-term phosphorus security has no obvious home in any sector. Phosphorus is by default governed by the market system, which may be appropriate for efficiency of trade, but is not sufficient to adequately address the much broader sustainability requirements, such as access to phosphorus for all farmers, the finite nature of phosphate rock resources and long-term security (Cordell 2010).

Global demand for phosphorus is expected to increase over the medium term at two to three per cent per annum (FAO 2007; Heffer & Prud'Homme 2008). While fertiliser demand has been stabilising in the developed world due to previous decades of over application, the demand in emerging and developing economies like China, India and Brazil is anticipated to soar over the coming decades, resulting in an increased demand for phosphorus globally. This increase in the future overall global demand for phosphorus is due to increasing:

- global population – nine billion expected by 2050 (UN 2007)
- per capita phosphorus demand (largely due to changing diets towards more phosphorus-intensive foods such as meat and dairy products) (FAO 2008)
- fertiliser demand for non-food uses such as biofuels production (IFA 2008)

2 The fertiliser industry also considers USGS phosphate rock reserve data to be unreliable (eg see Prud'Homme, 2010).

- soil fertility needs[3]
- need for farmer access to fertilisers.[4]

If no action is taken now to ensure long-term phosphorus availability and accessibility, a hard landing response to phosphorus scarcity is likely to result in a situation of increased: energy and raw material consumption; production and processing costs; waste and pollution; short-term price spikes; long-term phosphate prices; geopolitical tensions; and a reduction in farmer access to fertiliser markets, which in turn will lead to reduced global crop yields (Cordell 2010).

Averting a crisis, or a 'hard landing', is possible, but will likely require substantial physical and institutional changes. There is no single solution to meeting future phosphorus needs for global food production, rather, an integrated approach will be required that seeks to combine a range of supply- and demand-side measures. A preliminary future scenarios analysis (Cordell et al. 2009b) indicated that if the business-as-usual global phosphorus demand could be reduced by around 70 per cent (through demand-side measures of changing diets and phosphorus use efficiency in agriculture and the food chain), the remaining 30 per cent could be met through a high recovery and reuse rate of all sources of phosphorus (manure, human excreta, crop residues, food waste etc).

Significance of Phosphorus to Australian Agriculture, Economy and Environment

While Australia does not suffer from widespread food insecurity *per se*, it is still vulnerable to future global phosphorus scarcity in a number of ways, including ecologically, economically, nutritionally and environmentally.

3 Many of the world's agricultural soils are phosphorus deficient, and FAO estimate that 80 per cent of the growth in food production will need to come from intensification of existing farmland (ie improving productivity), rather than clearing natural landscapes for farming (FAO 2006). Significant phosphorus applications will be required to ensure all the world's soils have reached optimal or 'critical' levels, after which it will only be necessary to apply what is taken away in harvests (Koning et al. 2008).

4 There are many farmers today that currently cannot access fertiliser markets due to low purchasing power. However many of these farmers are working with phosphorus deficient soils, hence representing a significant 'silent demand'.

Australia's economy is dependent on phosphorus-intensive agricultural exports despite having naturally phosphorus-deficient soils. That is, we produce agricultural commodities (such as beef, live sheep exports, wheat) that require substantial amounts of fertiliser input per unit output. Most Australian soils are naturally deficient in phosphorus (particularly in the south) due to extensive weathering, fragile soils and shallow top soils (Commonwealth of Australia 2001). More than a century of continual harvesting and grazing depleted the little soil phosphorus that naturally existed in Australian soils by the 20th century (ABS 1996). Australia's agricultural productivity was 'revolutionised' due to the discovery and mining of cheap, high-grade, and readily available guano[5] phosphate on the island of Nauru (Garrett 1996). This led not only to exploitation of four-fifths of Nauru's non-renewable guano deposits but also resulted in the displacement of local populations to other Pacific Islands. Australia's fertiliser use for many decades was almost entirely dependent on imported phosphate from Nauru (Figure 2). The demand for phosphorus fertilisers increased rapidly in the post-World War II era, and agricultural production doubled between 1950 and 1980.

However this agricultural boom was relying on a finite resource. When high quality phosphate from guano was exhausted, Australia increased exploration and production of domestic high-grade phosphate, to maintain its high agricultural output. Phosphate rock was discovered in Australia at the turn of the 20th century, however serious exploration and mining commenced in the 1960s, and production dramatically increased in 1999 (mainly at Phosphate Hill). Today production from these reserves provides approximately half of Australia's demand for phosphorus (FIFA 2006b; Geoscience Australia 2008; Government of South Australia 2009).

Australia is today dependent on phosphate rock from imported and domestic sources for food and feed production to meet domestic food demand, support the economy through agricultural exports and contribute to feeding the world. It is estimated that the value of the fertiliser industry to the Australian economy is around A$8 billion (FIFA 2005).

5 Guano is the excreta from bird and bats that have been deposited over thousands of years, first discovered off the Peruvian Coast.

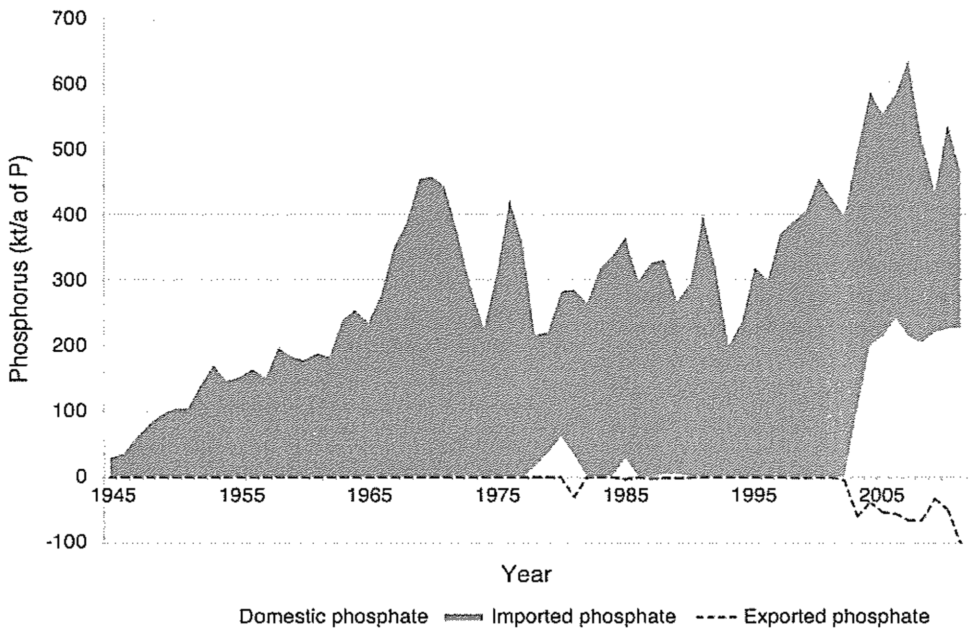


Figure 2: Australia's historical phosphate trade, indicating Australia's substantial dependence on phosphate imports (largely from Nauru).

Sources: Various mineral statistics (see Appendix in White et al. 2010).

Widespread use of fertilisers, together with land use changes, gully and stream erosion and sewage effluent; caused eutrophication of susceptible waterways leading to cyanobacteria (blue-green algal bloom) outbreaks in inland and coastal waterways. Toxic algal blooms can affect river and lake health, poison or reduce the quality of human and animal drinking water supplies, reduce the quality of recreational waters and lead to large fish kills with substantial costs for the fishing industry in addition to aquatic ecosystem health. In 2000, the annual cost of algal blooms in Australia was estimated at $180–$240 million per year (Atech 2000, in DEWHA 2006). The fertiliser and agriculture industry responded to pressures to improve efficiency of fertiliser application and uptake, and to reduce losses; such as the voluntary *Fertcare* initiative (FIFA 2006a).

Despite decades of fertiliser application, many Australian cropping and pasture systems today have phosphorus-deficient soils due to natural deficiencies, sub-optimal fertilising strategies, and sub-optimal land use practices leading to erosion. The National Land and Water Resource Audit has highlighted nutrient depletion as a major issue, however there is no discussion about where additional nutrients will come from to ameliorate the problem in the future (Commonwealth of Australia 2001).

Following the 2008 fertiliser price spike and substantial impact on Australian farmers, a Senate Inquiry was held into the drivers and impacts of the global fertiliser market on Australia and the nature of potential monopolistic and cartel behaviour by the fertiliser industry and price manipulation (Commonwealth of Australia 2009). The Inquiry concluded that there is need for effective competition in the industry and for greater transparency. A few large players dominate the current market and this in turn compromises effective competition in the industry and has implications for the pricing of fertiliser products in Australia. Serious concerns were raised during the Inquiry regarding the degree of protection available to farmers and others from anti-competitive practices and exploitation of market powers by fertiliser companies (Commonwealth of Australia 2009). It is believed that the powers of the ACCC need strengthening in order to fulfil its role in promoting competition and fair trading, and that ABARE should collect and publish international input price information on fertiliser products to ensure farmers are well positioned to make judgements about the timing and quantity of their purchases (Commonwealth of Australia 2009).

Australia's Phosphorus Balance

Understanding the current flows of phosphorus through the Australian food system can assist policy prioritisation and management responses to phosphorus scarcity. That is, quantifying the inputs, outputs and stocks (in tonnes of P per year) between key sectors (from mining to agriculture to consumption) can aid the identification of current inefficiencies, potential points for recovery, reduction in losses and facilitate prioritisation of measures (Figure 3).

Roughly half of the 455 kt/a of P in fertilisers applied to Australian soils comes from domestic rock (from Phosphate Hill in Queensland[6]), the remainder comes from imported rock or finished fertiliser products. Domestic phosphate rock reserves are not as high quality as those in Northern Africa, and thus Australia also imports phosphate rock (containing approximately 92 kt/a of P) and finished fertilisers (amounting to approximately 223 kt/a of P) (FIFA 2007). According to the Fertilizer Industry Federation of Australia (FIFA), all Australian fertiliser manufacturers import significant quantities of phosphate rock (ABARE 2007; FIFA 2003). A significant amount of the phosphorus imported in either rock or fertiliser product, originates from Morocco and Western Sahara – the largest high quality reserves in the world.

6 Other domestic production of phosphate rock occurs on Christmas Island in the Indian Ocean (for which there is no available public data), and South Australia (mainly for non-fertiliser industrial purposes) (Geoscience Australia 2008).

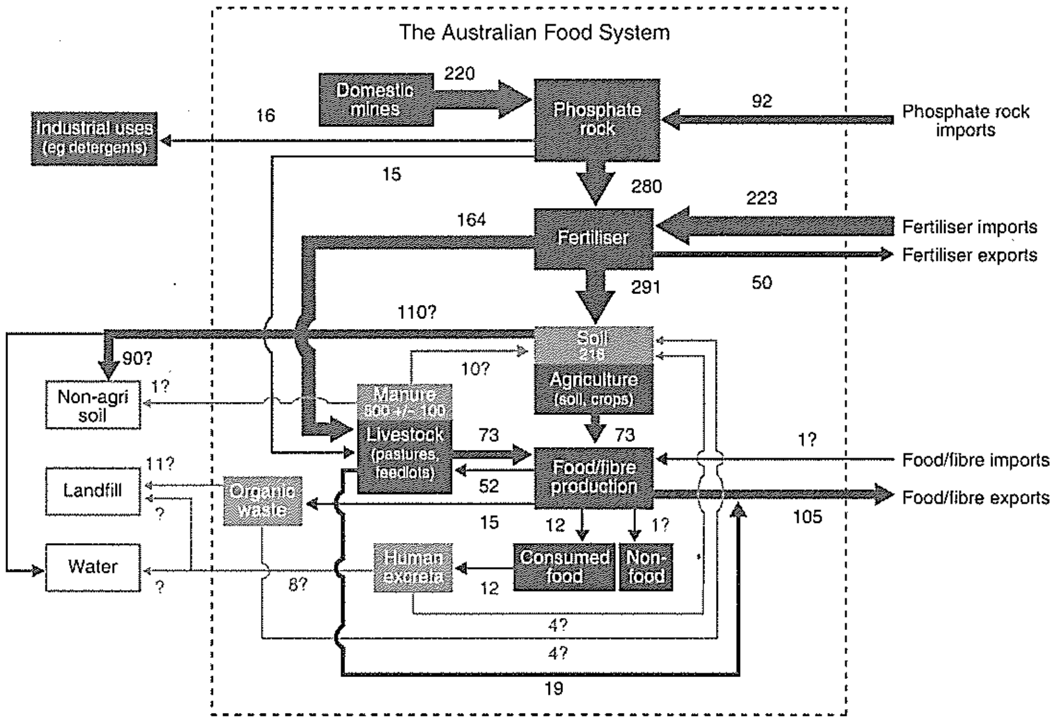


Figure 3: Australia's phosphorus budget: major phosphorus flows through the Australian food production and consumption system – from mine to field to fork. Units are kt/a of P.[1]

Source: Updated from Cordell (2010).

1 '000 tonnes of elemental phosphorus per year.

Only a small fraction of phosphorus in applied fertilisers is taken up by crops in the same year. This can be as low as 20–30 per cent uptake, according to the Australian Soil Fertility Manual (Wakelin et al. 2004; Richardson et al. 2009) or approximately 70 kt/a of P (FAO 2006). This leaves in the order of 220 kt/a of P which either accumulates in the soil 'stock' (a proportion of which is taken up by crops in subsequent years), or is permanently lost to waterways or non-agricultural land via erosion of top soil. Agricultural run-off along the Queensland coast is even causing damage to the Great Barrier Reef (Commonwealth of Australia 2001).

The livestock sector represents a significant part of Australian agriculture. Unlike Europe, most of Australian sheep and cattle are grazed rather than feedlot fed due to large available land areas. For example, around 86 per cent of cattle are grazed in Australia[7] (ABS 2007; ALFA/MLA 2007). Reasonably high and increasing levels of phosphorus fertiliser are applied to dairy pastures (which demand nearly half the fertilisers applied to Australian pastures) (Commonwealth of Australia 2001). Almost all the phosphorus consumed by livestock in feed grains (52 kt/a of P), feed supplements (15 kt/a of P) and via grazing on fertilised pastures (164 kt/a of P) is excreted in manure. This makes up the largest phosphorus output from the livestock sector (approximately 500 +/-100 kt/a of P). While this figure is comparable to the total amount of phosphorus applied in mineral fertilisers each year, most of this is recirculated to soils within the livestock sector (ie directly on grazelands and pastures).

The smaller phosphorus fraction that is taken up by the animal's body ends up in animal products (meat, milk, carcases, eggs) and is estimated to be around 82 kt/a of P – most of which is exported and hence consumed overseas. Live export of sheep, cattle and goats result in a permanent export of approximately 19 kt/a of P from the Australian food system. Demand for live animals from various markets due to cultural, religious and practical reasons, and the positive economical impact of the live export trade is a reason why Australia continues to meet the request of high P-laden stock (ACIL Tasman 2009). Food imports make up only a minute amount of phosphorus inputs into the food system (approximately one kt/a of P).

A substantial fraction of the phosphorus in harvested crops is lost due to spillage, non-edible by-products and wastage during crop and food processing, retail (eg supermarkets) and household consumption (estimated at approximately 16 kt/a of P). These losses either end up buried in landfill with other solid waste, lost to water bodies or reused. Whilst crop residues left on the field are often ploughed or burnt, returning the phosphorus to the soil stock, only a small proportion of organic waste from the food commodity chain is currently composted and productively reused in the food system as fertiliser (Zero Waste Australia 2008).

An analysis of the embodied phosphorus[8] in meat and vegetal foods produced in Australia indicates that while meat production requires approximately 10 times the phosphorus to produce, vegetal products require four times the phosphorus to produce. This indicates the higher phosphorus intensity of meat-based diets compared to vegetable-based diets. Similar results were found on the global scale (Cordell et al. 2009a).

Close to 100 per cent of the phosphorus consumed in food is excreted from the human body (Jönsson et al. 2004), equivalent to about 12 kt/a of P in Australia in urine and faeces. It is estimated around 40–50 per cent of the phosphorus reaching our wastewater treatments plants is currently reused on agricultural soils in the form of treated effluent or biosolids[9] (Michael Warne, 2008, CSIRO Land and Water, pers. comm., 19 February). Urine and faeces, in addition to detergents and other industrial uses of phosphorus, are the sources of the phosphorus in these biosolids (Tångsubkul et al. 2005). The remainder of biosolids not reused are stockpiled, sent to landfill, leached to soils from septic tanks in rural/remote areas, or blended with compost and used as a soil conditioner.

7 Data for period 2006/07.

8 The amount of phosphate rock depleted to produce a food commodity, based on the Australian phosphorus balance. See full report White et al. (2010) for analysis and assumptions.

9 Biosolids reuse varies dramatically from state to state, from close to 100 per cent in South Australia to negligible rates in Victoria (Michael Warne, 2008, CSIRO Land and Water, pers. comm., 19 February).

The phosphorus balance indicates that overall, the Australian food system is far from 'close-looped' or sustainable from a phosphorus perspective. A substantial amount of phosphorus is imported into the Australian food system (as rock and fertilisers) however only a very small fraction of the fertiliser applied to Australian fields ends up in the food consumed by the nation. This is because equally large amounts of phosphorus are permanently exported from the food system either in food and livestock exports or via erosion and other permanent losses. There is also a substantial amount of phosphorus accumulating within the system (largely in soils).

Long-Term Phosphorus Scenarios for Australia

Whilst the current phosphorus situation is unsustainable, there is a substantial lack of data and research on current and future trends. Developing future scenarios can trigger debate among scientists and policy-makers about preferred phosphorus futures, alternative pathways and feasibility.

Business-as-usual

Australian phosphorus demand is likely to increase over the next 40 years, due to population growth (35 million expected by 2050), changing diets (towards more meat and dairy), changes in export market, soil fertility status (extra phosphorus required for Australian agricultural soils to reach critical phosphorus levels).

Unlike Europe and India, which are totally dependent on phosphate imports, Australia has domestic mineral resources. Estimating Australia's mineral phosphate resources is however fraught with difficultly due to errors and uncertainties associated with reporting, exploration and assumptions. The best available figures indicate an Economic Demonstrated Resource (EDR) of 81.6 Mt phosphate rock (containing 8.6 Mt of P), and a recent increase in Inferred Resources at 1574.4 Mt phosphate rock[10] (Geoscience Australia 2009). All EDR is from Phosphate Hill in Queensland and has an average grade of about 24 per cent P_2O_5. Whilst the inferred resources are substantial in apparent magnitude, several important factors mean these resources are limited and hence not ultimately a sustainable source for the future. Firstly, the grade (P_2O_5) is substantially lower (16–20 per cent and as low as four to seven per cent (Leesa Carson, 2010, Geoscience Australia, pers. comm., 14 May). These are also more difficult to access, contain higher amounts of contaminants and therefore require more energy and input costs to produce. Further, a large share of the products from these new operations are assumed destined for overseas markets, and therefore not available for domestic use. Legend Holdings International Inc. (Legend) for example has an agreement with the Indian Farmers Fertiliser Co-operative for the purchase of up to five Mt/a Direct Shipping Ore grading 30–34 per cent phosphate, which Legend hopes to meet by 2013 (Geoscience Australia 2009).

Important future challenges (exogenous or endogenous factors) that will contribute to an unsustainable scenario if not actively addressed include:

- The average grade (percentage P_2O_5) of phosphate rock (reserves and inferred) is declining globally due to the non-homogeneity and finiteness of phosphate rock (Cordell 2010; Prud'Homme 2010).
- The physical accessibility of potential (inferred) reserves is more difficult.
- The lower grade of remaining reserves means increased energy use and the greenhouse gas emissions associated with mining, processing and in particular transporting phosphate rock and fertilisers around the world (Cordell et al. 2009a).
- Costs will increase as a consequence, thus cheap fertilisers will become a thing of the past.
- The natural presence of uranium, thorium and cadmium in phosphate rock, which must be removed and managed to avoid downstream ecological and societal health risks when phosphorus is handled and used (the by-product currently stockpiled as radioactive phosphogypsum stacks) (Cordell et al. 2009a).

10 This increase is the result of several mining companies investing or developing phosphate operations, mostly within the Georgina Basin, which spans Queensland and Northern Territory boundaries.

- Global environmental challenges, including oil scarcity, water scarcity, climate change, eutrophication. For example, future societies and systems will need to use water and energy more efficiently. However in some cases these sustainable systems have adverse impacts on phosphorus, such as alternative fuels (eg biofuel crops that require fertilisers to grow, or some electric vehicle batteries that contain 60 kg of phosphate in every battery pack – both which will increase demand for phosphorus and speed up the rate of depletion) (Cordell 2010; Renard 2010).
- Rising fossil fuel costs directly impact farmgate phosphate fertiliser prices (due to sea freight costs) (FIFA 2010).
- Environmental costs associated with landfills (eg landfill gas) and rising landfill costs in and around Australia's urban areas puts pressure on reducing waste to landfill (including the large phosphorus-rich organic waste fraction) (Commonwealth of Australia 2010).
- Australia's naturally phosphorus-deficient soils, which means building soil fertility (and avoiding depletion) is key to ensuring productivity.
- Spatial spread of cities (and potentially habitable land) and fertile land. Distances are often large, which can be a barrier to returning urban nutrients back to agricultural systems.

Further, the 'weights' of the past may also compound a hard landing situation if not addressed. These include:

- Due to globalised trade, sea freight costs associated with shipping phosphorus commodities will affect both imported and domestic phosphate prices (FIFA 2010), leading to fertiliser farmgate price volatility (as demonstrated in 2008).
- While all Australian farmers need access to phosphorus fertilisers, there are very few phosphate producers in the current market structure (Incitec Pivot Limited control 70 per cent market share at the wholesale level in eastern Australia and CSBP control approximately 65 per cent of the market share in Western Australia) (Commonwealth of Australia 2009). The major phosphate rock producers and importers in Australia at present represent an oligopoly (Commonwealth of Australia 2008), and hence farmers accessibility to fertilisers is compromised.
- Lag times (averaging three months) between fertiliser orders and farmgate arrival can contribute to short-term scarcity (FIFA 2010).
- Inefficiencies in the current food production and consumption system resulting in substantial phosphorus losses (permanent or accumulation).
- The Australian economy is dependent on agricultural exports, and is a net food producer. Many of these export commodities are phosphorus-intensive to produce.
- The geopolitics of phosphate resources, future usage trends and the uncertainty associated with global reserves, which all impact on the accuracy of reserve estimates and hence the timeline of peak phosphorus (Cordell et al. 2009a).
- Lack of adequate accounting for the continuous generation of a phosphorus 'waste' stream that can pollute water bodies (Neset & Andersson 2008).
- A significant share of imported phosphate rock and fertilisers are sourced from phosphate rock mined in Western Sahara by Morocco, which is supporting a UN-condemned occupation. Wesfarmers recently committed to reducing imports of Western Saharan rock via Moroccan authorities, in line with Scandinavian firms that have also boycotted trade with Morocco (Hagen 2008).
- The general mainstream perception that use of human excreta as a fertiliser is bad or a health risk (Cordell 2006).
- The existing phosphate rock knowledge base (or 'know how') creates a perceived barrier to changing to other forms of phosphorus (such as excreta etc).
- There are no clear institutional roles and responsibilities regarding securing a

sustainable phosphorus future. Current institutional arrangements are fragmented (Cordell 2010).

Whilst difficult to quantify, the business-as-usual situation is likely to result in a growing gap between phosphorus demand and supply in Australia. This could lead to a 'hard landing' for Australian agriculture and the Australian community in response to phosphorus scarcity, with escalating and volatile prices. However, this situation is neither desirable nor inevitable. A soft-landing is possible, which takes in account a wide range of integrated sustainability measures, long-term timeframes, and seeks synergies with solutions to other pertinent challenges such as climate change and water scarcity.

A preferred sustainable future scenario

A preferred scenario to ensure long-term phosphorus security must explicitly identify key aspirations of a future sustainable vision, in addition to future global challenges and weights of the past. Key objectives of future phosphorus security for Australia include:[11]

- Reduce Australia's *dependence* on increasingly scarce mineral phosphate sources (imported and domestic).
- Maintain or improve Australia's *agricultural and food productivity* in the long term, including investing in *healthy soils*.
- Ensure *farmer needs* are met.
- Maximise the *efficient use* and *recovery* of phosphorus throughout the food production and consumption system.
- Minimise the deleterious environmental impacts of phosphorus use, particularly related to *eutrophication*, energy consumption and mobilising heavy metals into the environment.

Taking into account the current phosphorus balance, future challenges and objectives of a sustainable phosphorus future, Figure 4 below indicates conceptually how the gap between demand and supply could be met through a range of measures. While there are substantial uncertainties regarding demand and supply trends and timing of peak phosphorus, there will be a growing gap that will need to be addressed. To ensure Australia's long-term future demand for phosphorus is met, without compromising soil fertility, economic sustainability, the environment and farmer livelihoods, a range of options will be required. It is unlikely that any single measure could secure a sustainable phosphorus future, and hence measures that seek to increase efficiency in the entire food production and consumption chain will play an important role, as will sourcing phosphorus from other, more local and renewable sources. Further, it is important that the demand management strategy considers not only increasing efficiency (ie optimising the existing system), but also how the overall demand for phosphorus can be reduced in the first place.

Sustainable Phosphorus Use Measures – Potential Roles for Key Sectors

In order to achieve a sustainable phosphorus future, new measures and policy instruments will need to be implemented by different stakeholders and sectors. Whilst substantial opportunities exist in the agricultural sector, it will be essential that sustainability initiatives also take place in other sectors related to the food system.

In the **agriculture** and **livestock** sectors, sustainable phosphorus use measures can substantially reduce the overall demand for phosphorus, while maintaining Australia's productivity, reducing deleterious environmental impacts and supporting farmer livelihoods. Measures include fertiliser selection, placement and timing; soil improvement and plant selection and optimisation. These measures can minimise the need for external phosphorus application, maximise productive uptake of phosphorus by plant roots and/or reduce losses to soil or water (Cornish 2009; Richardson et al. 2009). Interventions in the livestock sector can include animal selection or breeding for minimising phosphorus requirements, feed management for maximising productive use of phosphorus in feed

11 The factors have been drawn in part from the national phosphorus stakeholder workshop (Cordell & White 2009) and other recent research on global phosphorus scarcity and implications for Australia (Cordell 2010).

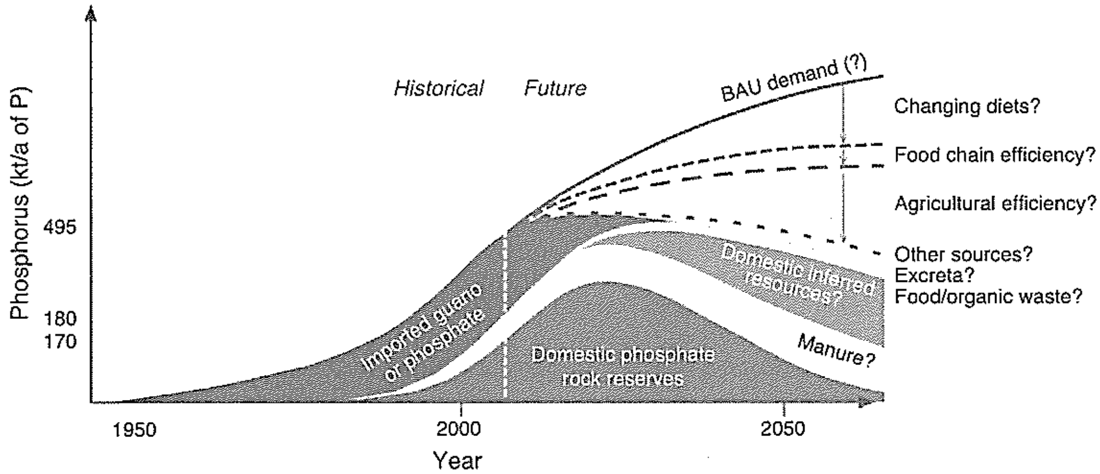


Figure 4: Filling the gap: a conceptual sustainable phosphorus scenario for meeting Australia's long-term phosphorus needs.

(eg through phytase enrichment), and productive use of manures and farmyard organic material as fertiliser supplements.

Potential sustainable measures in the phosphate **mining and fertiliser** sector include:

- Minimising onsite environmental and social impacts (eg pollution/breaching of tailings dams).
- Invest in renewable phosphorus fertiliser products and markets.
- Invest in efficient technologies (eg for cadmium removal).
- Contribute to mitigating downstream impacts, in accordance with Extended Producer Responsibility frameworks.
- Contribute to strategies that ensure short- and long-term phosphorus availability and accessibility to farmers.

Following harvest, there are numerous intervention points in the food production and consumption system. In the **food production, processing** and **retailing** sector sustainable measures might focus on either reducing avoidable phosphorus losses in organic and food waste (eg edible food or spillage) and seeking to compost and reuse the phosphorus in unavoidable waste (such as banana peels and oil press cake waste). This includes all food processing stages post harvest to food retailing to final consumers.

Food consumers (the final end users of most phosphorus) can collectively contribute through:

- Improved food planning and shopping to reduce wastage (eg spoilage), use leftovers, and avoid disposal of edible foods (even if their used by date has passed).
- Compost unavoidable waste (including both kitchen and garden and other organic matter around the house).
- Reduce meat consumption, particularly more phosphorus intensive animal products.
- Participate in management of excreta to facilitate recovery and reuse of nutrients.
- Active participation in phosphorus-related decision-making fora where possible.

Important sustainable measures by **water** and **sanitation** service providers include the treatment of sewage in a way that facilitates efficient recovery of nutrients not just to prevent downstream pollution, but also to generate an effective and uncontaminated fertiliser product, through energy-efficient and cost-effective means.

Policy-makers at the federal, state or local government levels will play an important role in securing a sustainable phosphorus future for Australia through such measures as:

- Initiating dialogue and consensus building between key stakeholders.
- Facilitating or initiating a coordinated response to phosphorus scarcity, including further independent research and indentify stakeholder roles and responsibilities.
- Identify key policy priorities for Australia.
- Build in sustainable phosphorus knowledge into relevant educational curriculum, including practical 'hands on' aspects (such as school garden that may be fertilised from organic waste produced from urine-diverting toilets and/or food and green waste compost).

Policy instruments to implement measures could include:

1. Regulatory instruments, such as targets (eg phosphorus recovery targets from excreta, manure, food waste); bans or limits (eg discharge limits on phosphorus to sensitive waterways).
2. Economic incentives such as taxes (eg P tax) or trading schemes (eg P trading scheme within a catchment).
3. Communicative/Educational instruments such as stakeholder engagement processes and outreach (eg workshops, seminars); developing stakeholder-specific resource material.

Conclusions

If no changes are made to the current phosphorus use trajectory, future phosphorus scarcity will likely compromise the world's ability to produce food in the long term, including the productivity of the Australian food system. The Australian food system is far from sustainable in that it has substantial inefficiencies and is highly dependent on phosphorus imports and hence vulnerable to global changes, such as peak phosphorus and volatile markets.

Securing a sustainable phosphorus future can be achieved through decreasing dependence on imported and domestic rock, diversifying phosphorus sources by investing in renewable phosphorus fertilisers, increasing efficient use throughout the system (not just in agriculture) and maximising recovery and reuse of phosphorus. These measures will also have positive environmental impacts by reducing water pollution, water demand, landfill waste and energy consumption.

However, achieving such a scenario will require substantial changes to the currently fragmented institutional arrangements surrounding the food system. For example, developing new partnerships and policies between the wastewater and fertiliser sectors. Further science and research is urgently required due to the limited knowledge of the stocks and flows and the historical lack of attention to this crucial issue. New knowledge regarding baseline phosphorus flows is required, in addition to seeking the most cost-effective and energy-efficient means to reduce phosphorus demand and increase recovery. There is a need to build capacity within government, industry and the research community to develop frameworks for dealing with the issue.

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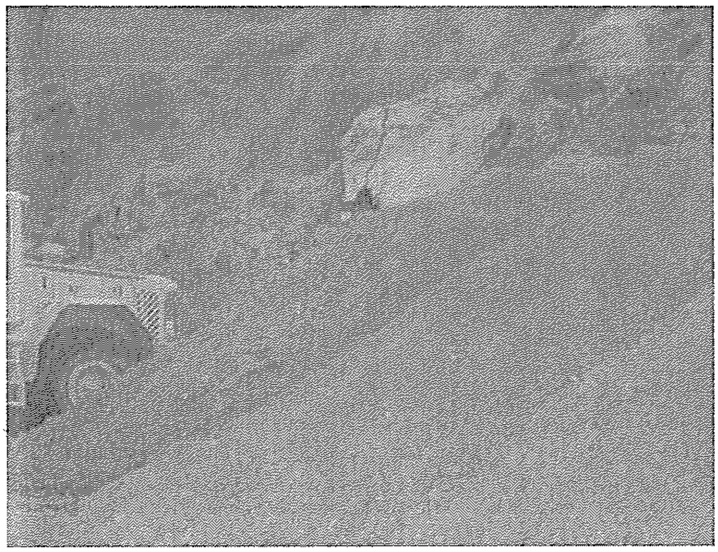

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Professor Stuart White is the Director of Institute for Sustainable Futures at the University of Technology, Sydney and leads a team of researchers across a range of aspects of 'creating change towards sustainable futures'. His own research has focused on the future of resources use, including technical, economic and policy means to reduce the inefficiency of resource use. He is widely published in many areas of sustainability. Stuart is a founding member of the Global Phosphorus Research Initiative, and has had a lifelong interest in the use of phosphorus in agriculture, starting with his early years growing up on a sheep and cropping farm in Western Australia.