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Towards global phosphorus security through nutrient reuse

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ABSTRACT: It is not widely recognised that the reuse of phosphorus will be crucial to achieving future food security, supporting farmer livelihoods and buffering against emerging geopolitical risks. All farmers need access to phosphorus fertilisers to grow crops, yet just five countries control 85% of the world's main source: phosphate rock. Morocco alone controls three-quarters of the world's remaining phosphate. These phosphate reserves are non-renewable, and becoming increasingly scarce and expensive. Already one in six farmers cannot access fertiliser markets. The 800% phosphate price spike in 2008 demonstrated the vulnerability of global and local food systems to even a short-term disruption in supply. At the same time, a staggering 80% of phosphorus is lost or wasted in the supply chain between mine, farm and fork. Much of this ends up in rivers and lakes, leading to widespread nutrient pollution and algal blooms. The good news is that phosphorus can be recovered and reused from all organic sources in the food system: food waste, human excreta, manure, crop waste. Indeed, there are over 50 low- to high-tech solutions. However, phosphorus vulnerability is very context-specific, and what works in one country may be inappropriate or ineffective in another region. This case study highlights a path forward, including examples from Vietnam, Malawi and Australia. Investing in phosphorus reuse creates locally available 'renewable fertilisers'. This simultaneously: reduces dependence on imports from geopolitically risky regions and therefore buffers against future price spikes and supply disruptions; reduces phosphorus waste in the food supply chain; and reduces the risk of nutrient pollution.

Keywords: phosphorus recovery, fertiliser price buffer, food security

This paper is about nutrient reuse in response to one of the biggest emerging global sustainability challenges for food security: global phosphorus scarcity. Without phosphorus we cannot grow food anywhere in the world. Hence we urgently need to be looking at innovative ways to recycle phosphorus and other nutrients. There are many dimensions to the global phosphorus challenge (e.g. Figure 1), including reuse of waste. Eighty per cent of phosphorus is lost between mine and farm and fork. Much of that lost nutrient ends up in waterways where it can feed toxic algal blooms.

Phosphorus is a resource that every farmer in the world needs; yet the world's high-quality mineral resources are finite and becoming increasingly

This is an edited transcript of the presentation, with some of the powerpoint slides shown.

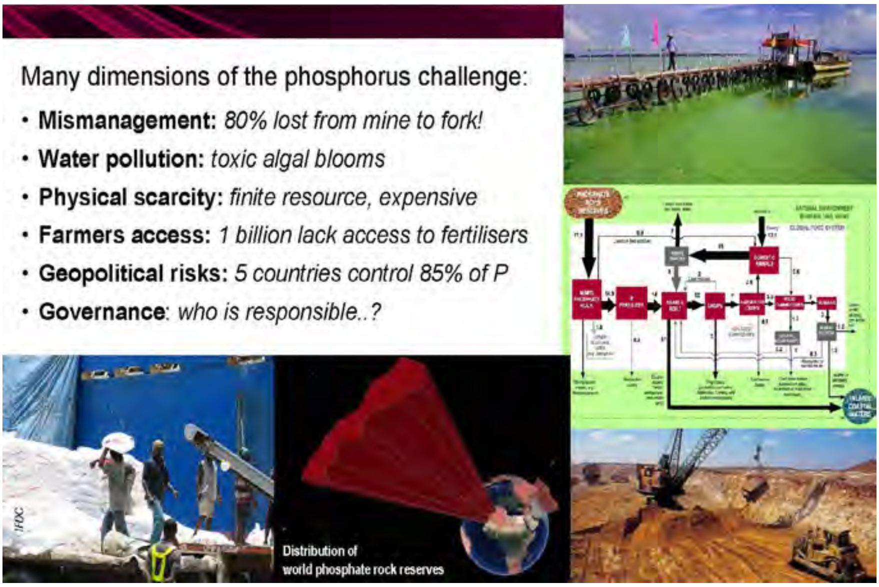

Figure 1. The global phosphorus challenge.

scarce and expensive. Several scientific studies suggest demand could exceed current supply by mid-century. Yet even today there are already up to a billion smallholder farming families in the world who cannot access fertiliser markets. In landlocked countries in sub-Saharan Africa in particular, farmers can pay 2–5 times more for their fertilisers than farmers do in, say, Europe.

Perhaps one of the most concerning dimensions of global phosphorus scarcity is the geo-political risk. Only five countries control 85% of the world's remaining phosphate rock, and one family alone controls three-quarters of that supply.

Given the gravity of this situation, it is quite concerning that there is scant or no effective governance on global, national or local scales to ensure phosphorus security into the future. We define phosphorus security as ensuring all farmers have access to phosphorus; that our soils are fertile and agriculture is productive; that up to 9.5 billion people have access to healthy diets; and that our rivers, lakes and oceans are clean, free from nutrient pollution.

The good news is it is possible to avert the crisis. Indeed, there is a whole toolbox of technologies and behavioural change options that we can think about, systematically through the food system. Examples (Figure 2) of this spectrum range from efficient phosphorus use on-farm, to changing diets, to recycling of phosphorus from manure or food waste, crop residues and human excreta.

Even for recycling phosphorus from human excreta, there are over 50 different technologies available, from the small-scale low-tech urine-diverting composting toilet which can be used, for example, to grow onions in Burkina Faso, right through to the large-scale high-tech expensive technologies like phosphorus recovery from wastewater treatment plants. The bottled white crystals (Figure 2,

Figure 2. Toolbox of sustainable phosphorus supply and demand measures.
Source: Cordell & White 2013

bottom-left) are struvite, produced by dosing a side-stream of wastewater with magnesium; pure magnesium ammonium phosphate crystals emerge, which a wastewater treatment plant can bag and sell on-site.

These technologies are all context-specific. Although there is a suite of options, it is very important to implement only those that are most appropriate and cost-effective for a given city, country or region. Implementation also needs policy instruments, and for policy makers and other stakeholders to make the right technologies work effectively in practice.

Case studies of phosphorus recovery and recycling opportunities

Malawi

In Malawi, agriculture is largely based on subsistence maize farming. The fertiliser subsidy was scaled back somewhat in the last budget. The country is vulnerable to phosphorus scarcity, partly because it is landlocked and very heavily dependent on phosphate imports via their neighbours – hence good relations with neighbours such as Mozambique are important (Figure 3).

We have calculated that human excreta in Malawi contains roughly as much phosphorus as they are importing from Morocco, China and other countries. There is only one major fertiliser company in this country, and one product manager. There is an opportunity to see how Malawi might implement some of these phosphorus recovery options. While there was not much initial interest in phosphorus recovery from human excreta, it emerged that a major concern was the economies of scale: 'Don't talk to me about five tonnes a day. Come back when you've got a hundred tonnes a day and then we'll talk business.' So now we are looking at how we can mobilise action there.

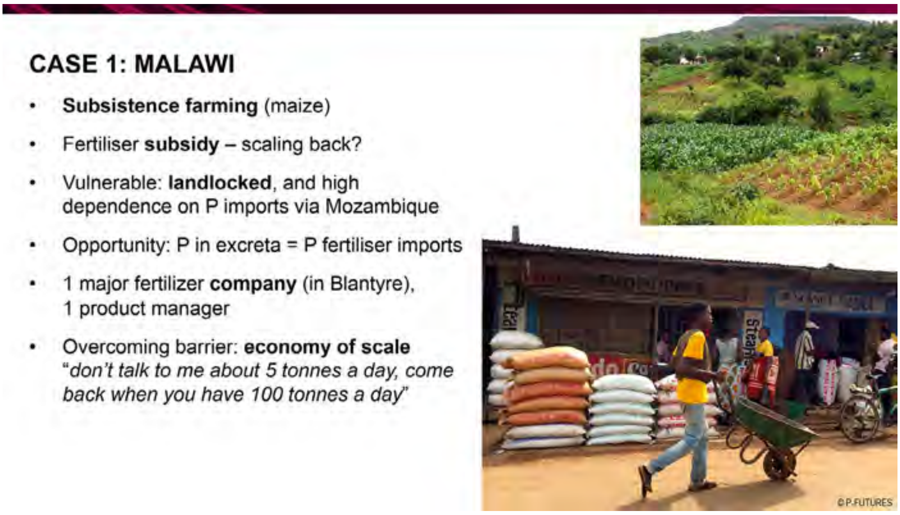

Figure 3. Phosphorus recycling opporunities in Malawi

Vietnam

The next case study comes from peri-urban Hanoi, in Vietnam (Figure 4). This city's jurisdiction recently expanded to 'Greater Hanoi' which now encompasses one-third of the province, including areas that used to be rural and that, because of the centralised governance in that part of the world, were designated 'safe food districts'. One district might be designated for fruit and vegetables, while another might be the livestock district. Traditional recycling of organic waste meant that there was some reuse of manures, but not much reuse of household organic waste, most of which went to landfill. However, in some instances, mixed municipal waste (topped with some sewage sludge) is composted but

Figure 4. Phosphorus recycling opporunities in Hanoi, Vietnam.

largely untested. So the levels of pathogens, heavy metals, etcetera, are largely unknown to farmers who are collecting the compost for free and using it on their farms.

Hanoi has an extremely ambitious and green '2030 Greater Hanoi Master Plan' which includes targets for 70% recycling of compost. Therefore, working with urban planners and other stakeholders in Hanoi can potentially fast-track phosphorus and nutrient recycling through these ambitious targets.

I want to stress the importance of engaging urban planners when we are talking about food consumers, who are largely in the cities. We need to be thinking about strategically designing waste-recycling systems upfront.

Australia

My final example comes from Australia (Figure 5). Although Australia is a net food-producing country and food exporter we are very vulnerable to phosphorus scarcity, though in a different way. Australia is a net importer of phosphorus, because while our soils are largely naturally phosphorus deficient we have invested quite heavily in phosphorus-intensive agricultural export industries. In our beef and live animals, wheat and dairy products, we are literally shipping phosphorus off our shores. Even if we were to recover all the phosphorus in human excreta in Australia, it would represent less than 5% of Australia's total phosphorus demand.

We need to think about different options in this country. Up to 90% of Australia's population lives in the cities, and they are therefore phosphorus hotspots for excreta and food waste and other sources. My team has been geo-spatially mapping those hotspots. We are also working with the major fertiliser retailer in the Sydney Basin.

This fertiliser producer has a really innovative business model, selling not a product but a service. When a customer comes to them asking for fertilisers,

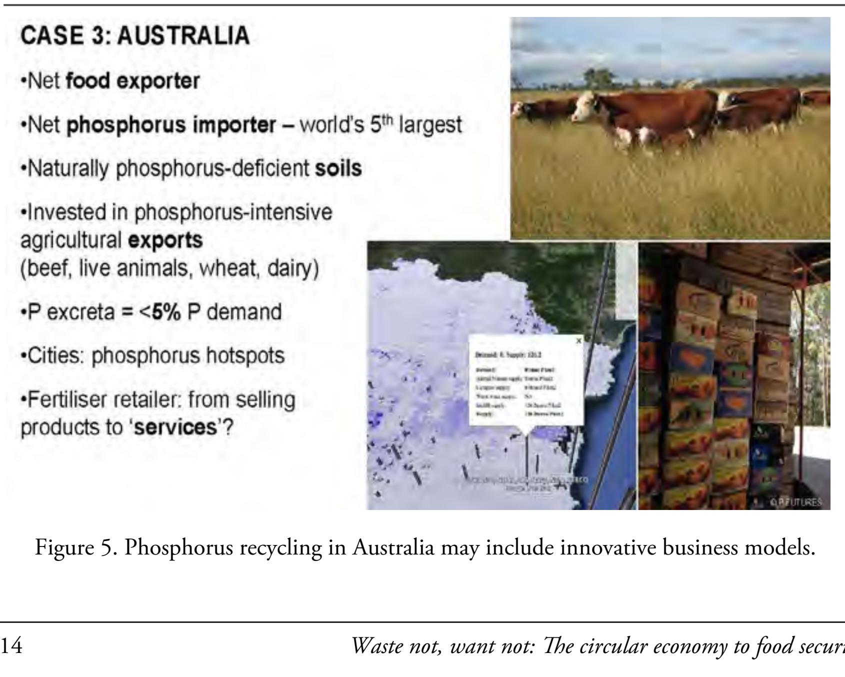

Figure 5. Phosphorus recycling in Australia may include innovative business models.

they only sell them fertiliser after they have tested the customer's soil. Most (99%) of the time the soil is already saturated in phosphorus largely as a result of the use of excess poultry manure in the Sydney Basin. This business is selling an agronomic service, and this is a really good business model which is a win–win for them and gives them a market edge. It is good for the farmer customer's productivity and it is good for the environment because it results in less phosphorus being applied to the soil to later run-off into our waterways.

Why recycle phosphorus and nutrients

Recycling can and must play a role in achieving future phosphorus and food security, both in this country and in the rest of the world, because it creates locally available renewable fertilisers.

We talk about renewable energy, and we really need to become serious and talk about *renewable fertilisers* as well. Human excreta alone can contain 3 million tonnes every year of elemental phosphorus, globally. The opportunities are right there.

Recycling also would facilitate what we can call 'phosphorus sovereignty', particularly for communities around the world where farmers have poor access to fertilisers.

At the national scale, renewable fertilisers can reduce countries' dependence on imports from some of the geo-politically risky areas where phosphate is being produced, and so buffer against some of the future price spikes and supply disruptions. You may not have been aware that in 2008 there was an 800% price spike in phosphate. It had dramatic consequences around the world, including in Australia.

With the shorter phosphorus cycles in a circular economy, of course we have less waste and potentially less lifecycle energy – and of course less risk of phosphorus run-off to waterways, feeding algal blooms.

Important considerations

Finally, a few considerations we need to keep in mind on this pathway towards nutrient recycling and phosphorus security (Figure 6).

- **Context matters**. We have all these technologies available, and we cannot import solutions from one country to another. Therefore there needs to be a framework for thinking about the most cost-effective and appropriate measure for each situation.
- **End-user preferences matter**. In designing new products, we need to engage the market end-user to understand their needs and preferences, because that is often where some of the barriers are.
- **Look for partnership opportunities**. In a circular economy, we need to be forming new partnerships between the sectors and stakeholders in the circular value chain. As I mentioned, those partners also need to include the urban planners when talking about cities.
- **Look for new business models**, such as selling services instead of products. Using 'Uber farm machinery' (Gulati, this Proceedings) is another example.

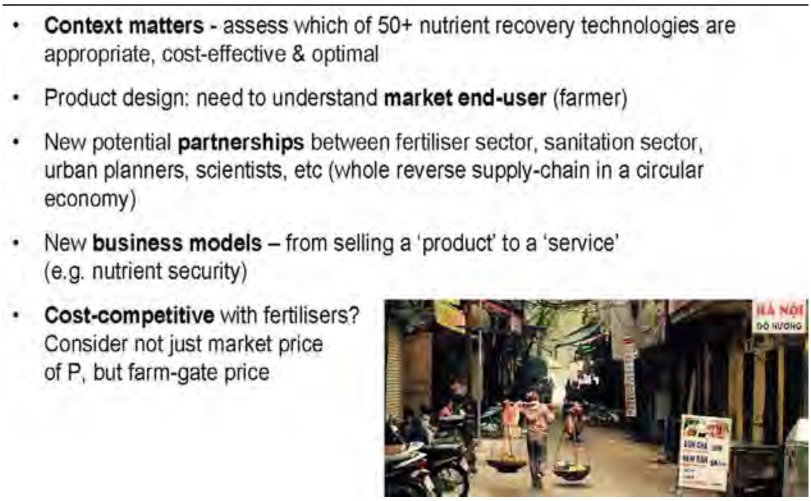

Figure 6. Considerations on the pathway to nutrient recycling and phosphorus security.

- **Cost competitiveness**. Is recovering nutrients cost-competitive with fertilisers based on rock phosphate? It is not appropriate to compare fertilisers on the basis of the market price alone, because for the farmers it is the farm-gate price that matters. If recovered nutrients are compared to rock phosphate fertilisers at the farm-gate price, then there are opportunities to show that recovered phosphorus can be a cost-competitive product that has the added advantages of building food security, environmental integrity and livelihood security as well.

Acknowledgement: The partners named in the image below, as well as numerous others, support this work.

References

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Dana Cordell leads and undertakes international and Australian research projects on sustainable food and resource futures. Many projects involve high-level stakeholder engagement to improve the policy relevance and impact, and foster mutual-learning. Dr Cordell leads the collaborative P-FUTURES project across Australia, Vietnam, Malawi and the US, which, together with local stakeholders, aims to identify how urban food systems can cope with or transform in response to the emerging global phosphorus challenge. In 2008, Dr Cordell co-founded the Global Phosphorus Research Initiative – the first global platform to undertake research, policy and public engagement to ensure food systems are resilient to the emerging global challenge of phosphorus scarcity. Dr Cordell currently leads the Mapping Sydney's Potential Foodsheds project, which brings together key stakeholders such as NSW Farmers, Department of Primary Industries, Department of Planning and RDA-Sydney. The project aims to increase the resilience of Sydney's food system to global and local challenges (from climate change to urban growth) through participatory stakeholder workshops and geospatial mapping scenarios. As a global food security expert, Dr Cordell provides expert advice and commentary to the United Nations Environment Programme (UNEP), Australia's Chief Scientist and the UK Parliament. She most recently joined UNEP's Global Environment Outlook team as a global food security contributor. Dr Cordell's research contributions have led to numerous prestigious recognitions, including one of Australia's top science prizes, the Eureka Prize for Environmental Research (2012). She has been named as one of the 100 Women of Influence (*Australian Financial Review*/Westpac 2013) and the Top 100 Most Influential People (*Sydney Magazine* 2012). She is frequently interviewed for the media, including Radio National, ABC *Lateline*, and *The Times* in UK.

Sessions 4 & 5 Q&A – Supermarkets & the management and reuse of waste

with Dr Arief Daryanto, Professor Alice Woodhead, Dr Steve Lapidge, Dr Cedric Simon, Dr Bernadette McCabe & Dr Dana Cordell

Chair: Ms Jo Evans

Q – Isaac Jones, Western Sydney University
Bernadette McCabe, I know it wasn't the focus of your talk, but with municipal solid waste I know one of the key issues is heavy metal residue in soil and also physical particles of glass and things like that. Does the incineration of municipal solid waste (MSW) alleviate those problems and also, in your opinion, is incineration of MSW even adequately viable, or would you prefer one of those other options?

A – Bernadette McCabe
To answer your last question first, no, I do not think incineration of the MSW is the best use of it. I will reiterate a point from Professor Fresco's Sir John Crawford Address last evening, and say that what we need to do is to get the most benefit out of our waste, whether it is inorganic or organic. The 'jury is still out' on incineration as a recovery method, though a decision is being spurred on by legislative requirements and landfill and so on.

Australia has huge potential for using sewage digestate that may contain heavy metals. We need to consider digestate handling and use, and at the moment our wastewater treatment facilities are not using sewage in the best way. They may be trucking the sewage and ploughing it into land without knowing what heavy metal accumulation could be happening.

If you look at the UK experience with WRAP (Waste & Resources Action Programme), they have done some brilliant work around bio-solids application, and understanding dosages. What farmers really want to know when using bio-solids on land is what sort of NPK levels they are applying, just as they do when using a synthetic fertiliser. If you are going to put a tonne of digestate onto land, you do not want to be guessing what you are adding. Some of the guidelines that are coming out are giving users a better idea of the content, so that farmers can be confident in what they are applying. I think that is something that Australia should really look at, in closing the nutrient recovery loop, as well as understanding dewatering technologies and granulation of bio-solids.

Q – Sally Beer, University of New England
My questions are for Steve Lapidge and Dana Cordell. Steve, could you clarify what 'printed food' is. Dana, how are you planning to overcome consumer resistance to using excreta as fertiliser? I am thinking there could be some logistics issues in that.

This is an edited transcript of this Q&A session at the conference.

A – Steven Lapidge
Printed food is a new idea coming from the Netherlands and a few other countries in that part of Europe. It is amazing. They use a feedstock such as food waste to print a 3D carrot or a biscuit. You can put whatever ingredients and nutrition you want in there, so it certainly may be something we can use in the future. At this stage it may look quite crazy, but if you think about elderly people who may not want to bite into a hard carrot but would like the nutrition that comes in the carrot, this technology means you can 'print' a 3D carrot with whatever texture you want and whatever nutrition you want, so it meet the consumer's needs. They reckon the costs of food printers will be down to a few hundred dollars in the next 1–2 years. I am sure we shall be using this idea one day.

A – Dana Cordell
Fertilising crops with excreta is already happening in many parts of the world. For example, when I lived in Sweden for six years, on a farm near a very small town, we could go to our local hardware store and buy a urine-diverting composting toilet that we could put in our house. Then we could use our urine to fertilise our gardens for example. Urine is perhaps the most confronting, because it is used without being processed in any way. I think it becomes much more socially accepted once people understand why we are doing it. A lot of studies have actually engaged with users of these new types of toilets and also with consumers of the food that has been produced using human excreta and other forms. You find that when you engage people so they deeply understand the why, then they become much more open to the idea. You especially need to answer their questions around health concerns, which of course are the number one issue after the yuck factor. There are a lot of examples showing how objections can be overcome. There's a professor in Sweden who talks about 'urine blindness' for example. He is referring to the blindness of policy makers and industry to the fact that wastewater treatment plants, say, are sitting on a gold mine because excreta is going to become one of the most valuable of resources in the future. The reason they are not there yet is all because of this yuck factor – which we can overcome. We are toilet trained as we start life, and we can be toilet trained again, to use these different types of toilets and to understand why we should be eating these food crops, and that we do not necessarily need to feel concern over their healthiness.

Steve and I both showed photos of struvite. It looks exactly like fertiliser. It is pure white crystals and so in appearance it is far from the idea of human waste. It looks very nice and clean. I have a jar of it on my desk at work, as well as a jar of other things I will not tell you about. Use of these materials will become normalised once we realise there is so much value in them. In some parts of the world, they cannot afford to acknowledge the yuck factor. Farmers realise that some of these products are 'clean' and processed. They produce higher yields and farmers can see their benefits. It is just a no-brainer really..

Q – Gerry Gillespie, *Resource Recovery Australia*
This question is specifically about source separation of organic waste and I think Alice Woodhead will be the most appropriate person to answer it. According to the New South Wales Department of Primary Industries, in Australia 75%

of our agricultural soils have less than 1% organic matter, so we have a soil-organic-matter crisis in Australia. In 2011 we passed a piece of legislation in Federal Parliament called the *Product Stewardship Act 2011*. Currently we use that legislation on a mandatory basis, just to recycle computers and televisions. If about two paragraphs of it could be modified, that legislation could direct every bit of organic waste in Australia to be source-separated and returned to agriculture as a high-quality nutrient-rich product. Would that make sense to you, Professor Woodhead?

A – Alice Woodhead
Thank you for that tricky question. Yes, it does make sense, but nothing is ever as simple as it seems it should be. There is always a cost and the question then is 'who bears the cost?'. The Product Stewardship work was done with supermarkets and other sectors, and apart from the supermarkets the stakeholders are not necessarily in a good enough financial position to be able to bear the cost. So you can get a kick back. I am not exactly sure of the details of where the cost would be borne in that particular scenario.

The way to get around that is to create an economy around doing this recovery process and to create a market that rewards the recycling of the goods. But we have always had some resistance to putting an enforced market price on some of these policy initiatives. I think that is the answer to why it is not happening, and yes, it does make sense, in principle.

Q – John Radcliffe, *Australian Academy of Technology and Engineering (ATSE), South Australia*
First, it has to be made clear that somebody has to have a business plan which is positive, before any of these ideas can be pursued. There are a number of ideas around, to do with nutrient recovery. ATSE last year produced a report on the resources in wastewater streams, and that showed clearly that the most valuable components are carbon and water. We have been given the example, today, of SA Water's wastewater treatment plant at Glenelg in Adelaide. South Korea abolished the export or dumping of food waste to the ocean a few years ago, and it now requires it to be combined with wastewater treatment, which generates energy and makes those plants energy-exporting. That is a legislated example.

In Australia, a lot of the current waste systems in urban areas derive from the old Environment Protection and Heritage Council of state and federal ministers, which was abolished two or three years ago. You have to consider the environment and the legislative structure within which people will operate. The people who run the sewage treatment plant at Werribee, near Melbourne, for example, are not going to pursue a couple of tonnes of struvite when they can get much more value by improving the quality of the wastewater that they discharge to ocean so that they are not prosecuted. There are a whole lot of sticks and carrots in this process.

My question is, can we re-establish a Commonwealth–State structure that would facilitate the development of some of the ideas that have been enthusiastically put forward?

A – Steven Lapidge
Environment Minister Greg Hunt announced a National Food Waste 2025 Strategy last year, which is tied to the Emissions Reduction Fund. It will be interesting to see what happens in that space. I am not saying it is the total answer, but certainly in terms of a federal initiative that may see more work in this area, I think it is a promising start. We are yet to see the fine print.

Q – Eric Craswell, *Crawford Fund and the Australian National University*
There was a passing mention about 'peak phosphorus'. I understand the latest estimate is that it is 200–300 years away, because of the revised Moroccan Reserve. However, I want to ask the panel a question in general. There seems to be a trend among the younger generation to look for organically grown food and farmers markets, certainly in Canberra. I wonder whether those two trends are significant enough to affect the waste of food and food losses?

A – Steven Lapidge
Unfortunately there is still a lot of waste happening on organic farms as well that could be utilised. So yes, those trends potentially help with the nutrition side of things, but there is still a lot of waste happening.

A – Dana Cordell
I can add two things in response to that, working backwards. One is a project that my colleague Elsa Dominish and I are working on at the moment. It is about creating demand for recycled organics (compost). Part of that is looking at the demand or the market pull, so it actually engages exactly the consumers you are talking about – those who use farmers markets and who buy organic produce – to understand if we can market, say, vegetables that have been produced using these kinds of recycled organics, such as compost.

Also, about 'peak phosphorus', that revised date you mentioned was not a peak phosphorus date; it was in relation to a new assumption about the phosphorus concentration of Moroccan rock phosphate, updated from 1989. When you use that new reserve data that they have come up with, and put it into a peak phosphorus analysis, it pushes out the peak phosphorus crunch time by a couple of decades. We have moved on to what can we do about sustainable phosphorus use, but there are now a number of studies that show that we could see a crunch time around mid-century, plus or minus a decade or two.

Q
A question for, perhaps, Dr Daryanto and Professor Woodhead. In that 'last mile', if you have printed food and then a shift back to organic farming and famers markets, given the different type of retailing structure in some of these countries, where are those new technologies going to fit in?

A – Alice Woodhead
Well, every technology has to be adapted to the particular situations. If you have organic waste and printed food – which I hope would be organic with some flavours in it – then the solutions are the same as those we need in the current supply chain. If food can be preserved and shelf life extended and infrastructure maintained that keeps the food in a whole state, then you will have less waste.

That is basically the scenario that we work to. Where there is waste, if you can create a by-product rather than thinking of it as a waste, then regardless of whether it is functional food or an organic source of printed food, the same scenario would fit.

A – Arief Daryanto
I think that Indonesia has to deal with food waste issues like those of developing countries and also those of Australia. Jakarta has an inner city population of over 14,000 people/sq km, or over 4000 people/sq km if you consider the metro area as a whole. This is 1.6 times the density in Singapore. We have the highest income and also the lowest one. The Government needs to be balanced, in focusing on food security and on food safety. We have classical food loss from primary products and also processing and service. So we are now introducing industrial models of agriculture industrialisation, to combine primary processing and also the service industry in the one model for our country.

Q – Joanne Daly, *CSIRO*
My question is for Steve Lapidge. You mentioned that 90% of nutrients are lost from farm to fork. It is an interesting figure because most of the speakers have talked about quantities in tonnes or as dollar value. Can you clarify: does the 90% loss, for example, mean that after your tomato leaves the farm, only 10% of its nutrients reach the consumer unless the right quality or processing strategies are applied along the way, or is it that the 90% of the nutrients are the ones that are disposed of before they end up in the consumer market?

A – Steven Lapidge
The figures I've seen are quite general; not specific calculations. Any organic produce that goes back into the soil is obviously adding nutrients back into that soil. If instead the produce goes into landfill or out to sea, then obviously those nutrients are being lost. That is where the bulk of nutrients are being lost, as well as in fertiliser that never gets taken up by the plants. That is where the 90% figure comes from.

A – Dana Cordell
For phosphorus specifically, a lot of the losses occur during mining and fertiliser production. The phosphate mining process used today is the same as was being used 50 or 60 years ago. At the moment, there are no incentives for industry to do things differently. When you produce phosphate fertilisers, for every one tonne of fertiliser you get five tonnes of a radioactive by-product called phosphogypsum which has to be stockpiled. The USEPA considers it too radioactive to reuse because it contains isotopes of uranium and thorium, so there are huge stockpiles of it sitting in Florida. It is another really important pre-farm loss. We often start at the farm. I think we need to go further back, looking at those raw inputs to agriculture as well.

Q – Justin Borevitz, *the Australian National University*
Can anybody on the panel discuss their thoughts about urban agriculture, either high-tech vertical sky-farms or low-tech aquaponic agriculture?

A – Dana Cordell
Can you grow prawn pellets on the top of roofs?

A – Steven Lapidge
Grow the food where the waste is.

A – Cedric Simon
There has been more and more work looking into recirculation systems to recycle nutrients: aquaponics, for example, possibly to produce eels or tilapia. There are a range of aquatic species that can be reared at high stocking density, on top of roofs and in cities. It remains a niche market to provide fresh seafood to local restaurants etcetera, generally associated with low production volumes.