GLOBAL WATER RESEARCH COALITION

FACTSHEET

GLOBAL SUMMARY ON PHOSPHORUS RECOVERY

OVERVIEW

This factsheet is a summary of the outcomes of a compendium that was produced for GWRC members and provides an overview of *technology implementations* in the field of phosphorus recovery from sewage/sludge. It focuses on centralized infrastructures and covers *operational and regulatory issues*. Besides general information on specific technologies or recovery concepts, regional aspects regarding the implementation are addressed.

WHY PHOSPHORUS RECOVERY IS IMPORTANT

Whether or not there will be a phosphorus (P) peak within decades, centuries or millennia, one thing is for sure – phosphorus is a *limited* and, in its function as a nutrient, an *essential and irreplaceable resource*. As Isaac Asimov stated in April 1959, in his essay 'Life's bottleneck', phosphorus limits the biomass potential on Earth. Essentially, all phosphorus in fertilisers and feed is originally mined from phosphorus-rich rocks, which are finite and distributed in just a few places on the planet. From the Global food security perspective, the geopolitics and economic vulnerability are issues to be taken seriously. Most countries are highly dependent on phosphorus imports.

Recovery and recycling can play an important role in improving resource efficiency and sustainable nutrient management. Although there are various relevant and in the case of manure even bigger waste streams, carrying huge quantities of phosphorus and other nutrients dissolved in liquids or fixed in solids.

Phosphorus is an essential macro-nutrient that cannot be replaced by any other element, nor synthesized its recovery and recycling is an incremental of sustainable nutrient management and long-term food security on global scale!

PHOSPHORUS RECOVERY AND RECYCLING ROUTES

In industrialised countries, sewer systems and wastewater treatment have been implemented to protect human health and the environment and especially water bodies such as rivers, lakes and finally the sea. As a positive consequence phosphorus is collected and concentrated in a manageable mass flow providing several hot-spots for recovery. In *centralised sanitation schemes*, the wastewater is collected in sewer systems and transported to wastewater treatment plants (WWTP). It can be assumed, that 90% of the P entering the WWTP are transferred into the sludge by intended so-called phosphorus removal. Phosphorus is typically removed from the wastewater by *biological accumulation in biomass* (Enhanced Biological Phosphorus Removal, EBPR) or by *chemical precipitation*, in the form of barely water-soluble phosphates (normally as iron or aluminium phosphates), leading to the highest P loads in the waste activated sludge (WAS).

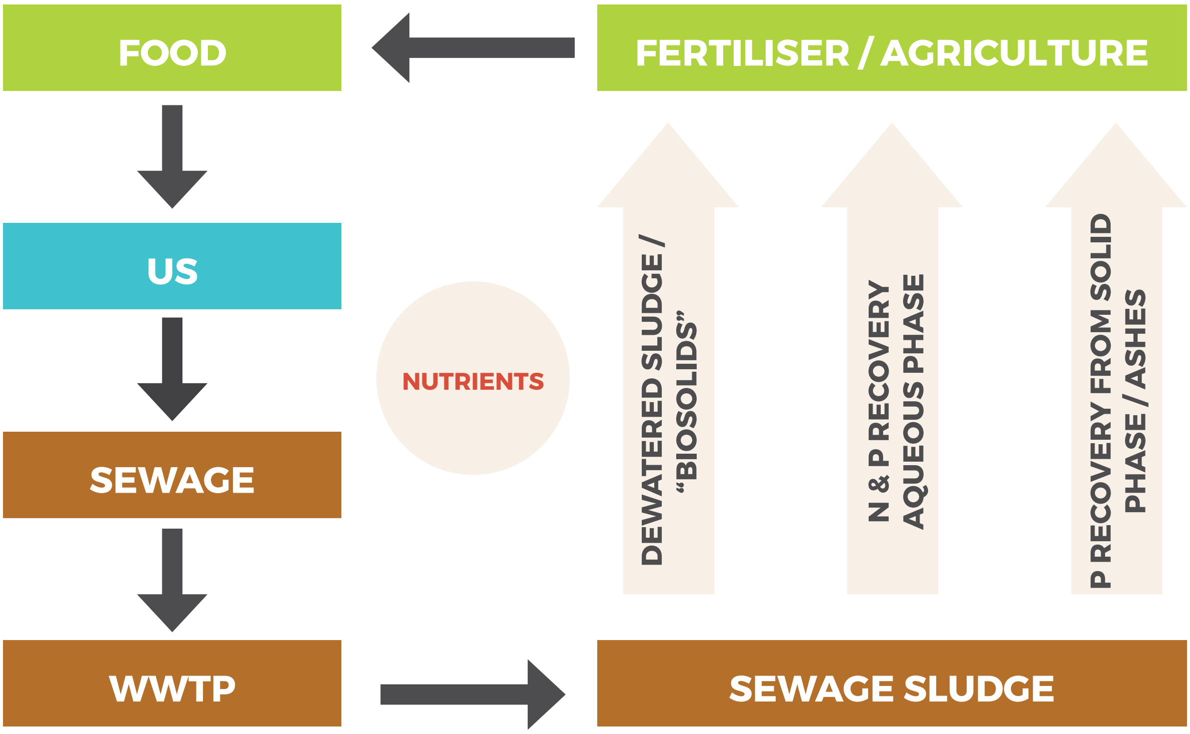

Figure 1: The three principal routes for P recovery and recycling from the wastewater stream as a nutrient

Direct application of stabilised sewage sludge or biosolids on arable land is the traditional route to valorise all contained nutrients in agriculture. Since this valorisation route can be considered low tech and low cost, it will remain one of the main pillars for nutrient recycling on global scale. Initiatives like GlobalG.A.P.(https://www.globalgap.org/uk_en/) have the ambition to harmonize applicable standards to ensure reasonable levels of quality and to reduce the risks for human health and environment.

Where direct application of biosolids in agriculture is no longer an option, alternative routes need to be implemented to keep or even increase phosphorus recycling rates. This is especially the case in regions with high population density of humans and livestock and very limited land area available for reasonable nutrient recycling. Also increasing concerns about pollutants, whether known (heavy metals) or unknown (organic contaminants and pathogens), are questioning the application of biosolids increasingly, especially in industrialized countries, where more and more sewage sludge is incinerated.

The main driver for advanced P recovery is not a potential scarcity of the nutrient, it is rather more an acute regional surplus or simplified: too much of the nutrient in the wrong place.

PHOSPHORUS RECOVERY AND RECYCLING OPTIONS

Solutions for *technically advanced P recovery* and recycling providing defined nutrient concentrates of good quality can be considered proper alternatives, when direct application of biosolids in agriculture is no longer an option.

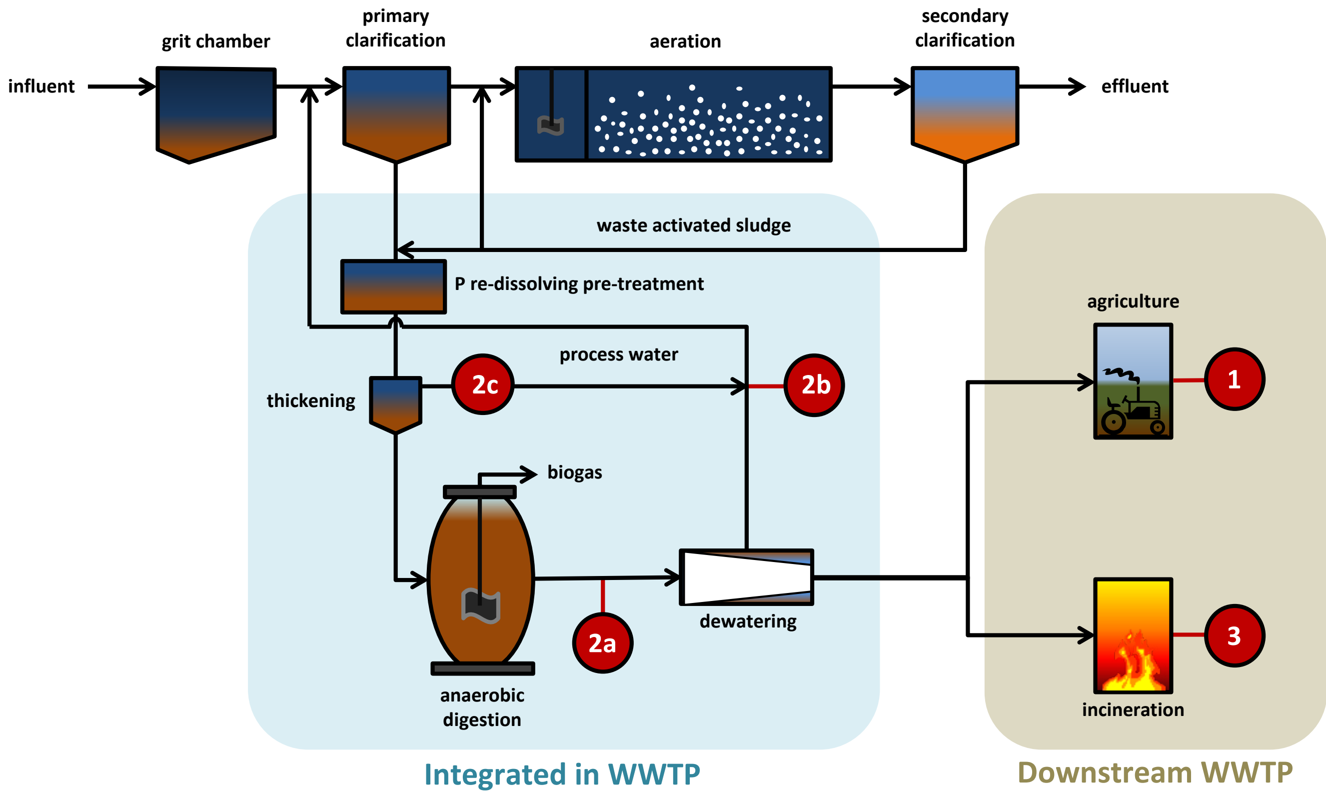

Figure 2: Hotspots for P recovery from the wastewater stream (simplified for centralised sanitation systems) (updated from Kabbe, 2013). Legend: 1 = direct sludge (biosolids) application in agriculture; 2a = P recovery within digested sludge prior to dewatering; 2b = P recovery from sludge liquor after dewatering; 2c = P recovery from liquor of pre-treated WAS; 3 = P recovery from mono-incineration ash.

On-site P recovery

Depending on the design of the wastewater treatment process and type of P removal, several P recovery options can be integrated. All of them finally capture dissolved phosphorus from the aqueous phase of the sludge. Currently, the most applied option is the P recovery from the centrate after dewatering (2b). Another option is represented by P recovery directly within the digested sludge prior to the dewatering process (2a). Second generation enhanced P recovery concepts include a WAS pre-treatment step, biologically redissolving a part of phosphorus contained in the biomass already prior to anaerobic digestion. The redissolved phosphorus can be recovered in a separate system in the form of Calciumphosphates (2c), for example, or being combined with the nitrogen and phosphorus rich liquor of the dewatering (2b). If sludge is exclusively incinerated in sludge monoincinerators, the resulting ash contains the highest available concentrate of P within the wastewater stream (3 in Figure 5). Due to the very limited plant-availability of the nutrient within most of the ashes, further treatment is required.

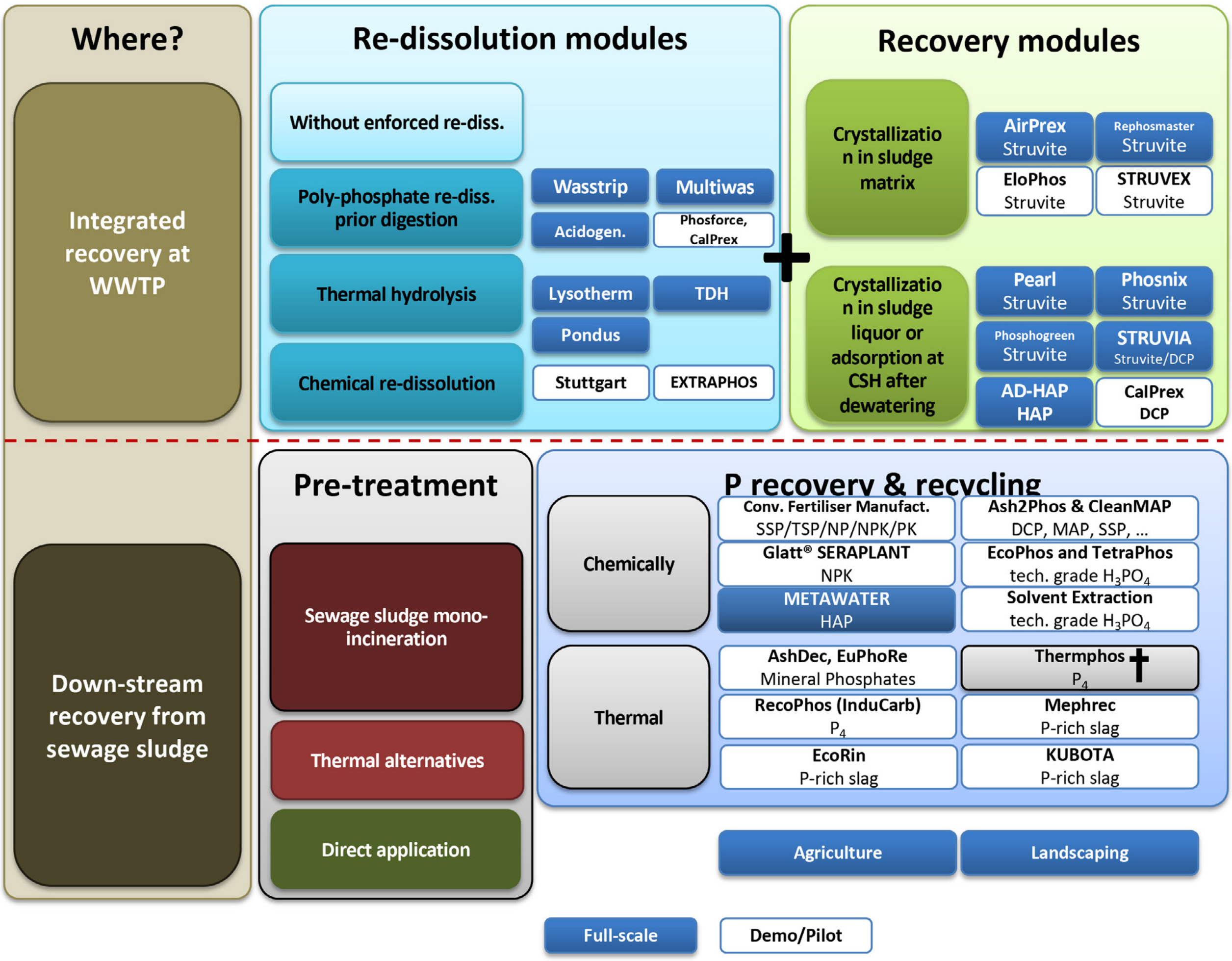

Figure 3: Prominent and already applied concepts for P recovery and recycling from sewage sludge;

The global distribution of P recovery installations reveals three hotspot regions: (Central)Europe, Japan and North America.

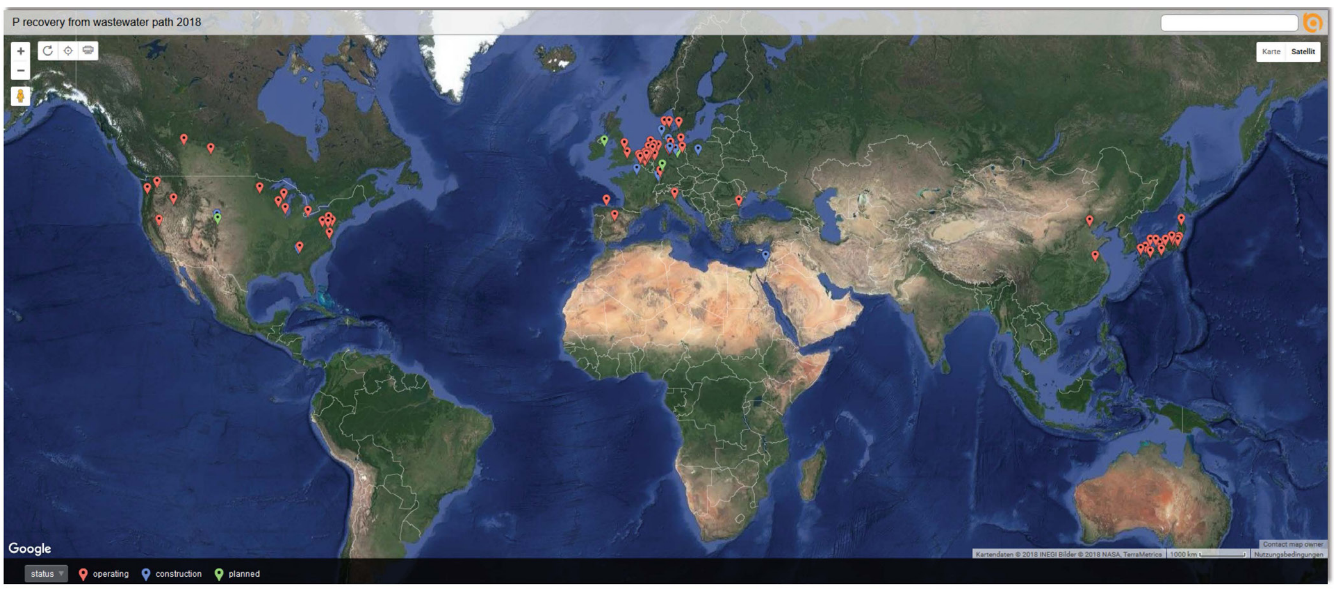

Figure 4: Global distribution of P recovery from sewage installations (Kabbe 2018)

Next generation recovery concepts are not just focusing on energy or phosphorus recovery, they make use of synergies between them both and can optionally include nitrogen recovery as well.

So far none of the mentioned concepts achieved phosphorus recovery rates of 50% or more under viable conditions. But, many suppliers intend to provide alternative solutions to comply with the new sewage sludge ordinance in Germany.

No matter how future legal framework developments will look like, the above mentioned on-site WWTP technology concepts have not exclusively been installed to recover P in the first place, but to provide plant operators benefits and improvements in the overall WWTP performance. The recovered phosphates are "nice to have" side effects.

Considerable factors to generate monetary benefits for the WWTP operator are:

- Reduced return load to achieve stricter P discharge consents
- Reduced maintenance due to mitigation of unintended struvite scaling in the sludge train
- Improved sludge dewaterability and reduced flocculation aid consumption
- Reduced sludge volume to be disposed off
- Potential to generate an income from struvite or brushite sales
  (strongly dependent on quality, physical shape, regional demand and legislation)

Downstream WWTP P recovery

Intending phosphorus recovery from incineration residues calls for an exclusive incineration without dilution of the contained phosphorus. On global scale, *fluidized bed incinerators* are the most established types for sludge incineration, yielding very fine ashes with less than 1% organic carbon left. The organic remains play an important role for further options to use these ashes/residues. Higher TOC levels pose rather obstacles and limitations than opportunities.

Looking at the phosphorus recovery from *ash technologies*, an obvious trend can already be seen. The most promising ones are wet chemical processes dissolving ash in mineral acids and extracting the phosphorus and separating it from undesired heavy metals with varying efficiencies. Only a few of these technologies are aiming to yield ready to use fertilisers. The most promising tend to yield known phosphates like calcium phosphates (i.e. DCP), ammonium phosphates (i.e. MAP, DAP) or phosphoric acid (i.e. MGP). Even the production of *white phosphorus* (P4) from suitable ashes has been targeted in the past but has been paused due to economic reasons.

Phosphorus recycling – not without value chains

The need to *create value from recovered materials* underlines the importance to generate recyclates that are known on the market with a real demand. Per definition, a material is only a product, if someone pays a positive price for it.

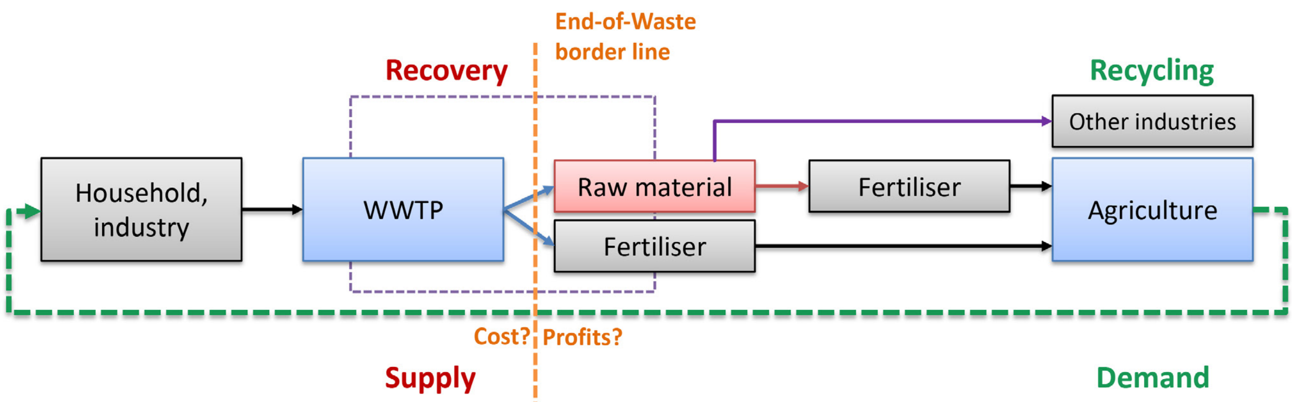

Figure 5: Bridging the gap between nutrient recovery from sewage/sludge/ash and nutrient recycling – value chains

Thus, it is preferable to recover phosphates in known, already established forms which are traded in large volumes and considered commodities. Under this light, technologies delivering commodities like phosphoric acid, calcium phosphates or ammonium phosphates are the most promising candidates. *Struvite*, given its unique and beneficial properties and purity is a prime candidate to replace soft-ground phosphate rock as mineral P source in organic farming, thus being one of the few materials actually having a chance as premium niche product.

Besides economic aspects, legal aspects turn out to be even more important and lead to the same conclusion: To avoid additional burden for bringing a certain material to the market, also existing materials and infrastructures are the route of choice. From the legal side, we observe enabling frameworks, but also a disabling framework, depending on targeted application of the material or country.

TECHNICAL AND OPERATIONAL ASPECTS

So far phosphorus recovery has only been implemented when there was an operational need or the prospect to safe or reduced operational cost within the wastewater/sludge treatment train or downstream along the disposal route.

Besides existing infrastructures of the utilities themselves, the availability of sludge disposal routes plays one, if not the most important role.

It is obvious, that sludge incineration is preferred in regions, where the amount of sludge is exceeding the land area having been traditionally used for disposal – meaning the nutrients are succeeding the capacity or demand of the domestic agriculture. This is especially the case in urban areas and rural areas with excessive livestock farming. The obvious option to reduce the volume of material and to concentrate the nutrients is incineration or thermal mineralization.

The resulting ashes or mineral concentrates have been disposed in the past, but, if P recovery becomes obligatory, they will have to be stored separately and recoverable or directly fed into an ash treatment plant for P recovery. Thus, in case of the ash route, technical needs for the wastewater utility are not the driver, it is the compliance with regulation and/or cost reduction for disposal.

Installations implemented on-site WWTP are characterised by the following general aspects:

- Prevention or mitigation of unintended scaling along the sludge train
- Improved sludge dewaterability
- Reduced polymer consumption for dewatering
- Reduced sludge volume for disposal (reduced cost)
- Partly better energy recovery (depending on additional modules)
- Improved effluent quality (reduced return load); better compliance with regulation

CONCLUSIONS

No doubt that phosphorus is a limited essential resource.

Efforts should be taken to increase the resource efficiency of phosphorus while we have a choice.

The existing infrastructure already provides the opportunity to recover and recycle substantial quantities of P, including from ash.

The current legal framework and the low prices for raw materials have to be considered as market barriers.

A 'level playing field' is needed for fertilisers, so that it does not matter if they are made from fossil or from renewable secondary sources.

Whereas P recovery on-site will be limited to WWTP where they really meet operational needs and reduce cost, the "big P fish" will be caught down-stream of the wastewater treatment itself.

Incineration can be seen as the biggest source of the still untapped P potential from sludge in the future, in regions, where direct application of sludge/biosolids is banned or no longer possible.

Although P scarcity is often linked as told to be the motivator for recovery and recycling, the reality shows the opposite.

Most P recovery installations are operated in countries or regions with nutrient surplus, often linked to excessive livestock farming, limited land area, and high population density.

OUTLOOK

A few countries are ahead of the game and seen as frontrunners. But already today, a trend for more and more countries towards technical P recovery becomes visible, also revealing, a demand for a streamlined global knowledge and know-how base covering phosphorus recovery not only from wastewater, but also from other relevant nutrient containing wastes like manure, biowaste, etc. Besides the traditional biosolids application to land, the technical nutrient recovery and recycling alternatives need to be incorporated under the GlobalG.A.P. umbrella as well.

Although some countries have already implemented or are about to implement legal requirements for P recovery, the bridging of the gap towards actual recycling remains the biggest challenge.

In the end, it will be the question of available land area and population/livestock density, that gives the answer, if the traditional route for direct land application of sludge/biosolids can be considered sustainable or not. Where the pressure of sludge and/or manure is high, alternative routes provide the better solutions. Both routes will be common practice, depending on the regional/national conditions.

Unlike biosolids application on land, the alternative recovery of mineral nutrient concentrates provides new opportunities, towards better balanced nutrient budgets due to the following properties:

- Definable composition
- Defined fertilising efficiency (less nutrient losses to the environment)
- Enable better handling, storage and longer transport distances up to even exports, esp. relevant for countries with high food and feed imports, but limited agriculture
- Other fields of industrial application and therefore value creation

The time is now to implement and exploit the results of numerous projects conducted in the past.

"Wisdom just written on paper will be dust (or ash) one day; only the wisdom applied will shape our future!

"Think forward, act circular!!!"

ACKNOWLEDGEMENTS

The authors Christian Kabbe P-REX ® Environment and Stephanie Rinck-Pfeiffer (Global Water Research Coalition) wish to thank the members providing the essential financial support to gather all the data, intelligence and practical insights compiled in the compendium and fact sheet. The Global Water Research Coalition (GWRC) wishes to express its appreciation to the Water Research Foundation (US) and in particular Christine Radke for acting as the GWRC's lead organisation for this joint effort and to recognise the high quality contributions by all organisations involved in this activity including Suez (France), KWR Watercycle research institute (Netherlands), STOWA (Netherlands), PUB (Singapore), UKWIR (UK), Water Research Commission (South Africa), Water Services Association of Australia (Australia).