PHOSPHORUS RECYCLING - NOW!

Building on full-scale practical experiences to tap the potential in European municipal wastewater

EXECUTIVE SUMMARY

Phosphorus is a non-substitutable raw material whose availability has been identified as a globally relevant bottleneck for fertiliser and food supply. Europe has an import dependency above 90% with regards to mineral phosphorus. As a consequence, phosphate rock was declared a critical raw material by the European commission in 2014. At the same time, a quantity equalling 15% of Europe's mineral phosphorus demand is being wasted as disposed sewage sludge and its ashes. Technologies enabling phosphorus recovery from the wastewater stream have developed tremendously in the past few years and are able to overcome limitations to direct sewage sludge application on arable land. Several technologies are already proven in industrial scale recovering plant available phosphorus. Still, extensive phosphorus recovery, enabling efficient recycling of the valuable resource on European scale is yet to be established.

Legal, societal and market barriers stand against the environmental and supply security reason. The pre-defined responsibility for wastewater treatment is nutrient removal, and not their recovery and recycling. Therefore investments for phosphorus recovery are hampered. The scope of the current legal framework of the European Union fits focuses on traditional mineral and organic, rather than recovered mineral, nutrient sources. Contradictory interpretations of European legislation by member states cause confusion, hampering the recycling of phosphorus-containing materials. A harmonised and reliable European quality control framework is needed to increase stakeholder and consumer confidence in materials containing recycled phosphorus.

Phosphorus is already recycled in organic form at regional level, through application of high quality sludge (conventional recycling). This is complemented by mineral phosphorus from fossil (primary) sources, mostly non-European. This fossil phosphorus must be complemented by recovered (secondary) sources. Technical recovery and recycling from the wastewater stream can:

- triple the European mineral phosphorus supply from 8% to 23%.
- provide phosphorus in marketable quality
- convert the nutrient in stable, transportable and storable form and so enable distribution and storage to match the regional and seasonal demand of agriculture
- safeguard the soils against pollution and pathogens
- recycle phosphorus with an annual cost of less than 5€ per capita (i.e. less than 5% of wastewater treatment cost)

Mineral phosphorus recycling not only saves jobs in Europe, it creates additional green jobs and industries with high export potential.

P-REX Policy Brief

"Phosphorus recycling - Now!" represents the views of the 15 partners in the practice driven P-REX consortium. The policy brief was edited by Sirja Hukari (FHNW), Anders Nättorp (FHNW) and Christian Kabbe (KWB). The company-related information has been validated by the company representatives and the content reviewed by the expert advisory board of the P-REX project, including representatives of the European Sustainable Phosphorus Platform (ESPP).

P-REX

POLICY MESSAGE

Several technologies for P-recovery are already there for implementation. Conventional recycling is questioned in many countries and technical phosphorus recovery and recycling can complement it, thus answering obstacles caused by sludge quality and nutrient logistics. Wide-spread implementation of P-recovery and gradual market penetration of products containing recycled phosphorus-containing materials requires the following:

1. Realistic and reliable **European phosphorus recovery targets**, especially from wastewater. It should be combined with a European overall road map and defining Best Available Technologies for phosphorus recovery and recycling.
2. **Obligation for national or regional action plans** for phosphorus recovery, in line with the European goals, implementing technical recovery of phosphorus and/or agricultural valorisation of high quality sludge.
3. Clear **guidelines stopping contradictory national interpretation of the current European legislation** around recycling of phosphorus from waste, especially into fertilisers. Better integration of secondary raw materials and introduction of quality standards including end-of-waste criteria to the European Fertilisers Regulation .
4. National **mechanisms for fair distribution of the cost** of phosphorus recovery (e.g. fertilizer mixing quota, recovery obligations). **Financing of demonstration projects**, since references are obligatory for market penetration of innovative technologies and products.

GLOBAL CHALLENGE

Phosphorus is a non-replaceable element, essential for food production and our existence. Phosphorus (P) is one of the three main plant nutrients besides nitrogen (N) and potassium (K). There is no way of replacing the phosphorus in mineral and organic fertilisers by other chemical elements [1]. The mineral phosphorus demand of Europe (see Figure) consists mainly of the needs of the fertilizer, feed additive and the chemical industry. Phosphorus limits the biomass potential on planet Earth.

The supply of phosphorus, mined from fossil resources, is estimated to last for several hundred years, but the quality of the ore is expected to decrease over time [2,3]. The world phosphate rock reserves are controlled by a handful of countries, for instance Morocco/Western Sahara (75%) and China (6%) [4], making the imports sensitive for geopolitical changes. Today, the price of this commodity is low, but given the low purchasing power of farmers in many countries, even small price spikes are a potential trigger for food crises, as seen in 2008.

The lost phosphorus in the European wastewater stream could cover 15 % of the European mineral phosphorus demand.

... GLOBAL CHALLENGE

EUROPEAN PERSPECTIVE

The EU's only phosphorus mine is situated in Finland. The European Union faces a 92% import dependency1 today, explaining why phosphate rock has recently been announced as one of the 20 Critical Raw Materials of the EU [5].

Phosphorus is cycled between animal and crop production in the form of manure and animal feed. The food produced goes to human consumption. The nutrients concentrate in the sewage sludge of wastewater treatment plants (WWTP) and thereafter are often lost for the economic cycle [6], depending on the valorisation and disposal routes applied.

Rates of the conventional recycling by direct application of sewage sludge on arable land vary from zero to 90 % within the EU-27. Yearly more than 200'000 tons, or 60%, of phosphorus within the sewage sludge remains unutilized for crop production [7-9]. Recyclable phosphorus in the waste-water stream could be further increased by implementing completely the Wastewater Framework Directive.

The sewage sludge is typically used for landscaping, incinerated or landfilled. The valuable nutrient phosphorus is often lost either due to dilution with waste or by incorporation into other matrices such as concrete. Valorisation of these phosphorus quantities has a recovery potential almost twice as large as the current European mineral phosphorus supply (see figure).

Major challenges for higher recycling rates include concerns regarding pollution of the sludge with heavy metals, organic pollutants, or pathogens, as well as transport and storage of large quantities (wet sludge). The needs and abundance of nutrients varies regionally, due to seasonality of agricultural production, spatially separated food production in rural areas and food consumption in urban areas. In particular nutrient surpluses are found in regions with high livestock density.

OPPORTUNITIES TO GRASP

The concentrated, constant and substantial phosphorus loads in wastewater and sewage sludge need to be recovered and brought back to fields and industry more efficiently. Technical options for phosphorus recovery and recycling can help closing the nutrient cycle, complementing direct sludge application. They provide alternatives, addressing the concerns regarding sludge contamination and/or plant availability of the sludge phosphorus.

Technical recovery of phosphorus from sewage sludge and consequent recycling as nutrient and in other functions reduces Europe's dependency on imported phosphorus and creates green sustainable jobs. Innovative recovery and recycling technologies have a high export potential due to the global essentiality of phosphorus.

WHY TECHNICAL P-RECOVERY FROM WASTE WATER STREAM?

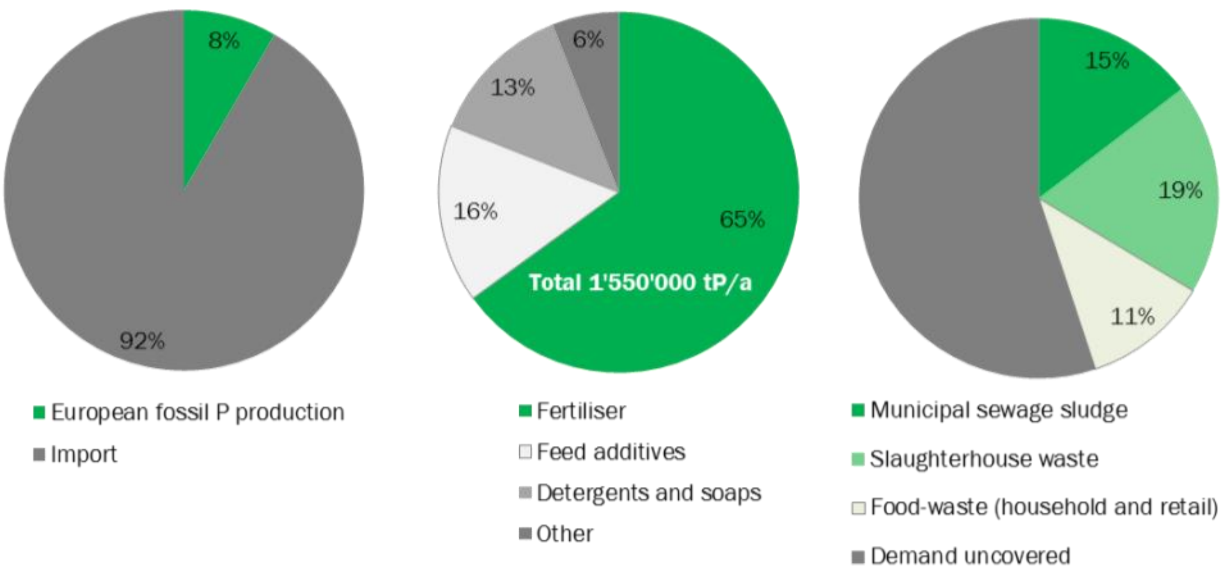
- Large unutilized potential
- Renewable source
- Constant, slightly increasing rate of accumulation
- Well-known point sources
- P is more concentrated in sewage sludge dry matter (~4% P) and its ashes (~10% P) than in the environment

Recycled phosphorus:

- Reduces risks caused by impurities in comparison to conventional recycling of sludge
- Enable transport of nutrients over long distances

Supply **Demand** **Recovery potential**

in relation to the total mineral phosphorus demand 1‘550‘000 tP/a



Data sources: European production[10], demand[10-13], recovery potential[9]

BUSINESS EXPERIENCES

Business **models of companies utilizing P-streams from wastewater present different combinations of technologies with strategies for market access.** The following examples reflect different recovery and recycling strategies in the European market. Five different cases are summarized in the Annex as Business Model Canvases.

Case 1: Ostara and CNP-Technology

Pearl® (Ostara) and AirPrex® (CNP-Technology) technologies enable phosphorus recovery on-site at the WWTP as struvite (magnesium ammonium phosphate). The business model behind these technologies is two-fold: for one, the modular technology improves the overall WWTP performance due to reduction of pipeline incrustations, return load, sludge volume and the consequent disposal costs, and need for chemicals. Additionally, the controlled precipitation of struvite creates a market-ready slow-release fertiliser. The target group for the technology are the WWTP operators, which then turn into small-scale fertiliser or fertiliser raw material producers. Generally moderate recovery rates up to 15% of the phosphorus eliminated at the WWTP are achieved.

Fertiliser sales strategies vary between the technology providers: the Ostara business model guarantees marketing of the established product through their own marketing structures. The key customer segments are small specialized blenders and distributors of fertilisers. The AirPrex®-product is sold by the WWTP operators themselves. CNP-Technology provides the WWTP operators with initial contacts to potential endusers.

In both cases the fertiliser price is not directly dependent on the investment in technology, as the costs are typically off-set already by the reduced disposal and chemical costs. The Ostara "Crystal Green" is being sold as a specialized fertiliser for turf, horticulture and specialty agriculture and sold at market prices comparable to commercial grade commodity phosphorus fertilisers. AirPrex® struvite, on the other hand is mainly being sold directly for the fertiliser industry for further processing or to farmers, using it directly on the fields, with a price around 100 €/t.

Further info: www.ostara.com, www.crystalgreen.com, cnp-tec.com
Similar technologies: NuReSys, Ekobalans, Phospaq

Case 2: Thermphos

Thermphos, a former phosphorus chemicals producer from the Netherlands, integrated suitable sewage sludge ashes to their existing industrial production of white phosphorus (P4), as a complementary raw material to phosphate rock. By this, Thermphos reduced their operational costs, as the price of suitable ash was lower than the price of the rock phosphate. Additional challenges, such as higher iron, copper and zinc concentrations of the new raw material were overcome. Essential partners were sewage sludge incinerators, attracted by the offer to turn the ash, a typical waste and cost factor, into an asset. The price also enabled Thermphos to procure high quality ashes, relatively low in impurities. Meat and bone meal ashes were also processed on a large scale. Thermphos, the only white phosphorus (P4) producer in Europe, produced for high end markets such as chemical and food industry, etc. The recycling operation of the company with reputation as a reliable European supplier was not questioned by the customers. Thermphos went bankrupt in 2012, due to causes unrelated to the recycling activities.

Similar technologies: Recophos, FP7 project

Case 3: ICL Fertilisers

ICL Fertilisers, with European production sites in the Netherlands and Germany, is one of the few large phosphate fertiliser producers in Europe. They import phosphate rock from their own mines in Israel thus gaining a market advantage through low-priced raw materials. The company committed to include 15% of recovered phosphorus to their raw-materials until 2015, a feasible goal currently awaiting the necessary investments. The recovered phosphorus could include struvites, meat- and bone meal ashes and, if low in impurities, sewage sludge ashes.

No clear economic incentive can be seen behind the commitment, unless the raw-material price would be below the already competitive phosphate rock price. The government of the Netherlands, together with several private partners, has initiated the Dutch Nutrient Platform, which aims to create a sustainable market for recovered nutrients, addressing the nutrient surplus in the country. This initiative, consisting of voluntary commitments and support of other partners along the value chain, has spurned ICL to take the lead in phosphorus recycling among fertiliser producers. Existing marketing structures and experience on coping with the legal requirements ease the market access.

Further info: www.iclfertilizers.com, www.nutrientplatform.org

SCALING UP

SUMMARY OF BUSINESS MODELS*

Organisations recovering phosphorus include WWTPs, technology start-ups and fertilizer industry

Currently, no business model is based on "sales of recycled phosphorus-materials" only.

The market entry is enabled through either

- A combined fertilizer and P-recovery-technology sales (dependent on each other, both require their own value propositions and customers) **or**
- Addition of secondary P-sources to already existing P-product sales (adjustment of the existing production and sales -system) **or**
- Further processing of waste/by-products (which are available more or less free of charge) and creation of a market-niche for novel products

The revenue streams are made of

- Sales (different models: sale of operation plants or products as such or through licensing/leasing-models etc.)
- Cost offsetting (cheaper input materials than at state-of-the-art process, reduced process costs)

*Annex

TECHNOLOGY OPTIONS

The aim of phosphorus recovery and recycling technologies is production of a user-friendly end-product or marketable raw-material for existing industries. Many efforts concentrate on production of phosphorus containing fertiliser with low content of impurities and a highly plant available nutrient. Several technologies for P-recovery and recycling from waste water streams exist, some of which have already been implemented (see Cases 1-3). Typical products include struvites and calcium phosphates, which can be utilized as slow release fertilisers or even as animal feed additive. Further technology improvement and innovation can only be achieved after implementation under real-life conditions within existing market structures.

The P-REX demonstration project has summarized and analysed 10 recovery and recycling technologies, ranging from pilot via demonstration to industrial scale (Annex). There are processes that can recover close to 100 % of the phosphorus load removed at the wastewater treatment plant (WWTP). The annual cost of the recovery ranges from 0 € (even beneficial) to 15 € per capita. If existing undiluted sewage sludge ash were used, the annual recovery costs would be less than 5€ per capita, envisaged to be covered by product sales. For comparison, the annual costs of the waste water treatment varies in Europe between 40 and 140 € per capita. Environmental assessment of P recovery pathways in their life cycle show that P recovery can be realized with distinct benefits to the environment compared to P fertilizer production from fossil P rock. Plant availability and safety (toxicity, risk assessment) of several products have been demonstrated and improvements are on-going. A summary of the technology characteristics can be found below.

TECHNICAL REQUIREMENTS

The technologies require certain boundary conditions for implementation. Sludge liquor processes require a certain minimum of dissolved P in the aqueous phase, which is mainly limited to biological phosphorus removal (EBPR) at the WWTPs. Currently only about 10% of the European WWTP use EBPR. Further, iron and aluminum salts, commonly used for phosphorus removal can complicate recovery and reduce the plant availability of phosphorus in the end-product of some technologies, an effect observable also in direct application of sewage sludge. Prerequisite for the ash based processes is a separate incineration of the sewage sludge, avoiding dilution and contamination with phosphorus poor wastes (e.g. municipal waste).

Table: Overview of the recovery technologies as evaluated in the P-REX project

Process	Industrial full scale implementation	Max. recovery rate in relation to P removed at the WWTP	Annual cost per capita
Precipitation from sludge liquor/sludge	Several	15% y	0-5 €
Leaching of sludge	One x	50 %	5-15 €
Recovery from sewage sludge ash	Planned x	100%	0-5 € z

x Several successful demonstrations
y 50% with enforced redissolution
z Up to 3 €/y is added to the cost if a switch from direct application of sludge in agriculture or co-incineration to mono-incineration is required.

LEGAL, SOCIETAL AND MARKET BARRIERS

Due to the novelty of the approach, the European market and legislation have not yet been adapted to meet the needs of the secondary phosphorus containing fertilisers and their producers. The analysis of the business models of phosphorus recyclers, current legal framework governing recycling and the market for fertilisers revealed the following challenges:

Competence-expansion of public services.

WWTP operators could act as future fertiliser producers. But, their key business and societal task is wastewater treatment according to the requirements of the Water Framework Directive (WFD). Their task is not P-recovery, selling fertilisers or enabling thereof. This discourages or prevents technical adjustments and new nutrient recycling business models at and around the WWTPs.

Economies of scale.

The fertiliser market is controlled by companies producing yearly several hundred thousand tons of fertilisers. For start-ups outside the wastewater treatment sector, pooling large quantities of secondary phosphate raw-materials for economic fertiliser production requires high up-front investments and long-term supply contracts for sludge or ash. But, since waste disposal is a matter of public tender, long term contracts between sludge and ash supply and recovery/ processing are exemption.

Legal status and environmental impact of phosphate rock.

Phosphorus recycling within Europe according to today's legislation guarantees internalization or minimisation of the environmental impact caused by the recovery activities. The same does not always hold true for the mining activities outside Europe, e.g. due to poor waste management (phosphogypsum) around the mines. The imported fossil phosphorus materials enjoy product status and are easy to import and use in commercial processes. Recovered phosphorus on the other hand is initially classified as waste, making its handling subject to more obligations, according to the Waste Framework Directive. Thus, the market structures and legislation of today favor use of phosphate rock over the renewable P-sources.

Legal challenges.

Placing secondary phosphorus material on the fertiliser market as a product can be a challenging process. A market entry is possible in compliance with REACH, the Fertilisers Regulation, the Waste Framework Directive and the Mutual Recognition Regulation. Lack of established European procedures on accepting secondary phosphorus in or as fertiliser leads to variable interpretations of the corresponding legislation and their interplay in the member states. Companies planning to recycle and export either secondary phosphates or recycling technologies depend on consistent implementation of the European legislation .

Some authorities see the wastewater derived secondary phosphorus as nutrient recovered from waste, which is exempted from REACH registration (REACH Art. 2(7)d)) (e.g. UK Reach HelpDesk, European Commission). Others see them as by-products of a manufacturing process, and thus subject to REACH registration.

Products recycled from waste are dependent on the End of Waste (EoW) status, defined in the Waste Framework Directive. Approval of the EoW status depends on the national authorities. In case of fertilisers, fulfilment of the technical requirements of Fertilisers Regulation or national fertiliser acts is necessary. The current Fertilisers Regulation lays focus on fertiliser-admission of primary mineral phosphorus compounds. Also, no limit values for impurities are defined, but national regulations often cover this aspect. Under these conditions, acceptance secondary phosphorus in and as EC-fertilisers is uncertain. The planned recast of the Fertilisers Regulation should improve the situation for phosphorus recycling. The scope needs to be extended from fossil mineral fertilisers to include both recycled and organic sources. Furthermore quality criteria, especially impurity thresholds, should be set. This will enable a level playing field for both fossil and recycled fertilisers from primary and secondary sources. Only then the marketing of fertilisers containing recycled nutrients from secondary sources and improvement of confidence in their quality across member states can be achieved.

Today, there is no Europe-wide quality control framework for contaminants in fertilisers in place. At the same time, according to the Free Trade Agreements, fertilisers accepted in one Member State can be marketed in any other member state. Products with questionable quality are jeopardising the reputation of recyclers with high performance .

Utilization of.recovered phosphorus under waste regime.

Alternatively, the recovered phosphorus can be applied on agricultural land as waste subject to the obligations of the WFD, such as source tracking and compliance with certain quality criteria. Similar national practices are known for e.g. composts, digestates or sewage sludge. The status as waste decreases the marketability of the material, but can be of importance for small operators on regional scale. Also in this case, established procedures for better nutrient management from secondary sources are lacking in various regions .

Acceptance.
With transparent quality control of the outputs of the recovery and recycling processes, safety and the intended effectiveness of the secondary materials is guaranteed. To ensure market success the end-users, farmers and consumers, need to be informed about the product quality and the importance of recycling efforts.

CONCLUSIONS

- **Technologies for technical P-recovery from sewage sludge are applicable already today.** Recovery and recycling from the wastewater stream is possible with annual costs of less than 5 €/capita or less than 5% of wastewater treatment cost. Environmental gain has been shown and improvement of the phosphorus supply security is obvious .
- **Where concerns regarding the sludge quality and logistics exist, technical P-recovery and recycling can help closing the nutrient cycle.** Nutrients contained in sewage sludge are often wasted today. Recovery technologies can concentrate the phosphorus, improve its plant availability and reduce the amount of contaminants.
- **Market entry of recycled nutrients is possible today, but for large scale implementation there are legal and market complexities to overcome.**

POLICY IMPLICATIONS

1. LONG-TERM STABILITY FOR ESTABLISHMENT OF EFFICIENT TREATMENT TECHNOLOGIES THROUGH RECOVERY TARGETS

Business experiences presented above were "add-ons" to existing systems. Long -term advantages of recycling efforts in Europe such as security of supply and internalized environmental costs are not accounted for in market-based decision-making today. Efficient phosphorus recovery and recycling systems call for new market players needing market drivers and long-term reliability of the legal framework to back up their investments. A systemic change from exclusive use of fossil phosphorus to a mix of fossil and recovered phosphorus is needed.

Possible solutions:

- Realistic European long-term goal for phosphorus recovery rates from wastewater or import dependency reduction combined with a European overall implementation road map, based on sound mass flow data
- Sectoral (wastewater treatment, agriculture, etc.) toolboxes describing the best available technologies for different boundary conditions

2. REGIONAL SOLUTIONS FOR SMART P-RECOVERY AND RECYCLING SCENARIOS, IMPLEMENTING THE OVERALL GOALS, ARE NEEDED

Use of sewage sludge and nutrient demand in agriculture differ from country to country and region to region. Due to existing infrastructure and needs some technologies are better suited for use in certain places than the others. Overall coordination enables efficient, coordinated investments on country-level. One example is phosphorus recovery from ash. It enables the highest recovery rate, but needs centralized sludge management and high investment costs for incineration facilities. Challenges in raw-material supply contracting need to be overcome. Another example is that individual steps in the treatment chain such as high WWTP phosphorus removal rates and EBPR provide synergies for phosphorus recovery, but are not necessarily the cheapest solution. Collaboration along the value-chain will lead to higher efficiencies, when disadvantages of system-change at one point are compensated by the advantages of the subsequent recycling steps.

Possible solutions:

- Implementation of regional action plans for phosphorus recovery, with private and public sector participation, taking into account the local nutrient demand, sources and other boundary conditions
- Legal and organisational support to enable reliable supply with ash as input material for the recovery from ash facilities
- Establishment of value chains from WWTP to farm is needed to enable efficient P-recovery and recycling, fitting the needs of agriculture

3. SUPPORT FOR FULFILLING THE LEGAL OBLIGATIONS, WITHIN AND OUTSIDE THE FERTILISER FRAMEWORK

Legislation affecting recycling is interpreted differently in the member states. Recyclers and authorities alike would profit from unambiguous guidelines describing how to best address all legal obligations relevant to phosphate recycling from the wastewater stream. For safety assurance and acceptance of the recycled phosphates Europe-wide quality standards within and outside of the Fertiliser Regulation are of central importance. Allowing raw-material from secondary sources in the Fertiliser Regulation is essential for market penetration of products containing recovered phosphorus. Allowing a wider range of possible starting materials for fertilisers together with heavy metal and other limit values were planned to be integrated into the Fertiliser Regulation recast. Rapid incorporation of these aspects is central for end-users and recyclers alike.

Possible solutions:

- Guidelines for meeting the legal obligations regarding valorisation of recovered phosphorus, covering the Waste Framework Directive, Sewage Sludge Directive, Fertilisers Regulation and REACH. Differentiation between the cases
    a. wastewater derived mineral materials with and without fertiliser status (e.g. underlying Fertiliser or Waste Framework Directive) and
    b. high quality (safe) sewage sludge
- Continue and finalize the work started: integrate secondary raw materials, quality standards and end -of waste criteria into the Fertilisers Regulation

4. FINANCING

Who pays, who benefits?
Phosphorus recovery, as most of the environmentally sound actions benefiting the society as a whole, come with cost. Transparent discussion on acceptable cost, allocation of these costs, as well as transition timeframes and market entry need to be started now. Hard legislation, such as mixing quota or recycling obligationsfrom phosphorus rich wastes, lead to forced market entry in a given timeframe. It provides planning reliability for investments, encourages initiatives due to clear transition periods and can help enforcing adequate quality criteria for recycled phosphorus. Soft legislation, such as tariffs on fossil phosphorus or subsidies for recovered materials, is beneficial, but lacks the clarity of the hard legislation. Both types of legislation can be used to implement a European roadmap.

First Movers Risk
Innovation and start-ups are typically challenged by large up-front investments, which can, in time, be paid back completely or at least partially. First movers making long-term investments face the risk that a competitor within few years will implement a similar but more competitive technology and profits from changes in the market structures forced by the first-movers.

Possible solutions:

- Mechanism for distribution of cost. Either hard legislation (mixing quota, recycling obligations) or soft legislation (tariffs or subsidies)
- Substantial financing of and investments support for demonstration plants would speed up implementation, which would in turn lead to product market development and lessons for policy and further process development. A market will only develop with references

P-REX FOCUS

P-REX or "*Sustainable sewage sludge management fostering phosphorus recovery and energy efficiency*", is a demonstration project financed by the 7th Framework Programme, running from 2012 to 2015. The project consortium consists of 15 market stakeholders and research institutes. The participants represent a variety of technology providers, market experts and researchers with in-depth knowledge in phosphorus markets and streams, technical P-recovery, waste water treatment and fertilizer use.

The project strives to speed up the implementation of technical phosphorus recovery from the wastewater stream. In order to achieve this scaled-up processes are assessed, nutrient markets and legal framework are analyzed and described and regional implementation strategies are developed. Other research projects focusing on different aspects of fertilizer efficiency, nutrient recovery and reuse include End-o-Sludge and ManuReSource.

Consortium:
Kompetenzzentrum Wasser Berlin gGmbH (DE), Fachhochschule Nordwestschweiz (CH), BAM - Bundesanstalt für Materialforschung und -prüfung (DE), IASP - Institut für Agrar - und Stadtökologische Projekte an der Humboldt Universität zu Berlin (DE), Veolia Eau (FR), Outotec (Finland) Oy (FI), Agro Plus Handelsunternehmen eU (AT), BSH Umweltservice AG (CH), Ingitec GmbH (DE), LimCo International GmbH (DE), Proman Management GmbH (AT), ASIO, spol.s r.o. (CZ), Solintel M&P, S.L. (ES), P.C.S. Pollution Control Service GmbH (DE), PFI Planungsgemeinschaft GbR (DE)

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REFERENCES

1. European Commission. Consultative Communication on Sustainable Use of Phosphorus. COM(2013) 517 final (2013).
2. Kauwenbergh, J. Van, Stewart, M. & Mikkelsen, R. World Reserves of Phosphate Rock... a Dynamic and Unfolding Story. Better Crop. 97, 18–20 (2013).
3. Cordell, D., Drangert, J.-O. & White, S. The story of phosphorus: Global food security and food for thought. Glob. Environ. Chang. 19, 292–305 (2009).
4. U.S. Geological Survey. in Mineral Commodity Summaries (ed. Jasinski, S. M.) 118–119 (USGS, 2014). at <http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2014-phosp.pdf>
5. European Commission. Communication from the Commission: On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative. COM (2014) 297 final (2014).
6. Ashley, K., Cordell, D. & Mavinic, D. A brief history of phosphorus: from the philosopher's stone to nutrient recovery and reuse. Chemosphere 84, 737–746 (2011).
7. WRc. Environmental, economic and social impacts of the use of sewage sludge on land, part I: Overview report. (milieu Ltd, RPA, 2010).
8. Science Communication Unit. Science for Environment Policy in-depth report : Sustainable Phosphorus Use. 57 (European Commission DG Environment, 2013). at <http://ec.europa.eu/science-environment-policy>
9. Van Dijk, K. C., Lesschen, J. P. & Oenema, O. Phosphorus flows and balance of the European Union Member States.
10. Jasinski, B. S. M. in 2011 Minerals Yearbook (U.S. Geological Survey, 2013).
11. Inorganic Feed Phosphates. The contribution of Inorganic Feed Phosphates to European soils. (CEFIC, 2009).
12. Eurostat. Agri-environmental indicator - mineral fertiliser consumption. (2012). at <http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_mineral_fertiliser_consumption>
13. Schrödter, K. et al. Phosphoric Acid and Phosphates. Ullmann's encyclopedia of industrial chemistry 679–724 (2012).
14. Schoumans, O. F., Bouraoui, F., Kabbe, C., Oenema, O. & van Dijk, K. C. Phosphorus management in Europe in a changing world. Ambio 44, 180–92 (2015).

FURTHER INFORMATION

Full project results at
www.p-rex.eu

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OVERVIEW OF THE PHOSPHORUS RECOVERY TECHNOLOGIES EVALUATED BY P-REX

Results of the assessments will be published within the P-REX project in 2015. Some recovery technologies for full scale recovery were not evaluated. For the latest results, please refer to www.p-rex.eu. A rather complete list f available technologies for phosphorus recovery can be found in Schoumans et al (2015)[14]

				Assessed by P-REX					
				Technology			Product		
Company	Raw Material	Process provider/contact	Experience in what scale?	Re-covery rate	Cost	LCA	Chemical character-ization	Plant availabil-ity and toxicity	Risk assess-ment
Airprex	Sewage sludge	CNP-Technology Water and Biosolids GmbH/ Rudolf Bogner	Commercial production	X	X	X	X	X	X
Ostara	Sludge liquor	Ostara Nutrient Recovery Technology Inc./ Derek Lycke	Commercial production	X	X	X	X	X	X
Struvia	Sludge liquor	Veolia Environment/ Hervé Paillard	Pilot	X	X	X			X
Stuttgarter	Sewage sludge	Universität Stuttgart/ Carsten Meyer	Pilot	X	X	X	X	X	X
Gifhorn	Sewage sludge	Seaborne EPM AG	Test production	X	X	X			X
Mephrec	Sewage sludge/ Sewage sludge ash	Ingitec GmbH/ Joachim Mallon	Pilot	X	X	X	X	X	X
ASH-DEC	Sewage sludge ash	Outotec Oy/ Ludwig Herrman	Test production	X	X	X	X	X	X
LEACHPHOS	Sewage sludge ash	BSH Umweltservice AG/ Alois Sigrist	Test production	X	X	X	X	X	X
EcoPhos	Sewage sludge ash	EcoPhos s.a/ Rob de Ruijter	Production, P-Rock	X	X	X	X	X	X
Reference material	Sewage sludge	-	-	-	X	X	X	X	x
Reference material	Sewage sludge ash	-	-	-	X	X	X	X	X
Reference material	Fertiliser: Triple Super Phosphate (TSP)	-	-	-	-	X	X	X	X

Ostara (Pearl®, Crystal Green®)

Struvite recovery at WWTPs with EPBR
P-source: sludge liquor.
P-output: Crystal Green - fertiliser

P-REX **Policy brief**
Business Model Canvas 1/5

Key Partners

- Established relationships with more than 30 key players in the water and wastewater treatment sector throughout North America and EU. Select partners include: Veolia, Grontmij, Black & Veatch, CDM-Smith, Stantec, Hazen & Sawyer, NORAM
- Established network of fertiliser distribution partners throughout North America and Europe in turf, ornamentals and specialty agriculture.

Key Activities

- Sales

Production plant
- Individual solutions for installations
- 24/7 operations support of the plant included.

Fertiliser
- Agronomic research, marketing and sales

Key Resources

Production plant
- Engineering / WWTP understanding (EBPR, sludge management, etc.)
- Technology

Fertiliser
- fertiliser / Agronomy background

Value Propositions

Production plant (Pearl®)
- Modular element for WWTPs with EBPR, which improves the overall WWTP performance due to controlled struvite precipitation
- Reduced need of chemicals, reduced sludge volume → savings
- Minimum investment risk for the operator due to fertiliser offtake and leasing-model
- Proprietary, state-of-the-art process software

Fertiliser (Crystal Green)
- Slow-release struvite, certified fertiliser, high uniformity index
- Proven turf performance benefits and success in specialty agricultural markets
- Evidence-based enhanced environmental profile

Customer Relationships

- Personal (to the level of retailers, blenders or WWTPs)
- Ongoing relationships with WWTP due to offtake agreement and included operational support

Channels

- Large marketing section
- Dedicated online presence for both, technology/plant sales and product/fertiliser sales

Customer Segments

Production plant
- Large WWTPs with EBPR (Enhanced biological P-removal)
- Indirectly: municipalities (owners of the WWTPs) → *private-public partnerships*

Fertiliser
- Specialized blenders, distributors, growers and retailers serving
  - turf
  - horticulture
  - speciality agriculture

Cost Structure

- Operation, personnel
- Product development (research) and marketing
- Investment cost for leased plants

Revenue Streams

- Leasing model for facilities (monthly fee based on P-removal)
- Production plant/Technology sales
- fertiliser sales (operator, Ostara)

www.businessmodelgeneration.com
www.p-rex.eu

Sources and further information:
www.ostara.com www.crystalgreen.com

CNP-Technology (Airprex®)

Struvite recovery at WWTPs with enhanced biological phosphorus removal (EBPR).
P-source: digested sludge
P-output: Struvite

P-REX **Policy brief**
Business Model Canvas 2/5

Key Partners

Fertiliser industry/Farmers
Struvite uptake

Legal consultants
Assist the WWTPs with struvite production on legal issues (REACH, registration as fertiliser)

Technical University of Berlin, Berliner Wasserbetriebe
- Technology development
- REACH certification and fertiliser registration (DE) of the AirPrex®-Struvite

Key Activities

- Technology sales
- WWTP optimisation
- Contact establishment between the WWTP, fertiliser industry and - consultants

Key Resources

- Know-how around EBPR WWTPs
- Process design
- Engineering
- Construction

Value Propositions

Production plant (AirPrex®)
- Modular element for WWTPs with EBPR, which improves the overall WWTP performance due to controlled struvite precipitation
- Reduced need of chemicals, reduced sludge volume → savings
- **Possible revenues for the WWTP from struvite sales**
  - Crystalline structure, odourless , hygienic, slow-release fertiliser
  - REACH registered

Customer Relationships

- Personal assistance

Channels

- Dedicated online presence for technology/plant sales
- Representatives world wide
- Subsidiary in the US

Customer Segments

Production plant:
- Mid size and large WWTP with EPBR and anaerobic digestion
- Indirectly: municipalities (owners of the WWTPs)
- Engineering firms

Cost Structure

- Operation, personnel
- Process development (R&D) and marketing

Revenue Streams

- Production plant/Technology sales

*CNP-Technology Water and Biosolids GmbH acquired the rights for the AirPrex® process from PCS (Pollution Control Service GmbH)
www.businessmodelgeneration.com
www.p-rex.eu

Sources and further information:
www.cnp-tec.com www.cnp-tec.de

Thermphos

Production of phosphorus chemicals
P-source: P-rock, sewage sludge ash (SSA).
P-output: Various P-Chemicals

P-REX **Policy brief**
Business Model Canvas 3/5

Key Partners

SNB (sludge incineration)
- 5 year supply contract for Fe-poor SSA
- Contract for increasing delivered amounts
- SNB received a price for the SSA and thus saved disposal fees

P-Rock suppliers

Wastewater treatment plants
- Sludge suppliers which do not use Fe for P-precipitation (or were prepared to replace Fe by Al)

Key Activities

- Turning P-rock and SSA into high quality chemicals
- Offering offtake of SSA from the WWTPs for a price

Key Resources

- Good reputation as a reliable European supplier
- High quality standards
- Technological knowledge of replacing P-rock with SSA

Value Propositions

High quality **phosphorus chemicals** and raw materials (**intermediates**) for industry
- Elemental P
- Phosphoric acid
- Others

Customer Relationships

Channels

Customer Segments

Fertiliser-
Plastic-
Food-
Ceramic-
Etc.-
-industry

Cost Structure

- Operation, personnel
- Raw material costs (P-rock, SSA)
- Investment costs for the production plants
- Development of processes enabling SSA usage in production

Revenue Streams

- Product sales
- Savings of raw material price in comparison to state-of-the-art (SSA is cheaper than P-rock)
- Chemical savings (no silica additives needed in process, because SSA contains silicates)

www.businessmodelgeneration.com
www.p-rex.eu

Sources and further information:
N.V. Slibverwerking Noord-Brabant. *SNB Phosphate Recovery*. 2014
DutchNews.nl. 2014. http://www.dutchnews.nl/news/archives/2012/11/europes_only_phosphorus_firm_t_1.php

Sandoz (Biosol)

Nutrient containing soil amendment from fungal residues of medicine production.
P-source: fungal residues.
P-output: Biosol – soil amendment

P-REX **Policy brief**
Business Model Canvas 4/5

Key Partners

- Former Novartis plant protection chemicals marketing/distribution - network

Key Activities

- Production and sales of pharmaceuticals
- Case studies for specific applications of Biosol

Key Resources

- Fungal residues as by-products from pharmaceutical-manufacture

Value Propositions

Soil Amendment (Biosol)

- Licensed for use in organic farming
- Licensed for use at water protection areas
- Slow nutrient release (low nutrient content: 7-8% organic N, 1-2% P and 1-2% K)
- Nitrate fixation potential
- Promotes humus formation, soil improving
- Less odorous, pelletized material for home gardeners

Customer Relationships

Channels

- Worldwide retailers
- Website with information on the product and plant studies

Customer Segments

Specialized retailers serving:

- Organic farming
- Home gardeners
- Skiing areas
- Water protection areas
- Vineyards, horticulture

Cost Structure

- Operation, personnel
- Marketing

(**no material costs**; fungal residues are a by-product of the medicine production within the same company)

Revenue Streams

- Product sales (1.5-2 €/kg product); not in relation to the nutrient content
- Offsetting of disposal fees for the fungal residues

www.businessmodelgeneration.com
www.p-rex.eu

Sources and further information:

http://www.biosol.com/finland/002/index.html?auswahl=finland%2F002
Müller, Christian. *2013 Sustainability Report with integrated environmental statement.* Company report, Kundl: Sandoz GmbH, 2013
Bund Ökologische Lebensmittelwirtschaft. *Zahlen, Daten, Fakten - Die Bio-Branche 2014.* Statistical Report, Berlin: BÖLW Bund Ökologische Lebensmittelwirtschaft, 2014

ICL Fertilisers

Conventional fertiliser production with optional inclusion of recycled materials.
P-source: P-rock, secondary P-sources (SSA, struvite, MBM, other)
P-output: P-chemicals and -fertilisers

P-REX **Policy brief**
Business Model Canvas 5/5

Key Partners

- **The Nutrient Platform:** Value Chain Agreement with several Dutch partners to create a sustainable Market for secondary P-streams
- **European Sustainable Phosphorus Platform:** Promotion of issues around sustainable P-use

Key Activities

- P-Rock mining, shipping
- fertiliser and P-acid production and distribution
- Research on use of secondary phosphates in the fertiliser production

Key Resources

- Own phosphate rock resources (Israel)
- Control of the whole value chain from mine to fertiliser

Value Propositions

Fertiliser
- Phosphoric acid
- Phosphate rock
- Compound fertilisers
- Feed additives

with...
- High quality
- Competitive pricing
- Responsive sales & support

Customer Relationships

Channels

- Network of distributors

Customer Segments

Fertiliser-
Plastic-
Food-
Ceramic-
Etc.-
-industry

Fertiliser retailers, serving farmers

Cost Structure

- Operation, personnel
- Input material (low price of P-rock due to own mining activities)
- Research activities on secondary P-usage

Revenue Streams

- Product sales
- Offtake cost for the secondary P-sources (or lower price in comparison to P-rock)

www.businessmodelgeneration.com
www.p-rex.eu

Sources and further information:
www.icl-group.com/Pages/default.aspx
Langeveld, ten Wolde. "Phosphate recycling in mineral fertiliser production." Proceedings 727 (2013). IFS