European Sustainable Phosphorus Platform

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SCOPE NEWSLETTER

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Challenges of phosphorus: International IPW8 Conference, Rostock, identifies solutions

Agenda:

- 1 Dec. Brussels, ESPP workshop on **sustainability and innovation in the phosphorus chemicals industry**. info@phosphorusplatform.eu
- 8 - 9 Dec. Cambridge, UK, **IFS agronomic** conference & EU Fertilisers Regulation http://fertiliser-society.org/event/ifs-agronomic-conference-2016.aspx
- 13-15 March 2017, Tampa, Florida, **Phosphates 2017** *http://www.crugroup.com/events/phosphates/*
- 8-10 May 2017, Marrakesh, **SYMPHOS** Innovation and Technology in the Phosphate Industry *http://www.symphos.com/index.php*
- 19 May 2017, Washington DC, North America **Sustainable Phosphorus Alliance (SPA)** stakeholder meeting *https://sustainablep.asu.edu/about*
- 21 June 2017, Belfast, Ireland **Phosphorus from wastewater conference** *https://phosphorusie.wordpress.com/*

The partners of the European Sustainable Phosphorus Platform

Policy

German P-recycling obligation proposed

After more than 10 years of revision, the new draft of the German sewage sludge ordinance (AbfKlärV), which will make phosphorus recovery obligatory for most of Germany's sewage, has been sent by the Federal Ministry of Environment (BMUB) to the European Commission for notification at September 26th 2016.

This notification is the standard procedure for new member state regulations (directive 2015/1535/EU). Once approved by EC, the content cannot be generally changed afterwards except for minor adaptions. During notification, there is a three months stand-still agreement.

The next steps after notification will be cabinet resolution within the German Federal government in January 2017 and presentation for enactment to the Federal Council of Germany and the Parliament in spring 2017. **The new ordinance may thus enter into force with a date 1st January 2018**.

Obligatory phosphorus recovery

The ordinance will make **phosphorus recovery from sewage sludge obligatory for all German sewage works larger than 50,000 person equivalents** (p.e.), that is, around 500 out of a total of c. 9 300 sewage works in Germany. These 500 larger sewage works represent around 2/3 of the total phosphorus removed from German wastewater and transferred into sludge.

For these larger sewage works, phosphorus recovery will be obligatory if the sludge contains more than 2% phosphorus (dry solids), either by P-recovery from the sludge or by mono-incineration and recovery from sewage sludge incineration ash. If P < 2%, then co-incineration will be authorized.

Land application of sludge will only be allowed for sewage works < 50,000 p.e. Currently 29% of German sewage sludge is spread on farmland, and will have to respect the quality criteria of the new German fertilizing ordinance (DüV).

The entry into force of these two new ordinances (AbfKlärV and DüV). Is expected to be **cut by half the amount of sewage sludge going to farmland**.

The new fertilizing ordinance is the German implementation of the **EU Nitrates Directive** and will already dramatically impact sewage sludge use in Germany in 2017.

Article by Christian Kabbe. See also: http://www.bmub.bund.de/themen/wasser-abfall-boden/abfallwirtschaft/wasser-abfallwirtschaft-download/artikel/abfklaerv-klaerschlammverordnung/

EU Fertilisers Regulation revision

The proposed new EU Fertilisers Regulation is currently under discussion by Council (Member States) and the European Parliament, a process likely to take until at least summer 2017.

Now is therefore the time to input information to your national Government or to MEPs (Members of the European Parliament).

The Commission's proposed text COM(2016)0157 was March 2016 is available here http://ec.europa.eu/DocsRoom/documents/15949

The proposed new Fertilisers Regulation is summarised in ESPP's SCOPE Newsletter n°*120*
See also *http://phosphorusplatform.eu/regulatory*

At a meeting between stakeholders and MEPs organised by Fertilizers Europe in Brussels, 16th November, ESPP and other stakeholders indicated some key points and challenges with this proposed new Regulation:

ESPP welcomes the proposed new regulation, which will open the European market both for recycled nutrient products, and also for nutrient recycling technologies.

To sell a nutrient recovery technology across Europe, it is important that the recycled fertiliser produced can be placed on the market in all Member States.

The text is **very wide and ambitious**, covering not only mineral fertilisers (as does the current Regulation 2003/2003) but opening to also cover organic fertilisers, recycled nutrient products, organic soil improvers, liming materials, fertilisation bio-stimulants and polymers used in fertilisers.

Safety and confidence: need for traceability

ESPP shares the concerns of industry, farmers (e.g. COPA-COGECA) and NGOs that the announced objective of the new Regulation, to **guarantee safety** of CE labelled fertilisers, must be ensured with certainty.

ESPP therefore proposes to clarify in the Regulation full traceability. Traceability should be from the final fertiliser packet placed on the market (code bar on packet or with delivery to farmer), back to the initial sources of any organics present in the final product (which farms' manures or food factories' by-products are included in a given batch of product). Such traceability should be required wherever the final product is susceptible to contain organics from by-products other than mechanically processes plant materials (that is not in ashes after incineration).

This would be comparable to traceability of meat products already in place (the bar code on a meat on a supermarket shelf enables to identify the cow, the abattoir, the farm …). It could be **coherent with the production process traceability already required through the CE-label and with animal by-product traceability obligations**. A delay should be fixed for the definition and introduction of such a traceability system.

At present, **sewage sludges** are excluded from CE-labelled digestates and composts in the proposed text. ESPP suggests that traceability could facilitate confidence in sewage-sourced organic products in the future.

Wording and definitions need resolving

The ambition and wide scope of the new Regulation pose a number of wording and definition challenges, which need to be resolved in the decision process, in order to ensure that the final text **will not pose legal doubts, or suffer varying implementation interpretations in different Member States**.

- **Criteria for adding new CMCs (Component Material Categories)** should be clarified in art. 42.1 (clarify whether criteria such as trade potential and contaminants apply to the raw materials or the finished fertiliser product as placed on the market)
- **Coherence of wordings and definitions** for "mechanically processed" plant materials, food industry by-products. Should this include food-industry processes such as salting, pickling (vinegar), smoking, sugar or gelatine preservation?
- **Mineral fertilisers** should have a maximum of maybe 1% organic carbon content, as this is what farmers expect. **Organo-minerals** should have at least 7.5% organic carbon, again to correspond to expectations. What term should then be used for products placed on the market with 2 – 7.5% C_{org}?
- **Not use the term "blend" for mixtures** (blend has a specific meaning in the mineral fertiliser industry)

If these issues are not resolved in the text, then there is a risk of widespread development of "national" fertilisers in addition to the CE-label fertilisers, resulting in parallel markets.

Safety specifications should be relevant

Excessively demanding monitoring requirements or unnecessary contaminant limits could **add significant costs to recycling**, and risk closing the market to some recycling technologies or recycled nutrient products.

- **Sterilisation of animal manure** should not be necessary where it is used as input material for compost or digestate production, on condition that the composting or digestion process ensure Animal By-Product Regulation "end point" sanitary safety
- **Limits on copper and zinc** should be replaced by labelling requirements, because these elements can be micro-nutrients.
- **Not add additional contaminant limits, which would result in monitoring costs for no added safety benefit** (e.g. there is discussion on total chromium in addition to chromium-VI, or contaminants not susceptible to be found in a product given its production route and input materials)
- **Pathogen monitoring** should be sufficient to guarantee safety, based on existing Animal By-Product Regulation requirements, and new or additional testing should not be added
- **Tolerances should be at point of production** for organic products, which can vary with storage and transport
- **Monitoring for digestates containing only (mechanically processed) plant materials** should be as for "Energy Crop Digestate" (CMC4)

Stakeholders' positions

Concerns raised by other stakeholders at the Fertilizers Europe meeting include:

- Need to define **criteria for adding bio-stimulant micro-organisms**. The current proposal names, just four micro-organisms, and does not specify the strain. Such a nominative list would exclude innovation, because naming micro-organisms means opening know-how to competitors.
- Authorise **natural, plant derived polymers**
- Clarify the **definition of "fossil" materials** (intended to exclude crude oil or phosphate rock from "recycled" products) as concerns materials such as peat in soil improvers
- Importance of **plant availability specifications for P and N in fertilisers**

Future new accepted materials (CMCs) and Animal By-Products

Work is already engaged by the European Commission (JRC STRUBIAS process) to develop an impact assessment and criteria for possibly adding **struvite, biochars and ashes** to the list of materials from which EU-label fertilisers can be produced (Annex II, list of Component Material Categories, CMCs). The objective is to complete this work ready in time for the publication of the new Regulation.

ESPP is currently working with stakeholders on a **list of further materials which could be considered for addition as CMCs**. To date this possible list includes: recovered mineral nitrogen fertilisers, precipitated phosphates (other than struvite, which is already underway see above), mineral concentrates (after membrane filtration), dried/pelletised manures (may be covered by CMC11 see below), sewage sludge derived products, calcium carbonate sludge from drinking water treatment, paper mill biosolids.

ESPP is also working on criteria for authorisation of Animal By-Products as CMCs (CMC11). The European Commission (DG SANTE, at the European Fertilisers Working Group, 7th November) has indicated that a proposal to complete the currently blank box (empty in CMC11 in the published draft Regulation text) will be put ready by the time the Regulation is adopted.

Any input or comment on the above are welcome to *info@phosphorusplatform.eu*

The Commission's proposed text COM(2016)0157 was published in March 2016 and is available here http://ec.europa.eu/DocsRoom/documents/15949

Procedure status can be followed on EUR-Lex http://eur-lex.europa.eu/homepage.html

*The proposed new Fertilisers Regulation is summarised in ESPP's SCOPE Newsletter n°*120
See also http://phosphorusplatform.eu/regulatory

Marketing and value-chains for recycled nutrient products

Marketing of digestates and composts

Four recent studies, based on surveys of professionals and farmers in different European countries, assess the challenges to marketing of digestates, barriers to farmer uptake of composts and expectations of organic farmers. These studies indicate that relatively few publications to date address recycled nutrient use with a market approach, rather than from the position of the producer of the products.

Dahlin et al. (2015) assess biogas digestate marketing, based on a survey of digestate marketing information online and on 21 in-depth interviews (June – December 2014) with companies marketing digestate, based in Germany, Switzerland, Austria, Netherlands and France, selected after identification of 48 websites commercialising digestate. Interviews included biogas plant operators, agricultural contractors, soil and organic fertiliser manufacturers, brokers and technology suppliers.

Based on a literature search, the authors note that **marketing issues have largely been ignored in publications on digestate management** to date (see e.g. Schüsseler 2009).

The authors underline that digestate marketing is complicated because **digestates are very variable**, depending on the input materials and treatment processes. Dry matter content, nitrogen, phosphorus and potassium content can vary widely. Digestate treatment can reduce volume and facilitate transport to areas with nutrient demand. Such digestate upgrading processes include solid-liquid separation, evaporation – drying and membrane separation (more information in **Vaneeckhaute et al.** 2016 and **Drosg et al.** 2015, see ESPP News n°4).

In some cases, regulation or subsidies can drive processing, e.g. the German renewable energy heat incentive bonus includes digestate drying and the German bio-waste ordinance obliges treatment of digestate used on grassland if feedstock includes household wastes. Nonetheless, the authors estimate that only c. 3% of digestate produced in Europe is currently being upgraded.

They note that although upgrading increases the sale price of digestate, this **may not be sufficient to cover the processing costs** if digestate is sold to mainstream agriculture. Markets such as horticulture, private gardeners and soil manufacturing (inc. substitution of peat) can however offer higher prices (see Probert et al. 2005 concerning compost sales to landscape contractors and retailers). Today c. 17% of digestate processed to solid forms is sold to such markets (BGK 2015).

Key issues for digestate marketing

- digestate marketing is often driven by **difficulties to dispose locally of digestate**, because of local / regional nutrient surpluses or because the digestate plant operator itself does not control farmland
- **new business niches**: e.g. agricultural contractors or organic fertiliser manufacturers can act as value-chain intermediates finding customers and suitable applications for digestates
- certain digestates can be used in **specific markets**: organic farming, chicken litter (dried fibre fraction), horticulture, home gardening
- **marketing mix**: digestate production and processing can be adapted to produce digestates corresponding to different market demands, including with different nutrient balances, or with different physical properties for spreading or transport (e.g. pelletising increases bulk density, so reducing transport costs). Some digestate producers offer a catalogue of different digestates (up to 24 for one producer) and organic fertiliser manufacturers process to even wider specifications (up to 200)
- **digestate quality is key to marketing**, including hygienisation (pathogen limits), nutrient content, contaminants and foreign materials (glass, stones). Quality control systems, for both feedstock and output digestate, are important
- **quantities** produced will define possible markets and require appropriate product packaging
- **distribution** channels

Indicative figures on **digestate sale prices** are given, which depend strongly on whether it is sold in bulk or in small-scale retail-type “on the shelf”, as well as on the degree of processing.

The authors note that farmers often understand the **interest of digestate in bringing organic carbon to the soil** and also calculate the economy in mineral fertiliser costs related to digestate nutrient content. However, local excesses of digestate availability enable farmers to negotiate down prices.

Farmers are noted to be sceptical concerning digestate containing household wastes as input materials, although this can also be a price bargaining strategy.

The authors conclude that there is a **need for better understanding by companies marketing digestates of what are users’ concerns and preferences**, and a better education of potential users concerning both the safety and the benefits of digestate. The authors advise that specific digestate marketing competence is developed and used, rather than marketing being attempted by actors whose core competence is digester plant operation. This can be facilitated by **cooperation of producers to develop brands or labels, share marketing costs, and provide a range of specialist digestate products for different target markets**. The authors note that new players, such as agricultural contractors, digestate upgrading/processing technology providers or franchise marketers, are entering the market and can provide such marketing competence. Marketing can also use the positive arguments that digestate enables renewable energy production and nutrient stewardship.

Barriers to compost use

Viaene et al. (2016, partly FP7 CATCH-C project) investigated **barriers in Flanders, Belgium, to on-farm composting and to agricultural use of composts**, based on interviews of 86 stakeholders (including 21 farmers) and questionnaire returns from 83 farms (all in conservation areas or organic). Nearly all the farmers use inorganic fertilisers and slurry/manure, and most also plough in straw (mainly maize grain straw, incorporation of cereal straw is less common).

The authors also note that some 40 companies produce compost at a commercial scale in Flanders (c. 360 000 t/y, containing c. 3 000 tN) but that only around 5% of this is used in agriculture, most goes to parks and gardens.

Identified barriers to on-farm composting are

- **shortage of woody biomass**, resulting from subsidies to green energy (combustion, anaerobic digestion biogas)
- **licencing obligations** if farmers wish to use off-farm materials in composting, whereas this is necessary to achieve viable scale and appropriate input material mixtures
- **investment costs** for equipment for aeration of compost and for monitoring
- **lack of knowledge**
- costs or perceived (anticipated) costs and so **profitability**

Barriers to use of composts by farmers:

- **regulatory complexity and overlap**, e.g. Manure Decree (Nitrates Directive and phosphorus limitations), soil organic matter (CAP Mid Term Review, greenhouse emissions mitigation)
- **competition with regional manure supply surplus**
- **transport regulations**
- real or perceived issues with **compost quality**: respondent farmers believe that compost composition is variable (e.g. unpredictable availability of nitrogen to crops) and that all compost poses risks of weed seeds and diseases (lack of confidence in compost sanitisation)
- **lack of experience and knowledge** concerning compost use

The authors note that compost **quality, availability and price have been identified as barriers** by previous authors (Rahmani et al 2004 in Florida, Walker et al 2006 in Illinois).

Denmark farmers' attitudes to organic nutrient sources

Case et al. (2016) obtained questionnaire returns from 448 Danish farmers (representative of farms > 10ha using nitrogen fertilisers). Whilst only 35% had livestock, 72% indicated using at least one form of organic fertiliser, mostly manures received from neighbouring farms. 80% indicated that three years from now they expect to use the same amount of organic fertiliser as today, but **nearly half indicated that they would be interested to use a form of organic fertiliser not currently available to them** (most interest for unprocessed manure, then processed manure, and lastly sewage sludge or municipal bio-wastes).

Farmers' motivations for using organic fertilisers were (1) improvement of soil structure by organic content (2) low cost (particularly manure) and (3) availability nearby. The most important barriers to organic fertiliser use indicated by the farmers were (1) odour nuisance (2) uncertainty of nutrient content (3) difficulty in planning for application (supply and nutrient availability) and (4) cost of specific equipment needed for handling.

Organic farmers and secondary P sources

Løes et al. (NORSØK, Improve-P project) collected 213 questionnaires at stakeholder workshops held in seven countries to discuss the use of secondary phosphorus sources in **organic farming**. Nearly 40% of questionnaires were from farmers.

The authors note that the following are the principal phosphorus sources currently authorised under the **EU Organic Farming Regulation**: animal manure, including after processing (if not from factory farming), digested or composted source-separated household organic wastes and green waste from recreational areas, certain animal by-products (meat and bone meal, fish meal). Rock phosphate (soft, ground) is also authorised, but is not readily plant available in most soils. Some other materials are authorised under certain conditions but are generally available only in certain local situations, such as seaweeds, stillage extracts, freshwater dredge sediments.

Conventional animal manure is an important P input to organic farming. The respondents were concerned about residues of pesticides and pharmaceuticals, but the majority accepted manure from cattle (75% accepted), sheep (73%) and horses (72%). Results varied in different countries, and the acceptance for conventional manure was clearly lowest in Germany. Manure from poultry or pigs were on average accepted by c. 55%,and 31% found manure from fur animals to be acceptable.

Appropriately treated park and recreation green waste achieved the highest acceptance (>90%) along with **source-separated municipal food waste** (85%) and (non animal) **food industry residues** (77%) and **catering food waste** (71%).

More than 60% of respondents also considered acceptable the use of human urine and human sewage in organic farming, with a general order of preference precipitates (69%) > urine > sewage sludge > sewage sludge incineration ash (56%). Meat and bone meal ash was also acceptable to over 70% of respondents, but with comments that this often comes from non-organic / intensive production or should be applied under specific safety conditions (e.g. injected into the soil). Phosphate rock was considered acceptable to only 50% of respondents, with concerns expressed concerning the country of origin.

The authors note that **farmers were generally somewhat more sceptical** than farm advisors and scientists or other stakeholders, concerning use of secondary phosphorus sources in organic farming.

Environmental impacts of compost nutrients and carbon

In previous papers, **Vandecasteele, D'Hose and Vanden Nest et al.** showed that **long term amendment (4, 8 or 16 year) of farmland with plant-based compost improved soil quality and did not increase phosphorus / nitrogen leaching**, even when such compost was used in addition to manure application. Phosphorus in soils amended with manures was more readily available and prone to leaching.

"Biogas digestate marketing: Qualitative insights into the supply side", Resources, Conservation and Recycling 104 (2015) 152–161 http://dx.doi.org/10.1016/j.resconrec.2015.08.013 *J. Dahlin (a,b), C. Herbes (b), M. Nelles (a,c). a = Faculty of Agricultural and Environmental Sciences, University of Rostock, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany. b = Faculty of Business Administration, Nuertingen-Geislingen University, Neckarsteige 6-10, 72622 Nuertingen, Germany. c = DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Str. 116, 04347 Leipzig, Germany.* Johannes.Dahlin@hfwu.de

"Opportunities and barriers to on-farm composting and compost application: A case study from northwestern Europe", Waste Management Volume 48, February 2016, Pages 181–192 http://dx.doi.org/10.1016/j.wasman.2015.09.021 *J. Viaene (a), J. Van Lancker (b), B. Vandecasteele (a), K. Willekens (a), J. Bijttebier (b), G. Ruysschaert (a), S. De Neve (c), B. Reubens (a)* jarinda.viaene@ilvo.vlaanderen.be

"Farmer attitudes and potential barriers to the use of processed organic fertilisers" SLU 19th Nitrogen Workshop, Skara, Sweden, 27-29 June 2016 http://akkonferens.slu.se/nitrogenworkshop/wp-content/uploads/sites/18/2014/05/Nitrogen-Absracts-USB_ny.pdf *S. Case (a), Y. Hou (b), M. Oelofse (c), O. Oenema (c), L Stoumann Jensen (a). a = Dept. Plant and Environmental Sciences, University of Copenhagen, Frederiksberg C, Denmark. B = Soil Quality Group, Wageningen University, Wageningen, The Netherlands. c = Alterra, Wageningen University and Research Centre, Wageningen, The Netherlands* lsj@plen.ku.dk

"Phosphorus supply to organic agriculture. What does the organic sector think about different phosphorus fertilisers?" NORSØK report vol. 1 / nr. 3 / 2016 http://orgprints.org/30368/1/NORS%C3%98K%20RAPPORT%20nr%203%202016%20P%20FERTILIZERS.pdf *A-K. Loes, Norwegian Centre for Organic Agriculture, Gunnars veg 6, N-6630 Tingvoll, Norway* anne-kristin.loes@norsok.no

Schüsseler, P., 2009. Gärrest für eine Pflanzenbauliche Nutzung – Stand und F+E Bedarf; Gülzower Fachgespräche. Aktueller Stand bei der Gärrestaufbereitung Band 30, 160–165 http://refhub.elsevier.com/S0921-3449(15)30073-2/sbref0175

Rahmani, M., Hodges, A.W., Kiker, C.F., 2004 "Compost Users' Attitudes Toward Compost Application In Florida", Compost Science & Utilization. 12, 55–60 http://dx.doi.org/10.1080/1065657X.2004.10702158

Walker, P., Williams, D., Waliczek, T.M., 2006 "An analysis of the horticulture industry as a potential value-added market for compost", Compost Science & Utilization. 14, 23–31. http://dx.doi.org/10.1080/1065657X.2006.10702259

Vanden Nest, T., Ruysschaert, G., Vandecasteele, B., Houot, S., Baken, S., Smolders, E., Cougnon, M., Reheul, D., Merckx, R. 2016. The long term use of farmyard manure and compost: effects on P availability, orthophosphate sorption strength and P leaching. Agriculture, Ecosystems and Environment 216, 23-33 http://dx.doi.org/10.1016/j.agee.2015.09.009

D'Hose, T., Ruysschaert, G., Viaene, N., Debode, J., Vanden Nest, T., Van Vaerenbergh, J., Cornelis, W., Willekens, K., Vandecasteele, B. Farm compost amendment and non-inversion tillage improve soil quality without increasing the risk for N and P leaching. Agriculture, Ecosystems and Environment 225, 126–139 http://dx.doi.org/10.1016/j.agee.2016.03.035

New value chains for P-recycling

An innovative process to recover phosphorus from rapeseed press cakes (a colza oil by-product, which goes to animal feed) illustrates how a new value chain would be needed and the challenges to current industry players to implement this.

At present, colza oil production leads to 40% oil (with nearly 60% of the added value) and 60% cake (with only 40% of the added value). The cake consists of 80% kernel cake and 20% shell cake (the latter having half the market value). The kernel cakes are used as an ingredient for chicken feed production. **Much of the phosphorus in the cake, however, is not digestible to chickens** because it is in the form of phytate.

Phytase innovation to produce polyphosphate

The innovation consists of treating the cake in a bio-reactor with a specific targeted variant of the phytase enzyme. This breaks down the phytate, mobilizing the phosphate which will be stored by a yeast and then released in a **new form of value added polyphosphate** which can be recovered and – if it is in an appropriate form – used to substitute conventional polyphosphate, which is currently produced from phosphate rock (via phosphoric acid) and used for fertilizers and other industrial applications such as detergents and food additives.

Additionally, the level of phosphorus remaining in the cakes is lower, and is more available to chickens, **enabling more balanced nutrient management in the poultry feed**, and leading to a higher value for the cake, as well environmental advantages because of lower P levels in manures (undigested P).

Value chain challenges and solutions

This paper analyses the possible value chain organisation to **ensure the implementation of the innovation between the existing actors**: colza pressing company, enzyme supplier, polyphosphate producer (phosphate industry) with market to polyphosphate user, and chicken feed producer (combining cake with other nutrients and feeds).

A challenge is that **none of the current players in these value chains have the competence to operate the bio-reactor** necessary to control production of polyphosphate using the enzyme in order to ensure that the polyphosphate is appropriate for industrial applications (and so markets).

On the other hand, only the **phosphate industry** player has the know-how of which polyphosphates are suitable, and the capacity to take these to the market.

One possible solution would be to involve a new actor, who would collect the cakes from the colza mill, operate the bio-reactor, and then supply the polyphosphates to the chemical industry for use/sale to industrial application users. This would on the one hand pose **logistical costs**, by adding an additional processing site to the value chain, but on the other hand could enable the **development of a processing hub**, taking cake from several mills and producing different polyphosphates for different users. To be optimised, such a new site should be installed close to a colza mill or cake user. The new actor might have other benefits by providing a link between the different existing value chain actors to optimise or develop new synergies.

"Emerging value chains within the bio-economy: structural changes in the case of phosphate recovery" *http://purl.umn.edu/244788*, L. Carraresi, S. Berg, S. Bröring, Institute for Food and Resource Economics, University of Bonn, Germany, 149th EAAE Seminar 2016.

Part of the project entitled "Efficient phosphate recovery from agro waste streams by enzyme, strain, and process engineering" (P-ENG), funded by the North-Rhine-Westphalia Strategy Project BioSC (Bioeconomy Science Center, http://www.biosc.de/peng_en*). Project Coordinator: Prof. Lars Blank (RWTH Aachen University). Project partners: Prof. Dr. Ulrich Schwaneberg (RWTH Aachen University), Prof. Dr. Marco Oldiges (Forschungszentrum Jülich GmbH), Prof. Dr. Stefanie Bröring (University of Bonn).*

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Manure and Animal By-Products

Environment challenges for pig production in Europe

The European Forum organised by COOPERL, Rennes 13th September, France's biggest pig production cooperative brought together farmers' organisations and experts from six regions with high livestock intensity: Brittany, Flanders, Netherlands, Lombardy, Catalonia and North-West Germany. Although production systems and environmental contexts may be very different between these regions, a number of regulatory and market trends were identified as shared.

Bertrand Convers COOPERL, explained that the Brittany and North West France pig farmers cooperative **COOPERL brings together 2 300 farmers, employs 5 700 staff and produces nearly 6 million pigs per year (20% of France's production).** The cooperative deals with the whole pork production chain, from the farm and manure management, through to slaughterhouses, meat processing and marketing.

COOPERL research and innovation

Prior to the Forum, speakers visited **COOPERL's research farm at Ville Poissin, near Lamballe, Brittany**, a **full scale installation where 300 sows and 900 pigs/year pigs are raised**, including fattening through to slaughter and piglet production and weaning, under fully controlled conditions.

COOPERL's piggery research farm, Ville Poissin near Lamballe

This full-scale research farm enables **testing of feeds, equipment, light cycles, genetic pig races and other factors**, so that COOPERL can develop, test full scale and provide to farmers efficient production innovations. The farm also enables operational testing of manure treatment systems.

Currently, a new stable building is under construction to enable full-scale and full production cycle testing of the **stable scraping systems (TRAC).**

Cécile Crespel indicated that today around 10% of COOPERL pig farmers have **manure solid / liquid separation and biological treatment** installed, enabling production of some 50 000 tonnes/year of organic fertiliser products.

COOPERL sells some 400 different formulations of recycled organic fertiliser, with controlled and reliable nutrient balance adapted to different crop needs or regional products.

Environmental progress and manure traceability

COOPERL's **TRAC stable floor scraper system** results in solid / liquid separated manure production in the stable, so enabling separation of most of the phosphorus (in the solid fraction) in a region where P is becoming a limiting factor for manure spreading. The system also results in **c. 50% lower ammonia emissions** (reduced air emissions, improved animal welfare). The urine fraction can be spread locally by farmers (90% of phosphorus and 55% of nitrogen are in the solids) and the solid fraction can be transported for centralised treatment. A new version of this scraper system now under testing (roll-out planned for 2018) includes thin lightweight, modular concrete slab elements and an autonomous robot scraper (rather than fixed mechanical scraper mechanism) which enable **installation into existing stable buildings**.

COOPERL are building a **150 000 t/y input biogas production plant to treat the collected manure solids, as well as meat production wastes, and process to organic fertiliser products** (see ESPP News *n°3*), to be commissioned in 2018. Operation will allow traceability of organic fertiliser products, indicating from which farms input manure was used, considered important for user confidence.

Manure intensive regions

Christine Roguet, IFIP (French pig industry institute), presented the geographical concentration of pig production in Europe. **Six countries produce 70% of Europe's pigs:** Germany (esp. Lower Saxony, North Rhine Westphalia), Spain (esp. Catalonia, Aragon), France (Brittany), Denmark (Jutland), The Netherlands (North Brabant, Limburg), Poland. This spatial concentration is the result of interactions between market mechanisms and regulations, the consequence of political choices (competition on a global non-subsidised market). European policies are needed (e.g. CAP) to encourage environmental protection, animal welfare and actions need to be developed to convince consumers to pay for quality.

Kees Kroes, LTO (Netherlands national farmers organisation) explained that manure in the Netherlands contains some 77 000 tonnes of phosphorus (P) per year, with the biggest share coming from cattle, whereas land application is limited to 56 000 tP/y. **Costs for pig manure disposal** in the Netherlands are 15- 25 €/tonne, equivalent to c. 0.07€ per kg pork.

Regulatory complexity

There are many complex regulations impacting manure use. Trends include low ammonia emissions field application, GPS and weighing control of manure transport, precision farming and manure processing to generate products adapted to farmers' needs, circular economy initiative and biodiversity conservation objectives. **Treatment technologies** include mobile on-farm solid-liquid separation units, composting to ensure sanitisation (pasteurisation), co-digestion with other organic wastes to produce biogas with drying and palletisation of digestate, reverse osmosis separation and ammonia stripping (with problems that waste heat is needed to fuel this, and generated nitrogen products are too dilute to transport).

New actors are entering manure processing and marketing of recycled manure fertiliser products, including cooperatives, contractors, co-digesters and lead farms taking several farms manures. There are currently around 100 manure processing installations in the Netherlands.

Emilie Snauwaert, VCM (Flanders centre for coordination of manure processing, Belgium) also underlined the difficulties posed to farmers and to manure processing by complex and overlapping regulations, including **Nitrates Directive implementation, phosphorus spreading limitations and manure processing obligations**. Average manure disposal costs in Flanders for different locations/arrangements range from around 4€/tonne for spreading on nearby farms to 17€/tonne for processing.

The most widespread manure treatment system in Flanders is biological treatment of liquid manure, often with shared installations between a few farms and recently with development of smaller single farm systems (< 10 000 t/y).

Trends in manure management

Manure processing **trends** include:

- **Post treatment** (after biological treatment of liquid fraction) to address potassium, sodium, chlorine: e.g. wetlands, membrane treatment
- on-farm **solid-liquid separation** (screw press or centrifuge), with the liquid fraction used on-farm and the solids transported to central processing
- **nitrogen recovery** stripping/scrubbing technology, the status of the end-product still needs to be clarified (Nitrates Directive (see SCOPE Newsletter *n° 100*)
- on-farm **pasteurisation of solids**, so enabling cross-border export into France
- **black soldier fly larvae** used to convert manure solids to lipids for industrial applications (see SCOPE Newsletter *n° 118*)

Christian Auinger, Schauer Agrotonic (Austria) summarised key issues facing pig producers in Germany and Austria as **air emissions**, **animal welfare**, **Nitrates Directive** implementation (including manure spreading limitation and reducing nutrient losses by **changing soil management**: e.g. low tillage, cover crops). Around 40% of ammonia emissions occur in stable buildings, 20% in storage and 40% in field spreading. Ammonia air stripping on stable buildings is expected to become a federal obligation in Germany (> 2 000 fattener pigs)

Market opportunities

Consumer studies suggest that organic production will increase from 2% of consumer meat demand today to 5%, but that **a further 30% of consumers are prepared to pay higher prices for animal welfare labelled meat**. 65% of consumers will continue to buy the cheapest meat on sale. Straw on stable floors is expected to become obligatory, for animal welfare reasons, as well as implementation of floor scraper systems. Reducing air pollution offers synergy with animal welfare.

Francesca Malpei, Politecnico di Milano Dept. of Civil and Environmental Engineering (DICA), presented developments in Lombardy.

Lombardy region has 4.5 million pigs, 1.4 million cattle as well as 10 million human population and industries. Today, around 400 anaerobic digestion plants treat a quarter of the region's pig manure. Other manure treatment systems are less common: around 250 screw press solid-liquid separation, 21 biological treatment of liquid fraction, 9 ammonia stripping, 2 ultrafiltration/membrane installations.

Livestock production accounts for around one third of Lombardy's ammonia emissions, a quarter of methane emissions and 30 % of PM_{10} fine particles in the atmosphere in Lombardy's urban areas (ammonia and acidic gases generate secondary aerosols and so PM_{10} particles).

To date there is no government action in Lombardy on phosphorus spreading in manure, despite very strict limitations for sewage works.

Environmental challenges in pig production in Catalonia

Jaume Boixadera, Catalonia Region, indicated that the region has **6.4 million pigs (over one quarter of Spain's pigs) and 24 million poultry**.

Catalonia has a Mediterranean climate and highly calcareous soils. Agricultural demand for raw manure is low because the driest lands and tree crops have limited needs of nutrients, only moister and irrigated lands (250 000 ha) need significant nutrient input. A difficulty is that **over 60% of Catalonia pig production is "integrated", with the farmer effectively producing as a contractor for food industry companies**. This poses problems for manure management, because the companies leave this responsibility to the farmers, without costing into contracts.

Six manure processing plants in Catalonia closed when renewable energy subsidies were terminated but one large biogas manure treatment plant with reverse osmosis and ultrafiltration is still operating. Composting plants include three poultry manure composting plants.

Regulatory and **policy priorities** in Catalonia include: animal management on-farm (water, feed), improving manure field application (transport, manure treatment, developing nutrient products instead of spreading up to nutrient load limits, so improving nutrient use efficiency) and reducing ammonia emissions. Phosphorus is not yet seen as an issue for manure management.

Identifying common trends for manure management in different EU regions

Bernard Rouxel, pig farmer and Vice-President of COOPERL, concluded that **environmental performance is an obligation for European pig farmers**, and that solutions need to be identified to enable this to be achieved whilst maintaining economic competitivity. This will require moving from manure processing a cost to making it an added value.

The following trends appeared as shared common concerns between the six European regions with high levels of pig production present at the Forum:

- Opportunity to **develop markets towards consumers who are prepared to pay higher prices** for pork produced respecting animal rights (e.g. straw in stables, scraper systems, non-castration, abattoir welfare concerns …) and environmental criteria. Quality label and marketing systems are needed to enable this added value.
- **Phosphorus spreading limits** (beyond the 'literal' implementation of the Nitrates Directive which limits only nitrogen)
- **Processing manure to enable production of fertiliser products**. Processing to solid organic fertilisers adapted to crop / user needs and compatible with transport can be economic and compatible with biogas production. Other manure treatment processes, such as osmosis or air stripping, have yet to demonstrate economic viability and a capacity to generate marketable products.
- **Combinations of on-farm initial processing** (or several grouped farms), such as solid-liquid separation or biological treatment, **and centralised further processing to produce and market fertiliser products**. Involvement of new actors (contractors, farmers' cooperatives, organic fertiliser companies) in manure processing and marketing.
- Value of **traceability** to ensure user (farmer, food industry) confidence in recycled fertiliser products
- **Reducing ammonia emissions**, because of both greenhouse gas impacts and local air quality (including PM_{10} particles) in stables (e.g. scraper systems, air stripping), storage (e.g. covering of manure storage) and field application (injection into soil, on-tractor acidification …)

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Understanding Animal by-products and phosphorus recycling

Animal slaughter by-products contain around 310 000 tP/y (EU) of potentially recyclable phosphorus. How are they processed and what are the issues?

Processed Animal Protein (PAP), and Meat and Bone Meal (MBM) are the products generated by "**rendering**" (specified separation and heat processing for sanitation and drying) of animal parts not used for human consumption, in particular bones and meat residues (proteins). This article, after consultation of stakeholders, explains the different animal by-products, current treatments and phosphorus recycling potential.

EUROSTAT indicates 46 million tons live weight animals slaughtered in the EU in 2015 (Eurostat 2016).

EFPRA *http://www.efpra.eu/Objects/3/Files/EUInfographic.pdf* (European Fat Processor and Renderers Association, 35 members) indicate that **328 million pigs, sheep, goats, beef and dairy cattle are slaughtered in the EU each year** together with 6 billion poultry.

However, 25% (poultry) to 42% (cattle, beef) of the animal is not used for human consumption and goes to "rendering" (animal by-product processing), that is a total of around 14.5 million tonnes. Additionally some 2.5 million tonnes of dead animals (not slaughtered but died on farms) are also collected and rendered.

EFPRA indicate that these **17 million tonnes (fresh weight) of animal by-products (not including manures)** are processed to fats and proteins mainly used for pet food, oleochemicals, animal feed additives, aquaculture feed, fertilisers, biodiesel and energy valorisation.

What are Animal By-Products (ABP)?

Animal by products are divided into three Categories by the EU Animal By Products Regulation 1069/2009

Category 1 (highest risk)	Animals suspected or confirmed as being infected by a TSE (transmissible spongiform encephalopathies, such as BSE, scrapie), animals killed in the context of TSE controls, animals other than farmed and wild animals such as pets, zoo and circus animals and experimental animals.	Must be disposed of: mainly rendered into fats (for combustion or biodiesel) and Category 1 MBM (incineration in power stations and cement kilns)
Category 2	Other high risk material for example: condemned meat, digestive track contents, animal by-products presenting a risk of contamination, animal materials collected when treating waste water from slaughterhouses, non ruminant dead farm animals … Animal manures are also classified category 2.	Unprocessed Category 2 material cannot go to landfill: must be removed from the food and feed chain. Mainly rendered into fats (for combustion or biodiesel) and Category 2 MBM (fertiliser, fur feed, incineration)
Category 3 (lowest risk)	Slaughter by-products from healthy slaughtered animals, mainly human food grade downgraded to category 3 for commercial reason, like bones, trimmings, offal, blood or simply not edible like hooves, hairs, horns, feathers; also includes former food stuff and catering waste.	Cannot be taken to landfill, but can be incinerated or reused via a number of routes such as rendering, composting or anaerobic digestion (subject to other legislative control), or be used in pet food. Rendered products like fats and PAP can be used in (certain) farm animal feed, pet food, fertiliser, oleochemical plants and biodiesel.

Prepared by EFPRA

Explaining the different terms MBM, PAP, ABC …

- **What is rendering?**
  Rendering is the process by which slaughter by-products / dead animals are treated to produce MBM or PAP (see below). Rendering includes a size reduction, sanitation, drying and separation step into fat and protein. The sanitation step is mainly at 133°C at 3 bars pressure for at least 20 minutes[i], to ensure sufficient elimination of bacteria and viruses. Prions[ii] are considerably reduced but not totally.

- **What is PAP - Processed Animal Protein?**
  PAP - Processed Animal Protein is made only from Category 3 (lowest risk) animal by-products from healthy slaughtered animals, by rendering under similar conditions as MBM (see below), however the temperature, pressure, time combination may vary depending on the destination. The broad variety of PAPs includes blood meal (90-95% proteins), poultry PAP (65-68% proteins), feather meal (80-85% proteins), pork PAP (55-65% proteins), mixed species PAP and fishmeal. PAP is used for high protein content in pet food, fur animal and – if produced from non-ruminants – in aquaculture feed (fish, shrimps).
- **What is MBM – Meat and Bone Meal?**
  MBM - meat and bone meal can be made from ABP categories 1 and 2 by rendering. To avoid their return into the food and feed chain those animal by-products with a high load of prions are classified as category 1 and treated by incineration or equivalent (cement kilns). MBM of category 2 can be used as fertiliser or feed for non-food production animals (e.g. fur animals). MBM typically contains about 48–52% high protein content, 33–35% ash, 8–12% fat, and 7-10% moisture.
- **What is MBMA – Meat and Bone Meal Ash?**
  MBMA is produced by mono-incineration/treatment of MBM in a heat process conform to the Industrial Emissions Directive (*2010/75/EU* previously Incineration Directive) Article 6 = conditions of incineration at minimum 850°C for at least 2 seconds, TOC (total organic carbon) in ash <3%. These conditions ensure complete elimination of all pathogens and result in an "ash" which can be an effective fertiliser product.
- **ABC** is used as an acronym for "Animal Bone biochar" – this corresponds to a specific technology (one installation operating) for making a biochar from food grade animal bones (REFERTIL / 3R Pyrolysis technology, see SCOPE Newsletter 117). This type of biochar can be used as a fertiliser or as an adsorbent.

i - These conditions are defined in Chapter II of Annex X of the Animal By Products Directive

ii - Prions are infectious agents which consist only of protein which can fold in structurally different ways. The "normal" protein is naturally produced in the body. Prions may propagate by transmitting their misfolded protein state: When a prion enters a healthy organism, it induces existing, properly folded proteins to convert into the misfolded prion form. All known prion diseases in mammals affect the structure of the brain or other neural tissue; all are currently untreatable and universally fatal.
https://en.wikipedia.org/wiki/Prion

Recycling phosphorus in MBM

PAP / MBM contains around 8-9%N, 5-6%P, 0,4-1%K and 10-13% Ca (3)

The best recycling of phosphorus in animal proteins can be considered to be the **use in animal feed**, because its digestibility for (non ruminant) animals is much higher than that of P in plant materials which is partly non-available phytates About 630.000 tonnes of category 2 MBM and PAP was used in fertiliser in 2015 in the EU.

European regulation EC 181/2006 on "organic fertilisers and soil improvers other than manure"* specifies these be produced solely from Category 2 and 3 ABP material and specifies use limitations, such as grazing restrictions and the obligation to document where and when such fertilisers are used.
** Here, the term organic means containing organic carbon, not as in "organic farming".*

However, it should be noted that **category 2 MBM and PAP (category 3) are accepted and widely used for organic farming.**

The recycling of category 1 MBM into MBMA requires a waste incineration process following the IED (Industrial Emissions Directive). Only a mono incineration guarantees a high P-Content in the MBMA. With declining BSE cases and changing prevention measures it is questionable whether there will be enough Category 1 MBM in the future to run profitably an incineration plant only on MBM.

SARIA produce around 12 000 t/year of phosphorus fertiliser/soil conditioner from MBM ash, sold as Kalfos brand.

Examples of MBM recycling today in Europe

- **Saria UK** process around 1 000 tonnes P/year in MBM to a phosphorus fertiliser (FluidPhos process producing a slow-release mainly calcium phosphate mineral fertiliser c. 22% P_2O_5 plus magnesium, potassium, sulphur, etc), see SCOPE Newsletter n°105
- **EPR, UK**, more than 2 800 tonnesP/year in MBMA sold as "P-grow" fertiliser in the UK
- **ACL/Wykes Engineering UK**, mono-incineration of MBM generating a fertiliser product
- **ICL** uses MBMA (MBM ash) as an ingredient in commercial mineral phosphate fertiliser production (see SCOPE Newsletters 113, 115)
- **ITS SA Portugal** produce around 2 500 tonnes/year of ash from Cat. 1 and 2 ABPs, for which authorisation as fertiliser is under consideration
- **COOPERL** Brittany use slaughterhouse MBMA as an ingredient in fertiliser production (combined with organic dried and processed digested manure), see SCOPE Newsletter 118
- **ECOPHOS** can use MBMA (MBM ash) as raw material in their P-recycling process (demonstration plant operating today in Varna Bulgaria, and a 220 000 t product/year plant under construction Dunkerque France, see SCOPE 120
- **Elosato** OY produces organic fertilisers from MBM, widely used as an organic fertiliser in Finland

Flows and uses of ABPs in Europe

EFPRA indicate that after processing (including drying), the 17 million tonnes of animal by-products indicated above (not including manures) generate:

- 2,5 million tonnes of PAP (see below), which is used mainly in **pet food** (70-75%) and fertiliser (20%)
- 180.000 tonnes of Category 2 MBM which is used mainly in **fertiliser** (80%), as an energy substitute (15%) or in feed for fur animals (5%)
- 1 million tonnes of Category 1 MBM

Lesschen et al. and van Dijk et al. (2) and **Van Dijk** et al. (4) estimate animal by-products (ABP) in Europe to contain c. 310 000 tonnes of phosphorus per year compared to around 215 000 tP/year is in food wastes and food industry by-products/wastes (other than those going to animal feed).

Niemann (1) suggests that Europe processes 15 – 20 million tonnes per year of ABP of which 30-45% is category 1, 5-10% category 2 and 50-55% category 3.

Published papers estimate that a better overall recycling rates of animal by-products – whilst still ensuring pathogen safety – could be an economic and significant phosphorus recycling route, e.g.:

- **Leesschen**, van Dijk et al (2) estimate that MBM could substitute 3-5% of P in animal feeds in The Netherlands (SCOPE 102)
- **Lamprecht** et al. (2011) estimate that MBM in Switzerland could substitute $^1/_3$ – $^1/_2$ of national mineral P fertiliser use (but this is not currently authorised in the EU as indicated above, except for non-food animals)
- **Van Dijk** et al. (4), updated by van Dijk for P-REX (2016) estimate 312 000 t/y of phosphorus in slaughter wastes in the EU, of which only 18 000 is accounted for in recycling in fertilisers or animal feeds.

These figures suggest that **a better integration of industry data into phosphorus flow studies** is needed to obtain a clear overview of potential for phosphorus recycling from (non manure) animal by-products, and of how much phosphorus is already recycled to different end uses.

(1) Niemann, Statistik der Verarbeitung tierischer Nebenprodukte 2011 http://www.stn-vvtn.de/2012_2.html

(2) Lesschen et al." Options for closing the phosphorus cycle in agriculture; Assessment of options for Northwest Europe and the Netherlands", Alterra Wageningen UR, Statutory Research Tasks Unit for Nature and the Environment, Wageningen, The Netherlands, 2013

(3) "Effects of meat bone meal as fertilizer on yield and quality of sugar beet and carrot", Kivela J., Chen L., Muurinen S., Kivijarvi P., Hintikainen V., Helenius J., Agriculture and Food Science (2015) vol. 24, 68-83
http://ojs.tsv.fi/index.php/AFS/article/view/8587

(4) Van Dijk et al. "Phosphorus flows and balances of the European Union Member States", Science of the Total Environment Volume 542, Part B, 15 January 2016, Pages 1078-1093 http://dx.doi.org/10.1016/j.scitotenv.2015.08.048

Struvite

Struvite as fertiliser

Since publication of the summary of recent field and pot trial test data of struvite as a fertiliser, published in SCOPE Newsletter n° *121*, four further papers have been communicated to ESPP. With the data reviewed in SCOPE *43* (2001) and in SCOPE *121* (June 2016), this brings to over 50 the number of publications to date.

This considerable data converges to confirm that struvite is an effective fertiliser for a wide range of crops, both in acidic and also neutral or slightly alkaline soils.

Additionally, a *report* by **Ehlert et al**. (Wageningen, 2013), financed by the Netherlands Ministry for Economy, summarises the legal issues relating to marketing struvite as fertiliser (progressively changing waste regulation, fertiliser regulation). This report notes that in many cases the phosphates precipitated from waste streams are not pure struvite (magnesium ammonium phosphate), but can include significant levels of potassium, calcium, magnesium, aluminium or iron phosphates. The report includes tables summarising levels of different elements (N, P, Mg, K, Ca) and levels of heavy metal contaminants in over 25 different precipitated phosphates.

This report shows that **care is needed when referring to "recovered struvite" to ensure that the product is indeed struvite**, and not a mixture of other phosphates which may not have the same fertiliser value (possibly lower nutrient plant availability or not so well studied to date). The report indicates that struvite products should also be differentiated between whether or not they are susceptible to contain pathogens (precipitation from waste streams such as manure or sewage, or high pH in precipitation process which will kill pathogens).

Additional evidence of struvite fertiliser value

The new papers presenting data on struvite as a fertiliser are:

Grunert et al. (publication pending, presented at *WEF/IWA Nutrient Removal and Recovery* Denver, July 2016). Pot trials (5 litre rhizotrons) using tomato (*Solanum x.*) and lupin (*Lupinus angustifolius*) from seed to 5 weeks, comparing an organic fertiliser, recovered struvite and no fertiliser. **Struvite gave significantly increased leaf area and fresh weight compared to no fertiliser** (8-10x increase for tomato, c. 25% increase for lupin). Greater increases were given by the organic fertiliser, but this contained e.g. 5% potassium and 2% sulphur as well as higher nitrogen (and six times lower phosphorus) than struvite, so that results are not comparable.

Degryse et al (same conference as above) carried out petri dish solubility tests of different struvites and six week pot trials with wheat (*Triticum aestivum*) in soils pH 5.9 and 8.5. Results show that some recovered struvites with excess magnesium oxide (MgO, used in this case as a reagent in the recovery process) is significantly less soluble in soil. **Pot trial results show very similar results from ground (<0.15mm) commercial mono ammonium phosphate (MAP) and ground commercially recovered struvite (Ostara CrystalGreen)** mixed throughout the soil, whereas if only one c. 50 mg granule of fertiliser was placed in the pot then in alkali soil MAP was more effective. These results suggest that granular struvite releases nutrients more slowly in alkali soil than does MAP, but that this can be redressed by grinding and mixing into the soil.

Robles (same conference as above) tested wastewater recovered struvite (Lequia pilot struvite reactor, Girona – Tarrago et al. 2016) to triple super phosphate (TSP) in 40-day pot trials with maize and lupin, soil pH 4.8, with two different nitrogen sources: ammonium (acidifying) and nitrate (alkalizing). **Struvite gave the same biomass as did TSP for lupin, and significantly higher for maize**. Ammonium gave in most cases higher biomass and higher P uptake than did nitrate.

Kern, Heinzmann et al. (*2008* but missing in previous reviews) tested wastewater recovered struvite (Berlin Wasser, Wassmannsdorf) in 8-week pot trials on maize and wheat (sand and nutrient solution). **P uptake rates of 67-87% were shown**. A no-fertiliser control was included but no comparison to commercial P fertiliser.

'MagAmp' = commercial struvite a much sought-after specialist fertiliser

We have now also obtained copy of an older paper (**Tawagan & Boodley, 1963**). These authors tested one application of Grace Co. '**MagAmp**' (commercial struvite) for pot-plant Pointsettias, grown from cuttings for three months, using one dose of the struvite in several different pot plant soils / peats / perlite / vermiculite (pH not specified), plus added potassium nitrate to provide N and K.

Conclusions were that **single in-pot applications of struvite resulted in good quality plants**.

'MagAmp' commercial fertiliser was struvite (magnesium ammonium phosphate). The production from phosphoric acid was patented (patent *US4153441*). The name *trademark* filed by W.R. **Grace Co**. in 1962, and subsequently was sold on to **Hyponex Japan** and then **Sumitomo Corp**. Grace Co. *documentation* from 1966 presents MagAmp as "***A non-burning solid fertilizer, only slightly soluble in water, for nursery stock and fruit trees. Available in two formulations, 7-40-6 and 8-40-0***".

Including recently, MagAmp and struvite are recommended fertilisers in publications for specialist products, for example tomatoes in "Hydroponics: A Practical Guide for the Soilless Grower" (**J. Benton Jones, CRC 2005**).

Enmag fertiliser

Struvite mixed with ammonium sulphate was being sold as "*Enmag*" into the 1990's in the UK. Until 2013, MagAmp was still being sold by *FukuBonsai*, Hawaii, and was a sought-after fertiliser for bonsai specialists.

Degryse F. et al., "Dissolution rate and agronomic effectiveness of struvite fertilizers – effect of soil pH, granulation and base excess", Plant Soil 2016 http://dx.doi.org/10.1007/s11104-016-2990-2

Grunert O. et al. "Struvite and Organic Fertilizer Impacting The Rhizosphere Microbial Community, Nutrient Turnover and Plant Growth Performance" WEF/IWA Nutrient Removal and Recovery *Denver, July 2016*

Kern J, Heinzmann B. et al., "Recycling and Assessment of Struvite Phosphorus from Sewage Sludge", Agricultural Engineering International CIGR Ejournal. Manuscript number CE 12 01. Vol. X. December 2008
http://www.cigrjournal.org/index.php/Ejounral/article/view/1071

Robles A. et al. "Effectiveness of Recycled Phosphorus as Struvite is Modulated by the Nitrogen Source Applied" WEF/IWA Nutrient Removal and Recovery *Denver, July 2016*

"Wettelijke Onderzoekstaken Natuur & Milieu. Opname van struviet als categorie in het Uitvoeringsbesluit Meststoffenwet", P. Ehlert, T. van Dijk, O. Oenema, Wageningen Werkdocument 332, funded by the Netherlands Ministry for Economics, 2013
http://edepot.wur.nl/262471

"Results of one-shot feeding for pointsettias", Florists' Review, 133, p28-30 and 80-81, September 1963, A. Tawagen & J. Boodley, not available online.

Opportunities and barriers for struvite as fertiliser

A STOWA (Netherlands Water Industry Research Organisation) study assesses the market potential of struvite, looking at the Dutch regulation and farmers demand.

In the Netherlands, **struvite recovered from municipal sewage and other organic waste streams is authorised for use as a fertiliser in agriculture, horticulture and gardening**. Authorisation, contaminant levels and safety criteria are specified in regulations: Uitvoeringsbesluit Meststoffenwet and Uitvoeringsregeling Meststoffenwet. Also, recovered struvite is already used as input material for conventional fertilisers production process (ICL Fertilizers, see SCOPE Newsletter *n° 115*).

Netherlands struvite regulations: Uitvoeringsbesluit Meststoffenwet http://wetten.overheid.nl/BWBR0019031/2016-01-01 *and Uitvoeringsregeling Meststoffenwet* http://wetten.overheid.nl/BWBR0018989/2016-01-01 *(summary in English at* http://phosphorusplatform.eu/images/download/Reststoffenunie-summary-NL-struvite-legislation-29-3-2016.pdf *).*

In the Netherlands and some other European countries national fertiliser Regulations provide a clear context but in others it poses barriers to place struvite on the market for use in agriculture.

Agronomic comparison

Based on a **desktop comparison** between nutrient composition of struvite and theoretical crop nutrient demand, the authors conclude that recovered struvite on its own (not blended with other nutrients) would only be useful for crop types with a relatively low nitrogen (N) demand. However, this can be resolved (as for other phosphate fertilisers) **by combining struvite with application of other nutrient products** (N, K, other).

Fertilisation quality experiments

In the STOWA study the fertilisation quality of struvite was also tested by fertilisation experiments in pots (iceberg lettuce, dike grass, gladiola flowers and the garden shrub Elaeagnus ebbingei) and in the field (gladiola). Pots with unfertilized sandy soil with very low P concentrations (Pw = 7) and pH 5.0 had a control (no fertilisation) and three types of treatments with different fertiliser types: mineral fertiliser (triple super phosphate, 14% P), organ-mineral fertiliser (Vivifos, 4% N and 9% P) and washed recovered struvite (2% N, 6% P and 10% Mg, sourced from Waternet sewage works, see SCOPE Newsletter n° 115). Soil pH for field trials is not indicated. For all treatments the soil P stock concentration was fertilised to the same P quantity per ha, equally mixed at the start and in line with agronomic recommendations. At the start of the experiment, all pots had a similar concentration of N, P, K and Mg in line with recommendations. The irrigation and growing period were in line with agricultural recommendations.

The authors conclude that for tested crop types used in aforementioned sectors with a high potential**, the use of struvite as fertiliser can have agronomic benefits compared to conventional fertilizer products**. Lettuce showed an equal to better head forming with the use of struvite. For grass it leads to better and more rapid growth after seeding, higher grass density and better rooting system, especially useful for grass that is used on dikes for water management. A better root forming has also been observed for the Elaeagnus, which can be useful for rapid further growth after transplantation to a larger pot or into the ground. For most tested crops soil fertility measured after the experiments were similar between the three treatments with mineral, organic and struvite fertiliser, given the similar concentrations of essential macro- and micronutrients for plants.

Valuation by users

Based on opinions of agronomic advisory experts in the Netherlands, pelletized struvite would have the largest preference of farmers. Changing the N:P ratio of struvite by combination with nitrogen fertilisers or other fertiliser products could open potential markets, e.g. potatoes, unions, crocuses, various nursery trees, perennials, and for roof gardens.

At present in the Netherlands based on present mineral fertiliser prices, the **realistic market value of struvite is estimated at €55 per ton** as pelletized fertiliser or raw material for the fertiliser industry. If the replacement value is taken into account for all nutrients (i.e. P, N and Mg) in the aforementioned high value potential markets, struvite has a hypothetical market value of about €350 euro per ton.

STOWA. Struviet en struviethoudende producten uit communaal afvalwater. Stichting Toegepast Onderzoek Waterbeheer (STOWA), Amersfoort, Netherlands, 2016. ISBN 978-90-5773-731-2. Report number 2016-12. http://www.stowa.nl/publicaties/publicaties/marktverkenning_en_gewasonderzoek_struviet_en_struviethoudende_producten_uit_communaal_afvalwater *(in Dutch)*

Another STOWA study on the quality of struvite from communal waste water treatment:

STOWA. Verkenning van de kwaliteit van struviet uit de communale afvalwaterketen. Stichting Toegepast

Onderzoek Waterbeheer (STOWA), Amersfoort, Netherlands, 2015. ISBN 978-90-5773-711-4. Report number 2015-34 http://www.stowa.nl/publicaties/publicaties/verkenning_van_de_kwaliteit_van_struviet_uit_de_communale_afvalwaterketen *(in Dutch)*

Recovered struvite processed to fish feed

Struvite recovered from swine manure was heated to remove ammonium, giving magnesium phosphate. This was tested as a feed additive for young catfish for 8 weeks, showing significant increases in growth and feed efficiency, comparable to commercial mono calcium phosphate (MCP).

The **struvite was recovered from pig manure** in a pilot scale reactor in Kangwon National University, Korea, using CO_2 stripping by aeration and magnesium chloride dosing.

Ammonium was then removed from struvite by heating at 550°C for 30 minutes, producing mono magnesium phosphate = magnesium hydrogen phosphate ($MgHPO_4$). Then the product was finely ground for use as a fish feed additive.

Struvite -> magnesium phosphate -> fish feed

Magnesium phosphate was added to standard fish feed (consisting of fish meal, soybean meal, wheat flour, gluten, fish oil, soy oil) at 0.5 - 1 - 1.5 and 2% and results compared to control (standard feed only) and to 2% commercial MCP feed additive. 540 juvenile Far Eastern Catfish (*Silurus asotus*), a species widely farmed in Korea, were used for testing, in 6 groups x 3 replicates, for 8 weeks.

The magnesium phosphate at 1% showed to be as **effective in increasing fish growth** as MCP (calcium phosphate) at 2%, but higher doses of magnesium phosphate did not significantly increase growth. 1% feed addition of magnesium phosphate increased fish growth by 10-15%, despite the standard feed was considered not to be deficient in phosphorus. Results were similar for feed efficiency. The plasma phosphorus levels in the fish were highest in the 2% magnesium phosphate group.

The authors also assessed a number of **haematological and serological characteristics in the fish** after 8 weeks. Comparisons are given with data on fish phosphorus requirements for other species from other studies in literature.

"Optimal Incorporation Level of Dietary Alternative Phosphate (MgHPO4) and Requirement for Phosphorus in Juvenile Far Eastern Catfish (Silurus asotus)", Asian-Australas J Anim Sci. 2015 28(1):111-9. Open Access http://dx.doi.org/10.5713/ajas.14.0378

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Food waste

New EU food waste estimates

A new study estimates food waste in the EU-28, produced throughout the food production chain, at 88 million tonnes fresh matter for 2012 including both edible food and inedible parts associated with food. This is c. 173 kilograms of food waste per person.

The total amounts of food produced in EU for 2011 were around **865 kg / person / year,** this would mean that in total we are wasting 20% of the total food produced. The table below shows the food waste estimates per stage in the food chain, from this study: the largest share is households (53%), followed by food processing (19%), food service (12%), agricultural primary production (11%) and wholesale and retail (5%).

Estimates of food waste in EU-28 Member States in 2012

Sector	Food waste (million tonnes) with 95% CI*	Food waste (kg per person) with 95% CI*
Primary production	9.1 ± 1.5	18 ± 3
Processing	16.9± 12.7	33 ± 25
Wholesale and retail	4.6 ± 1.2	9 ± 2
Food service	10.5 ± 1.5	21 ± 3
Households	46.5 ±4.4	92 ± 9
Total food waste	**87.6 ± 13.7**	**173 ± 27**

**Confidence interval*

FUSIONS (*www.eu-fusions.org*) is an EU funded research project that tries to reduce food waste through social innovation including the development of a quantitative framework to monitor food waste flows.

The data for this food waste study was obtained from national waste statistics and findings from selected research studies. Estimates of food waste quantities were sought for 2013. However, in most cases such recent information was not available and most estimates were for 2012 or earlier. Therefore, the estimates produced are most closely aligned to 2012. In some cases newer information has been used as well. However, the data behind these figures comes from different sources, which use a variety of definitions for what is considered 'food waste'. In addition, different studies use different methods, which can affect the resultant estimates. Data which was judged to be not sufficiently robust or containing other uncertainties was available from some countries and this data was excluded from this study. However the data might be useful for other purposes.

The study shows that that there are **large quantities of food waste along the food chain in agricultural primary production, food processing, wholesale and retail, food service and households**. Although the final destination are not always clear, potentially the wasted food contains large amounts of nutrients that could be recycled as shown by the European phosphorus (P) flow analysis at the Member State level by Van Dijk et al. 2015 (see SCOPE n°*117*).

Phosphorus losses

Taking an extremely approximate and non-scientific "ball park" figure of an average 1.5mgP/g of food waste*, the food waste estimated by this study would contain around **130,000 tonnesP/year** (3.4 gP/person/day), that is of the order of 6% of EU net P imports (see Van Dijk et al. 2015 in SCOPE Newsletter n°*117*) . However, this represents P recycling potential but does not take into account the P losses in producing the crops for this food, so the actual P "footprint" of the food waste would be significantly higher.

The next step would be to use this new source of EU food waste data in nutrient flow analysis studies at the EU and national level. For effective nutrient management in the food chain not only the quantity, but also the nutrient concentration as well as the final destinations of food waste is important knowledge. ESPP tries to contribute to the need for data on nutrients to support stewardship, the results of the **DONUTSS workshop** can be found here: *http://www.phosphorusplatform.eu/DONUTSS*

Stenmarck Å, Jensen C, Quested T, Moates G. Estimates of European food waste levels. IVL Swedish Environmental Research Institute, Stockholm, Sweden, 2016.

http://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf

See also SCOPE Newsletter n°107: 0.4 MtN/y are estimated to be thrown away in food waste, resulting in 1.1 MtN/y emissions in producing this wasted food.

** Average EU food consumption is around 2.5 kg/person/day (source: http://www.nationalgeographic.com/what-the-world-eats/) which is similar to the figure given above of 865 kg food/person produced (not consumed) annually in the EU. Average EU P quantity in supplied food (1.4 gP/person/day, Van Dijk in SCOPE Newsletter 108), so P concentration of food is on average very approximately 1.8 mgP/g food. A different calculation estimated 1.5 mgP/g food in SCOPE Newsletter n°95. This lower figure of 1.5 gP/g food is taken as conservative and because food wastes may have lower nutrient levels (less protein) than in food on average.*

Food waste recycling to fish food

Global demand for aquaculture feed is expected to reach 71 million tonnes by 2020 (more than doubling since 2008). Use of food wastes to produce aquaculture feed can offer economic benefits, ensure performance feeds and maintain food safety / contaminant standards, by using appropriate food waste combinations, accompanying technologies and fish production systems.

Fish feed costs represent more than 50% of total aquaculture costs, and prices have increased considerably: +55% to + 250% for different soybean or grain feed materials from 2000 to 2009.

This review paper summarises results of experiments comparing different **food waste based fish feed materials** to commercial fish feeds for several species of freshwater fish cultivated in China, including grass carp *(Ctenopharyngodon idella)*, bighead carp *(Hypophthalmichtthys nobilis)* and mud carp *(Cirrhinus molitorella)*. Polyculture of different species with different feeding modes in the same pond enables optimisation of use of feed energy content. The use of pig manure to fertilise ponds and promote growth of phytoplankton, consumed by fish, is traditional in China.

Literature studies cited show that **wastes from food production or processing industries including poultry, soy sauce rice wine, beer and papaya** can be effectively incorporated into fish food pellets. This paper presents results on different feed pellets produced from Hong Kong hotel food wastes (including fruit and vegetable peels and discards, raw and cooked meat and fish, cereal wastes and bones) combined with fishmeal and corn starch. Results show that some fish species prefer plant protein to meat, and that the higher lipid levels in meat wastes hinders fish growth.

Food safety

Results also show that the highest levels of persistent toxic substances are in fish meal (mercury, DDT), but also PAH (poly aromatic hydrocarbons) in bone meal. Analysis indicated that levels found in the flesh of fish fed either food waste derived or commercial fish feed did not show any Life-Time Cancer Risk for consumers. Filter and bottom feeding fish tended to have higher levels of contaminants. The authors recommend to develop food waste based aquaculture feed products not containing fish meals.

Upgrading food waste to high performance fish foods

A range of **different technologies for improving aquaculture performance of recycled food waste based fish foods** are presented, summarising literature data:

- Use of **enzymes** such as bromelain (from pineapples), papain (from papaya), with effectiveness similar to the use of enzymes in livestock feed. These enzymes help hydrolyse feed proteins to smaller peptides, with higher digestibility for fish.
- **Addition (premix) of minerals and vitamins**. Studies have shown that not only are vitamins and minerals necessary for fish growth, but also their addition can improve protein digestibility.
- **Probiotics**, such as 2% live baker's yeast (*Saccharomyces cerevisiae*) which both releases amylase enzymes improving feed digestibility and also attach to fish intestine walls stimulating the immune system and reducing infections.
- "**Prebiotics**", for example inulin (oligosaccharide), mannan-oligosaccharides (glucomannoprotein complex derived from yeast cell walls), fructo-oligosaccharides, galacto-olgosaccharides
- Chinese **medicinal herbs, used to enhance fish immunity to infections**, e.g. anthraquinone extract from rhubarb (*Rheum rhabarbarum*), huanqi (*Astragalus radix*), goji (*Lycium barbarum*), *Radix scutellaria*, *Rhizoma copitidis*, *Herba andrographis*, *Radix sophorae flavescentis.*

The authors conclude that **food wastes and food production / processing wastes can be used to produce safe and effective aquaculture fish foods**, and that **enzymes, probiotics (baker's yeast) and medicinal herbs can be cost-effective** in improving the performance of such aquaculture feeds, both by enhancing feed digestibility for fish and by reducing fish infection risks without antibiotic use.

"Recycle food wastes into high quality fish feeds for safe and quality fish production", Environmental Pollution 2016 http://www.sciencedirect.com/science/article/pii/S0269749116305231

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Science and conferences

Phosphorus science special edition

The journal Science of the Total Environment has published a 163-page special, edited by Andrea Ulrich of the Swiss Federal Office for Agriculture (FOAG), with 16 articles looking at different aspects of phosphorus resources and management. Under the title "P supply in the 21st century", papers cover both primary phosphorus resources (phosphate rock and production costs), secondary resources (phosphorus recycling, legacy phosphorus in agricultural soils), with several papers specifically addressing phosphorus flows.

Andrea Ulrich, Swiss Federal Office for Agriculture (FOAG), in the editorial, argues that arguments about phosphate rock resource levels and possible scarcity are "historical artefacts" but that they can provide important **lessons for a transition towards a sustainability approach to phosphorus management and resource conservation**, taking into account environmental impacts, social and economic aspects. The different papers on primary and secondary phosphorus resources, contaminants, phosphorus recycling and on assessment of phosphorus flows at different levels show the importance of innovation, both in technology and in social aspects (data management, regulation …), and of a joined-up approach between industry, administrations and society.

Overall, the 16 papers show that **there is no one single solution to address the question of secure phosphorus supply, necessary for food security**. A continuing effort, involving both research and stakeholders is necessary to move forward towards sustainable phosphorus management.

Phosphorus price fluctuations

Michael Mew, CRU International, presents the links between phosphate rock production costs, world price variability and consequent expected volatility of world food prices. CRU are the leading phosphate industry consultants and organisers of the annual "Phosphates" industry conferences (see *http://www.crugroup.com/events/phosphates/*). Data from SRI and CRU shows that **world average phosphate mining operational costs fell by over 1/3 (in real value) from 1983 to 2013, whereas capital costs of opening new phosphate mines increased**.

However, the market effects of these price changes are not predictable because **2/3 of world phosphate rock production is government controlled**.

Phosphate prices on the world market are susceptible to **considerable price peaks**, as occurred in 1975 and 2008. Phosphate rock prices are linked to food prices, with peaks often exacerbated by other energy and resource price peaks. Phosphorus production cannot increase rapidly in response to demand, because of the long mine opening lead-in delay. On the other hand, price increases can lead Western farmers to strongly reduce P fertiliser application, using instead phosphorus accumulated in soils, and so accentuating price slumps after peaks.

The paper calculates that a doubling only of phosphate prices can result directly in a 3% increase in the price of bread, whereas the 2008 price peak was an 8 – 10 x price increase.

This paper concludes that **world phosphate rock reserves are unlikely to be overestimated**, and that industry's general position of low concern about resource scarcity is probably justified. New processes are likely to become operational which can use low grade phosphate rock, including previously stockpiled mine tailings. However, most of the world's resources are controlled by Morocco, which may drive phosphorus mining companies in other countries to **invest in the future in phosphorus recycling**.

Contaminants in fertilisers

Kratz, Schick and Schnug present results of analysis of **trace elements in 162 mineral and organo-mineral fertilisers** sold in Germany 2000 – 2014. 68 samples of phosphate rock and 2 samples of processed sewage sludge incineration ash were also tested. The authors state that "some PK and many straight P fertilisers" exceeded the German limit of 50 mg cadmium (per kg P_2O_5). In fact, the average cadmium levels in PK fertilisers were 51 and in triple superphosphates were 54 mgCd/kgP_2O_5, whereas they were considerably higher in the single super phosphates and in phosphate rock.

Phosphorus recycling

Metson et al. compare the **potential for phosphorus recycling** to P fertiliser needs in the USA. Using most recent available data (2002), they estimate potentially recyclable P (consumed food = human excreta, food wastes, animal manures) and P offtake in corn (P content of harvested grain + silage) for the 3 105 continental US counties. Human food intake is estimated at 1.3 gP/person/day. The authors conclude that in theory (without any system losses), **<40% of potentially recyclable phosphorus could cover national P demand for corn production** (P offtake). Nearly ¾ of this demand could be met from recycled P sources within the same county and that recycled P would have to travel around 300 km on average to fully replenish P offtake in the US "corn belt". These results have reached the media (*e.g. LINK* "New study finds recycled phosphorus could fertilize 100% of US corn") and present a proof of concept (as opposed to a detailed substance flow analysis or feasibility study as losses from the system are not considered) on the potentially important role that recycling could play in US agriculture.

Hukari, Hermann and Nättorp summarise **markets, technologies and regulatory challenges to phosphorus recycling from municipal wastewaters** in Europe, based on the P-REX project conclusions (SCOPE Newsletter n°*115*). Regulations impacting P recycling are summarised: REACH (chemical legislation), End-of-Waste, installation permitting (Industrial Emissions Directive), EU Fertiliser Regulation (currently under revision, see SCOPE n°*120*). Market segments for recycled phosphorus products are addressed, in particular possible use in organic farming.

Herzel et al. present results of a **sampling survey of ash from sewage sludge mono-incineration installations in Germany** and the thermochemical treatment (ASH DEC process) of sewage sludge incineration ash in a pilot scale test (see also SCOPE n°*115* and n°*109*). The sampling survey discovered that **the bioavailability of phosphorus in the sewage sludge ash is poor and that more than half of the ashes cannot be used directly as fertilizers due to high heavy metal content**. The pilot scale test (7m x 0.3m diameter kiln) of calcination at 950°C of sewage sludge incineration ash with sodium sulphate as additive and sewage sludge as reducing agent were carried out with the objective of making the phosphorus in ash more plant available and reducing heavy metal contaminant levels. **2 tonnes of recycled phosphate product was produced and tested in field trials in the project P-REX** (see SCOPE n°*115*).

Hupfauf et al. presented results of **8 week pot trials** using sorghum and amaranth and comparing different recycled nutrient products (cattle slurry, slurry digestate, energy crop digestate, with or without solid-liquid separation) to mineral fertilisers. Soil microbial respiration and metabolic quotient were in all cases higher with the digestates than with untreated slurry or mineral fertilisers. However, results also showed that impacts on soil microbes were different for the two crops (the high P uptake of amaranth can result in soil microbe stress) and were modified by solid-liquid separation, with the optimal digestate form and application being crop specific.

Krähenbühl, Etter and Udert showed that Nepal **magnesite**, a local mineral, could be used as a local magnesium source for P-recovery as struvite from separated urine, subject to grinding and calcination at 700°C for one hour.

Phosphorus flows

This special edition includes the **key study on phosphorus flows in Europe by Van Dijk**, already summarised in SCOPE Newsletter n° *117*, which gives the first and only comprehensive data to date for phosphorus flows at the EU and Member State levels.

Thitanuwat et al. estimate phosphorus flows through households and fate for **Bangkok** (not for any particular year). Input is based on resident and tourist population and estimated P through food consumption (estimated at 0.7 gP/person/day), food wastes, green yard wastes and domestic hygiene and cleaning products. A total of nearly 11 000 tonnes P/year input is estimated for 7.9 million population plus 0.8 million equivalent tourists (33.8 million tourists x 9 day average stay). At present, nearly 81% of this input phosphorus is lost to landfill, 14% to surface waters and 3% to composting.

Wu, Franzen and Malmström studied phosphorus flows for the city of **Stockholm** for 2013 (880 000 population) and proposed scenarios for 2030, covering human and pet food, personal care and cleaning products, textile and paper products. In 2013 total P input was around 800 tonnes P/year and only around 10% of input P was recycled. The highest sources of P input were 514 tP/y in food products, of which 76% were consumed (average diet P 1.2 gP/day, based on data from Malmö in Welch et al. 2009) and the remainder lost to food wastes, detergents 75 tP/y and pet foods 43 tP/y. For 2030, the most effective scenarios for improving phosphorus management were a full population change to a vegetarian diet (0.7 gP/person/day in diet, -20% reduction in total city P input) and phosphorus recycling of sewage sludge.

SCOPE Editor's note: **Welch et al. 2009** presents **diet estimates for intakes of five minerals** (Ca, P, Mg, Fe, K) from 36 034 subjects, aged 35 - 74 years, in 27 centres in 10 EU countries (Denmark, France, Germany, Greece, Italy, Norway, Spain, Sweden, The Netherlands, United Kingdom), obtained using 24-h dietary recall software (EPIC-SOFT). Average diet P intake for men ranged from around 1.5 gP/day (e.g. Germany, Sweden, UK) to over 2 gP/day (some centres in Spain, Greece, Norway) and similarly from around 1.2 to 1.5 gP/day for women. The main sources of P in diet were dairy products, cereals and meat products, together contributing c. 65 – 75% of total P intake.

"Variation in intakes of calcium, phosphorus, magnesium, iron and potassium in 10 countries in the European Prospective Investigation into Cancer and Nutrition study" AA Welch et al. European Journal of Clinical Nutrition (2009) 63, S101–S121
http://www.nature.com/ejcn/journal/v63/n4s/full/ejcn200977a.html

Viscarra Rossel and Bui produced a 90m resolution map model of **topsoil phosphorus stocks for Australia**, estimating at 200 – 4 000 million tonnes the total P in 30cm top soil across the continent. The objective is to provide a benchmark for impact of future changes in climate, land use or nutrient management.

Matsubae et al assess **phosphorus flows in global steel production**, estimating that c. 4% of world P flows are in steelmaking.

SCOPE Editor's note: to date, there is no indication that recovery of phosphorus from steel slags could be economically or ecologically feasible, given that it is strongly bound to iron and other contaminants.

Phosphorus in agriculture

Xie and Zhao present use of **magnesium-iron oxide nanoparticles** to reduce phosphorus release from poultry litter, claiming that the nanoparticles after phosphorus adsorption could be a slow-release fertiliser and that the nano-particles at low doses are innocuous to the environment. Plant availability of the nutrients is now being investigated.

Rodriguez et al. compared impacts on phosphorus availability of **no tillage** to conventional tillage agriculture in Brazilian tropical oxisols receiving long-term inputs of P fertiliser. No tillage resulted in nearly all cases in increased organic P cycling, improving crop P availability. However the majority of the total added (legacy) P was still strongly bound to iron or aluminium oxyhydroxides in the soil and much less plant available. These unutilised reserves of P need to better exploited to improve P use efficiency in Brazil and reduce reliance on large imports of expensive fertiliser.

Łukowiak et al. studied the impacts of **long-term crop rotation** (oilseed rape, maize) on soil phosphorus, showing that crop rotation is important for phosphorus management, and can improve soil P availability and so reduce the need for fertilisation.

Ulrich, Malley and Watts present **participatory Action Research into phosphorus management** in the Lake Winnipeg basin, Canada, an area of intensive agriculture and extreme surface water eutrophication. Actions included interviews and a questionnaire to a range of stakeholders including scientists, government, NGOs and farmers organisations, a first summary report and then collection of feedback on this report. The authors conclude the importance of mutual learning between stakeholders to build consensus accepted policies and confidence.

Science of the Total Environment (STE) special edition, Ed. Andrea Ulrich "Taking Stock: Phosphorus Supply from Natural and Anthropogenic Pools in the 21st Century", Science of the Total Environment 542 (2016) pages 1005–1168
http://www.sciencedirect.com/science/journal/00489697/542/supp/PB

Anaerobic digestion and the circular economy

European Biogas Association (EBA) Circular Economy workshop, 6th April 2016 in Brussels, discussed valorisation of digestates as fertilisers and proposals for Fertiliser Regulation (FR), waste legislation, REACH and Animal By-Product Regulation (ABPR).

The biogas sector uses a wide variety of input bio-materials including food waste, bio-waste, manure, sludge, forestry by-products and crop residues, producing digestate which can be a bio-fertiliser or further processed to additional fertiliser products.

Jan Stambasky, EBA president, opened the workshop. Biogas is a **growing industry** and a crucial sector for the bio-economy producing fertilisers, bio-based materials and renewable energy. Decentralized energy and fertiliser production can function as a **potential source of local income in rural areas**.

Erik Meers, University of Ghent and the Biorefine network (*www.biorefine.eu*), explained that anaerobic digestion and production of fertiliser from digestate can **address the nutrient disconnect resulting from both regional concentrations of livestock**, but also from the agronomic paradox that crop requirement and nutrient release from manure are not in line along the growing season, with the release of nutrients lagging behind. Digestate can be refined by the separation into solid and liquid fractions. The solid fraction can be treated by pyrolysis, drying or biothermic treatment to products like bio-oil, biochar and organic fertiliser. The liquid fraction can be treated by ammonia stripping, microbiological N removal, membrane filtration, evaporation and precipitation to products like ammonium sulfate, K-rich effluent, clean water, mineral concentrates, struvite and calcium phosphate.

Jonathan De Mey, the Biogas-E / DIGESMART project (*www.digesmart.eu*), presented the DIGESMART project: DIGEState from Manure Recycling Technologies. Solar energy could be used to enhance and improve drying of the solid fraction, both direct with an inclined roof dripping system or indirectly with electric energy from solar PV panels. The liquid fraction of separated digestate is the most difficult to valorise: nitrogen stripping reduces the N content and reduces transport distances (and so costs) for application in agriculture. Nitrogen stripping and absorption can reduce 80-90% of N in the digestate and reduce more than 88% of ammonia emissions. About **240 tonnes N/year can be recovered by a full scale stripping plant with a treatment capacity of 4,000-6,000 tonnes per year**. The end product (using HNO_3 for stripping) is a liquid ammonium nitrate solution (c. 52% solution = c. 18%N), which is almost free from odours, impurities, and is chemically stable making storage and transport easy. The product can be applied by fertigation or as a foliar fertiliser.

Detricon (*http://www.detricon.eu*) claims an energy footprint of about 34 MJ/kgN for this process, compared to 43 MJ/kgN for average conventional ammonia production in Europe. Challenges were discussed regarding regulation, registration, storage, transport, commercialization and distribution of the product. At present, it is difficult to establish a good value for the product because it is bio-sourced and **market demand still needs to adapt** to a different supply source.

Franz Kirchmeyr, vice president of EBA (*www.european-biogas.eu*), presented the potential of digestate and biogas within the Circular Economy Package (CEP). He suggested that if available bio-waste would be treated with anaerobic digestion (AD) it would bring Europe 4000 additional biogas plants each with a size of 500 kW that **could deliver 100,000 additional jobs**. At the same time an energy reduction of about 15 PJ could be achieved by N recovery. In that case there is a large fertiliser potential including:

- 400,000 tonnes N
- 52,800 tonnes P (= 120,000 tonnes P2O)
- 373,545 tonnes K (= 450,000 tonnes K2O)
- 3,000,000 tonnes carbon

Summer catch crops do absorb nitrogen, but can also create losses through rotting process during winter time. About 50-60% from nitrogen and carbon in summer catch crops will be lost during winter rotting. On the other hand, **digestate can be a good source of nutrients for agriculture but also improve soil properties**: reducing soil bulk density, increasing water holding capacity, organic matter content and microorganisms. The main nutrient concentration of digestate (n=2000) on the basis of dry matter is about 10% N, 4.2% K and 1.3% P.

The **digestate can be upgraded with separation, drying, pelletising, composting and liquid upgrading**. After digestate separation 65-75% of total N and 70-80% of total K is in the liquid fraction, and 55-65% of total P and 60-70% total C is in the solid fraction. The current market shares of separated digestate in Germany is 91% for agriculture, 4% for landscaping, 4% for hobby gardening, and 1% for market gardening/horticulture.

Piotr Barczak, European Environmental Bureau (EEB, *www.eeb.org*), facilitated a discussion in favour of **separate collection of biodegradable waste**. EEB lobbies for a mandatory separated collection of bio-waste within the circular economy package. In present regulation separation is only obligatory if it is practically possible. According to EEB separated bio collection has always a (technical) solution. Even in urban areas collection is possible and there are several examples of cities doing very well pre- and post-separation of bio-waste like in the city of **Milan**. EEB Association advocates for mandatory separated collection of bio-waste since there are clear benefits, also for better recycling of other non-bio material such as paper, plastic and glass.

The European Compost Network (ECN, *www.compostnetwork.info*), made clear they are **in favour of mandatory separated collection of bio-waste**, but with a transition time for specific regions and situation to adapt. A good alternative is home composting but best practice guidelines should be communicated.

Paolo Patruno, HEILIFE (*www.heilife.bio*), presented their **compostable bioplastic/biocomposite product development** with a focus on bio-based diapers. 25 billion diapers are used each year within the EU. HEILIFE wants to create a full bio-based and degradable material value cycle, with composting or AD via municipal bio-waste collection and centralized treatment as final end step by which resources are recycled. Biodegradable plastics from natural sources are used instead of plastics based on petrochemicals. Additionally, bio-based diapers enable recycling of the nutrients contained in babies' urine and excreta. The price of the HEILIFE bio-based diapers is at present 15% higher, but this does not take into account the lower waste disposal cost to local authorities.

Johanna Bernsel, European Commission DG Growth presented the **EU Fertilisers Regulation revision** made public on 17th March 2016, see SCOPE Newsletter n° *120*. The regulation proposal includes:

- Compliant products **cease being waste**
- Limit values for known **contaminants**
- An extension of the scope, notably to **organic fertilisers**
- A new **legislative framework** with generic safety and quality requirements, standards, and conformity assessment procedures
- **Optional harmonization**.

The **objectives of the new Fertilisers Regulation** are:

- Improved **marketing** conditions for sustainable fertilisers including levelling the playing field for primary & secondary raw materials, and the introduction of contaminant limit values
- Proportionate **requirements** including a main responsibility for the manufacturer, and keeping regulatory barrier as low as possible and as high as necessary
- A fertiliser with a **CE mark** can brought on the EU market irrespective of national fertiliser regulation
- No unnecessary market disruptions, **Member States** may allow other fertilisers on their markets without the CE marking.

Not yet covered, but being part of the discussion and could be implemented after adoption of the new regulation are, amongst others, processed manure and certain other animal by-products, struvite, ashes and biochar.

The link with the Animal By-Product Regulation is now internally discussed with the objective of defining a point in the manufacturing chain at which animal by-products are free from ABP-Regulation and are taken over by the new Fertiliser Regulation. The interlinkages with the Nitrates Directive for processed manure and REACH for digestate are both subject to internal discussions.

Dominique Dejonckheere, Copa-Cogeca (*www.copa-cogeca.be*), presented their vision on the role of biogas in strengthening European agriculture. Copa represents 23 million European farmers and family members, Cogeca represents 22,000 European agricultural cooperatives. Their mission is to ensure a viable, innovative and competitive EU agricultural and agri-food sector, capable of meeting growing food demand. In promoting the views of European farmers, they are committed in developing the bioenergy/bio-economy sector.

Biogas should be part of the bio-economy for alternative source of income at the farm level, better use of agricultural by-products, and better protection of the environment.

As potential barriers Copa-Cogeca mentioned that the negative general public's perception of bioenergy from biomass creates uncertain climate for investment. Additionally, they see biogas production only based on livestock manure as not efficient and realistic.

In relation to the revision of the EU Fertiliser Regulation and organic waste valorisation, COPA-COGECA advocate that:

- Farmers still predominately rely on **organic matter of agricultural origin**
- Exporting organic matter from **regions with a surplus** to those with a deficit must be facilitated
- Further **incentives and investments** to recycle nutrients in manure as a response to the increasing scarcity of phosphorus are necessary
- Problems with organic fertilisers are linked to **contaminants**, heavy metals and microbiological organisms
- Farmers need **high-quality fertilisers**, and safe and appropriate labelling
- The **cadmium level** below 60 mg/kg P2O5 puts pressure on fertiliser prices, which further strengthens Copa-Cogeca's proposal to cut import duties to zero
- End-of-waste criteria for **digestate** must provide a solid basis for their safe use
- **Soil quality and consumer confidence** must not be endangered in order to get rid of municipal waste
- **EU end-of-waste criteria** must not be less stringent than stricter criteria already in place at national level.

Discussion and conclusions

Concerning the **proposed EU Fertilisers Regulation**, participants made clear that "Digestate from bio-energy crops" is seen as strange category, and suggest a generic category for plant based digestates.

Sustainability in sourcing of recycled fertilisers is important, but is not taken into account as such in the present Fertiliser Regulation proposals: in the future sustainable labelling could fill this gap. See ISO 13065:2015 "Sustainability Criteria for Bioenergy" in SCOPE Newsletter n°*117*.

Participants underlined the **need for an exemption for digestates from registration under REACH** through (Annex V entry 12, see SCOPE Newsletter n°*101*) and possibility for digestates to no longer be subject to ABPR (Animal By-Products Regulation, c.f. EU Fertiliser Regulation revision above)

Within the **Waste Framework Directive**, EBA proposes:

- Clear classification of AD as recycling (R3) technique and R1 (energy recovery)
- End of Waste status for digestate (c.f. Fertiliser Regulation revision above)
- AD treated manure via digestion shall not be considered waste
- AD treated by-products shall not be considered waste
- Ban on landfilling and incineration of bio-waste
- Obligation for separate collection of municipal bio-wastes
- Possibility to obtain product status (under revised EU Fertiliser Regulation and Waste Framework Directive) for further products from digestate which are at the moment under development.

Participants discussed **difficulties with data for flows of organic carbon and nutrients** in anaerobic digestion in Europe, both for "integrated AD" (e.g. on-site digestion of sewage sludge in many municipal waste water treatment plants) and separately operated AD plants, taking either mixed or specific wastes and by-products.

Often, **flow data** does not clarify whether it is upstream or downstream of AD, which is often an intermediate treatment step, possibly resulting in double accounting and confusion of data. Clear data is important to support decision making both on policy and on commercial investment in AD plant and in digestate processing to fertilisers. See for more discussion about the need for better nutrient flow data quality the **DONUTSS** work of ESPP (*http://www.phosphorusplatform.eu/DONUTSS*).

An ESPP summary of the draft Fertiliser Regulation proposal can be found in SCOPE Newsletter 120: http://www.phosphorusplatform.eu/SCOPE120

Outcomes of this European Biogas Association workshop on the Circular Economy, 6th April 2016, Brussels can be found here: http://european-biogas.eu/wp-content/uploads/2016/04/EBA-Circular-Economy-Workshop-Report-.pdf *Information on further EBA workshops which are organised regularly:* peon@european-biogas.eu

Latest news from phosphorus research

At the 8th International Phosphorus Workshop (IPW8), Rostock, 12-16 September 2016, 230 scientists from around the world identified the most important results of current phosphorus research.

The workshop was titled "***Phosphorus 2020: Challenges for synthesis, agriculture, and ecosystems***" and discussed possible solutions arising from their latest research regarding the responsible use of this finite raw material.

The aim is to avoid serious damage to the environment, such as the eutrophication of water bodies, and to ensure that, through its sustainable use, there will be enough phosphorus to maintain the world's food supply in the future.

According to IPW8 participants, **the most important results of phosphorus research in recent years** include those related to the following aspects:

Phosphate fertilizers and inputs into water

The latest research continues to show that **large amounts of phosphorus still end up in water**. The binding water protection objectives set by various guidelines will therefore not be reached.

As an important reason, the researchers cited the persisting **inefficient use of phosphorus in intensive farming** and the inability of traditional **agricultural soil testing** of plant-available phosphorus to adequately assess the risk of phosphorus seepage.

In addition, it was demonstrated that established water protection measures (for example buffer strips, reduced fertilization) have yet to show success because of the **long delays** until the phosphorus is transported from the soil into water. It was also demonstrated that more **extreme precipitation events** due to climate change promote the mobilization and leaching of phosphorus.

Improved investigation methods

In recent years, the refinement of numerous analytical methods has allowed environmental monitoring of the presence of **a large number of phosphorus compounds**, for example, the weed-killer glyphosate, and their reaction products. Research methods already include the use of very sophisticated isotope and spectroscopic techniques, e.g. synchroton-based X-ray absorption, to carry out very detailed investigations of phosphorus compounds and their transformations.

Developing technology implementation

IPW8 discussed developing two areas where phosphorus chemistry research is leading to new technologies and businesses. Industrial phosphorus-based catalysts are a developing application area using new reaction pathways and connections for phosphorus chemistry, enabling energy or chemical efficiency improvement, or new processes, in a range of chemical synthesis and petro-chemical industries. In a different approach, a wide range of both mature and new technologies and pathways for phosphorus recovery and recycling were presented, including P-recovery from sewage sludge, slaughterhouse waste or biogas digestate as important targets, with recovered products ranging from fertilisers to high-grade technical phosphate chemicals.

Genetic research approaches

As our understanding of the genetic basis of phosphorus utilization by microorganisms, plants, and animals continually improves, new possibilities and processes related to phosphorus uptake, utilization, and dispersion are opening up. Examples are the **identification of gene variants** for the breeding of pigs such that they utilize the phosphorus in their feed more effectively, or **new feed supplements and feeding regimes** that increase the digestibility and utilization of P compounds by animals.

Important **research goals and call for action** identified by the IPW8 participants were:

Integrated system-based research

So far too little is known about the similarities and differences exhibited by phosphorus transformation processes in various environmental systems, such as in water or on land, and how they are **coupled with Earth's other biogeochemical cycles**, including those of carbon and nitrogen. In addition, there is little integrated research into the relationship between phosphorus reactions at different size scales, from individual cells to organisms to entire ecosystems. This is important because most ecosystems processes are coupled and can therefore be properly understood only through a holistic approach.

The translation of innovative methodologies into applications

Both in the area of phosphorus recovery as well as with respect to analytical methods for the detection of plant-available phosphorus in agricultural soils — both of which are important prerequisites for the efficient use of fertilizers — major scientific and technological progress has been made.

Yet so far widespread practical application of these technologies is lacking. Among the many different reasons are that either the **practical application stage has yet to reach maturity** or there are **legal obstacles**, such as those related to guidelines and regulations, that did not foresee the use of certain procedures. The problems partly lie in the unclear political conditions, such as revision of the Sewage Sludge Ordinance in Germany and European requirements for the recycling of manure. Here the IPW8 researchers recognize the need for action in research as well as in politics.

Encourage awareness and a constant rethinking of problems

A new perspective for the IPW was the inclusion of **ethical as well as legal- and political-environmental issues** affecting the use of phosphorus. Various aspects, such as the benefits of a **balanced diet** in the light of phosphorus availability and load or the ability to effectively control phosphorus use through **incentives or bans** were lively topics of discussion at the conference. It became clear that the biological and agricultural research approaches pursued almost exclusively thus far must now be complemented by **social science approaches** aimed at making the sustainable use and recovery of phosphorus, via its more environmentally mindful utilization, an accepted practice.

Need for integrated action

Conclusions: The participants agreed that only a wide range of individual measures implemented "in concert," such as advances in breeding methods, improved agricultural analyses and management measures, new techniques and technologies for the conservation and recovery of phosphorus, new societal norms, greater consumer awareness and complementary policy programs can solve the phosphorus problem. This joint strategy requires the development of new academic structures, such as the Leibniz ScienceCampus, that support the transfer of technologies, methodologies, and ideas.

The **International Phosphorus Workshop (IPW)**

The **International Phosphorus Workshop (IPW) takes place every three years** in different European countries and is one of the most important events in the field of phosphorus research in Europe. This year, for the first time, Germany was the host and was able to welcome a record number of participants. The workshop organizer was the Leibniz ScienceCampus Phosphorus Research Rostock, a consortium of five Leibniz institutes, and the University of Rostock.

Ulrich Bathmann, Inga Krämer & Peter Leinweber

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Prof. Dr. Peter Leinweber, University Spokesman for the Leibniz ScienceCampus Phosphorus Research Rostock

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IPW8 was coordinated by the Leibniz ScienceCampus Phosphorus Research Rostock, an interdisciplinary research network between five Leibniz Institutes and the University of Rostock addressing sustainable phosphorus management. The Leibniz ScienceCampus Phosphorus Research Rostock promotes interdisciplinarity between established fields of expertise in phosphorus, its different chemical compounds and reactions, and its specific modes of action in agricultural and environmental systems as well as in technical and industrial processes. The ScienceCampus is co-funded by the Leibniz Association and the Ministry of Agriculture, Environment, and Consumer Protection Mecklenburg-Vorpommern.

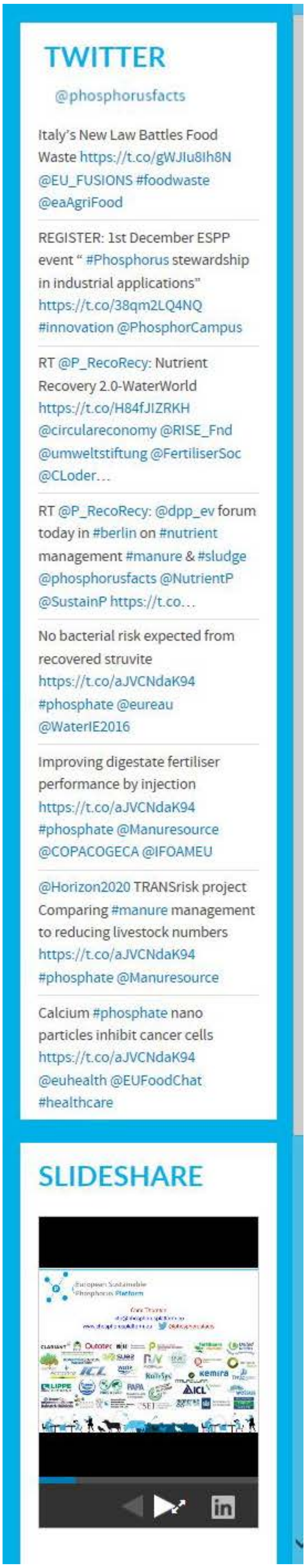
Nutrient Platforms

Europe: ***www.phosphorusplatform.eu***

Netherlands: ***www.nutrientplatform.org***

Germany: ***www.deutsche-phosphor-plattform.de***

North America Phosphorus Sustainability Alliance SPA ***https://sustainablep.asu.edu***



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