

European Sustainable Phosphorus Platform

Meetings

Phosphorus in the chemicals industry

Innovative industry uses of phosphorus, sustainable processes, recycling to chemicals sector applications

German Phosphorus Platform (DPP)

The DPP general assembly and annual conference FORUM 2016 took place in Berlin, 11th November.

1st Nordic Phosphorus Conference, Malmö

Conference on P management in Nordic countries. P Network announced by Nordic Council of Ministers.

ESPP workshop: p Pharmaceuticals in sewage biosolids

The evidence base on impacts of organic contaminants in sewage sludge used in agriculture

Biochar

Nutrient recycling via biochar

Based on two 2016 review papers, completed by experts' input, ESPP summarises factors relevant to biochars as a route for P-recycling.

Biochar questions

EU-COST and ANS Symposium: research is needed into different possible agri-environmental functions of biochars

Struvite fertiliser value and safety

Struvite field fertiliser tests and ecotoxicity

Report of testing of recovered struvite, Naskeo process, Castres sewage works, France

Testing antibiotic adsorption to struvite

In pure chemical solutions, tetracyclines show to adsorb to struvite, but the possible significance for real-life phosphorus recovery is not assessed

SCOPE NEWSLETTER

Marketing recovered nutrients

Marketing digestate and green fertilisers

How home gardening consumers choose fertilisers and soil improvers and opportunities for digestates

Agenda:

- 13-15 March 2017, Tampa, Florida, Phosphates 2017 http://www.crugroup.com/events/phosphates/
- Save the date 11 or 12 April, Paris, COMIFER / ESPP P recycling in agriculture (in French)
- 27 April 2017, Leeds, UK, Strippers and Scrubbers nitrogen recovery, recycling and removal http://www.aquaenviro.co.uk/events/conferences/
- 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
- 12 14 June 2017, Fort Lauderdale, Florida, WEF Nutrient Symposium http://www.wef.org/Nutrients/
- 21-23 June 2017, Belfast, Ireland, P from wastewater conference https://phosphorusie.wordpress.com/
- 3-5 July 2017, Paris, PBSi 2017 P, B & Si http://premc.org/conferences/pbsi-phosphorus-boron-silicon/
- 4-5 July, Manchester, UK, BIG Phosphorus conference http://www.aquaenviro.co.uk/events/conferences/
- 5-9 August, New York, IWA Resource Recovery conference www.irrc2017.org

Updated events listing online at http://www.phosphorusplatform.eu/events/upcoming-events



Phosphorus uses and stewardship

Phosphorus in the chemicals industry

A thematic meeting, following the ESPP annual General Assembly, looked at innovation in the phosphorus chemicals industry, covering new industry applications for phosphorus, phosphorusbased catalysts for green chemistry, sustainable processing routes and phosphorus recycling into high-grade chemical industry applications.



As part of the EU Raw Materials Week, some 60 participants from different industry sectors, R&D and policy makers, discovered innovative initiatives in industrial phosphorus use and discussed opportunities for cooperation and implementation.



Why we need to change

Janez Potočnik, Co-chair of the **UNEP International Resource** Panel previous EU and Environment Commissioner, and elected member of ESPP's Board earlier in the day, opened the meeting.



He reminded that "business as usual in the 20th century" is not conceivable in the 21st, as the **planet is** under pressure from growing population, climate resource change, accelerating consumption. Phosphorus is one of the factors for which planetary boundaries are reached (see Kahiluoto et al. summarised in SCOPE Newsletter $n^{\circ}103$).



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Four of the factors which are critical for planetary boundaries are related to the food system, for which phosphorus is critical.

UNEP has identified **food systems** as being central to the Sustainable Development Goals. Critical shifts are needed. Economic growth must be decoupled from resource consumption, and both from environmental impact. The Sustainable Development Goal

 n° 12 "Ensure sustainable consumption and production" patterns" makes the link with industry and technology. The circular economy is an essential response for this resource decoupling and can enable reduced climate and environmental impact, but also resilience and security by reducing dependence on primary resource supplies. ESPP's position is to make links between the food system, agriculture, phosphorus recycling and industry, so facilitating technology transfer and synergies.

A critical aspect is concentrations in the food chain (see figure distribution below). This concentration of power with food suppliers and supermarket chains poses governance challenges but offers opportunities for implementing change.



Source: Netherlands Environmental Assessment Agency http://www.pbl.nl/en/infographic/concentrations-within-the-dutch-food-chain

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The many industrial applications of phosphorus chemicals



Willem Schipper, phosphorus industry consultant and expert, presented the different industrial phosphorus, uses of and opportunities for recycling. The world consumes around 21 million tonnes of phosphorus (P) per year from phosphate rock, of which 95% goes to food production through fertilisers

or animal feed additives. Phosphorus is indispensable for food production, because it is essential for life and health.

Fertilisers are mostly produced from phosphate rock via phosphoric acid (MGA = merchant grade acid), which is a very widely traded international commodity. Some "technical" phosphates (animal feed and human food additives, polyphosphates) can also be produced via phosphoric acid, but many other industrial phosphorus chemicals can today only be produced via elemental phosphorus (white phosphorus = P_4). P₄ is produced in high-temperature reducing furnaces, and the EU no longer has such a furnace (following closure of Thermphos in 2012) and is dependent on imports, principally from Kazakhstan and Vietnam.

Elemental phosphorus P₄

P₄ is then reacted to phosphorus chlorides, oxides, sulphides or "thermal quality" phosphoric acid (extremely pure, for example for etching electronics component microchips). Industry applications using such P₄ derivatives include: lubricant additives, pharmaceuticals (both in the pharmaceutical molecule, and as intermediates in drug synthesis), agrochemicals, anti-scaling agents, detergents, flame retardants, matches and pyrotechnics, nickel plating, asphalt and plastic additives, catalysts, luminescent materials, metal extraction (most of the world's cobalt is produced using a phosphorus intermediate).

Today, some of the quantitatively more important applications are flame retardants (developing in particular to replace brominated flame retardants) and wildfire fighting chemicals, phosphonates used in industrial water treatment and reverse osmosis and glyphosate (the world's most widely sold herbicide).

An area of strong potential development is use of lithium or lithium-iron phosphates in batteries (electronics, electric vehicles) enabling lower fire risk than existing types of lithium-ion batteries.



Industrial P and recycling: making the link

Mr Schipper's analysis shows strong possible links between the agricultural/biological phosphorus cycle and phosphorus use in industrial applications. Firstly, there are possibilities to "up-cycle" phosphorus from bio-wastes to P_4 and so to high added-value, high purity industrial uses (see Alex Maurer, ICL, presentation below). Secondly, the very wide range of industrial phosphorus applications end up in five existing management routes, and phosphorus recovery should be addressed in each of these:

- Food additive and detergent applications -> municipal wastewater, where recycling is possible along with biological phosphorus
- Plastic additives and flame retardants -> plastics end-of-life routes can enable material recycling
- Surface treatment and speciality chemicals -> industrial side streams, where recovery is possible
- *Lubricant additives* -> existing lubricant collection and waste treatment routes
- *Agro-chemicals* -> the same environmental fate as fertiliser phosphorus

Challenges implementing recycling in industry



Carl Szöcs, Prayon, presented the company's initiatives towards phosphorus sustainability. Prayon is a world leader in phosphorus processing technologies and itself produces a range of phosphorus products, from fertilisers to purified chemicals. Nearly half the company's turnover is technical phosphorus chemicals, and one

quarter is food phosphates.

Prayon has assessed the feasibility of recycling in some 20 different projects over the last two years, mostly business-to-business (confidential with concerned customer) and covering food industry byproducts, biomass energy and other ashes and spent reagents (on average, 8 000 t/y of phosphoric acids recycled since 2000).

Challenges with implementing recycling within Prayon include: too low P contents of secondary materials, variability, logistics, and impurities.

Reliability of supply of secondary materials is essential because Prayon's production is highly integrated, and a problem or stoppage in one unit can affect the whole production system. Variability can also pose safety and environmental issues, e.g. organic contaminants. Finally, recycling must be economically viable, including taking into account any additional costs (e.g. increase in waste streams).

Prayon also notes that there are **regulatory and social obstacles to recycling**: unclear legislation over what is waste / by-products / End-of-Waste and public and food industry acceptance of use of recycled materials to produce food additives.



Innovative chemistries

Chris Slootweg, SUSPHOS, outlined twelve principles of circular chemistry (see presentation online) and presented some examples of how the SUSPHOS (EU Marie-Curie FP7) network is looking to implement these for phosphorus chemistry:

- Investigation of possible routes to avoid using chlorine (PCl₃) as an intermediate between P₄ and organophosphorus compounds needed for industrial applications
- Possible routes to recycle phosphorus containing by-products generated in vitamin A production (>2 000 t/y worldwide)
- New phosphinates and phosphonic acids as possible basis for safer flame retardants
- **Replacing phosphines** (hazardous industry intermediates) with safer borane protected phosphines
- New sources of phosphorus for industry from secondary raw materials, and appropriate new processing routes.

He concluded that there is a continuing **need for dialogue** between industry and research to develop innovation and sustainability in phosphorus chemicals processes and applications.

Steve van Zutphen, Magpie Polymers, explained how his company has developed around innovative applications of phosphorus derivatives as ligands for high value applications, such as precious metal capture, recovery and refining. The phosphorus derivatives used (phosphonates, phosphine oxide) can





be produced using P-H bond chemistry, without using chlorine. Refining and recovery applications include silver refining, recovery of palladium from surface treatment (plating) recovery rinse waters, of precious metals from mining waste waters. The ligands are cost effective and more selective than ion exchanger solutions, and

the phosphorus content reduces risk of explosion in harsh refinery conditions.



Maria Cristina Pasi, Italmatch Chemicals SpA, presented the LIFE TRIALKYL project, which aims to set up an innovative. sustainable and efficient industrial continuous process to obtain high quality Trialkyl Phosphites, used in pesticides, flame retardants,

plastics, childcare products and pharmaceuticals. The objectives are to avoid the generation of hazardous intermediaries and by-products, to avoid the use of dangerous chemicals for waste water treatment, to **reduce water consumption** and avoid waste water production compared to the current production process, to **reduce energy consumption** in the process by 20-30%, and to ensure complete recovery and recycling of solvents used in the process. The process will have the additional advantage of **reducing VOC emissions and health risks**, avoiding remaining VC (vinyl chloride) traces which are incompatible with some polymers, and enabling production of Trialkyl phosphites compatible with toys or food contact plastics. A pilot process is currently under testing.

Recovering phosphorus to industrial quality



Alex Maurer, ICL, presented the **RECOPHOS** process for which ICL has purchased the patent and is now developing. This process, which has been tested at pilot scale (see SCOPE Newsletter $n^{\circ}112$), enables production of elemental phosphorus P₄ from sewage sludge incineration ash, bone meal ash and phosphate rock.

Electrical inductive heating is used, so enabling smaller scale, more efficient and more flexible installations than current thermal P_4 furnaces.

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ICL's objective is to develop in coming years one or two full scale installations to recover P₄ from secondary raw materials to supply ICL's own needs of P₄ for chemicals production for applications such as ceramics, flame retardants, paints, metal surface treatment, toothpastes and pharmaceuticals.



Remondis. Andreas Rak. presented the company's TetraPhos® process, developed to be a clean process producing high-purity phosphoric acid for industry applications and clean by-products. A pilot plant is today operating. It takes as raw material sewage sludge

incineration ash from Hamburg sewage works, after removing metal pieces. The sewage works uses iron and aluminium salts for P-removal and the sludge is mono-incinerated with excess oxvgen. The TetraPhos® process generates phosphoric acid. gypsum (with low contaminant levels, can be used by industry) and a residual ash containing sand and heavy metals. The phosphoric acid is purified by ionexchange (extracting iron and aluminium salts (recycled to the sewage works as coagulants) and then by nano-filtration, followed by concentration, to produce a high quality industrial grade product.



Marco Michelotti, ProPHOS Chemicals. presented the PhoSave (Horizon2020) project, a full-scale industrial project to recycle phosphate from exhausted fire extinguisher powder. "ABC" fire extinguishers use mono ammonium phosphate and ammonium sulfate powder (A =combustible materials, B =

flammable liquids, C = flammable gas). These are both fertiliser compounds, but the powder is sprayed with silicone oils to ensure water repellence, making recycling difficult. Some 100 000 tonnes of fire extinguisher materials go to waste annually because ABC fire extinguishers must be renewed every 3-5 vears (depending on the European country).

The recycling process consists of sieving the initial waste to remove metal parts and plastic debris, homogenisation, extraction of the silicones. Different solutions are being tested for the silicone removal, including organic solvents, filtration, ultrasounds, and biological processes.



Heavy metal extraction is accomplished by using magnetic micro-aggregates, chelating agents and bioadsorbents, including olive stones. Finally this recovered raw material can be granulated to produce fertilisers or flame retardants for timber.

Assessing sustainability of phosphorus chemicals



Wolfgang Wanzke, Clariant, explained that the company's vision is to produce phosphorus chemicals from recycled phosphorus using renewable energy, as part of a circular economy.

At the same time, Clariant has implemented a Portfolio Value

Programme System to assess the sustainability of all of the company's products, covering the full life cycle of the products from raw material sourcing to production, application as well as end-of-life.

In 1995, the company phased out halogenated flame retardants from its portfolio, and started to develop new phosphorus-based flame retardants to respond to multiple needs to improve fire safety of engineering plastics and thermosets by using halogen free flame retardants.

Aluminium and zinc phosphinate derivatives (DEPAL, DEPZN) have proven effective, offering a positive health and environment profile, and synergy with other phosphorus, inorganic and nitrogen flame retardants to provide solutions for many different polymers used in electronics and other sectors.

Ammonium polyphosphate, mainly used in flame retardant coatings, and (after recently completing some data gaps) and DEPAL are both rated Benchmark 3 by the GreenScreen Safer Chemicals programme, that is best level a few flame retardants have achieved to date. Clariant is also actively looking at recyclability of plastics containing phosphorus flame retardants, the challenge being to develop polymer - flame retardant combinations which maintain their mechanical and fire safety characteristics after several reprocessing cycles.

EU innovation and implementation support



Tomas Turecki. European **Commission DG Research and Innovation**, noted that industry is active in innovation towards phosphorus sustainability. He noted that the Berlin workshop on P-recycling R&D (P-REX, EU Commission, ESPP), 2015, see SCOPE Newsletter *n*°*111*) showed that phosphorus-related projects emerge from wider

funding calls for R&D on water or eco-innovation.

This Berlin workshop called for **large nutrient** recovery demonstration projects, and two will be funded following the CIRC-2a-2016 call (selected projects will be known very soon). A further project addressing **livestock manure** is funded under CIRC-1a-2016.

Relevant calls in 2017 on raw materials include SC5-14b processing lower grade materials and CS5-15c mapping data. The **SME instrument** (which is funding the PhoSave project above) is also an important potential route.



Solon **EASME** Mias. (EU **Executive Agency for SMEs**) presented the Water topic under the Environment and Resource efficiency topic of the EU LIFE funding programme, underlining that the aim is true impact on environment through implementation and demonstration, not research. Innovation is promoted but it

does not have to be world-wide innovation but could be innovation within the specific geographic or sectorial context of the project. Pilot projects close to market are preferred, and these can be small projects with one beneficiary alone. The Water topic under the LIFE programme call is very wide in terms of areas covered.

The **2016 LIFE programme call** included nutrient management, and submissions are currently under evaluation.

In 2015, a number of projects concerning nutrient management in waste water treatment or agriculture were funded by LIFE:



- **DRAINUSE** re-utilisation of drainage solution from soilless culture in protected agriculture. *Link*.
- *LEMNA* duckweed technology for improving nutrient management and resource efficiency in pig production systems. *Link*.
- *Electro-Sludge* electro dewatering of sludge. *Link*.
- *Anadry* dry anaerobic digestion of sewage sludge. *Link*.
- *Siamec* Integrated anaerobic system for wastewater reclamation. *Link*.
- *In-Brief* anaerobic digestion to convert bio-waste and sewage sludge into energy and fertilisers. *Link*.
- *Sto3Re* anaerobic digestion and ozonisation in sewage works. *Link*.
- Smart Fertirrigation. Link.
- *SURE* sediment dredging to address coastal eutrophication, with nutrient reuse. *Link*.

Circularity and the phosphorus chemicals industry



Hartwig Wendt, CEFIC (European Chemistry Industry Council), indicated that circularity is a key to the future of the chemical industry in **Europe**, both to facilitate public acceptance chemicals of production and use, and for competitiveness. Europe still ensures around 12% of global chemicals production, however it

is envisaged that this share will further decrease over the years to come. **Innovation and resource efficiency, including enhanced cooperation right through the user and value-chain**, are therefore absolutely needed to keep a propelling future for Europe's chemical industry alive.

CEFIC has contributed to an assessment on how to implement circularity in practice in Europe's chemical industry. This identifies the **need for training and information at all levels of industry**, and looks at **how to enable technology development and deployment**, showing the importance of bottom-up innovation based on both chemistry science and practical industrial know-how (production, applications, market). This assessment includes examples of best practice from CEFIC member company products and sites.

Phosphorus is a positive example of circularity in the chemical industry. Phosphorus circularity and stewardship are strategically important, because phosphorus' vital use in agriculture, because of EU dependency on imported phosphorus raw materials (in different forms: phosphate rock, phosphoric acid, elemental P4) and because of environmental impacts of phosphorus losses.

Mr Wendt notes that a range of **phosphorus recycling technologies** are already operational and innovations are in the scale-up phase

EU Critical Raw Materials

The EU Critical Raw Materials list is currently being updated. Phosphate rock is currently one of the 20 materials included in this list, added in 2014 (see SCOPE Newsletter $n^{\circ}104$). This is important, because it is a driver and reference for EU and also Member States policies, such as Circular Economy, Fertilisers Regulation, R&D priorities, ... Participants noted that it would be more coherent to include phosphorus in any form (be it in manure, imported animal feeds, phosphoric acid ...) rather than "phosphate rock", but this does not seem to be possible in the conceptual model used by the European Commission. Phosphate rock is included in the model as an indicator of phosphorus resource consumption, because it focuses on the virgin input material.

Companies using **white phosphorus** (elemental P4) in Europe are dependent on imports (see above), but are not at present concerned about supply risk. However, image and life cycle analysis are of considerable concern, and problematic for marketing of phosphorus chemicals, because imported P4 has a very high energy footprint. Supply from production in Europe, from secondary raw materials, would offer benefits.

Participants underlined the need for **dialogue between** scientists, industry and stakeholders. ESPP (European Sustainable Phosphorus Platform) facilitates such dialogue for sustainability and policy questions, and it was noted the need to widen this to the agri-food system. Such dialogue is also valuable on the chemistry of phosphorus, to promote transfer of ideas between industry and science, and between different sectors of chemistry (different industrial sectors, water treatment, P-recycling, biochemistry, agriculture and soil ...). The SUSPHOS network which ensures such dialogue closes in 2017 (3-year EU project funding) and participants noted interest to find solutions to take this network further.



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Ludwig Hermann, the new President of ESPP, concluded the meeting by underlining that - as demonstrated by Janez Potočnik - circularity and resource efficiency are vital for the future both of industry and of humanity. Business as usual is not an option. Phosphorus can here be an example for other materials and other sectors, both because it is essential and non-substitutable in life and in food, and because of the wide range of industrial sectors in which it is important. including many innovations, new technologies and in sustainable chemistry (substitution of more hazardous chemicals). To take forward these objectives, ESPP will continue to bring together the different competences of fertilisers, waste water and phosphorus chemistry, to transfer ideas and find new solutions for sustainability.



Presentations from this ESPP conference on phosphorus stewardship in industrial applications are available online : Opening: Janez Potocnik - Co-chair of the UNEP International Resource Panel and previous EU Environment Commissioner Phosphorus: global resources perspective Willem Schipper – Willem Schipper Consulting Phosphorus in industry and society Carl Szöcs – Prayon Phosphorus recycling initiatives in a multi-sector P company Chris Slootweg - SUSPHOS network Circular phosphorus chemistry and knowledge transfer from one sector to another (chemistry, agriculture, industry) Steve van Zutphen - Magpie Polymers Metal Scavenging: using low-value phosphorus materials to make metal refining more sustainable Alexander Maurer - ICL Fertilizers The RECOPHOS-Process P4 from Sewage Sludge Ashes Andreas Rak and Martin Lebek - Remondis Clean technology for P-recycling to phosphoric acid: REMONDIS TetraPhos® Marco Michelotti and William Grandi - ProPHOS Chemicals Innovative solution for phosphate recovery from exhausted extinguishing powders (PhoSave Horizon2020 project) Wolfgang Wanzke – sustainability manager Clariant Sustainability in the Phosphorus Value Chain: P-based flame retardants and fire retarded plastics Maria Cristina Pasi - Italmatch Chemicals, Coordinator of the TRIALKYL LIFE project Reducing the impact of P chemistry Tomas Turecki – European Commission DG RTD Industry innovation and phosphorus sustainability in FP7 & H2020 Solon Mias - EU Executive Agency for Small and Medium-sized Enterprises (EASME) LIFE Environment Water

German Phosphorus Platform (DPP) Forum

German Phosphorus-Platform DPP has The gained a lot of awareness during 2016, especially due to the upcoming phosphorus recovery legislation in Germany and the platform's comments to this ordinance. The platform is active with close to 50 members and the general assembly held in Berlin was one of the frequent DPP meetings to meet all members and partners in person.



DPP's work plan for 2017 was discussed and agreed, with focus on national legislation, the advancement of the EU Fertilisers Regulation STRUBIAS working group (struvite, biochars, ashes), of which DPP is a member, and the development of criteria for recycled phosphates in organic farming; stating only the key activities from the upcoming work plan.

The general assembly was attended by almost 80% of the members – another success in bringing people together to discuss phosphorus management.

The GA was followed by DPP's national conference on 11.11.16, also in Berlin. More than 100 participants were informed about P recycling approaches in Germany and in surrounding European countries, opening chances to bring new ideas to the German market.

The FORUM was sponsored by EIT RawMaterials (https://eitrawmaterials.eu), the largest and strongest consortium in the raw materials sector worldwide with 100 partners from 20 EU countries, because they recognise phosphorus as a key element for the minerals circular economy.



The key note was given by **Dr. Hübner, CEO of** Eliquo water group, giving an insight view of an investor in nutrient management technologies.

The morning session was dedicated to the manure topic, with reports from Denmark, Flanders, Germany and the Netherlands on how to recover either phosphorus, nitrogen or both from animal manures and slurries. All speakers mentioned that a complete valorisation of manure is key to cost-effective nutrient management and to reducing transportation costs. However, to implement nutrient recovery strategies for agricultural residues needs more experience with large demonstration plants, where the financial credibility of successful pilot projects can be proven.

In the lunch break EIT and DPP offered world café tables for presenting their work dedicated to circular economy implementation.

The afternoon session of the conference presented examples of full-scale plants already operating phosphorus recovery as struvite and discussed how to achieve markets for the recovered nutrient products. A concept for centralising sewage sludge recycling by building a mono incineration plant and cost-sharing amongst shareholders was presented, followed by an overview of current German and European regulatory barriers and a short presentation of an ongoing research project where phosphorus is released by bacteria from sewage sludge ashes.

During panel discussions the participants raised questions about possible market prices of the gained recyclates and production costs – leading to the conclusions that with current legislation cost effective treatment technologies can already find their way into the market.

All presentations can be found on the DPPs website www.deutsche-phosphor-plattform.de



First Nordic Phosphorus Conference, Malmö

The Nordic Phosphorus Conference, organised by Swedish Norwegian Danish. and waste associations (DAKOFA, Avfall Norge, Avfall Sverige), Malmö, 27-28 October, brought together nearly 150 companies, policy makers and experts to discuss phosphorus management in the Nordic region. A Nordic Phosphorus Network was announced by the Nordic Council of Ministers and came together to discuss actions.

In cooperation with the Conference, ESPP organised an international workshop on organic contaminants in sewage biosolids (summary and conclusions in a separate article).



Michael Höysti, Secretariat of the Nordic Council of Ministers, opened the Conference by underling that the Nordic countries can and should take the lead in phosphorus sustainability in Europe, including addressing issues such as phosphorus efficiency in the use chain and changing dietary choices to reduce phosphorus demand.

Launch of Nordic Phosphorus Network

Mr Höysti indicated that, after discussions with concerned industries, stakeholders and the Nordic States' governments over recent months, the Nordic Council of Ministers has decided to launch a "Nordic Phosphorus Network". This will provide a platform for phosphorus recycling and reuse, valuechain cooperation, information exchange, and will identify challenges and define a Nordic phosphorus strategy.

A first meeting took place immediately after the Conference, bringing together representatives of Nordic countries' EPAs. This meeting began to define Network objectives and how the Network can contribute to international action on sustainable phosphorus.

First actions considered include collating phosphorus flow data from the Nordic Countries, information about Nordic States' policies and identifying and promoting success stories in nutrient recycling in the Nordic countries.





Helen-Ann Hamilton, Norwegian University of Science Technology and (NTNU), presented а **Phosphorus Substance Flow** Analysis (SFA) for the Nordic countries. This was an extension of her research at NTNU, where she focuses on phosphorus consumption in Norway with the

key objective of identifying value-chain hotspots of losses or recovery and recycling potential. A comparison with other Nordic countries shows that the phosphorus flows vary significantly between the different countries. Denmark shows high phosphorus imports in animal feed for pig production. Norway's phosphorus flows are dominated by aquaculture, with considerable phosphorus losses to the open sea.

Phosphorus losses from aquaculture

Today, the losses of phosphorus from Norwegian aquaculture (9 kt P/yr) are comparable to Norwegian fertilizer consumption (8.4 kt P/yr). These amounts are expected to increase very considerably, as Norwegian aquaculture is projected to grow 5 times by 2050 (compared to 2010 levels). Scenarios developed by Hamilton and colleagues estimate that, in 2050, environmental phosphorus losses from Norwegian aquaculture (45 kt P/yr) will be comparable to today's total mineral fertiliser consumption of all the Nordic countries (64 kt P/yr). Aquaculture phosphorus (excrements and feed losses) is lost to fjords. Eutrophication concerns in fjords are limited by the strong currents that quickly exchange nutrients with coastal waters. However, drastic increases in phosphorus emissions could result in P concentrations that exceed the fjord's flux capacities.

Regulatory pressure to reduce discharges from onshore smolt (young fish) farms is developing. Phosphorus recovery for recycling from offshore fish farms is not yet economically feasible but technologies are being tested at the lab scale, e.g. integrated multitrophic aquaculture production. However, the primary driver behind technological developments within aquaculture is concern about sea lice. Closed aquaculture systems could present a win-win solution for both phosphorus recycling and sea-lice containment, as well as temperature control. This will be a key challenge for the Nordic phosphorus situation in the future.

Other potential future challenges related to Nordic phosphorus flows include:

- Shifting **diets** (to include higher meat intake) which drives phosphorus consumption
- The **spatial distribution** of phosphorus: areas with high animal densities and so large phosphorus surpluses are often far removed from areas with phosphorus deficiencies where crop production occurs. Technologies to make manure transportable (i.e. low in weight and, thus, economical) are key to solving this problem.
- Large **dependency on imports**. The Nordic phosphorus flow data shows the high level of dependency on imports for all Nordic countries, highlighting their vulnerability to supply shocks.
- Secondary phosphorus quality. Secondary phosphorus has variable plant-availability. This is a barrier for phosphorus recycling, particularly for those products that are poorly plant unavailable, e.g. chemically precipitated sewage sludge. Phosphorus waste treatment technologies should be assessed on their ability to produce high quality secondary phosphorus products that provide replacements for mineral fertilizer.

There are other opportunities to develop phosphorus recycling in Norway, in particular transport of manure nutrients from the livestock concentrations of the South-West to the arable regions of the South-East.

Linda Bagge, Denmark EPA, presented the country's strategy on phosphorus in municipal wastes (solid waste / food waste, wastewater). The "Denmark without waste 2018" strategy adopted by the Government in 2013 targets 80% reuse of sewage phosphorus on farmland by 2018 (currently 60 - 70%of Denmark's sewage biosolids are spread on land). The strategy also targets 55% of household and 60% of service-sector food waste to go to biogas production (mixed with manure), compared to only around 35% at present.

Incentives and actions engaged include

- Pilot plant testing technology to recover phosphorus from sewage sludge incineration ash
- LCA (life cycle analysis) and socio-economic assessment of different P-recycling processes
- Recovery of phosphorus from "P-banks", that is separate landfills of sewage sludge incineration ash (Copenhagen region)
- Launch in 2015 of a **Denmark Platform** to support phosphorus recovery



European Sustainable Phosphorus Platform

Denmark Phosphorus recovery platform

The Denmark EPA platform's objectives are to identify value chains and stakeholders, regulatory barriers and technologies.

A first workshop took place on 11th November 2015 (report pending publication) and a second meeting is planned 16th November 2016.



Terje Farestveit, Norway EPA, indicated that Norway considers the most cost effective and sustainable route for phosphorus recycling from sewage to be the appropriate use of biosolids in agriculture. Following a first report on phosphorus recycling from sewage published by the

Norway EPA in May 2015 (SCOPE Newsletter n° 121), the EPA is now preparing a further report for 2017 which will establish a base for a national ambition level on phosphorus recycling and promoting demand for sewage biosolids in agriculture, options for P-recycling from fish farms. This will provide a basis for a Norwegian strategy for phosphorus removal in sewage works, for sewage sludge management and for phosphorus sustainability.

Although 98% of Norway's sewage sludge is today spread on land, only two thirds go to arable farmland, and the remaining third is used on parks and green areas. On one hand, farmers have little concerns about using sewage sludge. On the other hand, the EPA questions whether P in sewage sludge is really being **recycled** (crop availability when iron or aluminium are used for chemical phosphorus removal in wastewater treatment plants).

Crop availability of sewage sludge phosphorus

An informal Nordic workshop on plant availability of phosphorus in sewage biosolids took place in Oslo 24th of August 2016. It concluded that P-removal chemical (iron and especially aluminium) dosing in sewage works could be optimised, that phosphorus removal could be improved by partly replacing precipitation by biological phosphorous removal. It was also pointed out that introduction of microfiltration would improve phosphorous removal with less chemical consumption. The workshop also discussed how plant availability could be improved.

Sewage biosolids can also be processed to organic fertilisers, to facilitate transport and farmer uptake. The company Minorga Vekst in Stavanger (http://minorgavekst.no/) is successfully processing sewage biosolids to granulated organic fertiliser, currently exported to Vietnam, partly because of regulatory barriers to sale in Norway and Europe.



Anna Maria Sundin, Swedish EPA, presented the work on a national ordinance on sustainable phosphorus recycling proposed to Government by the EPA in 2013 (see SCOPE Newsletter n° 97). The objective was to promote reuse of phosphorus without causing harm to human health or

the environment. The 2013 proposal suggested an objective of 40% of sewage phosphorus recycled via crop application of sewage biosolids, with tighter sludge contaminant limits (TVs threshold values). This compares to the objective of 60% P-recycling proposed (for 2015) by Sweden EPA in 2002, and currently only around 30% of Sweden's sewage sludge going to agriculture. To date, however, there is no Sweden government response to the EPA 2013 proposals.



Mikko Rahtola. LUKE (Natural Resources Institute **Finland**) underlined regional differences in Finland, and resulting **need to transfer** nutrients livestock from intensive regions to arable

regions. Improving the quality of nutrient recycling is essential, in particular by upstream actions to improve the quality of by-products and by control of application on fields.

Finland's 'Country Brand' strategy of 2010 – 2011 fixes the objective that Finland become an international leader in nutrient recycling, with a Ministry of Agriculture objective of 25% of manure nutrients to be recycled by 2025.

The 2016-2018 national R&D funding programme allocates 12.4 million Euros for innovation in nutrient management (see Finland 'Clear Waters' conference, SCOPE Newsletter *n*° *121*).



UNEP global action on phosphorus

Achim Halpaap, United Nations Environment commenced with a forward looking message from Erik Solheim, Head of UN Environment stating that "We have the knowledge and technology to address the global phosphorous challenge. What we need is scaled-up political momentum, action, and capacity development. The 2030 Agenda creates an opportunity for all stakeholders to forge new partnerships and implement innovative and integrated solutions for effective nutrient management."

He stated that the Phosphorus topic relates to a number United Nations Sustainable Development Goals in particular (2) zero hunger, (3) health and well-being, (12) sustainable production and consumption economy and (14) land and water. Relevant UN Environment Action the Global Programme of Action for the Protection of the Marine Environment from Land Based Activities, through the Global Partnership on Nutrient Management (see SCOPE Newsletter n° 117). Depending on interest and commitment by stakeholders, further action could be considered, for example, under the Strategic Approach to International Chemicals Management SAICM), Global Chemicals Outlook II) and the International Resources Panel.

Mr Halpaap concluded that phosphorus management is complex, with a number of different aspects and drivers such as resource depletion, eutrophication, waste management and recycling, local circular economy, etc. Complete global data or analysis is missing and could be addressed through a global assessment of both the challenges and possible solutions, bringing together science and stakeholders, in order to inform governments and support considerations in international policy making.



Challenges and policies

Julie Hill. Green Alliance UK. gave an overview of policies needed to develop phosphorus recycling, identifying two main and market areas (supply instruments), in addition to information and value-chain coordination actions:

• Supply issues include ensuring reliable quality of recovered nutrient products, and ensuring reliable supply availability and production cost. Waste regulation, quality standards, labels and bespoke supply contracts can contribute to addressing these issues, and dialogue with users and upstream actors

(supermarkets, consumers) on quality and safety is essential.

• Market instruments could include blending mandates (obligation to include a % of recovered nutrients in fertilisers, pose policing problems), recycling credits, tax on primary resources (international trade obstacles), voluntary agreements (but these can fail to resist price variations which are significant for nutrients), CAP cross-compliance requirements and public sector procurement.

Julie Hill also stressed **the need to prevent food waste**, so as to reduce demand for phosphorous inputs, and to have land management strategies that consider the full range of environmental issues within a single strategy.



Arno Rosemarin, Stockholm Environment Institute, summarised and updated the geopolitical concentration of the world's phosphate rock reserves and the uncertainties in the data. Although China is today the world's biggest producer of

phosphate rock, Morocco is estimated to hold some 70% of world resources and reserves. A re-evaluation of data suggests that Finland (Yara) has significant reserves, but will nonetheless never supply more than 10 - 20% of Europe's needs – although this % could be significantly higher if Europe actively develops recycling.

Currently phosphorus fertiliser prices are continuing to drop, so not providing an incentive for recycling, and in disconnect to policy and geopolitical risks around reserves. Arno Rosemarin identifies the following as **key policy challenges**:

- EU farmer subsidies (c. 1 billion Euros per week) which develop a false sensation of food security,
- the absence of political lead on food prices and of a UN (UNEP) lead on phosphorus sustainability.

He reminds that fertilisers are massively globally traded, so that **any future crisis or price instability will affect most countries worldwide**, in particular Europe which is 90% dependent on imported phosphate and strongly dependent on imported food and animal feed.

He also raised the question of **cadmium in phosphate rock**, currently being discussed within the EU Fertilisers Regulation, pointing to studies and a recent *position* from Sweden Government, based on several recent scientific publications which suggest that



cadmium in the diet is related to osteoporosis. The Swedish Chemicals Agency *estimated* in 2013 that cadmium in food was causing health care costs related to bone fractures of around 400 million €year in Sweden.

Chris Thornton, European Sustainable Phosphorus Platform, explained that new solutions are today needed to enable nutrient recycling. In Europe, only 40% of sewage biosolids now go to crops, and increasing concentration of livestock production make processing and transport of manures necessary. A number of European and national policies are driving phosphorus recycling, including the inclusion of phosphate rock on the EU Critical Raw Materials List, and policies on fertilisers, food waste, agricultural environmental emissions (phosphorus losses to water, atmospheric ammonia emissions), Circular Economy objectives and standards for secondary raw materials ...

These developments open a range of **new business opportunities**. To illustrate, ESPP presented business success stories in nutrient recycling and nutrient management from the UK, Belgium, France, Switzerland, Bulgaria, The Netherlands, Sweden, Finland, in sectors such as sewage treatment, diary and pig production, chemical and fertilisers industry. Further success stories are presented at *www.phosphorusplatform.eu*



Margrethe Askegaard, SEGES Denmark, outlined the need of organic farming for recycled phosphorus and the challenges identified. Organic farming currently suffers from a lack of effective phosphorus inputs. Manure from extensive farms is increasingly not available, and in many countries manure or meat

and bone meal is not accepted in organic farming if it comes from intensive livestock production. Phosphate rock is authorised, but is not an effective fertiliser.

The use of recycled phosphorus products corresponds to organic farming sustainability objectives, but poses challenges of product quality in order to address consumer concerns about possible contaminants. She welcomes positively the recent EGTOP (EU organic farming committee) *opinion* that struvite and phosphate products recovered from sewage sludge incineration ash should be authorised in organic farming (subject to their integration into the EU Fertiliser Regulation revision).

Even in conventional farming, Denmark faces a need to process and transport manure nutrients, because livestock production is concentrated in Western Denmark, whereas the phosphorus balance in arable crop soils in Eastern Denmark is negative.



Jean-Benoît Bel. ACR+ of (Association Cities and Regions for **Recycling**) presented innovative actions and success stories in reducing food waste, in separative collection of household food waste, and in bio-waste valorisation. Today in Europe only c. 30% of household bio-waste is recovered, whereas some regions achieve much

higher collection rates (e.g. Province of Styria: 85%, Flanders 70 %).



The proposed EU municipal waste recycling targets (65-70%, Waste Framework Directive revision within Circular Economy package) will be difficult to reach without implementing a separate management of biowaste. He introduced the new H2020 project **DECISIVE** which will develop decentralised bio-waste management systems in urban centres.

Parallel sessions

Three parallel sessions included presentations on biogas production from organic wastes and byproducts (Lindum, Billund Biorefinery, Biogas **Oslofiord**). phosphorus recycling technologies (BGORJ, Ekobalans, Ecophos) and public policies for nutrient stewardship, recycling and reduction of contaminants in organic secondary materials (COWI, ESPP, Silvberg, Svenskt Vatten, JTI Sweden).

REVAQ: upstream action to improve sewage sludge quality

Anders Finnson, Svenskt Vatten (Swedish water & wastewater association), presented REVAQ Sweden. This is a voluntary sewage biosolids quality certification system, bringing together the water industry, farmers' organisations, the food industry and the food retailers' federation.



Around 50% of Sweden's sewage sludge is today REVAQ certified. The certification not only guarantees jointly-agreed contaminant limits, but importantly drives upstream action to reduce contaminants entering the sewage works which are susceptible to then be found in the sewage sludge. Traceability is important in REVAQ and central to ensuring farmer and food industry confidence. REVAQ ensures this through open-access GIS maps.

These **REVAQ** upstream actions target companies policy), households (education (connexion and information) and chemical policy (regulatory phase-out of problematic chemicals). These actions have enabled reductions in contaminant levels in sludge: -37% for cadmium since 2000 (2/3 of sewage works now achieve the 2025 objective of 7 mgCd/kgP₂O₅), -54% mercury (will continue to fall with the phase out of mercury use in dental fillings), -74% for silver, -54% for lead.

REVAQ acts with connected companies to not use identified contaminant chemicals, with reference to the Sweden EPA PRIO list of c. 2 500 chemicals. This is more effective and less expensive than trying to monitor these chemicals in company discharges

Presentation of REVAQ:

https://www.iea-biogas.net/case-studies.html?file=files/daten-redaktion/download/case-studies/REVAQ_CAse_study_A4_1.pdf



Conference conclusions and discussions

- Feasible phosphorus recycling technologies are today available.
- \geq These have a **cost**: this is only a low % of total wastewater treatment costs, but is higher than the market price of recovered P as fertiliser
- Real **incentives** are needed to move to implementation of phosphorus recycling, not only indicative national targets
- The EU Fertilisers Regulation revision will be a \geq step forward in fixing quality constraints for recycled nutrient products and opening a European market for recycling technologies, but it is regrettable that sewage sludge is excluded from the lists of input raw materials
- The use of appropriately treated sewage **biosolids to feed crops** is an optimal recycling route for nutrients, organic carbon, micronutrients, as well as being cost-effective for sewage works and so for the local taxpayer
- Conference participants expressed different opinions concerning the availability to crops of phosphorus in sewage biosolids where iron or aluminium has been used for chemical P-removal in sewage works. Further applied research appears to be needed on this question to ensure that phosphorus in sewage biosolids is effectively recycled to crops.
- Cooperation with users is essential to produce recycled nutrient products in forms in which farmers want them and will use them
- \succ Existing **biogas installations** in Nordic Countries have a high potential to treat separately collected household food waste
- Digestate processing and digestate quality \succ standards can facilitate marketing of digestate as a valuable nutrient product and organic carbon soil input for farmers

Future actions

Conference participants showed strong expectations of the **new Nordic Phosphorus Network**, announced by the Nordic Council of Ministers and launched at this conference (see above). The network should, it was suggested, enable sharing of experience and different perspectives between Nordic countries and different sectors (industry, farmers, NGOs, governments ...).

The panel discussion suggested the following followup actions from this first Nordic Phosphorus Conference:

- \geq Move forward on nutrient recycling from fish farming, where Norway has the potential to become world leader
- Collect and promote success stories of nutrient management and business opportunities in phosphorus recycling in Nordic countries
- Develop a common R&D platform
- Establish nutrient and phosphorus flow and data systems across the Nordic region
- Define shared indicators, measures of success for phosphorus stewardship
- ≻ Propose and test **innovative policies**, in particular to internalise externalities of nutrient losses
- \triangleright Define a specific Nordic countries' position on cadmium
- \triangleright Challenge questions of diet choice and of cheap food

First Nordic Phosphorus Conference 27-28 October 2016, Malmö, organised by Danish, Swedish and Norwegian waste associations (DAKOFA, Avfall Norge, Afvall Sverige). Speaker slides are available at https://dakofa.com/conference/conference/programme/ (click on the speaker's name in the programme)

ESPP workshop, Malmö, November 2016 Pharmaceuticals in sewage biosolids

Seventy scientists, regulators and water industry experts met at the workshop on organic contaminants and pharmaceuticals in sewage biosolids used on crops, organised in Malmö, Sweden, 27th November 2016, by the European Sustainable Phosphorus Platform (ESPP) and the Swedish Norwegian Danish. and waste associations (DAKOFA, Avfall Norge, Afvall Sverige).



All speakers' slides are available on the ESPP website www.phosphorusplatform.eu/downloads and on the Nordic Phosphorus Conference website https://dakofa.com/conference/conference/



The conference was opened by Finnson. Anders **Svenskt** Vatten water (Swedish & wastewater association). He explained that the water industry's mission is to ensure health, safety and environmental quality in the two cycles, water cycle (sewage works purified discharge water,

returning to the aquatic environment) and the sludge cycle (sewage biosolids containing nutrients and organic material used on farmland) and presented the **REVAQ sludge quality certification** scheme (see above).



Chris Thornton. ESPP. workshop moderator, outlined the meeting objectives. Currently, around 40% of Europe's sewage biosolids are spread to fields, so returning to farmland some 115 000 tonnes P/year.

This provides low-cost nutrients for farmers, or an income when

sludge sale price is negative. In addition to phosphorus, nitrogen organic carbon and trace elements are also returned to farmland.



However, the continuing use of sewage biosolids on farmland faces questions from consumers, from the food industry and retailers, and from regulators, because of concerns about contaminants and their possible uptake by crops.

Workshop objectives

ESPP proposed as workshop objectives to bring together information on the status of data, science and current research, and to discuss possible joint actions or input to R&D policies.

Heavy metal contaminants in sewage biosolids are identified, well understood, relatively easy to monitor, and can (for most them) be successfully reduced at source (see REVAQ below). Pathogens can be addressed by specific sanitisation processes, and are significantly reduced in composting or anaerobic digestion operated under appropriate conditions. Organic contaminants are much more difficult to address. Problematic consumer chemicals can be addressed by phase-out or use limitations, through REACH, the EU Chemical Regulation or through voluntary industry action (perfluoroalkyl substances (e.g. PFOS), polychlorinated naphthalenes and polydimethylsiloxanes were identified as priorities by Clarke & Smith 2012). Pharmaceuticals, however, are much more difficult to reduce at source.

Status of knowledge on pharmaceuticals in biosolids



Andrii Butkovskyi, Wageningen University, The Netherlands, summarised his group's work on pharmaceuticals and organic consumer chemicals fate in source separated sanitation These systems. systems are shown to not really separate pharmaceuticals: (analgesics and anti-

inflammatories, such as paracetomol, are also found in "grey water", that is non toilet, kitchen and bath water) and household products (triclosan, galaxolide) are found in toilet wastewater.

Information is lacking concerning sorption of different pharmaceuticals to biosolids in sewage. Only a minority of pharmaceuticals tend to be significantly transferred to sludge in anaerobic (UASB) sewage treatment (many remain mostly dissolved in discharge water), but personal care and household products are largely found in biosolids.

Biological sewage treatment systems, which are designed for BOD (available organic carbon) removal are not optimal for removing pharmaceuticals and household chemical biocides. On the other hand, composting shows to be effective in achieving >90% reduction for some organic household chemical biocides (e.g. triclosan triclorocarban).



Damià Barceló Cullerés, ICRA Catalan Institute for Water **Research** / CSIC Spain, presented conclusions of 2 years of monitoring of over 200 chemicals in 15 sewage works in Concentrations Spain. of contaminants from small industries were observed to have decreased.

However, a range of consumer organic chemicals, pesticides (in particular from urban use) and pharmaceutical substances (including illicit drugs, with increased levels at weekends), as well as their metabolites, are found.

Partitioning of these compounds between water and sludge has been studied. A number of pesticides are identified as adsorbing to sludge (e.g. chlorpyriphos). As above, the perfluorinated chemical PFOS (released from Teflon coatings) is identified as a problem, being found in both the water and sludge fractions. PFOS is considered an endocrine disruptor and is now on the Water Framework Directive "priority substances" list, requiring monitoring.

Prof Barceló noted that Arizona State University, USA, manages the NSSR (National Sewage Sludge Repository) and the Human Health Observatory (HHO), two archives and shared resources including sewage sludge and biosolids from over 200 cities in the U.S. and around the world, accompanied by meta data on contaminant concentrations and wastewater treatment plant information. Collaborative use of these resources is invited. He also noted that Halden 2015, a meta-analysis of 143 000 publications on emerging concern in contaminants of the environment (in general, not in sewage in particular), showed regulation of identified pollutants to be slow, with 14 years passing on average before action is taken. International sharing of knowledge and data on organic contaminants in sewage biosolids could help forward understanding and speed up the process of improving the safety and value of biosolids.

Natural robustness of soil





Jakob Magid, University of **Copenhagen**, presented data on heavy metals, soil biology, antibiotic resistance, pathogens, genetic contamination and nutrients. resulting from 'accelerated' application of sewage biosolids, manure and urban waste compost on the **CRUCIAL** farm test site near **Copenhagen**. The project has

been running since 2003 with application at both normal as well as artificially high levels, the latter today equivalent to 130-210 years normal application. Results show a doubling of soil carbon, and a improvement soil concomitant of physical properties (e.g. increase in water retention and decrease in bulk density).

Soil concentrations of copper and zinc increase, and the higher zinc can increase the crop value (micronutrient) but accumulation in soil must be limited.

The results show that **soil microbial activity increases** in proportion to applications, but that soil bacterial functions and soil bacterial diversity are not impacted.

Antibiotic resistance of soil bacteria (pseudomonads) results from application of these materials, but this is largely reduced after 3 weeks and is no longer detectable after 6 weeks. Dr Magid concludes that the soil bacterial system is highly resilient and that organic contaminants in sewage sludge or other organic material, as applied, do not seem to pose problems.

The CRUCIAL study sites offer potential for specific study of impacts of pharmaceuticals and organic contaminants, and collaboration with interested research groups is invited.



Hannah Rigby, Imperial presented College London work with the UK Food Standards the Agency on potential for transfer and uptake of organic contaminants to food from the use of biosolids and other recycled wastes as nutrient sources in agriculture. The UK Food Standards Agency is

supportive of use of sewage biosolids and other recycled wastes in agriculture, but wants an evidence base to demonstrate the safety of this practice.

She presented 'worst case scenario' testing where dairy cows were fed, under controlled experimental conditions, sewage biosolids, compost-like-output (the organic fraction from mechanical biological treatment of MSW = municipal solid waste), meat and bone meal ash, poultry litter ash and paper sludge ash, mixed into their feed (at up to 5% dry matter). Crop trials were also conducted. A range of priority organic contaminants were tested in the wastes and in the milk and crops. Preliminary results showed a significant increase in milk of dioxins (PCDD/F) compared to control cows for sewage biosolids fed to cattle at 5% dry matter intake to simulate ingestion of contaminated foliage by cattle. This is an unrealistic 'worst case' in that use of such materials on grassland should normally avoid risk of direct ingestion of biosolids by cattle, and even in this case, the dioxin levels in milk remained below one third of EU limits. Tests on arable fields showed no detectable uptake of ortho PCBs, ortho PBBs, PBDEs or PAHs into grain.

This work concludes that there is a minimal risk to the food chain from agriculture use of these secondary nutrients materials, but work is ongoing to complete chemical analysis of milk and crop samples for the range of priority organic contaminants found in the waste materials.

Does sludge treatment remove pharmaceuticals?



Anita Rye Ottosen, Rambøll engineering Denmark. presented data on the fate of pharmaceuticals and personal care chemicals in composting of biosolids. Studies have been by carried out Aarhus University with two Denmark composting companies (KomTek

Miljø And Odense Nord Miljøcenter) and Rambøll, in outdoor "mile" composting systems, as widely used in Denmark. This followed a literature study in 2009 which suggested that data was insufficient on fate of organic contaminants in composting.

Studies in real composting (of a mixture of sewage biosolids, garden green waste and straw) looked at 20 organic contaminants, showing variable levels of degradation of household chemicals such as triclosan, musks, DEHP plasticiser, anti-inflammatory drugs (30 - 50% degradation), antibiotics (>85%) but zero degradation of female sex hormones. The degradation took place principally in the first few days of composting.



Conclusions are that organic contaminants are (mostly) significantly reduced in composting, but that further work is needed to identify which substances are degraded and under what conditions.



Jörgen Magnér, IVL Sweden, presented studies of the fate of pharmaceuticals different in sewage sludge hygienisation processes and in soils. Degradation of pharmaceuticals in anaerobic digestion (38°C, 55°C), pasteurisation, advanced oxidation (AOP). ammonia treatment and thermal hydrolysis was tested using sewage sludge

spiked with 13 different pharmaceuticals (at $1 \mu g/kg$). Although results were complex, the highest level of degradation was mostly noted in anaerobic digestion. Female hormones were however not degraded except with thermal hydrolysis. In further tests hydrothermal carbonisation showed to reduce total pharmaceuticals levels to around one third at 200°C/2h or to one tenth at 220°C/4h.

Dr Magnér also presented tests using lysimeters at Petersborg Farm, Skåne. Of 23 pharmaceuticals analysed, 15 were detected in sewage sludge, but **only** 4 were detected in soil after 35 years of sludge application and only one (caffeine) in water coming out of the bottom of the lysimeter. Acidic pharmaceuticals seem to move through soil more than others.

Conclusions are that sewage sludge application to farmland insignificant is an source of pharmaceuticals to the environment compared to works discharge sewage water. and that pharmaceuticals in sewage sludge are mostly retained in the surface soil and biodegraded there.

Kai Bester, Aarhus University, Denmark, summarised studies of pharmaceuticals in sewage sludge from four different Danish sewage works (wwtps) and fate in different sludge treatment suggest processes. Results that transfer of pharmaceuticals to sewage sludge can be estimated by the substance's partition coefficient (if $>10^4$, then 90%) will go to sludge rather than being discharged in water), but that degradation is very difficult to predict. Some pharmaceuticals were not degraded in any of the four wwtps studied, others were degraded rapidly in some of the wwtps but not in others. No relation to biosolids properties or sludge retention time could be identified.

Further studies show that ozonation removes some, but not all pharmaceuticals, but with a high energy cost.

Composting different degradation shows pharmaceutical performance for different substances, with significant differences according to composting temperature. Biofilm reactors (fixed sand or moving bed, both anaerobic and aerobic) are effective in degrading a range of pharmaceuticals (21 out of 26 tested pharmaceuticals degraded >20% after 20 hours residence time), including recalcitrant molecules such as beta-blockers and X-ray contrast media. Further work is needed to reduced residence time and optimise the biological conditions.

Dr. Bester concludes that activated sludge degrades some pharmaceuticals, and that this can be today partly predicted for different substances. Different sludge treatments, on the other hand, have varying impacts on pharmaceutical degradation, information is lacking and degradation of different substances in different sludge treatment systems is not predictable.

sludge post-treatments Overall, can remove significant amounts of pharmaceuticals, but cannot guarantee removal of all pharmaceuticals, and further work is needed into the identity and levels of metabolites generated in these degradation processes.



Marilyne Soubrand and Magali Casellas, Limoges University **France**, indicated that **60%** of pharmaceutical substances tested entering sewage works are detected in sludges and confirmed that today there is little data available on pharmaceutical removal in sludge treatment, particularly because this is very variable for different sludge treatment and different processes pharmaceutical molecules.

They presented data from the SIPIBEL project, studying the fate of pharmaceuticals in the Bellecombe (Haute Savoie.

France) sewage works (activated sludge process) which treats a mixture of hospital and municipal wastewater, with sewage sludge treated by either liming or mesophilic (c. 37°C) anaerobic digestion.



Lachassagne et al. 2015 presents data from this site for 11 pharmaceuticals, showing that the **pharmaceuticals** were generally removed in anaerobic digestion, but not in liming, but possible degradation metabolites were not assessed. For some of the pharmaceuticals, sludge treatment modifies the solid/liquid partitioning.

They further presented studies of pharmaceutical behaviour in soils. Soil column tests, with application of sewage biosolids, showed very low or non detectable concentrations of pharmaceuticals in leachate water coming out of the bottom of the soil columns. Tests showed that did not show toxicity of this leachate.

These studies are part of ongoing work in France to better understand the behaviour and possible significance of organic contaminants in sewage sludges, including the ESCo MAFOR report (see SCOPE Newsletter 109) and the IMOPOLDYN project (funded by ADEME France - interactions micro-pollutants / organic matrices in fertiliser materials of waste origin: influence on the dynamics of micro-pollutants during land-spreading. Results suggest that pharmaceuticals behaviour is not related to the 'composition' of sludge (e.g. lipid content) but to interactions between molecular properties (in particular, different functional chemical such hydroxides, metal groups. as ions. cationic/anionic groups) of the pharmaceutical molecule and of sewage sludge flocs.

New treatment options, such as sludge pre-treatment upstream of anaerobic digestion (e.g. by ozonation) can both reduce pharmaceuticals and increase biogas production.



Poster presentations

Marissa de Boer, SUSPHOS, presented studies of uptake of pharmaceuticals (spiked into to different recycled urine) fertiliser products, which were then used to grow tomatoes. The lowest pharmaceutical uptake was in struvite. Uptake to tomatoes was very low: 750 kg dry weight tomatoes would have

to be consumed daily to reach the ADI limit (1% of the therapeutic dose, in the worst case).



Meritxell Catalan Gros, Institute for Water Research. presented the occurrence of 40 multiple-class antibiotics and veterinary pharmaceuticals in field trials, fertilized with dairy cattle manure and pig slurry at a rate of 170 kg N/ha per year.

Soil sampling was performed prior to fertilization and two and seven months after fertilization, at soil depths up to 120 cm. In cattle manure amended fields only three substances were detected at low µg/kg levels, while in pig slurry amended fields up to eight pharmaceuticals were identified at concentrations from ten to hundred µg/kg.

Most of the pharmaceuticals detected were identified at all soil depths, indicating the liability of these substances to leach to groundwater bodies and deteriorate the quality of aquifers.



Håkan Jönsson. Swedish Agricultural University, Uppsala (SLU), presented the collaborative work group "Upstream work for sustainable recycling" started by VA-kluster Mälardalen. This is an open work group on upstream knowledge synthesis and research projects to address

pharmaceuticals and consumer chemicals inputs to sewage, biosolids, soil and crops. Possible questions include modifying prescription/prescription free drug choices, actions in health institutions, treatment by enzymes in sewage, impacts of composting and digestion.



Trine Eggen, Norwegian Scientific Committee for Food Safety (VKM) Panel on Animal Feed, presented risk а assessment of contaminants in sewage sludge applied on Norwegian soils in 2009 using a tier-approach for prioritising pharmaceuticals. Her poster identifies 12 areas where

knowledge necessary to support such risk assessments is currently lacking.

She suggests that **antimicrobial resistance** should be an issue in future risk evaluations of sewage sludge. http://www.vkm.no/dav/2ae7f1b4e3.pdf



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Zulin Zhang, James Hutton Institute, Scotland, presented results of a field trial where municipal sewage sludge, manure (mainly cattle) and compost (food wastes) and then soil analysed for a number of organic contaminants (industrial chemicals, combustion pollutants) and for ARGs

(antibiotic resistant genes). Concentrations of the organic contaminants (e.g. DEHP) were higher in sludge > compost > manure and resulted in correspondingly higher levels in soils. Multiple applications of organic fertilizers resulted in higher ARGs in comparison to inorganic fertilizer although ARG (antibiotic resistant genes) abundance in soil showed to decrease over time.

Workshop conclusions

- **Incineration** of sewage sludge can be an appropriate solution depending on local conditions (e.g. contaminated sludge, lack of agricultural space for spreading ...) but is **lower down the recycling hierarchy** (energy "recovery" not recycling). Even if phosphorus is recovered from ash (to produce fertiliser or for industry applications), organic carbon, nitrogen, potassium, sulphur and micronutrients are lost.
- Concerns about sludge contaminants must be taken seriously and addressed both by developing data and information to support risk assessments, and by taking **upstream actions** wherever possible to reduce contamination of sewage sludge. For industrial chemicals and consumer chemicals, this is possible by actions targeting users and households (reduce discharge to sewers), but for pharmaceuticals it is much more difficult.
- Public exposure risk to organic contaminants via sewage sludge should be put into context of exposure from other routes (both the same and other organic contaminants via direct contact and in household dust, air, water). However, this does not absolve the need to address sewage sludge use in agriculture in order to inform farmers, the food industry, consumers and decision makers.
- Veterinary pharmaceuticals and hormones are also present at significant levels in **manures**, and this should also be addressed, both by reductions at source where possible, and by monitoring and treatment where manure nutrients are recycled.

- There still a **need for more data** regarding fate of organic contaminants, including pharmaceuticals in sewage sludge. There is more data on heavy metals, and more data on organic contaminants in water (sewage works discharge, rivers, drinking water) than in biosolids. The question is multi-faceted: contaminants in biosolids, fate in sewage treatment and in sludge treatment processes, in soils, in crops, both short and medium term presence and impacts.
- Pharmaceuticals and other organic chemicals in sewage sludge are varied and complex, and cannot be considered as a single issue. Of the wide number of molecules, new pharmaceuticals and chemicals, breakdown products, which to monitor? Further data and understanding is needed to try to identify different families of substances which have similar behaviour, but without over-simplifying.
- **Pharmaceuticals and hormones** are important challenges, because of the inherent obstacles to upstream reductions, both in sewage sludge and in animal manures.
- More immediately however, **industrial and household chemicals** require monitoring and action, in particular:

- PFOS (perfluorooctane sulfonate) and other perfluorinated chemicals, e.g. from Teflon - triclosan and triclocarban

- brominated flame retardants and substitute chemicals

- dioxins
- PAH (poly aromatic hydrocarbons).
- **Composting** is generally effective for removing many, but not all pharmaceuticals. Female hormones however are largely not degraded.
- Removal of organic contaminants in sewage treatment systems is very variable and difficult to predict, depending on contaminant molecule chemistry, sludge properties, dewatering and treatment conditions.
- Anaerobic digestion can break down some pharmaceuticals, but further work is needed to better understand how to improve this, including looking at sludge disintegration upstream of digesters (e.g. Cambi, Haarslev, Biothely). Further work is needed on degradation metabolites to verify if these pose issues.
- There is potential to develop **new sludge treatment process chains** in order to improve



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- Female **hormones** are often not degraded in sludge treatment, but this may be not of environmental or health significance. Manures either spread or going directly to soils from animals in the field often contains significant levels of such hormones.
- Antibiotic resistance is a globally important health issue, and should be better studied for sewage biosolids application. Knowledge shows that soils can naturally adapt, because soil organisms naturally release antibiotics, so that antibiotic resistance appearing after sludge application seems to be only temporary.
- Several studies confirm that **movement of organic contaminants to groundwater** is very low from sewage sludge land application. This is unsurprising, as the contaminants found in sludges are those which tend to partition to solids, and not to water.
- Data is needed to develop **robust risk assessments** of agricultural use of sewage biosolids, and also of manures, taking into account fate of and possible impacts of pharmaceuticals in sewage treatment processes, sludge treatment, in soil and possibly in crops and for grazing livestock. This cannot be feasibly done for the large number of pharmaceutical molecules and other organic contaminants, so screening is needed to identify priority substances.

Research needs and knowledge gaps

The Norwegian Food Safety Authority indicated that the 2009 VKM food safety report (Eriksen et al. 2009) assessed heavy metals and organic contaminants pharmaceuticals in sewage sludge used on farmland, concluding that use was safe if guidelines are respected. A risk assessment was also carried out for antibacterial-resistant bacteria and resistance genes in soil following application of sludge by evaluating the likeliness of development of resistance based on the drug residues in the STP water, in the dry sludge and in soil. A mandate has recently been made by the Norwegian Food Safety Authority to engage update of this report, including the issue of antibiotic resistance.

The **Swedish EPA** also concluded in 2005 (Österås et al. 2015): *"The results indicate that levels in soil after long term sludge additions do not pose a risk to the soil ecosystem or humans. These findings are in line with earlier findings".*

The workshop also noted that EU R&D funding has a JPI (Joint Programming Initiative) on Antimicrobial Resistance http://www.jpiamr.eu/ It could be proposed to include sewage-born pharmaceuticals in this work.

Priorities for further research

The workshop identified the following areas as priorities for further research:

- Data, and communications summaries of data, to justify the contribution of sewage biosolids use in agriculture to nutrient recycling and to soil carbon, in particular as regards the Paris Climate Change commitment to increase soil carbon by 4/1000 (CO₂ fixation).
- Antibiotic resistance in soil microbes after sewage sludge application. Is it possibly transmissible to health-relevant microbes? Is it consistently transient (natural soil adaptation) or is it a potential lasting issue of concern?
- Understanding of how **different molecular properties of organic contaminants and pharmaceuticals** (partitioning coefficients, chemical functional groups) fate in different sewage works processes (impacts of retention times, microbacterial species ...), sludge treatment processes, sludge dewatering, in different sludges, in soils. An initial 'wish list' could be defined of data linking different molecular properties to behaviour.
- Fate of pharmaceuticals in anaerobic digestion of sewage sludges, including breakdown metabolites, as a function of digester operating conditions.
- Adaptation of sewage works or sewage sludge treatment process chains, or new treatment systems, to improve removal of organic contaminants.
- **Risk assessment models** for organic contaminants in land application of sewage biosolids, and also of manures, after different treatments, based on contaminant molecule characteristics, sludge treatment processes and parameters.



Recommendations for action

The following actions were proposed to take forward the objectives identified above:

- Establish a simple data base of key relevant papers and reports, concerning organic contaminants in sewage sludges and their possible transfer to soil and crops. A first list of papers as proposed by workshop participants, is included below. This is open to input to update.
- Propose collaboration at a global level with similar work in other continents, e.g. US the *NSSR* (National Sewage Sludge Repository) and the Human Health Observatory (HHO) see above.
- Develop a document presenting the advantages of sewage biosolids recycling to agriculture: circular economy and jobs, farmers' income, nutrient recycling, organic carbon – soils and climate change (4/1000), safety and environmental aspects, with recognition that other solutions for sludge management are appropriate according to local situations. ESPP or joint document? For decision makers.
- Input to definition of R&D programmes (EU Horizon 2020, other EU programmes, national R&D funding ...) proposing relevant work on organic contaminants in sewage solids (see research priorities above), in particular data to support **risk assessments**:

workshop participants to identify and communicate consultations and opportunities for making such inputs
develop a joint document outlining R&D needs and priorities.

• Identify R&D needs relevant to EU and national policies:

- EU Sludge Directive (86/278/EEC) and national sludge spreading regulations and plans

- EU and national circular economy policies
- End-of-Waste and fertiliser regulations.
- Joint projects: workshop participants may develop joint projects (R&D, water industry). ESPP is not an R&D brokerage operator, but can circulate proposals or partner search offers.

Workshop on pharmaceuticals and organic chemicals in sewage biosolids: questions for recycling,Malmö (near Copenhagen) 27th October 2016, organised by ESPP in cooperation with the Nordic Phosphorus Conference (DAKOFA, Avfall Norge, Afvall Sverige). Speaker slides are available at https://dakofa.com/conference/conference/programme/ (click on the speaker's name in the programme)

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Papers and reports identified by workshop participants

Andersen et al. "Fate of pharmaceuticals and personal care products (PCPs) by composting of biosolids" Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium

https://www.tuhh.de/iue/iwwg/publications/conference-proceedings/sardinia-2009.html

Clarke & Smith "Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids", Environment International 37 (2011) 226–247

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.652.771 1&rep=rep1&type=pdf

Butkovskyi et al. "Fate of pharmaceuticals in full-scale source separated sanitation system", Water Research, 85, 384-392, 2015 http://dx.doi.org/10.1016/j.watres.2015.08.045

Butkovskyi et al., "Mitigation of micropollutants for black water application in agriculture via composting of anaerobic sludge", J. Hazardous Materials, 303, 41-47, 2016 http://dx.doi.org/10.1016/j.jhazmat.2015.10.016

Smith "Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling", Philosophical Transactions of the Royal Society A-Mathematical Physical and Engineering Sciences 367, 4005-4041, 2009 http://dx.doi.org/10.1098/rsta.2009.0154

Halden "Epistemology of contaminants of emerging concern and literature meta-analysis", J. Hazardous Materials 282 (2015) 2-9 http://dx.doi.org/10.1016/j.jhazmat.2014.08.074

Hörsing & Ledin, SVU (Svenskt Vatten Utveckling) 2016-08 "Identifiering av fokusämnen för slam – organiska miljögifter" (identification of priority organic contaminants in sludge) http://www.svensktvatten.se/contentassets/41ce07e942c24bbfad6a 612525da572e/svu-rapport_2016-08.pdf

Hörsinget et al. al., SVU 2014-12 "Organiska miljögifter i sockerbetor och blast odlade på mark gödslad med kommunalt avloppsslam" (risk assessment for organic contaminants when sewage sludge after mesophilic anaerobic digestion is applied to fields) http://www.svensktvatten.se/globalassets/avlopp-ochmiljo/uppstromsarbete-och-kretslopp/revaq-certifiering/svurapport-2014-organiska-miljogifter-i-sockerbetor-och-blast--slamgodsling.pdf

Jelic, et al. "Occurrence, partition and removal of pharmaceuticals in sewage water and sludge during wastewater treatment", Water research 2011, 45 (3), 1165-1176 http://dx.doi.org/10.1016/j.watres.2010.11.010

Gorga, et al. "Determination of PBDEs, HBB, PBEB, DBDPE, HBCD, TBBPA and related compounds in sewage sludge from Catalonia (Spain)", Science of the Total Environment 2013, 444, 51-59 http://dx.doi.org/10.1016/j.scitotenv.2012.11.066

Mastroianni, et al. "Illicit and abused drugs in sewage sludge: Method optimization and occurrence", Journal of Chromatography A 2013, 1322, 29-37 http://dx.doi.org/10.1016/j.chroma.2013.10.078

Gorga, et al. "Analysis of endocrine disrupters and related compounds in sediments and sewage sludge using on-line turbulent flow chromatography-liquid chromatography-tandem mass spectrometry", Journal of Chromatography A 2014, 1352, 29-37 http://dx.doi.org/10.1016/j.chroma.2014.05.028



Campo et al. "Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants", Science of the Total Environment 2014, 472, 912-922 http://dx.doi.org/10.1016/j.scitotenv.2013.11.056

Campo et al. "Occurrence and removal efficiency of pesticides in sewage treatment plants of four Mediterranean River Basins", Journal of hazardous materials 2013, 263, 146-157 http://dx.doi.org/10.1016/j.scitotenv.2013.11.056

Levén et al., JTI 2016, ISSN-1401-4955 "Pharmaceuticals in blackwater and fecal sludge – Treatments and risks" http://www.jti.se/uploads/jti/R-54%20LL%20m.fl.pdf

Magnér et al., IVL B2264 September 2016 "Fate of pharmaceutical residues - in sewage treatment and on farmland fertilized with sludge" http://www.ivl.se/download/18.29aef808155c0d7f05054e/1473086

619449/B2264.pdf

Malmborg, SVU 2014-21 "Reduktion av läkemedelsrester och andra organiska föroreningar vid hygienisering av avloppsslam"(assessment of reduction of pharmaceutical and other organic contaminants in sewage sludge under seven different sludge treatments) http://vav.griffel.net/filer/SVU-rapport_2014-21.pdf

Malmborg & Magnér, J. Env Management 153 (2015) 1-10 "Pharmaceutical residues in sewage sludge: Effect of sanitization and anaerobic digestion" http://dx.doi.org/10.1016/j.jenvman.2015.01.041

Österås et al., WSP 10196232, 2015 "Screening of organic pollutants in sewage sludge amended arable soils", report for Sweden EPA http://www.svensktvatten.se/globalassets/avlopp-ochmiljo/uppstromsarbete-och-kretslopp/revaqcertifiering/naturvardsverket-rapport-screening-of-organicpollutants-in-sewage-sludge-amended-arable-soils_151124-2.pdf

Rigby et al. "Organic contaminant content and physico-chemical characteristics of waste materials recycled in agriculture" Agriculture 5(4), 1289-132, 2015 http://dx.doi.org/10.3390/agriculture5041289

Eriksen et al. / VKM (Norwegian Scientific Committee for Food Safety) "Risk assessment of contaminants in sewage sludge applied on Norwegian soils", 20th August 2009 http://www.vkm.no/dav/2ae7f1b4e3.pdf

Smith "Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling" Philosophical Transactions of the Royal Society A – Mathematical Physical and Engineering Sciences, vol 367, 4005-4041 http://dx.doi.org/10.1098/rsta.2009.0154

Venkatesan, et al. "United States National Sewage Sludge Repository at Arizona State University – A New Resource and Research Tool for Environmental Scientists, Engineers, and Epidemiologists", Environ. Sci. Pollut. Res. Int. 22(3):1577-1586 http://dx.doi.org/10.1007/s11356-014-2961-1

Zhang et al. "A study on temporal trends and estimates of fate of Bisphenol A in agricultural soils after sewage sludge amendment", Science of the Total Environment 515/516:1-11, 2015 http://dx.doi.org/10.1016/j.scitotenv.2015.01.053

Rhind et al. "Short- and long-term temporal changes in soil concentrations of selected endocrine disrupting compounds (EDCs) following single or multiple applications of sewage sludge to pastures" Environmental Pollution 181: 262-270, 2013 http://dx.doi.org/10.1016/j.envpol.2013.06.011

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Biochar

Nutrient recycling via biochar

Based on two 2016 review papers, completed by experts' input, ESPP summarises factors relevant to biochars as a route for P-recycling.

Conversion of organic by-products and wastes to biochar will conserve phosphorus (but 'lose' nitrogen). The phosphate fertiliser value of biochar will depend strongly on the phosphorus content of the materials from which it is produced, but also the chemical nature of the phosphorus which is considerably changed, modifying both plant availability and risk of loss into surface waters. The fertiliser effect of biochar also results from content of different forms of organic carbon and of minerals, which can affect soil phosphorus sequestration or retention, as well as soil microbial activity and so nutrient metabolism.

This summary is based on the overview paper on biochar as a potential route for P-recycling by Lichun Dai (Chengdu, China) et al. 2016, and the review of biochar properties by Fernanda Aller (Lancaster University, UK) 2016, completed with input from ESPP's network of biochar contacts and experts.

Phosphorus in biochars

Biochars are very variable, depending on the input materials used, on additives and on the processing parameters.

Biochars produced from materials with high phosphorus contents (such as animal bone meal or manure, and to a lesser extent certain sewage sludges) will have a relatively high phosphorus content, and may have direct value as phosphate fertilisers, whereas biochars produced from e.g. biomass will have a low phosphorus content and may have agronomic value rather as soil improvers, maybe improving nutrient availability as explained below. Biochars may also contain significant levels of potassium or other nutrient minerals.

What is biochar?

Biochar can be defined as below. This was the proposal of the ESPP biochar working group (Brussels, 15/3/2016). Currently there is no recognised standard definition, but this may be partly addressed by the EU Commission (JRC) STRUBIAS work which should define criteria for "biochars" as a CMC



(component material category) for the EU Fertiliser Regulation revision (Annex II).

"Biochar is produced from various types of biomass, under controlled pyrolysis or gasification: a thermal process whereby organic substances are transformed (partly decomposed) in a low-oxygen (reductive) conditions. The pyrolysis also results in gas and/or oil products (pyrolitc oils or bio-oils), useable for energy production or chemical industry feed, in addition to biochar Torrefaction, hydrothermal carbonisation and coke production are other carbonisation processes whose end products are not covered by this definition of biochar."

(ESPP working group proposal for EU Fertiliser Regulation criteria for biochars, 2016 www.phosphorusplatform.eu/regulatory).

For illustration, examples of biochar production processes include

- Traditional charcoal stacks
- Rotary kilns
- **PYREG**
- Wood gasifier (e.g. Spanner RE2)
- REFERTIL (3R) animal bone biochar •
- **EPRIDA**
- Hitachi Zosen
- Kon Tiki
-

Biochars can be produced from different organic secondary resources, including manures, crop residues, slaughterhouse wastes, food wastes, sewage sludge, organic fraction of municipal wastes ...

Phosphorus recycling, but not nitrogen

Biochar production, because of the thermal process, will effectively remove a significant part of the nitrogen content of organic streams. The nitrogen will be mainly lost to the atmosphere as inert nitrogen gas, but there may also be emissions of ammonia and nitrogen oxide gases in the production process.

Phosphorus is conserved in biochar production processes, effectively concentrating the phosphorus. Biochars can contain from <0.1% to 13% phosphorus, depending on the input organic materials (the highest P concentrations are when for example meat and bone meal or chicken manures are used as input materials). Biochars can also contain up to c. 1% potassium.

Schneider & Haderlein (2016) analysed eight biochars from dry and hydrothermal pyrolysis processes. Biochars from woodchips and biomass had

low nutrient contents (0.06-0.4% P, 0.4-1.5% N, 0.2-0.9% K) whereas biochar from sewage sludge had nearly 5%P, 4%N and 2%K.

The chemical forms of phosphorus are considerably modified in biochar production:

- Soluble / available inorganic phosphates tend to be transformed to insoluble phosphate minerals (aluminium, calcium, magnesium, iron phosphate compounds)
- **Organic forms of phosphorus** containing O-alkyl groups (e.g. phytic acid) will tend to be modified and bound to organic matter containing refractory alkyl and aromatic carbon groups, so making it less easily available to soil micro-organisms

Complexity of plant P availability

Biochar application to soil can in some cases increase plant available phosphorus, either by direct release of AP in biochar, or by changing soil characteristics (pH, phosphatase enzyme efficiency, formation of organomineral complexes, plant and microbial structure).

Schneider & Haderlein (2016) showed that phosphorus in biochars tested was mostly not readily plant available (<15% water or bicarbonate soluble), confirming previous studies (Brindle 2004, Hossain 2011, Ippolito 2015, Wu 2011). Their analysis showed that the biochars were weak sorbents for phosphates, so potentially reducing net plant available P or reducing risk of phosphorus leaching in P-rich soils.

On the other hand, biochars can render phosphorus more plant available in soils with strong P-binding affinity, that is where phosphorus is poorly available for crops. In these soils, the dissolved organic matter (DOM) in the biochars can bind to minerals in soil, so reducing the fixing of phosphorus by these minerals and so potentially increasing net plant availability of P in such soils.

Chen et al. (2016) tested biochar from pine and willow tree wood chips (respectively c. 0.05% c. 0.4% total P and 0% and 18% CaCO₃ liming equivalence) in two New Zealand soils (pH 6.2) growing Lotus pedunculatus for 32 weeks. The willow wood biochar increased plant growth in phosphorus deficient soil by nearly 60% and phosphorus uptake by nearly 75% whereas the pine wood biochar had no effect. The pine biochar led to significantly increased plant growth and phosphorus uptake in a phosphorus rich soil. Observations in the root zone enabled the authors to



deduce that the willow wood biochar was both providing phosphorus input and improving soil P availability by a liming effect in the low-P soil, whereas the pine wood biochar was stimulating arbuscular mycorrhizal fungi (AMF) in the root zone so improving phosphorus uptake in high-P soil.

They conclude that biochar phosphorus effects depend considerably both on the nature of the biochar and on the soil conditions in which it is applied.

Dai et al. (2016) indicate that application of 1% cattle manure brings approx. 156 kg/ha of total phosphorus (TP) and 125 kg/ha of available phosphorus (AP), whereas the same 1% application of cattle-manure derived biochar brings 400 kgTP/ha and only 4 kgAP/ha. This means that conversion to biochar can avoid oversupply of available phosphorus, susceptible to be lost to surface waters in run-off.

Liang et al. (2014) showed that phosphorus in dairy manure derived biochar is released slowly from incubated soil, indicating the value as a slow-release fertiliser reducing risks of phosphorus losses.

Some biochars not effective fertilisers

Kammann et al. (2015) tested wood-derived biochar in pot trials on quinoa (*Chenopodium quinoa*), tropical conditions, soil pH not specified. This biochar contained low nutrient levels and reduced plant growth when applied on its own (60% reduction at 2% biochar application). When co-composted with manure, straw and phosphate rock there was a positive impact on crop growth.

Schmidt et al. (2015) tested shrub vegetation derived biochar (3.7gP/kgDM in biochar) on pumpkins in the field in Nepal (soil pH 4.6 - 6.7), showing an approx. increase pumpkin production double with application of biochar alone, and an even higher increase with application of biochar mixed with cow urine.

G. Ruysschaert, at the Joint International EU-COST and ANS e.V. Biochar Symposium, Geisenheim University, Germany 29-30 September 2015 presented a meta-study on results from 32 European field trials in which significant loadings of pure biochar were applied. In 80% of cases no effect was found, in 6% a negative effect on crops and in only 12% a positive effect (in 2% the data were not usable).

M. Pugliese, at the REFERTIL conference 17-18 September 2015, Toledo, Spain (see SCOPE *Newsletter* n° 117) showed that animal bone meal derived biochars were an effective fertiliser (in pot trials on tomato, peppers, lettuce) but not plant material derived biochars. A. Vestergaard, at the same conference, presented field trials of biochars from wood waste and from straw on cereals in Denmark, showing in most cases no fertiliser effect, or a negative effect.

Full 2016 overview of biochars and their properties

Maria Fernanda Aller (2016) lists and reviews around 350 publications on biochars, classified according to the biochar production input materials and the processing (conventional pyrolysis or HTC high temperature carbonisation). This 112 page review presents an overview on different properties of biochars (structure, particle size, surface area and porosity, chemical and nutrient content, H:C and O:C ratios).

The review then assesses agronomic impacts of biochars, in particular pH, cation exchange capacity, soil carbon and nutrients.

She reminds that biochars (in the form of charcoals) have been used for soil improvement for many centuries, with examples of their effectiveness in developing agricultural soil quality.

Dr Fernanda Aller discusses in detail the contaminants which can be present in some biochars, depending on input materials and production process: VOCs volatile organic carbon compounds, PAHs poly aromatic hydrocarbons, BTEX aromatic hydrocarbons (benzene, xylenes ...), dioxins and chlorinated hydrocarbons. If significant contaminants are present then biochars should not be spread on soils. However, methods of analysis for some of these contaminants in biochar matrices are today lacking. Questions are also raised concerning carbon fullerenes (hollow carbon molecules, often nano-particles or nano-tubes), which are mainly present in HTC hydrochar.

Dr Fernanda Aller's very complete review confirms that the agronomic value of biochars depends on a range of properties: particle size distribution, structure, surface area, porosity and pore size, pH (can vary from 4 to 12), cation exchange capacity (CEH), conductivity, macro and micro nutrient contents.



Nutrient and carbon contents of biochars

- Biochars generally have **high carbon content**. From 745 reported data records in this review, total carbon (dry weight) in biochars varied from 0.1% to over 97%, with an average of c. 65%.
- Total **nitrogen contents** (707 records) varied from 0% to 7.5%, total phosphorus (200 records) varied from 0.01% to 7.3%.
- The **phosphorus content** of biochars depends greatly on the feedstock materials used to produce it, because P losses in pyrolysis are near zero (maybe higher in HTC, as P volatilisation starts at c. 800°C), with higher levels in biochars from manure pyrolysis (average c. 1.8%P).
- Biochars can also other nutrients and micronutrients. Average levels reported were 0.4% Ca, 0.07% Mg, 1.7% K, 0.4% NA (number of records 116 – 166).

The author quotes a number of studies proving that biochar impacts soil nitrogen cycles, in many cases increasing plant nitrogen availability and decreasing leaching losses. Research has also shown that biochars can reduce ammonia volatilisation and atmospheric losses of nitrous oxide (N₂O). Biochar has also been shown to increase nitrogen fixation by legumes.

She notes that biochar sorption capacity is a controversial property, because in some cases it may reduce the efficiency of agrochemicals but on the other hand it can protect the environment by reducing the leaching of these chemicals.

There are few studies on the impacts of biochars on soil micro-organisms, but these suggest that biochar can have positive effects by increasing soil microbial activity. Also, a consistent methodology to assess biochar carbon stability in soil is lacking (carbon sequestration), whereas the carbon stability in biochar directly impacts properties and effects in soils.

Overall, this wide review of data on biochars concludes that biochars generally have a positive effect by enhancing soil fertility properties such as cation exchange capacity and macro and micro nutrient content and that biochars "can be a good soil amendment with capacity to enhance physical, chemical, and agronomic soil qualities".

However, most studies concern use of freshly produced biochar and short-term effects. More research is needed on agronomic impacts of aged biochar and long-term effects, in particular as regards nutrient bio-availability. Also, many of the published studies concern laboratory produced biochars and more data is needed on commercially manufactured biochar products.

These different studies show that biochars can be effective fertilisers on their own, either directly (biochars made of input materials such as manure, with high nutrient content) or by improving plant availability of nutrients in soils, but this latter effect is highly dependent on specific combinations of biochar - soil - existing nutrient levels, and in other circumstances biochars may not be effective fertilisers.

Biochars, depending on their porosity and other physico-chemical characteristics, can also be used to produce or improve recycled nutrient fertiliser products, because of their capacity to adsorb nutrients: biochars can thus be used to either remove nutrients from waste streams or to 'immobilise' nutrients in secondary nutrient materials (e.g. manures, urine), so stabilising the nutrients into a form better adapted to agricultural application (product handling characteristics, nutrient loss avoidance).

Dai et al. (2016): "Biochar: a potential route for recycling of phosphorus in agricultural residues", Dai L., Hong L., Tan F., Zhu N., He M., GCB Bioenergy (2016), http://dx.doi.org/10.1111/gcbb.12365

Fernanda Aller (2016) "Biochar properties: Transport, fate, and impact". Critical Reviews in Environmental Science and Technology 2016, vol. 46, n°s 14-15, 1183-1296 http://dx.doi.org/10.1080/10643389.2016.1212368

Liang et al. (2014): "Phosphorus release from dairy manure, the manure-derived biochar, and their amended soil: effects of phosphorus nature and soil property", Liang Y, Cao X, Zhao L, Xu X, Harris W, JAQ Journal of Environmental Quality, 43, 1504-1509 http://dx.doi.org/10.2134/jeq2014.01.0021

Kammann et al. (2015) "Plant growth improvement mediated by nitrate capture in co-composted biochar", Nature Scientific Reports Scientific Reports 5:11080 http://dx.doi.org/10.1038/srep11080

Schmidt et al. (2015 "Fourfold Increase in Pumpkin Yield in Response to Low-Dosage Root Zone Application of Urine-Enhanced Biochar to a Fertile Tropical Soil" Agriculture 2015, 5, 723-741; http://dx.doi.org/10.3390/agriculture5030723

Schneider & Haderlein (2016) "Potential effects of biochar on the availability of phosphorus - mechanistic insights", Geoderma 277 (2016) 83-90 http://dx.doi.org/10.1016/j.geoderma.2016.05.007

Shen. Et al., "Can biochar increase the bioavailability of phosphorus?", J Soil Science and Plant Nutrition, 2016, 16 (2), 268-286 http://dx.doi.org/10.4067/S0718-95162016005000022



Biochar research questions

The Joint International EU-COST and ANS e.V. Biochar Symposium, 28-30 September. Geisenheim, Germany, explored the range of possible agri-environmental functions of biochars in soils, concluding in all cases a need for further research to clarify and quantify these properties and their possible applications in agriculture or forestry.

The Geisenheim Biochar Symposium brought together some 190 researchers, practitioners and stakeholders from Europe and overseas, with 50 oral and 50 poster contributions. It was jointly organized by the EU COST Action TD1107, "Biochar for sustainable **environmental management**" (COST = cooperation in science and technology, an EU funding program for inter-European knowledge exchange and transfer), and the non-profit Organization ANS e.V. by (Arbeitskreis für die Nutzung von Sekundärrohstoffen und Klimaschutz = working group for use of secondary materials and climate protection).

This article summarises the conference discussions:

What is biochar?

"Biochar" is a recalcitrant form of biogenic carbon that can be used to sequester ("lock up") atmospheric CO_2 that has formerly been fixed by photosynthesis into biomass as carbon (C), with the general idea to use this "recycled atmospheric carbon" for beneficial environmental and agricultural purposes. Biochar can be produced by modern clean pyrolysis techniques from a range of biogenic feedstock materials such as green waste, greenhouse residue, grape and fruit tree wood and prunings, wood-chip sievings, grain husks, paper fiber sludge, nut shells, digestate and so on. Biochar may be called "charcoal" if the feedstock is pure wood. In modern pyrolysis techniques the generated heat and oil can be used to substitute fossil fuels. Another technique, hydrothermal carbonization, was also touched as a conference subject, mainly for P recycling from waste streams such as sludge.

SCOPE Editor's note: biochar can also be produced from animal by-products, manures, sewage sludge. ESPP is a member of the EU Commission expert group STRUBIAS working on criteria for "biochars" under the EU Fertiliser Regulation revision process. Please contact info@phosphorusplatform.eu if interested.

Research questions

Biochar represents a relatively new and emerging research area. The first research looked at fertile anthropogenic dark earths found e.g. in the Amazon basin (Terra preta do Indio). These soils contain considerable amounts of biochar, have high soil organic matter contents (in addition to biochar), nutrient stocks and soil pH values and are generally much more fertile than adjacent low organic matter acidic soils. Around a decade ago, the idea developed to sequester atmospheric CO₂, via photosynthesis then pyrolysis of biomass, in the more stable form of biochar, and use biochar to eventually enhance soil fertility. Since then, unexpected findings have emerged.

The following questions were addressed:

- Durability (persistence) of the organic carbon in biochars in soils, including contact with plant roots
- Stimulation by biochars of organic carbon sequestration (from the atmosphere into soil) or carbon degradation by soils
- Impacts of biochars on greenhouse gas emissions from soils, in particular N₂O (nitrous oxide)
- Use of biochar as a "nutrient carrier", thus constituting a carbon-based fertiliser
- Possible contaminants in biochars, including e.g. heavy metals, PAHs (poly aromatic hydrocarbons)
- Possible impacts of biochars on plant disease resistance
- Biochar production as a route for **phosphorus** recycling
- Applications for biochars in industry including building materials that catalyse NOx degradation

CO₂ sequestration or soil organic matter loss?

A key feature to biochar use is its stability against degradation, however there were also fears that biochar addition to soils may trigger faster degradation of soil endogenous organic matter (called "positive priming"). These issues were addressed by a session led by Saran Sohi (UK **Biochar Research Centre).**

Yakov Kuzvakov (Göttingen University, Germany) demonstrated, using sophisticated ¹⁴C labeling-tracing techniques, that even after 9 years of incubation under controlled conditions only small amounts of biochar (maximum 6%) had been degraded, and most of it during the first months.



The question was also tackled if the addition of biochar may lead to an accelerated degradation of endogenous soil organic carbon (which was not the case, particularly if studies were longer-lasting); or if greenhouse gas emissions (CO_2 , N_2O) can be predicted by the physico-chemical properties of different carbon amendments (which was the case).

Interactions with plant roots

Finally, detailed stable isotope studies from Australian subtropical grassland and an Italian forest crop plantation demonstrated that the role of plants is often overlooked in biochar research, but may be crucial: On one hand, the Italian research group (Mauricio Ventura, Giustino Tonnon et al.) showed that the biochar itself may be mineralized faster in the presence of plant roots than in bare soil. The Australian research group (Zhe Weng, Lukas van Zwieten et al.), on the other hand, found considerable "negative priming" in the presence of biochar, i.e. they showed that plants (ryegrass), via root biomass and root exudates, were able to increase the soil organic carbon content significantly faster/stronger when the soil was amended with biochar than without.

From a global perspective, it is this "C return on investment" that may be more important than the C sequestration within the biochar itself. The topic of biochar-C persistence was also highlighted by Johannes Lehmann, Cornell University, New York (USA). He demonstrated how biochar mineralization may be overestimated with short-term experimental approaches, and "how much stability" is really needed to implement C-negative biochar strategies.

One session dealt with biochar production, led by Ondrej Masek (UK Biochar Research Centre), looking at how this can influence biochar properties and effects in soils. Stephen Joseph (University of Newcastle, Australia) presented case studies where they had achieved economically viable success onfarm, mainly in land remediation and fertility improvement using biochar-mineral complexes and biochar-based fertilizers where biochar is used in economically viable small doses even below 1 t ha⁻¹. He reported biochar feeding to cows in Australia, then "transport" of the biochar contained in the cows' manure into the soil by dung beetles after the manure had been spread, enabling fast fertility improvement of degraded land within a few years.

Biochar, contaminants, greenhouse gases

Biochar can potentially both contain contaminants (e.g. heavy metals or polycyclic aromatic hydrocarbons PAH) or act as a remediation agent by adsorbing contaminants. The session led by Gerard **Cornelissen (Norwegian Geotechnical Institute) and** Thomas Bucheli (Agroscope, Switzerland), concluded that the risk from contaminants is more or less negligible, if sufficient control over the feedstock and modern pyrolysis techniques are exerted, whereas, on the other hand, chances for soil remediation and waste-water treatment using biochar to adsorb contaminants are recognized via the latest research results, particularly when it is the bioavailable fractions that are investigated, rather than total loads.

A session led by Claudia Kammann (Geisenheim University, Germany) considered the potential of biochar or biochar-blends for reducing non-CO₂ greenhouse gas emissions, in particular nitrous oxide (N_2O) which increases globally due to the excessive use of N fertilizers and legume production. Nele Ameloot (Ghent University, Belgium) and Kurt Spokas (USDA, USA) suggested possibly mechanisms for this effect but further research is needed.

Another session, led by an Israeli group around Ellen Graber and Omer Frenkel (both Volcani Centre Bet Dagan, Israel), looked at the potential of biochar or hvdrochar (produced via hvdrothermal carbonization) for peat substitution in horticulture. Moreover, recent research suggests that only small amounts of biochar used in horticultural media can considerably increase plant disease resistance. The possible causes, mechanisms and effects of biochar on plant resistance against pests and pathogens were discussed.

Application of biochar in agriculture

The sessions on biochar use in agriculture and animal husbandry. opened by Alessandro Peressotti (University of Udine, Italy) concluded that spreading pure, production-fresh biochar onto agricultural lands does not generally improve crop productivity and is not economically viable, particularly in temperate fertile soils. Greet Ruysschaert (ILVO, **Belgium**) presented a meta-study on results from 32 European field trials of biochar application, showing that in 80% of all cases no effect was found, in 6% a negative effect and in 12% a positive effect. This shows that there are no significant negative impacts to using biochar to sequester carbon, however biochar application is too expensive for such a use.



Stephen Joseph and Hans-Peter Schmidt (Ithaka Institute) discussed the potential of biochar as a nutrient carrier to create "carbon-based fertilizers" to improve crop yields and reduce fertilizer needs. The biochar can adsorb nitrogen, particularly in the form of nitrate and also phosphate, resulting in a nutrient-rich organic material which can be used as an organic fertiliser.

One likely effect of biochar root-zone fertilizers may be the protection of plant nutrients against leaching, and the timely delivery of these nutrients concentrated in one spot to accelerate young plant growth and further soil exploration. Their field trial results from Australia, China, South America and Nepal showed yield increases by +30 to +300% compared to (mineral) nutrient-only controls in agriculture and forestry.

Thus, it seems economically more promising to use small doses of biochar in contact with nutrient-rich materials. At the moment the majority of biochar (charcoal) used in middle Europe is sold in animal husbandry. Here, biochar-charcoal (when it meets the very high standards demanded by national laws) is used e.g. as silage additive for quality improvement (reducing mould), as animal fodder additive to improve the health of e.g. cattle or chicken by improving the gut microbiome, or as manure conditioner which strongly reduces bad odours in animal stables. The latter two applications are mostly combined with additions of lactobacilli solutions, i.e. the combination likely delivers changed microbial milieu from putrid processes towards lactic fermentation. The costs for these extra materials are "paid back" to farmers by improved animal health and performance (reduced veterinarian costs, and reduction or zero antibiotics use). The practice delivers small doses of a few hundred kg of biochar per hectare and year; however, to date, research is still lacking in the area of biochar use in animal husbandry.

Biochar technologies

possible technologies Several for recyclinge phosphorus from waste streams (e.g. sewage sludge) by either pyrolysis or hydrothermal carbonization were presented. Thomas Appel (Bingen Technical University), presented an approach developed with the **Pyreg** GmbH to convert sewage sludge by pyrolysis at 500°C into a hygienised phosphorus-containing product, intended for use as a fertiliser.

Non-agricultural uses of biochar were also discussed, e.g. as a component in building materials in concrete. Michele Di Tommaso (IMM-Istituto Meccanica dei Materiali, Switzerland) reported successful tests of biochar as a substitute for special fibres in fire-proof concrete mixtures for tunnel construction. Resistance to high temperatures was facilitated by allowing water vapour to escape through the porous biochar particles. Using biochar in concrete mixtures was also shown to reduce NO_x (NO, NO_2) air concentrations from cars and vehicles in e.g. tunnels or inner cities.

Taken together, the overall picture that emerged at the Joint Biochar Symposium in Geisenheim is that of a steady, **knowledge-driven "biochar evolution"** instead of, as originally anticipated by some, a "biochar revolution". Nonetheless, biochars open up new pathways for recycling and re-using (fossil) atmospheric carbon dioxide via photosynthesis plus subsequent pyrolysis. The overall consensus was that we cannot afford to dismiss even one good and feasible idea that may be turned into a tool for combatting and mitigating global warming.

Joint International Biochar Symposium 2015, Geisenheim (Germany), 28-30 September 2015 http://cost.europeanbiochar.org/en/ct/165

"Fourfold Increase in Pumpkin Yield in Response to Low-Dosage Root Zone Application of Urine-Enhanced Biochar to a Fertile Tropical Soil", H.-P. Schmidt, B. Hari Pandit, V. Martinsen, G. Cornelissen, P. Conte, C. Kammann, Agriculture 2015, 5, 723-741; doi:10.3390/agriculture5030723 http://www.mdpi.com/2077-0472/5/3/723

"Plant growth improvement mediated by nitrate capture in cocomposted biochar", C. Kammann, H-P. Schmidt, N. Messerschmidt, S. Linsel, D. Steffens, C. Müller, H-W. Koyro, P. Conte, S. Joseph, Nature Scientific Reports 5:11080, DOI: 10.1038/srep11080 http://www.nature.com/articles/srep11080



Struvite fertiliser value and safety

Struvite field fertiliser tests and ecotoxicity

Report presenting results of industrial scale demonstrator struvite precipitation at Castres municipal sewage works, South-West France, with pot trial fertiliser testing of the recovered struvite and ecotoxicty tests on land and water plants, earthworms and daphnia

The Naskeo struvite recovery industrial-scale pilot plant operated at Castres municipal sewage works, France, treating 60% of the 130 000 pe biological removal sewage phosphorus works digestate dewatering flow, is presented in SCOPE Newsletter $n^{\circ}120$. Naskeo use a fluidised-bed struvite reactor operated on the dewatering liquor (belt-press) downstream of the sludge digester (the digester is fed with mixed secondary, biological and primary sludge). The struvite reactor treated an average of 90 m^3/day of digestate liquor with an average soluble phosphorus concentration of 165 mgP-PO₄/l.

The struvite recovery as operated **reduced the sewage works phosphorus discharge concentration of 2.4 mgP/l to 1.4 mgP/l**, and it is estimated that this would be further reduced below the discharge consent level of 1 mgP/l if the reactor treated 100% of the digester outflow.

Agronomic testing of recovered struvite

Organic matter content of the recovered struvite was around 10% OM (*note: not measured as organic carbon which would be lower*). The **product was stable** over 4 months storage, with organic matter content not changing.

Pot trials of fertiliser effectiveness are reported (1 kg pots, rye grass, 3 month duration), comparing to triple super phosphate TSP, single super phosphate SSP and phosphate rock. Soil pH was 7.4. Results showed plant **phosphorus uptake with struvite similar to TSP and SSP**, with all of these significantly higher than for phosphate rock. However, in this experiment, plant growth (dry matter production) was significantly higher with SSP than with TSP, whereas TSP gave similar results to struvite and phosphate rock.

The report concludes that struvite shows **fertiliser efficiency equivalent to reference fertilizers** super single phosphate and triple super phosphate.

Product safety

Tests show that 7% of the struvite particles are <10µm diameter size, that is "respirable". This struvite product as tested would therefore require safety labelling and use of respiratory personal protective equipment (PPE) by farmers. Note that this only applies to this struvite as tested, and not to struvite produced in larger particles, or granulated.

Heavy metals and certain organic contaminants (fluoranthenes, benzo pyrenes) were analysed, but only zinc, chrome, nickel and arsenic proved detectable. with both of these at very low levels. Analysed after one year of storage, this struvite showed very low levels of pathogens (E. coli, staphylococci and anaerobic micro-organisms not detectable, nematode larvae and enterococci at very low levels).

Ecotoxicity tests

Toxicity was tested on plants, by seed germination inhibition, using Barley Hordeum vulgare and cress Lepidium sativum), using the French test method XP U 44-167 (AFNOR, 2005), showing no toxicity. As would be expected, the struvite did result in an increase in plant biomass in both cases.

Toxicity to earthworms (Eisenia fetida) was tested using NF ISO 11268-1 showing no toxicity at three doses tested (doses comparable to fertiliser use).

Toxicity to water plants (duckweed Lemna minor, 7 days) was tested using NF EN ISO 20079 - OCDE 221 showing no growth inhibition at 100 mg/l and low inhibition at 1000 mg/l, that is "no significant toxicity" as defined by regulation.

The report summary also indicates that ecotoxicity tests on aquatic micro-crustaceans were carried out on soil eluate, showing no toxicity, Toxicity to Daphnia magna was tested using NF EN ISO 6341 (AFNOR, 2012c) showing no effect of the struvite on mobility after 48 hours of exposition to a concentration of 37% eluate. That shows no toxicity of struvite to aquatic micro-crustaceans at doses comparable to fertiliser use (comparable to possible leaching from soil).

PREPHOS project report "Récupération de phosphore à partir d'eaux usées: Réalisation d'un démonstrateur industriel et étude de la valorisation agronomique de struvite" (Phosphorus recovery *from sewage – industrial scale demonstration plant – study of the* agronomic value of struvite). Naskéo - Rittmo – Timab (Roullier), contract n° 1306C0064, funded by Adour Garonne water agency and ADEME, November 2016. Full report online (in French) at http://www.rittmo.com/



Laboratory testing of antibiotic adsorption to struvite

Four tetracyclines (veterinary antibiotics) were dosed to pure ammonium, phosphate, magnesium and chloride solutions and adsorption to struvite tested, both during struvite precipitation and to pre-prepared struvite crystals, under different conditions (pH, magnesium concentration).

The results confirm a previous study (Kemacheevakul, Otaniet al. Thailand, Japan, 2012, see SCOPE *Newsletter* n°96 and *DOI*) which showed that certain pharmaceuticals (3 out of 11 tested) can adsorb to struvite in pure solutions.

However, in this new study, no data is given concerning the final concentration of pharmaceuticals in the struvite, nor concerning the significance of such possible levels of pharmaceuticals in terms of safety of recovered struvite for handling, the environment or the food chain.

Manure antibiotics

Four different tetracycline veterinary antibiotics (tetracycline, oxytetracycline, chlortetracycline, doxycycline) were tested, in all cases at $50 - 750 \mu g/l$, considered comparable to concentrations detected in pig slurry digestate in China (Chen 2012, Zhou 2013).

Adsorption to struvite was tested with 4 hours stirring, testing both adsorption to pre-prepared struvite crystals (precipitated from pure chemical solutions, crystal size not specified) and during struvite crystallisation, at different ionic concentrations (3-4 mmol/ P, 0.8 - 2.4Mg:P ratios), and at different pH 8.5 - 10.5.

Adsorption isotherms were in similar ranges for the four tetracyclines for adsorption during crystallisation as for onto existing struvite crystals (q = 150 - 750µg/kg) and also varied considerably with different pH and with different magnesium concentrations.

The authors note that the **tetracyclines are** hydrophilic compounds, so that the magnesium ion in solution would be expected to have a competitive effect, reducing adsorption capacity to struvite. They note that in theory sodium, potassium and calcium ions would also have such competitive effects.

SCOPE editor's note:

The competition with other ions indicated above may mean that adsorption to struvite may in fact prove lower in real P-recovery from digestates or other liquors. However, the organics present in these liquors may also impact the adsorption to the recovered struvite product.

Overall, this paper confirms that in theory pharmaceuticals from e.g. sewage sludge digestate or manure digestate are susceptible to be present in recovered struvite.

It is therefore important to collect data on the actual concentrations present in different recovered struvites, in order to carry out a scientific and robust risk assessment of whether these levels in fact pose any issues for health or environmental safety for users of struvite, for soils or for the food chain.

This work is currently underway in The Netherlands and data will also be gathered in the EU Fertilisers Regulation "STRUBIAS" impact assessment process, so that science-based answers to these questions should become available, and be validated by experts in coming months.

If you have access to data on pharmaceuticals or organic contaminants in recovered struvite, including tests where such substances were below detection limits. please send them ESPP to info@phosphorusplatform.eu If such data is companyconfidential, please do not send but contact us to ensure appropriate data handling.

"Adsorption behavior of tetracyclines by struvite particles in the process of phosphorus recovery from synthetic swine wastewater", Chemical Engineering Journal 2016 http://dx.doi.org/10.1016/j.cej.2016.11.062

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Marketing recovered nutrients

Marketing digestate and green fertilisers

20 interviews with private gardeners in Southern Germany show how they chose which fertilisers and soil improvers they purchase, their attitudes to recycled products, and suggest approaches to market digestate products to private consumers.

In *SCOPE Newsletter* $n^{\circ}122$ is summarised a study by Dahlin et al. (2015) looking at marketing of digestates, based on a survey of sales information and 21 interviews of companies marketing digestate. These two new studies (Dahlin et al. 2016 and 2017) assess marketing of digestates and green fertilisers to home gardeners (private consumers).

The first study assessment uses the Engel Kollat Blackwell consumer decision process model and MAXQDA software, and is based on 20 face-to-face interviews with private gardeners, mostly women, from Southern Germany, selected by convenience sampling (researchers' direct or indirect contacts selected to cover different backgrounds).

Lack of consumer knowledge

The results show that although German garden stores offer a very wide variety of fertilisers and soil amendments. most interviewees are not sure which fit their needs, nor how to use the products, and this despite mostly coming from families with a farming background. Therefore, the consumers tend to choose bespoke products such as "fertiliser for tomatoes". Most were not aware of questions such as environmental impacts of peat. Colour, smell, moisture, structure and presence of foreign materials were key characteristics of soil improvers for consumers.

Most consumers expressed negative perceptions of soil improvers susceptible to contain sewage or kitchen biowastes (as input materials for biogas digestate), with manure being perceived positively, but with some concerns about antibiotics.

Criteria for marketing digestates to home gardeners

Physical form of digestate material and packaging showed as key criteria for successful marketing to private consumers. Texture should be loose, fine and not compacted. Digestate pellets were considered less desirable as a fertiliser than finer structures, because perceived as not mixing well into soils. **Smaller packaging sizes** (20 kg) were desirable to the (mainly female) customers. Perception of digestate smell was variable, sometimes positive, sometimes negative. **Packaging and brand are important** in private gardener purchase decision, and a key to product confidence.

The authors conclude that the home gardening sector offers potential for digestate marketing, but **requires investment to understand consumer decision criteria**, and to develop a product in an appropriate physical form with attractive packaging and marketing.

Consumer choice

The second study is based on a **Discrete Choice Experiment**, presenting over 500 respondents (recruited from an online panel by TNS Deutschland market research, criteria: house or flat with garden, recent purchaser of fertiliser) with a total of over 6 000 fertiliser product attribute choices in purchase simulations experiment. Attributes considered include brand status, nutrient content, fertiliser type (universal, flowers), brand name, labelling as "organic", organic or mineral, price.

Nearly 85% of respondents purchase fertiliser in physical sales outlets, mainly from DIY stores. This means that access to these store chains is key to placing green fertilisers, and in particular digestate, on the market to private gardeners.

Although **price shows to be the most important decision factor**, consumer preference is highly segmented. For example, some consumers prefer low price, whereas others prefer high price products (considered to be better quality). The second most important decision factor is brand status, again showing the importance of access to either garden product brand range or store brand range.

Some consumers are sensitive to sustainability criteria, but this does not necessarily correspond to a preference for "organic" labelled products, suggesting **scepticism towards labelling schemes**.



Many consumers also consider "more nutrients is better", confirming a lack of information / educations about appropriate nutrient dosing (known from other studies of home gardeners).

"Biogas digestate management: Evaluating the attitudes and perceptions of German gardeners towards digestate-based soil amendments", J. Dahlin (1,2), M. Nelles (2,3), C. Herbe (1), Resources, Conservation and Recycling 118 (2017) 27–38 http://dx.doi.org/10.1016/j.resconrec.2016.11.020

"Marketing Green Fertilizers: Insights into Consumer Preferences", J. Dahlin (1,2), V. Halbherr (1), P. Kurz (4), M. Nelles (2,3) and C. Herbes (1), Sustainability, 2016, 8, 1169 http://dx.doi.org/10.3390/su8111169

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