European Sustainable Phosphorus Platform

August 2015 n° 115

SCOPE NEWSLETTER

Agricultural phosphorus

Reducing agricultural P losses
Update needed for farm nutrient management BMP information

Summary of information sources for BMPs (Best Management Practices) for on-farm phosphorus / nutrient management shows that work is now needed to update research and its dissemination.

Chesapeake Bay, USA
Maryland State Phosphorus Management Tool (PMT) Regulation

Maryland's new PMT Regulations set new standard for ensuring farm nutrient best management practice

Conferences

OCP Morocco
Symphos 2015

3rd International Symposium on Innovation & Technology in the Phosphate Industry

P-REX (EU FP7)
P-recovery technology assessment

Final meeting presents conclusions of assessment of eight P-recycling technologies and policy developments.

Struvite sales success in UK

Workshop 3-4 Sept. 2016, Ghent, Belgium
Data on Nutrients to Support Stewardship project DONUTSS
Contact brusselsoffice@phosphorusplatform.eu

Lake Erie
Eutrophication research and management

Phosphorus Land – River – Lake Continuum workshop on eutrophication and agricultural P management challenges

P-recycling workshop
EU Commission report published

"Circular approaches to P": conclusions of the 4th March 2015 Berlin workshop on P-recycling.

Aquaculture and plants
Nutrient recovery as biomass

Experience of biomass production for nutrient recycling

Vietnam
Recirculating aquaculture hydroponics

Hydroponic plant production enables water purification and nutrient recycling in aquaculture

P-recovery
Technology review

Ten P-recovery technologies tested at industrial or pilot scale are reviewed and implementation obstacles discussed

Manure treatment
Microwave enhanced oxidation

Solubilisation of P in diary manure to enable P separation and recovery

Struvite recovery
Airpex process patent

CNP-Technology Water and Biosolids GmbH has acquired exclusive worldwide licensing for AirPrex®

Success story
NuReSys P-recycling plants

Ten struvite recovery installations now operational

Public consultation

IMPORTANT ! – respond now to the EU Circular Economy public consultation: deadline 20th August **see p27**

http://ec.europa.eu/environment/consultations/closing_the_loop_en.htm

The partners of the European Sustainable Phosphorus Platform

Agricultural phosphorus

Reducing agricultural P losses

Update needed for information on farm nutrient BMP

A number of organisations have collated information on agricultural BMPs (Best Management Practices) for phosphorus (P) / nutrient management, developing toolkit inventories of BMPs with Best Practice factsheets. This information is summarised by ESPP in this SCOPE Newsletter, below.

Work needed

This overview of information shows that **work is now needed to update BMP factsheets, to take in new practices and recent knowledge of efficiency, maintenance challenges and economics, and to improve dissemination**.

Current information on BMPs

Three major sources of information on agricultural phosphorus best management practices (BMPs) are summarised available:

- **EU COST Action 869**, 2006-2011, resulting in 81 BMP measure factsheets available online and a 142 page report assessing these different measures
- **Baltic Deal and Baltic Compass – Baltic Compact**
- **SERA-17** (USA), which includes USDA (US Department of Agriculture) documents

The collation of this information shows that the **BMP factsheets available at the European and USA level are now 5 years old, or more, and need updating**.

More recent BMP information is available from certain regions (e.g. Baltic, Lake Erie) and there is considerable knowledge in recent scientific and agronomic publications, but this information is not integrated into the Europe (COST *http://www.cost869.alterra.nl*) and USA (SERA-17 *http://sera17.org/*) reference factsheets.

Need for update and dissemination

In particular, there is a **need to update the existing BMP factsheets** to take into account:

- **New technologies and approaches,** including nutrient recycling, manure amendments, by-product generation, nutrient mitigation technologies (some of these are addressed in the Baltic Deal factsheets)
- Update knowledge concerning characteristics and application of **"new" products from developing sewage biosolids and manure treatment processes**, including digestates
- New understanding of **interactions of practices**, for example no-till can effectively reduce soil erosion and associated particulate P, but can accentuate dissolved / soluble P runoff (with high immediate bioavailability)
- Accumulating data concerning maintenance **challenges for BMP measures** (e.g. for buffer strips, manure treatment costs), and the implications regarding effectiveness in reducing P pollution to surface waters
- Relevant **economic data, including costs of maintenance and impacts on crop production** value and on other farm input purchases

Call for information !

It also is apparent that it would be useful to complete the process (which this SCOPE Newsletter article hopes to launch) of **collating available BMP information** and providing, available at one information point, references both to

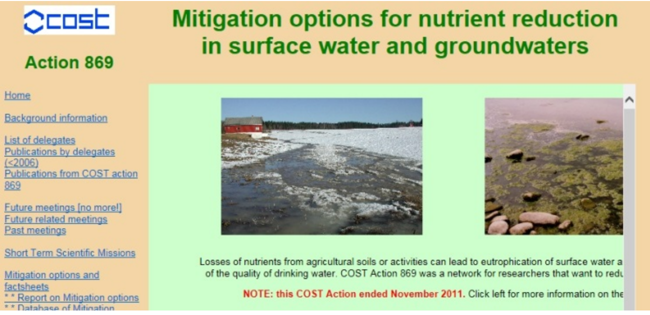
- **websites for BMP factsheets** for different continents and regions: although climate, ecology and agronomy are different, there can be significant shared experience and information
- **key scientific references and other assessment reports** supporting the factsheet information
- enlarge the inventory below to other continents (Asia, Australia …)

ESPP, in Europe, and the North American Partnership for P Sustainability (NAPPS) in the USA/Canada, will take this proposal forward to possible funding organisations, in consultation with relevant scientific experts and agriculture stakeholders.

COST Action 869

The EU COST Action 869 "**Mitigation options for nutrient reduction in surface water and groundwaters**" *http://www.cost869.alterra.nl* involved 30 European countries. Scientists evaluated the sustainability and cost-effectiveness of over 80 different farm nutrient emission mitigation options, from over 100 initially proposed.

The evaluated measures were grouped into categories: nutrient, crop, livestock, soil and (on-farm) water management, land use change, landscape and surface water management.



Over eighty 2-4 page factsheets were generated, for each NMP measure, including: description, rationale and mechanism (how P and N emissions are reduced); relevance, applicability and potential for targeting; effectiveness and uncertainty; time frame; environmental side-effects and trade-offs; administrative issues; costs for investment and maintenance; references and evaluation studies. These are at *http://www.cost869.alterra.nl/dbase/default.aspx*

The different types of action and their potential are summarised in the **12 page paper by Schoumans et al.** (2014) and in the **full 142 page project report** (Alterra 2141, 2011). Key operational conclusions are:

➔ For **fertilisation and livestock management**:

- **Nutrient management strategies**, e.g. agro-environmental recommendations
- **Minimising fertilisation surplus**, including applied manure
- **Reducing N – P content of livestock feeds and increasing uptake availability**
- **Treatment of manure** to separate a high P-content / low volume fraction to reduce transport costs

➔ For **soil and crop management**:

- **Direct drilling and shallow cultivation** are preferable to ploughing as erosion and P losses are reduced
- **Spring tillage** is preferable to autumn tillage, to reduce winter losses
- **Cover crops** can reduce erosion and P losses
- **Accumulated or stratified P near the soil surface** poses a risk of soluble P loss to surface waters
- Over several years, crops can be used to “mine” and **reduce high soil P levels**

➔ Concerning **land and water**:

- Controlling **water flow** from fields is very important
- Consideration that BMPs designed to trap P on a landscape may in some cases **transition from sinks to sources of P** (they are not be infinite sinks for P)
- **Infield overland water flow nutrient losses** can be mitigated by creating ponds, grassing waterways, installing sediment boxes
- **Drainage** modifications can mitigate subsurface nutrient losses
- **Vegetated buffer zones** can trap nutrients, but require appropriate structuring and management to be effective
- **Surface water management** to increase nutrient removal and retention can be effective, particularly in river basin management
- **River and stream maintenance and restoration** can improve nutrient retention and also ecology

COST full evaluation report (142 pages) “Mitigation options for reducing nutrient emissions from agriculture A study amongst European member states of Cost action 869”, Alterra-Report 2141, ISSN 1566-7197, Wageningen, February 2011 O. Schoumans (Ed.), W. Chardon (Ed.), M. Bechmann, C. Gascuel-Odoux, G. Hofman, B. Kronvang, M. Litaor, A. Lo Porto, P. Newell-Price and G. Rubæk http://www.cost869.alterra.nl/Report2141.pdf

Summary paper (12 pages) “Mitigation options to reduce phosphorus losses from the agricultural sector and improve surface water quality: A review”, Science of the Total Environment 468–469 (2014) 1255–1266, http://dx.doi.org/10.1016/j.scitotenv.2013.08.061

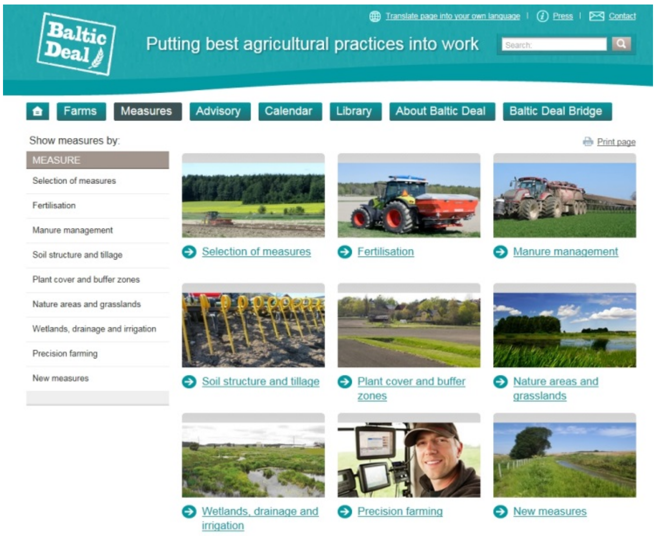
O. Schoumans, W. Chardon, M. Bechmann, C. Gascuel-Odoux, G. Hofman, B. Kronvang, G. Rubæk, B. Ulén, J.-M. Dorioz
oscar.schoumans@wur.nl

Baltic nutrient action programmes

The **Baltic Compass, Baltic Compact and Baltic Deal action programmes**, funded by the EU and by Sweden, aim to accompany farmers in reducing nutrient losses to the Baltic Sea, which faces major eutrophication challenges (SCOPE Newsletter n° 111).

The Baltic Compass (2007-2013) website *http://www.balticcompass.org/project_reports.html* makes available online a number of tools for nutrient management including:

- 54 page report on **Best Available Technologies (BAT) for water protection and retention of nutrients**, particularly assessing buffer zones, sedimentation ponds and constructed wetlands
- **Identification of priority measures** for each Baltic country, with implementation status
- **Training materials** on priority measures
- A range of **documents to support investment preparation**, assessment and scenarios, governance and policy



The Baltic Deal (2010 – 2013) website *http://www.balticdeal.eu/measures/* "Putting best agricultural practices into work" presents **54 factsheets, each 2-4 pages**, covering different Best Management Practices for nutrient mitigation under the themes: fertilisation, manure management, soil structure and tillage, plant cover and buffer zones, nature areas and grasslands, wetland – drainage and irrigation, precision farming, new innovations and selection of measures in different cases.

The fact sheets provide the measure's primary purpose, description, proven effects (on phosphorus P, nitrogen N and biodiversity), farm financing and reference sources of information.

Further support for agricultural nutrient mitigation in the Baltic regional can be found in

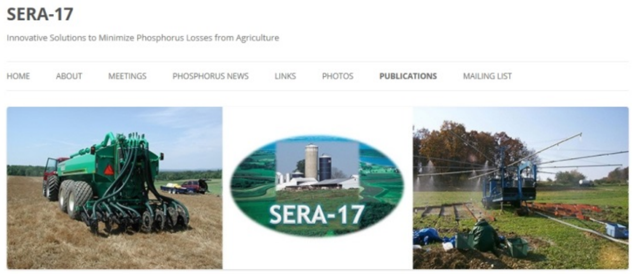
- Baltic Impulse project (Sustainable resource management for a healthy Baltic Sea *http://www.bsag.fi/en/focus_areas/cross-sectoral_activities/Pages/Baltic-Impulse.aspx*)
- the Baltic Manure project (*http://www.balticmanure.eu/en/knowledge_forum/reports/project_results/manure_and_soil_nutrients/manure_and_soil_nutrients.htm* providing data and information on manure analysis and manure nutrient management)
- **WWF 2012 "Sorting out the goods. Agri-Environment Measures in the Baltic Sea Member States"** (34 pages) *https://wwf.fi/mediabank/2003.pdf*
- the official document published by **HELCOM** and adopted by the Baltic Sea interministerial convention "**Revised Palette of measures for reducing phosphorus and nitrogen losses from agriculture**" *http://www.helcom.fi/Documents/Ministerial2013/Ministerial%20declaration/Adopted_endorsed%20documents/Revised%20palette%20of%20agri-environment%20measures.pdf* (2013). This palette (17 pages) specifies 32 BMP measures, providing for each a short summary, effectiveness and applicability/suitability and references / links.

Baltic Compass report (54 pages), 2011 "Measures for water protection and nutrient reduction", S. Owenius and D. van der Nat, WRS Uppsala AB 2011-05-26
http://www.balticcompass.org/_blog/Project_Reports/post/Measures_for_Water_protection_/

USA & Canada: SERA-17 and USDA

The SERA-17 ("**Innovative Solutions to Minimize Phosphorus Losses from Agriculture**" *http://sera17.org/*) group of scientists and stakeholders in the USA provides on their recently-updated website:

- **33 factsheets** for farm nutrient BMP measures
- **Protocols** for P evaluation and study
- 8 **recommendations** covering soil P levels, risk assessments, P-loss predictions
- **Reports** on agricultural phosphorus and eutrophication and on nutrient BMPs



SERA's 33 factsheets are attractively presented 3-4 page documents *http://sera17.org/publications/* including photos, diagrams and tables. They include the definition of a measure, purpose, how it works, where applicable and limitations, effectiveness, cost of installation and management, constraints on operation and maintenance, references and contacts.

The SERA-17 website also includes **two US government reports** (USDA US Dept of Agriculture):

- "**Agricultural phosphorus and eutrophication**", 44 pages, 2nd edition 2003, A. Sharpley et al., USDA ARS149 *https://sera17dotorg.files.wordpress.com/2015/02/ars-149-ag-p-eutrophication-2nd-ed-2003-1.pdf*
  This covers soil P, losses in agricultural runoff (forms of runoff P and dependence on soil P levels) remediation actions (source, transport = runoff or leaching, targeting remediation, management decisions).

- "**Best Management Practices to Minimize Agricultural Phosphorus Impacts on Water Quality**" *https://sera17dotorg.files.wordpress.com/2015/02/bmps-for-p-ars-163-2006.pdf* 42 pages, 2006, A. Sharpley et al., USDA ARS-163.
  This summarises 24 nutrient BMP measures and outlines implementation issues: watershed identification, targeting remedial efforts, BMP selection, watershed and surface water response, education and technical assistance, incentives for BMP adoption.

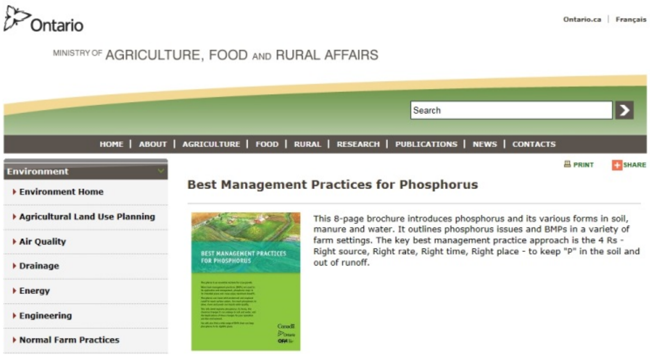
Other relevant US publications include:

- "**Evaluating the Success of Phosphorus Management from Field to Watershed**", A. Sharpley et al., J. Environ. Qual. 38:1981–1988 (2009) *https://www.soils.org/publications/jeq/abstracts/38/5/1981*
- "**What is causing the harmful algal blooms in Lake Erie**?", D. Smith et al., J. Soil & Water Conservation, vol. 70, n° 2, 2015 *http://www.jswconline.org/content/70/2/27A*
- "**Assessments of Practices to Reduce Nitrogen and Phosphorus Nonpoint Source Pollution of Iowa's Surface Waters**", detailed assessment of 23 N and P BMPs, 380 pages, D. Dinnes, Prepared for the Iowa Department of Natural Resources In Cooperation with the USDA-ARS National Soil Tilth Laboratory, Ames *www.iowadnr.gov/portals/idnr/uploads/water/standards/nps_assessments.pdf*
- Chesapeake Bay BMP assessment report: "**Effectiveness estimates for nitrogen, phosphorus and sediment in the Chesapeake Bay watershed**", 822 pages, T. Simpson and S. Weammert, 2009 *http://archive.chesapeakebay.net/pubs/BMP_ASSESSMENT_REPORT.pdf*
- T. Simpson and S. Weammert. This includes detailed **assessment reports of specific types of BMP measures**: Ammonia emissions reductions for poultry, Field and pasture erosion control, Conservation tillage, Cover crops, Dairy feed management, Dry retention and hydrodynamic structures, Forestry, Infiltration and filtration, Mortality composting, Off-stream livestock watering, Buffers, Urban systems, Wetland creation and restoration, Dirt and gravel roads, Horse pastures, Cattle pastures. *http://www.chesapeakebay.net/about/programs/watershed_implementation_plan_tools/*

See also the AMBIO Special Edition 2015 "Future agriculture with minimized phosphorus losses to waters: Research needs and direction", summarised in SCOPE Newsletter n° 112.

A **draft BMP toolbox document, Lake Erie basin, offers a list of 31 farm nutrient BNPs** (19 pages, 2011) with short comments (1-2 paragraphs) on each one (plus references) *http://www.heidelberg.edu/academiclife/distinctive/ncwqr*

The **Ontario Ministry of Agriculture** offers 29 publications on a range of agricultural Best Management Practices, including a number relating to nutrient management, at *http://www.omafra.gov.on.ca/english/environment/bmp_books.htm* Most of these are available as ordered books only but work is underway to group resources into one web access.



See also *http://www.agr.gc.ca/eng/?id=1285354752471* for information on "**Watershed Evaluation of Beneficial Management Practices.**"

Further action

As indicated above, **ESPP and NAPPS intend to progressively complete, maintain and update the above summary of information sources and links on farm nutrient BMPs.**
Please therefore **send us any corrections or additional information** to include online to *info@phosphorusplatform.eu*

Chesapeake Bay, USA
Phosphorus Management Tool (PMT) Regulation

The State of Maryland's new PMT (Phosphorus Management Tool) Regulation entered into force on 8th June 2015, after 2 ½ years of preparation, consensus between lawmakers, agriculture and environmental organisations, and "reflecting the nation's best science".

The objectives are to reduce phosphorus losses to the highly sensitive Chesapeake Bay whilst maintaining agricultural performance.

Requirement to apply PMT

The regulation will require, after a **transition period**, the use of the PMT to define farm phosphorus applications and farm nutrient management plans.

The regulation is "*based on a national body of science of how phosphorus moves from farm fields into rivers and streams*".

The PMT regulation replaces, after the transition period (to 2022), **Maryland State's existing Phosphorus Site Index**. It incorporates a description of the PMT into the **Maryland State Nutrient Management Manuel**, establishes a consultative implementation committee, defines reporting and monitoring obligations for farms. Specific obligations are specified for container and out-of-ground production.

Requirements to improve manure management and nutrient application

The new PMT regulation will provide **comprehensive information on soil phosphorus conditions** statewide: every farm in Maryland earning more than $2,500 or managing more than 8,000 pounds of animal weight must, by law, **submit and follow a nutrient management plan** and **soil test phosphorus data will be collected for all farms subject to nutrient management plan requirements**.

The PMT will impact farms with high soil phosphorus levels and additional nutrient management will be required where there is a higher risk of phosphorus losses. **Phosphorus applications will be graduated based on the level of risk**.

In some cases, manure application will therefore not be possible and farmers may have to purchase mineral nitrogen fertiliser. Transport of manures to other areas may therefore be necessary.

PMT requirements, after the transition phase, differ depending on the **identified level of "potential phosphorus loss"** which must be assessed if soil testing shows a P Fertility Index > 150:

- Low P-loss risk: P application must not exceed expected crop P-removal calculated over 3 years,
- Medium P-loss risk: P application must not exceed expected crop P-removal of the next crop (or 2 crop rotation)
- High P-loss risk: no phosphorus may be applied

The following apply in all cases:

- If **BMPs (Best Management Practices)** are implemented then the P-loss risk status can be adjusted
- Specific limits apply for **Organic Farming**
- Advantages for agricultural operations implementing **technologies which reduce manure P content** by > 75%
- Phosphorus may be applied under conditions **if crops are analysed and shown to be P-deficient**

Cost-benefit analysis

Cost benefit analysis suggests **net costs resulting from the regulation of c. 23 million US$ compared to 100 million US$ benefits from water quality improvement in Chesapeake Bay, Eastern Shore**.

Costs to some farmers will include manure processing and transport, but this is partly offset by **new business** in these sectors and cost advantages for farmers receiving the manure (replacing current mineral fertiliser purchase). Further on-farm economic assessments will be carried out as the PMT regulation is implemented.

Joe Bartenfelder, Secretary of the Maryland Department of Agriculture, has underlined that the new regulation ensures adequate time for farmers to fully understand and plan for new requirements. This is important because **the regulations will require many farmers to significantly change the way they operate** and manage their farms, some will have to purchase new, expensive equipment to apply commercial fertilizer rather than manure.

Sites web http://mda.maryland.gov/Pages/PMT.aspx

"Notice of Final Action for PMT Regulations Published in the Maryland Register; New Phosphorus Management Tool Regulations in Effect", 8th June 2015
http://news.maryland.gov/mda/press-release/2015/05/29/notice-of-final-action-for-pmt-regulations-published-in-the-maryland-register-new-phosphorus-management-tool-regulations-in-effect-june-8/

"Hogan's phosphorus regulations reflect the nation's best science", Joe Bartenfelder in the Baltimore Sun, 4th March 2015
http://www.baltimoresun.com/news/opinion/oped/bs-ed-phosphorous-regulations-20150304-story.html

Conferences

OCP Morocco Symphos 2015

The third SYMPHOS conference, organized by OCP, Marrakesh, 18-20 May 2015, “Innovation insights for Sustainable Agriculture”, brought together 1300 delegates, and is now the world’s biggest conference on phosphates. SYMPHOS 2015 marked a departure from the concept of a purely technical conference based on phosphate technologies to a strong focus on innovation.

The conference underlined the **ambitions of OCP to become and remain a world class company, driven by eco-responsible innovation**, the need for sustainable resource management, and responsibility for the world we live in.

OCP world leader

As an example of OCP’s **dedication to innovation**, some recent developments were highlighted, such as the 190 km pipeline allowing the transport of rock slurry from the Khouribga mine to the processing site at Jorf Lasfar. This massive engineering feat allows savings in energy, CO2 emissions, transport cost and

water use. It also allows for a much larger transport capacity. **The pipeline started operating in April 2014 and transports 38 million tonnes of beneficiated phosphate rock per year**.

This pipeline realization is presented in a videos available at *https://www.youtube.com/watch?v=q8mDxHV9Oa0* (E-line, 3 ½ mins) and *https://www.youtube.com/watch?v=risFtbSXzc4* (pipeline, 2 ½ mins) showing how the pipeline fits into OCP’s integrated production chain, from the Khouribga phosphate mine through the continuous slurry pipeline supply to the Jorf Lasfar E-Line phosphoric acid production units, including heat recovery and water reuse. See also summary in SCOPE Newsletter n° 86.

A significant part of the plenary sessions was devoted to the broader subject of **innovation**, not necessarily focused on the phosphate mining and fertilizer sector, with such luminaries as Robert B Tucker and Rachid Yazami providing expert insight into the subject.

The growth of SYMPHOS is significant, with **1300 delegates from 48 countries** attending the 2015 edition. The huge Palais des Congrès venue in Marrakech was fully booked to accommodate the event. Out of 300 submitted papers, 164 were accepted (with 109 in parallel sessions). 76 companies had exhibition booths all over the conference center.

Soufiane El Kassi – president of Symphos - welcomed the delegates and invited them to share knowledge and achieve a more sustainable agricultural model through innovation and inclusive growth.

Innovation and the phosphate industry

In line with the main theme, the first plenary session was about innovation. **Robert B Tucker**, innovation visionary, delivered a passionate address entitled “**Innovation is everybody’s business**”. As the title implies, innovation is not a fad, but an increasingly important tool for the long-term survival of companies. Challenging common conceptions and established thinking is central to achieving innovation (differentiation and disruption). Successful companies make sure that all employees are aware of what is needed and expected from them to help the company improve and innovate.

It is actually quite easy to fail at innovation, and this happens quite often. Mr Tucker suggests that this can be addressed by **implementing a structure to manage innovation**, which is the next stage after innovation by coincidence, working in development teams, using suggestion schemes, etc- which are often not integrated and focused on the overall goals and strategy of the company.

Robert Tucker recommends to **make innovation a strategic imperative**. This can be done by implementing an idea management system, to collaborate with stakeholders and partners, to cultivate and encourage risk taking, and to involve everyone in the enterprise – there is a role for everyone.

Examples were given of where and how companies have failed and what could have saved them. As recently indicated by several large mining and fertilizer companies at Phosphates 2015, Florida (see SCOPE Newsletter 112) **this is a vital message for the phosphate and mining industry**, which can indeed be seen to act on this.

Mining new resources and mining more efficiently

As an example of innovation, **Paul Lever from CRCMining** presented a number of **recent innovations in mining** that are set to change the industry significantly. A typical example is the cost of extraction of copper, which has gone down by a factor of 5 over the course of a century due to innovations in technology. Technologies such as sharp angle drilling, hard rock drilling and selective mining will allow the mining industry to cope with grade deterioration and make hitherto unavailable deposits mineable. Incremental improvement of current practices will not change the underlying model which becomes increasingly difficult to uphold. **Selective mining, the smart use of low grades and tailings, and innovative equipment** will bring about a new model for mining. But also a subject like employee fatigue monitoring, a highly relevant subject for mining personnel, will make mining more effective and safer.

Two more developments will shape the future of mining: **working in difficult locations** (at great heights, in harsh climates, or in politically unstable regions) and the **more rapid development of mines**, which typically take a decade to develop but could be developed much faster by using innovative technology. It should be possible to half the cost and double the speed of developing a mine.

Stockpile management at OCP was explained by **Mansour Asri, OCP**. As mining always gives a product varying in composition over time, it is important to manage intermediate stockpiles in such a way that the quality of the final product is stable, and the best use is made of higher and poorer fractions, thus optimizing ore efficiency and profits. So far, this has been done on a practical, trial and error basis. OCP has now implemented an extensive modelling and inventory system to optimize the management of the intermediate stocks. This has successfully streamlined operations and optimized the use of all fractions.

D. Gagnon, MetChem, and **Abdallah Massoun, OCP**, presented several **innovations in mining**. Working on the long edges of mines which work on layered deposits may allow to mine several layers at the same time. Spreading deposits over the remainder of the mine can also improve mining speed. In addition, rethinking where transport and crushing takes place can lead to remarkable improvements (e.g. optimized/larger trucks, in-pit crushing by mobile units, and hydraulic transport such as also implemented by OCP).

Garth Kirkham of the Canadian Institute of Mining CIM delivered a plenary on **standards and best practices**. These subjects are highly relevant for a modern mining and processing facility wishing to be a world class operation.

In the future, we need to rethink flowsheets and mining. As an example, the **Santa Quitera project in Brazil** extracts both uranium and phosphate. For each separate element, the project would not be economical but by combining the two, it becomes profitable. Another example is the goal of **Wengfu Group (China)** to become a zero waste producer of fertilizers. This means Wengfu will convert phosphogypsum to ammonium sulfate, thus eliminating waste from the phosphoric acid production process.

Such new ways of thinking will lead to a **sustainable license to operate**, where mining doesn't leave a negative legacy, but just takes what is needed and leaves a positive and a restored landscape. This needs to include engagement with the relevant stakeholders such as local communities.

In parallel sessions, **examples were given for former mining site remediation and recovery in Morocco**. A typical example was presented by **Rachid Hakkou** for the abandoned Kettara mine in Morocco, suffering from acid mine drainage (AMD). AMD can be remediated with tailings from the mines at Khouribga at relatively short distance.

Technology transfer to improve P processing

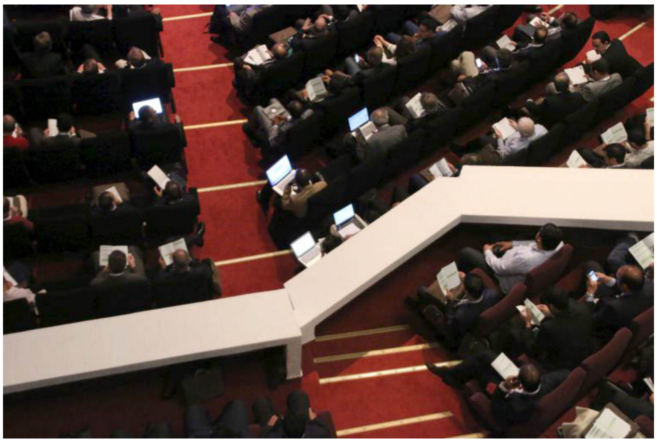
Thomas Lager of EMINES School of Industrial Management, Mohamed VI Polytechnic University in Benguerir, Morocco elaborated on the downstream side of things: chemical processing. **Innovation in the process industry** can be enticing, but customers in such industries often just want affordable commodities. This needs to be realized when innovating in this industry. The speaker, like in the opening address, recommends to formalize the innovation process, moving away from innovation driven by chance.

A new technology to concentrate ores could be **electrostatic separation and beneficiation**. In contrast to most other methods, ES uses a dry material. Especially where densities of mixed materials do not differ greatly, this technology could offer a difference, as materials often exhibit different charging characteristics. Impressive separation ratios and yields were presented by **Frank Hrach of ST Equipment and Technology**. The technology is already implemented for coal-fired power station fly ash and is currently being developed to work with coarser materials (> 500 micron).

Michael Wienker of ThyssenKrupp Industrial Solutions introduced the delegates to the subject of **advanced maintenance**. This needs to be converted from a reactive model (replace components when they fail) to proactive management, to avoid lengthy equipment failure and capacity reductions or standstills. The system in question, called "Computerized Maintenance Management System", is a tool which is as good as the data it is fed. It relies on up-to-date information, well-populated databases, adequate IT infrastructure, support by management for employee behavior and external experts, and the integration of existing IT systems.

As a **take-home message** and by way of example, some insights were shared:

- perhaps some **non-P technologies** will work for phosphate mining such as taking place at OCP;
- **not everything works everywhere**;
- **bigger/newer is not always better**;
- **integration of several technologies** is sometimes beneficial, sometimes not;
- and finally, **always a pilot is needed** before implementing anything at large scale.



OCP and excellence

Abdelghani Ghasni of OCP introduced the OPS system, a **comprehensive tool to improve performance and prevent losses**. It supersedes various existing quality systems which operated in parallel, and takes aboard safety, operations, environment, human resources, and much more, allowing a full integration of all aspects of the company's activities and have all relevant data available at a glance.

André P Kotlarevsky, of DuPont OCP Operations Consulting, a joint venture between DuPont and OCP, informed the conference on **Operations Excellence**. The top 3 priorities as defined by the management of OCP are Human Capital, Operational Excellence and Innovation. Existing initiatives were integrated under one umbrella, which created alignment and sense of one company. Modules consist of a technical model (which integrates previously used systems), capacity building, and cultural transformation (mindsets/behavior) with an overlying management system. Output is constantly used to align the strategy. The system was cascaded down. As a result, the returns improved. Interestingly, the model was also deployed externally at Sibur, with success.

Phosphorus applications

As an example of downstream products of phosphate rock, **Norbert Weferling of WefCon** gave an overview of **organophosphorus compounds**, which are high-added value downstream products of the element (white phosphorus). A full family tree of white phosphorus derivatives exists, with **hundreds of downstream products and applications**, including herbicides, lubricant additives, and flame retardants. The latter field has seen relatively recent innovation in the form of phosphinate based products.

Removing or recovering impurities

A full session was devoted to the **removal of phosphogypsum from the phosphoric acid process**, where compromises are often to be made between yield, filterability and rock crushing (fineness). Also the shape of the crystals, influenced by impurities, defines the throughput of a plant. This remains an area of intense research with often tailor-made solutions, as no rock is the same.

Also, **impurities removal, such as iron, magnesium and aluminium, continues to be a topic of development**. Several options to remove or reduce these from rock or acid were presented, which allow for purer products and higher acid concentrations. **Lev Filippov of Université de Lorraine** highlighted some of the options available for flotation separation of P rock, which strongly depend on the nature of the rock.

Geology associated with the formation of sedimentary phosphate deposits was covered in parallel sessions. Vertebrate biodiversity during these geological epochs (Cretaceous/Tertiary) were addressed.

Analysis of materials was addressed in a separate session. **LIBS (Laser induced breakdown spectroscopy)** allows to analyze the composition of ores at up to 25 m distance instantaneously at great precision, by shooting a laser pulse at a sample which then partially vaporizes into a plasma and releases light/radiation characteristic of its element composition. **This and other technologies will revolutionize the way various mining grades and tailings are handled and valorized**.

Rare earth, fluoride and uranium extraction from rock or acid continue to generate a lot of research and development. **Vaughn Astley of Dr Phosphate**, and **A Rollat of Solvay** explained the various methods of **cogenerating value from phosphoric acid** by extracting these valuable metals. The choice of extraction agent is crucial in setting up such processes. **Thomas Dahlke of Buss (Switzerland)** explained the recovery of fluoride from the phosphoric acid process, as H_2SiF_6 or HF.

OCP and energies

The ambitions of Symphos are also demonstrated by the focus on new energy. **Jamal Chaouki, of Université Polytechnique, Montréal**, gave a concise overview of the **options to use biomass as energy source**. The amount of waste generated scales with GDP, but developing countries have relatively more waste, much of which is disposed of in unsound ways.

Waste has a tremendous energy potential, potentially providing one third of the US need for power. The energy can be released in the form of straight **incineration**, **gasification** (with a minor quantity of air to convert solid material to gases) or **pyrolysis**, which converts solids to liquids and gases without oxygen. The latter two techniques suffer from operational problems associated with tar formation, making large scale rollout difficult. Still, promising innovation is taking place such as microwave heating, which is being developed by a new company, Ecolomondo.

Phosphorus in rechargeable batteries

Electrical energy storage – and its link to phosphorus – was highlighted by **Rachid Yazami**, the inventor of the anode in lithium ion batteries and one of four scientists who laid the foundation for the lithium ion battery, the dominant electricity storage technology of our time and the coming decades. The inventors were honoured with a **Draper prize in 2014**. He introduced the audience to the remarkable history of this technology, which generates thousands of scientific papers and patents each year. Several storage systems were elegantly highlighted with their merits and drawbacks. Charging and discharging time, energy density and cell voltage determine the usefulness of a battery chemistry. The lithium ion platform has superior performance over other systems. While untl now portable devices were the largest application of such batteries, **in the future the market will be dominated by electric vehicle and smart power grid applications**.

The existence of a rechargeable battery is actually a miracle, as the demands imposed on battery components (electrodes, electrolyte, spacer) are tremendous. They should **store large amounts of energy in a small space in a safe way** (with the separator between electrode components being absolutely critical), components should not change shape and volume dramatically during charge/discharge, and such batteries should not degrade after repeated charge/discharge cycles. A host of materials were highlighted that may store energy but most suffer from critical disadvantages, such as that they expand in volume when charged.

Phosphorus is found in a new, reliable cathode material (LiFePO4) slated to be used in electric vehicles and smart power grids, as well as in the **electrolyte (LiPF6**), thus highlighting phosphorus to be a fascinating link between energy and the core subject of the conference. Further aiding in the spread of these batteries is the fact that the price of a lithium ion battery is nearing that of older technologies.

Fabrice Renard of Prayon elaborated on the merits of LiFePO4 and its merits as cathode material in large Li on batteries in a parallel session.

Feeding the world

Julian Hilton of Aleff Group underlined the **vision of OCP to feed the world and look at long term strategies** to do so. In addition, he made a passionate appeal to regard phosphogypsum as a resource rather than a waste. It can be used as fertilizer in sulfur deficient soils (such as found in India) or in road construction, as also elaborated upon in a parallel session.

Furthermore the presentation explored the meaning and **definition of a critical resource**. This means there is no control over its availability. Julian made an appeal to regard fertile soil as a critical resource, perhaps the most critical to be found. In this respect, one needs to ask what fertile soil needs (and doesn't), and also what goes in currently, what really should not go in, and how all of this is managed.

Julian Hilton's presentation also contained an **overview of waste hierarchies** in the EU and US (the latter including energy) and concluded that OCP has many common voices and initiatives to become more sustainable. He finished by underlining that Morocco and OCP have just a resource, but also a challenge to manage it for the future generations.

Agriculture in Northern Africa was addressed in a parallel session. In many countries in the region, small-scale farming and especially subsistence farming is quite relevant to GDP and employment, typically contributing 8-20%. Rainfall constitutes the majority of water input here. Sensible nutrient management (4Rs – right dose, right time, right time, right place) will contribute to improved productivity. With the aid of experts and computer modelling this can be implemented throughout the developing world (e.g. India).

Further sessions included:

- The use of improved **crushing and grinding** equipment, which allows for better recovery and lower energy use
- The improvement of **gypsum crystallization** and its implication for capacities, recovery rates and capacity of a phosphoric acid facility
- **Safety management** in mining and processing operations
- the use of **mining tailings** and various other process waste to form e.g. aggregates for road construction, which reduces or eliminates the need for landfilling.
- **Nutrient-plant interface**, such as the use of mycorrhiza to mobilize nutrients
- **Corrosion resistant materials**
- Digital and **virtual mining**, including digital tools to optimize operations, as well as geological mapping tools

3rd SYMPHOS conference, International Symposium on Innovation & Technology in the Phosphate Industry "Innovation Insights for Sustainable Agriculture", 18-20 May Marrakesh, Morocco, www.symphos.com

P-REX (EU FP7)

P-recovery technology assessment

The EU funded (FP7) P-REX project final meeting, Amsterdam, 11th June 2015, presented the conclusions of the project's assessment of a selection of P-recovery technologies (technical P-recovery from municipal wastewater) and proposals for policy to support P-recycling. The EU Commission presented policy developments underway. Site visits to Waternet and ICL Fertilisers saw phosphorus recycling in action.

The P-REX project (which terminates 8/2015) was based on **assessment of technologies developed by the project Consortium members and by several other companies** (see SCOPE Newsletter 98).

The project included **testing of the fertiliser** value (phosphorus availability) of different recovered phosphate products from these and other processes (comparison to Triple Super Phosphate), **LCA assessment, economic, regulatory and market studies**, and preparation of a **Policy Brief for decision makers and regulators** (policy developments needed for P-recovery from wastewater to move to wide implementation, already presented in SCOPE Newsletter n° 111).

Technology assessment

The conclusions of the assessment of the P-REX Consortium members' technologies, as simplified and interpreted for SCOPE Newsletter, are as follows:

Technology	*Owner / developer*	*Implementation status*	*Fertiliser value*	*Operating temp.*	*Organic contaminants*	*Heavy metals*	*Effects of Fe, Al*	*Development perspectives and constraints*
Different struvite recovery technologies	In P-REX: Ostara, Airprex, Veolia. Outside P-REX: NuReSys and others	Mature technology, proven and operational full scale	Good	Ambient	Lower than proposed EU fertiliser requirements	Lower than fertiliser requirements and lower than conventional mineral phosphate fertilisers	NO	Sewage: in biological nutrient removal plants only. Also opportunities in food industry, manure processing …
Sludge leaching in sulphuric acid (pH <4.5)	Gifhorn (ex. Seaborne)	One pilot operational since 2000 (50 kg struvite / day). One larger pilot tested (270 kg struvite/day)	Good (2)	Ambient	NO	Separated using Na_2S	Reduce P recovery or increase chemical use	High chemical consumption (application in sludge)
	Stuttgart	One pilot (Offenburg) operational since 2011 (50 kg struvite/day)		Ambient		Separated using citric acid		
Sewage sludge incineration ash (SSIA) leaching in dilute sulphuric acid	LeachPhos / BSH	2 pilots (batch), one 10 kg SSIA/hour), one 2t ash/h (45 tonnes SSIA processed).		Ambient		Partly separated using high pH (NaOH or lime)	YES	Chemical consumption (acid then alkali pH). Need to dry product and dispose of wet filter cake waste.
SSIA thermal treatment with reducing agent	Outotec (ex. AshDec)	300 kg SSIA/hour pilot operated. 1500 tonnes SSIA processed.	Good when sulphate compound used in process	1000°C		Partly removed with reducing agent.	?	Energy cost could be reduced if integrated to incinerator or dryer
Thermal metallurgic slag process	Mephrec / Ignitec www.ingitec.de / Nürnberg Fraunhofer Umsicht	Only data is from pilot tests 2008 at Freiburg Tech. University (300 kg/h input) operated using other wastes for 22 months (4)	P-REX tests suggest slag not useful as fertiliser (1)	1450°C		Removed to by-product metal alloy.	YES (removed to metal alloy)	Energy consumption ? (3) Plant availability or not of P in product needs further research.

(1) *This is contrary to technology provider's previous claims published in 2009 and 2011*
(2) *Properties will depend on what substance is precipitated from the orthophosphate solutions generated by these processes*
(3) *Claimed to be net electricity producing if operated on sewage sludge*
(4) *Note: similar Kubota process operating in Japan at 11 sites.*

Presentations by P-REX at the conference were as follows:

- **Verena Wragge, IASP: Product quality and fertiliser value of recovered products**. A range of recovered phosphate products were tested for plant availability using maize pot trials (fully controlled and replicated) and in small field tests (controls but no replicates). **Plant uptake and growth were compared to standard mineral phosphate fertiliser** (TSP triple super phosphate). The pot trials used P-poor soils at pH 5.5 and 6.6. Results demonstrated that **all the recovered phosphate products, except the Mephrec slag (at pH 4.9 and 7.1) and the Outotec processed ash at pH 6.6, showed plant availability comparable to TSP** (relative fertiliser efficiency > 80%)
- **Christian Remy, KWB: Life Cycle Assessment**. ISO 14040/44 LCA methods were applied, but the data quality available for the processes other than struvite precipitation was limited (pilot tests only) and the data for struvite precipitation is site-specific. However, site-specific data was transferred to a defined reference system to enable better comparability between the different processes and pathways. P-REX LCA also accounted for upstream and downstream effects of P recovery by including sludge dewatering and disposal, but also effects of a decrease in return load on the mainstream WWTP process. Results show that **P recovery processes and pathways differ heavily in their amount of P recovered in relation to the total P in sludge, and that energy needs and related greenhouse gas emissions are also highly different.** A key issue is that **results may depend strongly on LCA hypotheses**, e.g. whether chemicals used are wastes/by-products or specifically manufactured.
- **Anders Nättorp, FHNW**: **costs of P-recovery**. For the different processes**, P-recovery is estimated to cost 0 – 3 € per capita, without taking into account 0 – 1.40 €/kgP income from sales of recovered product as a fertiliser**. One-off investment costs are estimated at 0 – 10 € per capita. For recovery from ash, a further 2 € per capita must be added for installation of "mono-incineration" (incineration of sewage sludge incineration ash separately, not mixed with low-phosphorus wastes such as municipal refuse)
- **Fabian Kraus, KWB: contaminants and risk assessment**. Human health and eco toxicity risks were assessed for the contaminants in different recovered phosphate products studied and compared to scenarios of use of appropriately treated sewage sludge by agricultural spreading and use of mineral fertiliser. **Human health risks are very unlikely**. Eco toxicological risks for soil organisms could not be excluded for zinc due to sewage sludge, ash and one of the recovered products in neutral soils (long-term accumulation). Risks to groundwater via leaching could not be excluded for zinc and cadmium especially in acidic soils. Overall, **the recovered products and treated sewage sludge showed a risk ratio similar to that of phosphate rock derived mineral fertilisers**. Struvite products showed the lowest heavy metal contents of all fertilizers. Regarding the observed organic pollutions, the input via atmospheric deposition is more of importance than by sewage sludge or struvite application.

The need to avoid sludge mixing

P-REX concludes that **significant obstacles to phosphorus recovery** from sewage sludge incineration ash are mixed incineration (sewage sludge co-incinerated with municipal solid waste) and iron/aluminium contents of sewage (some P-recovery processes cannot recover Fe or Al bound phosphorus).

Mono-incineration (municipal sewage sludge only) ash shows variable levels of phosphorus: 9 – 12 % P, whereas ash from incineration of municipal sewage sludge mixed with industrial sludges shows levels of phosphorus at 3 – 7 % P. In Germany, a significant number of incinerators do such mixing of municipal sewage sludge and industrial sludges, misleadingly calling this "mono-incineration". **This sludge mixing poses a significant obstacle to P-recovery because of the lower phosphorus content**.

An ongoing study by BAM is assessing ash tonnages potentially available for P-recovery in Europe (see also SCOPE 109 for BAM study in Germany). **Fabian Kraus, KWB,** notes that in Germany, around 200 sewage treatment works serve > 100 000 p.e, making up a total of 45-50% of sewage phosphorus. **At present 26 mono-incinerators treat 24% of total German sludge, so potentially enabling a high level of P-recovery** (c. 450 000 tonnes sludge dry matter). **A further 25% of German sewage phosphorus is currently recycled to agricultural land in treated sewage biosolids**. Furthermore, many large sewage treatment works are using (partial) biological nutrient removal, and could recover part of the inflow phosphorus as struvite, instead of using iron or aluminium dosing as at present.

From R&D to implementation

Sirja Hukari, FHNW, summarised P-REX conclusions as to **how to move P-recovery towards market implementation**, including a "pre-normative matrix" linking quality of the recovered products and their projected price with requirements of different market segments and the **online eMarket tool** (ESPP website www.phosphorusplatform.eu) which enables suppliers of recovered nutrient products to make contact with potential users.

Discussion confirmed **advantages from producing a higher-quality or higher-value product**.

- **Concentrated, low-contaminant phosphoric acid**, for example, would have a market value because it is readily tradable, or **elemental phosphorus** (from a thermal process, see e.g. RecoPhos Thermal in SCOPE Newsletter 112) would have a high market value.
- Recovered phosphate fertiliser products will in many cases have a **low value on the bulk agricultural fertiliser market**, because of logistic costs.
- **Higher quality recovered fertilisers or niche products**, which match user needs (purity, pellet size …), can find a market, as is shown by the success of Ostara: the company has more demand for their recovered CrystalGreen® struvite product, in agriculture and grass turf applications, than they can supply from the Thames Water, Slough sewage works, P-recovery unit.
-

Public policies needed

The P-REX consortium members consider that **the following public policies are needed for widespread implementation of nutrient recovery from municipal wastewaters** (see also in SCOPE Newsletter n° 111):

- EU phosphorus reuse and recycling target
- Roadmap for implementing this European target
- Regional phosphorus policies
- Adaptation of existing legislation to better take into account recycled (secondary) nutrients
- Guidelines for implementation of existing legislation impacting nutrient recycling
- Mechanisms to share the costs of P-recovery and recycling: e.g. quotas for inclusion of secondary nutrients in fertilisers and for their agricultural use or recovery obligations for the water industry
- Funding of full-scale demonstration installations

Struvite sales success in UK

Ostara are proving that struvite has a real market as a fertiliser. The 150 tonnes struvite/year recovered at Thames Water's Slough sewage works is being successfully sold to farmers and for turf applications. Demand is exceeding supply and Ostara has even had to import struvite from its several operating plants in North America. Struvite is a slow-release phosphorus & magnesium fertiliser, adapted to plants' needs for nutrient supply over time. The high quality (purity, granulometry) of Ostara's CrystalGreen® product is considered by the company to be key to this market success. http://www.crystalgreen.com/
See also http://www.gcsaa.tv/view.php?id=2624

European Commission actions

Eric Liégeois, European Commission DG GROW, outlined actions **engaged to develop circular economy for nutrients**:

- **European Commission / European Investment Bank loan fund**. Nutrient recycling is a target sector. Loans can support innovative, private investments (> 15 million €), and also upscaling and feasibility studies. A first nutrient recycling project has already been given provisional approval: **COOPERL Brittany** project to process c. 500 tP/y and 430 tN/y from manure, municipal sewage and slaughterhouse waste to organic fertiliser (see in this SCOPE Newsletter). *http://ec.europa.eu/priorities/jobs-growth-investment/plan/index_en.htm* and *http://www.eib.org/about/invest-eu/index.htm*
- **Public consultation on Circular Economy policies. Open to general public and organisations' response to 20th August.** The questions of nutrients, phosphorus and organic recycled fertilisers are mentioned in the 'Roadmap' submitted to consultation. *http://ec.europa.eu/environment/consultations/closing_the_loop_en.htm*
- **Revision of the EU Fertiliser Regulation**. This is now fully on track, with the objective to finalise the

proposal for end 2015, for integration into the new Circular Economy policy proposals. Work is now underway at EU JRC to draw up EU criteria for **struvite** as a fertiliser (following submission of a proposal by ESPP, see www.phosphorusplatform.eu), for **sewage sludge incineration ash** as a fertiliser ingredient, for certain **manure ashes as fertilisers**, and for organic products such as **composts, biochar and digestates**.

Further actions which DG GROW intends to launch shortly include

- **Call for Model Demonstrator Regions** on nutrient circular economy: call September 2015
- **Feasibility study on risk-based contaminant limits for fertilisers** (2016)
- **Market perspectives study for secondary nutrients N, P, K** (2016)

Waternet struvite recovery

The P-REX meeting visited the phosphorus recycling installation at the Waternet sewage works, Amsterdam West. The works treats **sewage from one million person equivalents** (biological nutrient removal) and sludge from two million, incoming from other sewage works (anaerobic digestion). **Struvite precipitation** (magnesium ammonium phosphate), using the AirPrex process / magnesium chloride dosing in the digestate (anaerobic digester outflow) upstream of the sludge filter press, was installed to address major nuisance incrustation problems in pipes and other installations: **operational savings of 150 000 €/year**.

The **struvite precipitation also improves methane production in the anaerobic digester** (possibly by reducing ammonium return streams) and **allows biological nutrient removal to achieve phosphorus discharge consent** (of 1 mgP/l) without chemical dosing.

The biggest cost benefit comes from improved digestate dewatering (from 20% to 23% dry matter): this results in c. 250 000 €/year cost savings (gate fee for incineration of sludge in adjacent municipal waste incinerator and lower polymer dosage requirement), effectively resolving dewatering problems which resulted from moving from chemical to biological P removal in the plant. The mechanism of the improved dewatering is not yet understood, it may be related to reduced soluble phosphate or to the magnesium ions dosed in the struvite reactor.

The Waternet struvite plant started operation in 2013, and has a capacity of 900 tonnes struvite/year. **A contract has now been signed with ICL Fertilisers Amsterdam who will take the struvite produced by Waternet and use it in their fertiliser production process.**

Also, Waternet is developing public communication actions to raise awareness for phosphorus recycling, including separate urine collection in the **Heineken Music Hall and with mobile toilet units at festivals**, feeding the urine into the struvite plant to recover phosphorus.

ICL Fertilizers

The meeting also visited ICL Fertilizers' Amsterdam plant. **Kim ten Wolde, ICL**, explained that the company aims to use 100% secondary nutrient materials in its two European plants by 2025 (Amsterdam and Ludwigshafen, Germany) but faces administrative and investment challenges (see SCOPE Newsletter 113).

Ashes can be used in the factory's acidulation process (treatment with sulphuric or phosphoric acid) replacing part of the phosphate rock input.

Use of meat and bonemeal ash (MBA) has proven feasible in full-scale tests, but sewage sludge incineration ash has not, because of high levels of magnesium, iron and aluminium.

Struvite can also be used as a P source in the granulation-step of the process. Since the P is already slowly plant-available, mixing with the acidic SSP/TSP-ROP intermediate product (upstream of drying) will be sufficient to make it more rapidly plant available. **The magnesium also adds value to the final product**.

Water content issues with the (Airprex) Waternet product should be solved by improving the washing step at Waternet. Organic-, biological- and pharmaceutical residual content is not expected to be a hazard as the drying process is operated at over 300°C air temperature, reaching up to 90°C for the granules. The NH_4 in the struvite could potentially decompose – this is to be investigated further.

P-REX website: www.p-rex.eu

Lake Erie

Eutrophication research and management

The Lake Erie "Land – River – Lake Continuum" workshop brought together over 60 (how many) experts (plus 54 questionnaire returns) to define key challenges in agricultural phosphorus management and research needs to better understand the interactions between phosphorus in agriculture and on land, in river and lake water and sediments, and eutrophication in Lake Erie.

Conclusions underline questions regarding

- agricultural nutrient BMPs (Best Management Practices),
- P and N dynamics in wetlands, sediments and water
- interactions with algal blooms and anoxia.

The conclusions of this workshop, held 12-14 March 2014, Heidelberg University, USA, at the NCWQR (National Center for Water Quality Research) are published alongside c. **20 other papers addressing eutrophication management in Lake Erie in Journal of Great Lakes Research**, 40, 2014, plus ESM (electronic supplementary material) which lists the challenges and proposals defined at the workshop.

Lake Erie showed some signs of partial recovery from eutrophication from the 1970's to the mid-1990's, but has experienced a well-documented deterioration since 1995, with resurgence of hypoxia in the central basin and HABs (harmful algal blooms) in the western basin. This matches increases in soluble phosphorus (SRP) in primarily agricultural tributaries since 1995, whereas SRP remained low in an urban tributary, confirming that as strict discharge limits are in place for municipal sewage works, agriculture is now a key contributor to Lake Erie eutrophication problems.

Agricultural phosphorus

The workshop confirmed that **phosphorus is the root cause of both harmful algal blooms (HABs) and anoxia incidents in Lake Erie**.

Different restoration objectives for Lake Erie have been proposed, including 40 – 80% reductions in total and soluble phosphorus loads reaching the Lake, but the workshop noted that **setting targets was difficult because lake response varies** depending on climatic and other conditions and current understanding of internal lake P loadings and dynamics, and interactions with nitrogen and other factors is inadequate.

Photo: Laura Johnson

Best Management Practices

Although there is considerable information available concerning **agricultural nutrient Best Management Practices (BMPs),** this was identified as a key area where more work is needed

- **Effectiveness of agricultural BMPs** in reducing runoff of soluble phosphorus (not only total phosphorus)
- **Socioeconomic issues of implementation** by farmers of proposed nutrient BMPs
- Identification of BMPs that will work equally well during **extreme circumstances** (storm flow, drought)
- BMPS to address "**legacy P**" (accumulated soil P)
- **Monitoring and quantification of BMP effects** on the land – river – lake continuum

More technical questions concerning nutrient BMPs include: stratification of phosphorus on the soil surface (in particular related to no-till), interactions between hydrology and fertiliser application methods, targeting areas with high P runoff risk, interactions of phosphorus with other soil nutrients and with soil organic matter, quantification of drain and soil macropore P losses, combined impacts of cumulative BMPS, calculations of appropriate fertiliser application rates (obtaining better estimates of soil plant available P).

Overall, the key question is how to achieve a **feasible compromise between ensuring phosphorus availability for crops and reducing agricultural P run-off**.

Farm BMP implementation

A number of questions were identified concerning farm nutrient **BMP implementation**:

- What are the most important factors affecting farmers' **adoption** of BMPs?
- **Who needs to be adopting BMPs** to achieve intended targets? Should the goal be large changes in the behaviour of few, or small changes in the behaviour of many?
- What are the **trade-offs** among different kinds of BMPs in terms of cost to farmers and benefits to water quality?
- How can BMPs be encouraged for farmers on **rented land**?
- What is the most effective policy instrument to **incentivize farmers' adoption of BMPs**? Is a tax on P fertilizer more effective than payments for voluntary adoption of BMPs?
- Is **volunteer BMP adoption** working at the watershed scale or **are regulations needed**?

A **draft BMP toolbox document already exists** (19 pages, 2011), consisting of a list of 31 farm nutrient BMPs with short comments (1-2 paragraphs) on each one (plus references). This should be developed, updated and improved: *http://www.heidelberg.edu/academiclife/distinctive/ncwqr* or (direct link) *http://www.heidelberg.edu/sites/default/files/jfuller/images/8%20Toolbox%2011-21-2011draft.pdf*

Photo: Remegio Confesor

Wetlands – rivers - lake

Although the impacts of wetlands on reducing phosphorus loads to Lake Erie are considered potentially important, **reductions in wetland surfaces** have resulted in little scientific understanding of the widespread effects on Lake Erie. Information concerning phosphorus retention in wetlands and benefits of wetland restoration or construction needs to be collated and assessed.

Important **questions identified regarding lake phosphorus dynamics** included internal lake P loading from sediments, dreissenid mussels, effects of timing and seasonality of external P loadings, nitrogen impacts on algal bloom formation and on bloom toxicity, effects of winter ice on blooms, and interactions with microbial food web.

In the **rivers**, questions included river nutrient retention, impacts of nutrients on river and stream ecosystem health, nutrient retention of riparian zones and river floodplain functioning, expected impacts of climate change, and increases in droughts and flooding.

Key issues are the **education of farmers in the Western Lake Erie watershed on the proper BMPs** to reduce soluble phosphorus, and the upcoming challenge of meeting targets in the face of increasing spring precipitation associated with climate change.

"Research to help Lake Erie: Proceedings of the 'Phosphorus along the Land–River–Lake Continuum' research planning and coordination workshop", Journal of Great Lakes Research 40 (2014) 574–577 http://dx.doi.org/10.1016/j.jglr.2014.07.001

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***J. Great Lakes Research, vol. 40, issue 3, 2015 "Special Section on Lake Erie Watershed to Open Water",** ed. C. Pennuto, L. Dayton, D. Kane, T. Bridgeman*
http://www.sciencedirect.com/science/journal/03801330/40/3

- *Lake Erie nutrients: From watersheds to open water, C. Pennuto, L. Dayton, D. Kane, T. Bridgeman*
- *Demonstrating the relationship between soil phosphorus measures and phosphorus solubility: Implications for Ohio phosphorus risk assessment tools, E. Dayton, S. Whitacre, C. Holloman*
- *Lagrangian analysis of the transport and processing of agricultural runoff in the lower Maumee River and Maumee Bay, D. Baker, D. Ewing, L. Johnson, J. Kramer, B. Merryfield, R. Confesor, R. Richards, A. Roerdink*
- *Re-eutrophication of Lake Erie: Correlations between tributary nutrient loads and phytoplankton biomass, D. Kane, J. Conroy, R. Richards, D. Baker, D. Culver*
- *Phosphorus loading to Lake Erie from the Maumee, Sandusky and Cuyahoga rivers: The importance of bioavailability, D. Baker, R. Confesor, D. Ewing, L. Johnson, J. Kramer, B. Merryfield*
- *Systemic, early-season Microcystis blooms in western Lake Erie and two of its major agricultural tributaries (Maumee and Sandusky rivers), J. Conroy, D. Kane, R. Briland, D. Culver*
- *Summer phytoplankton nutrient limitation in Maumee Bay of Lake Erie during high-flow and low-flow years, J. Chaffin, T. Bridgeman, D. Bade, C. Mobilian*
- *Sediment resuspension in the Lake Erie nearshore, G. Matisoff, M-L. Carson*
- *Spatiotemporal characteristics of nitrogen and phosphorus in the benthos of nearshore Lake Erie, C. Pennuto, L. Burlakova, A. Karatayev, J. Kramer, A. Fischer, C. Mayer*
- *Twenty five years of changes in Dreissena spp. populations in Lake Erie, A. Karatayev, L. Burlakova, C. Pennuto, J. Ciborowski, V. Karatayev, P. Juette, M. Clapsadl*
- *Changes in Lake Erie benthos over the last 50 years: Historical perspectives, current status, and main drivers, L. Burlakova, A. Karatayev, C. Pennuto, C. Mayer*
- *Commentary: Climate change adaptive management in the Great Lakes, S. Abdel-Fattah, G. Krantzberg*
- *Interacting effects of climate change and agricultural BMPs on nutrient runoff entering Lake Erie, N. Bosch, M-A.Evans, D. Scavia, J. Allan*
- *Identifying useful climate change information needs of Great Lakes fishery managers, K. Mulvaney, C. Foley, T. Höök, E. McNie, L. Prokopy*
- *Phytoplankton trends in the Great Lakes, 2001–2011, E. Reavie, R. Barbiero, L. Allinger, G. Warren*
- *Molecular characterization of bacterial communities associated with sediments in the Laurentian Great Lakes, A. Winters, T. Marsh, T. Brenden, M. Faisal*
- *Cladophora, mass transport, and the nearshore phosphorus shunt, A. Dayton, M. Auer, J. Atkinson*

Phosphorus reuse and recovery

P-recycling workshop
EU Commission report

The European Commission has published a report "Circular approaches to phosphorus, research to implementation", presenting conclusions of the 4th March 2015 Berlin workshop on P-recycling.

The workshop was organised by the European Commission, P-REX and ESPP parallel to the ESPC2 (2nd European Sustainable Phosphorus Conference) and brought together 80 participants and 28 nutrient recycling projects (see list below). Initiatives present included R&D and demonstration projects funded by the EU (FP7, LIFE+, InterReg) as well as national funded projects and industry initiatives.

The workshop noted that some processes are **already at the commercial production scale**, e.g. processing manure to organic fertiliser, calcium silicate filter media for diffuse farm P-removal, struvite recovery, EcoPhos P-recovery from manure and sludge ash.

Participants underlined the need for policy support for phosphorus recycling and coherent interpretation of pertinent EU and national legislation as preconditions for widespread implementation.

The workshop identified the following R&D needs:

- **Phosphorus flow studies** (mass flows, characteristics), to identify points for P-recovery implementation
- **Social science** (attitudes, acceptance, choices) to accompany P-recycling implementation
- **Actions covering the whole value-chain,** from P-recovery to market of recycled P products
- Detection & risk assessment of organic **contaminants in sewage sludge** and recovered nutrient products
- Full-scale demonstration projects
- R&D to support standards, BAT, product criteria, best practices
- Coherency and interpretation of EU and national **legislation**
- **Regional approaches** and adapting to specific local situations or niche markets
- **Clustering** of projects and networking to enhance impact on policy, improve synergy and mutual learning and facilitate market uptake

"Circular approaches to phosphorus: from research to deployment", 48 pages, European Commission Directorate-General for Research and Innovation 2015, ISBN 978-92-79-46827-8 http://bookshop.europa.eu/en/circular-approaches-to-phosphorus-pbKI0115204/ *See also SCOPE Newsletter n° 113.*

Aquaculture and plants

Nutrient recovery as biomass

Several recent publications summarise and update experiences of using sewage to feed biomass production, so combining wastewater treatment and nutrient recycling, through e.g. sewage-fed fish production (aquaculture), constructed reedbeds and wetlands.

Kumar et al. (2014) present ten years' experience of **sewage fed aquaculture at the City of Karnal, Northern India** (population nearly 300 000). One of the city's two sewage treatment plants (8 million litres/day sewage treatment capacity) is based on waste stabilization ponds (4 cascading ponds) used for aquaculture for the last 10 years. The treatment system been found **effective in removal of pollutants** including BOD, TKN and P in the range of 86% (BOD_5 down to 31 mg/l), 58%, and 24%, respectively.

Sewage-fed fish production

The plant achieves compliance with India government standards for on-land disposal or discharging into the water body. Through the aquaculture, **12 – 16 tonnes of fish per year are produced and the treated wastewater is used on fields for a range of crops**, so reusing both water and nutrients, and economising fertiliser costs for farmers. Bacteria (coliforms, streptococcus) are largely eliminated, probably by protozoa in the fish ponds.

Wastewater treatment using reedbeds and wetlands

Brix et al. have published a number of papers presenting **experience of use of reedbeds and constructed wetlands in treating municipal sewage and industrial effluents**.

Brix et al. (2007) assesses 20 years' experience with **constructed reedbeds** for treatment of municipal wastewater in Denmark. Around 170 such systems are operational (100 public, c. 70 private), plus c. 50 willow-based evaporative systems and >50 constructed wetlands.

The soil-based, phragmite reedbed systems have shown to be **effective in removing BOD (generally to < 5 mg/l) and suspended solids**, but are not effective in phosphorus and nitrogen removal. The data from Othfresen, Germany, on which these systems were based has not fulfilled treatment promises, with P and N removal of only 30 – 60%. Some reedbed systems have therefore been extended by adding aerated fixed-bed or tank installations for nitrification, and chemical dosing plus a sedimentation tank for phosphorus removal.

The initial extensive (using c. 5 m^2 per person) horizontal reedbed concept is increasingly replaced by one of the following:

- **compact vertical flow, recirculated, planted filter systems**, with an **additional P-removal tank**
- **evaporative (no outflow) willow growth systems**, where the willow trees are harvested as wood fuel
- **constructed wetlands**

Kolecka and Obarska-Pempkowiak analysed sewage sludge after treatment in Sludge Treatment Reed Beds (STRBs) in Denmark. The four STRBs had been used to treat sewage sludge. The systems had been operated for 7 to 15 years.

These reed beds ensure a **combination of composting and dewatering** (drying by evaporation and evapotranspiration) of the treated sewage sludge. The analyses of sludge treated in reed beds showed that organic matter content was 40 – 51 % of dm, N_K concentration was 1.9 – 2.7 % of dm and total P concentration was 3.6 – 5.2 % of dm. Whereas phosphorus concentrations increased along vertical profile (from the bed surface downwards), nitrogen concentrations decreased. This indicates that progressive nitrification-denitrification is taking place in the root-soil system in the reed bed, whilst also over time phosphorus is accumulating as a consequence of decomposition of organic matter.

The authors note that **these reedbed sludges (STRBs) have a good value as fertiliser**, because of the P and N concentrations, but that there is a risk of accumulation of heavy metals. In these four cases, however, heavy metals remain below limits for agricultural application of sewage sludge defined by the EU Sewage Sludge Directive.

Intensified wetlands systems

Wu, Brix et al. (2014) review updated information on performance of **intensified constructed wetlands for removing organic and nitrogen content** from wastewaters, using new approaches:

- **Operation strategies**: effluent recirculation, aeration, effluent drop aeration, tidal operation, flow direction reciprocation, bioaugmentation (specific microbe addition), earthworms
- **Design configurations** to intensify (reduce footprint): circular flow corridors, tower hybrid systems, baffled subsurface
- **Combinations with new wastewater technologies** such as microbial fuel cells
- **Electron donors** to enhance removal of specific inorganic anions: organic carbon dosing, organic filtration media, episediment layer-integrated systems, step-feeding, autotrophic denitrification
- **Specific soil substrate selection** to facilitate microbial biofilms
- **Adaptation to cold climates**: insulation (e.g. mulch layer), improving oxygenation, greenhouse installations

These new approaches particularly aim to **improve oxygenation** (because redox conditions are known to impact wetland performance in nitrogen, organic matter and organic contaminant removal), to reduce the **footprint** of constructed wetlands and to alleviate **clogging** (e.g. flow reciprocation).

Industrial and food-sector wastewaters

Wu, Brix et al. (2015) review current knowledge on **use of constructed wetlands to treat industrial effluents**, particularly looking at challenges of high organic loading, salinity, extreme pH, low biodegradability and colour removal.

Data and/or experience from full-scale operating constructed wetlands treating wastewaters from the following sectors are presented: wineries, distilleries, textile, oil field and refinery, tanneries, potato processing, seafood, starch, slaughterhouses, acid mine, pulp and paper mill, coking.

Effective treatment adaptations include inflow dilution by effluent recirculation, pH adjustment, plant selection, aeration, bioaugmentation (addition of specific microorganisms).

"Integrated Management of Wastewater through Sewage Fed Aquaculture for Resource Recovery and Reuse of Treated Effluent: A Case Study", ICESD 2014: February 19-21, Singapore, APCBEE Procedia 10 (2014) 74 – 78
http://www.sciencedirect.com/science/article/pii/S2212670814001699

D. Kumar, A. Hiremat, S. Asolekar, Centre for Environmental Science & Engineering, Indian Institute of Technology Bombay, Mumbai, India asolekar.wp3@gmail.com

"Twenty years experience with constructed wetland systems in Denmark – what did we learn?" Water Science & Technology, vol 56, no 3, pp 63–68, 2007
http://www.iwaponline.com/wst/05603/wst056030063.htm

H. Brix, H-H. Schierup, C. Arias, Aarhus University, Department of Biological Sciences, Ole Worms Allé, Building 1135, 8000 Aarhus C, Denmark hans.brix@bios.au.dk

"Potential fertilizing properties of sewage sludge treated in the sludge treatment reed beds (STRB)", Water Science & Technology, 68.6, 2013
http://www.iwaponline.com/wst/06806/wst068061412.htm

K. Kolecka, H. Obarska-Pempkowiak, Dept. Civil Environmental Engineering, Gdansk University of Technology, 11/12 Narutowicza Street, 80-952 Gdansk, Poland katkolec@pg.gda.pl

"Development of constructed wetlands in performance intensifications for wastewater treatment: A nitrogen and organic matter targeted review", Water Research 57, 40-55, 2014
http://dx.doi.org/10.1016/j.watres.2014.03.020

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"Treatment of industrial effluents in constructed wetlands: Challenges, operational strategies and overall performance" (Review), Env. Pollution 201, 107-120, 2015
http://dx.doi.org/10.1016/j.envpol.2015.03.006

S. Wu, R. Dong, W. Kipkemoi Kirui, F. Masi, as above. S. Wallace, Naturally Wallace Consulting, 7801 Vauxhill Drive, PO Box 99587, Raleigh, NC 27624, United States. H. Brix, P. Kuschk, as above.

Vietnam
Recirculating aquaculture hydroponics

A pilot-scale (1 m^3) aquaculture (fish production) – hydroponics installation was operated for 50 days (considered to be sufficient to stabilise microbial community) to test the capacity of hydroponics plant production to purify the aquaculture effluent and recycle nutrients.

Fish cultured were Tilapia (*Oreochromis niloticus*) at c. 70 fish/m^3 (each fish c. 70g), fed with commercial fish feed containing 1.1% P and 4% N at c. 3% initial fish weight per day. **The aquaculture water was circulated intermittently through three parallel plant aquaponics trenches** (each 2m x 0.7m x 0.35 m) with total throughflow for the three trenches 0.3 m^3 day. Three different plants were grown: water spinach (*Ipomoea aquatic* Forssk.), lettuce (*Lactuca sativa* L.) and an ornamental plant canna lily (*Canna glauca*), planted in gravel substrate, 35, 35 and 15 plants per trench.

Nutrient recycling to crops

The **plant uptake of nutrients** was c. 6% of N and 7% of P in fish food, with 45% of N and 76% of P being integrated into fish meat. Nutrient uptake but was very variable between the three different plants. The canna lily plants had high nutrient uptakes (estimated at 730 kg N/year and 230 kgP/year), relating to higher biomass production (3.8 kg above and below ground dry mass biomass per m^2 per year) compared to the other two plants (0.7 and 0.1 kg for water spinach and lettuce). However, the canna lilies are ornamental and not edible by humans or animals.

The system was operated without water renewal for 50 days. Water was added only to replace losses by evapotranspiration, with a total water consumption of c. 1 m^3 water per kg fish produced. **Water quality in the fish tank remained fairly constant** throughout the experiment, except for slightly increase electric conductivity and phosphorus..

The authors conclude that integrated recirculating aquaculture – hydroponics (aquaponics) systems **enable significant water savings and nutrient recycling**, but that further research is needed to identify efficient plant species which are also useful crops.

Further research is also needed to assess **long term operation full-size**, including maintaining long-term water quality compatible with fish growth, accumulation / release of nutrients from the hydroponics trench sediment, fish and crop sanitary safety.

"Use of planted biofilters in integrated recirculating aquaculture-hydroponics systems in the Mekong Delta, Vietnam", Aquaculture Research, 45, 460-469, 2014 http://dx.doi.org/10.1111/j.1365-2109.2012.03247.x

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P-recovery
Technology review

Already a number of reports and reviews on phosphate recovery technologies have been published. Wetsus (for ESPP) maintains an inventory of these reports (*www.phosphorusplatform.eu* under downloads), which has been updated for this SCOPE Newsletter. One of the new additions is this peer-reviewed article, assessing ten phosphate recovery processes that are (or were) applied on a reasonable scale rather than reviewing theoretical approaches or results from laboratory experiments.

The review focuses on applications to **recover phosphorus (P) from industrial and municipal wastewater** (liquid phases, sludge, ash) and from manure. The paper explains how economic feasibility and national and international legislation prevent a wider application of these techniques.

The article introduces some background information about P application (95 % in agriculture), its role in biology (DNA, ATP, hydroxyapatite) and highlights needs for recovery (increasing fertilizer demand in future, finite and centralized reserves, eutrophication).

Technologies in operation

The article introduces **10 full-scale technologies to recover P from wastewater and several others are under development.** The scale of some of these processes however should rather been seen as pilot or demonstration scale. Also some of these installations are currently not in operation (for instance Seaborne, Thermphos, Ashdec/Outotec).

Six processes are discussed that crystallize P from dewatering reject streams as **calcium phosphate or struvite** (ANPHOS, PHOSPAQ, NuReSys, Ostara Pearl, Phosnix, Crystalactor) and one targets on liquor of digested sludge (Airprex). These techniques usually require biological P removal. They are often relatively simple to handle (little chemical and energy input and thus lower costs) but have lower recovery potentials based on influent P (40 – 50 %) compared to sludge and sludge ash technologies (90 %).

One full-scale process for **P extraction and recovery from digested sludge** exists (SEABORN).

Two processes, one thermochemical (OUTOTEC) and one electrochemical (Thermphos), have been applied to **recover P from sewage ash**.

Recovery of phosphate from sewage or sewage sludge mainly takes place via struvite. Beside struvite also calcium phosphate, white P or calcined P fertilizer are recovery products. Chemical (pH, alkalinity, presence of other ions), biological (phosphate accumulating organisms) and physical parameters (temperature) that influence and that are used to induce the formation of the recovery product are discussed. Also two full-scale technologies to recover P as calcium phosphate rich sludge from liquid swine manure or as potassium struvite from calf manure are introduced.

Currently, **P recovery from liquid phases** takes place in few potato processing companies and in sewage treatment rejection water. In companies, recovery takes place on rather small scale resulting in higher costs and varying struvite quality. Recovery products should have a good and constant quality and should be attractive for further industrial application. A remarkable alternative to the highly diluted sewage streams is the recovery from source separated streams and manure which are highly concentrated in N and P. However, this route requires further research. Current recycling processes for sludge and ash require infrastructure and are considered especially interesting for industrialized countries.

Lack of implementation strategy

According to the authors, the **lack of uniform strategies for sustainable P use** prevents spreading of P recovery. Current installations are a result of national regulations and industrial infrastructure to handle recovery products. Examples from The Netherlands, Belgium and Sweden show that legislation (limiting sludge application in agriculture, demanding P recovery, adapting fertilizer legislation) can direct the way for changing P practice.

For instance, struvite is not yet recognized as fertilizer on a European level but is variously authorised on national level in some EU Member States.

Economic feasibility plays also an important role for establishing P recovery. The economic feasibility depends on the parameters that are taken into account. P recovery prevents economical loss due to eutrophication; P recovery may prevent struvite scaling and may reduce the costs for sludge disposal. However, it is usually considered cheaper for the fertilizer industry to use rock phosphate for fertilizer production but this could change by more intense research, changing legislation and market stimulation.

The authors predict that in many countries agricultural application of sludge will not play a big role in future due to problems with heavy metals and toxic organic substances. Finally, the authors summarize that, most likely, several socio technical solutions will develop that differ due to regional circumstances. **International and national legislation play an important role** in spurring the path for more widespread application of P recovery.

"Global P Scarcity and Full-Scale Phosphorus-Recovery Techniques: A Review", Critical Reviews in Environmental Science and Technology, 2015, Volume 45(4), pp. 336-384
http://dx.doi.org/10.1080/10643389.2013.866531

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Summary prepared by WETSUS www.wetsus.nl *for ESPP*

Manure treatment

Microwave enhanced oxidation

In areas with a high livestock density the amount of manure that can be applied regionally is often limited by the phosphorus content in the sludge even though the organic matter in the manure would be beneficial. Therefore removal and recovery of phosphorus from the thick fraction of manure can help to apply the manure to nearby farmland (without oversupply of nutrients), while the recovered and concentrated phosphorus can be transported over longer distances to places where there is a demand for phosphorus fertiliser.

Dairy manure is rich in magnesium (Mg^{2+}), ammonium (NH_4^+), and phosphorus (P) suggesting the possibility to recover P as struvite (magnesium ammonium phosphate). However, **P is mainly present in particulate forms** and furthermore the **presence of Ca^{2+} in the liquid phase** impedes this recovery option.

The authors researched a technology to release phosphorus from dairy manure using **acidification and microwave enhanced oxidation**.

They used a pilot scale set-up (c. 60 l/hour) to recover phosphorus (P) as struvite from undigested liquid dairy manure slurry (the thick fraction after liquid-solid separation) with the following steps:

(1) **Acidification** of the liquid slurry using concentrated acid to reach pH: 4, 3.5 or 3

(2) **Hydrogen peroxide** (H_2O_2) injection (0.1, 0.3 and 0.5 % v/v), immediately prior to introduction into the microwave unit (3)

(3) A continuous flow **microwave** (MW) unit (6 kW MW, effluent T= 96 °C), consisting of a 9m long tube (3/4 inch diameter, volume 2.5 l)

(4) **Clarification** of the suspension by gravity settling

(5) **Ca^{2+} removal** from the supernatant by oxalic acid addition

(6) **Struvite crystallization** in a 6.3 l volume fluidized bed reactor (with different upflow velocities, effluent recirculations and different supersaturation ratios between Mg^{2+}:NH_4^+: PO_4^{3-}), seeded with struvite crystals and prior pH adjustments using NaOH.

Acidification and oxidation

Lowering the pH increased the proportion of soluble phosphate (PO_4^{3-}) expressed as % of total P in untreated manure slurry from about 45 % to values between 60-72 % at pH≤4. At lower pH dissolved Ca^{2+} and Mg^{2+} also increased and both elements were almost completely dissolved in solution at pH=3.

Oxidation by peroxide dosing (H_2O_2) further increased release of PO_4^{3-} (90 % of total P as PO_4^{3-} at pH=4 and 100 % of total P as PO_4^{3-} at pH= 3) even at the lowest H_2O_2 concentration tested. Furthermore, H_2O_2 decreased the suspended solid content in the manure (e.g. from 1000 to as low as 50 mg/l) and improved settleability (no settling in untreated or acidified manure vs. 40-60 % decantable clear supernatant after gravity settling in H_2O_2 treatments).

The resulting supernatant matched the molar demands of struvite with P as the limiting compound. The resulting **clear supernatant considerably facilitates P recovery** is in this way possible from raw manure.

Ca^{2+} was removed from the supernatant using oxalic acid (molar ratio Ca^{2+} : oxalic acid of 2.2:1 decreased Ca^{2+} by 90 %) in order to facilitate struvite precipitation.

Based on these optimisations, **relatively pure struvite was precipitated (1-2 mm grains** with different colours) in duplicate experiments using a fluidized bed struvite reactor achieving 95 % soluble phosphate removal.

Anaerobic digestion or raw manure ?

Most studies on nutrient recovery from manure targets effluents from anaerobic digesters or anaerobic lagoons. These streams require further clarification and lack sufficient concentrations of Mg^{2+} and/or have too high calcium levels to allow pure struvite precipitation. The authors suggest **treating the manure with MW, H_2O_2 (0.3 %) at pH=3 could be an optimal route for phosphorus removal and recovery as struvite**.

SCOPE comment: The article does not provide an economic outlook for the applied technology. The probably significant treatment costs (chemical reagents in particular: acidification, sodium hydroxide to return pH for struvite precipitation) will have to be balanced by economic benefits of easier manure application and phosphate recovery. The possibly *significant cost of oxalic acid to chelate calcium could maybe be avoided by precipitating a mixed calcium / magnesium phosphate (instead of pure struvite), subject to this product offering appropriate granulation and fertiliser properties.*

"Recovery of phosphorus from dairy manure: a pilot-scale study". Environmental Technology, 36(11), 1398–404, 2015
http://dx.doi.org/10.1080/09593330.2014.991354

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Summary prepared by WETSUS www.wetsus.nl *for ESPP – SCOPE Newsletter*

Struvite recovery

Airpex process patent

The rights of the existing struvite removal technology AirPrex® developed by Berlin Water and licensed to PCS was acquired by the company CNP-Technology Water and Biosolids GmbH, based in Hamburg, Germany, in July 2014.

AirPrex® represents a sludge optimization process that recovers the high-phosphate mineral struvite (magnesium ammonium phosphate) after anaerobic digestion but before the dewatering process – thereby **saving operating and maintenance costs while adding a revenue source for municipalities**.

Biological nutrient removal

In the past few years more and more sewage treatment plants have implemented enhanced biological phosphorus removal to treat their wastewaters as this procedure can be realised easily from the technical point of view and offers several advantages compared with chemical phosphate precipitation.

The switch from chemical phosphate precipitation to enhanced biological phosphorus removal (EBPR) however frequently leads to undesired consequences:

- Undesired deposits due to the formation of magnesium ammonium phosphate (struvite)
- Poorer sludge dewatering and, simultaneously, rising polymer consumption
- High phosphorus recycle load due to the separated sludge water in biology

Very often, deposits lead to plant equipment and parts failures that push up costs substantially.

In EBPR sewage works, if sewage sludge becomes anaerobic (e.g. in storage, dewatering, digestion), the stored polyphosphates taken up by micro-organisms during the EBPR process can be released as orthophosphates. **Values ranging from 50 - 250 mg/l PO_4-P in the sludge water of anaerobic sludge treatment processes are not unusual**, and result in a high struvite precipitation potential.

Struvite precipitation, resulting in **nuisance deposits**, can happen in particular if and when pressure differences caused by pumping processes occur, especially if the sewage sludge is dewatered by centrifugation. Furthermore, precipitation may already occur in the anaerobic digester itself or in the digester outflow pipe (reduction of the hydrostatic pressure) and further on in the pipe system. After all, even small pH changes, caused by the labile buffer system, can trigger the precipitation process.

Operating benefits

The negative effects and costs associated with struvite deposits in pipes and process equipment can add up quickly for treatment plant operators. Using the AirPrex® system, operators can prevent crystallization in their biosolids treatment chain and reduce phosphate return to the sewage works by more than 90 percent. AirPrex® creates a slow-release fertilizer (struvite) that can be sold, so beneficially recycling phosphorus, and lowers maintenance requirements and reduces dewatering costs. The existing AirPrex® installations have shown that removing struvite before the dewatering process leads to substantial operations and maintenance savings for any plant encountering struvite deposit problems.

AirPrex® P-recovery installations are today operational or coming on line full-scale in the following urban waste water treatment plants (WWTP):

- **Berliner Wasserbetriebe, Wassmannsdorf WWTP, Germany** (1.200.000 P.E.), see SCOPE Newsletter n°101, producing since 2010, 700 tonnes of struvite per year
- **Niersverband, MG Neuwerk WWTP, Germany** (995.000 P.E.), producing since 2009, 365 tonnes of struvite per year
- **Reest en Wieden, Echten WWTP, The Netherlands** (190.000 P.E.), producing since 2013, 180 tonnes of struvite per year

- **Waternet, Amsterdam WWTP, The Netherlands** (1.000.000 P.E.), producing since 2014, 1250 tonnes of struvite per year
- **ASG Salzgitter Nord WWTP, Germany** (120.000 P.E.), start-up 2015)
- **Uelzen WWTP, Germany** (83.000 P.E.), start-up 2015
- **Tianjin WWTP, China** (1.000.000 P.E), start-up 2015

CNP press release www.cnp-tec.com/CNP-Acquisition-Release-Final.pdf *CNP Airprex* http://cnp-tec.com/

Success story
NuReSys P-recycling plants

Belgian SME NuReSys now has eight struvite recovery plants operating in dairy processing, potato processing, pharmaceutical industry and municipal sewage works. The struvite is sold to a fertilizer processor and blended in one of their products.

ESPP member, NuReSys (Nutrient Recovery Systems) installed their first struvite recovery installation in 2006, and now have **ten plants now operating in four different countries** (Germany, Belgium, The Netherlands, Italy).


NuReSys installation at Humana Milchunion E.G., Altentreptow, Germany, 2006

Recovery of a quality fertiliser product

In Belgium, NuReSys-P plants recover about 1.200 tonnes of struvite (= 125 tonnes of phosphorus) per year. The struvite (magnesium ammonium phosphate) produced is a **granular product, with 2-3 mm prills, adapted to use in existing agricultural equipment, with a low organic content (< 1 % carbon), ensuring no odour, easy transport and storage and low contaminant levels.**

Heavy metals are very low in the recovered struvite: arsenic, chromium, copper, lead, nickel and zinc are all < 15 ppm (dry matter), that is 5 – 20 x lower than fertiliser specifications and cadmium and mercury < 0.3 ppm(dry matter), that is 20 – 50 x lower than e.g. specifications for compost (Flanders).

Operating advantages

For biological wastewater treatment, the NuReSys-P struvite removal process offers a number of operating advantages, which contribute to **cost-effectiveness**.

Installation of P-recovery to struvite in digestate before dewatering:

- **avoids nuisance deposits** in the dewatering process, improves dewatering
- **reduces polyelectrolyte additive consumption** needed for dewatering


NuReSys installation at Clarebout Potatoes, Comines-Warneton, Belgium, 2012

- removes phosphorus, so reducing P concentrations in the return stream back to biological nutrient removal process (so **improving biological P removal and facilitating achievement of discharge consents**).

The NuReSys-P process operates in two reactor tanks, a first air-stripper (bubbles) and second stirred crystalliser in which magnesium chloride is precision dosed to enable struvite granule growth. The reactors **reduce inflow (soluble) phosphorus concentration** to 20 mg P-PO_4/l, from inflow concentrations of 60 – 750 mg P-PO_4/l at the eight different sites currently equipped by NuReSys.

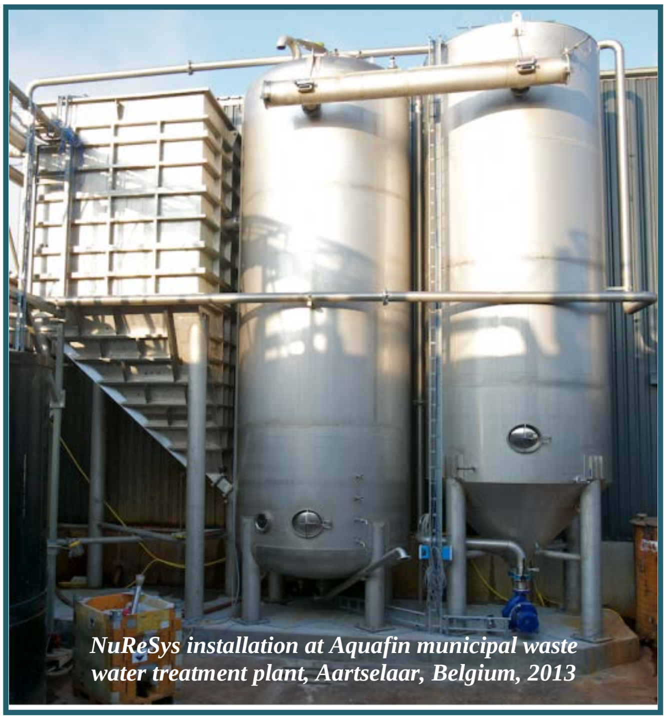
The NuReSys installations operational to date have **capacities ranging from 4 to 125 m^3/hour**.

The latest installation is a **hybrid installation** partially installed on the sludge line and partially installed on the centrate line.

NuReSys currently has a **further 5 projects in discussion** with 4 water companies and 1 industry.

Carl Dewaele, NuReSys, presentation, Berlin ESPC2 March 2015 http://www.phosphorusplatform.eu/conference/espc2015/47-espc2-highlights/596-presentations-at-the-espc2.html

YouTube video (5 mins) https://www.youtube.com/watch?v=t0KK-olGirs



NuReSys installation at Aquafin municipal waste water treatment plant, Aartselaar, Belgium, 2013

Blog

Sustainable P Initiative blog

http://www.phosphorusplatform.eu/blog.html

Nutrient Platforms

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

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

Flanders (Belgium): ***http://www.vlakwa.be/nutrientenplatform/***

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

North America Partnership on Phosphorus Sustainability NAPPS ***https://sustainablep.asu.edu***

Upcoming events

- 19-22 August, Tampere, Finland: **Global Dry Toilet Conference** *www.huussi.net/en*
- 30 Aug – 2 Sept, Ghent, Belgium, Bridging towards the chemical industry1st **IWA Resource Recovery Conference** *http://www.iwarr2015.org/*
- 2 Sept, Ghent, **BioRefine** final conference *http://www.biorefine.eu/biorefine/news/save-date-biorefine-final-conference*
- 3-4 Sept. 2016, Ghent, Belgium. **Workshop on nutrient data & monitoring to support decision making**. Data on Nutrients to Support Stewardship DONUTSS. *brusselsoffice@phosphorusplatform.eu*
- 8-10 September, Son, Norway (50 km from Oslo), 23rd Symposium Int. Sci. Centre for Fertilisers – **Plant nutrition and fertilisers for cold climates** *http://www.bioforsk.no/ikbViewer/Content/118311/CIEC%208.-10.%20september%202015.pdf*
- 18 Sept. Milan (San Rocco wwtp) **Resource Recovery in Wastewater Treatment Plants** *www.metropolitanamilanese.it*
- 15-16 September, Toledo, Spain **REFERTIL** EU FR7 project final meeting *http://www.refertil.info*
- 16-17 Sept, Padeborn, Germany "**Sewage sludge handling**", 17 Sept. P recovery workshop (in German) *www.vdi.de/klaerschlamm*
- 17-18 September, Toledo, Spain REFERTIL **Advanced compost and biochar processing solutions for P-recovery** *http://www.refertil.info*
- 23 Sept, Milan EXPO, **RISE Sustainable Intensification and Nutrient Recovery and Reuse in Agriculture** *http://www.risefoundation.eu/news/135-expo-conference-nutrient-recycling-2*

- 28-30 Sept, Wexford, Ireland, **Catchment Science 2015** *http://www.teagasc.ie/agcatchments/catchmentscience2015.asp*
- 1-2 October, Vienna University of Technology, "**Mining the Technosphere**: Potentials and Challenges, Drivers and Barriers" *http://iwr.tuwien.ac.at/mining-the-technosphere/home.html*
- 5-6 October, Frankfurt, **Energy from Chemical Fuels**, session on P-recovery and use *http://www.kic-innoenergy.com/event/energy-from-chemical-fuels-2015/*
- 5-8 October, Karlsruhe, Germany, **CMM (Materials Processes Systems)** DPP P-recovery session (8/10) *www.cmm.kit.edu*
- 11-14 October 2015, Ithaca, New York, USA, 2nd International Conference on **Global Food Security** *www.globalfoodsecurityconference.com*
- 12-13 October, Manchester UK, 9th European **Waste Water Management Conference** *http://www.ewwmconference.com/*
- 30 October 2015, Berlin. **DPP German national phosphorus plan meeting**. *www.deutsche-phosphor-plattform.de*
- 2-6 Nov, **Amsterdam International Water Week** *http://internationalwaterweek.com/*
- 9-11 Nov, Manchester UK, 20th European **Biosolids & Organic Resources** Conference *www.european-biosolids.com*
- 15-18 Nov. Minneapolis, US **ASA-CSSA-SSSA-ESA soil science meetings** *www.acsmeetings.org* including session 'Tracking Legacy Phosphorus in Lakes and Rivers' *https://scisoc.confex.com/scisoc/2015am/webprogrampreliminary/Session14624.html*
- 18-19 November, Minneapolis, **SERA-17** promoting promote innovative solutions to minimize phosphorus losses from agriculture *http://www.cvent.com/events/2015-sera-17-meeting/event-summary-4eb969f0be224a25821b4372c54c34a5.aspx*
- 25-26 Nov., Berlin, Germany, **Global BioEconomy Summit 2015** *http://gbs2015.com*
- 2-4 Dec 2015, Ghent, Belgium, **ManuResource II** (manure valorisation) *http://www.manuresource2015.org/*
- 14-18 December, San Francisco, AGU (Am. Geophysical Union) Conference, Workshop '**Human alteration of the P cycle**' *https://agu.confex.com/agu/fm15/preliminaryview.cgi/Session8517*
- 15-19 Jan. 2016, Arizona, **US P-RCN** (Sustainable Phosphorus Research Coordination Network) *https://sustainablep.asu.edu/*
- 10 Feb2016, Leeuwarden Netherlands, **EIP Water Conference** *http://www.eip-water.eu/save-date-next-eip-water-conference-10-february-2016-leeuwarden*
- 13-15 March 2016, Paris, **Phosphates 2016** (the phosphate industry conference) *http://www.crugroup.com/events/phosphates/*
- 7-10 Mar. 2016, Berlin, **European Workshop on Phosphorus Chemistry** and 2nd **International Conference on Sustainable Phosphorus Chemistry** (**SUSPHOS**) *www.susphos.eu*
- 5-9 Sept 2016., Windermere, Lake District, England, **International Organic Phosphorus Workshop 2016** *http://soilpforum.com/*
- 12-16 Sept 2016 Rostock, Germany, **8th International Phosphorus Workshop (IPW8),** Phosphorus 2020 – Challenge for synthesis agriculture & ecosystems *http://www.wissenschaftscampus-rostock.de/*

Public consultation

IMPORTANT ! – respond now to the EU Circular Economy public consultation: deadline 20th August

*In particular, you may wish to respond to the following questions relevant to "**Bio-nutrients**"*

Q. 5.1 & 5.2 development of markets for secondary raw materials

Q. 5.3 priority markets for action (→ Bio-nutrients)

Q.6.1 & 6.2 sectoral measures (→ agriculture, bio-nutrients, water)

http://ec.europa.eu/environment/consultations/closing_the_loop_en.htm