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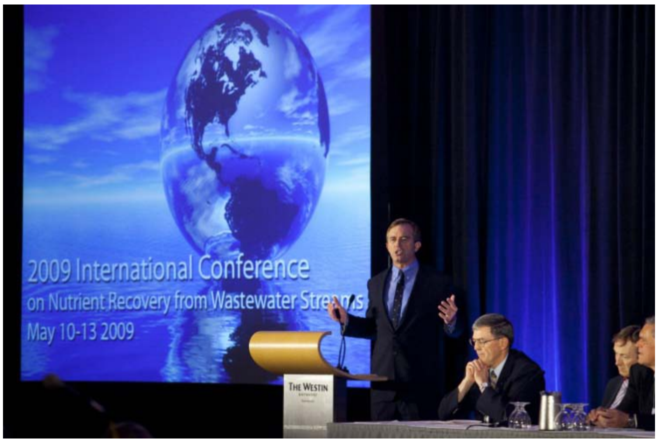
The International Conference on Nutrient Recovery and Recycling, held in Vancouver May 2009, brought together over 200 delegates from across the world, confirming the increasing recognition that recycling phosphorus and nitrogen will be essential for sustainable development.

This was the first major conference on this theme on the American continent, following conferences on P-recovery from sewage and animal wastes organised in 1998, 2001 and 2004 in Europe, under the initiative of the phosphate industry.

The Global Phosphate Forum, which brings together the worldwide detergent phosphate industry, contributed to the organisation of the Vancouver Conference, providing information, contacts, expertise and seed funding. The detergent phosphate industry recognises the importance of phosphate recycling and sees it as part its own sustainable future.

The detergent phosphate industry has clearly positioned phosphate recycling in its strategy for the future since 1998, in recognition that phosphates are the only recyclable component in detergents. This is demonstrated by its ongoing commitment to promoting R&D in this area, for example by supporting the International Nutrient Recycling Conference in Vancouver, but also by actual recycling of phosphate as by Thermphos in the Netherlands.

P-recovery from sewage is necessary for a sustainable future whether or not phosphates are used in detergents, because most of the phosphates in sewage come from natural human emissions. Phosphates from detergents are the same molecule in sewage as human phosphates, and so are recovered and recycled where P-recovery is installed, or where sewage sludges are used in agriculture or aquaculture. **Phosphate recovery from sewage is essential for a sustainable future and phosphates are thus the only recyclable detergent component**.



*Robert F. Kenned, **include** Dr. James Barnard (2007 Clarke Prize), Robert F Kennedy (Chief Prosecuting Attorney for the Hudson Riverkeeper and President of Waterkeeper Alliance) opening the conference*

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Nutrient recovery conference

Decisions on nutrient management

Today, many developed countries are at a key decision point for phosphorus recycling. The coming few years will see massive investments in nutrient <u>removal</u> in sewage works, to achieve fresh water quality objectives (USA TDMLs, Water Framework Directive in Europe). The water industry's "easiest" solution is chemical P-removal, which involves dosing with alum or iron, so generating increased sludge which has to be transported and disposed, and for large cities where there is little farmland or if sludge is contaminated, with the complete loss of the phosphate, nitrogen and other nutrient values of the sludge. The decision to move to biological P-removal and P-recovery will depend largely on regulators, who fix the requirements under which water companies operate.

Johnny Carline Metro Vancouver

Biological P-removal in sewage works implies higher investment costs and requires better process engineering, but avoids chemical consumption, and can be combined – as many of the presentations at the Conference showed, using various technologies – with recovery of the phosphate and nitrogen for recycling. It is now that <u>regulators</u> must decide to target sustainable sewage treatment, making sewage into a resource, rather than continuing to treat it as a waste, with loss of the nutrients, and increasing energy consumption, chemical use and greenhouse emissions. **Regulators must bring recycling objectives into the regulatory framework requirements for sewage treatment**.

The UK recently published an official assessment, concluding *"the feasibility of reusing phosphates recovered from sewage treatment plants should be investigated … Recovery and use of phosphorus as struvite also offers a number of major sustainable advantages, including natural resource protection of phosphate rocks and environmental enhancements through nutrient recovery / recycling and reduction in greenhouse gases…"*

http://www.defra.gov.uk/environment/chemicals/achs/

Phosphate recycling in practice

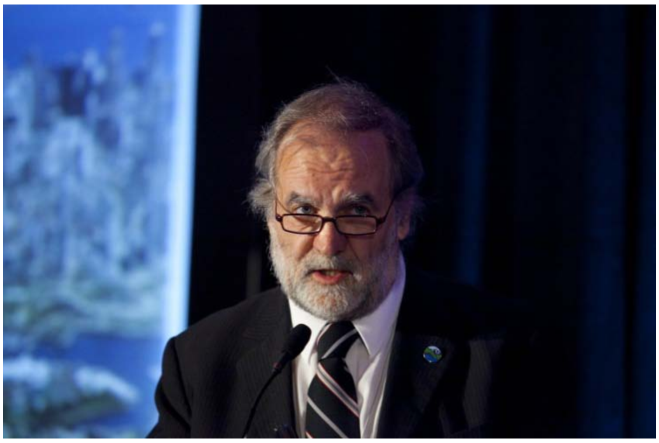
P-recovery is already operational in a number of places across the world, showing development from isolated pilot projects at the time of the first international conference organised by the phosphate industry in 1998 to full scale operations today. The routes and technologies for P-recovery vary widely depending on local circumstances, as was shown by the variety of processes presented at this conference.

In the Netherlands, for example, the phosphorus factory of Thermphos International uses a process which allows the use of sewage sludge incineration ash as a replacement for phosphate rock as a raw material. Already around 8,000 tonnes/year of ash are being used by Thermphos from SNB, which manages sludge incineration plants for about one quarter of the country's municipal sewage, thus recycling the phosphorus content. It is intended to increase this to around 20,000 tonnes of ash/year by 2010, by convincing the sewage works operators to modify their processes to avoid adding iron chemicals which are incompatible with this P-recovery route.

The Ostara process, developed by University of British Columbia, host of this conference, is already proving successful in several sewage plants in Canada and the USA, and is now being tested in Israel and the UK. This process recovers phosphate from sewage works operating biological P-removal, as struvite, a high-quality, slow release fertiliser, with economic value.

A new vision for sustainable development

Robert F Kennedy opened the conference, setting a positive note, stating the urgency of addressing environmental issues in today's society, and emphasising that the new US Administration is taking this on board with plans for major investments in clean technologies and renewable energies. Carbon emissions and environmental degradation are a drag on capitalism he emphasised, as costs of depollution, protecting strategic oil reserves and importing oil and minerals all escalate. Changing to an economy dependent on renewable energies and recycling is a switch comparable to the abolition of the slave trade – another unacceptable form of energy which at the time was the motor for the economy – but this was done in years, and gave the innovation impetus looking for new energies and processes which caused the Industrial Revolution.



Johnny Carline Metro Vancouver

Nutrient recycling is as vital to our future as renewable energies, and the participation and papers at this Conference showed that this issue is now coming onto the agenda of international organisations, local authorities – as emphasised by Johnny Carline of Metro Vancouver in the opening session – and businesses. Indeed, recycling of phosphate, nitrogen and organics from “wastes” such as sewage or animal manure directly contribute to reducing greenhouse gas emissions (in fertiliser production, transport, etc). **Phosphate recovery from sewage is thus in synergy with reducing other environmental impacts**, and so makes long term economic sense.

Phosphate futures

Phosphate recycling is particularly critical in the long term, because there is no replacement. Oil can, no doubt with difficulty, be replaced by solar or biofuel energy, but without phosphates, crops simply cannot grow, and humans cannot live.

A number of speakers addressed how long the world’s phosphate reserves will last. The answer is not clear, and will depend strongly on demand for phosphate fertiliser to feed the world, and so on farming and population. However, it seems clear that high quality reserves will be largely used up in 50-100 years, and that the price of phosphates will progressively increase, as reserves become more difficult to exploit and depleted. The abrupt and several-fold price increases of 2008 were probably only temporary, related to mine equipment capacity problems, but the overall long-term trend will be price increases. Already farmers in many developing countries cannot afford phosphate fertiliser, and so agricultural productivity is reduced, accentuating the global food crisis. Appropriate techniques for phosphate recycling from sewage using urine recovery, aquaculture, composting, are vital for a sustainable future in these economies.

The pressure on nutrient supplies will also increase with the potential development of **biofuels**. Be it fuel crops such as corn or aquaculture of algae, productivity will depend directly on phosphate inputs, as phosphate is essential for any plant growth. So significant development of biofuels will only be possible if phosphates are recycled both from the biofuels themselves, and from other waste streams.

Dr. James Barnard (2007 Clarke Prize)

Peak phosphorus

Oil can conceivably be replaced by biofuels and other renewable energies, be it with major technical, social and economic obstacles, whereas phosphorus is a non-replaceable as well as non-renewable resource. **The world’s food production depends on phosphorus, as do a range of industrial products**.

- Cordell *et al.* put phosphorus recovery in the context of global sustainability, emphasising that all modern agricultural systems – and so feeding the world – depend on a constant input of phosphate fertilisers made from mined phosphate rock, of which resources are limited. They estimate that, under current practices, phosphate rock production will peak around 2033 and that P-recycling is essential to avoid the global food insecurity which would ensue (see also Phosphorus Futures: www.phosphorusfutures.net summarised in SCOPE Newsletter n°73)
- Barnard emphasised biological nutrient removal, with P and N recovery, as a sustainable choice for sewage treatment in response to the need to protect surface waters from eutrophication
- Sutton *et al.* presented an overall sustainability approach to waste water treatment, including carbon recovery (as methane for energy), removal and recovery of nitrogen and phosphorus
- Van Horn *et al.* examined the impacts of supply and demand on the price of phosphate fertiliser, predicting that the massive increase in prices of phosphate raw material prices in 2007-2008 would be largely reversed, but within a long-term context of increasing price as resources are depleted
- Li & Sommer (poster) presented an assessment of the global amount of phosphorus potentially available for recovery in waste streams

Direct recycling of sewage nutrients

The best route for recycling phosphate is to spread sewage biosolids on agricultural land, after treatment to ensure sanitisation. This enables recycling of phosphates, but also of nitrogen, potassium and other minerals, and organic soil improvement. Today more than half of phosphates in European sewage are recycled through agricultural spreading of sewage biosolids. In the UK, phosphate in sewage biosolids recycled to land is equivalent to 15% of national use of mineral fertiliser.

However, in some cases, agricultural use of sewage biosolids is not feasible, because of contaminants in sewage, public perception, or difficulties of transport and storage. In particular, large cities produce sewage all year, whereas cropland in urban areas is limited, and agricultural requirements are seasonal. In such cases, phosphate can be recycled in sewage works, in compost, through onsite biomass cultivation (aquaculture) or by pP-recovery as above.

The conference conclusions emphasised that all spreading of sewage sludge to land cannot be considered as recycling. If iron chemicals are used for chemical P-removal in the sewage works, then the sludge phosphate is poorly plant-available and, depending on soil type and pH, may even reduce long-term soil phosphorus available to crops. In many cases, sludge is spread not according to crop nutrient needs but "up to" disposal limits, resulting in both nitrogen and phosphorus being applied at seasons when not needed by crops, or beyond crop requirements, and so not being effectively recycled.

Phosphorus recovery by precipitation

A number of papers looked at precipitation of phosphates in a recyclable form from liquid waste streams, in particular digester liquors or return streams in sewage or animal manure treatment plants. **Struvite precipitation continues to appear as a promising route in many situations**, but this will depend on local conditions and constraints, and calcium phosphate precipitation also appears to be effective in some manure streams.

Several papers presented work **modelling the thermodynamics and control of struvite precipitation** (eg. Lobanov modelling increased crystal size obtained by progressive pH increases, Hanhoun *et al*., Gadekar *et al*.), approximate analysis of precipitation products (Hao *et al*.), as well as reviews of nucleation studies (Galbraith *et al.)* and modelling and process engineering (Schneider *et al*.).

Beier *et al.* presented process modelling assessment of P-recovery potential. Dockhorn examined the economics of P-recovery by precipitation, suggesting that the use of sea water as a magnesium source offers particular cost advantages

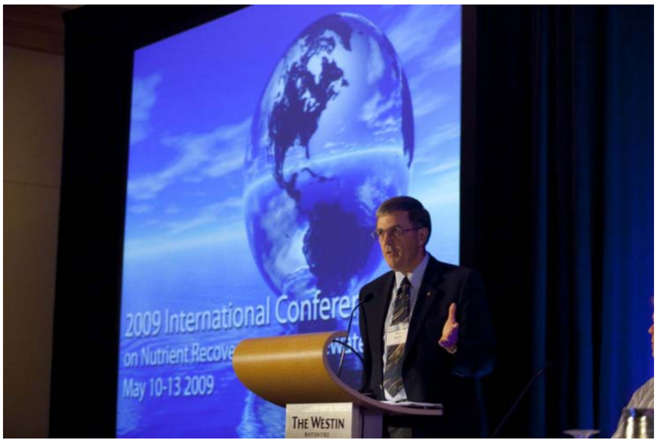
Work into struvite precipitation presented included a number of papers on experimental precipitation in pure chemical solutions in beakers or lab scale reactors, and a comparison with papers previously published (see eg. back issues of SCOPE Newsletter) suggests that although considerable investigation has already been done into struvite precipitation at the laboratory scale and in pure chemical solutions (or "synthetic" wastewaters), it would appear that in some cases "known" experimental results are being repeated without adequate exchange of information between groups doing such work at present or having done so in the past.

Although struvite precipitation in sewage works side streams will recover potentially only 50-60% maximum total sewage inflow phosphorus, it appears an **operationally feasible and effective route for significant P-recovery**.

Operational struvite recovery

On the other hand, a number of papers show that **struvite precipitation is already successfully operational at full industrial scale** (eg. Ostara, see above) or at the pilot plant scale:

- Sanchez *et al*.: 2.7 litre pilot operating in a seafood factory, Galicia, Spain
- Yuan *et al*.: in combination with biomass fermentation for VFA production (volatile fatty acids)
- the UBC (University of British Columbia, Vancouver, Canada) R&D work, which led to the development of the industrial Ostara process, is ongoing, with papers covering reactor hydrodynamics (Rahaman *et al*.), economic evaluation (Britton *et al*.), solubility products (Forrest *et al*.), process control (Fattah *et al*.), temperature and electrical conductivity (Ibqal *et al*.), CWS Durham operating experience in a municipal sewage works (Baur *et al*.), application after ATAD high temperature sludge treatment (Dirk *et al*.), in combination with membrane EBPR (Srinivas *et al*.)



Don Mavinic, University of British Columbia, ongoing struvite recovery research and development, and conference coordinator.

- Stumpf *et al*.: 45 litre pilot testing at Berlin Wasser sewage plants, Germany
- Moerman *et al*., Belgium: 200 litre pilot reactor operated in three different potato industry plants and full scale NuReSys 125 m^3 reactors in a dairy products industry plant and

in a potato processing plant (influent around 60 mgP/l)

- Lew *et al.*, Israel: 32 litre pilot operating in sludge dewatering liquor at Karmiel municipal STP
- Song *et al.*, Beijing, China: 10 m^3/day pilot recovering struvite from swine wastewater after anaerobic treatment
- Daumer *et al.*: flask scale struvite precipitation from two piggery wastes after biological treatment and acidification
- Marti *et al.*, Valencia, Spain: pilot scale assessments of a struvite recovery reactor (the LAGEP Lyon reactor, see Mangin *http://www.phosphorus-recovery.tu-darmstadt.de/index.php?option=com_docman&task=doc_download&gid=2* as part of an overall analysis of P-precipitation and P-recovery in development of biological nutrient removal and digester processes

Magnesium sources

A number of authors emphasised the **potential of alternative sources of magnesium for struvite precipitation**, in order to avoid chemical purchase costs. Ostara at Lulu municipal sewage works, Vancovuer, are using seawater as a magnesium source, as has also been tested by other authors (eg. in Japan). Bittern (seawater desalination liquor, see SCOPE Newsletters 66 and 70), magnesium industry byproducts (see Qunintana, SCOPE Newsletter no 73), natural magnesium rock deposits (see Gunay, SCOPE Newsletter no 73) have been demonstrated as potential secondary magnesium sources. Lobanov at the Vancouver conference also suggested that a by-product liquor from the potassium fertiliser industry could also provide a good magnesium source.

Experience presented at the previous P-recovery conferences (eg. Thames Water UK, Berlin Wasser Germany …) has shown that **struvite deposit problems occurring in biological nutrient removal (BNR) sewage works are often the key driver for installing struvite precipitation**. This was confirmed by papers presented in Vancouver:

- Baur explained how struvite deposit problems appeared in the anaerobic digester centrate holding tank at Clean Water's Durham sewage works, Tigard, Oregan, after conversion to ENBR. Ostara struvite recovery is being implemented to address this problem. The recovered struvite is sold as fertiliser to the local nursery plant industry.
- The Edmonton sewage works site visit after the conference, also saw a situation where deposit problems in a long underground pipe between the BNR sewage works and sludge lagoons had been has been the driving force for installing Ostara struvite recovery technology
- Barat *et al.* presented modifications to the sludge line upstream of the digester at the Taragona waste water treatment plant, Spain, aiming to avoid struvite precipitation problems and deliver a high concentration phosphate liquor suitable for P-recovery as struvite.
- Barat *et al.* presented the struvite precipitation problems at this WWTP following a detailed mass balance.

Fertiliser value of recovered phosphates

- Cabeza Perez *et al.* presented field and pot trial results with recovered struvites, a recovered calcium phosphate, a meat and bone sinter ash and a furnace slag. The struvite showed the best fertiliser effect of the recovered products, but with lower short-term effect than commercial phosphate fertilisers (54% to 138% of triple super phosphate 60 depending on soil type). The struvite with a higher iron content showed a lower fertiliser effect. Long-term effect studies are now planned.
- Weinfurtner *et al.* also presented maize pot trials using the same range of recovered phosphate products, plus sludge incineration ashes, concluding that no correlation could be found between the products' measured effects on plant-available P and plant P-uptake. Only the Seaborn recovered struvite (see below) and one of the other two recovered struvites showed plant uptake comparable to (or marginally better than) triple super phosphate in both sandy and loamy soils.
- Pellet *et alI* and Stockner *et al.* (posters) presented the need to fertiliser salmon rivers in the Pacific Northwest, to compensate the loss of nutrients no longer imported from the sea by migrating salmon whose movements are prevented by dams, and of nutrients retained in upstream dams on tributaries (see SCOPE Newsletter no 53). Ostara's sewage-recovered struvite has been successfully tested as a nutrient source for such fertilisation, giving positive results compatible to other organic and mineral fertilisers used.

Calcium phosphate precipitation

Other papers looked at calcium phosphate precipitation from waste waters, showing that although this is generally unrealistic in sewage treatment plants (eg. because of carbonate interference, resulting in the need for high chemical demand), it can be effective in animal manure streams:

- Vanotti *et al.* presented full scale calcium phosphate recovery from manure at two c. 4,000 head pig farms. The phosphate precipitation is part of an integrated process, replacing manure lagoons, with solid-liquid separation producing a saleable compost used as artificial soil in vegetable production (and containing a majority of the inflow phosphate), denitrification, and calcium phosphate precipitation to remove and recover the remaining phosphate.

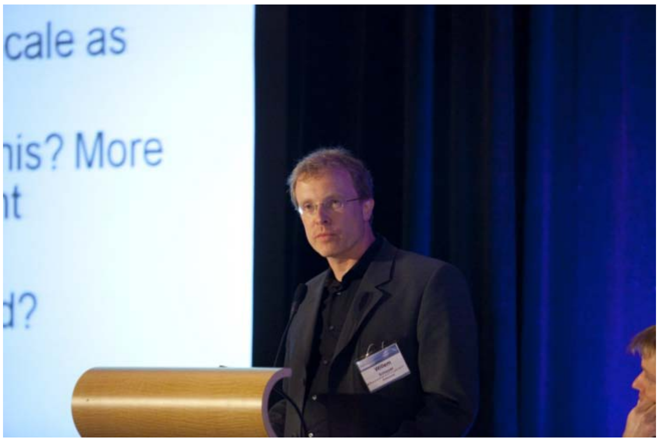
Other processes

Other more novel or specific processes presented for phosphate recovery by precipitation from sewage liquors included:

- P-precipitation using a CSH (calcium silicate hydrate) substrate : at the 5 litre bench scale (Karlsruhe, Germany, Ehbrecht *et al.*), and at a 40 litre scale with municipal STP clarifier effluent and at a 150 litre scale precipitating into sludge (TU Darmstadt, Germany, Petzet *et al.*)
- BoironTech process using iron reducing bacteria (Ivanov *et al.*)
- ozonisation and phosphorus adsorbent (Kozo *et al.*)
- using ochre from mine water treatment (Carr *et al.*)
- using zinc aluminium layered double silicates (Cheng *et al.*)
- RGU + RoHM Seaborne sludge treatment process, where anaerobically stabilised sludge is treated with sulphuric acid, solids are incinerated, and the soluble part is treated to remove heavy metals by precipitation prior to P-recovery by struvite precipitation (Phan *et al.*)
- using scum-forming filamentous bacteria which widely appear in BNR plants (biological nutrient removal) offer an interesting potential for improving both P-removal performance and P-recovery potential. Such floating scum can be easily collected and offers a higher bio-accumulated concentration of phosphorus than most BNR sludge. This P is also readily released, so that such bacteria could provide a route for improving availability of phosphorus for recovery in side streams (Suschka *et al.*)
- nutrient recovery from household urine in Sweden using P-precipitation and zeolites (Ganrot *et al.*)
- urine concentration (Massoom *et al.*)
- struvite recovery from urine, as particularly adapted to the infrastructure, economic and social challenges or developing countries (Tilley *et al.*)
- membrane capacitive deionisation (MCDI) for concentration of urine prior to nutrient recovery, showing increases in ammonia, potassium and phosphate concentrations of 78%, 13% and 85% (Kuntke *et al.*)
- re-use of urine in bamboo cultivation as a route fur nutrient recycling, water purification and production of a valuable crop (Ndzana *et al.*).

Sludge incineration ash

A number of papers looked at **routes for recycling of phosphorus from sewage sludge incineration ashes**, where sludge cannot be recycled by other routes and has to be incinerated. These contain phosphate levels which can approach those in mined phosphate rock.



Willem Schipper, Thermphos International

Such recycling is already operational at the Thermphos International phosphorus factory at Vlissingen, The Netherlands (Schipper *et al.*) where some 8,000 tonnes/year of sludge incineration ash is already used today to substitute phosphate rock. The ash is supplied by SNB (Sliberverwerking Noord-Brabant), which produces some 37,000 tonnes/year of ash from 95,000 tonnes of sewage sludge dry matter, that is around 28% of The Netherlands total sewage sludge (that is, sewage sludge from around 2 million population, 70 municipal sewage works). Although copper and zinc in sewage pose some difficulties for use of the incineration ash by Thermphos, the main obstacle is sludge iron content. By separation of high and low iron sludge streams, by economic incentives to STP operators, SNB and Thermphos hope to be able to recycle phosphate from around 20,000 tonnes of sludge by 2010.

Transport and storage costs, relating to the fact that the **sludge incineration ash is a fine powder requiring specific dust-free handling**, render problematic for Thermphos to take ash from longer distances from its Vlissingen site on the Netherlands coast. However, technical solutions in incineration ash processing may be able to address this issue in the future.

For situations where direct recycling of sludge incineration ash is not possible, several papers looked at possible but **more complex processes for recovering phosphates from sludge incineration ashes**, also from meat and bone meal ash:

- high temperature treatment (Ashdec process – firing with $MgCL_2$: acid elution - Hermann *et al.*, Nanzer *et al.* ; PASH process: Dittrich *et al.*)
- nanofiltration (Niewersh *et al.*)
- shaft furnace (Scheidig *et al.*)
- overview of different such routes (Adam *et al.*, Schaum *et al.*, Eichler-Loeberman *et al.* and Montag *et al*.).

Nitrogen recovery

It is clear that although there is no "one" best solution, **biological nutrient removal from sewage is more sustainable than chemical P-removal**: no chemical addition, reduced excess sludge production, phosphate available for recycling, or plant-available if sludges are used on crops or for aquaculture.

Where sludge phosphate cannot be recycled to crops, in response to agronomic plant requirements, **the potential of P-recovery (struvite precipitation, sludge incineration ash use in the phosphate industry ...) is now recognised to further improve waste water treatment sustainability**. To date, however, only limited work has been done into nitrogen recovery, despite the significant greenhouse gas emissions gains possible in recovering nitrogen (and so substituting fertilisers manufactured from atmospheric nitrogen, at considerable energy cost). Struvite P-recovery ensures recycling of some nitrogen, but only a small proportion of that present in sewage because of the 1:1 P:N ratio in struvite. Several papers at the conference did address specific nitrogen recovery routes:

- ThermoEnergy Ammonia Recovery Process ARP (Orentlicher *et al.*)
- Ammonium absorption of nitrogen to vermiculite (Akerback *et al.*)
- Optimising anoxic – aerobic processes in waste water treatment for nitrogen recovery (Wäger *et al.*).

Nutrient recovery from animal wastes

Animal manure waste streams offer a major potential for nutrient recovery, with total nutrient resources available higher than those in municipal wastewaters, and important nutrient pollution abatement drivers in regions with concentrations of livestock production. Different papers presented various aspects of nutrient recovery from animal wastes (in addition to those covered under struvite and calcium phosphate precipitation above):

- Recovery of phosphate from incineration of meat production wastes and bone measl, already operational at several sites in Europe following restrictions on the use of this "waste" for food applications because of mad cow (BSE) concerns (*Kabbe & Jakob*)
- Membrane plus biological treatment in maze processing plants (Rausch *et al.*)
- Membrane reverse osmosis in swine manures (Masse *et al.*)
- Phosphate and nitrogen separation in pig dairy manures (Jorgensen *et al.*)
- Microwave enhanced oxidation for dairy waste waters (Kenge *et al.*)
- Flocculation solid separation of swine manures using polymers and iron chloride (Hjorth *et al.*)
- Manure incineration ash as a P-recovery source (Thygesen *et al.*)
- Technologies for better application of manures to fields (Nyord).

Following the considerable interest and developments presented at this conference, organisation of a further meeting (or meetings) at the world or continental levels in 2010 or 2011 is currently being considered, as well as an information exchange forum on nutrient recovery.
If you are interested, please contact: *coordinator@global-phosphate.org*.
For further updates, please consult the phosphate recovery website: *http://www.phosphorus-recovery.tu-darmstadt.de/*

Full proceedings are available from: IWA (International Water Association)
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For further information and updates on phosphorus recovery and recycling:

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