SCOPE NEWSLETTER

NUMBER 87 July 2012

P resources and policies

Phoenix, Arizona

Spatially represented urban phosphorus budget

Phosphorus fluxes and pools were assessed for the Phoenix urban area, Arizona. Spatial assessment enabled analysis of the relationships between phosphorus management, water management and land uses.

Manitoba, Canada

Province regulators push nutrient recycling

Regulations in Manitoba Province, Canada, require nutrient reuse, and promote P-recycling as a Best Available Technology for sewage and manure treatment.

Germany

Routes for P-recovery from sewage

Overview of routes and processes for recovering phosphorus from sewage or sewage sludge, including P-recover potential, technology development.

Denmark

Policy options for a sustainable P cycle

A report to Denmark's government assesses policy options for addressing phosphorus scarcity and promoting a locally sustainable phosphorus cycle.

Nutrient recovery in biomass

Biodiesel and nutrients

P and N recycling in biofuel algae production

Effective recycling of nutrients in algae cultivation and processing for biofuels will be essential for sustainability.

Lemna duckweed

Sewage nitrogen recovery in aquaculture

Duckweed ponds were used to pre-treat experimental sewage treatment effluent input to fish aquaculture in order to improve nitrogen removal and recovery rates.

India

Recycling sewage in carp aquaculture

Experimental use of sewage to provide nutrient inputs to carp aquaculture production showed similar fish productivity to fertiliser use and 64% better water productivity.

France-China

Biomass production for nutrient recovery from swine wastewater

Vermiculture, artificial wetlands and macrophyte ponds were combined to treat piggery wastewater and enable partial recovery of nutrients.

P-recovery from sewage

Berlin Wasserbetriebe

Through R&D to full-scale P-recovery

After a decade of R&D, Berlin Wasserbetriebe is now operating full-scale struvite recovery at its Wassmannsdorf sewage treatment plant, producing some 500 tonnes of struvite per year, sold locally as a fertiliser.

Sewage sludge

Acidic oxidation and nanofiltration P-recovery

Lab scale testing of an integrated acidic oxidation - nanofiltration process for sludge treatment and P-recovery.

Switzerland

Calcium phosphate fertiliser from sewage sludge ash

Acid leaching, heavy metal removal and lime addition were tested to recover calcium phosphate from sewage sludge incineration ash. Plant growth experiments assessed the fertiliser value.

Review

Phosphorus recovery from biomass ash

Review and data summary for the potential for nutrient recovery from ashes produced by incineration of different biomass wastes and by-products.

Sludge incineration ash

Acid - alkali elution of aluminium and P

Laboratory tests suggest that sequential acid and alkali elution of sewage sludge incineration ash can recover phosphates and enable aluminium recycling as a wastewater P-precipitation salt.

Conferences and publications

è See page 2

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Publication

Plant and Soil special issue

Phosphorus sustains life – P in soil

A special issue of "Plant and Soil" addresses P-forms and availability in soils, P in plants and agriculture, P dynamics, management and environmental impacts. See page 15

Conferences

Harbin, China, 23-25 September 2012

Nutrient Removal and Recovery 2012

International Water Association's third conference on nutrient removal in sewage works (following two first conferences in Poland in 2005 and 2009), with sessions on phosphorus recovery and low carbon nutrient recovery. Biological nitrogen removal processes

- New technologies of biological phosphorus removal and recovery
- Bioreactors applied for NRR
- Low carbon technology involving nutrient recovery
- NRR in wastewater treatment plants (WWTPs)
- Emerging molecular methods of identifying microorganisms in NRR processes
- Round tables including: Nutrient Removal and management in China, Nutrient Removal and Recovery technologies of the future: new challenges and new concepts

http://www.iwanrr2012.org

Cincinnati, 21-25 October 2012

P Removal and Reuse From Manures

Wednesday 24th October, international symposium: "Opportunities and Limitations of Phosphorus Removal and Reuse From Manures", looking at policy perspectives and technologies for phosphorus recycling from manures.

21-24th October ASA, CSSA and SSSA International Annual Meetings "Visions for a Sustainable Planet"

24-25th October SERA-17 (USDA / Phosphorus Index Core Team) 2012 meeting addressing minimising phosphorus losses from agriculture

- **P-recycling symposium:** ***http://scisoc.confex.com/scisoc/2012am/webprogram/Session9632.html***
- **ASA, CSSA and SSSA Meetings:** ***https://www.acsmeetings.org/***
- **SERA-17:** ***www.sera17.ext.vt.edu***

Netherlands, 1 November 2012

European Conference on Sustainable Phosphorus Management

Looking at European policies, including the legislative framework and business cases).

Organised by the Dutch ministries of Economic Affairs, Agriculture and Innovation, Infrastructure and Environment and Foreign Affairs with the Dutch Nutrient Platform and within the Netherlands Value Chain Agreement.

www.nutrientplatform.org

P resources and balances

Phoenix, Arizona

Spatially represented urban phosphorus budget

This paper takes three approaches to understanding phosphorus cycles in the Phoenix metropolitan area, Arizona. A mass balance is developed to estimate natural and anthropogenic fluxes of phosphorus into, within and out of the area. Principal pools of stored phosphorus in the environment were estimated, including in built environment. Finally land use and land cover data were used to visualise this information spatially.

The Phoenix metropolitan area and surrounding desert area, as studied, has a population of c. 4 million in c. 6 400 km^2, of which around 25% is urbanised. The city population grew >30% from 2000 to 2010, and today **only 11% of land area is used for agriculture**, with the remainder undeveloped desert, or used for recreation or water surface, in addition to the urbanized area. The region is semiarid, with water supplied by three rivers (Salt, Verde and Colorado) and groundwater, and then largely treated after use and recycled to agricultural irrigation and industrial uses.

Water management

Phosphorus cycling showed to be closely related to water management. Phosphorus inputs to the area include phosphorus carried in the river waters (dissolved and particulate phosphorus), though these inputs are very small compared to inputs of food and fertilizer. Much of the phosphorus produced by industry, from human population, and from other sources goes to wastewater, which in part goes to agriculture after treatment. Stormwaters carry phosphorus from land to rivers and phosphorus leaves the area in the Salt and Gila river outflows.

A water budget for the area was constructed to calculate phosphorus flows in this water subsystem, and data for water chemistry, wastewater treatment effluents and biosolids P concentration were used.

Pools and fluxes of phosphorus were estimated for non-agricultural vegetation (including garden trimmings which were assumed to be landfilled or composted), and for agriculture. Crops were assumed to be consumed locally until demand is met (consistent with the methodology of Baker et al. 2001, nitrogen budget for Phoenix), except cotton which is exported.

Pools and fluxes were estimated for the human population, pets (dogs and cats) and agricultural livestock, taking into account food consumed, food wastes, manures and municipal wastewater.

Net P sink

The Phoenix metropolitan area is shown to be a net phosphorus sink, **accumulating 8 500 tonnes P per year**. The largest inputs are human food (48%) and fertilisers (24%). Phosphorus leaving the area represents just 0.7% of inflows.

Spatial analysis, shown as coloured maps, shows that high accumulation of phosphorus occurs in agricultural areas, and that high throughput (input plus output) occurs in both agricultural and urban areas.

The principal pool of phosphorus present in the area is soils (total P present in the pool, not annual change): desert soils, agriculture soils, residential soils. Asphalt also represents a significant phosphorus pool, as well as desert and residential vegetation.

The principal sink for phosphorus is to landfills (annual accumulations in pools), with significant accumulation also in soils and vegetation. The authors estimate separately that annual accumulation of phosphorus in asphalt alone over recent years is around 0.15 tP/year, and that the figure would be significantly higher if other construction materials were taken into account.

Overall, a significant proportion of phosphorus was effectively cycled locally, largely as a result of **local water recycling through waste water treatment**. Similar conclusions were reached for the Phoenix nitrogen cycle (see above).

The authors conclude that the fluxes and pools of phosphorus in Phoenix are **regionally specific** (the situation would be very different in a temperate region, or an area with a different human or geographical organisation), because of the particular semi-arid climate and water management systems, showing the need for specific phosphorus local budgets as a basis for any management strategy.

Future strategies for phosphorus management are examined, emphasising that if current trends for increasing population continue, resulting in increasing urbanisation of land and decreasing agriculture, then the current local cycling of phosphorus will be disrupted because imports for human food (and phosphorus resulting in wastewater) will exceed local agricultural use.

"Phosphorus in Phoenix: a budget and spatial representation of phosphorus in an urban ecosystem", Ecological Applications, vol. 22, n° 2, March 2012, pages 705–721

http://esapubs.org/esapubs/journals/applications.htm

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Manitoba, Canada

Province regulators push nutrient recycling

Manitoba Province is highly sensitive to nutrient management issues, in particular because of the eutrophication problems of Lake Winnipeg which is impacted by municipal wastewater discharges and agricultural nutrients. Recent policy studies and legislative developments identify nutrient reuse and specifically phosphorus recycling, as an important part of an overall strategy of reducing phosphate losses to surface waters and of upgrading wastewater and manure treatment.

The Manitoba "*Water Quality Standards, Objectives and Guidelines Regulation*", 28th November 2011, acted in implementation of the Water Protection Act (2005), indicates that the "*Best practical technology for* ***beneficial use of valuable resources such as nutrients, organic matter and energy*** *contained within municipal biosolids and sludge*" should be implemented for all new or expanding industrial and municipal wastewater treatment plants discharging into a water body.

This follows a report published by the Manitoba Provincial Government in 2006, which states that: "*The Province of Manitoba and rural municipalities should consider the conversion of lagoons to wastewater treatment plants with nutrient removal capabilities … Phosphorus removed by these plants should be recycled/reused. … A review of the use of alum, ferric salts, and other salts in wastewater treatment should be conducted. …Those strategies which facilitate the recycling of phosphorus should be favoured over those strategies that immobilize the phosphorus*."

Phosphorus removal costs

A recent report by ICF Marbek for Environment Canada assesses the cost effectiveness of different strategies for **reducing nutrient discharges** to Lake Winnipeg (cost per tonne of phosphorus removed). This confirms previous Environment Canada conclusions (Wilson 2009) for water regulation, where wetlands and water filtration by forests provided the best cost-effectiveness, better than man-made management systems.

For phosphorus reduction, ICF Marbek conclude that **agricultural management (Best Management Practice), including actions such as vegetation filter strips and crop changes give a much lower (even negative) cost** per tonne of reduced phosphorus loading than municipal wastewater treatment.

Manitoba Provincial Government report 2006 "Lake Winnipeg Stewardship Board : Reducing Nutrient Loading to Lake Winnipeg: Our Collective Responsibility and Commitment to Action"
http://www.gov.mb.ca/waterstewardship/water_quality/lake_winnipeg/lwsb2007-12_final_rpt.pdf

Manitoba "Water Quality Standards, Objectives and Guidelines Regulation", 28th November 2011:
http://www.gov.mb.ca/waterstewardship/water_quality/quality/website_notice_mwqsog_2011.html

ICF Marbek "Costs and Benefits of Instruments to Reduce Nutrients in the Lake Winnipeg Basin: Using an ecological goods and services approach - Synthesis Report", 30th January 2012, for Environment Canada.

S. Wilson, 2009 : "Status of Current Work – Measurement and Valuation of Ecological Goods and Services in Canada".

Germany

Routes for P-recovery from sewage

The authors consider that a complete recovery and recycling of phosphorus from sewage is possible in Germany, via either land spreading of biosolids or recovery from sewage sludge incineration ash (SSA). Recovery within sewage works, by precipitation of struvite or calcium phosphate, offers lower potential as generally only at most 40% of sewage inflow phosphates can be recovered here.

Effective recovery from sludge ash will required sewage works operators to **avoid the use of iron for chemical P-removal**, adjust other additives and discharges appropriately, and not send sludge to co-incineration in power plants or municipal waste incineration plants, where the phosphorus is permanently lost.

Where biological or chemical P-removal is operated in sewage works, **sewage sludge contains c. 90% of works total inflow phosphorus**. However, sludge can also contain heavy metals and persistent organic contaminants or pharmaceuticals. Sludge incineration at 800 – 900 °C eliminates organic contaminants and pharmaceuticals, but not heavy metals. This generally prevents direct agricultural application of sewage sludge incineration ash.

Sewage sludge incineration ash (SSA) was estimated in Germany in 2007 to contain c. **15 000 tonnesP/year, that is 11% of total phosphorus inputs to Germany**, and the proportion of German sludge going to incineration is increasing.

Substitution of phosphate rock

Sewage sludge incineration ash (SSA)can be used by Thermphos, Netherlands, following some adaptation of their process and plant, to replace imported phosphate rock used to manufacture phosphorus (P_4) for specific applications, high purity phosphoric acid and phosphates. However, **this is only possible if the incinerated sludge does not contain added iron**, that is the incinerator does not accept sludge from sewage works using iron salts for chemical P-removal, and only accepts sludge from works using biological P-removal or aluminium salts.

Thermphos are currently using c. 10 000 tonnes of SSA per year (500 – 1 000 tonnes P) and intend to increase this to 80 000 tonnes P/year by 2020.

At present, only around 20% of SSA in Germany has appropriately low iron, meaning that a reorganisation of water industry sludge incineration and treatment practices would be necessary to achieve higher recycling rates through this route.

P-recovery from SSA

Various technologies are being developed to recover phosphorus from SSA. The thermal route, developed by the **SUSAN Consortium** (see SCOPE Newsletter n°78) heats SSA to 1000°C with calcium or magnesium chloride. Heavy metals are volatised and can be trapped for disposal. The phosphate compounds resulting are plant available, so that the heavy metal – free product can be used as a fertiliser. A 2 000 tonnes of SSA/year pilot plant was operated by ASH-DEC Umwelt AG in Leoben, Austria (see *http://eartheasy.com/blog/2010/04/peak-phosphorus-german-recycler-to-mine-phosphorus-from-sewage/*).

The **MEPHREC process** (metallurgic P-recycling, Ingitec GmbH, Leipzig) uses smelting – gasification technology at 2 000 °C to produce a phosphorus slag which is low in heavy metals and can be used as a fertiliser. The organic fraction of the sludge can be valorised as energy. A pilot plant was operated at Freiburg Bergakadamie, Germany.

This paper also presents detailed chemical analysis of 15 different sewage sludge incineration ashes.

"Towards a complete recycling of phosphorus in wastewater treatment – options in Germany", Water Science & Technology, Vol 64, No 1, pages 29–35, 2011, IWA Publishing http://www.iwaponline.com/wst/

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Denmark

Policy options for a sustainable P cycle

Denmark's Environment Ministry has commissioned a report from the 'Copenhagen Resource Institute' (CRI) on "Recycling and Sustainable Materials Management", looking particularly phosphorus scarcity, critical metals in electronics and reduction of landfilling. The report situates these issues within EU initiatives on resource efficiency and critical raw materials (Roadmap towards a Resource Efficient Europe).

CRI note that commercially viable world mineral phosphate rock reserves are estimated at somewhere between 50 – 250 years, under increasing pressure because of the growing world population, increasing meat in the global diet and production of bio-energy crops. **The EU food system is "*highly vulnerable to future phosphorus scarcity*"** because nearly 90% of phosphorus use is in agriculture and the EU is highly dependent on imported phosphates. As phosphate rock resources are consumed, lower quality rock with higher cadmium content will be accessed.

The report notes that the situation is very different across Europe, with **Denmark's soils largely saturated in phosphorus, because of intensive livestock production**, whereas in other areas of Europe soils require constant phosphorus inputs.

Phosphate recycling, phosphorus management

Only around one fifth of mined phosphate actually reaches humans in food, most is lost between mine and farm, with significant environmental consequences underlined by CRI including eutrophication, greenhouse gas emissions, water consumption, radioactivity, cadmium and fluorine pollution.

CRI estimate that **today in Europe around 37% of phosphorus in municipal wastewater is recycled back to agriculture**. A long term solution for phosphorus management would require a 70% reduction in demand, the remaining 30% being supplied by phosphorus recycling.

Policy options and actions

The report concludes that no single policy can ensure a sustainable phosphorus cycle, but that **a number of current technologies and policy options should be developed**, preferably in a common European strategy for phosphorus. This should be an integrated phosphorus policy, including improving phosphorus efficiency in the food system and recovering phosphorus where wastes are inevitable.

Phosphorus management and recycling, CRI indicate, should be **integrated into European policies such as the Common Agricultural Policy (CAP), water policy, marine strategy and sustainable food consumption**.

Actions proposed include: awareness and education, studies including phosphorus balances, regulatory and economic measures (for example a financial 'deposit' to phosphorus in agriculture), developing phosphorus recycling technologies (from biomass ashes, sewage, manure, slaughtering waste), improving plant availability of phosphorus and plant uptake, an EU Phosphorus Directive, a global platform for phosphorus cycle governance.

"Recycling and Sustainable Materials Management – Analytical Paper for the Danish Ministry of the Environment", Copenhagen Resource Institute (CRI), C. Fischer, B. Kjaer, H. Wilts, D. McKinnon, Jan. 2012
http://www.cri.dk/images/downloads/reports/Recycling%20and%20Sustainable%20Materials%20Management_final.pdf

Biodiesel and nutrients

P and N recycling in biofuel algae production

Microalgae can convert up to 5% of solar energy to chemical energy but producing 1 litre of biodiesel is estimated to require 0.23 – 1.55 kg of nitrogen and 29 – 145 g of phosphorus. The effective recycling of nutrients in biofuel production is thus essential. These papers assess the recycling rates possible for N and P in biofuel algae cultivation and biodiesel production, with different scenarios for algae type and waste use.

Microalgae offer five times higher solar energy fixing potential than terrestrial plant systems, and could in theory produce 10 – 100 x more biofuel oil per hectare. However, such **productivity requires high nutrient (N and P) inputs**.

Wastewater nutrients

Using wastewaters as a nutrient source for microalgae cultivation is one important route to recycle nutrients and reduce "new" nutrient requirements for biofuel production, however this poses problems of contamination in high-performance algae cultures which aim to produce a single species in highly controlled conditions. Another route is to **recycle the N and P present in the wastes when the algae are processed** to extract biodiesel.

Algal lipid content

Rösch et al. consider that microalgae can achieve lipid contents of up to 80%, but that 15-35% is more general. The content of triacycglycerols (TAGs) which are neutral (non-polar) lipids produced only for energy storage, with no structural role in the algal cell, is more significant for biodiesel production. Production of such lipids can be increased by cultivating the algae in stressed conditions, in particular **nitrogen starvation** can increase TAG production in many species. This has the benefit of also reducing nitrogen input requirements.

For optimal biodiesel production, a combination of high biomass production with high TAG content is important. **Nannochloropsis strains** can offer robust biomass production, and over 40% dry mass lipid content, corresponding to 16 – 22% dry mass fatty acid methyl ester yield in processing.

Algae are generally processed by first drying and destruction of the cell structure, then solvent extraction to obtain fatty acids or triglycerides, followed by transesterification with a short chain alcohol (e.g. methanol) to produce biodiesel.

In Rösch et al., three **different hypotheses for microalgae productivity and TAG content** were considered, including cultivation under nitrogen stressed condition.

Downstream processing and nutrient recycling

Nutrient recycling can take place at different stages of the algae processing. During harvesting, algae are separated by centrifuge and the separated water contains nutrients which are returned to the cultivation. In the stage of lipid separation, an oil free residue is produced (algal cell remains after lipid extraction), consisting mainly of carbohydrates and proteins. The biodiesel produced is treated to remove phospholipids (degumming). Three different possible routes for processing this by-product are considered: thermal gasification, anaerobic digestion, use as animal feeds.

Nitrogen is lost from the system by volatising of NH_3, both in the algal cultivation, in by-product processing, and finally in the animal feed cycle. Nitrogen in the effluent of hydrothermal gasification and digestion is mostly present as ammonia, which may not be optimal for algae cultivation and could result in significant NH_3 losses. A nitrifying step before returning using these effluents for cultivation could thus be appropriate.

Nitrogen can also be lost because it is in an organic or non-soluble form in the effluents, and so cannot be taken up by the microalgae. Agricultural use of the effluents might allow long-term use of this nitrogen by plant uptake from soils.

Phosphorus can be lost by precipitation in the cultivation or by-product treatment stages, by remaining in the biofuel (not all removed during degumming), or in the animal feed cycle. Again, insoluble phosphates in precipitates or sludges, while not available to the microalgae, could be recycled through agricultural use.

Overall, Rösch et al. conclude that **30 – 90% of nitrogen and 48 – 93% of phosphorus could be potentially recycled** back to the algal production, with the highest nutrient recycling rates being achieved through hydrothermal gasification of residues after biofuel extraction. The technical feasibility and the possibility of heavy-metal accumulation when these residues are recycled need to be assessed.

Life Cycle Analysis

Yang et al. present a **water and nutrients footprint** and balance for biodiesel production from microalgae, looking at different water sources, operation with and without recycling, different algal species and geographical implantation. Chlorella vulgaris cultured in open ponds in the California summer are taken as a representative species and conditions.

Water footprint under these conditions is estimated as **3 700 litres of water / kg biodiesel**, with 84% of the water discharged after harvest and the remainder lost in evaporation from the culture pond and drying. This water footprint can be reduced to 591 litres if the harvest water is recycled. The water footprint is found to be somewhat lower in warmer, sunnier climates

Nutrient footprints are estimated at 0.33 kg nitrogen / kg biodiesel, 0.71 kg phosphorus, 0.58 kg potassium, 0.27 kg magnesium and 0.15 kg sulphur. These consumptions can be reduced by c. 55% if the harvest water is recycled.

Seawater

If **seawater** is used for the microalgae culture, this could avoid the need to add potassium, magnesium or sulphur and reduces nitrogen consumption by c. 50%, but the phosphorus consumption is not reduced. If wastewater is used, this could avoid the need for any nutrients other than a very small amount of nitrogen, but again with phosphorus consumption not significantly reduced.

"Materials Flow Modeling of Nutrient Recycling in Biodiesel Production from Microalgae", *to appear in: Bioresource Technology 2011*
http://dx.doi.org/10.1016/j.biortech.2011.12.016

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"Life-cycle analysis on biodiesel production from microalgae: Water footprint and nutrients balance", Bioresource Technology 102 (2011), pages 159–165
www.elsevier.com/locate/biortech

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Lemna duckweed

Sewage nitrogen recovery in aquaculture

An integrated experimental system was tested with a 40 l UASB (Up-flow anaerobic sludge blanket) reactor sewage treatment plant discharging effluent into three duckweed ponds (*Lemna gibba*), and then the effluent from these ponds along with the harvested duckweed went to fishponds producing Nile tilapia (*Oreochromis niloticus*). Two experimental runs of 5 plus 4 months were carried out.

The UASB reactor was **fed raw sewage** from the Cairo region, Egypt, with a 6 hours residence time. Effluent was fed to three consecutive 0.48m deep, 1 m^2 area ponds (flow from the UASB reactor into the first pond, overflowing into the second pond, etc.), each inoculated with 600 g/m^2 of duckweed. The duckweed was maintained at 1000 g/m^2 after harvesting. The third duckweed pond overflow, along with the harvested duckweed, was fed to aquaculture ponds stocked with Nile tilapia, with the fish being fed fresh duckweed to satiation.

For comparison, a separate fishpond was fed by providing as water input settled (untreated) sewage supernatant, with nitrogen input adjusted to be the same as for the duckweed treated ponds, at c. 4 kgN/ha/day.

Duckweed nitrogen recovery

The three consecutive duckweed ponds achieved **removal of approx.. 50 – 65% COD, 70 – 75% BOD and 10 – 40% TSS**. The lower suspended solids removal rates were probably related to the presence of daphnia and copepods in the duckweed pond overflows.

Nutrient removal rates in the three duckweed ponds were 70 – 98% for ammonia, 70 – 80% for total nitrogen (TKN) and c. 70% for total phosphorus. The duckweed ponds reduced faecal coliform bacteria by 4 logs, probably by a combination of solar irradiation and nutrient deficiency.

Duckweed production rates of 120 – 140 kg dry matter/ha/day, comparable to the rates indicated in literature. Around 80% of the total nitrogen removal in the duckweed ponds was in plant uptake, resulting in overall c. 60% capture of the UASB effluent total nitrogen in the duckweed, that is 4 – 6 kgN/ha/day.

Fish production

No fish mortality was observed in the tilapia ponds fed with duckweed pond effluent, compared to 60% adult fish mortality in the pond fed with settled raw sewage supernatant, possibly because of higher ammonia and nitrite concentrations. As a result, the final fish density (g/tank) was nearly 25% lower at the end of the experiment in this case.

In the tilapia ponds fed with duckweed and duckweed pond overflow, the **fish density (g/tank) was multiplied by 2 – 3 times**, giving estimated net fish yields of 12 – 16 tonnes/ha/year.

The nitrogen recovery from duckweed fed to fish flesh in the tilapia ponds was 14 – 20%, that is 12 – 17% of the UASB reactor effluent nitrogen content.

The authors conclude that **duckweed and aquaculture ponds systems can provide a potentially marketable by-products from sewage effluent** (duckweed fish feed, fish production), thus offering financial benefits for sewage treatment and nutrient recycling.

"Nitrogen recovery in an integrated system for wastewater treatment and tilapia production", Environmentalist (2007) 27, pages 287–302, Springer
http://www.springerlink.com/content/0251-1088

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India

Recycling sewage in carp aquaculture

340 m^3 concrete tanks at the Rahara, Kolkata, Central Institute of Freshwater Aquaculture were used for 184-day tests of carp aquaculture using different nutrient sources: primary treated sewage effluent, raw cow dung plus urea and single super phosphate, control (no nutrient addition). Each tank was stocked with small carp of four different species, and then fed with duckweed (Wolffia arrhiza).

Temperature, physical-chemicals parameters were evaluated, primary productivity (comparative estimation by light and dark bottle method), fish number and mean body weight were measured and estimated economic costs were estimated.

Results showed that **fish growth was significantly higher in all three systems with nutrient addition than in the control** (2 – 4 x higher harvested fish weight) and that biological production was significantly correlated to nutrient inputs of ammonia-nitrogen, total nitrogen and soluble phosphorus.

Higher doses of sewage resulted in higher growth levels, comparable or slightly higher than growth achieved using the cow dung plus mineral fertiliser nutrient input.

The experiments showed that sewage dosing at c. 8 million litres / hectare (every two weeks), that is the higher sewage dosage, gave **fish yields similar to fertiliser dosing, but with 64% better water efficiency**.

"Evaluation of water productivity and fish yield in sewage-fed vis-a`-vis fertilized based carp culture", Bioresource Technology 99 (2008) pages 3499–3506
http://www.journals.elsevier.com/bioresource-technology/

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France-China

Biomass production for nutrient recovery from swine wastewater

A pilot scale installation was tested in different configurations and conditions treating screened manure and wastewater from a 30 pregnant sow pig shed. The system included vermiculture beds (96 m^2), followed by a settling tank, then artificial wetlands and macrophyte ponds (total 340 m^2), and finally a storage lagoon with macrophyte coverage (180 m^2).

The objective was to ensure **sufficient treatment of the manure wastewater to enable its reuse for pig shed washing** (recycling of water) and to recover the manure nutrients as macrophyte biomass.

Initial work showed that the **vermiculture, in a mixture of wood chips, similar wastes and compost**, did not achieve adequate COD and nutrient removal. The settling tank was added and the sludge returned to part of the vermiculture.

The **constructed wetlands** used a mixture of reeds (*Phragmites australis*) and other plants on gravel (the most interesting being *Glyceria aquatica*), with horizontal (and in one case vertical flow). The macrophyte ponds used water hyacinths (*Eicchornia crassipes*), water ferns (*Azolla caroliniana*) or water lettuces (*Pistia stratiotes*).

The water ferns produced in the constructed wetlands were partly fed to the pigs.

The paper describes in detail different configurations tested and presents results for **removal of COD, nitrogen, phosphorus, potassium, pathogens and endocrine disruption potential** at different stages of the treatment.

Treatment effectiveness

Total inflow was around 4500 litres/day with 5600 mgC/l, 820 mgN/l, 210 mgP/l and 790 mgK/l.

Overall, the set up removed 96% of COD, 95% of nitrogen, 76% of phosphorus and 71% of potassium. Pathogens and endocrine disruption potential were both also considerable reduced, sufficiently to allow reuse of treated water for rinsing the animal shed.

However, for the period reported for the full-scale pilot (it is still operating and has now been operating for three years), only a relatively small proportion of nutrient inflow was effectively recovered in the harvested biomass. The nutrients input from the pigs were estimated for this period at 320 kgN, 80 kgP and 210 kgK, but only 25 kgN, 6 kgP and 20 kgK were recovered in the biomass. The authors suggest that most of the nutrients are being instead retained in sediments or adsorbed onto organic matter in the system (or lost to the atmosphere for nitrogen).

It is hoped to pursue research work on this operating plant further, in particular to **improve nutrient recovery** by recovering the vermicompost and by more efficient harvest of the floating plants.

"Biomass production and water purification from fresh liquid manure– Use of vermiculture, macrophytes ponds and constructed wetlandsto recover nutrients and recycle water for flushing in pig housing", Procedia Environmental Sciences, vol. 9, pages 130 – 139, 2011
http://www.sciencedirect.com/science/journal/18780296/9

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P-recovery from sewage sludge

Berlin Wasserbetriebe

Through R&D to full-scale P-recovery

Berlin Wasserbetriebe began investigating struvite precipitation in the late 1990's, because of significant incrustation problems in the sludge treatment lines of the Wassmannsdorf sewage treatment plant (STP), Berlin. Research and testing were carried out in cooperation between the company's waste water treatment plant operation experts and R&D, university specialists and engineering companies, investigating strategies to prevent struvite deposits, conditions for struvite precipitation for P-recovery, reactor design and optimisation, cleaning of the precipitate, fertiliser value and properties of the recovered struvite, regulatory status and marketing of the product as a fertiliser.

Phosphate recovery is now operational full scale, in a patented process, producing over 500 tonnes of struvite per year since 2012 (250 tonnes in 2011 with part year operation only), that is c. 7% of total sewage works phosphorus inflow.

Wassmannsdorf STP treats some 180 000 m^3 of sewage per day, serving a population of 1.2 million (around 34 % of the Berlin conurbation). The plant uses **biological nutrient removal to reduce phosphorus levels in discharge to <0.5 mgP/l**, that is around 77 kgP/day leaves the STP in discharge compared to around 2355 kgP/day inflow (c. 3%).

Struvite incrustation problems

In 1994, massive incrustations were first noticed in the sludge dewatering lines, downstream of anaerobic sludge digestion, at the Wassmannsdorf STP, resulting in blockages of pipes and damage to pumps. The deposits were identified to be mainly struvite (magnesium ammonium phosphate, MAP). For further details, see SCOPE Newsletter n° 54.

Different investigations were carried out into **possible routes for avoiding these struvite problem deposits**, including studying struvite and calcium phosphate precipitation conditions, possible deposit-inhibiting additives and possibilities for precipitating the

Deposit and incrustation problems, Wassmannsdorf STP, before struvite recovery installation

phosphates within the sludge to avoid nuisance deposits elsewhere (by addition of magnesium chloride and aeration).

Precipitation of the phosphates into the sludge resulted in lower concentrations of phosphorus in the dewatering liquor returned to the sewage works (so improving the operation of the works biological P-removal), reduced maintenance costs due to less incrustations, improved sludge dewatering and reduced the dosing of cationic flocculants, as well as reducing the need for anti-deposit agents. Overall, this resulted in around 300 000 Euros/year cost saving.

However, the precipitation in the sludge resulted in some 120 tonnes per year of **phosphate depositing on the floor of the (then) digested sludge storage tank**, requiring removal every three months. Also, the precipitate particles increased the abrasion of the sludge in the dewatering centrifuges. It was estimated that precipitating separately the phosphates would avoid these problems, and result I a 40 000 Euros/year cost saving.

Berlin TU and struvite recovery optimisation

In cooperation with Berlin Technical University, **design and operating conditions for a struvite precipitation system** were investigated in order to optimise phosphorus removal from the sludge liquor.

Parameters investigated included aeration rate (using aeration to drive off CO_2 and so increase pH), magnesium chloride dosing, influence of other ions and stoichiometry, geometric design and operating parameters of precipitation reactor.

A 45-litre, cylindrical reactor was tested, with an inner cylindrical zone mixed by air upflow, with a settling zone between this inner cylinder and the outer cylinder. In particular, **reaction conditions and residence time in the reactor were shown to be important** for achieving appropriate struvite particle

Struvite washing installation

size, and reactor floor design for enabling recovery of the struvite.

Struvite cleaning by sand washing equipment

Sand washing equipment produced by the company Passavant with a flow of 1 m^3/h of process water was tested and adapted to **ensure cleaning and purification of the recovered struvite**. Today, a new sand washing equipment from the company Huber with a continuous flow of around 5 m^3/h of process water is in operation, this enables organic contamination in the recovered struvite to be reduced to less than 0.5 % TOC/mass.

By 2011, the whole struvite recovery process had been optimised to efficiently reduce the sludge liquor soluble phosphate concentration from 350 to below 50 mgP-PO_4/l, using 3000 m^3/h air to treat around 100 m^3/h sludge liquor in a precipitation reactor with liquor residence time of c. 8 hours and a total reactor volume of 800 m^3. Struvite production is thus 1.53 tonnes/day (over 500 tonnes/year), that is c. 7.3% of total STP phosphorus inflow. The cost of the installation is estimated at 2.3 million €.

The recovered product is 60 - 70% struvite (MAP, including crystallisation water), and around 10% each of (free) water, sand and organic contamination, plus some other minerals at low levels.

Quality and value of recovered struvite

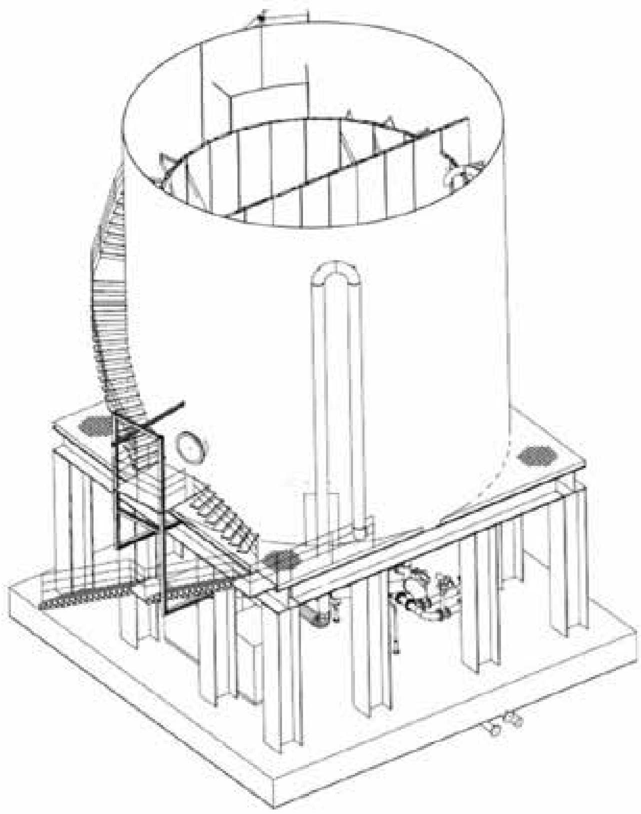
Analysis of the recovered struvite showed that heavy metals and organic pollutants (PCB, poly aromatic carbons = PAK) were at least 5x lower than regulatory limits for sewage sludge agricultural recycling fixed by the German Sewage Sludge Ordinance. These pollutants were clearly not being significantly transferred into the struvite in the precipitation process.

The recovered struvite was tested as a fertiliser in rye grass plant trials by Römer et al. showing good plant phosphorus availability, and plant growth the same as for commercial phosphate fertilisers. See SCOPE Newsletter n° 68.

In 2008, the Brandenburg Land **authorities certified that the recovered struvite is conform to German fertiliser regulations** and can therefore be marketed as a fertiliser.

Berlin Wasserbetriebe has patented the struvite recovery process and is marketing the recovered struvite locally under the trade name of "***Berliner Pflanze***" (Berlin Plant) through cooperation with the fertiliser industry and distributors.

"Stand des Phosphorrückgewinnung in Berlin – von wissenschaftlichen Untersuchungen zur großtechnischen Anwendung" (Phosphorus Recovery in Berlin – From Scientific Investigations to Large Scale Application), B. Heinzmann, A Lengemann, Berlin Wasserbetriebe, Proceedings oft he International Symposium Re-Water Braunschweig, Wiederverwertung Energie Wasser und Nährstoffe, 21-22 November 2011. In German.



Full-scale patented struvite recovery reactor, Berlin Wasserbetriebe, Wassmannsdorf STP, 2011

Sewage sludge

Acidic oxidation and nanofiltration P-recovery

A hybrid process (PHOXNAN) for integrated sewage sludge treatment and P-recovery, combining acidic oxidation with ultra- and nanofiltration, was tested using a 10 litre capacity laboratory experimental reactor. The acidic oxidation process breaks down organic molecules in the sewage sludge, enabling the ultrafiltration to function without fouling. Inorganic ions only pass through the ultrafiltration, and the nanofiltration membrane then selects for phosphorus, giving a solution of phosphoric acid and orthophosphate.

Phosphate could be recovered from this solution by precipitating struvite or other routes, the solids generated in the filtration steps should be compatible with landfill disposal, and the other liquors generated can be returned to the sewage treatment plant after heavy metal precipitation.

The proposed acidic oxidation (**LOPROX**) was operated at 160 – 200 °C and a pressure of 12 – 20 bar at pH 1.5 (obtained by adding sulphuric acid). Pure oxygen is added, and organic molecules in the sewage sludge are thus broken down. In particular, micropollutants such as PAHs or pharmaceuticals are eliminated.

The experimental results showed that **organics** present in the treated sewage sludge (pharmaceuticals, triclosan, LAS) were considerably reduced in concentration, in many cases to below detection concentrations.

The remaining solids are mainly inorganic, and therefore the **ultrafiltration can be operated with little fouling**. The ultra-filtration used a tubular, ceramic filter with an active layer of titanium dioxide and a pore diameter of 50 µm. Crossflow velocity was 4 m/s and the filters were backwashed every 16 minutes.

In the continuous process, the **nanofiltration** was operated at 60 – 70 °C and at the same pressure as the acidic oxidation (transmembrane pressure of c. 16 bar). The nanofiltration used flat sheets of polyamide membranes (GE Osmotics type DL).

Differing sewage sludges

Experiments were carried out using sludges from seven different sewage works in the North Rhine-Westphalia region of Germany. All seven works were operating P-removal, using different methods: biological nutrient removal, iron dosing, aluminium dosing.

The presence of iron resulted in a number of problems, mainly less effective dissolution of the phosphorus during the acidic oxidation, and thus resulted in less phosphorus in the permeate from nanofiltration. The authors conclude that **the PHOXNAN process cannot be applied to sludge from sewage works using iron salts for P-removal**. For these plants a different process can be applied, using thermal hydrolysis instead of acidic oxidation prior to nanofiltration (presented in Blöcher et al. 2010 referenced below, in German).

Ash content of solids

Total solid content of the treated sludges was reduced by 65 – 85%, principally by the acidic oxidation. The solids then removed during the filtration stages of the process were analysed for organic content (ash content = non organic part), showing that when digested sludge was treated ash content was > 95%, which is the condition for sending to landfill in Germany. When non-digested sludge was treated, ash content of c. 85% was achieved, meaning that the process would need to be improved to achieve landfill standards.

P-recovery

Overall, the process enabled recovery (separation to the permeate of nanofiltration) of 54% of the phosphorus in the treated sludges (when iron had not been used for sewage works P-removal). The **principal phosphorus losses were in the LOPROX process** (incomplete dissolution) **and in the nanofiltration stage** (phosphorus compounds not passing through the membrane).

An **estimated mass balance** was calculated for a 100 000 pe sewage works, based on 24 g/kg P in sewage sludge suspended solids and 50 g/day sludge solids (1.2 gP/pe/day), concluding that around 3 kgP/hour could be recovered.

The authors conclude that the process offers an integrated solution for sewage sludge treatment with phosphorus recovery in sewage works, with expected costs to be similar to existing sludge disposal routes, but with lower CO_2 emissions. Because the process is a fully integrated system, it would not be economical to implement in sewage works with existing sludge treatment, but could be viable in new or upgrade sewage or sludge treatment investments.

Phosphorus recovery from sewage sludge with a hybrid process of low pressure wet oxidation and nanofiltration, Water Research, vol. 46, issue 6, pages 2009-2019 (2012)
http://dx.doi.org/10.1016/j.watres.2012.01.022

C. Blöcher, work done at Bayer Technology Services GmbH, now with Currenta GmbH & Co. OHG, Chempark, Building 4242, D-51368 Leverkusen, Germany, christoph.bloecher@currenta.de and C. Niewersch, T. Melin, RWTH Aachen, Lehrstuhl für Chemische Verfahrenstechnik, Turmstrasse 46, 52056 Aachen, Germany. C. Niewersch now with University of Applied Sciences and Arts Northwestern Switzerland, Gruendenstrasse 40, CH-4132 Muttenz, claudia.niewersch@fhnw.ch

C. Blöcher, C. Niewersch, T. Melin, H-F. Schröder, W. Gebhard (2010) Optimierte Phosphor-Rückgewinnung aus Klärschlämmen durch ein Hybridverfahren aus Niederdruck-Nassoxidation und Nanofiltration (Verbundprojekt PHOXNAN). Gemeinsamer Abschlussbericht BMBF-Vorhaben 02WA0796/97/98

Switzerland

Calcium phosphate fertiliser from sewage sludge ash

Laboratory scale experiments were used to test the recovery of phosphorus from sewage sludge incineration ash through a three-stage process: sulphuric acid dissolution, heavy metal separation (by ion exchange, by sulphide precipitation), calcium phosphate precipitation by lime neutralisation. The recovered calcium phosphate was then tested for fertiliser value on three different plants Swiss chard, kohlrabi and corn.

Sewage sludge incineration ash was supplied by incinerators operating at municipal sewage treatment plants in the cities of Basel and Winterthur. Both plants operate biological phosphorus removal. The phosphorus content of the ashes were approx.. 4% (Basel) and 9% P (Winterthur) (dry weight). The lower phosphorus level in the Basel ash is because the incinerator is fed approximately half sewage sludge and half pharmaceutical industry waste with lower P content. **Phosphorus was identified as being principally present as hydroxyapatite in the ash**, with low content of iron oxide phosphate $FE_4(PO_4)_2O$.

The two ashes had iron contents of 9 and 11% and aluminium contents of 6 and 4 %. In both cases, **heavy metal content of the ash were significant**, high enough to prevent their direct use as fertiliser under Swiss regulations.

Acid phosphorus extraction

Phosphorus leaching was tested by adding 0.5 to 3 molar sulphuric acid to 200g ash samples, mixing for ten minutes, then filtering. The leachate was analysed for phosphorus content, other elements and heavy metals.

A pH below 2 proved necessary to achieve reasonably high levels of phosphorus dissolution, with approx. 90% phosphorus recovery being achieved at pH 1.8 or below.

Heavy metals separation

Three **different resins were tested for ion exchange separation of heavy metals**: Amberlite ARC748, Dowex M4195 and Lewatit TP207; in each case previously washed with sulphuric acid. However, of these resins, only the Dowex offered effective selective ion capture at pH<2 (necessary for application in the acid leachate) and this resin required the use of a different chemical for regeneration (ammonium not sulphuric acid).

Sulphide precipitation was also tested for heavy metal removal. Na_2S solution was added, stirred for 5 minutes, then filtered at 0.45µm. This showed that critical heavy metal concentrations could be reduced considerably by adding 2.5 g Na_2S per litre of acid leachate. This heavy metal reduction was sufficient to ensure that phosphates then precipitated by lime addition respected Swiss fertiliser regulation limits for heavy metals (cadmium, copper).

Calcium phosphate precipitation

Phosphate was precipitated from the heavy-metal reduced acid leachate by adding 20% caustic lime solution (CaO), stirring rapidly for 15 minutes, filtering and then drying at 105°C The 15 minutes stirring was identified as optimal by prior testing. Increasing lime dosing led both to increasing quantities of precipitate and to decreasing phosphorus content of this precipitate.

A dosage of 60g CaO per litre of leachate appeared as optimal for preicipitate production and phosphorus content. In this case, the precipitate contained 28% phosphate (12 % P) and 5% MgO which is also a valuable plant nutrient (3 % Mg). Heavy metal content was compatible with Swiss fertiliser regulations.

The phosphate in the precipitate was not water soluble, but was significantly soluble in citric acid, formic acid and alkaline ammonium citriate. **Plant uptake tests were therefore carried out to assess whether this corresponded or not to plant availability**.

Plant fertiliser tests

Some 5 kg of precipitate was produced as described above for plant testing in peat to which lime (4 kg/m3) and trace elements were added, using Swiss chard, kohlrabi and corn plants. A total of 240 pots were tested, with no nutrient addition (control), N+K addition only, N+K+P (commercial phosphate fertiliser) and N+K+P ash precipitate). Plant weight and dimensions were measured, and soil phosphorus before and after 6 weeks growth.

For all three crops, plant growth was similar to the control (marginally lower) when N+K only were dosed, and significantly higher (nearly 2x) when N+K+P were dosed. **The ash precipitate gave in each case marginally lower growth (-5 to -10%) compared to commercial phosphate fertiliser**.

The authors note however that because the phosphorus in the ash precipitate is only plant available progressively, that is as dissolved by root exudates, it is **likely to remain plant available for longer**. Commercial phosphate fertiliser, on the other hand, is water soluble and if not taken up by plants immediately will tend to react with soil minerals to produce stable, non plant available complexes.

The authors conclude that the sulphuric acid extraction, sulphide heavy metal reduction and lime precipitation, followed by filtering and drying, can **produce from sewage sludge incineration ash a recovered phosphate fertiliser with >20% plant availability of its phosphorus content**.

"Phosphate fertilizer from sewage sludge ash (SSA)", Waste Management 28 (2008) 1809–181, www.elsevier.com/locate/wasman

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Review

Phosphorus recovery from biomass ash

The authors present data concerning the energy potential, combustion properties and mineral and organic content (C, H, O, N, S, Si, K, Ca, Mg, Al, Fe, P) for a range of biomass fuels and for the ashes resulting from their incineration ashes. Fuels covered include different types of wood, wheat and rice straw, seed husks, olive residues, peach stones, reed canary grass, sugar cane bagasse, sewage sludge, paper sludge, bone meal.

Combustion of biomass by-products is increasing worldwide, as a route for reducing CO_2 emissions and for making economic savings by producing energy from what had previously been considered a "waste". Incineration with energy recovery is the most widespread route, with fluidised-bed combustion its most advanced form.

Nutrient recovery

Biomass fuels usually contain a high content of alkali metals and other minerals, resulting in considerable ash production. This can pose problems in the combustion and energy recovery process (ash deposition reducing heat transfer, boiler corrosion, agglomeration during combustion causing operating problems). **Certain biomass ashes can on the other hand contain significant levels of valuable nutrients such as phosphorus and potassium**.

Of particular interest is phosphorus, which is a limited and non-renewable resource at the world level. The paper provides **figures for P content of a large number of different biomass fuels and their combustion ashes** and an overview of behaviour of P in the combustion/ash system and of processes currently available for reuse or recovery of P from different biomass ashes.

Potassium and ash agglomeration

Potassium is generally present in significant concentrations in biomass fuels, up to 35 – 50% K_2O in ash from rice straw, peach stones, olive wastes, sunflower seed shells. At high combustion temperatures (particularly > 600 - 800°C) potassium content of ash is reduced, because potassium is volatised during combustion. At these temperatures, potassium can also react with SiO_2 producing potassium silicates (melting point c. 750°C) which from a sticky layer on combustion bed particles, causing their aggregation, and interfering with combustion efficiency and bed fluidisation. Sodium can cause similar problems, but tends to be present at much lower concentrations and to cause agglomeration only at higher temperatures. Other elements (Ca, Mg, Si, Al, Fe) tend to not cause such problems, because they only volatise at higher temperatures.

To reduce this problem, **potassium concentrations can be lowered by leaching prior to incineration**, but this also tends to reduce phosphorus concentrations, resulting in an ash with significantly lower value for nutrient recovery. Addition of lime or peat has also been shown to reduce this problems for certain biomass fuels. The lime probably acts by reacting with the potassium to form calcium potassium phosphates, which only melt at high temperatures.

Phosphorus recycling

Previous authors have shown that **a majority of phosphorus in biomass combustion is found in the fly ash, rather than the bed ash** (see also "P-recovery from incineration ash" in SCOPE Newsletter n°78).

Phosphorus can be present in ashes as $Ca_3(PO_4)_2$ (with calcium being often enriched relative to phosphorus during ash formation), in oxides such as P_4O_{10}, P_2O_5, PO and PO_2, at lower temperatures as H_3PO_4 and as combinations with other minerals including FE_2O_3, $Ca_9Fe(PO_4)_7$, $Fe_7(PO_4)_6$.

Bioavailability of phosphorus in ash

The authors note that **opinions vary concerning the availability to plants of the phosphorus in biomass combustion ashes**. Some opinions consider that the phosphorus is in mineral forms which are not bioavailable, whereas others consider that if spread on soil then the minerals will evolve under plant root and microbial action and eventually become plant available.

A number of **thermo-chemical processes for extracting the phosphorus from biomass combustion ashes**, or for rendering it more plant available and/or for reducing levels of heavy metal contaminants are presented.

Processes intended to remove heavy metals from sewage sludges by bioleaching also remove a large proportion of the phosphorus and some of the nitrogen, so may also represent a potential route for nutrient recovery.

The authors conclude that **chemical extraction/leaching methods** provide a promising route for separating nutrient and metal elements, in particular phosphorus, from biomass combustion ash, enabling nutrient recovery and separation of contaminant heavy metals.

"Phosphorus recovery from the biomass ash: A review", Renewable and Sustainable Energy Reviews, 15 (2011) 3588– 3602 www.elsevier.com/locate/rser

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Sludge incineration ash

Acid and alkali elution of aluminium and phosphate

Laboratory tests suggest that sequential acid and alkali elution of sewage sludge incineration ash can recover phosphates and enable aluminium recycling as a wastewater P-precipitation salt.

The **SESAL-Phos (Sequential elution of sewage sludge ash for aluminium and phosphorus recovery)** proposes treatment with acid then alkali, without using high temperatures or pressures, to recovery phosphates and recycle aluminium from mono-incineration sewage sludge ash, that is from wastewater plants operating P-removal by addition of aluminium salts only (not iron salts).

Such sewage sludge incineration ash contains 5 – 10 % P (phosphorus), and approximately 90% of total sewage works phosphorus inflow, but also heavy metals which are usually not volatised in sludge incineration (c. 850°C).

Previous work has shown that **alkaline elution of sewage sludge** can dissolve phosphates without heavy metals, but that only c. 30% of P in sludge (aluminium mono-) incineration ash is thus dissolved, probably because of the presence of calcium from hard water. This work shows that prior acid elution can increase alkaline P dissolution to c. 80%.

SESAL-Phos

The proposed SESAL-Phos process first uses **acid elution** (10 litres of 0.4 mol HCl to 1 kg ash), **followed by solid-liquid separation**, followed by **further acid elution** using 0.01 mol HCl to remove remaining calcium. The acidic pre-treatment dissolves calcium phosphates and forms new alkaline soluble aluminium phosphates. The treated ash is then **finally eluted with sodium hydroxide** (10 litres of NaOH 1 mol to1 kg ash).

The alkaline elution of the treated ash, followed by solid-liquid separation, enabled extraction of c. 60% of phosphorus and c. 40% of aluminium from the sludge ash. Calcium chloride is then added to the alkaline leachate, resulting in **precipitation of calcium phosphate**, which can be recovered for recycling, and an aluminium solution which can potentially be reused for P-removal in wastewater treatment plants.

Use of 10% of the alkaline leachate is sufficient to neutralise the acid leachate from the first step to conform to discharge consents.

Some 350g of calcium phosphate were recovered during laboratory testing of the process and are currently undergoing testing as a fertiliser. This recovered phosphate showed low heavy metal levels (cadmium <1 g/kg) and of other metals (copper 5 g/kg, zinc 21 g/kg, lead 4 g/kg). Only arsenic was found in higher concenrations of 28 g/kg.

"Recovery of phosphorus and aluminium from sewage sludge ash by a new wet chemical elution process (SESAL-Phos-recovery process)", Water Science and Technology, Vol 64, No 3, pages 693–699 (2011), IWA Publishing http://www.iwaponline.com/wst/

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Publication

Plant and Soil special issue

Phosphorus sustains life – P in soil

The 4th International Symposium on Phosphorus Cycling in the Soil – Plant Continuum (ISPDSPC), in Beijing, China, 19th - 23rd September 2010 followed on from previous Symposiums in China 2000, Australia 2003 and Brazil 2006. Over 180 participants were present, with 181 abstracts and 140 posters. The Symposium's theme was "Phosphorus Sustains Life" addressing five themes:

- Phosphorus forms and availability in soil
- Plant acquisition and utilisation of phosphorus
- Genetics and molecular biology of phosphorus nutrition
- Phosphorus in agricultural, horticultural and forest production
- Phosphorus dynamics and environmental impact in natural and managed ecosystems

A special issue of the Springer Journal "Plant and Soil" (vol. 349, n°s 1-2, December 2011) presents 27 of the main papers from the Symposium. These cover themes including mechanisms of crop plant uptake of phosphorus and interactions with acidification, phosphorus management in different agricultural systems and phosphorus accumulation in farmland soils, improving agricultural systems for P-efficiency and to reduce phosphorus losses to surface waters (see list below with links).

In the editorial, Z. Rengel and F. Zhang underline that **estimates for world phosphate rock reserves are variable, but that phosphorus consumption will inevitable increase in coming decades** with world population increases and rising living standards (diet). Food production will need to double, with shrinking areas of farmland, posing an immense challenge for phosphorus management.

The next (5th) International Symposium on Phosphorus Cycling in the Soil – Plant Continuum is planned for Montpellier, France, in 2014

Phosphorus sustains life *Z. Rengel, F. Zhang*

Adaptation of plasma membrane H+ ATPase and H+ pump to P deficiency in rice roots *R. Zhang et al.*

Positive feedback between acidification and organic phosphate mineralization in the rhizosphere of maize (Zea mays L.) *X. Ding et al.*

Rhizobia enhance acquisition of phosphorus from different sources by soybean plants *L. Qin et al.*

Scope to improve phosphorus (P) management and balance efficiency of crop and pasture soils with contrasting P status and buffering indices *D.. Weaver, M. Wong*

Phosphorus requirements of tropical grazing systems: the northern Australian experience *J. McIvor et al.*

The chemical nature of P accumulation in agricultural soils—implications for fertiliser management and design: an Australian perspective *M. McLaughlin et al.*

Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems, *R. Simpson*

Plant and microbial strategies to improve the phosphorus efficiency of agriculture *A. Richardson et al.*

Integrated soil and plant phosphorus management for crop and environment in China. A review H. Li *et al.*

Managing agricultural phosphorus for water quality protection: principles for progress *P. Kleinman*

4th International Symposium on Phosphorus Cycling in the Soil – Plant Continuum (ISPDSPC): http://isp4.cnnm.org.cn/

"Plant and Soil", vol. 349, n°s 1-2, December 2011: http://www.springerlink.com/content/0032-079x/349/1-2/