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Global food and resource use

20% of world food goes to waste

Tristram Stuart's book uncovers the vast scale of food wastage worldwide, and with it the waste of valuable land and resources, including loss of phosphorus. The European Union is now recognising the scale of this problem.

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Process to extract P from iron precipitate in sludge

A microbial fuel cell is experimented to solubilise P from iron phosphate $FePO_4$ in sewage sludge, thus making P-recovery feasible.

Algal blooms

Ontario

Climate change and eutrophication

Studies of the US-Canada border Lake of the Woods suggest total phosphorus has not increased since the C19th and that climate warming is a likely driver of the increasing algal blooms occurring in moderately nutrient-enriched sites.

Conferences and publications

Toulouse, France

Recycling and reuse of phosphates

Phosphate recycling, P-recovery processes, phosphate precipitation, uses of recovered phosphate products. 23rd November 2011, Toulouse, France. In French

The Phosphorus cycle

Chemosphere special issue

Chemosphere journal (Elsevier publishers) special issue on "The Phosphorus Cycle": Volume 84, Issue 6, Pages 735-854 (August 2011).

CRU report

Phosphate Rock – Ten Year Outlook

CRU, leading fertiliser market forecasts, have published a new 2011 report: "Phosphate rock: ten year outlook"

Phosphates 2012

Phosphate industry conference

Major 2-yearly conference for the worldwide phosphate industry (rock production, fertiliser, animal feeds, food, detergents, other industrial uses). El-Jadida, Morocoo, 19th - 21st March 2012:

http://www.crugroup.com/events/phosphates/

Call for abstracts

3rd sustainable phosphorus summit

29th February – 2nd March 2012, Sydney, Australia

http://sustainablepsummit.net/

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Phosphorus resources

Green Alliance

Phosphorus stewardship for a circular economy

Green Alliance is a UK NGO, an independent thinktank centred on environmental leadership. The organisation has published a report on "*A circular economy for resource security*", looking at three key resources: water, metals and phosphorus. The work was funded by SITA UK, and involved the UK Environment Ministry DEFRA and a wide range of stakeholders, including industry, users and environmental NGOs.

The **essential role of phosphorus in all forms of life**, and the consequent necessity of phosphate input to agriculture, are emphasised. In addition to the question of phosphorus resource depletion, where there is at present considerable uncertainty regarding the quantities and quality of global phosphate rock reserves, Green Alliance point to other important reasons for concern about phosphorus supply security: increasing demand (growing world population, increasing meat and dairy consumption in developing countries, phosphate fertiliser needs for energy and other non-food crops), geopolitics (phosphate rock reserves are held by only very few countries) and declining quality of available rock (lower P content, higher problem impurities).

Need to cycle nutrients

The report indicates that a **more circular economy for phosphorus, with both more efficient use and increased recovery and recycling**, is necessary both to address supply security (essential both for long-term national food supply, and for many other user industries) and to reduce negative environmental impacts of phosphorus loss to the environment. Phosphorus stewardship and recovery and recycling would reduce discharges from inadequate sewage treatment, livestock and poultry production, agricultural run-off or industrial processes, which in some circumstances can contribute to eutrophication.

The first identified target for action is **reduction in demand**. Better agricultural management and fertiliser use are important, but significant improvements have already been made over recent decades. A move to public diets with lower meat and dairy content would also have a major impact. This is controversial, and UK policy documents to date have preferred instead to advocate a "lower impact diet" or "increasing proportion of vegetables, fruit and grain in diets".

Some countries have enacted policies to influence diet, for example Denmark has introduced a "fat tax" on foods with high fatty acid content and France a tax on carbonated drinks, but these are not related to phosphate content and do not specifically target meat and dairy products.

Reusing sewage sludge phosphorus

The UK currently spreads 65% of sewage sludge on land, one of the highest proportions in the EU. Green Alliance emphasise the importance of maintaining this route for P-recycling, and note the **organic movement Soil Association's recent position that EU regulations should be modified to allow sludge biosolids use on organic farms**, subject to quality controls.

Mechanisms to encourage phosphorus reuse on land therefore need to be developed, including regulatory formalisation of quality constraints, variation of subsidies to farmers and/or to water companies depending on how sludge is reused, or possible recycling credits, obligations or tradable quotas.

Biological or chemical P-removal

However, it is emphasised that not all sludge spread on land is really recycling phosphorus: **the real availability of the phosphorus to crops should be taken into account, and this can be very low where iron is used for chemical nutrient removal in sewage works**.

Furthermore, chemical P-removal systems in sewage works are incompatible with current technologies for phosphorus recovery and recycling. Green Alliance indicate that chemical P-removal is widespread in the UK because investment costs are lower than for biological nutrient removal, but that **chemical P-removal is less sustainable** because of the ongoing consumption of chemicals and the increased sludge production.

P-recovery and P-recycling

Reuse of animal manure phosphorus is also very important, and techniques need to be developed to enable processing for storage, transport and appropriate use.

P-recycling from sewage works, animal manures and industry waste streams (e.g. food industries) is important in cases where reuse to land is not possible. Technologies exist, but implementation has been slow because of the **absence of coherent public policies**.

Because of the regulation and subsidy-driven nature of both the water industry and farming, P-recovery will only develop if appropriate instruments are enacted to either push or pull secondary nutrients through the system (set quotas for recovery or incentives to use recovered P).

Phosphorus tax

Green Alliance recommend the introduction of **a phosphorus tax, to incite to reduce consumption, and to collect revenue to fund recovery and recycling**.

A phosphorus tax would principally impact farmers (agriculture, through fertilisers and animal feeds accounts for 90 – 95% of P consumption), and so would be passed on to consumers in food prices, or taxpayers through subsidies to balance the cost for farmers. If phosphorus chemicals (fertilisers, phosphoric acid …) only were taxed, then **UK industry and farmers would be placed at an economic disadvantage** compared to overseas producers of finished products or food containing "embedded" phosphorus.

The report considers that a P-tax on both phosphorus chemicals and **imported products containing embedded phosphorus** (as a function of an imported product or food substance's P content) would be legal under World Trade Organisation rules, but complex to implement. However, the exemption of recycled phosphorus from the tax base, which would be desirable to encourage recycling, could be implemented in the UK but could probably not be applied to imports under WTP rules.

Need for support

The report concludes that **regulatory obligations and/or financial incentives for phosphorus recovery are needed now**, **to initiate the move towards more sustainable phosphorus stewardship. Investments in P-recovery and in biological nutrient removal in sewage works** (to replace chemical P-removal) will last for many years, but are not profitable in the short term for water companies, and so need public support.

Metals and water

Concerning **metals** resource stewardship, Green Alliance recommends product standards for electrical and other consumer goods, to design both for durability and for recovery and recycling to improve stewardship of metals. A product levy is also recommended, again (as for phosphorus) with the intention of funding recycling infrastructure. Rewards and incentives for recycling (consumer product return) are also considered necessary.

For **water**, Green Alliance recommends the introduction of universal water metering (many UK households still today do not have a water meter, and simply pay a fixed charge irrespective of quantities used) and structured tariffs to reflect local and seasonal scarcity. Embedded water consumption, in imported goods and foods, needs to be addressed, initially by consumer information and promoting company stewardship.

Green Alliance, UK: "Reinventing the wheel. A circular economy for resources security. Phosphorus, metals, water", H. Hislop, J. Hill, October 2011, ISBN 978-1-905869-46-6, 58 pages. Available online at: http://www.green-alliance.org.uk/grea_p.aspx?id=6044

Phosphate resources

P resources and consumption scenarios

Over the past 30 years, published estimates of world phosphate resources and reserves have varied widely, as have estimates of future consumption and depletion rates. This paper proposes a coherent model for P consumption and resource depletion, including at the regional level, deriving credible ranges for likely resources depletion horizons.

The authors develop a set of demand scenarios and track the phosphate flows through the world economy in different scenarios in 2050. The authors underline the **build-up of phosphorus in agriculture soils** over past decades in many parts of the world, but also the **depletion of phosphorus in some grazed grasslands** which implies a risk to ruminant production.

The depletion model is based on different resource categories, making a clear distinction between resources and reserves. The following **definitions** are used:

- **Reserves**: P resources which are known to exist, with a reasonably high accuracy of estimation of quantity and quality, and which are economically exploitable under current conditions

- **Reserve base**: the above plus P resources which are known, but are not economically exploitable at present
- **Inferred reserve base**: the above plus P resources which are not known (that is, not yet discovered), or unconventional occurrences which cannot be exploited with currently available technologies (such as deep sea deposits, or very low grade ores)
- Finally, there are also large quantities of P in sediments on ocean floors, but these are **not considered to be probably exploitable in the foreseeable future**

In the paper, the authors use the term "**resource base**" to cover the first three categories.

The authors analyse the **different published estimates** available for these resources categories, concluding that there is a high degree of uncertainty, be it for reserves or for the reserve base, both regarding the geological resources and their potential exploitability.

Resource depletion model

A model for resource depletion is presented, which has been applied earlier for metals and energy resources. The model uses data on P resources and P demand in 14 world regions. The phosphorus scenarios were derived and extended from the flow descriptions in Bouwman et al. 2009 and Van Drecht et al 2009 for agricultural and non-agricultural (waste water) flows respectively, combined with data on phosphorus consumption from a number of different authors. These scenarios were based on the scenarios of the **Millennium Ecosystem Assessment**, describing trends in demography, agriculture, waste water collection and treatment.

The same scenarios were also used to create **scenarios for phosphate use for detergents, animal feeds and industrial uses**, in combination with literature estimates on current use. Data on phosphorus resources was derived from different available sources, resulting in overall numbers somewhere between those from USGS (US Geological Survey) and those from IFA (International Fertiliser Association).

Scenario variability

In all scenarios, P use is expected to increase but with wide differences (range 22 – 34 million tonnes P, compared to 20 MtP in 2000). Demand increases in all areas of use: agriculture, animal feeds, detergents, industrial uses.

The authors conclude that rapid depletion of extractable phosphate rock in the near term is not very likely. However, **by 2100 around 20-35% up to 40-60% of the "resource base" may be depleted.**

As phosphorus is essential for world food production, **even partial depletion of the resource base could be significant for the sustainability of agriculture**. Partial depletion of the resource base will mean depletion of low-cost, high-grade resources. At the same time a concentration of production in Morocco is expected (reaching >50% of world P production), unless new resources are identified in other regions.

High uncertainty in data on P product, P consumption and particularly P resources is emphasised, and consequently the need to improve the quality of data on flows and resources.

The authors underline that **"major reductions" in the P consumption in fertilisers** can be achieved by improving plant nutrition management, making better use of nutrients in manure, and recovering and recycling phosphorus from human and animal wastes.

"Phosphorus demand for the 1970–2100 period: A scenario analysis of resource depletion", Global Environmental Change, 20, (2010), pages 428–439
http://www.sciencedirect.com/science/journal/09593780

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See also:

"Global nitrogen and phosphate in urban waste water for the period 1970–2050", Global Biogeochemical Cycles, 2009, 23, doi:10.1029/2009GB003458
http://www.agu.org/journals/gb/ *G. Van Drecht, A. Bouwman, J. Harrison, J. Knoop.*

"Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050", Global Biogeochemical Cycles, 2009, 23, doi:10.1029/2009GB003576
http://www.agu.org/journals/gb/ *A. Bouwman, A. Beusen, G. Billen.*

Global food and resource use

20% of world food goes to waste

Wasted food or lost agricultural production means wasted and lost phosphorus. Reducing unnecessary food waste and overproduction in developed countries and agricultural or post-production losses in poorer countries could save 20% of world food production. Around 1% of the agricultural land thus economised would suffice to feed all the world's hungry. If the remaining freed land was used to plant forest or energy crops, the world's net greenhouse emissions could be cut by 40%

Tristram Stuart's book "*Waste, uncovering the global food scandal*" presents in detail, but in a readable way with explanations, anecdotes and illustrations, **the shocking level of food waste and of loss of agricultural production in both developed and developing countries**. It is backed up by a complete collection of statistics, references and tables.

The author argues that current levels of food waste are both morally unacceptable and ecologically unsustainable, because they contribute considerably to world hunger and to environmental damage through **greenhouse emissions, deforestation and resource consumption (including of phosphorus).**

Supermarkets bins

The considerable level of food waste in supermarkets, small retailers and restaurants / convenience food outlets is explained and illustrated. This includes damaged products and products considered no longer saleable, but also **large quantities of perfectly edible food which is put in dustbins** because it is considered too near a "best by" date, because part of a packet is damaged, or because of in appropriate stock management.

Only a small part of this thrown-away food is recycled through organisations such as food banks for the needy, with attitudes varying considerably between countries and between supermarket chains. Increasingly in Europe, waste food is separated from other municipal waste in order to avoid organic (fermentable) materials going to landfill. This avoids methane production in landfill sites and food waste is increasingly sent to **anaerobic digestion**, enabling energy production (gas).

However, this is still a large waste of resources because this energy recovery is insignificant compared to the energy used to produce, transport and process the food, and because the other resources in the food are lost (nutrients, minerals …).

The **misuse of "best by" dates** is discussed: these dates are often fixed in a highly "precautionary" way and do not correspond to any real issue of food safety or even quality, and consequently result in widespread unnecessary wastage of good food products.

Considerable food waste is also generated upstream by supermarket purchasing policies, waste which does not appear in their own bins or statistics. Just in time ordering, over-ordering, aesthetic requirements (leading to a significant proportion of a crop being thrown away by farmers because it is the wrong size, shape or colour) … result in a scale of waste which is both largely unknown and undeclared.

For example, one supermarket's specifications for companies producing sandwiches for its shelves exclude not only the crusts but also the last slice from each end of each bread loaf used, resulting in 13,000 slices of bread going to waste in just one factory every day

Needs and excess

The author examines the **psychological (evolutionary) and social reasons for food surplus**, assessing the real need for society to ensure a safety margin of food production above actual needs (to allow for unexpected crop failures or losses), and showing that **the West's current levels of excess production and over-consumption are far beyond such justified needs**. He also presents various societies' approaches to saving food or wasting it (UK, USA, Japan, China, Taiwan, South Korea).

In many developing countries, on the other hand, there are **considerable food losses both on the farm and post-production, in particular in storage and food product transport and management**. The implementation of technology and know-how which exists and is largely applied in developed countries could considerably reduce these losses, with investments much lower than those currently made in improving productivity.

A key area where relatively low-cost, simple investments could considerably reduce losses of cereals and rice would be by building appropriate ventilated **storage facilities, protected from pests**

and birds. Such improvements could have immediate impact in reducing hunger and improving the economic situation of small farmers.

Culture and pigs

Cultural and historical processes for reducing food waste and recycling are presented, including **the place of pigs in many societies**, because of their efficiency in reusing food wastes and by products to produce meat. This link has been cut in many developed countries, both with the loss of the local village pig as societies have been modernised, and with recent legislation forbidding the use of many types of food wastes in pig feed in an attempt to reduce the risk of foot and mouth disease.

The author estimates that EU regulations banning pig swill (food wastes used as pig food) result in an annual economic loss of around 15 billion Euros for the European Union as lost pork meat production, without counting the costs of waste disposal to other routes for food producers, canteens and restaurants.

If the **land used to produce the pig feed necessary to replace pig swill now sent to landfill or anaerobic digestion** was returned to forest, 700 million tonnes of CO_2 emissions per year would be saved. The UK outbreak of foot and mouth disease which sparked this legislation cost only 8 billion Euros (once, not every year), whereas there is evidence that it was not the use of food waste in pig swill which caused the problem, but only failure of certain operators to respect the minimum heat treatment requirements. It must be remembered that foot and mouth risk does not concern possible human health risks (the disease concerns only certain farm animals) and is therefore not comparable to the banning of certain animal wastes fed to ruminants in order to prevent BSE (mad cow disease) contamination.

Need for action and data

To conclude, Stuart Tristram presents a compelling argument for **food waste to be made a priority theme for environmental and social action worldwide**, in developed countries to reduce over-consumption, waste and improve recycling (food banks etc) and in developing countries (to reduce post-harvest losses).

This necessitates recognising the issue as important, at the same level as international action to improve **crop productivity** for example, and instigating coherent collection of data to ensure that the information necessary to take action is available. This is not the case today, as **food and crop waste statistics are not available from supermarkets, the food industry or farmers**, who have no commercial or image interest to make such information available. Obligatory reporting of food and crop waste arisings and of their management (as exists for other industrial wastes) is suggested to be the only way to obtain reliable data necessary to define and implement action.

Food waste appears as a priority environmental and social issue, because of the impact on hunger and human suffering in both developed and developing countries, and because of the massive environmental impact of **related greenhouse emissions** (related to land use) and **resource consumption (including phosphorus).**

European Union action

The issue of food waste was highlighted in the European Commission's "*Environment for Europeans*" magazine, October 2011: "*A typical European household throws away between 20 % and 30 % of the food it buys. This wastes not only the food itself, but also the carbon, water and energy used to produce and to dispose of it*". The magazine suggests that 60% of this waste could be avoided. The European Union is currently clarifying "use by" date legislation as one route to try to reduce this waste.

"Waste, uncovering the global food scandal", Tristram Stuart, Penguin Books 2009, 297 pages plus 154 pages of tables, data and references, ISBN 978-0-141-03634-2.

EU Commission, Environment for Europeans, article on food waste, October 2011, page 8:
http://ec.europa.eu/environment/news/efe/flip/efe/index_gw2011.html#/page_11

Nutrient resources

Heatphos pilot

Biological polyphosphate route to P-recovery

The authors present a summary of current knowledge of the biochemical and enzyme processes involved in phosphate accumulation by sewage sludge microorganisms, present the Heatphos process where phosphorus is recovered for recycling through calcium precipitation of released biological polyphosphate (PolyP), and present other technological applications of knowledge of PolyP.

Biological phosphorus removal

Biological P-removal processes in sewage works (**EBPR** = enhanced biological phosphate removal) function by subjecting sludge to repeated aerobic and anaerobic-anoxic cycles. Under these conditions, the microorganisms in sludge will release inorganic phosphates (Pi) during the anaerobic/anoxic phases, but take up "excess" or "luxury" phosphate during the aerobic phase, thus removing phosphate from the wastewater (into microorganism cells in the sludge). **This take up requires available carbon, which is often lacking in sewage works, but can be supplied** by adding either artificial sources (e.g. acetate) or through recycling of carbon rich liquors from sludge or food waste digestion.

The "excess" accumulated phosphate is stored in the form of PolyP, that is biologically synthesised phosphate polymers with chain length of up to 1000 or more. This allows the microorganisms to store large amounts of phosphorus without disrupting cell ion concentrations (osmotic pressure). The phosphate can be removed from / added to the PolyP chain by exchanging with a phosphate ion from ATP/ADP (adenosine tri/di phosphate, the principal energy transfer molecule in most contemporary organisms).

Bacterial strains and P concentration

The authors present the detailed metabolic pathways of PolyP accumulation, and work with different microorganisms, including mutant strains, to **identify the rate limiting steps** in this process. *Pseudonomas* and *Acinetobacter* mutants were shown to accumulate 15 – 60x more PolyP than parent strains, reaching up to 9% P (27% as Pi) (% dry body weight). Mutant *E. coli* strains with addition of PPK enzyme (catalyses ATP + PolyP length N -> ADP + PolyP N+1) and *pst*-operon (Phosphate Specific Transport across cell membrane) reached 16% P (48% Pi) dry body weight.

In the past, biologists considered that *Acinetobacter* strains were principally responsible for P-removal in EBPR sewage plants, but recent work has identified *Accumilibacter phosphatis* (order: Rhodocyclales) as the principal microorganism in acetate-fed EBPR.

Heatphos

Heating phosphorus accumulating microorganisms was demonstrated to release PolyP, as such, by disintegration of internal cell storage structures and of cell wall membranes. The rate and extent of PolyP release was temperature dependent: nearly all PolyP was released in 10 minutes at 90°C, 30 minutes at 80°C or 60 minutes at 70°C, with little release at < 50°C. However, hydrolysis of PolyP to Pi also increased with temperature, with c. 20% conversion at 70°C but 60% at 90°C. At 70°C, the released PolyP had an initial chain length of 100-200 units, decreasing with time (no PolyP > 100 after 2 hours).

Released PolyP can be readily precipitated without pH adjustment by adding calcium chloride, resulting in a precipitant with 16% phosphorus and 18% calcium and only around 4% carbon. This offers advantages compared to P-recovery from solutions containing inorganic phosphates Pi, where precipitation as calcium phosphates is only possible by significantly increasing the pH.

Pilot and full scale Heatphos plants

This process of PolyP release by heating (70°C for one hour) followed by calcium precipitation, named **"Heatphos", has been tested in a pilot EBPR plant at a municipal waste water treatment plant (wwtp) in Kobe City, Japan, and at a full scale plant in Fukuyama City.** The pilot EBPR plant treated 100 m^3/day, generating 10-20 kg MLSS/day of sludge input to the PolyP precipitation process. The full scale plant (photo in paper) had a daily sludge flow or around 360 kg/day, producing around 70 kg of precipitate ("biophosphorite") per day (containing c. 10 kg/day phosphorus).

Other routes for P-recovery, including struvite precipitation and sorption onto materials such as TiO_2 or blast furnace slag are also discussed, as is Japan's phosphorus balance and processes to use recovered phosphates, for example by phosphoric acid addition (acidification) or recovered P products to improve availability of phosphorus.

Other biochemical information concerning PolyP is also presented, including possible enzymes allowing PolyP to place the role of energy vector in cell metabolism in place of ATP/ADP. New methods are proposed for detecting bacterial contamination of foods or other materials using PolyP related enzymes. PolyP has also been demonstrated to be usable to provide energy to modified or selected microorganisms for biosynthesis of specific molecules (potentially for industrial or medical applications), avoiding the problems which occur if ATP is used (cost, accumulation of inhibitory byproducts).

"Bacterial phosphate metabolism and its application to phosphorus recovery and industrial bioprocesses", Journal of Bioscience and Bioengineering, Vol. 109, n° 5, pages 423–432, 2010 www.elsevier.com/locate/jbiosc

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Spain

Optimising P-recovery

Adapting the configuration and management of the sludge treatment line from biological phosphorus removal can optimise the struvite P-recovery potential.

Four different management options for the sludge treatment line of a pilot EBPR (enhanced biological phosphorus removal) sewage treatment plant were tested, with the **objectives of minimising uncontrolled phosphate precipitation in the anaerobic digester and of optimising P-recovery as struvite**.

The studied pilot anaerobic digestion plant treated sludge from a pilot fermentation/elutriation plant and from a pilot EBPR plant, located in the **Carraixet municipal sewage treatment plant, near Valence, Spain**, as detailed in Marti 2008A (see SCOPE Newsletter n° 73), Bouzas 2007, Garcia-Usach 2006.

Four configuration options

The four options involve **separated or mixed thickening of the sludges**, use of a **contact tank**, **elutriation of the thickened sludge** and **flowrate** of this elutriation stream. The anaerobic digestion process was operated at mesophilic conditions and at a solids retention time of 20 days in all experiments. In Marti 2008B, detailed specifications and flow diagrams of the four configurations are found.

The influent sludge showed differences in characteristics between the four experimental runs, resulting from different conditions in the upstream pilot plants.

The four different options resulted in **variations in the anaerobic digester process**, with total volatile solids removal varying from 40 to 60%.

Reduced P precipitation in digester

The mixed sludge thickening combined with a high flowrate elutriation stream **reduced the phosphorus precipitation in the digester by 43%,** with respect to the separate sludge thickening configuration (common practice in WWTP). Analysis showed that the principal precipitate being formed in the digester was struvite.

Correspondingly, the **soluble phosphate in the liquor streams potentially available for struvite precipitation** (P-recovery) was increased from 20% to 68% of the P in the influent sludge. However, the calcium concentration (and specifically the Ca/P molar ratio=2.5) of the liquor stream is also significantly increased in the latter scenario, which is pointed out as a problem for the efficiency of struvite crystallization.

Struvite precipitation for P recovery

In a second paper, Marti 2010, experimental struvite precipitation results on the above liquor streams are presented. A 21 litre, stainless steel stirred reactor was used, as presented in Pastor 2008. This reactor was originally designed and constructed by LAGEP Lyon, France, for CEEP as presented in SCOPE Newsletter n° 57.

The reactor was operated in continuous mode with a hydraulic residence time in the reaction zone of 2.5 hours. Sodium hydroxide dosing was used to maintain pH 8.7, as described in Chanona 2006 (see SCOPE Newsletter n° 73). Struvite reactor inflow concentrations of soluble phosphorus varied between the four options, from 43 to 151 mgP-PO_4/l. Precipitation efficiencies of 83 – 87% (of soluble inflow phosphate) and **P-recovery efficiency of 70 – 85% (of total inflow phosphorus)** were measured in the reactor.

Overall P recovery rate

Results confirmed the expectations based on the liquor characteristics expressed in Marti 2008B above. The **optimal overall P-recovery rate was 40%** (% of total phosphorus in the initial sludges being transferred to precipitates in the struvite reactor), achieved in the scenario with sludge mixed thickening and high elutriation flowrate.

However, the rate of P-recovery as struvite is not optimal in this scenario (at 3.1 g struvite P per kg of sludge = 15% of total treated sludge phosphorus) because part of the recovered phosphorus is in the form of calcium phosphates.

A scenario with lower elutriation flowrates resulted in a lower rate of total P-recovery in the reactor but a **higher production of struvite (3.9 g struvite P per kg of sludge** = 26% of total treated sludge phosphorus).

The authors conclude that up to 40% of sewage sludge phosphate can be recovered through the configurations tested (this would be **32 – 36% of total sewage works inflow phosphorus** if the works is operating 80 – 90% P-removal), but that in this case the resulting product is only around 40% struvite, the remainder being principally calcium phosphates. The choices for optimisation of P-recovery will therefore depend on the form of phosphate targeted for recovery and on the calcium content of the water treated (hard or soft water).

Marti 2008B: "Optimisation of sludge line management to enhance phosphorus recovery in WWTP", Water Research (Elsevier), vol. 42, issue 18, pages 4609-4618, November 2008 www.elsevier.com/locate/watres *or direct link* http://dx.doi.org/10.1016/j.watres.2008.08.012

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Marti 2010: "Phosphorus recovery by struvite crystallization in WWTPs: Influence of the sludge treatment line operation", Water Research, vol. 44, issue 7, pages 2371-2379, April 2010. Authors as above. http://dx.doi.org/10.1016/j.watres.2009.12.043

Marti 2008 A: "Struvite precipitation assessment in anaerobic digestion process", N. Marti, A. Bouzas, A. Seco, J. Ferrer, Chemical Engineering Journal (Elsevier), vol. 141, issues 1-3, Pages 67-74, 15th July 2008: http://dx.doi.org/10.1016/j.cej.2007.10.023

Chanona 2006: "Application of a fuzzy algorithm for pH control in a struvite crystallisation reactor", J. Chanona, L. Pastor, L. Borras, A.Seco, Water Science and Technology (IWA Publishing), vol. 53, n°12, pages 161-168, 2006: http://www.iwaponline.com/wst/05312/wst053120161.htm

Garcia-Usach 2010: "Calibration of denitrifying activity of polyphosphate accumulating organisms in an extended ASM2d model", F. García-Usach, J. Ribes, J. Ferrer, A. Seco, Water Research, vol. 44, issue 18, October 2010, Pages 5284-5297 http://dx.doi.org/10.1016/j.watres.2010.06.061

Garcia-Usach 2006: "Calibration and simulation of ASM2d at different temperatures in a phosphorus removal pilot plant", F. García-Usach, J. Ferrer, A. Bouzas, A. Seco, Water Science & Technology (IWA Publishing), vol. 53, n° 12 , pages 199–206, 2006 http://www.iwaponline.com/wst/05312/wst053120199.htm

Bouzas 2007: "Fermentation and elutriation of primary sludge: Effect of SRT on process performance", A. Bouzas, J. Ribes, J. Ferrer, A. Seco, Water Research, col. 41, issue 4, February 2007, pages 747-756 http://dx.doi.org/10.1016/j.watres.2006.11.034

Iron phosphate

Process to extract P from iron precipitate in sludge

Wherever iron dosing is used for nutrient removal in sewage treatment plants, the resulting precipitation of iron phosphate into the sludge is a major obstacle to P-recovery or P-reuse, because $FePO_4$ is insoluble, is poorly available to plants, and phosphate is no longer available for recovery by either thermal or struvite processes. This paper presents an innovative microbial fuel cell in which $FePO_4$ is reduced through electrons and protons obtained from metabolic activity of bacteria, thus giving soluble orthophosphate that can be recovered and recycled by struvite precipitation.

The microbial fuel cell used provided a bioreactor volume of 2.5 litres (stirred), a 40 ml cathode module (stirred) and six carbon anodes and one carbon cathode.

The cell was tested using both **digested sewage sludge** containing 13.6% $FePO_4$ (2.9% phosphorus), and pure $FePO_4$.

In the cathode compartment, electrons and protons generated by the microbial activity are shuttled as hydrogen equivalents by Methylene Blue. The electrons reduce the iron cations, and the cations are also reduced by collision with the electrode, and these charges are replaced by protons, and consequently orthophosphate is released into solution.

The system functions because a **stoichiometric current of electrons and protons is produced**. The electrons are harvested by the carbon tissue anodes (total surface 0.13 m^2) and the coupled protons pass through a membrane into the cathode. Current density varied between 0.1 and 0.7 mA.

Orthophosphate solution

The orthophosphate solution was extracted by removing the cathode supernatant (40 ml), after approximately one week, and filtrated. Thus the supernatant obtained contained 48% orthophosphate with only 0.6% iron from pure $FePO_4$ and **up to 82% orthophosphate from the digested sewage sludge** after 21 days.

The precipitated struvite did not contain toxic metals such as arsenic, cadmium lead or chromium, despite their presence in the digested sewage sludge used.

The authors discuss issues to address the improvement of the iron phosphate reducing capacity of the microbial fuel cell, and **factors influencing efficiency** such as particle size, proton migration across the membrane, electrical resistance of the cathode set-up.

The **limited accessibility of the reduction site in the iron phosphate molecules** represents a major intrinsic constraint for orthophosphate production, but proved nonetheless adequate for struvite production.

This work shows **a possible route for recovering and recycling phosphorus from iron-containing sewage sludges** (where iron is dosed for P-removal), but also shows the **complexity of achieving this**.

"Microbial fuel cell enables phosphate recovery from digested sewage sludge as struvite", Bioresource Technology 102 (2011) pages 5824–5830
http://journals.elsevier.com/09608524/bioresource-technology/

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Algal blooms

Ontario

Climate change and eutrophication

The Lake of the Woods is a c. 385 000 ha complex waterbody (49°N, 94°W), with many bays, over 14 000 islands and 10 000 km of shoreline, in Ontario and Manitoba, Canada, and Minnesota, USA. The main southern bay, Big Traverse Bay, is shallow (5-10 m) whereas the northern part of the waterbody is deeper (14 – 66 m). The Lake's watershed is predominantly forest and wetland, with only c. 5.5% agricultural land surface. Leisure cottages are scattered along both the north and south shorelines.

Recently, residents and authorities have expressed **concerns that cyanobacteria blooms in the lake are becoming more frequent and more extensive**, and suggestions have been made that increasing nutrient concentrations may be the cause. In the absence of continuous, long term monitoring data, **paleolimnological techniques can be used to track historical changes in water quality** using biological indicators preserved in lake sediments. The results of this study suggest that total phosphorus (TP) concentrations have not increased in the northern parts of the lake and that the **compounding effects of recent warming with the existing mesotrophic conditions have likely led to the intensification of algal blooms in the Lake of the Woods**.

This paper estimated **historic TP concentrations** from a suite of sites throughout the Ontario portion of the Lake of the Woods using siliceous algae (diatoms) identified in lake sediments. Sediment cores were collected from 17 sites in the lake system, and for each core, the diatom assemblages preserved in the modern sediment (top 0.5 cm interval) were compared with the assemblages preserved in sediments that were deposited before ~1850 (bottom 0.5 cm interval) to provide a lake-wide assessment of environmental change. Based on radioisotopic dating of detailed cores from this region, 17 – 30 cm core depth generally pre-dates 1850.

To aid in determining whether changes in nutrients can explain the diatom trends, a **diatom-based inference model** was used to reconstruct changes in TP concentrations. Following the methods of Pla et al. 2005 (J. Great Lakes Res. 31, p 253-266, 2000), diatom assemblages from the Lake of the Woods pre-industrial sediments were compared to the modern diatom assemblages / water chemistry matrices from 55 Minnesota lakes spanning a gradient of measured TP, plus data from the 16 sites collected from the lake itself.

Changes in diatom populations

The nature and direction of change from pre-1850 to today in diatom assemblages were coherent in all Lake of the Woods sediment samples, but with varying magnitudes of change. In particular, the most notable shift was an increase in the relative abundances of planktonic diatoms including small, centric *Cyclotella* taxa and several planktonic, pennate diatoms and a concurrent decrease in heavily silicified *Aulacoseira* taxa and small, benthic *Fragilaria* taxa in the modern sediments.

This is consistent with a similar widespread taxonomic shift observed in non-acidified, non-enriched lakes across the northern hemisphere (Rühland et al., Glob. Change Biol. 14, p 2740-2754, 2008). These taxon-specific shifts were found to be the result of warming-induced changes in water properties, such as an increase in the ice-free period and changes in thermal stratification patterns.

Total phosphorus

Weighted averaging partial least squares (WA-PLS) techniques were used to estimate pre-industrial diatom-inferred TP (DI-TP) concentrations. The application of this model on the 17 top and bottom samples from the Lake of the Woods suggested that **TP levels had either not increased, or had slightly decreased since pre-1850** in 88% of Lake of the Woods sites.

Total phosphorus levels in the lake were indicated to have been moderately high before the onset of human impacts (i.e., pre-1850). The authors conclude that the changes in the diatom community observed today, and **possible increases in algal blooms, are caused primarily by climate change,** resulting in warmer lakewater temperatures, reduced ice-cover and changes in water column properties, and to a lesser degree by human phosphorus inputs (for example from the lakeside cottages).

"Examining 20th century water quality and ecological changes in the Lake of the Woods, Ontario, Canada: A paleolimnological investigation", Journal of Great Lakes Research 37, pages 456–469, 2011 (Elsevier)
http://dx.doi.org/10.1016/j.jglr.2011.05.007

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Conferences and publications

Toulouse, France, 23rd November 2011

Recycling and reuse of phosphates from effluents

This seminar will look at the issues surrounding phosphate recycling, P-recovery processes, phosphate precipitation, uses of recovered phosphate products.

The seminar will include a presentation of the Phosph'OR continuous process for precipitating and recovering struvite from treated pig manure (Cemagref), the LISBP process for recovery of phosphate by biological granulation, processes for recovery of phosphate from domestic sewage, methods and models for struvite precipitation, regulatory issues and plant availability of recovered phosphates.

Organised by INSA Toulouse, Cemagref, LISBP and Midi-Pyrénées Innovation.

8h30 – 17h00 Wednesday 23rd November 2011
INSA Toulouse, France
In French

https://phosphor.cemagref.fr/events/FlyerP.pdf

Phosphorus cycle

Chemosphere special issue

Chemosphere journal (Elsevier publishers) has published a special issue on "The Phosphorus Cycle": Chemosphere, Volume 84, Issue 6, Pages 735-854 (August 2011).

Individual articles can be purchased on the Elsevier ScienceDirect website:

http://www.sciencedirect.com/science/journal/00456535/84/6

or paper copies of the full special issue can be purchased for €160,50 (ex VAT, inc. price for postage to Europe) from

Journalscustomerserviceemea@elsevier.com

CRU report

Phosphate Rock – Ten Year Outlook

CRU, leading fertiliser market forecasts, have published a new 2011 report: "*Phosphate rock: ten year outlook*"

The phosphate rock market has rebounded after two years of decline. Production, international trade and prices are all increasing and are forecast to trend upward during the next ten years. Longer term, increases in capacity will be required. This report suggests that as demand for phosphate rock recovers, vertically integrated phosphate rock converters will increase their share of the international market allowing for only a modest increase in rock exports..

Report, including update and CRU staff consultation access UK£ 5400 http://www.crugroup.com/market-analysis/

Phosphates 2012

Phosphate industry conference

The 2-yearly conference for the worldwide phosphate industry (rock production, fertiliser, animal feeds, food, detergents, other industrial uses) will take place in El-Jadida, Morocoo, 19th - 21st March 2012:

- Phosphate rock production and project developments
- Global fertilizer outlook with a focus on key country demand projections and requirements
- Developments in optimizing / streamlining and maximizing the phosphate resource
- Survey of changing industrial phosphate demand, update of regulations and substitutes
- Outlook of future feed phosphate demand and focus on regional growth

The event also offers **site visits to the Jorf Lasfar Chemical Facility and to the Khourlbga Mine Facility**.

http://www.crugroup.com/events/phosphates/

Call for abstracts

3rd sustainable phosphorus summit

The 3rd Summit (29th February – 2nd March 2012, Sydney, Australia) will bring together key international science, policy and industry stakeholders from different parts of the food production and consumption chain concerned about the role of phosphorus availability and accessibility in global food security, about protecting the environment, and about supporting rural and urban livelihoods.

Themes include:

- Sustainable food systems
- Global phosphate rock production and reserves
- Phosphorus use efficiency in mining, agriculture, food processing
- Phosphorus recovery and reuse
- Phosphorus pollution and waste
- Sustainable phosphorus strategies and global governance

29th February – 2nd March 2012, Sydney, Australia
http://sustainablepsummit.net/

Call for abstracts (150 words) is open to 2nd November 2011