Inventory of inventories discussing P-recycling strategies

Compiled by Wetsus, centre of excellence for water technology and the European Sustainable Phosphorus Platform (ESPP)
Focus on studies inventories since 2010. Important studies before 2010 may also be included.

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Categories		
	R-Pol	Review of P-recovery strategies oriented at policy and business level decision makers.
	R-Sci	Review published in a scientific journal giving a critical review of different recovery strategies
	T-Sci	Review published in a scientific journal with review focussing on one technology or strategy
	LCA	Review giving a quantitative comparison between different technologies, preferably on a LCA-basis
	Other	websites, regulatory information, other sources of relevant information

title	authors	journal, publisher	Year	# pages	Type	web link / public access? / price(€)	types of technology covered	Streams treated	P-recycling only?	Abstract	Category
Production of slow release crystal fertilizer from wastewaters through struvite crystallization – A review	Md. Mukhlesur Rahman, Mohamad Amran Mohd. Salleh, Umer Rashid, Amimul Ahsan, Mohammad Mujaffar Hossain, Chang Six Ra	Arabian Journal of Chemistry (2014) 7, 139–155	2014	17	Peer reviewed article	Open access	Struvite crystallization technologies and use of struvite in agriculture	Sewage water, manure waste water and other nutrient rich waste waters	Focus on phosphate and nitrogen recovery via struvite.	The article reviews available literature on struvite crystallization technologies for recovery of nitrogen and phosphate from waste water. A first section focusses on the physical and chemical nature of different types of struvites. A second section discusses the influences that have been reported on struvite nucleation as wells as the different conditions that have been used in various literature sources for struvite precipitation (like molar Mg/P rati's, pH, aeration rate). The article concludes with an overview of literature describing the agrinomic benefits of struvite use a a fertilizer.	T-Sci
Technologies to Recover Nutrients from Waste Streams: A Critical Review	C.M. Mehtaa, W.O. Khunjarb, V. Nguyenb, S. Taita & D.J. Batstonea	Critical Reviews in Environmental Science and Technology	2014	42	Peer reviewed article	34 €	plant and micro-organism processes, digestion and bioleaching, membranes, precipitation, sorption, magnetic binding, liquid/gas stripping, electodialysis and thermal treatment.	Wastewater, sludge, biomass	No, also focus on N and K	The full range of nutrient recovery routes are reviewed, on a multi-criteria basis, considering recovery as a three phase process: nutrient accumulation (or concentration), nutrient release and nutrient extraction to a final nutrient product. The paper categorizes all technologies using operating parameters and wastestreams. The extend of published literature is discussed and each technology is analyzed according to implementation and uptake criteria. Most work on nutrient accumulation has addressed application in municipal waste water treatment. For nutrient extraction, struvite recovery is recognised as readily adoptable and already applied full scale. Electrodialysis and gas membrane ammonium recovery are considered to be embryonic, but probably essential in the future for N and K recovery. The authors recommend both to harness the value of biosolids products (low value but low production cost) and to develop production of high-quality products (e.g. comparable to mineral fertilisers). The appropriate and economically feasible technology will depend on context. Areas requiring further R&D are identified.	R-Sci
Phosphorus recovery from municipal solid waste incineration fly ash	Kalmykova, Y. and Karlfeldt Fedje, K.	Waste Management	2013	8	Peer reviewed article	Open access	- Acid dissolution–alkali precipitation - Two-step acid–base leaching	Municipal solid waste incineration ash	No, but it is intended to recover Al, Cu, Mg and Zn	The scientific article describes the potential to recover phosphate from municipal waste ash. The authors test two potential methods for recovery (already applied to other solid waste). Due to high calcium (Ca) content only acid dissolution-alkali precipitation recovered P successfully (70 %). The recovered product (contains 3 wt. % phosphorus) is high in trace metals, limiting direct use. The acid-base leaching resulted in a purer product but low recovery (1 %). Experiments to recover other elements and using liquid industrial waste instead of chemicals are planned. Additional efficiency of acid-base leaching should be improved. Economics and LCA were not evaluated at the early stage of the research.	T-Sci
Phosphorus sorption and recovery using mineral-based materials: Sorption mechanisms and potential phytoavailability	Laura A. Wendling , Peter Blomberg, Tuija Sarlin, Outi Priha, Mona Arnold	Applied Geochemistry	2013	13	Peer reviewed article	30,76	Phosphorous sorption by mineral-based materials	Solutions prepared in laboratory Seawater Lakewater Wastewater	Yes	The scientific article gives a detailed review of mineral based sorbents for P removal and also states the ideal characteristics for a P sorbent. The P can be reused by either applying the used sorbents directly on agricultural land or by regenerating the sorbent and recovering the P. It compares wide range of sorbents like phylosilicates, zeolites, oxides, oxyhydroxides, polymer ligand exchangers, Industrial byproducts and states their respective adsorption capacities and their limitations.The article does not adress economics of sorption of P as a means for P recovery.	T-Sci

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Life cycle assessment applied to wastewater treatment: State of the art	Ll. Corominas, J. Foley, J.S. Guest, A. Hospido, H.F. Larsen, S. Morera , A. Shaw	Water Research	2013	13	Peer reviewed article	Open access	Evaluation of LCA for activated sludge, microbial fuel and microbial electrolytic cells, advanced oxidation processes, membrane bioreactors	Wastewater, sludge	P recycling by sludge reuse in agriculture is considered in some of the LCA's	The article gives an overview of a large number of 45 peer reviewed papers adressing LCA studies of waste water treatment since 1990. The article concludes that the system boundaries for the studies vary widely and that there is a need for standardization. The author's conclude that these studies in general show that nutrient removal is important and compensates for uses of energy to reduce these emissions. With respect to sewage sludge management the author's conclude that sludge treatment can best be centralized and that energy should be recovered by digestion. Final treatment of sewage sludge can be incineration or agricultural applications. For the latter application is restricted because of pollutants (heavy metals, micropollutants) in the sludge.	LCA
Inventory, Techniques for nutrient recovery from digestate	V. Lebuf, F. Accoe, S. Van Elsacker, C. Vaneeckhaute, E. Michels, E. Meers, G. Ghekiere, B. Ryckaert	Arbor biomass for energy EU Interreg IVb project	2013	26	Inventory	open access, http://arbornwe.eu/downloads	Technologies for treatment of digestate and manure. Dewatering, composting and drying of the digestate. Nutrient recovery from the liquid fraction, the solid fraction and from air.	Digestate, with a focus on digestate from manure processing.	Focus on the nutrients phosphate and nitrogen.	The inventory gives an introduction to technologies that can be considered for treatment of digestate and can serve as an introduction for readers that are new in this field. The report gives some data on the composition of digestate and ways to process the digestate by means of dewatering and drying technologies. Furthermore technologies for nutrient recovery from the liquid fraction are discussed, like membrane concentration, struvite precipitation and ammonia stripping. Also some attention is paid to use of algea for biomass production from the nutrient rich liquid fraction. Another dicusses nutrient recovery from the solid fraction, but concludes that this requires thermal technologies like incineration or pyrolysis followed by treatment of the ash. Finally also ammonia recovery from ammonia-rich air streams is discussed.	R-Pol
Recycling and recovery routes for incinerated sewage sludge ash (ISSA): A review	Donatello, S. and Cheeseman, C. R.	Waste Management	2013	13	Review	35,95 $	Acid leaching; Thermochemical methods; Immobilization	Incinerated sewage sludge ash (ISSA)	Technologies for phosphate recovery from sewage sludge ash. Also discussion of several alternatives for use of sewage sludge, including subsituting raw materials in brick and cement production.	This review describes several recovery techniques of P from incinerated sewage sludge ash (ISSA). The author's conclude that research on reuse of sewage sludge ash is a relevant recent area of research that first focussed on reuse of the ash as building material. More recently processes have been developped for recovery of phosphate from this material. With increasing waste disposal costs and phosphate rock prizes these processes will become more and more interesting, but there is a need for industrial examples. The acid leaching processes is described with three different operational modes: Acid dissolution (H_2SO_4) of phosphorus and further precipitation as $AlPO_4$ by addition of $NaHCO_3$ and $Al_2(SO_4)_3$. Separation of heavy-metals by precipitation with calcium at high pH; Acid precipitation (HCl) and subsequent basic dissolution of $AlPO_4$ with $CaPO_4$ precipitation under alkanic conditions; Acid dissolution (H_2SO_4) of phosphorus with further ion-exchange and sulphide treatment to selectively remove heavy-metals. $CaPO_4$ precipitation at the end with $Ca(OH)_2$ addition. The thermochemical processes with additives are also discussed to remove the heavy-metals. 60 to 80% of the total phosphorus present in ISSA was recovered when acid leaching was applied. In the thermochemical processes all phosphate in the ash will be recovered.	T-Sci

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Energy - nutrients - water nexus: Integrated resource recovery in municipal wastewater treatment plants	Mo, W. and Zhang, Q.	Journal of Environment Management	2013	13	Review	41,95$	Biosolids land application, Urine separation, Controlled struvite crystallization and Recovering nutrients through aqua-species	Municipal sewage water	The review focus on three major recycling resources: energy, nutrients and water. Where phosphorus is referred as part of nutrients recovery	This review describes the available methods and the main challenges for onsite energy generation, nutrient recycling and water reuse in municipal wastewater treatment plants. The life cycle of these processes are evaluated as well as their integration under different scales. For nutrient recycling four processes are mentioned: Biosolids land application (high availability but there are concerns about the health and safety issues, odor and public acceptance); Urine separation (high nutrient recovery rates, but issues with faeces contamination and consequently presence of pathogens); Controlled struvite crystallization (high nutrient recovery rates, but high costs of operation); Recovering nutrients through aqua-species (high amounts of nutrient uptake by aqua-species, feasible cost and energy efficient, but there is a lack of awareness and expertise in developing the technique). The review concludes that different LCA-studies give different conclusions for for instance land application of biosolids compare to sewage sludge incineration.	R-Sci
A Theoretical and Practical Evaluation of Struvite Control and Recovery	Sharp, R.; Vadiveloo, E.; Fergen, R.; Moncholi, M.; Pitt, P; Wankmuller, D.; Latimer, R.	Water Environment Research	2013	12	Peer reviewed article	Open access	Technologies for control of struvite scaling: ferric dosage, struvite precipitation.	Digested sludge from sewage water treatment plants	Recovery of phosphorus by struvite formation	The article focus on operational issues around the formation of struvite in sewage water treatment plants. The controlled addition of ferric salts at specific locations is crucial for struvite control. Also, a BioWin model is experimentally tested and applied to optimize the chemical addition and nutrient recovery on struvite formation. The addition of ferric salts in either the digester or the centrifuges successfully reduces the struvite formation and consequently decrease the phosphorus content in the final effluent. As an alternative the controlled precipitation of struvite via the Ostara process is considerd. An economic analysis shows that struvite precipitation has a lower net present value compared to the dosage of ferric salts.	T-Sci
Prospects of Source-Separation-Based Sanitation Concepts: A Model-Based Study	Taina Tervahauta, Trang Hoang, Lućia Hernández, Grietje Zeeman, Cees Buisman	Water	2013	30	Peer reviewed article	Open access	Source separation concepts. Treatment of urine, black water and greywater.	Source separation concepts. Treatment of urine, black water, kitchen waste and greywater.	focus is on treatment of source separated concepts, with some attention to P-recycling	This article compares different source separated concepts for treatment of urine, feces and kitchen refuse with a classic centralized waste water treatment. Four cases are described.The effluent quality and consumption of energy, water and chemicals are compared for the four cases. The study concludes that source separation can improve the overall energy balance (both direct and indirect) compared to a centralized treatment. Separate collection and treatment of urine is beneficial in both centralized and source separated concepts.	T-Sci
(Comparative) Technical, environmental and economic assessment of Phosphorus recycling technologies from waste water	Lukas Egle, Helmut Rechberger, Matthias Zessner	Re-water	2013	15	Conference contribution	Via author	Phosphate precipitation and crystallization of phosphate from sewage sludge or sewage sludge ash with or without a leaching process. Thermal treatment of sewage sludge ash.	sewage, sewage sludge, sewage sludge ash	Yes	This article compares 18 different technologies for P-recovery from sewage, sewage sludge and sewage sludge ash. It uses a method called Material Flow Analysis to compare recovery percentages and ecological impacts like spread of heavy metals and POP's. Furthermore it compares economics and fertilizer quality. The report concludes that already P-recovery from P-rich side streams in sewage water treatment plant is economically feasible and give good value products with low concentrations of pollutants. However, these processes are limited to sewage treatment plants using enhance biological phosphorous removal. Such plants have a limited market share with for instance little applications in Austria. Recovery from sewage sludge requires more chemicals and is less economical. Recovery from sewage sludge ash however can be economical although also significant amounts of energy and chemicals are required. The higher P-recovery potential of these technologies makes this affordable. The authors also conclude that technologies that pay less attention to heavy metal removal are economical quicker and therefore other incentives or legal constraints may be necessary to stimulate this.	LCA

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Biologically and chemically mediated adsorption and precipiation of phosphorus from wastewater	Chris Pratt, Simon A Parsons, Ana Soares and Ben D Martin	Current Opinion in Biotechnology	2012	7	Peer reviewed article	26,3	.Filtration by chemically reactive substrates -Phosphorous adsorption by polymers/ nanomaterials -Phosphorous recovery as struvite	Municipal sewage effluent, River water	Yes	The article gives a short review on phosphourous removal using filtration and precipiation. It concludes that chemically reactive filters are most effective for smaller communities. It also states that in many cases struvite formation can occur without chemical dosing sice its constituents are already present in many wastewater treatment plants. Results from study show that struvite enhances growth of maize and wheat. The article also points that adsorption on biological polymers and nanomaterials can achieve P removal at very low concentration, but more studies are required for estimating the recovery of P from these materials.	R-Sci
Nutrient Removal and Recovery Market and Technology overview- BlueTech Insight Report	T. Evans	Bluetech Research	2012	70	Market review	2500 $	The report focusses on nutrient removal and recovery technologies from wastewater with a large focus on phosphate recovery. Classical phosphorus removal technologies are discussed as well as market ready recovery technologies like struvite precipitation. Also technologies using algae and some developping technologies for phosphate recovery are discussed.	Wastewater, Sewage water, sludge	The report focussed on P-removal and recovery, but also technologies for nitrogen removal are dicussed.	The report gives an overview of available nutrient removal and recovery technologies. It is written for new entrants to the market, investors and operators considering phosphate recovery. The report focusses on developments for phosphate recovery and gives an overview of available technologies and companies that market these technologies. The report pays attention to drivers for phosphate recovery and concludes that currently phosphate is mostly only removed and that recovery technologies are only slowly being introduced. The biggest potential for phosphate recovery can be found in side streams like sludge dewatering liquor. A section of the report also focusses on nitrogen removal and recovery and describes market ready technologies for this.	R-Pol
Comparative assessment of technological systems for recycling sludge and food waste aimed at greenhouse gas emissions reduction and phosphorus recovery	Nakakubo, T.; Tokai, A. & Ohno, K.	Journal of Cleaner Production	2012	16	Peer reviewed article	29$	Life cycle assessment (LCA) of various techniques including sludge transformation (digestion, low and high temperature incineration, composting, cement feedstock production, low-temperature carbonization, dry granulation, pyrolysis gasification) and P recovery techniques (alkaline extraction, partial reduction melting MAP and HAP).	Sewage sludge, food waste	Focus on P and energy recovery	LCA with specific indeces for Japan was used to evaluate P recovery (including heavy metals contamination of recovery products) and greenhouse gas emission (CO_2, CH_4, N_2O, fuels substituted) for alternative food waste and sewage sludge processing technologies. The traditional way to process food waste (incineration) and sewage sludge separately was compared with an alternative method (mixing both waste streams in digester). Based on these pretreatment various sludge transformation techniques followed by P recovery techniques were evaluated (see techniques covered). Techniques based on alternative method were always superior. Best results were calculated for pyrolysis gasification followed by alkaline extraction of the ash and MAP P recovery. - Do not take P availability into account => thus no evaluation of effects on lakes, rivers etc - Do not take P bioavailability into account - Do not take into account => organic pollutant	LCA
Land Application of Biosolids in the USA: A review	Qin Lu, Zhenli L. He and Peter J. Stoffella	Applied and Environmental Soil Science	2012	12	Review	Open access	Land application of biosolids from sewage sludge (regulations, benefits, precautions and best management practices). A description of the composition of biosolids is made. N, P, K, micronutrients and organic matter are quantified.	Biosolids from sewage sludge	Agricultural application of biosolids implies recycling of P, N and organic matter.	Experiences with land application of biosolids in the USA is described in this review. The article gives an overview on the regulations for application of biosolids, with specific attention to pathogens, trace elements and nutrients. Biosolids, as pellet, cake or liquid form contained lower amount of nutrients (N, P and K) than commercial fertilizers, but are able to provide essential micronutrients and organic matter to remediate degraded and disturbed soils. The slow release of nutrients is another advantage mentioned. Good management practices are crucial to make the use of biosolids environmentally acceptable.	T-Sci

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Review of best practice in treatment and reuse/recycling of phosphorus at wastewater treatment works	UK Environment agency	UK Environment agency	2012	65	Technical report	Open access	P-removal technologies: chemical precipitation, biological P removal, Tertiary filtration with granular medium filters, membrane bioreactors, reverse osmosis, decentralized technologies. P-recovery technologies:from nutrient rich liquors post digestion (struvite precipitation), P-enrichment in the sludge and recovery from sewage sludge ashes.	sewage, sewage sludge	Yes	This report points out various phosphorus removal technologies and recovery methods with a chief focus on application in the UK. It provides an assessment on the applicability and benefit of these technologies. It considers several factors of the techniques such as the cost, performance, feasibility, environmental impact. Furthermore it provides case studies on wetland systems and struvite recovery. It also provides a comparison between the approaches to P control in USA to that of UK and concludes by highlighting the points regarding best practice for environmental management of P. According to the report the application of biosolids is still the best option to reuse large amounts of phosphate. Recovery of struvite in waste water treatment plants has limited potential in the UK due to low P-levels in the UK wastewater and extensive use of iron salts for phosphate precipitation. However in certain cases struvite precipitation can be financially interesting.	R-Pol
Phosphorus Removal from Aqueous Solutions by Agricultural By-products: A Critical Review	Thi An Hang Nguyen, Huu Hao Ngo, Wenshan Guo, Tien Vinh Nguyen	Journal of water sustainability	2012	15	Peer reviewed article	Open access	Sorption using natural and modified agricultural byproducts	Wastewater	P recycling by directly applying the used adsorbents as fertilizers	The article gives an overview of phosphorus removal from aqueous solutions using agricultural byproducts. It gives a short comparison of different methods used for P removal before focusing on the merits of using agricultural byproducts for this purpose. It highlights the effect of various factors like temperature, pH, adsorbent dosage, interfering ions on the biosorption process. It also gives gives a compairson between using natural agricultural byproducts and modified agricultural byproducts for biosorption of phosphorus.It concludes that the modified biosorbent provide a greater adsorption capacity and even though the desorption is low, these phosphorus loaded biosorbents can be used directly as a fertilizer for agricultural production.	T-Sci
Nutrient Recovery as a Green Technology for Managing Phosphorus Removal	Ronald Latimer, Tina Hanson, Wendell Khunjar, Paul Pitt, Hazenand Sawyer	Water environment association of Texas	2012	5	Technical report	Open access	Phosphate control in return flows with Enhanced biological phosphorus removal (EBPR): precipitation with ferric or via struvite precipitation	Aerobic and anaerobic treatment, struvite precipitation	Yes	The technical report gives a short overview of P recovery alternatives and then explains two case studies for P removal and recovery .The techniques used include Fe addition at digesters, OSTARA Pearl's , WASSTRIP's nutirent recovery technology with or without $Mg(OH)_2$ addition. The results were modelled to assess effectiveness of the P control strategy and to perform a net present cost anaylsis. The findings indicated that P recovery using WASSTRIP's or OSTARA pearl technology was the superiror option as compared to precipiation with Fe. The results showed that successful implementation is highly dependent on the amount of nutrient to be removed.	T-Sci
Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality	Tanmoy Karaka, Pradip Bhattacharyyab	Resources, Conservation and Recycling 55 (2011) 400–408	2011	9	Peer reviewed article	35 $	Direct use of urine in agriculture. Also ammonia stripping and struvite precipitation in urine	urine	Foucs on phosphate and nitrogen recycling	The article reviews available literature on the composition of urine and it's use in agriculture. Also briefly attention is paid to phosphate recovery via struvite precipitation and ammonia recovery via stripping and absorption in sulfuric acid. The focus is on use in developping countries. The article concludes that urine shows potential to be used as a fertilizer, but also identifies research gaps with respect to medicin traces and other influences on the soils like salination.	T-Sci
Phosphorus recovery from the biomass ash: A review	Tan, Z. and Lagerkvist, A.	Renewable and Sustainable Energy Reviews	2011	15	Review	37,95$	Biomass incineration and supercritical oxidation as a means to concentrate P in the ash and subsequent treatment of the biomass ash: thermo-chemical treatment and chemical leaching.	Biomass ash	Focus on P recovery, but other nutrients are considered	A review of the composition of different types of biomass ash is done in the first part. The characteristics of thermal converted biomass ash are analysed. Additionally, technologies for subsequent recovering of phosphorus are evaluated. The supercritical extraction appears as a good pre-treatment method for a better release of phosphate in biomass ash, but it is still expensive. The use of phosphate-solubilizing bacteria with bioleaching of heavy-metals can efficiently recover phosphorus. However, the chemical extraction is the most promising method for separating elements from the biomass ash, with efficiency around 95 % of total phosphorus dissolved from the solid fraction.	T-Sci

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Towards a complete recycling of phosphorus in wastewater treatment – options in Germany	Petzet, S.; Cornel, P.	Water, Science and Technology	2011	6	Peer reviewed article	35 $	Phosphate recovery from sewage sludge with a focus on recovery from sewage sludge ash: direct application, Themrphos, Ashdec, Mephrec, wet-chemical)	sewage, sewage sludge, sewage sludge ash	Yes	The article gives an overview of possibilties to recover full P-recycling from sewage sludge from a German perspective. The authors conclude that recovery of P from sewage sludge ash is important to be able to recover all P in sewage. Different options for recovery of P are discussed with a focus on P-recovery from sewage sludge ash (wet-chemical, thermal: Ashdec, Mephrec and direct application).	R-Sci
Phosphorus Recovery from Wastewater – State-of-the-Art and Future Potential	Sartorius, C; Von Horn, J.; Tettenborn, F.	WEF, IWA	2011	19	Conference contribution	Open access, http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1304	Phosphate precipitation and crystallization of phosphate from sewage sludge or sewage sludge ash with or without a leaching process. Thermal treatment of sewage sludge ash.	sewage, sewage sludge, sewage sludge ash	Yes	This article discusses the various possible approaches to P-recovery from sewage sludge and sewage sludge ash. It gives a comprehenive overview of more than 20 different technologies and groups them in different categories. These technologies and the need for P-recovery were rated by questions to a panel of 200 experts in the field of P-recovery. These experts feel that economical P-recovery is possible in the short term. P-recovery from P-rich side streams has the highest priority, followed by P-recovery form the effluent. Recovery of P from sewage sludge ash may require more effort but the high recovery rate in combination with a trend toward incineration there is a high potential for this technology.	R-Pol
Recycling of Phosphorus - Ecological and Economic Evaluation of Different Processes and Development of a Strategical Recycling Concept for Germany (PhoBe)	Pinnekamp, J.; Everding, W.; Gethke, K.; Montag, D.; Weinfurtner, K.; Sartorius, Ch.; Von Horn, J.; Tettenborn, F.; Gäth, S.; Waida, C.; Fehrenbach, H.; Reinhardt, J.	Bundesministerium fuer Bildung und Forschung (BMBF, Germany)	2011	463	Technical report	Open access, http://www.phosphorrecycling.de/index.php?option=com_rokdownloads&view=folder&Itemid=67&lang=en	Phosphate precipitation and crystallization of phosphate from sewage sludge or sewage sludge ash with or without a leaching process. Thermal treatment of sewage sludge ash.	sewage, sewage sludge, sewage sludge ash	Yes	This report in German language describes the results of the Phobe project. It evaluates processesdeveloped in projects in the framework of a national funding initiative on P-recovery. Also, the generated products were investigated with a focus on quality as a fertilizer. All investigated processes are not yet economical in the German situation. However a cost neutral operation is possible due to positive side effects on the wastewater treatment plant e.g. improvement of dewaterability. An ecological assessment of the developed processes shows that a relevant amount of the phosphorus can be used without the negative effects when directly applying sewage sludge onto the fields. In case thermal disposal of sewage sludge becomes the preferred method, recovery of P from sewage sludge ash can be promising, especially for large centralized incinerators. The report concludes that the generated secondary raw materials are a comparable alternative to commercial mineral fertilizers. With the developed processes the concentration of phosphorous could be highly increased in comparison to the source materials together with a relevant reduction in the concentration of heavy metals. According to the results of an enquiry, experts believe in the cost-efficient use of phosphorus recovery in industrialised countries until 2030.	R-Pol
Phosphorus recovery and recycling from municipal wastewater sludge	Nieminen J.	Aalto University, School of Science and Technology, Department of Civil and Environmental Engineering	2010	111	Master's thesis	Open access	Crystallization and precipitation; Wet chemical and thermo-chemical methods	Municipal sewage sludge Municipal sewage sludge ash Digester effluent	Yes	The thesis gives a basic overview on main industrial, pilot and laboratory scale phosphate recovery technologies. Executives and operators can use the text as a starting point into phosphate recovery technologies. The economics, quality of recovered products are considered. The LCA of the technologies is not evaluated. The report introduces main principles of recovery technologies, phosphate legislation and reasons for phosphate recovery as well.	R-Pol

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Sustainable Use of Phosphorus Chapter 4.4.3: "Processes and technologies for the recovery and reuse of phosphorus"	Schröder, J.J.; Cordell, D.; Smit, A. L. & Rosemarin, A.	Wageningen University & Stockholm Institute for Environment	2010	140	Technical report	open access: http://ec.europa.eu/environment/natres/pdf/sustainable_use_phosphorus.pdf	Various centralized and decentralized technologies.	Blackwater, household wastewater, urine, mixed wastewater, ash, manure	Also other nutrients, energy and drinking water	General aspects of centralized (household) and large scale (decentralized) P recovery techniques including specific examples are introduced. Decentralized systems are often low cost techniques applied in remote areas and target on various waste streams. Beside maximum recycling of nutrients minimizing water consumption is important. The small scale systems require less infrastructure, energy, water and the systems can be supplied with source separated waste streams. The small scale techniques require more space and individual maintenance. Large scale techniques focus on various municipal wastewater streams. Economics of large scales and generating marketable products are an advantage. The risk of "technological lock-in" and the risk of P losses argue against these systems.	R-Pol
Phosphorus recovery from animal manure. Technical opportunities and agro-economical perspectives	Schoumans, O.; Rulkens, W.H.; Oenema, O. & Ehlert, P.A.I.	Alterra report, Wageningen University	2010	111	Technical report	open access: http://content.alterra.wur.nl/Webdocs/PDFFiles/Alterrarapporten/AlterraRapport2158.pdf	Digestion, Mechanical separation of solid/liquid, pyrolysis, gasification, incineration, ultra-filtration, reverse osmosis, calcium phosphate and MAP precipitation	Animal manure	Yes	P should be obtained as high value product from manure instead of direct application on fields. Prospective and current technologies for P recovery from manure are introduced. Dutch industries specialized on P recovery processes and solid manure export would be interested in processing raw manure respectively in exporting biochar. Based on these information options for different scales of P recovery from manure were economically evaluated. Recovery products comprise fertilizers, elemental P and biochar having similar production costs. Techniques should be evaluated and prioritized, scaled up and again evaluated. Generally, prioritized techniques should separate manure in liquid and solid fractions. Treatment of the liquid fraction can be costly and therefore direct application on the field is the prefered, economical option. The solid fraction could be dried in proximity of power plants.	R-Pol
Land Application and Composting of Biosolids	Water Environment Federation	Water Environment Federation	2010	6	Q&A/Fact Sheet	Open access	Land application and composting of biosolids	Biosolids from sewage sludge	Agricultural application of biosolids implies recycling of P, N and organic matter.	The Q&A fact sheet gives a summary of the regulations (503 rule) and reviews that have been performed on the safety and environmental effects of land application of biosolids. in the USA. The fact sheet states that to until know scientific reviews have not been able to determine adverse effects of the use of biosolids in agriculture. The concentration of nine trace elements (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc) are regulated because of possible adverse effects. According to the fact sheet the National Research Council (NRC) observed that “persistent uncertainties” regarding the safety of land application necessitate more scientific research, but it did not call for any specific changes to Part 503.	Other
Nutrient recovery state of the knowledge as of December 2010	Water Environment Research Foundation (WERF)	Water Environment Research Foundation (WERF)	2010	44	technical report	open access www.werf.org/c/2011Challenges/Nutrient_Recovery.aspx	Covers current and future technologies	Wastewater	Primarly nutrients but also other resources (oil, gas, building material)	This WERF document describes the research strategy of a project (covering 5 years) on a nutrient recovery from wastewater. The proposed research will try to summarize current and future technologies in relation to operational interests, comprising issues related to legislation, economics, technological challenges and market studies on recovered products. During the project current and future resource potential and related implementation strategies will be summarized, a decision making matrix for operators will be developed, material production via anaerobic digestion and other enhanced processes will be studied and full scale approaches for resource recovery will be evaluated. The project targets on the stimulation of implementing pilot and industry scale recovery technologies.	R-Pol

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Prospects for phosphorus recovery from poultry litter	Szogi, A. A. and Vanotti, M. B.	Bioresource Technology	2009	5	Peer reviewed article	30,50 €	Densification, Anaerobic digestion, Composting, Incineration, Pyrolysis, Gasification, Chemical Leaching	Poultry litter	Focus on the phosphorus by-products recovery	The article gives an overview of various technologies that can be considered to reuse the phosphate fraction in poultry litter. These technologies vary from simple densification technologies, via digestion and composting to thermal treatment (incineration, pyrolysis, gasification). The author's introduce a technology of acidic washing of the poulty litter to extract and subsequently recover phosphate from the litter. This procedure increases the N:P ratio in the litter and makes the litter more interesting for agriculture. Three scenario's are presented that all include the acidic washing step, but is then expanded with either anaerobic digestion or pyrlosys. According to an economic evaluation by the author's these scenario's have a higher economic potential than direct use of the poulty litter. A more detailed study is recommended so that all costs factors can be taken into accoutn (like capital costs, labor costs).	T-Sci
Nitrogen and Phosphorus Recovery from Wastewater and the Supernate of Dewatered Sludge	Dong-bo Wang, Xiao-ming Li, Yan Ding, Tian-jing Zeng, Guang-ming Zeng	Recent Patents on Food, Nutrition & Agriculture	2009	7	Peer reviewed article	Open access	Precipitation as struvite, hydroxyapatite, insoluble metal phosphate complexes,	Municipal sewage water, agricultural wastewater, supernate of dewatered sludge	P and N recycling.	This scientific explains methods to recover P and N by precipitation of the wastewater streams and explains the use of the precipitated material as fertilizers. The article reviewsn patents that describe the recovery of P and N by precipitation. It states that precipitation as struvite has been more commonly used since it can recover both P and N simultaneously. It also points that phosphorus is mostly removed in the form of soluble phosphate which is only a small fraction of the total phosphorus.	T-Sci
Rückgewinnung von Phosphor aus der Abwasserreinigung, Eine Bestandesaufnahme	Hermann Ludwig	Bundesamt für Umwelt (BAFU, Switzerland)	2009	198	Technical report	Open access, www.umwelt-schweiz.ch/uw-0929-d	Phosphate precipitation and crystallization of phosphate from sewage sludge or sewage sludge ash with or without a leaching process. Thermal treatment of sewage sludge ash.			This extensive report (in German language with English & French summary) describes the different options for recovery of phosphate from sewage, sewage sludge and sewage sludge ash. In detail it describes 33 different technologies for P-recovery but does not give a detailed assesment or comparison of the different technologies. At the time of the report the Japanese Unitika group had the most full scale references for P-recovery based on struvite precipitation. Other companies having full scale references where DHV, Ostara and Ashdec. The Airprex technology is mentioned as a technology close in moving to a full scale reference.	R-Pol
Phosphorus management for sustainable biosolids recycling in the United States	Elliott, H.A. and O'Connor, G.A.	Soil Biology & Biochemistry	2007	10	Peer reviewed article	26,2$	Evaluates and proposes managements strategies for sustainable use of biosolid in agriculture. Evaluation is based on customized P indeces which are a widespread approach in US P management policy.	Biosolids from sewage sludge	Yes	The article reviews the use of biosolids from sewage sludge in agriculture and highlights that a correct use of biosolids must include careful management of the P-balance on the field. Too high applications of biosolids may lead to eutrification due to P-losses. Most US states use customized indeces to evaluate potential P loss from soil and do not take biosolids into account. It is suggested that P management should include four principles to allow sustainable use of biosolid: apply biosolids following environmental risk of P loss instead of crop response, recognize characteristics of P buffer zones, consider biosolid P loss potential instead of total P and determine P fertilizer replacement value. Remaining challenges for sustainable biosolid use are to find and to apply a method to determine P bioavalability and P mobility based on water extractable P, perform long term field studies on biosolids showing high soluble P, evaluate role of buffer strip characteristics on P runoff and to valuate long term fate of P bound to biosolids dominated by low soluble P.	T-Sci
Phosphate recycling in the phosphorus industry	W.J.Schipper, A.Klapwijk, B.Potjer, W.H.Rulkens, B.G.Temmink, F.D.G.Kiestra and A.C.M. Lijmbach	Phosphorus Research Bulletin	2004	5	Conference contribution	Open access	Phosphate recovery by using seconfary phosphate sources instead of phosphate rock in the production of white phosphorus	Sewage sludge, Industrial and food industry waste steams	Yes	The article describes the potential and limitations for recovery of phosphate from secondary materials in the production process for white phosphorus. This thermal process involves the feeding of phosphate rock, cokes and pebbles to a furnace. The reducing conditions in the furnace promote the formation of white phosphorus. The article describes the limitations of feeding secondary phosphate sources to the process in terms of the amount of phosphate present, impurities present, water content, etc. It then explains possibility of phosphate recovery from different sources like sewage sludge, manure, bone meal ash, industrial and food industry waste streams. It states that waste legislation in different countries restricts the possibility of obtaining secondary phosphates from wastes and a less rigid legislation and regulation would help in obtaining waste as sources for phosphate recovery.	T-Sci

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Nutrient Management and Fertilizer	US Environmental Protection Agency (EPA)	EPA Website	n.a.	n.a.	Website	Open access, http://www.epa.gov/oecaagct/tfer.html	Focus on hygienization of sewage sludge and other nutrient rich waste material for use as biosolids/fertilizer in agriculture.	Sewage sludge, manure, fertilizers from waste materials	The website focusses on using biosolids/sewage sludge as a fertilizer. This includes recycling of phosphate, but also nitrogen and organic matter.	The website is a starting place to find information and legislation on applying biosolids (sewage sludge) as a fertilizer in the US. The US allows biosolids to be used in agriculture provided it is well hygienized and meets certain quality criteria. The website links to another website (http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm) that gives a "plain english" guide to EPA Part 503 Biosolids Rule.	Other