Bund/Länder-Arbeitsgemeinschaft Abfall

LAGA Ad-hoc-AG
(Joint Ad Hoc Working Group of the Federal Government and the Länder on Waste)

Resource conservation through phosphorus recovery

Final Report

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1 Summary

1.1 Assessment of phosphorus recovery processes

Studies and pilot plants have provided reliable evidence for the fundamental operating capability of a number of processes. Their large-scale implementation would appear to be justifiable and some initial large-scale plants are already operating. However, the assessment, which also drew on results of the KoMa[1] and P-REX[2] projects, concluded that currently it is not possible to make a universal judgement on the different processes as they are tapping into different material streams. Objective comparisons are hampered not only by differing local constraints but also by the circumstance that processes are at varying stages of development. Similarly, reliable assertions as to their cost-effectiveness can only be made to a limited extent and do not yet allow for a sound comparison of processes.

1.2 Assessment of the intermediate storage of ashes and the potential for landfill mining

With a view to the necessity of establishing, within acceptable timescales, a recovery infrastructure, the *LAGA AG Phosphor* would consider it a priority to strive for phosphorus recovery directly following the generation of sewage sludge or sewage sludge ashes. In contrast, the intermediate storage of these ashes should not be a priority measure and should thus not replace the establishment of an industrial phosphorus recovery infrastructure. The mining of existing ash or sewage sludge disposal sites is considered to be useful only in a very limited number of cases, given the high cost of landfill mining and given the fact that, in part, their phosphorus content is too low. It would be useful if, for example, there were other grounds for landfill site remediation, such as groundwater protection or site utilisation. For similar reasons, the mining of other landfill sites, such as those used for municipal solid waste, is considered expedient only in exceptional cases.

[1] KoMa: *Bewertung konkreter Maßnahmen einer weitergehenden Phosphorrückgewinnung aus relevanten Stoff-strömen sowie zum effizienten Phosphoreinsatz*, FKZ 3713 26 301 (Evaluating Concrete Steps for Advanced Phosphorus Recovery from Relevant Streams as well as for Efficient Phosphorus Utilisation)
[2] P-REX: Sustainable sewage sludge management fostering phosphorus recovery and energy efficiency, http://p-rex.eu/index.php?id=13

1.3 Assessment of the usability of recovered phosphorus

It is now possible to produce from sewage sludge and sludge ashes recycled phosphates that are sufficiently bioavailable and low in pollutants, especially in cadmium and uranium. Reliable evidence to this end is available for a number of phosphorus recovery processes. For precautionary reasons and to improve bioavailability, sewage sludge mono-incineration ashes should generally be processed and pollutants removed prior to land application.

1.4 Cornerstones of a phosphorus strategy

The cornerstones of a phosphorus strategy are as follows:

- Large-scale implementation of phosphorus recovery is feasible and useful and can be achieved using currently existing processes.
- Legal provisions on phosphorus recovery are useful and necessary, including with a view to the security of planning processes.
- It is not considered necessary to have provisions in place for the selection of phosphorus recovery processes, as a large number of processes is available and the choice of process must take account of the plant’s specific objectives.
- In future, the co-incineration of sewage sludge containing relevant amounts of phosphorus should only be allowed after prior phosphorus recovery.
- The implementation of phosphorus recovery should initially be phased in for sewage treatment plants belonging to facility size classes 4 and 5 (i.e. capacities exceeding 10,000 and 100,000 population equivalents respectively) and for mono-incinerators, and should later successively be extended to additional secondary sources of phosphorus (i.a. livestock by-products). For sewage treatment plants belonging to facility size classes 1 to 3 (capacities below 10,001 population equivalents) an assessment should be made, taking into account experiences made with implementation, as to the circumstances, including ecological and economic aspects, under which specific stipulations on phosphorus recovery may be required.
- Storage of sewage sludge ashes and landfill mining are considered to be of lower priority than recovery, as for economic and process-related reasons

recovery should target phosphorus currently arising in sewage treatment plants and incinerators.

– To facilitate industrial-scale phosphorus recovery, a voluntary commitment by producers of phosphorus mineral fertilisers to partly substitute secondary sources of phosphorus for phosphate ore would be desirable.

– Material quality specifications and test procedures must be developed and be made binding for all phosphorus fertilisers including secondary recycled phosphorus fertilisers.

2 The mandate for the LAGA ad hoc working group on phosphorus as issued by the 80th Conference of Environment Ministers (UMK)

In June 2012, the ACK[3]/UMK acknowledged the report produced by a LAGA ad-hoc working group entitled "Evaluation of Options for the Sustainable Use of Secondary Phosphorus Reserves" (*Bewertung von Handlungsoptionen zur nachhaltigen Nutzung sekundärer Phosphorreserven)*[4].

Phosphorus recovery was again on the agenda of the 80th UMK session on 7 June 2013. On Agenda Item No. 16 "Resource conservation through phosphorus recovery" the UMK decided as follows:

1. The Conference of Environment Ministers notes that phosphorus recovery techniques will in future play an important part in natural resource conservation and in safeguarding the supply of phosphorus. The development of phosphorus recovery processes in Europe has gained considerable momentum in recent years and such projects are now being implemented in individual countries. While a variety of approaches to and processes for phosphorus recovery have been developed, universal assessment criteria are not at hand. Decision-makers are therefore in need of additional knowledge so as to allow them to select the process suited to the use in question.

2. The UMK requests that the working group on waste (LAGA), with involvement of the working groups on water issues (LAWA) and soil quality (LABO) as well as the agricultural and horticultural experts assess the known phosphorus recovery processes with respect to their operating capability based on current research findings. In particular, as part of the assessment, the processes' cost-effectiveness as well as resource and energy efficiency are to be investigated. The requirements for intermediate storage of incineration ashes in long-term storage facilities are to be outlined. Based on current knowledge, the potential for landfill mining is to be documented. In addition, the fertilising effects, bioavailability and pollutant contents of secondary phosphorus are to be assessed in comparison to rock phosphates.

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[3] ACK: Conference of the department heads of federal and regional-state environment ministries (*Amtschefskonferenz*); UMK: Conference of the Environment Ministers of Germany (*Umweltministerkonferenz*)
[4] http://www.laga-online.de/servlet/is/23875/

5. The LAGA, with involvement of the LAWA, is asked to prepare, based on its assessment of the available technical processes for phosphorus recovery and based on the findings of the report by the LAGA dated 30 January 2012, a proposal for a phosphorus strategy with special consideration of phosphorus recovery, and to report on the matter at the 2015 autumn meeting of the Conference of Environment Ministers.

[. . .]

On this basis, the 101st LAGA General Meeting of 17 September 2013 took the following decision (Agenda Item No. 4.3.):

1. The LAGA General Meeting establishes an ad hoc working group tasked with preparing a report […] under the aegis of the LAGA committee on waste treatment technology (ATA). The federal states are requested to designate, by 1 October 2013 at the latest, members of staff and declare their willingness to assume chairmanship of the working group by 1 October 2013 at the latest.

2. The LAGA Head Office is asked to notify this decision to the LAWA, the LABO and the agricultural and horticultural experts with the request to nominate representatives for participation in the ad hoc working group by 11 October 2013.

3. The ATA is asked to present its report at the 104th LAGA General Meeting in April 2015.

On this basis, the ATA launched the ad hoc working group on resource conservation through phosphorus recovery under the abridged name of "LAGA AG Phosphor" and under the chairmanship of Baden-Württemberg. The working group prepared this report with the cooperation of the federal states of Hesse, Saxony, Rhineland-Palatinate, Lower Saxony, Schleswig-Holstein, North-Rhine/Westphalia, Berlin and Bremen as well as of representatives of the LAWA, LABO, agricultural and horticultural experts, the Federal Environment Ministry (BMUB) and the Federal Environment Agency (UBA).

3 Assessment of phosphorus recovery processes

3.1 General information on the assessment of phosphorus recovery

(1) The following assessment of phosphorus (P) recovery processes considers their operating capability (utility), research findings, cost-effectiveness and resource and energy efficiency. It must be noted that the information below is primarily based on results of studies, research at experimental facilities at different stages of development, and results obtained in individual pilot plants and large-scale implementations.

(2) Phosphorus recovery from municipal sewage is advisable given that just under 61,600 Mg P per year could potentially be recovered from the inflow of municipal sewage treatment plants (see Table A) while the demand for mineral phosphorus in Germany stands at approximately 124,000 Mg/year[5]. Locations of phosphorus recovery from municipal sewage generally include the liquid phase (wastewater and process water from sludge treatment), sewage sludge (raw sludge and digested sludge), and sewage sludge ash (following mono-incineration or comparable thermal treatment). These differ with regard to a multitude of parameters such as quantity, volume stream, characteristics and composition of the material stream in question, phosphorus concentration, type of phosphorus compound, and recovery potential. These parameters must be assessed separately for each sewage treatment plant or wastewater stream and play a significant role for the selection of a suitable recovery process, in addition to the consideration of economic aspects and bioavailability. Ultimately, each sewage treatment plant is operated individually and therefore – if the aim is to realise phosphorus recovery – the selection of a suitable recovery process must be undertaken on a case-by-case basis.

(3) In addition to the municipal wastewater stream, the report addresses opportunities for the application of phosphorus recovery processes to other material streams, i.e. food waste including related wastewater, livestock by-products (meat and bone meal) and livestock farm wastes such as liquid manure or slurry, insofar as recovery technologies for these material streams are known and would appear to be appropriate. Other material streams, such as organic wastes, are not

[5] Destatis, Fachserie 4, Reihe 8.2, 2014 (only available in German)

considered here, given that in part they are already being used as fertiliser or else because their phosphorus contents are too low.

Table A: Theoretical phosphorus potential from the inflows of municipal sewage treatment plants in Germany

Persons connected to sewage treatment plants	78,239,000 persons[6]
Specific P-load (persons)	1.8 g P/(p·d)
Industry connected	46,398,000 p/e[7]
Specific P-load (industry)	0.6 g P/(p·d)
Total P inflow to municipal sewage treatment plants	**61,564 Mg P/a**

3.2 An examination of the different material streams

(1) In the following examination each material stream will be considered separately with regard to possible approaches to phosphorus recovery. This section will outline the recovery potential for each of the material streams and the degree of effort required to exploit it. Additional details on process selection and on the individual processes are given in Annex 1 (selection based on sources of material streams) and Annex 2 (selection based on recovery processes).

(2) What all processes have in common is that the base materials' pollutant loads can significantly impact recyclate quality.

3.2.1 Wastewater (sewage treatment plant discharge)

(1) Phosphorus contained in wastewater entering the sewage treatment plant's inflow (see Table A) is largely incorporated into the biomass contained in activated

[6] Destatis, Statistisches Jahrbuch 2014 (German)

[7] Destatis, Fachserie Umwelt 19, 2013 (German)

sludge during secondary treatment. As a result, phosphorus concentrations in sewage treatment plant discharge are relatively low (see also limit values for discharges from sewage treatment plants under the German Waste Water Ordinance *(Abwasserverordnung)*).

(2) Theoretically, post-precipitation could be induced in sewage treatment plant discharge by adding magnesium salts for example, a process that is highly effective (cf. Ch. 1.2.2 Process water from sludge treatment and Ch. 1.2.3 Sewage sludge). In this way, almost all of the phosphorus contained in the discharge in the form of dissolved orthophosphates could be precipitated. The expected recyclate would contain relatively minor concentrations of particulate pollutants, as sewage treatment plant discharge can be expected to contain hardly any sludge particles etc.

(3) As volume streams are large and limit values for discharges low (max. 1 or 2 mg/l phosphorus for sewage treatment plants for facility size classes 5 and 4 respectively in accordance with the Waste Water Ordinance), the potential for additional phosphorus recovery from sewage treatment plant discharge is at most 10% of the phosphorus content entering at the treatment plant inflow. Therefore, recovery at this location is hardly worthwhile.

3.2.2 Process water from sludge treatment (sludge liquor)

(1) Sludge liquor is the water contained in sludge. Dependent on the sludge dewatering process used, it is termed supernatant water (thickener), decantate (decanter centrifuge), filtrate (filtration systems etc.), centrate (centrifuges) or digester supernatant (digester). In accordance with the DIN 4045 and DIN EN 1085 standards, the summary term “process water” will be used here.

(2) The “process water from sludge treatment” volume stream is significantly smaller than the total wastewater volume stream. Here too, phosphorus is in solution in the form of orthophosphate and can be precipitated at a relatively high efficiency using magnesium salts for example. However, given that only a proportion of the phosphorus contained in the sewage sludge is removed as part of the sludge liquor, the recovery potential is generally in the order of 5-30% relative to the sewage treatment plant inflow. It must be noted that the phosphorus content of sludge liquor is dependent on numerous operational processes in the sewage treatment plant

concerned and thus fluctuates significantly. Moreover, process water is circulated, with the phosphorus it contains concentrating in the sewage sludge.

(3) A specific treatment of sewage sludge prior to the separation of process water by thermal treatment (e.g. thermal hydrolysis) could increase the proportion of phosphorus that is transferred into the liquid phase and which thus could be precipitated. In how far this is feasible in practice is currently being tested at some initial demonstration facilities. Increased phosphorus yields can also be achieved through chemical sewage sludge disintegration, using sulphuric acid for example. An increase in phosphorus redissolution, however, also entails greater technical effort and thus higher costs. One benefit is that, for example, phosphorus precipitation and crystallisation from process water yields a relatively clean recyclate as most of the particles will have already been removed during sludge dewatering.

3.2.3 Sewage sludge (not dewatered / dewatered)

(1) Raw sewage sludge or raw digested sludge can be treated in a well-hydrated or dewatered form. The recovery potential and options for the volume stream of non-dewatered sewage sludge are roughly similar to that of sludge liquor, as the common recovery processes for non-dewatered sewage sludge target the easily accessible phosphate. All the phosphorus dissolved as orthophosphate in all of the water contained in the sewage sludge is available for phosphorus recovery.

(2) In principle, the same processes that are used for process water from sludge treatment (precipitation, crystallisation) can be used here (recovery potential of 5-30% relative to the sewage treatment plant inflow). In order to achieve a higher recovery potential of up to 50% relative to the sewage treatment plant inflow, the sewage sludge must be chemically or physically disintegrated. However, consideration must be given to the fact that, depending on the prior recovery process, the resultant recyclate may be contaminated with sludge particles and must therefore be subjected to post-processing (e.g. washing).

(3) In the “dewatered sewage sludge” volume stream, 55 to 80% of the water has been removed, significantly reducing the volume stream to be treated compared to sludge liquor. While the dewatered sewage sludge contains almost all of the phosphorus eliminated by the sewage treatment plant (minus the phosphorus contained in the treatment plant discharge and the phosphorus content of

discharged sludge liquor (dissolved phosphorus, orthophosphate)), this phosphorus is biologically and chemically fixed. Prior to phosphorus recovery, this fixed phosphorus must therefore be redissolved from the sludge matrix. This can be achieved by way of chemical (e.g. sulphuric acid) or thermal (e.g. metallurgical) treatment of the dewatered sewage sludge. Realistically, the phosphorus recovery potential is in the order of 50 and 80% respectively, relative to the sewage treatment plant inflow.

(4) However, the higher the recovery quota, the higher the required technical effort and financial cost. Depending on the treatment used, one can expect a relatively clean recyclate, as normally this would have been subject to a treatment (acid redissolution, thermal treatment) that destroys the bulk of organic contaminants. Whether or not the recyclate contains heavy metals largely depends on the concentration of pollutants in the sewage sludge and on the recovery process used. Suitable measures (e.g. addition of chelating agents) may have to be taken, as required, in order to prevent the redissolution of heavy metals.

3.2.4 Sewage sludge ashes

(1) Phosphorus recovery from sludge ashes requires prior thermal treatment of sewage sludge in mono-incinerators, which significantly reduces the volume stream to be treated. The sludge ash contains almost all of the phosphorus contained in the sewage sludge and treatment plant inflow respectively (minus the phosphorus contained in the treatment plant discharge and the phosphorus content of discharged sludge liquor (dissolved phosphorus, orthophosphate)). While sewage sludge ashes thus contain phosphorus at high concentrations, this is chemically fixed. Therefore, the redissolution of phosphorus, which can be achieved by wet-chemical, thermo-chemical or metallurgical means, is technically complex and costly. However, a recovery potential of at least 80% is feasible, relative to the sewage treatment plant inflow.

3.2.5 Food production

(1) Various volume streams and qualities of wastewater from food production are generated in food production and food processing; these are considered industrial wastewater. However, in terms of its quality and level of contamination it is comparable to municipal wastewater. It often contains phosphorus (e.g. in the

case of dairy effluent) which can be recovered in the course of wastewater treatment.

(2) Similar to the “municipal wastewater” volume stream, this phosphorus can be precipitated using e.g. magnesium salts. This precipitation is highly effective, allowing for the recovery of almost all of the phosphorus dissolved as orthophosphate. The use of other recovery processes is conceivable. The recovery potential and recyclate purity are highly dependent on the quality of the process water and on the industrial process.

3.2.6 Animal by-products (meat and bone meal (MBM) ash)

(1) Significant material streams that remove phosphorus from materials cycles include animal by-products, such as animal meal or MBM originating from the processing of Category 2 or 3 material (in accordance with Reg. (EC) No. 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption). Only substances produced from Category 2 or 3 material may be placed on the market as organic fertiliser.

(2) Under hygiene legislation, the use of ashes derived from the incineration of animal by-products categorised as Category 1 material for the production of fertilisers is not currently permitted despite the high incineration temperatures used. Due to the fact that often there is no separation of Category 1 and 2 materials respectively, phosphorus recovery from animal by-products has not yet gained much significance. Category 3 animal by-products are mostly used for the production of pet food.

(3) The ash fraction is the prime substrate for phosphorus recovery from animal by-products. Therefore, the permitted Category 2 and 3 material must first be incinerated in mono-incinerators or co-incinerated, where appropriate, together with other materials rich in phosphorus in suitable facilities. Subsequently, similar processes to those used for sludge ash processing can be used.

3.2.7 Slurry and other farm manure

(1) The German Fertiliser Act (*DüngeG*) defines farm manure as fertilisers that arise or are produced

– as animal excretions during livestock husbandry for food production, or during other agricultural livestock husbandry, or
– as vegetable matter during crop production or in agriculture,

including in the form of mixtures or following aerobic or anaerobic treatment. Farm manure is mostly landspread directly on agricultural land for the purposes of fertilising the soil.

(2) Phosphorus recovery from livestock slurry can be favourable in regions where there are surpluses of farm manure (phosphorus). Processes for phosphorus recovery from slurry are available, as is the process of slurry separation. Moreover, processing improves the nutrient-ratio in slurry; the nitrogen/phosphorus ratio in untreated slurry is unfavourable for plant nutrition, i.e. too high in phosphorus. Slurry applications calculated to meet nitrogen demand may therefore lead to soil phosphorus enrichment.

3.2.8 Assessment of the material streams

(1) In conclusion, the phosphorus recovery potential increases along the sewage treatment plant's process chain (material stream) (see Figure A). However, the technical complexity and cost required for phosphorus recovery rises in parallel with the recovery potential. Bioavailability generally decreases along the process chain, but high bioavailability can be achieved, depending on the recovery process and further treatment of the recyclates. Due to economic and operational advantages, currently implemented industrial-scale processes primarily include those that target material streams at the front-end of the process chain.

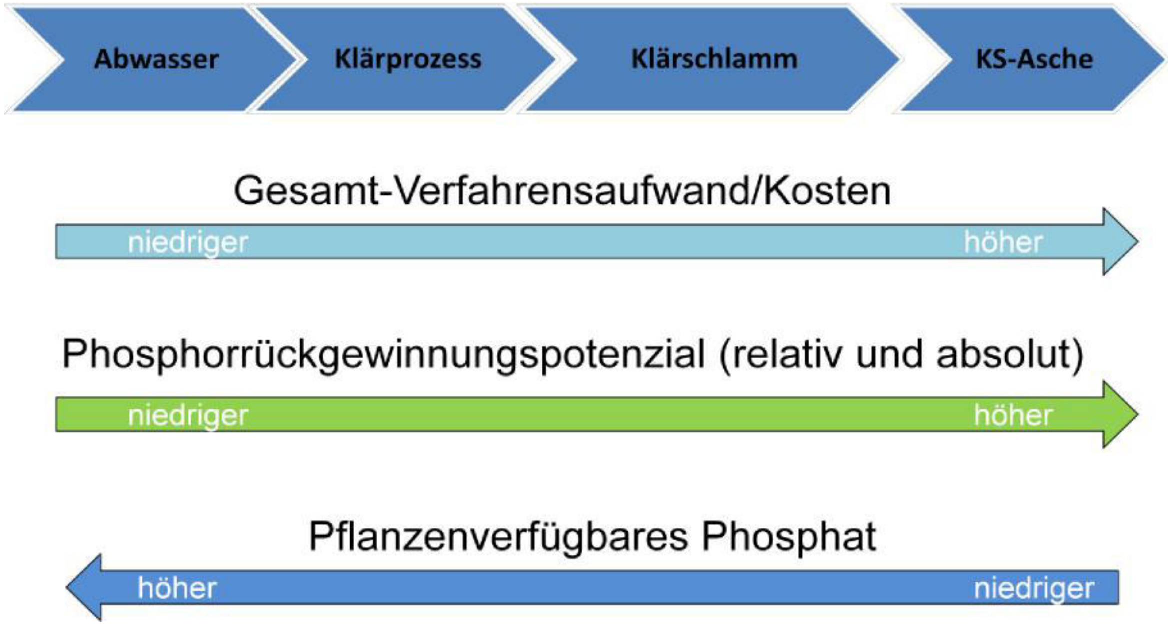

Figure A: General analysis of the effort/expense associated with phosphorus recyclate, its potential and bioavailability.

Abbildungselemente:

Abwasser	Wastewater
Klärprozess	Treatment
Klärschlamm	Sewage sludge
KS-Asche	Sludge ash
Gesamt-Verf ...	Overall effort/cost associated with process
niedriger	lower
höher	higher
Phosphorrück...	Phosphorus recovery potential (in relative and absolute terms)
Pflanzenverf...	Plant-available phosphate

(2) The following Table B provides a rough assessment of the various material streams offering phosphorus recovery options with regard to their operating capability, productivity, recyclate quality, cost-effectiveness, resource and energy efficiency, and the technical maturity of the technologies.

Table B: Assessment of phosphorus recyclates derived from wastewater treatment

Material stream (source material for P recycling)	Productivity (phosphorus recovery)	Recycle quality		Operating capability, utility	Consumption of operating consumables, energy efficiency	Maturity of process	Cost per kg of phosphorus
		Bioavailability	Contaminant dissipation[8]				
Wastewater (treatment plant discharge)	+	++	++	+	+	++	o
Process water (sludge liquor)	++	++(+)	++(+)	+	+++	+++	ooo
Sewage sludge (not dewatered)	++	+++	++	+	+++	+++	oo
Sewage sludge (dewatered)	+++	+++	+++	++	++	+++	oo
Sewage sludge ash (processed)	+++	++	+++	++	++[9]	++	oo

+ = low
++ = medium
+++ = good

o = high
oo = medium
ooo = low

[8] Organic and inorganic contaminants can be dissipated to varying degrees.
[9] Exception: Some processes allow for energy generation.

3.3 Examination of recovery processes

(1) The different technical phosphorus recovery processes will be examined below. The aim is to illustrate their individual advantages and limitations, the effort/expense associated with each of the processes, and the results that can be expected.

(2) The individual processes can be grouped under sewage treatment process, sewage sludge, and sludge ash respectively, as shown in Figure B. Example processes are listed in Annexes 1 and 2.

Figure B: General overview of options for phosphorus recovery

Abbildungselemente:

Klärprozess	Sewage treatment process
Klärschlamm	Sewage sludge
Asche	Ash
Kristallisationsverfahren	Crystallisation processes
Chemische Fällung	Chemical precipitation
Adsorptionsverfahren	Adsorption processes
Nasschemischer Aufschluss	Wet-chemical treatment
Metallurgische Verfahren	Metallurgical processes
Thermochemischer Aufschluss	Thermo-chemical treatment

3.3.1 Chemical precipitation, crystallisation and adsorption of dissolved phosphorus

(1) The presence of phosphorus dissolved as orthophosphate is a precondition for the use of chemical precipitation processes. In municipal sewage treatment plants this is particularly the case in facilities using biological phosphorus elimination. Special micro-organisms take up excessive amounts of phosphorus under aerobic conditions; they are then removed from the wastewater together with the sludge that is being generated and, under anaerobic conditions, they release the phosphorus again into the sludge liquor. Subsequently, the sewage sludge or the sludge liquor can be treated using chemical precipitation, crystallisation or adsorption processes.

(2) The treatment consists of raising the pH, e.g. by means of air stripping (injection of air) or by adding lime or sodium hydroxide solution. Crystallisation or subsequent precipitation are normally effected by the addition of magnesium or calcium salts. However, phosphorus that is biologically or chemically fixed in the sludge is not captured. The resultant recyclates are MAP (magnesium ammonium phosphate) or CAP (calcium ammonium phosphate) and include, depending on the source stream, a greater or lesser amount of precipitated impurities. Following further processing/cleaning (e.g. washing), as necessary, the recyclate can be used as a fertiliser with relatively good bioavailability (see Chapter 5).

(3) In addition to the technically and economically relatively easy process of recovering dissolved phosphorus, targeted phosphorus precipitation offers both operative and economic advantages, as it avoids spontaneous precipitation and the resultant deposits, e.g. in pipes. Moreover, its lowered phosphorus content makes it easier to dewater the sewage sludge. A recovery potential of up to 30% relative to the sewage treatment plant inflow can be expected from this process. Higher recovery rates are not currently feasible as the phosphorus that is biologically or chemically fixed in the sludge can not be captured.

3.3.2 Wet-chemical treatment

(4) In order to be able to recover the biologically or chemically fixed phosphorus in addition to the dissolved phosphorus, the former must also be transferred into the liquid phase. This can be achieved, for example, by wet-chemical treatment of sewage sludge. One advantage of these techniques is that they can also be used to treat sewage sludge in facilities using chemical (not only biological) phosphorus elimination.

(5) Phosphorus is transferred into the liquid phase by lowering the pH by means of mineral acids, i.e. sulphuric, hydrochloric or phosphoric acid, or by means of carbon dioxide. The rate of redissolution is dependent on the pH and thus on the amount of acid used. However, with acidic extraction, the redissolution of phosphorus goes hand in hand with the redissolution of heavy metals contained in the sewage sludge. Following the separation of solids, the pH is raised by adding alkaline solutions such as sodium hydroxide solution or limewater, which allows for the precipitation of dissolved phosphorus as described in the previous section (chemical precipitation, crystallisation and adsorption). Where necessary, chelating agents such as citric acid may be added to avoid the co-precipitation of heavy metals. Another option is the subsequent separation of heavy metals from the phosphorus fraction by way of precipitation (sulphide / hydroxide) or nanofiltration, solvent extraction (extraction of a solute from a liquid mixture) or ion exchange.

(6) A recyclate with relatively good bioavailability can be expected. The recyclate's degree of purity varies with the process used. Conceivably, organic contaminants will also largely be separated out during wet-chemical treatment. The higher the recovery potential and the purer the recyclate, the higher will be the processes' technical complexity and cost. A recovery potential from sewage sludge of up to 60% relative to the sewage treatment plant inflow can be expected.

(7) Comparable wet-chemical treatment processes can also be used with sewage sludge ashes, with a recovery potential of up to 90% relative to the sewage treatment plant inflow.

3.3.3 Thermo-chemical treatment

(1) Thermo-chemical treatment is particularly suited to sewage sludge ashes from mono-incineration. It also allows for the recovery of biologically and chemically fixed phosphorus. The sewage treatment plant is free in its choice of phosphorus elimination process.

(2) For thermo-chemical treatment, the ashes are mixed with magnesium chloride or sodium carbonate and heated to approximately 1,000°C in a rotary kiln. Due to the high vapour pressure, the heavy metals react with the reducing agent to form compounds, enter the gaseous phase and are subsequently removed from the

process with the exhaust stream. At the same time mineral phosphate phases are generated, such as magnesium phosphate or calcium-magnesium phosphate.

(3) This relatively complex process yields a recyclate that is comparatively clean; there is no reason to expect the presence of organic contaminants. Depending on the procedure used, the recyclate's bioavailability will be medium to good. A recovery potential of up to 90% relative to the sewage treatment plant inflow can be expected.

3.3.4 Metallurgical processes

(1) Biologically or chemically fixed phosphorus can also be recovered using metallurgical processes. Here too the sewage treatment plant is free in its choice of phosphorus elimination process. Dewatered sewage sludge with a minimum of 25% dry matter content, or sludge ashes are mixed with cement or other aggregates, pressed into briquettes and heated in a vertical shaft smelting furnace. At temperatures of up to 2,000 °C heavy metals evaporate (e.g. cadmium, mercury, lead, zinc) or are processed into a liquid metal phase (e.g. iron, chromium, copper, nickel). The resultant slag contains all of the phosphorus that was contained in the sewage sludge.

(2) A comparatively clean recyclate can be expected from this process. The high temperatures should destroy any organic contaminants. The resultant recyclate is similar to basic slag (Ca-silico-phosphate). While this process is technically quite complex, the fact that the sewage sludge's energy content can be utilised is an advantage. A recovery potential of up to 90% relative to the sewage treatment plant inflow can be expected.

3.3.5 Mono-incinerators and pyrolysis without direct post-processing

(1) It is generally possible to thermally treat sewage sludge in classic mono-incinerators (fluidised bed, pyrobuster, grate firing, and similar combustion techniques) and to directly use as fertiliser the resultant ashes which, due to the thermal treatment, should be free from organic contaminants. Due to the low bioavailability of phosphorus in such ashes and due to the lack of non-volatile heavy metal dissipation, sewage sludge mono-incineration ashes should in future not be directly used as fertilisers but as a raw material for the production of

recycled phosphorus fertiliser. Technologically, wet-chemical and thermo-chemical processes would be particularly well suited.

(2) Pyrolysis offers yet another option for thermal treatment of sewage sludge. The advantage of pyrolysis plants is that they can be dimensioned for lower throughputs than mono-incinerators. Process temperatures of 500°C destroy part of the organic contaminants. A disadvantage is the lack of heavy metal dissipation. The first pyrolysis plants for sewage sludge are currently operating as test and demonstration facilities. The resultant sewage sludge char is currently being studied and has not yet been approved as a fertiliser. It is possible that pyrolysis will merely be an intermediate step in the generation of a raw material for the production of recycled phosphorus fertiliser.

(3) Additionally, the resultant sewage sludge ash and char could be introduced into the process of mineral fertiliser production where they could replace mineral rock phosphate. Field trials using sewage sludge ashes have yet to be undertaken.

3.3.6 Assessment of the recovery processes

(1) In conclusion, wet-chemical treatment from sludge liquor primarily offers economic advantages; the relevant processes are most advanced and can be described as ready for the market. However, these advantages are offset by the low achievable recovery rates and the limitation to the few sewage treatment plant working with biological precipitation. Recovery from ashes can achieve the highest recovery rates but is more onerous. Recovery potential increases in tandem with greater technical complexity and higher costs of phosphorus recovery. Annex 1 provides an overview of the individual processes.

(2) The following Table C provides a rough assessment of the various recovery processes with regard to their operating capability, the utility of the phosphorus precipitation process used, their productivity, recyclate quality, cost-effectiveness, resource and energy efficiency, and the technical maturity of the technology.

Table C: Brief general characterisation of phosphorus recovery processes

Process principle	Productivity (phosphorus recovery)	Recyclate quality		Operating capability, utility	Consumption of operating consumables, energy efficiency	Maturity of process	Cost per kg of phosphorus
		Bioavailability	Contaminant dissipation[10]				
Precipitation, crystallisation, adsorption	+	++	++	++	++(+)	+++	OOO
Wet-chemical treatment	++	+++	+++	+++	+	++	OO
Thermo-chemical treatment	+++	++	++	++(+)	+	++	O
Metallurgical treatment	+++	++	++	++(+)	++	+	O(O)

+ = low o = high
++ = medium oo = medium
+++ = good ooo = low

[10] Organic and inorganic contaminants can be dissipated to varying degrees.

4 Assessment of interim storage and the potential of landfill mining

4.1 Assessment of requirements for the interim storage of sewage sludge ashes

(1) Priority should be given to the immediate processing into a marketable material and to phosphorus recovery from ashes resulting from the mono-incineration of municipal sewage sludge. Where this can not as yet justifiably be achieved, i.e. if, for example, as part of the transition period for the establishment of industrial-scale recovery processes greater interim storage capacities are required, the ashes can normally be stored at a Class II landfill site (*DKII-Deponie*). Such larger-scale interim storage at landfill sites is only of temporary significance and should be limited to what is necessary for technical production considerations.

(2) In order to avoid the intermixing of sewage sludge ashes and other types of waste, a long-term storage site including a mono-waste storage area must be established, preferably with a dedicated leachate collection system. If prior to storage it can be shown that the ash is fully inert (leaching test), the relevant authority may adapt the requirements for leachate collection accordingly or take a decision as to the necessity of constructing a leachate collection system. Contact with precipitation must be largely avoided. Cost-effective recoverability should be the prime consideration. Therefore, priority should be given to solutions facilitating such recoverability. This can be achieved by the ashes being delivered and installed in Big-Bags for example and by installing a temporary surface seal (mineral or plastic cover). These are preconditions that should be met as a matter of course at an operational state-of-the-art landfill.

(3) The German Landfill Ordinance (*DepV*) in Section 23(6) of the version dated 2 May 2013 (Federal Gazette I No. 21, p. 973) provides for long-term storage (more than three years) in principle: “For sewage sludge mono-incinerator ashes, without them being mixed with other substances or wastes, stored at a long-term storage facility for the purposes of phosphorus recovery at a later point in time, an exemption from the obligation to provide proof in accordance with paragraph 1(2) may be granted upon application. The derogation may be granted for a period not exceeding five years. The derogation may thereafter be extended for a limited period. A derogation in accordance with (1) may not be granted for storage beyond 30 June

2023."[11] In the course of amending the Sewage Sludge Ordinance (*AbfKlärV*) the periods provided for under Section 23(6) of the Landfill Ordinance should also be extended.

(4) In the case of landfill storage of sewage sludge ashes, the ownership and transfer of ownership (operator of mono-incinerator or landfill) should be clearly regulated in law.

4.2 Assessment of the potential offered by landfill mining

(1) The phosphorus potential in German landfill sites from deposits of sewage sludge and sludge ashes since 1980 has been estimated to be in the order of 350,000 Mg P. This quantity could meet the demand for phosphorus in Germany for a period of 2.5 years[12]. Additionally, slags (OBM[13] slag, LD[14] slag, and electric furnace slag) contain considerable amounts of phosphorus. However, existing data on recyclables that could potentially be recovered from landfill sites, and on phosphorus contents in particular, are no longer up-to-date.

(2) Sewage sludge deposited in landfill sites was often mixed with municipal solid waste, which makes phosphorus recovery more difficult. Moreover, the sewage sludge deposited often contains elevated concentrations of heavy metals. As part of the recycling process, attention must be paid to ensuring that heavy metals are separated out and do not end up in the recycled phosphate.

(3) There is as yet a lack of practical experience in the use of efficient pre-treatment and sorting technologies for landfill mining. Sufficient data on investment and operational costs as well as on relevant environmental impacts are similarly lacking[15].

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[11] Note: this is not an official translation.
[12] Franke M. et al. (2011): Landfill Mining – Rohstoffpotenziale in Deponien, in : Recycling und Rohstoffe, Vol 4, TK Verlag Karl Thomé-Kozmiensky, p. 403 (pp. 411-412)
[13] OBM: A steelmaking process using an oxygen blowing converter
[14] LD: A steelmaking process using an oxygen top-blowing process
[15] Fricke K. (2011): Landfill Mining – ein Beitrag der Abfallwirtschaft zur Ressourcensicherung, Müll und Abfall, 11 2013, p. 587

(4) Research on landfill mining is currently being undertaken in a R&D project by the Federal Ministry of Education and Research (BMBF)[16]. A particular focus of the R&D project is on the conditions under which landfill mining can be environmentally sound, cost-effective, and sustainable. The technical system design for the provision of secondary raw materials is also part of the R&D project. A separate guideline on legal requirements with regard to the approval of landfill mining will be made available to future users. A completed study on landfill mining at a district landfill site in Baden-Württemberg[17] has found that the cost of landfill mining is higher than expected and that the process would only be cost-effective if the price of raw materials, i.e. revenue obtained from the sale of recyclables, was significantly higher.

(5) An ongoing study by the federal state of North-Rhine/Westphalia on phosphorus recovery from landfill sites and legacy deposits, which is to be completed by the end of 2015, has shown that the phosphate contents of deposits in different types of landfill sites range from 1 to 80 g P/kg dry matter (DM). Overall, the following progression from high to low phosphorus contents is evident (Figure A).

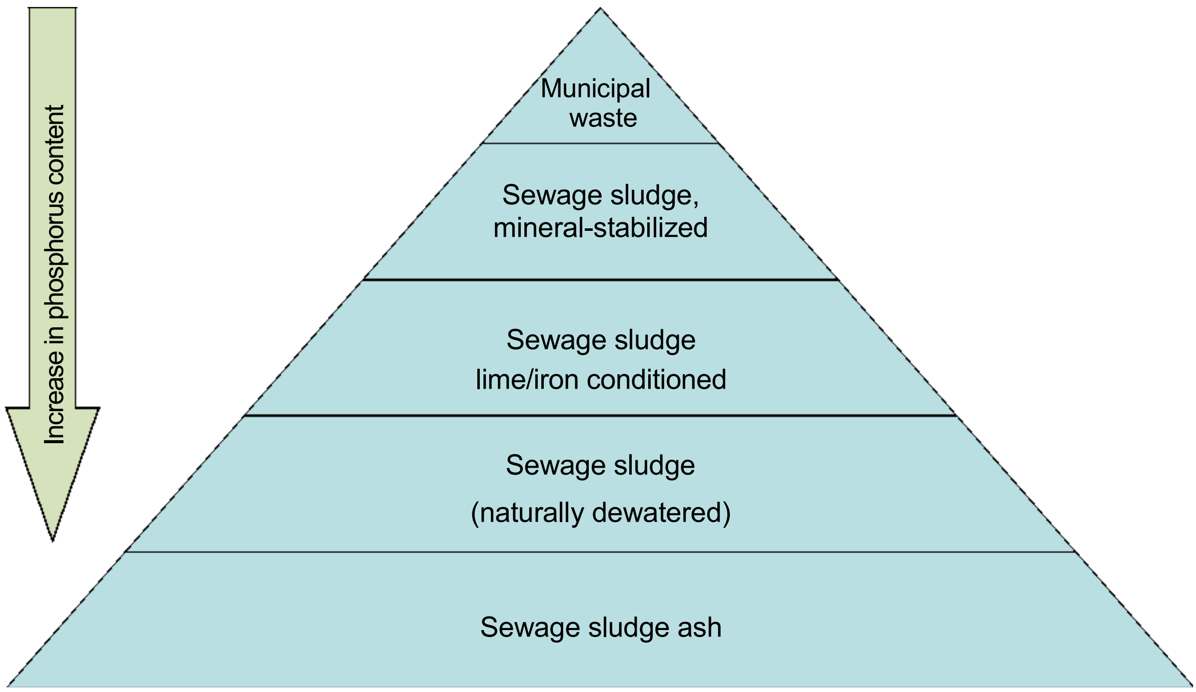
[16] Research and Development project by the Federal Ministry of Education and Research (BMBF) and the federal state of North-Rhine/Westphalia, coordinated by the waste management company Tönsmeier, the town of Porta Westfalica, and Minden Lübbecke District.

[17] Gäth S. & Nispel J. (2012): Betrachtung des Ressourcenpotenzials der Kreismülldeponie Hechingen, Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg.

Figure A: Progression of phosphorus contents of deposits[18]

(6) Not all deposits are worthy of being processed, with “worthiness” being based on a minimum phosphorus content of 20 g P/kg DM, as currently included in the draft amended Sewage Sludge Ordinance (*AbfKlärV*). Obligatory phosphorus recycling is envisaged where this value is exceeded.

(7) In landfill sites phosphorus is present in inorganic form which is primarily due to the long storage times. Analyses[19] have shown that the deposits contain elevated levels of heavy metals, which means that prior to their use as fertilisers they must undergo appropriate treatment. Other studies on the impact of storage duration on chemical bonding of phosphorus and thus on phosphorus recoverability, on bioavailability of phosphorus mined from landfills, and on the economics and environmental impacts have not yet been concluded.



[18] Research project of the federal state of North-Rhine/Westphalia, conducted by Braunschweig University of Technology: Phosphorus recovery from landfill sites and legacy deposits (*Phosphatrückgewinnung aus Deponien und Altablagerungen*), in conjunction with a BMBF research project (r^3) on landfill mining.

[19] Research project of the federal state of North-Rhine/Westphalia, conducted by Braunschweig University of Technology: Phosphorus recovery from landfill sites and legacy deposits (*Phosphatrückgewinnung aus Deponien und Altablagerungen*), in conjunction with a BMBF research project (r^3) on landfill mining.

(8) Waste legislation is considered to be the primary legal basis for landfill mining. Landfill mining for the purposes of recovering raw materials is currently not expressly covered by waste legislation or soil protection legislation.

(9) Mining for the purpose of phosphorus recovery of sections of landfill sites in which phosphorus-containing wastes were mixed with other wastes can not currently be recommended for economic reasons, given the diffuse presence of phosphorus content. It may however be appropriate if there are other reasons for landfill-site remediation such as groundwater protection or site utilisation. Dedicated sewage sludge disposal sites must however be considered separately. The cost-effectiveness of phosphorus recovery from such sites should be assessed on a case-by-case basis.

5 Assessment of recovered phosphorus

5.1 Regulatory framework for the utilisation of recovered phosphorus as fertiliser

5.1.1 Fertiliser law

(1) Any assessment of the fertilising effects and of proper recovery must respect the provisions of fertiliser law as well as substance-related sectoral statutory provisions (e.g. Sewage Sludge Ordinance (*AbfKlärV*) and, as appropriate, the Biological Waste Ordinance (*BioAbfV*)).

(2) Fertiliser law was enacted to regulate all substances placed on the market or applied as fertilisers (within the meaning of Art. 1 of the Fertiliser Act (*DüngG*)). Only approved substances may be placed on the market and used as fertilisers. Approval may be granted based on European legislation (here: Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers) or national statutes (here: Fertilisers Ordinance – Ordinance on the circulation of fertilisers, soil nutrients, soil substrates and plant protection substances – *DüMV* of 5 December 2012) or on the basis of approvals granted in another Member State of the European Union (EU).

(3) With a view to safety, the German Fertilisers Ordinance (*DüMV*) contains general provisions for all substances as well as substance-specific requirements with regard to contaminant content, restrictions and conditions for their use. Regulation (EC) No 2003/2003 does not contain any such provisions. Statutes in other EU Member States contain such provisions only in part.

5.1.2 End-of-waste status

(1) Various technical processes for the use of phosphorus resources contained in sewage sludge or other phosphorus-containing substances are currently operating under near real-life conditions. Phosphorus-containing fertilisers and source materials for additional products have already reached the markets and their market presence will increase in future.

(2) Pursuant to Art. 5 of the Closed Substance Cycle Waste Management Act (*KrWG*), a substance shall cease to be waste when it has undergone a recovery operation and its type and nature is such that

1. it is commonly used for specific purposes,
2. a market or demand exists for it,
3. it fulfils all technical requirements for its specific purposes as well as all existing legislation and standards applicable to products, and
4. its use will not lead to overall adverse environmental or human health impacts.

(3) Art. 5 *KrWG* empowers the Federal Government, by means of a statutory ordinance with the consent of the *Bundesrat*, to determine the detailed conditions under which certain substances and objects take on end-of-waste status. It is conceivable that detailed conditions for the end-of-waste status will be determined in particular in respect of processed sewage sludge mono-incineration ashes and MAP materials and that such requirements will be set out in a statutory ordinance, as required. It is likely that the two material groups will be comparable to primary fertilisers and will no longer pose potential waste-specific risks. In contrast, the consideration of these materials in the Fertilisers Ordinance (*DüMV*) does not automatically confer on these materials an end-of-waste status.

(4) As part of the requirements of Articles 5(3) and 4 *KrWG,* the definition of limit values for pollutants contained in sewage sludge ashes and secondary phosphates is of particular significance; hygiene parameters may also need to be established for phosphorus resulting from precipitation processes.

5.2 General criteria for the production and use of phosphorus-containing fertilisers from secondary phosphorus reserves

(1) Fertilisers can be approved for being placed on the market if they are effective and do not cause harm (Art. 5 Fertiliser Act (*DüngG*)). Fertilisers, soil nutrients, soil substrates and plant protection substances must not, when properly used, damage the health of humans and animals or pose a risk to the ecosystem (Art. 5 *DüngG,* Articles 3 and 4 *DüMV*).

5.2.1 Environmental characteristics

Contaminant content

(1) Generally, the fertiliser quality is determined by the quality of the phosphorus-containing source materials such as wastewater, sewage sludge, sludge ashes, or farm manure. A review of country-wide and state-wide analysis programmes in Germany has shown more than 100 known pollutants in untreated wastewater and sewage sludge; these have not yet been weighted as to their environmental relevance or potential interactions among each other (heavy metals, organic pollutants, residues of pharmaceuticals etc.).

(2) Incineration normally destroys organic pollutants, depending on the incineration temperature and residence time. Therefore, sewage sludge ashes mostly contain far lower levels of organic pollutants than sewage sludge.

Heavy metal content

(1) Sewage sludge incineration leads to a concentration of phosphorus as well as of non-volatile heavy metals. According to a study by Krüger und Adam (2014)[20], untreated sewage sludge ashes may show a significant accumulation of heavy metals. The investigations as part of this study have shown that of the 19,000 Mg of phosphorus theoretically available at present for recovery from mono-incineration ashes in Germany, 12,000 Mg can not directly be used as fertiliser as the ashes do not meet the limit values set out in the Fertilisers Ordinance (*DüMV*). However, targeted thermo-chemical treatment of the ashes can effect a significant removal cadmium, copper, lead, and zinc. In contrast, the treatments can only bring about an insignificant reduction in the levels of arsenic, aluminium, chromium, iron and nickel (Arnold *et al.* 2014)[21]. For example, increased residence times during incineration, increased temperatures (in so far as possible) or the conversion of chemical bonding mechanisms, e.g. conversion into highly volatile chlorides, can result in contaminant dissipation and improve the mineralisation of sewage sludge ash. According to Krüger and Adam (2014), ash quality may also be improved by separating the ash flows resulting from incineration. In this manner, the requirements of the Fertilisers Ordinance with regard to heavy metals could largely be met.

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[20] Krüger O. & Adam C. (2014): UFOPLAN-Projekt:“Monitoring von Klärschlammmonoverbrennungsaschen hinsichtlich ihrer Zusammensetzung zur Ermittlung ihrer Rohstoffrückgewinnungspotentiale und zur Erstellung von Referenzmaterial für die Überwachungsanalytik”; UBA-Texte 49/ 2014.

[21] Arnold U., Trimborn M. & Goldbach H. (2014): Effizienter Einsatz von Recycling-Phosphat in der Landwirtschaft: Pflanzenverfügbarkeit, Schadstoffe und Bewirtschaftungsmaßnahmen, INRES, Universität Bonn.

Organic compounds content

(1) Organic pollutants have primarily been studied and detected in recyclates obtained using wet-chemical treatments. Research guidance studies conducted at the University of Tübingen (2014)[22] have shown that during the recovery of MAP from sewage sludge, the majority of organic pollutants are not co-precipitated but remain in the phosphorus-reduced sewage sludge. Other research results (i.a. those of the BMUB/UBA-UFOPLAN project entitled "Evaluating Concrete Steps for Advanced Phosphorus Recovery from Relevant Streams as well as for Efficient Phosphorus Utilisation") are not yet available.

(2) Sewage sludge ashes from fluidised bed mono-incineration are normally very well burned out, containing little residual carbon. On average, the LOI (loss on ignition) and TOC (total organic carbon) values are below 1%.

(3) Some of the other sewage sludge mono-incineration ashes, such as grate-firing and tiered-firing ashes or fluidised bed gasification ashes have LOI and TOC values of more than 10%, which indicates that the ashes still contain significant proportions of organic carbon compounds and probably also contain soot. Pyrobusters are sometimes used to incinerate small or medium quantities of sewage sludge; the LOI and TOC values of the resultant incineration ashes are comparable to those of fluidised bed incineration ashes[23].

(4) Given that the organic pollutants content detected in sewage sludge mono-incineration ashes is generally well below averages found in sewage sludge, overall they may be considered less critical from the point of view of precautionary soil protection and consumer protection.

(5) Assessments of the organic pollutants content can currently draw on the requirements set out in fertiliser law (Fertilisers Ordinance (*DüMV*), Annex 2, Table 1.4) with regard to dioxins/furans (PCDD/PCDF) / dioxin-like polychlorinated biphenyls (dl-PCB) and fluorosurfactants. Similarly, the Federal Soil Conservation Ordinance (*Bundes-Bodenschutz- und Altlastenverordnung, BBodSchV*) contains limit values for benzo[a]pyrene (BaP) and the Sewage Sludge Ordinance (*Klärschlammverordnung, AbfKlärV*) contains limit values for adsorbable

[22] Final report on the sewage sludge pollutant screening project ("*Schadstoff-Screening in Klärschlamm*") University of Tübingen, 2014
[23] Krüger O. & Adam C. (2014), UFOPLAN-Projekt:"Monitoring von Klärschlammmonoverbrennungsaschen hinsichtlich ihrer Zusammensetzung zur Ermittlung ihrer Rohstoffrückgewinnungspotentiale und zur Erstellung von Referenzmaterial für die Überwachungsanalytik"; UBA-Texte 49/ 2014.

organohalogens (AOX) and polychlorinated biphenyls. These indicative parameters are currently suited to assessments of the pollutant quality and characteristics of ashes as well as of the phosphates derived from precipitation processes (Waida & Weinfurtner, 2011)[24].

Hygiene parameters

(1) Given the fact that almost all sewage sludges not subjected to hygiene treatments may contain salmonella, amongst other pathogens, it is reasonable to assume that these pathogens will also enter the process chain where wet-chemical processes are used for sewage sludge disintegration. In contrast, based on current knowledge, hygiene parameters are of no significance for sewage sludge ashes.

5.2.2 Fertiliser value

(1) Fertiliser types are approved in the Fertilisers Ordinance (*DüMV*), based on scientific research. Given the diversity of phosphorus source materials from secondary sources, it would appear appropriate to have available a unified assessment method for calculating phosphorus availability to give equivalence to all phosphorus-containing fertilisers. Standardised test procedures should be developed which are capable of establishing the suitability as fertilisers of these substances. The test procedures should take into consideration the following aspects, among others:

- Interactions between phosphorus and other nutrients
- Influence of soil nutrient content
- nfluence of soil phosphorus
- Influence of crop species on specific phosphorus uptake
- Influence of various phosphorus bonding types which are metabolised by plants in different ways.

(2) Additionally, for the purposes of being placed on the market, indications given of the phosphorus content on all fertilisers should be based on similar extraction

[24] Waida, C. & Weinfurtner, K.-H., (2011): Untersuchung der in der Förderinitiative erzeugten Produkte. In Bundesministerium für Bildung und Forschung (Ed.), Phosphorrecycling – Ökologische und wirtschaftliche Bewertung verschiedener Verfahren und Entwicklung eines strategischen Verwertungskonzeptes für Deutschland (pp. 97–162). Aachen: Bundesministerium für Bildung und Forschung. http://www.phosphorrecycling.eu/index.php?option=com_rokdownloads&view=file&Itemid=67&id=73&lang=en

methods (solubility). Three extraction levels (corresponding to three solubilities) should be given on the labels. We propose the following:

- Total content (mineral acid soluble phosphate content)
- Solubility in weak acid (neutral ammonium citrate)
- Solubility in water.

(3) A compulsory indication of the same solubilities for all phosphorus-containing fertilisers allows for better comparisons between fertilisers and contributes to their more appropriate use.

5.3 Recommendations

(1) To ensure soil and consumer protection and the prevention of water pollution, only effective fertilisers that are low in pollutants must be used.

(2) For the purposes of approving source materials for fertiliser production from secondary phosphorus-containing materials, we suggest that the following criteria be discussed and advanced in the Scientific Advisory Board on Fertiliser Issues (*Wissenschaftlicher Beirat für Düngungsfragen*) and in consultation with the competent experts at the waste management authorities and the agricultural and horticultural experts.

Proposals for the Scientific Advisory Board on Fertiliser Issues:

- Development of standardised testing methods for determining the bioavailability of phosphorus contained in phosphorus-containing substances and recycled fertilisers, and
- Requirements in terms of fertiliser use efficiency as a measure of the quantity of phosphorus absorbed by plants.

Proposals for provisions falling within the scope of the Fertilisers Ordinance (*DüMV*) or the Sewage Sludge Ordinance (*AbfKlärV*):

- General exclusion of fly ashes and filter sludges as source materials;
- Limitation of the organic compound content in incineration ashes (e.g. maximum TOC of < 1%) and secondary phosphates with a view to reducing organic pollutants;

- Introduction of compulsory labelling indicating the solubility of phosphorus-containing substances and recycled fertilisers;
- Adjustment of the scope of analyses of organic and inorganic pollutants to the state of knowledge;
- Continuous updates to pollutant and hygiene parameters for sewage sludge ashes and secondary phosphates in accordance with current knowledge;
- Specification of minimum requirements for secondary phosphorus-containing substances as a source material for phosphorus recovery; and
- Development and establishment of the scope of analyses in terms of microbiological and disease control parameters of wet-chemically treated sewage sludge.

(3) Until such time as definitive rules have been laid down on the end-of-waste status (product status), the use of phosphorus-containing substances should be accompanied by voluntary quality assurance measures. This voluntary quality assurance should later be developed into a compulsory quality assurance system.

(4) We recommend that the scope of analysis for organic pollutants in wet-chemical processes also be advanced to the state of knowledge.

6 Measures

6.1 Framework conditions for a sustainable phosphorus strategy

(1) The aim of a sustainable phosphorus strategy is to comprehensively save natural phosphorus resources by substituting secondary phosphates extracted from sewage sludge, slurry, animal by-products and other wastes and materials for rock phosphate-based mineral fertilisers. Such a strategy should also incorporate provisions aimed at limiting to the amount necessary the usage of phosphorus in farming and industry and at minimising the deposition of pollutants in soils and watercourses.

(2) Secondary phosphorus production processes designed to extract the highest possible proportion of phosphorus contained in the source material contribute to resource conservation. These processes should also consume as little energy and operating consumables as possible. Where secondary phosphorus is obtained from wastes, the obligation to strive for high-quality recovery (recycling) in accordance with the waste hierarchy must be taken into account. The aim is to obtain bioavailable phosphorus recyclates.

(3) Currently, sewage sludge that is not directly used as a fertiliser is in most instances disposed of by way of co-incineration or mono-incineration. The resultant mono-incineration ashes are currently mostly disposed of by being placed in mines as backfill, deposited in landfill sites or used in road construction, with the phosphorus resources they contain rarely being utilised. This disposal pathway makes it impossible to utilise the ashes at a later stage as a raw material for the production of recycled fertilisers or other products. The situation is similar when it comes to the disposal of residues from the incineration of animal by-products.

(4) Interventions to promote the sale of secondary phosphorus in the Single European Market must primarily be established at the European level in accordance with the EU rules on the free movement of goods. The scope for national measures in this regard is very limited.

(5) Similarly, under the requirements of the EU internal market, national measures regulating the use of raw materials in the phosphorus industry are not permitted. National contributions to a phosphorus recycling strategy are therefore limited to

waste management measures designed to ensure that phosphorus-containing wastes remain accessible to further or possibly future exploitation. EU Member States are free to make such measures mandatory[25].

(6) According to the EU Commission's "Consultative Communication on the Sustainable Use of Phosphorus" of 8 July 2013, no legal acts are planned at EU level laying down a mandatory share, to be reached within specified timescales, of phosphorus-containing products based on renewable sources in the total quantity of phosphorus-containing products placed on the market. Moreover, no other measures are planned which could achieve similar effects for phosphorus recycling. The Commission's Communication does however address the issue of soil contamination by cadmium and uranium associated with the use of mineral phosphorus-containing fertilisers.

(7) In effect – and backed by waste management law – secondary phosphorus could be promoted as part of product responsibility. After all, according to Article 23(2)(2) of the Closed Substance Cycle Waste Management Act (*KrWG*) product responsibility includes "priority for use of recoverable waste or secondary raw materials in the production of products". However, it is highly probable that the fulfilment of product responsibility obligations on the part of fertiliser manufacturers would be associated with significant costs, given that market prices for mineral phosphorus-containing fertilisers are currently significantly lower than the costs associated with the production of recycled phosphorus fertiliser from wastewater, sewage sludge, or sewage sludge mono-incineration ashes. Judging from the development over the past decade, it can reasonably be assumed that this situation in unlikely to change in the short term, or possibly even in the medium term, unless the external environmental costs are internalised in the market price of rock phosphate-based phosphorus fertilisers. Thus, a market-driven move towards the exploitation of the phosphorus recycling potential is not currently expected.

(8) While the inclusion into product responsibility provisions of a compulsory acceptance by the fertiliser industry of secondary phosphorus-containing materials (such as sewage sludge mono-incineration ashes and other such intermediate products) would in principle be constitutional and conformant with EU law, for macro-economic reasons the implementation of such provisions would likely run into insurmountable difficulties in the common market. For this reason, Germany

[25] KoMa: *Bewertung konkreter Maßnahmen einer weitergehenden Phosphorrückgewinnung aus relevanten Stoffströmen sowie zum effizienten Phosphoreinsatz*, FKZ 3713 26 301 (Evaluating Concrete Steps for Advanced Phosphorus Recovery from Relevant Streams as well as for Efficient Phosphorus Utilisation)

should follow the example of the Netherlands which, in agreement with the EU strategy (see Commission Communication COM(2013) 517 final of 8 July 2013), is using voluntary agreements between the state and the fertiliser industry. In these agreements the fertiliser industry commits to a gradual conversion of its raw material base from rock phosphate to secondary raw materials. This agreement should include a voluntary commitment by the industry providing for increasing inputs of secondary phosphorus-containing materials (such as sewage sludge mono-incineration ashes and other such intermediate products), including a roadmap with specified timeframes. In this context, consideration should be given to the question as to whether the government could promote the sale of secondary raw material fertilisers by way of subsidies and/or approval of the use of these fertilisers in organic farming.

(9) The analysis of technical options for phosphorus recovery from sewage sludge has shown that sewage sludge mono-incineration with subsequent phosphorus recovery achieves the highest recovery rates. The consistent implementation of this option calls for the establishment of new treatment facilities as the existing mono-incineration capacities are not sufficient. There are other recovery options in addition to mono-incineration with subsequent phosphorus recovery; as yet, these do not however match the recovery potential presented by sewage sludge ashes. The relevant processes can be implemented using less feedstock and energy and at a lower cost. All things considered, the LAGA AG is of the opinion that solutions must be found that are adapted to individual local conditions and it does not consider it advisable to establish a fixed methodology. Legal provisions should set a recovery target and allow for competition between technical solutions.

(10) By analogy, this also applies to other phosphorus-containing wastes and products, especially meat and bone meal and excess slurry. Quality assurance and material quality specifications are similarly useful for phosphorus-containing recyclates obtained from these sources.

6.2 Proposal for measures as part of the phosphorus strategy

6.2.1 Measures for the establishment of an infrastructure of phosphorus recovery plants

(1) The LAGA AG Phosphor takes the view that a move towards industrial-scale phosphorus recovery using currently available processes is both feasible and advisable.

(2) It is the LAGA AG Phosphor's view that the establishment of an infrastructure of phosphorus recovery plants should commence at the present time.

(3) In order to advance phosphorus recovery processes and achieve planning certainty for plant operators, from the LAGA AG Phosphor's point of view, legal provisions on phosphorus recovery are needed, such as those envisaged as part of the currently planned amendment of the Sewage Sludge Ordinance (*AbfKlärV*).

(4) The LAGA AG Phosphor concludes that the individual choice of phosphorus recovery process is primarily determined by local constraints. For this reason, preconditions as to the choice of process should not be laid down.

(5) In many cases, economically viable phosphorus recovery necessitates the use of large-scale facilities for the centralised treatment of sewage sludge and sludge ashes and the processing of the resultant secondary phosphorus into a marketable product. The implementation of phosphorus recovery should initially be phased in for sewage treatment plants belonging to facility size classes 4 and 5 (i.e. capacities exceeding 10,000 and 100,000 population equivalents respectively) and mono-incinerators.

(6) The LAGA AG Phosphor considers a period of less than ten years following the entry into force of the relevant regulations as a sufficiently long period of transition for the implementation of phosphorus recovery for sewage treatment plants belonging to facility size classes 4 and 5 as well as for sewage sludge mono-incinerators. Industrial plants that are processing municipal wastewater or municipal sewage sludge should generally be included. For sewage treatment plants belonging to facility size classes 1 to 3 (capacities below 10,001 population equivalents) an assessment should be made, taking account of the experience gathered with implementation, as to the circumstances, including ecological and economic

aspects, under which stipulations on phosphorus recovery may be required. Treatment of these sewage sludges in centralised phosphorus recovery plants (e.g. at the site of co-incineration or mono-incineration) is conceivable. Regardless of the facility size class to which a sewage treatment plant belongs, the LAGA AG Phosphor considers it necessary for plant operators to present a phosphorus recovery concept in due course. This requirement should be set down in law and coordinated at regional and supra-regional levels.

(7) Co-incineration of sewage sludge and other materials containing relevant amounts of phosphorus should be prohibited where the phosphorus content is greater than 20 g P/kg DM. An assessment should be made at a later point in time as to whether this limit could be lowered. In the case of co-incineration in coal-powered power plants, Germany's climate policy targets must be taken into consideration ("decarbonisation" of electricity generation by 2050 at the latest)[26].

(8) Phosphorus recovery processes should be designed to recover a minimum of 50% of the phosphorus contained in sewage at the treatment plant inflow. An assessment should be made at a later point in time as to whether this limit could be increased.

(9) Any stipulation on phosphorus recovery from the sewage sludge material stream must result in the appropriate disposal of the resultant phosphorus-reduced sludges. Generally, the only suitable option is co-incineration. The suitability and availability of co-incineration capacities must be evaluated as part of implementing the phosphorus strategy.

(10) Additional material streams such as animal by-products should be included in phosphorus recovery as soon as possible.

(11) We ask the Federal Government to present for voting, in a timely fashion, the draft amendment of the Sewage Sludge Ordinance, which also contains provisions on phosphorus recovery.

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[26] Pursuant to the final sentence of the first paragraph of the decision taken by the 83rd Conference of Environment Ministers (UMK) on 24.10.2014 on Agenda Item No. 42 (sewage sludge recycling)

6.2.2 Safeguarding phosphorus reserves contained in deposited sludge ash

(1) For economic and process-related reasons, phosphorus recovery should take place at the location at which phosphorus arises in sewage treatment plants and incinerators. Long-term storage of sewage sludge ashes and landfill mining are considered as being secondary.

(2) As long as the direct recovery of phosphorus from sewage sludge mono-incineration ashes is not possible, these mono-incineration ashes should temporarily be put into storage in long-term storage facilities with a view to future use. The exemption from the obligation to provide proof with regard to the storage of these ashes, as laid down in Section 23(6) of the Landfill Ordinance, should be extended to beyond 30 June 2023, the current deadline set out in the Ordinance. With a view to limiting the period of storage of the ashes, a determination should be made in cooperation with the industry as to the timeframe required for the implementation of phosphorus recovery from sludge ashes. The extension should not exceed a period of 10 years.

(3) With a view to promoting phosphorus recovery, the LAGA AG Phosphor considers indispensable the abolition of landfilling of incineration ashes. This necessitates the amendment of the Landfill Ordinance (*DepV*).

(4) The use of phosphorus-containing incineration ashes in landfill construction, backfilling of mines, and road construction should be prohibited as soon as possible.

(5) Requirements with respect to the necessary quality of sewage sludge mono-incineration ashes for phosphorus recovery should be defined and set out.

6.2.3 Measures for the production of high quality secondary phosphates, especially fertilisers

(1) With a view to approving source materials for fertiliser production from secondary phosphorus-containing substances, standardised testing methods should be developed for determining their bioavailability and fertiliser use efficiency.

(2) For precautionary reasons and to improve bioavailability, sewage sludge mono-incineration ashes should generally be processed and pollutants removed prior to land application.

6.2.4 Measures for the marketing of phosphorus recyclate

(1) With a view to promoting the sale of phosphorus recyclate, voluntary commitments and, if necessary, binding rules on the use of secondary phosphorus are deemed necessary.

(2) The LAGA AG Phosphor advocates voluntary commitments on the part of the fertiliser industry for the purchase of secondary phosphates and requests that the Federal Government engage in negotiations to this end.

(3) Direct sales of recovered phosphorus complying with relevant quality specifications must be possible. The LAGA AG Phosphor proposes that an expert committee, with the involvement of the Scientific Advisory Board on Fertiliser Issues, will address the relevant requirements and processes.

(4) The LAGA AG Phosphor asks that the Federal Government lobby the EU Commission for European legislation to be enacted on the obligation to purchase phosphorus recyclates.

6.2.5 Research measures

(1) Additional applications for secondary phosphates should be identified and assessed as to their suitability.

(2) As part of a research programme, viable concepts for the utilisation of ashes resulting from the mono-incineration of animal by-products should be developed. Category 1 animal by-products in accordance with Reg. (EC) No. 1069/2009 should be included in the considerations. Candidate phosphorus recovery processes should first be tested in pilot plants so as to ensure that they are fit-for-purpose.

6.2.6 Additional measures

(1) For reasons of soil and groundwater protection, regional surpluses and shortfalls of farm manures must be balanced out. As part of a transregional nutrient management strategy, such as has already been implemented in some neighbouring countries, particularly farm manures and digestates in nutrient surplus regions must be converted into a form suitable for transport and storage in nutrient-deficit regions. The extraction of secondary phosphorus plays an important role in this respect. From a crop physiological perspective, it can help achieve a phosphorus/nitrogen ratio that is more favourable for crop nutrient supply.

(2) The mixing of sewage sludge and other materials containing relevant concentrations of phosphorus with other wastes or substances prior to treatment must be prevented if this was to result in a reduced phosphorus concentration, an increase in the pollutant load, or if it was to complicate phosphorus recovery (ban on dilution).

(3) The approach taken to material stream management for sewage sludges originating from different sources and the blending of same with a view to thermal treatment should be based on the phosphorus recovery technologies suited to the different materials. Appropriate rules should be developed to this end.

(4) As part of the requirements for phosphorus recovery, initially a dilution ban should be put into place for materials with phosphorus contents of more than 2%. An assessment should be made as to whether this limit could be lowered at a later point in time.

(5) We ask the Federal Government to advocate measures which optimise and thus further reduce the use of phosphorus in farming and industry.

(6) In order to ensure consistent quality, quality assurance for secondary phosphorus should be introduced (defined process conditions, residual organic compounds, bioavailable phosphorus content, limit values for pollutants, certificates, and other parameters).

6.3 Outlook

(1) At the present rate of fertiliser use in Germany, recycled phosphorus fertiliser could theoretically reach a 40% market share in the total mineral phosphorus fertiliser market, provided the phosphorus recovery potential of wastewater, sewage sludge and sludge ashes is exploited. Even higher shares would be feasible if phosphorus was also recovered from meat and bone meal or surplus slurry.

(2) The phosphorus strategy proposed in this report envisages a gradual development of this potential. Based on the results obtained, the tangible proposals for initial measures to be taken in this regard must therefore be followed with further steps at the national and European Union levels. National-level options that should be assessed for possible implementation at a later stage include the greater inclusion of still unused phosphorus-containing waste and material streams as well as the lowering of the limit value to under 20 g P/kg TS (i.e. the value at which a phosphorus recovery obligation for sewage sludge is likely to apply).

(3) The extension of a phosphorus strategy to the level of the European Union is just as important as further national measures. The potential for phosphorus resource conservation and avoidance of environmental impacts associated with the extraction of phosphate ore can only be tapped to a greater extent if binding measures for the production of phosphorus products and phosphorus fertilisers in particular are put into place in the common market. Therefore the aim must be that more effective measures for phosphorus recovery are also conceived, decided and implemented at the EU level.

(4) Successful initial steps, as conceived here, of the national German phosphorus strategy are a motivator for the advancement of an EU phosphorus strategy. The implementation of a national strategy would set an example for the European and international levels. Given the as yet high cost of phosphorus recovery, in the implementation of the first phase of the phosphorus strategy care must be taken to ensure that the existing potential for increases in efficiency of the technologies used is exploited as quickly as possible.

Annex 1: Process selection based on sources of material streams

Location of P recovery		Plant boundary conditions		Process boundary conditions			Product
		Technical preconditions	Plant size (with reference to population equivalents or sewage sludge quantity)	Process (Process principle)	Recovery potential (with reference to treatment plant inflow / sewage sludge dry matter)	Product type	further uses (Direct use, processing required etc.)
Sewage treatment plant	Wastewater	no prior targeted P elimination, flocculation reactor and sedimentation tank after the secondary settling tank	Plant sized for > 50,000 PE	Post-precipitation	42% relative to inflow	Aluminium-magnesium phosphate	
		Dosing station after primary settling stage/at aeration tank inflow	Plant sized for > 10,000 PE	Alkaline precipitation using sodium aluminate (ALTON)	80-90%	Aluminium phosphate	Direct use in agriculture
		Separate reactor after biological treatment		Crystallisation	max. 37% relative to inflow	Calcium phosphate	Direct use in agriculture
		Ion exchange treatment after biological treatment		Ion exchange and crystallisation		MAP, Calcium phosphate, magnesium phosphate	
		Adsorption treatment after biological treatment		Adsorption/desorption and precipitation		Calcium phosphate	
		Magnetic separation after biological treatment		Precipitation		Iron phosphate or aluminium phosphate	
		Bypass flow and integrated P recovery		Biological with redissolution and precipitation	30% relative to inflow	Calcium phosphate	Phosphorus industry
		Packed bed reactor, stirred reactor or moving bed reactor after the secondary settling tank		Crystallisation	40% relative to inflow	Calcium phosphate with Calcium silicate hydrate	Agriculture, phosphorus industry
	Process water from sludge treatment		Plant sized for > 20,000 PE	Precipitation	40% relative to inflow; 90% of phosphate-P in process water	MAP	Direct use in agriculture
		Filtration facility, ion exchange treatment,, electro-deionisation treatment		Ion exchange and electro-dialysis		Phosphoric acid	
		Additional strip and precipitation reactors		Stripping and precipitation		Struvite	
	Sewage sludge (raw / digested)	Biological phosphate elimination; additional reactors for precipitation		Precipitation	max. 90% relative to inflow	MAP	Agriculture
		Additional reactors, filters, settlement tanks and precipitation reactor		Wet-chemical treatment using hydrochloric or sulphuric acid and subsequent precipitation	50% relative to inflow	MAP	Agriculture
		Additional extraction and precipitation reactors		Extraction and precipitation		Calcium phosphate	Agriculture
Sewage sludge ashe following mono-incineration - Phosphate content in the ash 3.7-10.1% P (average 7.2% P)				Wet-chemical treatment	approx. 90% [1]	Calcium phosphate, magnesium phosphate, also iron phosphate or aluminium phosphate [1]	Agriculture [1]
				Thermo-chemical treatment	approx. 90% [1]	Customised granulated fertiliser [1]	Agriculture Phosphorus industry [1]
				Metallurgical	approx. 90% [1]	Basic slag [1]	Fertiliser industry [1]
Food production				Precipitation		Calcium phosphate, magnesium phosphate	
Meat and bone meal				Metallurgical, thermo-chemical if necessary			
Farm manure (slurry, liquid manure, digestates)				Wet-chemical treatment		Calcium phosphate, magnesium phosphate	Agriculture

Annex 2: Process selection based on the recovery process

Process	Recovery location (at the sewage treatment plant, following mono-incineration)	Tech. preconditions (e.g. type of precipitation)	Characteristics (advantages and disadvantages)	Process (examples)	Recovery quota (of the process)	Maturity of the technology (state of implementation of the example processes)	Use of chemicals
Precipitation	Sludge water	Air stripping and subsequent precipitation		NuReSys /Belgium			
Precipitation	Wastewater following primary treatment	Precipitation using alkaline aluminium coagulation (ALTON) at a ratio of Al_2O_3 : Na_2O = 1:1.2	No increase in wastewater salt concentration, improved effectiveness of acrylate-based flocculation aids	EP 0383 156			Sodium aluminate
Ion exchange/ electro-dialysis	Filtrate from sewage sludge dewatering		No use of chemicals	Selective ion exchange (PHOSIEDI process)		Pilot plant, large-scale trial at Rastatt sewage treatment plant [4]	none
Crystallisation	Digested sludge water			Crystallisation with calcium silicate hydrate phases (P-RoC process/KIT); stripping and precipitation as MAP in conjunction with Bio-P precipitation (Air-Prex) [4]	80% laboratory 60% semi-technical	Laboratory trials, pilot plant	
Extraction	Sewage sludge	**Extraction using CO_2 and subsequent precipitation**	CO_2 and limewater	Budenheim Carbonic Acid Process [4]	60%	Pilot plant	**CO_2**, limewater
Wet-chemical treatment	Digested sludge subsequent to residence in digester; ash following mono-incineration	Disintegration using acids or alkaline solutions, extraction, separation of solids	Direct use in agriculture is possible, good bioavailability, low in heavy metals, requires treatment (neutralisation) of residual water [1]	Disintegration using acids or alkaline solutions (HCl, H_2SO_4, H_3PO_4 or NaOH) , separation of solids, treatment of process water with a view to metal/phosphorus separation (precipitation, crystallisation, liquid-liquid extraction); product precipitation using calcium/magnesium containers for disintegration and precipitation, mixer-settler for extraction, aggregates for separation of solids (e.g. PASCH process/RWTH Aachen, LEACH-Phos/BSH in Bern (CH), SESAL-Phos/IWAR Tu Da, SEPHOS, P-bac/INORE) [1, 2, 3], RecoPhos Consult Germany [4], TetraPhos)	approx. 90% [1]	Pilot plant, laboratory [1], large-scale trial at Offenburg sewage treatment plant [4]; production in Saxony-Anhalt, licensed for Bazenheid sewage treatment plant, Switzerland [4]	Mineral acids, limewater
Thermo- chemical treatment	Ash following mono-incineration	Rotary kiln	Good bioavailability, low in heavy metals, pellets or further processing into multi-component fertiliser; high Cl concentration can adversely affect materials in flue-gas purification [1]	a) Addition of calcium chlorides or magnesium chlorides, T > 1,000 °C in rotary kiln, conversion of phosphates into available form (calcium phosphate or magnesium phosphate), conversion of metals into gaseous phase in the form of metallic chlorides and separation by flue-gas purification. b) Treatment of ash, T > 1,300 °C, addition of coke, sand, separation of phosphorus via gaseous phase as P_4 (e.g. Rhenania, AshDec/AshDec Umwelt AG in Leoben, Austria, RETERRA/Remondis, Recophos/Montanuniversität in Leoben, Austria) [1,2,3]	approx. 90% [1]	Pilot plant, laboratory [1]	Chloride salts
Metallurgical	Ash following mono-incineration	Blast furnace	High temperature	T > 1,000°C Separation via slag with coke and oxygen addition to sewage sludge ashes briquettes (e.g. Mephrec/Ingitec, ATZ Eisenbadreaktor/Munich) [1,2,3]	approx. 90% [1]	Pilot plant [1]	

References

1 KA 2013 (60) Nr. 10, 11; Stand und Perspektiven der Phosphorrückgewinnung aus Abwasser und Klärschlamm, DWA-AG KEK 1.1

2 Projekttreffen UFOPLAN, 17.01.2014 "Bewertung konkreter Maßnahmen einer weitergehenden Phosphorrückgewinnung aus relevanten Stoffströmen sowie zum effizienten Phosphoreinsatz (KoMa) - Zwischenergebnisse

3 Tabelle Bewertungsverfahren E-Mail Fr. Roskosch vom 12.04.2014

4 Material workshop "Abwasser-Phosphor-Dünger" 28./29.01.2014, BAM Berlin