PHOSPHOROUS RECOVERY FROM MUNICIPAL SEWAGE SLUDGE

APPLICATION OBJECTIVE:
- After-treatment of municipal sewage sludge or of the ash remaining from the monovalent incineration of sewage sludge in order to recover phosphorous as an increasingly scarce resource

OUTLINE ON APPLICATION FRAMEWORK

PARTICULARLY APPLICABLE FOR WASTE TYPES

<table>
<thead>
<tr>
<th>Glass</th>
<th>Light-weight packaging</th>
<th>Biowaste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/paperboard</td>
<td>Mixed household waste</td>
<td>Bulky waste</td>
</tr>
<tr>
<td>Lamps</td>
<td>Textiles</td>
<td>Electrical &amp; electronic waste</td>
</tr>
<tr>
<td>Scrap metals</td>
<td>Wood waste</td>
<td>C&amp;D waste</td>
</tr>
<tr>
<td>Waste oil</td>
<td>Old paint &amp; lacquer</td>
<td>Waste tires</td>
</tr>
<tr>
<td>Hazardous wastes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Branch specific waste</td>
<td>potentially feasible with excess liquid manure, meat-and-bone meal, other phosphorous containing organic matter</td>
<td></td>
</tr>
<tr>
<td>Other waste materials</td>
<td>Sewage sludge from municipal wastewater treatment respectively ash from monovalent sewage sludge incineration</td>
<td></td>
</tr>
</tbody>
</table>

SPECIAL CHARACTERISTICS AND REQUIREMENTS OF THE APPLICATION:

Pre-treatment of the input material:
The phosphorous in products from the wastewater treatment is chemically differently bound which is why pre-treatment steps are required for its recovery. A large portion of the phosphorous is present in dissolved form so that a particulate condition must be induced by way of chemical precipitation or through a biological accumulation in the sludge while passing a plants biological treatment stage. The recovery process can be initiated then in the sense of a special extraction of phosphorous with the phosphate-enriched suspensions. Prerequisite for recovery procedures applied on sewage sludge ash is a preceding monovalent sludge incineration.

Options for the utilization of the generated output:
Recovered phosphorous compounds which passed a cleaning and possibly another form of processing have a relatively broad range of use. Depending on the recovery process various products for different applications are obtainable. Calcium phosphates are won in wet-chemical and from thermochemical processing. They are generated by precipitation or crystallization and also by a thermochemical accumulation in the product. Calcium phosphates are used as slow-release fertilizers mainly, thus substituting certain amounts of mineral fertilizers made from raw phosphate of sedimentary origin. Aluminium phosphate and iron phosphates are won in wet-chemical processes and by thermochemical treatment. Their usage as a fertilizer is limited, however. Elemental phosphorous for industrial applications and heavy metals for zinc and copper smelting can likewise be generated.

Aftercare requirements:
Remaining sewage sludge can be treated and mineralized in monovalent or co-incineration plants. Residual ash and process remains can ideally be utilized like residues from other combustion processes, for backfilling operations or otherwise they must be disposed of on hazardous waste landfills.

Protective needs:
Handling sewage sludge due to the high bacterial load of wastewater is at any time associated with a health risk. Depending on the operation, there can be a risk during the process of phosphorous recovery from operating aids and auxiliary agents and the harmful effects going out from them for health. In addition, the resultant products are directly dangerous to health and in some cases highly flammable and eutrophic. Precaution and personal protection measures are to be applied correspondingly.

Financing options:
Phosphorous compounds which can be obtained from recovery processes have the quality of fertilizers with good plant availability. This renders them to products the plants can sell to earn income for refinancing parts of the investment. Fee systems established for the wastewater collection and treatment services form an additional instrument for refinancing. European and national support schemes are occasionally in place to help financing the development and implementation of phosphorous recovery. Combining new investment projects for wastewater treatment with phosphorous recovery can be an asset when applying for international donor assistance.
RESTRICTIONS OR INFLUENCE OF EXTERNALITIES ON THE APPLICATION:

### Points of application:
The potential, effort and efficiency of phosphorous recovery differ, inter alia in dependence from the starting point of treatment. An orientation might be found in the following characteristic values:

<table>
<thead>
<tr>
<th>Extraction site</th>
<th>Total load of phosphorous (relative to incoming load)</th>
<th>Phosphorous concentration</th>
<th>present as</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effluent discharge</td>
<td>10 %</td>
<td>≤ 0.8 mg P/liter</td>
<td>dissolved + particulate</td>
</tr>
<tr>
<td>Sludge water</td>
<td>in the moment of precipitation: ≤ 5% biological P-elimination: up to 50 %</td>
<td>≤ 20 mg P/liter up to 400 mg P/liter</td>
<td>dissolved + particulate</td>
</tr>
<tr>
<td>Digested sludge (at 30 % dry residues)</td>
<td>90 %</td>
<td>&gt;10–approx. 20g P/kg sludge</td>
<td>biologically and chemically bound</td>
</tr>
<tr>
<td>Ash</td>
<td>90 %</td>
<td>approx. 60 g P/kg ash</td>
<td>chemically bound</td>
</tr>
</tbody>
</table>

Data source: Study Phosphorous recovery from waste water and sewage sludge, TBF + Partner AG, Zurich 2015 + empirical data UBA

### Infrastructural conditions:
Plants for phosphorous recovery should be set up near the points of sludge generation (thus mostly in the wastewater treatment plants) to keep the costs for logistics as low as possible. For the operation of the plants an access to the grid is important. In addition, appropriate storage areas are needed for the different material flows.

### Climatic conditions:
of no influence

### TECHNICAL DETAILS

#### GENERAL OVERVIEW

**ABSTRACT**
In sewage sludge the phosphorous is bound chemically and biologically. Three technical options have gained greater interest for the recovery of phosphorous in the process of handling sewage sludge thus far. These are:
- the wet-chemical processing and disintegration of the sewage sludge or sewage sludge ash with the help of caustic and acid products (e.g. Seaborne-process);
- a direct form of extraction and utilization from the digester sludge (e.g. Airprex-process);
- the thermochemical recovery of the phosphorous out of the sewage sludge ash.

**BASIC REQUIREMENTS**
- At the inflow to the wastewater treatment plant phosphorous is partly dissolved and partly in a chemically or biologically bound state. The particulate phosphorous can be extracted by sedimentation. A large part of the phosphorous is however present in a dissolved form. Since an elimination of phosphorous from wastewater is generally advisable, this part needs to be converted in a particulate state, too. This can be achieved by chemical phosphate precipitation based on the addition of precipitating agents, or by biological phosphate fixation through above-average phosphorous uptake of specialized bacteria in the biological stage of the sewage plant. Depending on the recovery method the sludge thus generated can be treated for the purpose of phosphorous extraction before respectively after the digestion process or after drying.
- In case of an application of recovery procedures on sewage sludge ashes is required the preceding monovalent incineration of sewage sludge and, if necessary, the briquetting or palletisation of the ashes.

**EXPECTED RESULTS**
- A substantial phosphorous elimination from sewage sludge or sludge incineration residues is taking place while at the same time industrially usable phosphorous respectively phosphates that have fertilizing quality can be obtained. With that a scarce raw material resource is protected and an eutrophication of water bodies prevented.
- The phosphorous loads in municipal wastewater treatment plants have their origin largely in human faeces, since phosphate-free detergents have meanwhile penetrated the markets. This makes it highly unlikely that phosphorous loads in municipal wastewater will decline in the future.
### SPECIFIC ADVANTAGES

- The recovery of phosphorous from sewage sludge allows the direct sludge use in a fertilizing function on land as method which for several reasons is not effective and any longer advisable (loads of hazardous, groundwater-polluting and endocrine disrupting compounds; limited plant availability of nutrient content) to be ceased. All processes described here provide products of fertilizing quality and with lower pollution than conventional mineral fertilizers produced from raw phosphate of sedimentary origin (inter alia less cadmium and uranium).

- The elimination of phosphorous has a positive impact on the further processing of the sludge, e.g. the efficiency of dewatering.

- Installations for phosphorous recovery can often quite easily be retrofitted in the plants and integration into the wastewater or sludge treatment process is therefore possible. In addition, the installations are not only suitable for sewage sludge but other phosphorous potentials can be tapped with them as well.

- In the thermal process is effected a simultaneous energetic and material use of the sewage sludge, a lasting destruction of organic pollutants is achieved as well.

### SPECIFIC DISADVANTAGES

- The construction and operating costs differ widely and can be very high depending on the type of plant.

- Incompatibilities can happen. Some processes are applicable in combination with specific plant configurations only. The process management is very complex and demanding.

- The phosphorous recovery rate of each process differs greatly and can in some cases also yield relatively small results. Optimization is taking a long way.

- Long-term valid conclusions concerning the economic efficiency of the various processes have not been derived yet because the experiences gained are rather limited and nearly on the pilot stage so far.

### APPLICATION DETAILS

### TECHNICAL SCHEME

Processes for the recovery of phosphorous can be integrated at different stages of municipal wastewater and sludge treatment. Portions of the dissolved phosphorous in the wastewater and most of the colloidal, fine particulate phosphorous load are incorporated into the activated sludge or excess sludge leaving the cleaning system, the phosphate released during the decomposition of organic substances in the digester for the most part is bound by flocculating agents. That is why the currently established methods for phosphorous recovery concentrate on the said suspensions mainly. The type of chemical bonding and concentration of phosphorous in the medium to which the technical measures for its recovery will be applied is critically important to achieve a high recovery rate. In Europe only a few process operators today can assert the economic viability of the applied phosphorous recovery processes, there are many more processes however that are just at the pilot stage and have not yet achieved market maturity. Now here further specified shall be processes which are applied on either the drained digested sludge or on the ashes from sludge incineration and already proved to yield reliable results over time.

### Phosphorous recovery from digested sewage sludge in the wastewater treatment process

Applied here are processes that work with crystallization and precipitation of the dissolved phosphorous, incompatibilities with other P-elimination must thus be observed. To the methods which right now are conceivable as reliably functioning and expandable recovery approaches from dewatered digested sewage sludge belong the following two processes:

**AirPrex®-Process:**

This process is based on the precipitation of magnesium ammonium phosphate (MAP) and was originally developed by the Berliner Wasserbetrieben (BWB) for preventing MAP-incrustations in pipelines of sewage plants. It is applied after the anaerobic stabilisation prior to dewatering. Sludge from the digester is fed directly to a multi-stage reactor system and subjected to air stripping. While carbon dioxide escapes the pH is raised and magnesium chloride added. MAP which precipitates during this process in crystalline form can be removed at a later stage from the sludge. It can be further processed into a product with proven potential as an agricultural fertilizer. For a successful process, the pH, phosphorous content and the quantity and type of precipitating agent must be precisely synchronized.
The following figure illustrates the process in a simplified manner.

**Figure 1:** Basic configuration for the application of the AirPrex®-Process (modified illustration of BAFU, 2009)

The plant in Berlin realized depending on the aeration effort a recovery rate of phosphorous between 3.5% and 8% of the phosphorous load on the wastewater intake of the plant.

**Seaborne-Process:**
This relatively complex and expensive process has been successfully adopted at the wastewater treatment plant in Gifhorn, Germany. Right after the digestion step, a separation of heavy metals and nutrient recovery is performed in two cycles. In the first process step heavy metals and nutrients are remobilized by adding sulphuric acid to the sludge and decreasing its pH-value. The solids are separated using a centrifuge and filter system. Biogas from the digester is then passed through the liquid phase in a reactor. Hydrogen sulphide in the biogas reacts with the heavy metal ions in the liquid to heavy metal sulphides. These precipitate from the liquid and are removed. The digester gas is desulphurised by that and better usable now in co-generation units. The next cycle serves the nutrient recovery. After the addition of sodium hydroxide (to adjust/raise the pH-level) and magnesium oxide as precipitating agent, ammonium, magnesium and phosphorous crystallize to MAP. The precipitate is separated from the liquid by a centrifuge and dried. Surplus nitrogen is separated as di-ammonium sulphate (DAS) in a stripping process. MAP and DAS can be used in agriculture. The following is a simplified process illustration:

**Figure 2:** Simplified illustration of Seaborne-Process (modified graphic of BAFU, 2009)

Good progress towards industrial-scale application and hence likewise considerable as alternative options in future are also processes such as Ostara Pearl®, NuReSys® oder Fix-Phos.
Recovery of phosphorous from the ashes of sewage sludge

The type recovery processes depicted hereafter can be done with the ashes from the monovalent incineration of sewage sludge only. Basically two approaches have emerged for that until to date. These are the wet-chemical processing and the thermal extraction. The phosphorous in the ash is chemically bonded in the form of iron-, aluminium and calcium phosphates. Latter is the most common compound. The content of phosphorous in the ash from sewage sludge is usually in the range of 5–10 % (in average 64 g P per kg ash). In the most favourable case a recovery rate of up to 90 % can be achieved by selected applications.

Wet-chemical processing methods:

In the wet-chemical approach, phosphorous is dissolved from the ashes by an acid suspension, for example with sulphuric acid. Problematic hereby is that parts of the heavy metals are also brought into solution with this. They can subsequently be precipitated, for example as sulphides and separated from the dissolved phosphate, however. Depending on the pH the phosphates then fall out during the neutralization as aluminium phosphate, iron phosphate and calcium phosphates. Calcium phosphates will be mainly won if the pH is raised with lime. On a good way to a larger-scale implementation and thus considerable as alternative options for acid hydrolysis processes are the Stuttgarter Process as well as the Tetraphos and the Budenheim Carbonic Acid Process.

Thermal extraction methods:

To describe this method two processes can be referenced, both which have evolved from the pilot stage in the past to processes which reached an industrial application in the meantime.

ASH DEC (Outotec)-Process:

The advantage of this proven technique lies in the separation of a small side stream of a heavy metal concentrate from the main material flow, while the phosphorous-rich stream is converted into a useful product. The ash is homogenized with alkaline chloride in an intensive mixer and then pelletized. Composition and dosage of the additives are essential parameters, which help the calcium and aluminium phosphates to be turned into soluble phosphate compounds and toxic substances to be removed via the gas phase. The pellets are placed in a thermal reactor and exposed to temperatures around 1000°C for 30 minutes. 99 % of the heavy metals, especially mercury, cadmium and lead, react at this temperature with the additives and evaporate. The concentration of other heavy metals which are permitted as trace elements for agricultural use are also lowered this way. 97 % of the ash input is converted into a directly usable P-rich granulate. 3 % of the ashes are kept back as a metal concentrate from a multiple stage flue gas cleaning system. A disadvantage of this process is the high energy demand. A snapshot of the original pilot installation can be seen below.

Figure 3: ASH DEC-pilot installation in Leoben, Austria, 2008 (photo courtesy of Outotec GmbH & Co. KG)
**TECHNICAL SCHEME - CONTINUATION**

**Mephrec®-process:**
The Mephrec-Process enables the recovery of phosphorous in a metallurgical process which does not only suit for sewage sludge but other material containing phosphorous too (e.g. meat-and-bone meal). Slightly dried sewage sludge (e.g. 25% dry residues content) alone or in mixture with sludge ashes or meat-and-bone meal of sufficiently high P₂O₅ content put in briquette form is exposed to a high-temperature (2.000 °C), oxygen driven melt-gassing process in a shaft furnace. The resulting phosphate slag is granulated in a water-bath and gives a ready-to-use fertilizer. High-melting heavy metals are removed in a separable metal alloy, whereas low-melting metals such as (zinc, cadmium, mercury) evaporate and deposit in an adequately installed flue gas cleaning system.

**QUANTITY ASPECTS**

Depending on the process, different mass flow proportions can be observed. The technical publication “Sewage sludge management in Germany” of September 2013 provides the following orienting values:

- The AirPrex®-Process supplies about 2 Mg MAP/day at an input of 100m³/h
- The Seaborn® process supplies from an input of 120 m³ digestion sludge per day an average quantity of 1.3 Mg MAP/day, equivalent to an annual quantity of phosphorous of about 60 Mg.
- Wet chemical processes with MAP as a precipitate enable a recovery of approximately 40% to 70% of the phosphorous contained in the inflow to the wastewater treatment plant.
- Thermo-metallurgical processes enable almost a complete recovery (>90%) of the phosphorous contained in the inflow to the wastewater treatment plant.
- Thermochemical processes of the company Outotec (formerly Ash Dec), based on a phosphorous content of around 9% in the plant inflow, were generating about 10,000 Mg/a phosphorous fertilizer at an input of 12,000 Mg/a sewage sludge ash within the framework of the EU project SUSAN.
- The Mephrec® process as a metallurgical process offered by the company Ingitec from Bavaria generates from approximately 60,000 Mg/a sewage sludge (25% dry residues content) the quantity of 12,000 Mg/a of a directly usable phosphorous-rich granule (slag). This ultimately corresponds to a phosphorous substitution of about 500 Mg/a.

*Conversion of phosphorous shares from P₂O₅ = 43,64% and MAP = 12,62%*

**INTEROPERABILITY**

- Phosphorous recovery processes are generally well integrable into the overall processes of wastewater treatment plants, the necessary technical installations can be additionally erected respectively retrofitted to existing processing lines directly on-site.
- As a recommended option for sewage sludge disposal monovalent incineration can be coupled with phosphorous recovery and thus simultaneously implemented.

**OPERATIONAL BENCHMARKS: RESOURCE CONSUMPTION**

**ENERGY BALANCE**

- The energy demand depends on the chosen process of phosphorous recovery and can be significantly high. For the ASH DEC (Outotec)-Process an energy consumption of 400–850 kWh per ton of ash has been earmarked. Co-generation with digester gas and sludge incinerating processes can supply (parts) of the energy needed.

**HUMAN RESOURCES NEEDED**

- Operating plants with installations for phosphorous recovery requires qualified and well trained personnel especially in the fields of process management and monitoring. The exact staffing requirements depend on the plant size and the level of process automation.
- Normally, a large part of the processes can be handled from ordinary plant staff, provided that adequate supervision and training is ensured.

**AIDS AND ADDITIVES NEEDED**

- Depending on the process, various chemical additives for precipitation and extraction of the phosphorous are needed; see details provided for the above described processes.
### SPATIAL NEEDS
- Depending on the process. Crystallization and precipitation processes generally have a small space requirement. In contrast, acid digestion methods need relatively more space.
- The space requirement moreover is related to the treated substrate(s). The smaller the volume flow to be treated, the lower the required reactor volumes and therefore also the space requirements.
- Installations for phosphorous recovery often can be directly integrated to the plant/site.

### AFTERCARE DEMANDS
- Process residues such as remaining sludge amounts and residual ash must be treated and disposed of in accordance with regular provisions and standards.

### OPERATIONAL BENCHMARKS: COST DIMENSIONS

#### INVESTMENT COSTS
- Highly variable. The capital investment for the referenced plant in Gifhorn, Germany, (user of Seaborne process), planned with a maximum daily MAP output of about 1.3–1.8 tons/day and realized in 2007, amounted to 7.6 million EUR in total (incl. demonstration and optimization). From this amount 4 million EUR were allocated to equipment and installation engineering.
- For processes adopting the wet-chemical approach on sewage sludge ashes a total investment of about 11 million EUR at an annual treatment capacity of 15,000 tons is generally earmarked.
- The known value range for investments into phosphorous recovery installations is stretching from 6 to 20 million EUR. (based on diverse sources/notifications available up until 2014)

#### OPERATING COSTS
- Operating costs respectively the costs needed for chemicals are the main cost drivers for most of the processes. Process costs are generally quite high and the recovered products therefore in most cases not yet competitive with the prices to purchase conventionally extracted phosphorous.
- The process costs to precipitate MAP were seen at about the level of 3–4 EUR /kg P in 2010.
- For the wet-chemical processing yearly operating costs up to 5.80 EUR/kg per dissolved phosphorous are reported, mainly as a result of the high chemicals consumption during extraction (based on diverse sources/notifications available up until 2014). Process optimization is meanwhile allowing to realize significantly lower costs.

### POSSIBLE PROCEEDS
- Income can be generated from the sale of the recovered phosphorous compounds (mostly fertilizer products). The annual revenue of the Ash Dec plant was expected to lie in a range between 4–12 million EUR.

### MASS-SPECIFIC OVERALL COSTS
- A fairly young record of industrial testing and limited experience in realizing continuous recovery operations still renders the costs of recovery processes a subject to considerable uncertainty. The costs of phosphorous recovery by crystallization and precipitation processes are generally below those for acid hydrolysis and thermochemical recovery. Overall, the recovery costs are significantly higher than the cost of conventional phosphorous fertilizers.
- Beside pure process expenses also the savings wastewater treatment plants can make from phosphorous recovery must be included in a comprehensive cost balance. Possibly the lowest overall recovery costs can be attained with the relatively expensive thermochemical processes when such possible savings are duly taken into consideration. Saved costs for sewage sludge disposal hereby play a fundamental role.

### MISCELLANEOUS
### MARKET INFORMATION

#### REFERENCE FACILITIES
(Important note: the list does not constitute a complete compilation)
- According to the information source referenced below as [1] following plants in Germany are known or have envisaged to run a phosphorous recovery in the frame of their permanent operations.
- Wastewater treatment plant Gifhorn (Seaborne-Process, MAP-precipitation), since 2007
- Wastewater treatment plant Waßmannsdorf, Berliner Wasserbetriebe (Airprex-Process)
- Wastewater treatment plant Offenburg, Baden-Württemberg (Stuttgarter Process)
<table>
<thead>
<tr>
<th>Waste treatment and material processing</th>
<th>Phosphorous recovery from sewage sludge</th>
</tr>
</thead>
</table>

- **Wastewater treatment plant 1, City of Nuremberg** (Mephrec-Process, melt-gassing process of sludge briquettes – currently in the stage of planning)

### RECOGNIZED PRODUCER AND PROVIDER FIRMS

(important note: the list of firms does not constitute a complete compilation of companies active in the specified fields)

To the providers and technology developers of the described process applications belong the following firms:

- **Seaborne - Process**
  - Oxytabs (former Seaborne), D-24768 Rendsburg

- **AirPrex®-Process**
  - Pollution Control Service GmbH, D-22143 Hamburg [www.pcs-consult.de](http://www.pcs-consult.de)

- **Mephrec®-Process**
  - Ingitec®Engineering GmbH, D-04178 Leipzig [www.ingitec.de](http://www.ingitec.de)

- **Ash Dec-Process**

### REMARKS AND FURTHER REFERENCE DOCUMENTS

Further details and supporting information on phosphorous recovery from sewage sludge can be obtained, among others, from:

