Chapter 10
Urban Phosphorus Mining in the Canton of Zurich: Phosphoric Acid from Sewage Sludge Ash

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Abstract The constitutional duty of sustainability in Switzerland requires economical use of valuable and scarce raw materials such as phosphorus. The government of Canton of Zurich recognised this as an opportunity around 10 years ago with respect to the bottlenecks in waste disposal threatening to materialise in 2015 in the existing sewage sludge disposal plan. In 2007, it already gave the Department of Public Works the assignment to design the future sewage sludge disposal so that phosphorus recovery is possible. In 2009, an evaluation of all then-known phosphorus recovery procedures as well as their integration into different sewage sludge disposal pathways showed that the procedures with P recovery from sewage sludge ash are clearly superior to P recovery from sludge and sludge water. The first milestone in the implementation was that it was possible within 6 years and with the involvement of all parties impacted to realign the existing sewage sludge disposal concept completely with respect to the new framing conditions. Since mid-2015, a new central sewage sludge treatment plant at the most optimal location in the Canton has been producing high-phosphorus ash from incinerated sewage sludge. It contains more than 90% of the phosphorus potentials of the entire potential in untreated community waste water from the Canton. By switching over the sewage sludge disposal system from an inefficient, decentralised one to an efficient, centralised system, it has been possible to cut the average sewage sludge treatment costs by more than half, including ash disposal. No modifications to the waste water treatment plants were needed. The Canton has worked with the Foundation ZAR and selected development partners on this implementation of the large-scale engineering

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of phosphorus recovery from sewage sludge ash since 2011 (Phosphorus-Mining-Project). The initial focus lay on the production of high-grade raw material for fertiliser. This led, among other risks in product sales, to settling on the production of technically pure, conventional phosphoric acid as an already established product. Currently there is development work going on using the Phos4life® procedure by Técnicas Reunidas. The attempts to this point demonstrate a P-recovery rate of >95% from the ash, a material recycling of the minerals and the separated metals as well as the use of iron as a precipitant.

Keywords Urban mining · Phosphorus mining · Sewage sludge · Waste water · Phosphorus recovery · Sewage sludge ash · Phos4life®

10.1 Introduction

Phosphorus (P) is a vitally important nutrient for humans and animals. This resource cannot be substituted for with another substance and is becoming more and more precious as a raw material. In contrast to nitrogen, for example, which is present in the air in nearly limitless quantities, P only appears in natural (geogenous) ore deposits and, after they are used, in the 'waste' (useable as anthropogenic deposit). Even other nutrients such as potassium (K), calcium (Ca), magnesium (Mg) and carbon (C) are from a current perspective no longer scarce. The recoverable geogenous phosphate ore deposits are on the other hand limited worldwide. Geopolitically they are concentrated in just a few countries, and they will only become scarcer in the foreseeable future.

Switzerland, like most other European nations, has no phosphorus deposits of its own. Explorations have shown that the quantity of phosphorus bound up in sewage sludge annually is as great as the total mineral fertiliser imported into Switzerland in which is approximately 6000 t P/a. Figure 10.1 presents a simplified version of the P-inventory in Switzerland at the start of this millennium.

Ores from these scarce geogenous sources also contain increasingly high shares of harmful substances (e.g. cadmium and uranium). These harmful substances, when used in fertiliser lead to an ever-increasing concentration of pollutants in the soil. Just how critical the situation is today with the concentration of pollutants in Switzerland can be seen in the studies commissioned by the Federal Department of Agriculture (BLW 2015; FitzGerald and Roth 2015). Figure 10.2 shows the situation in 2011–2012 with respect to the quality of fertiliser used in Swiss agriculture, for example, the cadmium pollution. This makes it apparent that just about half of all mineral fertilisers examined do not fall under the applicable limit of 22 mg Cd/kg P_2O5. At this limit the precautionary principle for soil protection can be satisfied

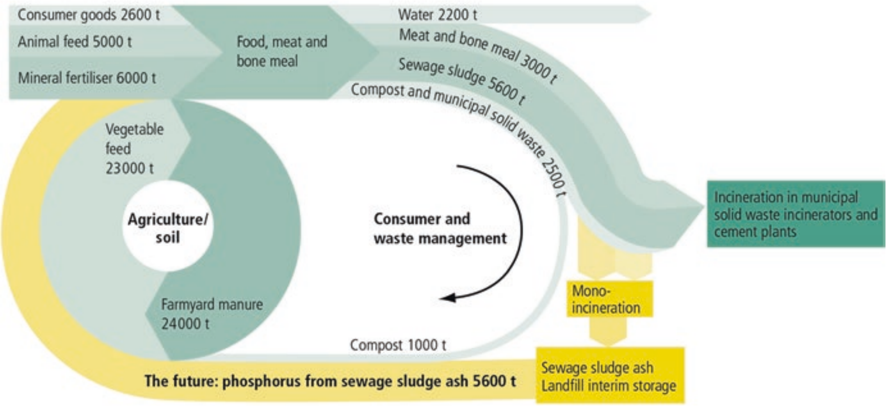

Fig. 10.1 Simplified depiction of phosphorus management in Switzerland (AWEL 2008)

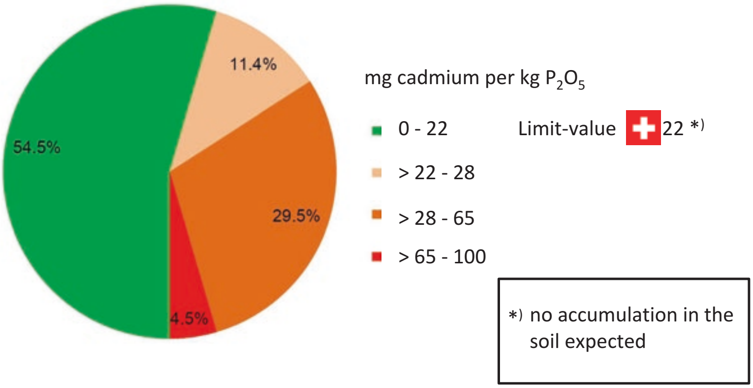

Fig. 10.2 Overview of the quality of the mineral fertiliser used in Switzerland for cadmium (BLW 2015)

so that no long-term accumulation is to be expected. The planned pathway to the limit from the European Union (EU) provides for a timed, gradual procedure for reaching a similar end value of 20 mg Cd/kgP_2O_5.

Both of these facts demand perspicacious and holistic action with respect to this highly valuable resource and its long-term use. The increasing soil pollution from mineral fertilisers with excessive heavy metals content is not sustainable. Along with phosphorus, there are other valuable resources such as iron and other metals together with the organic component, which is a valuable energy source; the best possible use should be made of all of them.

10.2 Urban Phosphorus Mining: New Strategy for Sewage Sludge Disposal in Canton of Zurich

10.2.1 Starting Situation

In Canton of Zurich, the most populous and economically strongest Canton in Switzerland, 69 public sewage treatment facilities treat 230 million m^3 of waste water annually and produce in total around 550,000 m^3 of digested sewage sludge with 6% dry substance (DS) per year. This corresponds approximately to 100,000 tons of dewatered sewage sludge (DSS) with a DS of approximately 30%. It was last possible in 2005 to deliver it directly for agricultural use. In 2003 the sewage sludge disposal plan already created a basis in Canton of Zurich for the thermal mineralisation of Zurich's sewage sludge and thereby anticipated the national ban on release that started in 2006. The precautionary principle in Environmental Protection Act was thus consistently applied in order to prevent the emission of pollutants in the direct release of this sewage sludge as a nutrient source in agriculture. The primary focus lay at that time on safety of disposal as well as utilisation of energy. The recovery of phosphorus played no role in it. As a consequence, the disposal pathway in the Canton was distributed approximately as follows: around 65% in waste-to-energy plants (WtE plants), around 9% – after being dried using fossil fuels – in cement works, ca. 25% in two smaller mono-incineration plants (with no separate deposition of ash containing P) and ca. 1% in plants outside of the Canton.

In 2006, it was recognised that the existing disposal concept would lead to bottlenecks in capacity starting in 2015. It also became increasingly apparent that phosphorus as a vital nutrient is a limited resource and the supply of low-pollutant mineral fertilisers is no longer adequately secured. Both were taken by the decision-makers in Canton of Zurich as an impetus, with respect to sewage sludge disposal to define a sewage sludge recovery strategy taking phosphorus recovery into account as the basis for the objectives of a modern, sustainable waste and resource management programme.

10.2.2 New Strategy

The government of Canton of Zurich therefore formulated the following clear limiting conditions already in 2007 in its decision to the "Implementation of sewage sludge disposal plan" (RRB 572/2007):

The limiting conditions for planning future disposal pathways derive from the decisions on phosphorus recovery and energy use. In the sense of sustainable resource management, planning of future disposal pathways, especially in the construction of new plants, must be designed so that the (later) recovery of the resource phosphorus is possible. The renewable energy trapped in sewage sludge should be used in the most economical way possible regardless of where it is treated.

The strategy is a concrete and important contribution to the urban mining strategy that is being used, defined in the plan of action for waste and resource management for the Canton of Zurich (AWEL 2010). It is based on the principles of sustainable development, the federal natural resources policy (BAFU 2006), and follows, e.g. the recommendations of the expert advisory board on the environment and the European resource strategy as well (SRU 2005).

10.3 Evaluation and Implementation of the Strategy

10.3.1 Preliminary Project and Field Observations for Selecting the Procedure

A specially assigned working group composed of representatives from all parties responsible for sewage sludge disposal in the Canton reached the conclusion in the framework of its first discussions that the greatest energy use benefit and at the same time the demand for future recovery of phosphorus can be fulfilled with a single sewage sludge treatment plant (SSTP) – designed as a sewage sludge mono-incineration plant – in the immediate vicinity of an WtE or a large waste water treatment plant (WWTP).

Parallel to the development of the preliminary project, the agency for waste, water, energy and air (AWEL) of the Canton of Zurich issued the commission for the project "Field Observation Sewage Sludge Disposal Canton Zurich" (AWEL 2009). The objective of this project was to clarify whether there are better, alternative pathways to the preferred method of sewage sludge disposal through sewage sludge mono-incineration with phosphorus recovery from the sewage sludge (incineration) ash that is produced.

In principle, there are four possible options for the use of P in the entire disposal chain (Fig. 10.3). Procedures in which the P recovery proceeds from waste water and sludge water (1 + 2), or from sludge (3) from a waste water treatment plant (WWTP). Construction on the WWTPs is necessary for these three options. The forth option is to recover the phosphorus from the ash from sewage sludge mono-incineration (4). In this case, there would be no need for structural and operational interventions in the WWTPs. The phosphorus present in the sewage sludge ash can be recovered most efficiently with respect to the total potential in the waste water input from the WWTPs.

Any alternatives would need to comply with the framing conditions of the council's decisions (see above) as well as the applicable laws, be compatible with the existing inventory of waste water treatment plants in Canton of Zurich and conform to the technical state of the art. In the first evaluation phase, all known P-recovery procedures in 2009 were assessed according to the following exclusion criteria:

- An operational start-up of the sewage sludge disposal variant with the selected P-recovery procedure must be possible according to the prescribed planning as

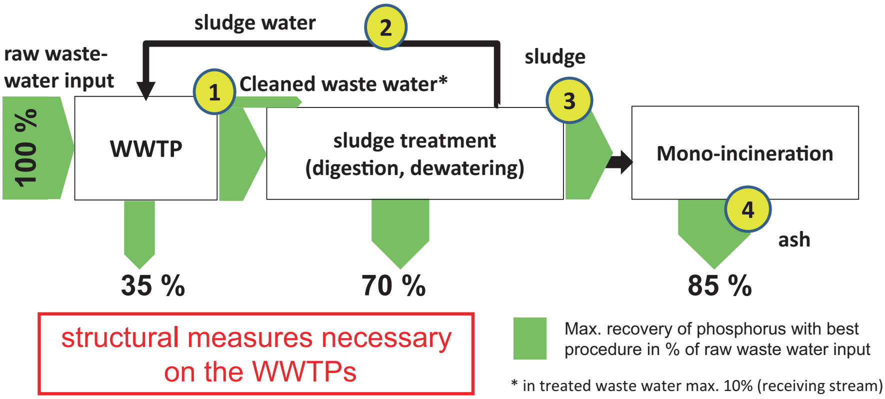

Fig. 10.3 Possible sites of maximum phosphorus recovery rates with the best procedures in % of the supply in the WWTP in waste water management and sewage sludge disposal (Source: AWEL, according to Montag 2008)

of 2015. This means that phosphorus recycling must be assured and/or secured as of 2015 (at best through later use from an interim storage facility to be constructed).

- The energy use from the sewage sludge must be secured.
- Applicable laws must be obeyed.

Only 8 of the 29 recovery procedures known from literature and practice at that time corresponded to the requirements stated above. For each of the eight selected P-recovery procedures, additional data were collected, and a detailed assessment was made with respect to the main criteria of costs, energy consumption and reclaimable quantity of phosphorus for the planned full expansion in Canton of Zurich.

The evaluation provided the following results (AWEL 2009):

Crystallisation procedures from waste water and sludge water in WWTPs yield a certain advantage with respect to costs and energy consumption at very low phosphorus recovery quotas. Procedures with recovery from sewage sludge ash from mono-incineration plants achieve the highest P-recovery rates, and the costs per quantity of phosphorus are lower than in procedures with P recovery from sludge. Procedures with P recovery from sludge are very expensive and require once again considerably more energy than procedures from incinerated sewage sludge ash (ISSA). They cannot compensate for this with the significantly higher P recovery compared to the procedures from waste water. From the insights gained at the time, it was clear that the procedure with P recovery from ISSA from mono-incineration plants was on the whole definitely superior to the alternative procedures with P recovery out of sludge and sludge water.

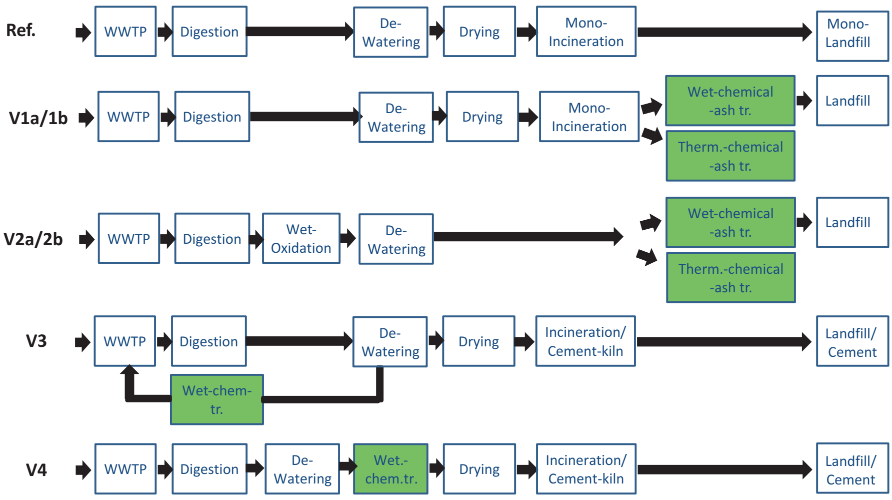

Fig. 10.4 Different variants of sewage sludge disposal chains with possible locations/procedures for P recovery compared with the reference disposal pathway of sewage sludge mono-incineration with P recovery from its ashes; system limit of process chains in each case from raw waste water input into the WWTP (AWEL 2009)

In the following the selected reference disposal pathway (Ref. = mono-incineration with interim storage of ISSA at a monofill) is compared with various alternative disposal pathways (V1a to V4: see Fig. 10.4).

The assessment was completed in an evaluation of the entire system with the system limit starting from raw waste water as input into the waste water treatment plant. For each process chain in the alternative disposal pathway, the following aspects were assumed: (a) compliance with applicable laws, (b) purification of the waste water until the required waste water input quality was achieved and (c) production of a market-ready fertiliser (raw material) or industrial raw materials and/or landfill-capable residual materials in the event that temporary interim storage of ash containing phosphorus is necessary. The same criteria were used for the assessment of the disposal pathways as were considered separately in the comparison of P-recovery procedures (see above). They were, however, supplemented with the criteria transport cost and CO_2 balance of the process chain. Thus, the three dimensions of the requirements for future sewage sludge planning were covered:

- Quantity dimension: Share of P in the waste water of Canton of Zurich, which can be recycled as fertiliser and/or industrial raw material (in %)
- Ecological dimension: Quantity of energy that can be obtained and/or must be used (in MJ/t DSS) as well as CO_2 balance (g CO_2/t DSS)
- Economic dimension: Costs/yield (in CHF/t DSS)

10.3.2 Summary of the Evaluation: Selection of Procedure

The clarifications by AWEL (AWEL 2008) led to the conclusion that the reference disposal pathway “sewage sludge mono-incineration with (future) P reclamation from the ash” with the prescribed criteria (state of the art, P recovery, energy and CO_2 requirements) best fills the criteria and evinces some additional clear advantages (low additional load on the WWTP, residual materials are compatible with landfilling, proven technology). For P recovery there are basically two variants that came into consideration: (V1a) wet-chemical processing and (V1b) thermochemical processing.

The following alternative disposal pathways were thus no longer given consideration for the implementation of the strategy:

- Wet oxidation in combination with wet-chemical or thermochemical processing out of ISSA (V2a/2b)

  This variant evinced in comparison with sewage sludge mono-incineration a considerable worse energy – and/or CO_2 balance at similar P-recycling rates and comparable costs. It had other disadvantages:

  (i) Added load on the WWTP.
  (ii) Compatibility of residual materials with landfilling in the event that the ash would need to be temporarily stored would not be assured.
  (iii) The technology is not adequately tested for community sewage sludge (disposal safety would be in danger).

- Thermal (co-)processing of sewage sludge in waste-to-energy plants (WtE) or in cement work with upstream P recovery from waste water (Var. 3). This is because it became apparent that P-recovery procedures from waste water plants evince unacceptably low in P-recycling rates.
- Disposal in the WtE plants (or cement works and/or wet oxidation) with P-recovery procedures from sludge (Var. 4). With a modest P-recycling rate, this variant was not economically feasible.

Based on these insights, the decision-makers responsible for sewage sludge disposal in Canton of Zurich reached the following decisions at the end of 2009:

- Mono-incineration of the sewage sludge which has been digested and optimally dewatered at various locations will be put into action as befits the state of the art.
- A single, centralised incineration line realised as fluidised bed combustion at the best location in the Canton in order to meet the required capacity (approx. 100,000 tDSS/a). WtE plants are still available for emergency disposal and/or revisions.

- The Canton will allocate all cantonal sewage sludge to the central plant (investment security).
- More detailed clarifications of P recovery from ISSA will be carried out.

Today (2017), around 10 years later, it can be stated that these insights are in essence still valid. Both the results of the comprehensive support initiative of the German Agency for Education and Research (BMBF) "Recycling Economy for Plant Nutrients, Especially Phosphorus" (Pinnekamp et al. 2011) and the final statement of the European research project P-REX (Kabbe et al. 2015) affirm the selection made in 2009 as expedient.

10.3.3 Selection of Location and Allocation Decision

Detailed investigation was done for a total of five possible locations in the Canton, to determine which would be the best location for a new, centralised sewage sludge mono-incineration plant. The assessment criteria are selected on the same way as for the assessment of the disposal pathways and in comparison with the P-recovery process (see Sects. 10.3.1 and 10.3.2).

The parties responsible for sewage sludge disposal in the Canton today then reached a unanimous decision in June 2010 that the location of the sewage treatment facility Werdhölzli in the middle of the city of Zurich with its approximately 400,000 residents was ecologically and economically the best solution. Decisive for the selection were the optimal possibilities for energy recycling and CO_2 reduction, since the location already has the infrastructure and sufficient potential for energy use. In the transports, the locations on the periphery of the Canton proved to be poor, as expected. The decisive factor there by is the proximity to the main accumulating point for sewage sludge from the city of Zurich itself with approximately a third of the total amount.

The City Council of Zurich then confirmed that it was taking charge of the planning and realisation of the plant. To assure planning security for the future construction and operation of the new centralised sewage sludge treatment plant in Werdhölzli starting in mid-2015, the currently valid cantonal sewage sludge disposal plan will be adapted, and all Zurich sewage sludge will be allocated anew to the central sewage sludge treatment plant for 20 years starting from mid-2015. In a consultation process in the 171 political communities as well as all WWTP joint management authorities, the draft for a new sewage sludge disposal plan met with great affirmation, thanks to a great deal of persuading, and it was approved by the government of Canton of Zurich at the beginning of August 2011 (Cantonal sewage sludge disposal plan 2015, RRB 1035/2011).

Fig. 10.5 New central sewage sludge treatment plant in Werdhölzli (Source: ERZ)

10.3.4 The New Central Sewage Sludge Recycling Plant Werdhölzli

On March 3, 2013, the people of the city of Zurich approved the building credit of around 68 million francs for the construction of the new central sewage sludge recycling plant on the property at Werdhölzli with around 93.9% AYE votes. Two and a half years after this vote, the company Entsorgung + Recycling Zurich (ERZ) as the operator of the plant for the city of Zurich opened the new central SSTP with a capacity of 100,000 tonnes of digested, dewatered sewage sludge (DSS) (Fig. 10.5).

Since August of 2015, around 85,000 tonnes of digested and dewatered sewage sludge (with dry substance of around 30%) per year from the entire Canton have already been recycled as energy. Annually around 13,400 tonnes of high-phosphorus ISSA and an annual average P content of just over 80 g P/kg ISSA accumulate (Fig. 10.6). This yields an approximate annual P quantity from the total quantity of Zurich's sewage sludge of 900 tonnes (or 0.6 kg P/resident per year).

The change of the sewage sludge disposal concept in mid-2015 resulted in the following advantages for the entire Canton:

- By using this proven, highly efficient fluidised bed technology, it is possible to assure a high availability, economical operation as well as security of disposal at all times.
- Compared to the situation before 2015, it results in a significant reduction of the average sewage sludge disposal costs for the communities of more than half, to

Fig. 10.6 ISSA containing phosphorus (Source: AWEL)

around 100 CHF/t DSS (digested, dewatered sewage sludge, with a dry substance of 30%).

- A good, positive energy balance (net heat yield in the form of natural gas for heating around 5000 apartments) could be achieved.
  - A CO_2 reduction of around 14,000 tonnes/year.
  - The Preparation of the way for the future posphorous recovery from ISSA.

With a fair, transparent transport cost compensation model, financed by the City of Zurich, there is also the assurance that differences in the transport expenses of the different suppliers form the entire Canton will be levelled out as much as possible.

10.4 Phosphorus Mining from Incinerator Sewage Sludge Ash

10.4.1 Evaluation of Optimal P-Recovery Process

Since there is as yet no procedure that is able to convert the phosphorus present in the ISSA into market-ready products on a large technical scale according to the objectives of the P-Mining-Project, the Department of Public Works of the Canton of Zurich has sought possible solutions with various partners since 2011, looking for ways to recover phosphorus from ISSA and feed it back into the economic cycle. Initial studies which focused on the production of a raw material for fertiliser showed (AWEL 2012/2013):

1. The use of phosphorus from ISSA is technically possible.
2. None of the procedures for producing fertiliser investigated at the time were suitable for immediate use in the Canton of Zurich.
3. The wet-chemical extraction procedure LEACHPHOS, however, offers an interesting potential for optimisation and will be actively refined.
4. Until a procedure is market-ready, the ISSA shall be stored in a monofill.

Since fall of 2013, the Department of Public Works for the Canton of Zurich together with the Foundation ZAR (Development Center for Sustainable Management of Recyclable Waste and Resources) has been exploring the promising optimisation potential of wet-chemical P recovery from ISSA. The LEACHPHOS process of the Swiss company BSH Umweltservice AG from Sursee has been made available to this end. It was possible to demonstrate its technical feasibility beforehand in a large-scale experiment in Bern. In the ongoing development, two goals were achieved:

- First, an increase in the quality of the extraction residue, so that it can be used as a valuable mineral resource or stored with inert material quality
- Secondly, an increase in the product quality of the phosphorus products obtained as a fertiliser or fertiliser component

These clarifications however also showed that on the one hand the market for raw materials for fertilisers both in Switzerland and in Europe as a whole is only in some degree able to integrate secondary phosphorus products and on the other hand that the creation of value in this process is very limited. Added complications are the high sales risk dependencies of individual consumers. Based on these insights, phosphoric acid production from ISSA was pursued as the most promising pathway starting in mid-2014. This pathway evinces decisive advantages over the direct production of fertiliser and/or fertiliser components:

- Phosphoric acid is a conventional trade product with good demand domestically and abroad.
- Phosphoric acid has a higher added value as a fertiliser or fertiliser component.
- It eliminates the uncertainties inherent in the currently discussed adjustment of the quality requirements for recycled phosphorus products in Switzerland and the EU (Fertiliser Ordinance) as well as time-consuming product registrations (REACH).

A comprehensive evaluation of the different options for phosphoric acid production from ISSA was carried out based on the criteria of phosphorus efficiency, reduction of material to be landfilled, product qualities, sales market, process stability, the providers' know-how, economic efficiency and potential for synergy in the Swiss systems context. The best possible technological implementation of these

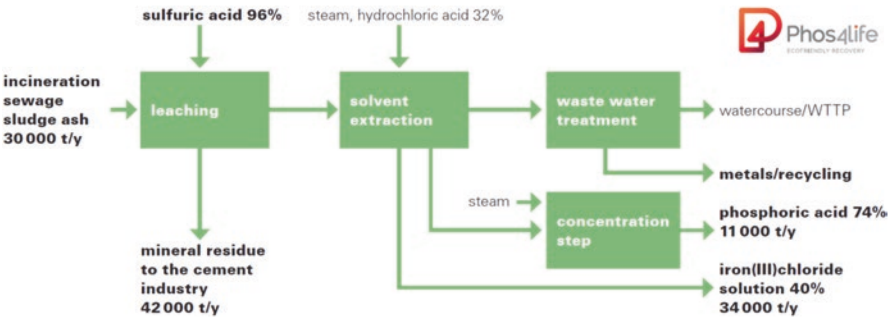

Fig. 10.7 Simplified process diagram of Phos4life® process (Source: TR)

objectives was found in solvent extraction to separate the heavy metals from the target component phosphorus. Since no tested large-scale technical procedure fulfils these criteria, the Spanish plant constructor and technology developer Técnicas Reunidas SA (TR) in Madrid was selected from the potential technology providers and development partners as the most suitable partner for collaboration, and the joint development of procedure was advanced. The goal of this development is a procedure which facilitates efficient phosphorus reclamation with simultaneous material recycling of other resources contained in sewage sludge such as iron precipitates, heavy metals and useable mineral components. The resulting products must be produced at a constant high quality while assuring high plant reliability at the same time.

10.4.2 PHOS4LIFE® Process

The development of a process for the production of technically pure phosphoric acid from ISSA began with a laboratory phase that lasted a year and a half. Once it was successfully concluded, continuous process operations were simulated in the framework of a pilot micro-plant operation, and the procedure was further optimised. In the current continuous pilot project, the insights gathered to date shall be confirmed and consolidated through March 2018.

With the new Phos4life® procedure (Fig. 10.7), it is possible to separate phosphorus and most heavy metals from sewage sludge using sulphuric acid so that the mineral leaching residue meets the highest Swiss quality requirements and material can be recycled for use in cement works. Table 10.1 shows the average annual element content of the starting material sewage sludge ash based on a 1-year sample as well as the resulting leaching residue in Columns II and III. In the first step of purification, the iron contained in the ISSAs that are added for the chemical elimination of phosphorus in the waste water treatment plant was extracted and recovered as saleable iron(III) chloride solution. Subsequently the phosphoric acid is released from the co-extracted heavy metals by means of solvent extraction. In the

Table 10.1 Typical element contents of ISSA, leaching residue and Phos4life® phosphoric acid. The limits for mineral recycling of leaching residue for Swiss cement works are shown supplementally (Source: ZAR, TR)

I	II	III	IV	V	VI
Element	Unit	Contents of ISSA	Contents of leaching residue	Maximum contents for secondary raw materials in Swiss cement clinker manufacturing plants	Phos4life® technical grade acid, 74% H_3PO_4
Al	mg/kg	30,000	3000	–	n.d.
Ca	mg/kg	130,000	190,000	–	<4
Fe	mg/kg	170,000	8000	–	<2
K	mg/kg	4000	2000	–	n.d.
Mg	mg/kg	15,000	400	–	<4
P	mg/kg	81,000	1000	–	234,000
Si	mg/kg	96,000	128,000	–	n.d.
As	mg/kg	15	2	15	<3
Cd	mg/kg	2	3	5	<1
Cl	mg/kg	160	<50	–	n.d.
Co	mg/kg	22	2	–	n.d.
Cr	mg/kg	92	23	250	<1
CrVI	mg/kg	0.05	<0.01	0.05	n.d.
Cu	mg/kg	850	47	250	<3
F	mg/kg	n.d.	n.d.	–	<10
Hg	mg/kg	0.1	<1	1	<1
Mn	mg/kg	1200	n.d.	–	<1
Ni	mg/kg	60	11	250	<1
Pb	mg/kg	90	130	250	<1
S	mg/kg	500	450,000	–	<100

(continued)

Table 10.1 (continued)

I	II	III	IV	V	VI
Element	Unit	Contents of ISSA	Contents of leaching residue	Maximum contents for secondary raw materials in Swiss cement clinker manufacturing plants	Phos4life® technical grade acid, 74% H_3PO_4
Sb	mg/kg	10	2	15	n.d.
Sn	mg/kg	60	9	–	n.d.
Tl	mg/kg	0.4	<1	–	n.d.
Zn	mg/kg	2100	180	500	<5

concentration stage, the conventional concentration of phosphoric acid of 74% H_3PO_4 is reached by vaporising the corresponding amount of water. The quality of the acid produced matches that of technically pure phosphoric acid (Table 10.1, Column V).

With the Phos4life® process, it is possible to fully meet the objectives for phosphorus recovery as well as material recycling of the mineral residue. In the future, it will be possible to recover phosphorus from ISSA with more than 95% yield and market it as a technically pure, conventional product. Iron can be recovered with a yield of >90% and used again in the waste water treatment plant for chemical phosphorus elimination. The separated heavy metals (>85%) are processed using techniques already existant in Switzerland and fed back into the materials stream. The near one hundred per cent recycling of ISSA reduces the landfill volume considerably and offers other impressive ecological advantages. With the thermal sewage sludge treatment and Phos4Life® process as central elements for sustainable phosphorus-mining strategy, it is possible, as shown in Fig. 10.8, to close important material circuits and conserve resources.

10.4.3 The Ecology of Phosphorus Mining

Worldwide phosphoric acid is primarily manufactured from raw phosphates (ores) by treating them with sulphuric acid. This raw phosphoric acid is mainly used in the manufacture of fertilisers. A part of it is refined to higher quality (technical quality TGA, food-grade quality FGA, etc.), in that harmful substances such as heavy metals, fluoride and organic materials are separated out. Today, the technology mainly used for this refining is solvent extraction, as a solvent-based liquid-liquid separating procedure.

Since the quality sources of raw phosphate that are laden with few harmful materials –especially heavy metals – are running out, the environmental pollution from

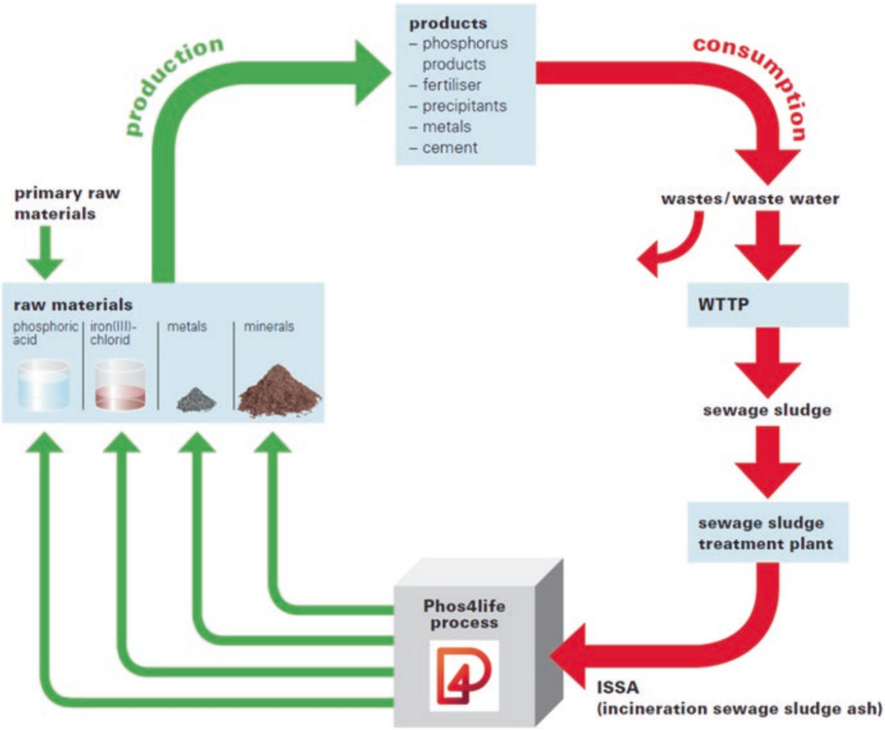

Fig. 10.8 The material cycle is closed – from ISSA to new raw material products (Source: AWEL)

fertilisers used around the world can constantly increase absent any new measures. The therewith associated increasing pollution of the soil with harmful materials coming from mineral fertiliser with excessive heavy metal content is not sustainable (see Sect. 10.2.1). The reasons for this lie on the one hand in the absence of a readiness to finance a phosphorus product that is low in harmful substances and on the other hand in the tolerance for exceeding the limits on such substances in mineral fertilisers. This practice is tolerated with the statement that the market does not offer any better products. The supply is controlled however by the demand, and so this development must be stopped by the strict compliance with established limits.

Compared to that the Phos4life® process and the phosphoric acid produced from it evince a significantly lower degree of environmental pollution. Important resources can thus be conserved more efficiently and replaced with less environmentally dangerous recyclates. Compared to the primary products, the recyclates are lower in cadmium and uranium content. By producing additional iron compounds, recycling the gypsum present in the residues in cement work and reclaiming the metals, additional environmental advantages are achieved which make a considerably lower degree of environmental pollution possible compared to the current-day practice of landfilling the ISSA. From the original waste product ISSA, high-value products are created which close the resource cycle and save valuable landfill space.

The Phos4life® process, as a sustainable and ecological process, shows a way for phosphorus to be fed back into the economic cycle free of heavy metals. Used correctly, this can also be an opportunity for our soil. As already explained in Sect. 10.2.1, in 2012 nearly half of the phosphorus fertilisers used in Switzerland exceed the permitted cadmium limit of 22 mg Cd/kg P_2O_5 in some cases considerably. Nearly 5% of the fertilisers tested in 2011–2012 showed cadmium content between 65 and 100 mg/kg P_2O_5. In another 41%, the cadmium content was in the range from 22 to 65 mg/kg P_2O_5 (BLW 2015). A telling example is the link between the cadmium content in the raw materials used to make the fertiliser based on the triple super phosphate (TSP) from phosphate rock and phosphoric acid, shown in Fig. 10.9. In the current starting scenario, typical cadmium contents of raw phosphate of approximately 100 mg/kg P_2O_5 (Kratz and Schnug 2005; Kharikov and Smetana 2000; Van Kauwenbergh 1997) and 50 mg/kg P_2O_5 (Gilmour 2013) in phosphoric acid used for fertiliser production are assumed as examples.

This results in a phosphorus fertiliser with a cadmium content of >50 mg/kg P_2O_5. With these raw materials, the objectives for fertiliser quality cannot be achieved without further technical process optimisation. This scenario thus covers approximately 11% of the fertilisers used in Switzerland. To qualitatively improve this situation, either higher-quality starting materials can be used, which in a global context however are becoming ever scarcer, or processes for separating heavy metals can be integrated into fertiliser manufacture, which will increase the cost of the products. In the second scenario, fertiliser manufacturing proceeds from the same raw phosphate with a high-quality phosphoric acid low in heavy metals, as can, for example, be obtained from ISSA using the Phos4life® procedure (see Table 10.1).

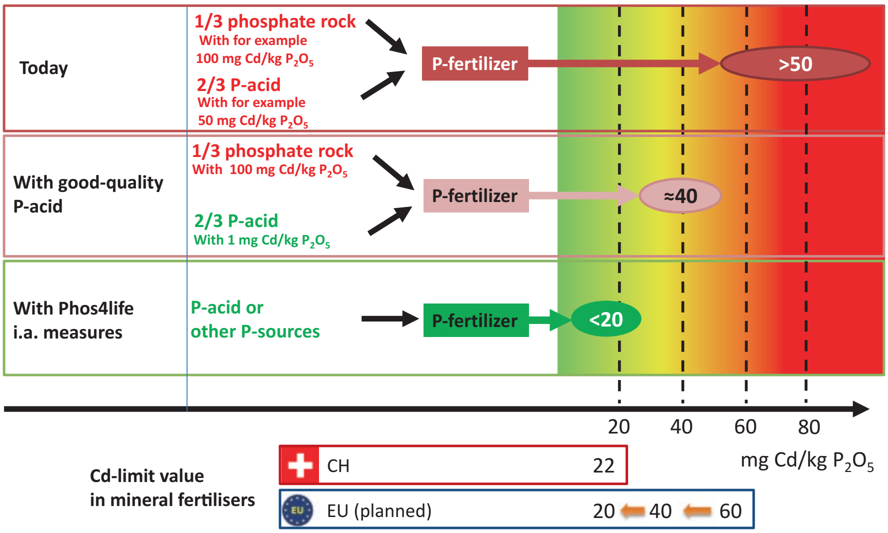

Fig. 10.9 Cadmium limits in mineral fertiliser depending on the quality of the starting materials, assessed on the currently valid Swiss limits and the planned future European limit with gradual tightening of the limit from 60 to 20 mg Cd per kg P_2O_5 within 15 years

The resulting fertiliser still evinces a cadmium content of approximately 35 mg/kg P_2O_5, which is slightly above the permitted limit. With reference to the fertilisers examined in Switzerland, this corresponds to a share of 34%, which evinced a cadmium content between 22 and 50 mg/kg P_2O_5. Only in the third scenario, in which, along with a pure phosphoric acid, phosphate rock low in heavy metals or alternative phosphorus sources are used, can the legally prescribed limit be observed. This corresponds to 55% of the Swiss mineral fertilisers tested. With a cadmium content in phosphoric acid of 1 mg/kg P_2O_5, the phosphate rock or alternative phosphorus source used may contain at most 60 mg Cd/kg P_2O_5 and still comply with the Swiss limit. Should the acid used likewise contain more cadmium, the phosphate rocks would have to be commensurately lower in cadmium. This applies analogously for the planned tightening of the limits in the EU, which aims at a reduction in the cadmium content from 60 to <20 mg/kg P_2O_5 within 15 years. This ecological achievement however also has its price, through the increased time and effort required for the procedure.

10.4.4 Costs

Completely financing the costs with revenue from the product's earnings from the Phos4life® procedure is currently not possible with the planned plant size of 15,000–30,000 t ISSA/a in Switzerland. The added expense of phosphorus mining cannot, under the strict environmental regulations in force in Switzerland, be compensated solely through product revenues. These also take into consideration the accumulated landfilling costs for ISSA. To implement a phosphorus recovery plant with approximately twice the capacity of the ISSA accumulating in the Canton of Zurich, one must reckon with added costs compared to the sewage sludge treatment of around 70 CHF/t DSS (Fig. 10.10). The total cost estimate for sewage sludge treatment (SST) and phosphorus recovery would then be at around 170 CHF/t DSS still lower than the average sewage sludge disposal costs for the Canton of Zurich before the operation of the central SSTP which were at around 210 CHF/t DSS.

If one were also to include the sewage sludge treatment steps digestion, dehydration and transport (see Fig. 10.11) so far not taken into account in the cost for the sewage sludge treatment, then the calculated additional costs of phosphorus mining would lie at around 20% compared to sewage sludge disposal as currently practised.

10.5 Conclusion and Look Ahead

In the Canton of Zurich, it was possible, together with the parties responsible for sewage sludge disposal, to make courageous and perspicacious decisions that completely realigned the existing sewage sludge disposal concept with a new strategy

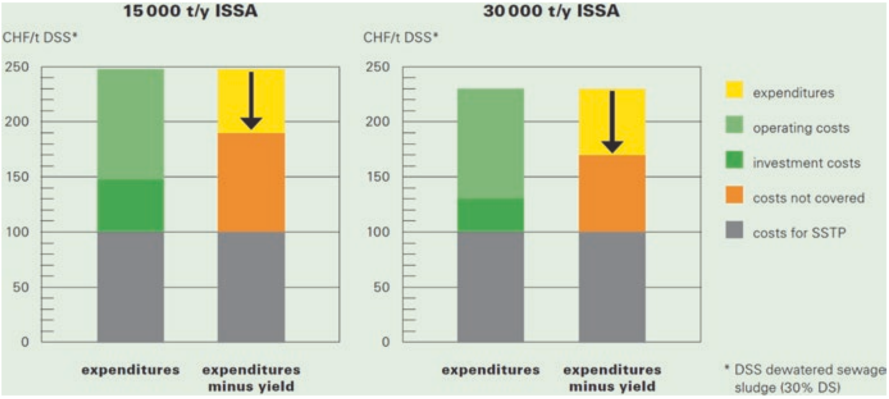

Fig. 10.10 Costs for sewage sludge treatment plant (SSTP), for the Phos4life® process and for the total phosphorus mining from sewage sludge in CHF per tonne of dewatered sewage sludge (DSS, 30% dry substance content). Two scenarios are shown with 15,000 and 30,000 t/a ISSA (Source: ZAR, AWEL)

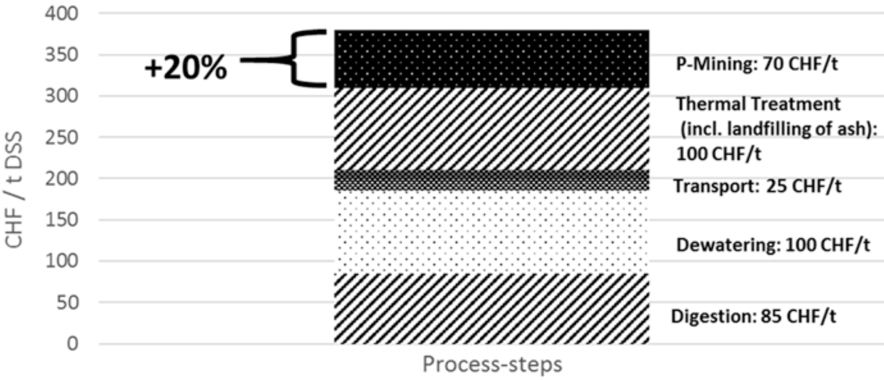

Fig. 10.11 Added costs for phosphorus mining from ISSA compared with the sum of today's total costs for sewage sludge disposal in the Canton of Zurich split into the individual process steps; thermal treatment includes the costs of landfilling the ash (Source: AWEL)

for phosphorus reclamation in fewer than 6 years. With that the Canton of Zurich continued to consistently apply the precautionary principle with respect to sewage sludge disposal as before. The high standards for surface water protection and air quality remain intact. Disposal safety is assured at all times, and the disposal costs for sewage sludge can be cut by more than half, thanks to the new central treatment plant. No structural or operational changes to the WWTP were necessary.

Around 90% of the total phosphorus potential in untreated waste water now stands ready for use in the ISSA that is produced. With the strategy now followed, which has as its goal production of phosphoric acid with the reclamation of other valuable substances, the urban mining concept defined by the plan of action for waste and resource management of the Canton of Zurich is consistently implemented.

The following next steps for the implementation of the strategy are already running or are being prepared:

- Pilot plant for the Phos4life® process (plan to be concluded by March 2018)
- Confirmation of the product qualities in the running pilot project
- More precise information about the costs for phosphorus mining once the pilot project is concluded
- Contacts with possible partners for a larger phosphorus recovery plant
- Final evaluation of the process selection once the pilot project is concluded (compare with any alternatives to P-recovery procedures from ISSA available on the market at the start of 2018)
- Evaluation of solutions for financing

References

AWEL (2008) Phosphor in Klärschlamm– Informationen zur künftigen Rückgewinnung (Phosphorus in sewage sludge – information about the future P-recycling), Baudirektion Kanton Zürich (Department of Public Works Canton Zurich), AWEL Amt für Abfall, Wasser, Energie und Luft. www.klaerschlamm.zh.ch

AWEL (2009) Synthesebericht für interessierte Fachpersonen – Zürcher Klärschlammentsorgung unter besonderer Berücksichtigung der Ressourcenaspekte (Sythesis report for interested qualified persons –sewage sludge disposal of Canton of Zurich under special consideration of resource aspects), Baudirektion Kanton Zürich (Department of Public Works Canton Zurich), AWEL Amt für Abfall, Wasser, Energie und Luft. www.klaerschlamm.zh.ch

AWEL (2010) Massnahmenplan zur Abfall- and Ressourcenwirtschaft 2011–2014, Urban Mining – Rohstoffe der Zukunft (Waste and resource management action plan 2011 to 2014, urban mining – future resources), Department of Pub-lic Works Canton Zurich. www.abfall.zh.ch

AWEL (2012/2013) Phospor- Mining im Kanton Zürich (phosphorus-mining in Canton Zurich), Projektblätter Nr.1–3. http://www.awel.zh.ch/internet/baudirektion/awel/de/abfall_rohstoffe_altlasten/rohstoffe/rohstoffe_aus_abfaellen/naehrstoffe.html#a-content

BAFU (2006) Nachhaltige Rohstoffnutzung and Abfallentsorgung, Grundlagen für die Gestaltung der zukünftigen Politik des Bundes. (Sustainable resource utilisation and waste disposal, fundamentals for the design of future national politics), Bundesamt für Umwelt, Bern (Swiss environmental protection agency, Bern)

BLW (2015) Marktkampagne Dünger 2011/2012, Kennzeichnung und Schwermetalle (Swiss fertilizer market campagne 2011/2011, identification and heavy metals)

FitzGerald R, Roth N (2015) Cadmium in mineral fertilisers – human and envi-ronmental risk update, SCAHT report for BLW

Gilmour R (2013) Phosphoric acid: purification, uses, technology and economics. CRC Press/Taylor&Francis Group, Boca Raton

Kabbe Ch et al. (2015) Phosphorus recycling – now! Building on full-scale prac-tical experiences to tap the potential in European municipal wastewater. www.p-rex.eu

Kharikov AM, Smetana VV (2000) Heavy metals and radioactivity in phos-phate fertilisers: short term detrimental effects. In: IFA Technical Conference, New Orleans, Louisiana

Kratz, S.; Schnug E. (2005) Schwermetalle in P-Dünger (Heavy metals in P-firtiliser) n. Landbauforschung Völkenrode 286 (Special Issue):37–45

Montag D (2008) Phosphorreklamation bei der Abwasserreinigung – Entwick-lung eines Verfahrens zur Integration in kommunalen Kläranlagen (Phosphorus recovery in waste water treatment –Development of a process to integrate in municipal WTTP). Dissertation ISA, Aachen, RWTH

Pinnekamp, J. et al. (2011) Resümee and Schlussfolgerungen aus den Gesamtergebnissen der Vorhaben der Förderinitiative „Kreislaufwirtschaft für Pflanzennährstoffe, insbesondere Phosporous („Phosporous-Recycling“) im Rahmen der Schlusspräsentation der in der BMBF-Förderinitiative geförderten Vorhaben (Conclusions out of the total results oft he project «circular economy of plant nutrigents, especially phosphorous («phosphorous-recycling»), conference with presentation), 14. September 2011, Umweltforum Auferstehungskirche Berlin

SRU (2005) Auf dem Weg zur Europäischen Ressourcenstrategie: Orientierung durch ein Konzept für eine stoffbezogene Umweltpolitik – Stellungnahme (On the way to a European resource strategy: orientation with a concept for a substance based environmental policy), November 2005, Nr. 9, Sachverständigenrat für Umweltfragen, Berlin

Van Kauwenbergh SJ (1997) Cadmium and other minor elements in world resources of phosphate rock, Proceedings of the Fertilizer Society No. 400, London