Phosphorus recycling from the waste sector

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An efficient use of phosphorus (P) is necessary as phosphate rock is a finite resource and P is essential for crop production. From the waste sector in the Netherlands, 23 Mkg P is sequestered in landfill, incineration ashes and cement. Flows containing P are discussed, together with options to recover P and reduce P losses, and the interactions between these options.

Keywords: phosphorus, waste water, compost, sludge, recycling

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Preface

This study was financed by the Dutch Ministry of Economic Affairs and is one of the projects on the Dutch phosphorus balance that have been carried out since 2005. One of the major results is the phosphorus flow model for the Netherlands that was used to describe phosphorus flows in 2005, 2008 and 2011. The results are described in a scientific paper:

> Smit, A.L., Van Middelkoop, J.C., Van Dijk, W., Van Reuler, H., 2015. A substance flow analysis of phosphorus in the food production, processing and consumption system of the Netherlands. Nutr Cycl Agroecosyst 103: 1-13.

More information and linkages to publications can be found at http://www.wageningenur.nl/nl/project/Mogelijkheden-evenwichtiger-fosfaatbalans-Nederland.htm

The present report describes phosphorus recycling from the waste sector, where phosphorus occurs in various materials and a variety of recovery options exist. An overview of recovery options is given, together with explorations of alternatives and interactions between recovery options. Interactions are sometimes very complex, and alternative recovery options can require system changes. Therefore, a full quantitative analysis of the effects of different options could not be made within the scope of this project, but estimates are given.

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Summary

An efficient use of phosphorus (P) is necessary as phosphate rock is a finite resource and P is essential for crop production. In the Netherlands there is a large surplus on the national P balance. In 2011, the national P surplus was 42 Mkg of P of which 12 Mkg accumulated in agricultural soil, almost 7 Mkg emitted to the environment and 23 Mkg sequestered in landfill, incineration ashes and cement. This report describes P losses from wastes from non-agricultural sectors, such as households, and the food industry, and options to reduce these P losses.
Losses occur via waste water and solid waste. Communal wastewater treatment plants (WWTP) process a major flow of P: 12.1 Mkg P from households (F9) and 1 Mkg from industry (F8). To surface waters, 2.4 Mkg P was lost by discharge of effluents, and 10.8 Mkg P was lost after incineration of sewage sludge. P losses in solid waste from industry mainly are in meat and bone meal that is incinerated by the cement industry and a power plant. P losses in solid waste from households and retail are from kitchen waste that is mixed with solid waste and incinerated.

For different flow types that lead to P losses, options are discussed to recover P and reduce or prevent P losses:

- Waste water from households/retail:
  - Source separation of toilet waste
- WWTP sludge:
  - Extraction of P as struvite
  - P recovery from dried sludge
  - P recovery from ash of mono-incinerated sludge
  - Agricultural application of sludge
- WWTP effluent discharge to surface water:
  - Reduced water flow
  - Reduced discharge concentrations of P below 1-2 mg P/l
  - Aquatic biomass production (e.g. algae bioreactor)
- Solid organic waste – industrial:
  - Fertilizer from meat and bone meal
- Solid organic waste – household & retail:
  - Reduce food waste
  - Increased source separation of organic household waste for composting
  - Kitchen waste to WWTP by using food waste grinders
- Runoff and leaching from agricultural soils:
  - Agricultural practices, mainly to prevent runoff

Perspectives for P recovery are highest from wastewater treatment, both because of the size of the flow and recoverability of P. Meat and bone meal also have good perspectives for P recovery because of the high P content, but it requires mono-incineration instead of use as co-fuel which implies a change of industry involved. Perspective for additional P recovery from kitchen waste is relatively small because of the limited flow size and of the required effort to implement increased source separation within society.
Within the wastewater sector, P can partly be recovered at WWTPs as struvite, but a more substantial recovery is expected by P industry that uses ash from mono-incineration of sludge. A large scale application of use of sludge ash is planned, which would mean that from 2018 more than half of the P in Dutch sewage sludge is being recovered. A further increase of P recovery from sewage sludge ash would require more mono-incineration of sludge. As a high P content of the ash is preferred, this would limit recovery as struvite. Mono-incineration of biologically dried sludge would also increase the amount of ash suitable for P recovery. This cannot directly be implemented within the current infrastructure as it requires other ovens than those currently used.
Optimization of P recovery requires weighing of several aspects of which technical options and perspectives are discussed in this report.

1 Introduction

An efficient use of phosphorus (P) is necessary as phosphate rock is a finite resource and P is essential for crop production. In the Netherlands there is a large surplus on the national P balance. In 2011, the national P surplus was 42 Mkg of P of which 12 Mkg accumulated in agricultural soil, almost 7 Mkg emitted to the environment and 23 Mkg sequestered in landfill, incineration ashes and cement (Smit *et al.*, 2015).

To improve P efficiency in the Netherlands, the so-called Phosphate Chain Agreement (see www.nutrientplatform.org) was signed in 2011 by various parties including farmers' organisations, industry, the waste sector, knowledge institutes and government. These parties expressed their ambition to create a sustainable market for recovered P. The agreement was an initiative of the Dutch Nutrient Platform that was founded in response to the P issue.

As mentioned before the highest P inefficiencies occur in the waste and agricultural sector. With regard to the latter the accumulation on agricultural soils decreased from 31 Mkg P in 2005 to 12 Mkg P in 2011 mainly due to a reduction of the maximum allowed P fertilisation level on agricultural soils. Between 2011 and 2015 these levels have been further decreased, however, the results of scenario studies showed that soil accumulation is still occurring at these fertilisation levels (De Buck *et al.*, 2012). Options to further improve the P efficiency in the agricultural sector are a reduced P input in feeds combined with a balance P fertilisation level on agricultural land (P fertilisation = P removal with harvested products) and export of manure P.

While in the agricultural sector the P efficiency was improved due to manure legislation, the P inefficiency in the waste sector is still high. The present report describes P losses from wastes from non-agricultural sectors, such as households, and the food industry, and options to reduce these P losses. An inventory of achievements since 2011 is made, as well as an exploration of the potential of options for further recovery of P. This exploration focuses on the most promising recycling options based on flow size and sustainability criteria such as energy requirements and cost efficiency. Interactions between different options are identified.

2 Losses of P in the Netherlands

2.1 P flows in the waste sector

P flows of the Netherlands have been described by Smit *et al.* (2010, 2015) for the years 2005, 2008 and 2011. A major part of the P inflow to industry flows back to the society in food and feed, and waste flows are about 6 percent of the total P inflow to industry; for households & retail, the entire P flow enters the waste sector (Smit *et al.*, 2015).

Figure 1 shows the P flows within the waste sector, and those leading to losses of P in 2011. Only a small part of the total P input in the waste sector, 4 Mkg P (12% of total input) is reused. The major part, 23 Mkg P (77%), is sequestered in landfill, incineration ashes and cement while 3.3 Mkg P (11%) is discharged to surface water. No significant trends in P flows within the waste sector were observed in the period 2005-2011.
Since 2011, the year in which the Phosphate Chain Agreement was signed and the Dutch Nutrient Platform was established, various activities have been initiated to recover P. An inventory is given in chapter 2.2.

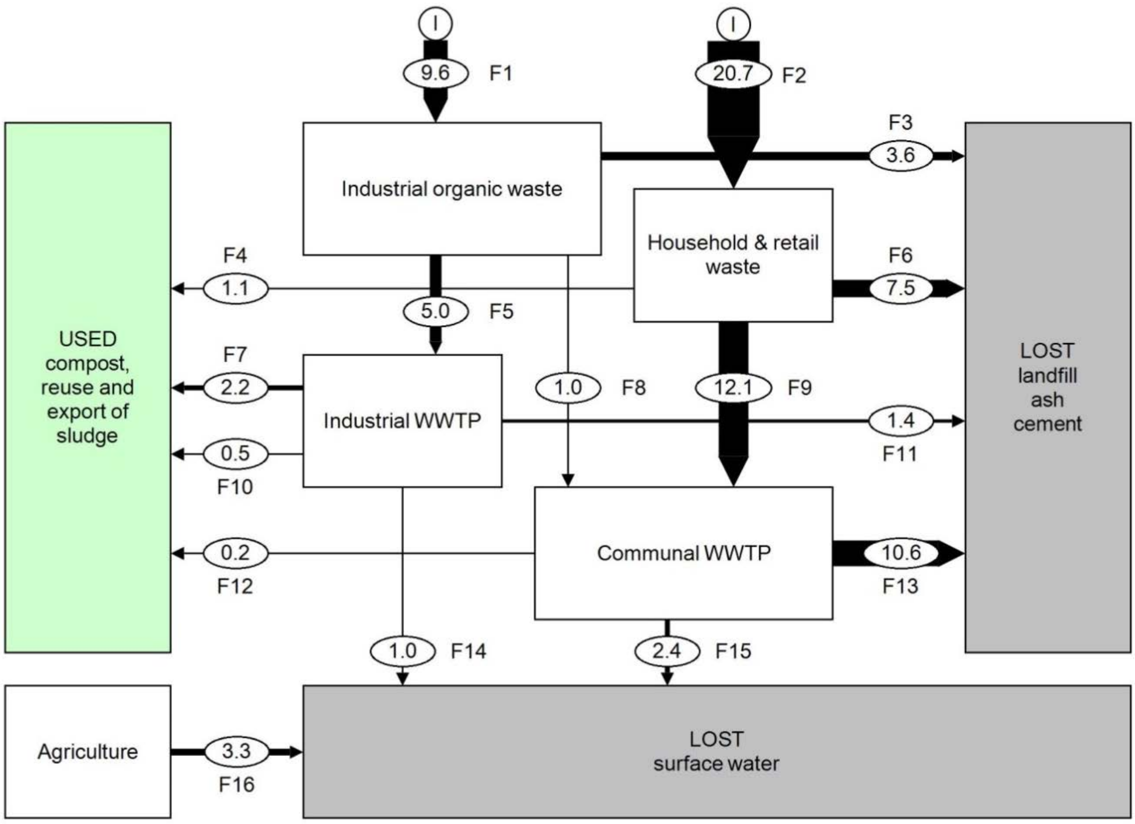

Figure 1 *Flows of phosphorus (Mkg P/year) related to losses in 2011 in the Netherlands (data from Smit et al., 2015; F12 and F13 adapted based on SNB).*

This chapter focuses on the P flows in waste from industry and household & retail, and especially the P flows that are being lost. Losses occur via waste water and solid waste.

2.1.1 Waste water

The waste waters are treated in industrial or communal waste water treatment plants (WWTPs) resulting in a sludge and an effluent. Over 80% of the total P inflow into WWTP's is found back in the sludge.
As the industry is very divers, this results in differences in sludge quality and differences in opportunities for recovery and reuse of P. Of the total P flow into industrial WWTP, in 2011 about 10 percent is reused in agriculture (F10 in Figure 1); this is mainly P in sludge originating from the food industry (CBS, 2015a). Sludge from other industries is often not suitable for use on agricultural land and are incinerated or landfilled.
The destination of sludge of industrial waste water treatment is registered by CBS (2015a) in several categories (incineration, landfill, composting, feed and agriculture), but more than half of the sludge is in the category 'other destinations', including use as inoculum sludge, anaerobic digestion and unknown. Smit *et al.* (2015) assumed 'other destinations' to be exported, but this is uncertain, as well as the destination of the P in this sludge (2.2 Mkg; F7 in Figure 1).

Communal WWTPs process a major flow of P: 12.1 Mkg P from households (F9) and 1 Mkg from industry (F8). To surface waters, 2.4 Mkg P was lost by discharge of effluents, and 10.8 Mkg P was lost after incineration of sewage sludge. The major part of P in waste water is still lost for use in agriculture or other purposes, but initiatives for recovery of P from waste water increase rapidly.

2.1.2 Solid waste

Smit *et al.* (2015) showed one major flow of P in solid waste (F3 in Figure 1) consisting of dead animals and high risk animal by-products from the food industry (category 1 and 2) that are treated by Rendac. The treatment produces meat and bone meal, blood meal, feather meal, and animal fat. P is primarily present in meat and bone meal which is incinerated by the cement industry (ENCI) and a power plant (E.ON). Incineration of high risk animal by-products is a legal requirement to prevent human and animal health risks (EC, 2009). When meat and bone meal is incinerated by cement industry, the P is fixed in cement and lost for agricultural use. When meat and bone meals is co-incinerated in a power plant, P is also lost for agricultural use as the remaining ashes have too low nutrient concentrations for direct use as fertilizer or as input for the fertilizer industry.

P in solid waste flows from households and retail is in vegetable, fruit and garden waste (VFG), for composting and reuse in agriculture (F4), and in mixed solid waste that is ultimately incinerated (F6). In 2011, total P inflow in household waste was estimated at 20.7 Mkg P from which 12.1 Mkg was present in waste water treated in communal WWTP, 1.1 Mkg P was reused as compost and 7.5 Mkg P was present in mixed solid waste and lost through incineration (Smit *et al.*, 2015). The figure of 7.5 Mkg P lost through incineration has some uncertainties as this P flow from households/retail is calculated as a remaining flow from P input to households/retail, P to WWTP and P to compost, thus accumulating inaccuracies in all the other flows. Part of this flow of P to lost is the kitchen waste that is not collected separately and incinerated. The amount of kitchen waste P in mixed solid waste from households is estimated[1] at 1.3 Mkg P.

[1] Calculation based on one third organic waste in solid household waste, a total amount of household waste of almost 4000 kton, a dry matter content of almost 50% and 0.2% P in dry matter.

2.2 P recovery from waste by Nutrient Platform members

In 2011, the Dutch Nutrient Platform was established, after signing of the Phosphate Chain Agreement by various stakeholders. Table 1 presents examples of P flows and P recovery in 2014 by some members of the Nutrient Platform. Some recycling flows in Table 1 occur already for quite some time, for example VGF compost from Attero and P in Betacal and animal feed from Royal Cosun. Traditionally, P recycling also occurs at Avebe through animal feed and the fertilizer product Protamylasse (concentrated potato juice), and at Darling Ingredients where part of the P in processed slaughter waste is recycled. This traditional P recycling was already acknowledged by Smit *et al.* (2015).

Sewage sludge ash is the largest P flow in Table 1, and P recovery from sewage sludge ash was relatively low in 2014. Supply of sewage sludge ash by SNB to Thermphos and/or ICL has varied over the years with a peak value of 978 ton P in 2012 (Table 2).

Table 1

Examples of P flows and P recovery from waste streams in 2014 (ton P/year) by some members of the Nutrient Platform.

Company	Flow type	P-content (ton/year)	Recycled P (ton/year)	Product type	Remark
Attero	VGF waste	495	495	VGF compost	Already included in Fig. 1
Evides	Waste water	?	0	-	Small scale tests only
GMB	Urine	0.46	0.36	Struvite	
HVC	Sewage sludge	2551	0	Ash	Future plans with EcoPhos
SNB	Sewage sludge	3086	31	Ash	Future plans with EcoPhos
Royal Cosun	Process Sensus	150	20	Pulp (animal feed)	12 to WWTP, 118 to soil storage
	Process Suikerunie	2100	2081	Betacal, animal feed, Betafert	4 in effluent, 14 to soil
Water boards	Communal waste water	13356[a]	223	Struvite	

[a] Influent data 2013 (CBS, 2015)

Table 2

Supply of P in sewage sludge ash by SNB to Thermphos and ICL (source: SNB).

Year	P in ash	Supply for recovery (ton P)			P recovery
	(ton)	Thermphos	ICL	Total	(%)
2003	*[a]	13	-[b]	13	*
2004	3092	27	-	27	1
2005	2987	-	-	-	-
2006	3069	83	-	83	3
2007	2968	106	-	106	4
2008	3023	239	-	239	8
2009	3190	229	-	229	7
2010	3353	69	-	69	2
2011	3252	176	-	176	5
2012	3032	879	99	978	32
2013	3126	-	83	83	3
2014	3086	-	31	31	1

[a] No data; [b] - equals zero

There are members of the Nutrient Platform that recycle P already for quite some time. In 2014, some recovery was similar to that in 2011, e.g. VGF compost, but other flows have increased since then, e.g. struvite recovery from waste water and urine. The recovery of 0.176 Mkg P from sewage sludge ash in 2011 was not included by Smit *et al.* (2015).
In the near future, struvite recovery at WWTP will increase further, and a major increase is to be expected by recovery of P from sewage sludge ash. Early 2015, SNB and HVC have signed an agreement with EcoPhos for recovery of P from all sewage sludge ash they produce in their mono-incinerators. SNB and HVC incinerate over 50% of the sewage sludge in the Netherlands, and recovery of P from this flow would be 25% of the total P estimated to be lost for agricultural use (Smit *et al.*, 2015). For realization of this recovery by EcoPhos, a production plant has to be constructed first. Currently there are plans for construction at a location near Dunkirk, France.

3 Options for P recovery

There are different options available to reduce or prevent losses of P by the different flows as indicated in Figure 1. Table 3 gives per type of flow different options to reduce P losses or to recover P. These options are discussed in the following subchapters.

Table 3
Potential options per flow of Figure 1 to reduce the amount of P to LOST and/or to increase the amount of P recovered.

Nr	Flow type	Flow size 2011 (Mkg P)	Methods to reduce P losses or to recover P	chapter
Waste water				
F9	Waste water from households/retail	12.1	Source separation of toilet waste	3.1.4
F11+F13	WWTP sludge	1.4+10.8	Extraction of P as struvite	3.1.1
			P recovery from dried sludge and from ash of mono-incinerated sludge	3.1.2
			Agricultural application of sludge	3.1.2
F14+15	WWTP effluent discharge to surface water	1.0+2.4	Reduced water flow	3.1.3
			Reduced discharge concentrations of P below 1-2 mg P/l	3.1.3
			Aquatic biomass production (e.g. algae bioreactor)	3.1.3
Solid waste flows				
F3	Solid organic waste - industrial	3.6	Fertilizer from meat and bone meal	3.2.1
F6	Solid organic waste – household & retail	7.5	Reduce food waste	3.2.2.1
			Increased source separation of organic household waste for composting	3.2.2.2
			Kitchen waste to WWTP by using food waste grinders	3.2.2.3
Other flows				
F16	Runoff and leaching from agricultural soils	3.3	Agricultural practices, mainly to prevent runoff	3.3

3.1 Waste water

The waste waters are treated in industrial or communal WWTP’s in a number of steps (Figure 2). After removal of course materials, the influent goes to a primary settler to separate fine particles. The next step is biological purification to extract dissolved P using micro-organisms (bio-P). The effluent from the primary settler is mixed with activated sludge from the secondary settler. An anaerobic tank followed by aerobic conditions stimulates phosphate accumulating organisms to absorb high amounts of P. After settling, the sludge is partly returned for mixing with new influent, and the remaining part can be dewatered, either directly or after anaerobic digestion to produce biogas. The dewatered sludge can be transported for further treatment elsewhere. In addition to P fixation by micro-organisms, or instead of, P can be extracted from wastewater by precipitation with Fe or Al. Nitrogen is removed from wastewater by alternating aerobic and anaerobic conditions, where bacteria first transform ammonia into nitrate, and then nitrate into nitrogen gas.
About 84% of the total P inflow of communal WWTPs is found back in the sludge, the remaining P being discharged with effluent to surface waters. The P removal efficiency of communal WWTPs has gradually increased over time and stabilized at this level of 84% in recent years (CBS, 2015b).

P recovery from WWTP has been described extensively in two reports of STOWA, the Foundation for Applied Water Research (STOWA, 2011-24; STOWA, 2013-32). P can be recovered from different flows (Figure 2):

- At the WWTP:
  - from digested sludge;
  - from sludge liquor (rejection water);
- Outside the WWTP, from the dewatered sludge:
  - by agricultural application of sludge;
  - by agricultural application of ash after mono-incineration of sludge;
  - by recovery of P at a central location from ash after mono-incineration of sludge.

Next to these recovery options, reducing the P load in effluent can reduce losses of P to surface waters and increase the possibilities for P recovery as a larger fraction of the P is in sludge. Reducing the P load in effluent may be achieved by reducing the total water flow and/or decreasing the P concentration in the effluent.

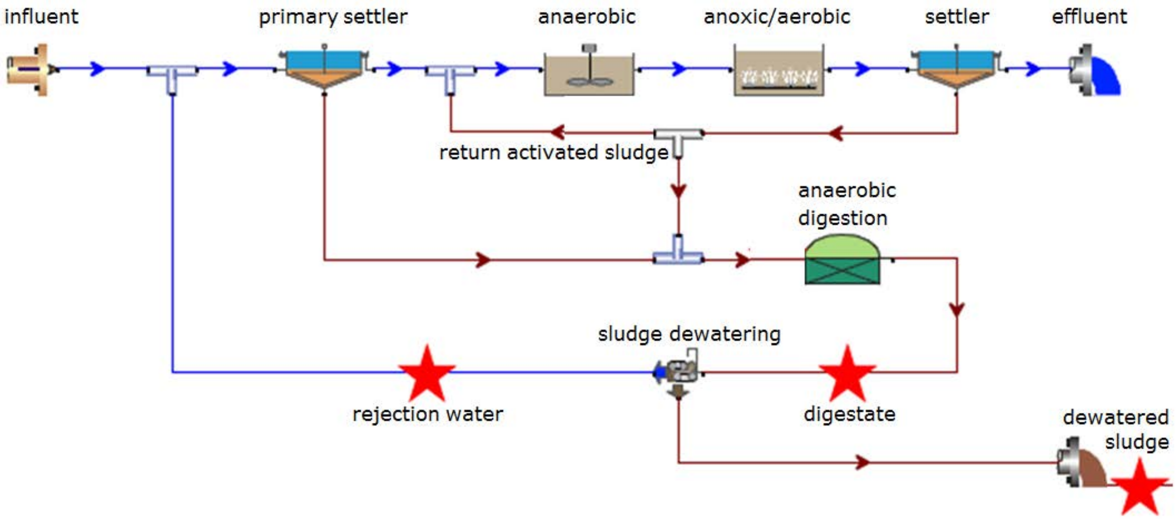

Figure 2 *Schematic overview of a WWTP. The anaerobic digestion is not always included. Asterisks indicate flows where P can be recovered (adapted from: STOWA, 2011-24; STOWA, 2013-32).*

In the following paragraphs, options for P recovery and for reduction of P losses will be discussed under the headings:

- P recovery at the WWTP by struvite precipitation
- P recovery from sludge
  - Agricultural application
  - P recovery from dried sludge and ash
- Reduced P discharge in effluents from WWTP
  - Reduced discharge water flow
  - Reduced amount of discharge water
- Reduced P input to WWTP

3.1.1 P recovery at the WWTP by struvite precipitation

Recovery of P at the WWTP is best when enhanced biological P removal (EBPR or Bio-P) is applied, compared to precipitation with chemicals. The Bio-P process is based on an anaerobic and aerobic phase and extraction of P from waste water by phosphate accumulating organisms (STOWA, 2001-15; STOWA, 2002). The combination of Bio-P with anaerobic digestion of the sludge gives the best opportunities for P recovery at the WWTP by struvite precipitation.

P can be recovered at the WWTP from digested sludge and from the process water after dewatering the sludge (the asterisks in Figure 2). P is recovered in the form of struvite (magnesium-ammonium-phosphate), and recovery efficiencies differ between the different flows and technologies. Two studies by STOWA (STOWA 2011-24; STOWA 2013-32) give a good overview of technologies and efficiencies. Efficiencies of P recovery as struvite vary between 30-40% of the total P flow in the WWTP. The highest recovery is reported for the Pearl system in combination with WASSTRIP: up to 40-50% (STOWA, 2011-24). Remy and Jossa (2015) gives efficiencies for P recovery as struvite ranging from 5% to 50%, where the highest efficiencies are achieved by mobilization of P from the solid phase into the liquid phase by acidic leaching.

The major advantage of P recovery at the WWTP is reduction of maintenance costs and treatment costs. Extraction of P prevents clogging by struvite precipitation in pipes and pumps. It also saves on treatment costs as the return flow of P within the WWTP is reduced because of lower P concentrations in rejection water. Moreover, the volume of sludge that has to be disposed of is reduced, both by extraction of material as struvite and by a reduced water content because of better dewaterability (Kleemann, 2015; Schitkowsky, 2015).

Struvite can be used in agriculture as fertilizer product when it complies with regulations on waste products and fertilizers, and when particle size and homogeneity are sufficient for a good spreadability (see also chapter 4.4). Otherwise, the struvite is a semi-finished product that can be used as input for the fertilizer industry.

3.1.2 P recovery from sludge

Agricultural application
Recovery of P by agricultural application of sewage sludge or ash from sludge does not occur in the Netherlands as heavy metal contents exceed maximum values for fertilizers, and mixing of sludge with other products is not allowed (Ministry of Economic Affairs, 2014). Agricultural application of communal sewage sludge or ash in other countries is possible, based on other regulations. E.g. in France, producing compost from a mix of sewage sludge and other organic products is possible.
From industrial WWTP, a small amount of sludge is used as fertilizer and/or to protect the soil against erosion by wind. Of the total P flow into industrial WWTP, in 2011 about 10 percent is reused in agriculture (F10 in Figure 1).

P recovery from dried sludge and ash
P can also be recovered from dried sludge or from the ashes that remain after mono-incineration of the sludge. Major part of the influent P ends up in sludge and, after incineration, in the ashes. The fraction of influent P that ends up in sludge or ashes depends on the amount of P that is extracted as

struvite in the WWTP. Different P recovery processes from dried sludge and ashes are available at lab scale or pilot scale, with P recovery from sludge or ash between 70-98% of the P content of sludge (Remy and Jossa, 2015). The options for recovery of P from dried sludge and ash are based on thermal processes, or extractions in acid or alkaline solutions.
Early 2015, SNB and HVC have signed an agreement with Ecophos for the recovery of P from flyash from mono-incineration of sewage sludge. For this, there are plans to construct a plant in Dunkirk which is expected to become operational in 2017 for P extraction from low-grade P rock, and in 2018 from fly ashes from waste water sludge incineration.
The Ecophos process is based on a number of steps that produce phosphoric acid at a concentration of 42% P_2O_5 which can be further purified to 62% P_2O_5 (see http://www.ecophos.com/#/en/technology/). The process can recover up to 95% of the P from the fly ash, as well as 90% of the Fe and Al as Fe/Al chlorides (pers. comm. Rob de Ruiter, Ecophos). The Fe and Al can be returned to the WWTPs for chemical precipitation of P, thus creating a short circular flow. The remaining residues after extraction of P, Fe and Al contain various impurities (mainly heavy metals). These residues needs to be disposed of, and may be delivered to external parties for extraction of elements such as Cu or Zn, or it may be stored in a depot for later use (pers. comm. Rob de Ruiter, Ecophos).

3.1.3 Reduced P discharge in effluents from WWTP

Reduced discharge water flow
Total load of P discharged to surface waters is determined by the total water flow and P concentrations. The amount of P that is discharged to surface waters can therefore be reduced by:
- Reducing the amount of discharge water;
- Reducing P content of the discharge water.

Reduced amount of discharge water
Reducing the amount of water that is going to WWTPs is already being achieved by the decoupling of storm water from the combined sewer system. Rain water falling on impervious surfaces such as rooftops, roads, sidewalks and parking lots from residential, commercial and industrial areas can be transported into the sewer system towards a WWTP, or it can be deviated from the sewer system for direct discharge to surface waters or infiltration into the soil. Decoupling of storm water reduces emissions after heavy rainfall because it prevents storm water overflows of the sewer system. It also leads to a smaller water flow to be treated by the WWTP, which gives a lower P load to surface water if the P content of the discharge water remains the same. However, decoupling of storm water as such does not necessarily reduce the P load to surface waters, as storm water from various surfaces also contains P. Precipitation water contains about 0.1 mg P/liter, but when storm water is collected from surfaces the P content increases depending on the location (STOWA, 2007-21). From roofs and roads in housing areas, the average total P content of storm water was 0.42 mg P/liter (median 0.26 mg P/liter; 107 measurements). A similar value was found in storm water from business parks. In addition, storm water contained high levels of Cu and Zn, with increased levels of other metals when from business parks (STOWA, 2007-21), indicating an advantage of treatment before discharge into surface and ground waters.

Concentrations of pollutants in storm water are highest after dry periods when there has been some accumulation on surfaces. Therefore, improved separate sewer systems have been developed that send the first flush of storm water to the WWTP, and discharge the remaining storm water directly to surface waters. This way, still 75 percent of the storm water is treated by the WWTP (Rioned, 2015).

A model has been developed to evaluate the effect of different configurations of the sewer system on emissions of eight pollutants (STOWA, 2009-W06). The effect of decoupling of storm water on total emissions depends on the influent concentration of storm water, and the effluent concentration of the WWTP. Therefore, the performance of the WWTP also plays a role. Average values per Waterboard of P concentrations in effluent of the WWTPs varied between 0.5 and 1.6 mg P/liter (CBS, 2015b). These values are above the average P content of storm water of 0.42 mg P/liter. However, between WWTPs within a Waterboard variations in effluent P concentrations exist, e.g. for the 28 WWTPs of Hoogheemraadschap van Rijnland in 2013, the average total P concentration of effluent was 0.72 mg P/liter, and 16 WWTPs had a concentration above 0.42 mg P/liter (Hoogheemraadschap van Rijnland, 2013). This indicates that for about half of the WWTPs decoupling of storm water would reduce the P load to the environment.

Reduced P concentrations in effluent
A measure to reduce the P load to the environment is a further reduction of the P concentration in the effluent from WWTPs. The Pollution of Surface Waters Act prescribes an average performance of WWTPs within a Waterboard of at least 75 percent, and a total P concentration of effluent depending on the capacity of a WWTP: 1 mg P/liter for a capacity of more than 100,000 population equivalents, and 2 mg P/liter for a capacity between 2,000 and 100,000 population equivalents (Ministry of Infrastructure and the Environment, 2014). Based on the current range of effluent concentrations, reductions are possible at several WWTPs. However, differences between WWTPs are also based on different legal requirements based on the type of surface water.

The sewage effluents contain on average 0.5-1.6 mg P/l (CBS, 2015b) when they are discharged to the surface water. That is considerably higher than the target values for vulnerable fresh surface waters (0.05-0.15 mg P/l). Growing aquatic biomass on the effluents may be an interesting method to decrease the P concentration before discharging. A pilot conducted at RWZI Alkmaar with microalgae in open ponds showed that P concentrations could be reduced below the environmental target levels (STOWA, 2011-04). As the reactor is sunlight driven, the performance in winter time is low. Also research with closed photo bioreactors with artificial light showed that a significant reduction of the P concentration is possible (Boelee *et al.*, 2011; Van Dijk *et al.*, 2013, 2014). Compared to open ponds the P removal is more stable but the costs are higher especially due to the energy demand of the artificial lighting. Possibly a combination of sunlight and artificial light can be a solution to create a stable and more costly system.
Besides microalgae also other aquatic biomass as duckweed can possibly be grown to reduce the nutrient content of sewage effluents.
As the produced biomass is grown on waste waters the reuse in the food chain will be restricted to low value applications e.g. fertiliser and raw material for basic chemicals and fuel. Application in the feed and food industry is expected to be possible only for biomass grown on waste and side streams of the food industry.

3.1.4 Source separation of wastes with high nutrient content

Various initiatives exist to decouple toilets from the sewer system and separately collect and treat toilet waste. Preventing or reducing dilution of toilet waste with flush water increases the options for nutrient recovery. Separate collection of toilet waste with minimal water use can be achieved by using vacuum toilets, water free urinals and urine separation toilets (Zeeman & Kujawa-Roeleveld, 2011).
Examples of initiatives are:
- Decentralised Sanitation and Reuse demonstration project in Sneek, since 2006: 32 houses have a vacuum toilet for collection of toilet waste and separate treatment from grey water (STOWA, 2014-W02).
- Use of separately collected urine for struvite production.
  - Waternet (www.waternet.nl) collects urine from various locations such as the Heineken Music Hall, where waterless urinals are installed, and with mobile toilet units at festivals;
  - Saniphos (www.saniphos.nl) collects urine from the organisation Mothers for Mothers (that extracts hormones from urine of pregnant women), and from events, festivals and health care institutions.

Urine contains about two third of all P excreted by humans (Richert *et al.*, 2010). Separate collection and treatment of urine can therefore generate a substantial flow of recovered P. There is a trade-off between P recovery from separately collected urine and P recovery at the WWTP or P recovery from (incinerated) sludge. Both systems will co-exist, and investing in source separation of urine will likely be at specific places such as with waterless urinals or at festivals. Use of waterless urinals contributes to a reduction of the total water flow and total P discharge (see chapter 3.1.3). The scale of separate collection and treatment of urine has to increase in order to have impact on the national flows of P. The current initiatives are estimated to collect less than 1000 kg P, which is only a small fraction of the total P input by households/ retail to WWTPs of 12.1 Mkg P. As about two third of all P excreted by humans is in urine (Richert *et al.*, 201), and urine contributes for about 50% of the P in domestic wastewater (Larsen and Gujer, 1996), a substantial flow of about 6 Mkg P can be achieved by source separation of urine.

3.2 Solid waste flows

3.2.1 Industrial flows

Ashes from meat and bone meal have fertilizer value (mainly P, Ca and neutralising value) and low concentrations of heavy metals (Postma *et al.*, 2011). Compared to mineral P fertiliser, plant availability of the P in the ashes is relatively low, and additional treatment may be needed to increase the plant availability. However, a more restricting factor for use as fertiliser is the fact that the meat and bone meal is used as fuel in cement industry, fixing P in cement, or as co-firing fuel in a power plant. Ashes from these co-fired power plants are unsuitable for direct use as fertilizer because the nutrient concentrations are lower than those required for mineral fertilizers (Uitvoeringsbesluit Meststoffenwet, 2015) due to dilution with the ashes of coal or other fossil fuel used. These low nutrient concentrations makes the ashes also unsuitable as input for the fertilizer industry. To enable use of the ashes as a P source, it should be mono-incinerated to prevent dilution of the P.

Use of meat and bone meal as feed instead of fuel may contribute to keeping P available for agricultural purposes. Category 1 and 2 material is not accepted as feed, but current regulations allow processed animal proteins (PAP) from category 3 as fish feed. The European Commission studies the option to allow PAP from pig in poultry feed, and PAP from poultry in pig feed. Currently, all category 3 material from the Netherlands is used in pet food and/or exported for use as bone china, fertilizer, and/or gelatine.

3.2.2 Households/retail

Separate collection of kitchen waste is a challenge in urban areas. Mixed waste can be separated after collection into an organic and inorganic fraction (Attero, 2015; Omrin, 2015). The organic fraction is processed in an anaerobic digester and produces biogas. The digestate of this organic fraction is unsuitable for agricultural use and is incinerated together with other household waste. Therefore, P in organic waste that is not separated at the source is lost for agricultural use.

To reduce losses of P from households and retail, there are a few options:
- reducing food waste in general, which can reduce both the amount of P in VFG and in mixed solid waste;
- increasing source separation by redirecting P from mixed solid waste towards VFG and composting;
- increasing source separation by redirecting P from mixed solid waste towards communal WWTP by use of food grinders in kitchen, and subsequent recovery of P at the WWTP or from sludge.

These options will be discussed in the following paragraphs.

3.2.2.1 Reducing food waste

Food waste receives increased attention, and various initiatives exist to reduce food waste (Milieucentraal, 2014). About two third of food waste is generated at the household level, and focus on consumer behaviour is therefore of major importance to reduce food waste (Soethoudt and Timmermans, 2013). The impact of reducing food waste can be a reduced compost production, but also a reduction in the amount of P that is lost with incineration of solid waste when the food waste is discarded together with residual waste. If programs to reduce food waste are effective, this will reduce the food demand and lead to a reduction in food production. Theoretically, this will also lead to a reduction in P inputs required for food production.

3.2.2.2 Increased source separation

Source separation of organic waste is already stimulated for many years, and organic waste is collected separately within each municipality, based on governmental regulations (RWS Leefomgeving, 2015). However, organic waste is not collected separately within the entire area of municipalities. Especially in city centres and neighbourhoods with blocks of apartments, source separation is difficult and in large areas of the bigger cities there is no separate collection of organic waste. In 2012, the Dutch Waste Management Association (DWMA) reported a decreasing willingness to separate kitchen waste from residual waste, and also an actual decrease in source separation in the preceding years, especially in urban areas as some municipalities had stopped collecting separate organic waste. At the same time, willingness to separate garden waste was stable at about 90 percent of the households (Vereniging Afvalbedrijven, 2012). Technological developments for better and cheaper treatment of VGF have changed the decreasing trend, and from 2015 onwards, municipalities such as Den Bosch and Rotterdam increase separate collection of VGF ('s Hertogenbosch, 2014; Rotterdam, 2015).

The organic waste fraction in mixed solid waste that is incinerated is almost 40% (w/w) (RWS Leefomgeving, 2015). This fraction also depends on separate collection of other waste flows such as plastics and drink cartons.

Milieucentraal (2015) presents quantitative data on amount of various wastes per person, based on data from RWS Leefomgeving (2015). In 2012, 168 kg VGF was produced per person, of which 78 kg was collected separately and the remaining 90 kg ended up in residual waste. Doubling of the amount of separately collected organic waste is theoretically possible (Milieucentraal, 2015). This would double the P flow from households to compost (F4 in Figure 1).

3.2.2.3 Food waste grinders

An alternative collection method that enables P recovery from kitchen waste may be through use of food waste grinders, and transport through the sewer system for treatment in WWTP. This enables recovery of some of the P content as struvite at the WWTP, or almost all P when sludge is incinerated in a mono-incinerator and the ashes are used for P recovery. Discharge of ground food waste into the sewer system is not allowed in the Netherlands, as it would negatively affect waste water treatment and energy use (STOWA, 2010). The practice, however, is part of studies and in a recent LCA-study, different methods for treatment of kitchen waste were compared (STOWA, 2015-07; Vereniging Afvalbedrijven, 2014):

1. Mixed with residual waste;
2. Source separated VGF;
3. Ground food waste into the sewer system;
4. New water chain (ground food waste and concentrated black water[2] into anaerobic digester at a WWTP).

For the first three options a best case and worst case scenario was studied, differing in efficiencies (Table 4). For each method, an average single score was calculated based on 18 environmental issues (Table 4). Source separated VGF with anaerobic digestion and composting showed the best score (lowest environmental impact). The best case version of 'Ground food waste into the sewer system' with primary settling tank and anaerobic digestion scored similar to the worst case version of 'Incineration with residual waste'. The worst case version of ground food waste into the sewer system without primary settling tank or anaerobic digestion had the highest environmental impact. Analysis of the new water chain was limited to the effect of food waste treatment and did not include the effects of concentrating black water and changes in the sewer system.

[2] Black water is wastewater from flush toilets containing faeces, urine and flushwater. It does not include wastewater from bathing and from washing food, clothes and dishes.

Table 4

Single score of LCA analysis of food waste treatment options. Lowest (and negative) numbers have lowest environmental impact (from: STOWA, 2015-07).

Treatment method	Case	Description	Score
Mixed with residual waste	Worst	low efficiency incineration	-2
	Best	high efficiency incineration	-7
Source separated VGF	Worst	composting only	-1
	Best	anaerobic digestion (biogas), followed by composting	-17
Ground food waste into the sewer system	Worst	WWTP without primary settler	20
	Best	WWTP with primary settler + anaerobic digestion (biogas)	0
New water chain	-	ground food waste and concentrated black water into anaerobic digester (biogas) at WWTP	-4

3.3 Other flows - runoff and leaching from agricultural soils

Runoff and leaching of P from agricultural fields (F16 in Figure 1) is a major source of the P load of the surface water. Different type of measures can be taken to reduce the P load ranging from source-oriented measures, focusing on the reduction of the P-soil surplus, to effect-oriented measures, focusing on P removal from soil water or surface water. Current mineral legislation in the Netherlands is aiming at balance fertilisation (P supply with fertilisation = P removal with harvested products). However, due to high P fertilisation levels in the past the soil P content is high and therefore balanced fertilisation levels will only decrease the P load to surface water in the long term. In the short term effect-oriented measures may be more effective. A number of measures have been evaluated as iron filters in drainpipes, buffer strips and constructed wetlands. Iron filters in drainpipes were most cost effective (Koopmans, 2012). P leaching was decreased with about 95% and the cost effectiveness was estimated on €15/ kg P. The reduction of the P load to surface water by constructed wetlands was tested on three different sites (De Haan *et al.*, 2011). At two sites the P load was reduced with about 50%. On the third site P concentration of the input water was too low to assess the P reduction capacity. Based on the results of the other two sites the cost effectiveness was estimated on €115/ kg P. This may be improved by combining the wetlands with other functions as water storage, recreation or biomass production. In 2006 a research was started on 5 hydrological different sites in the Netherlands to assess the effects of 5 m buffer strips on the reduction of N and P leaching from agricultural land to surface water (Noij *et al.*, 2012). Only on 1 out the 5 sites a reduction of the P leaching (about 60%) was observed. This site was characterized by a shallow non-permeable soil layer and slope of 2% indicating that runoff will probably have played a role. This soil type is however representative for only 2% of the soils in the Netherlands.
Although iron filters were most cost effective in removing the P, the perspectives of reuse of the removed P will be low due to the strong binding with iron. From that point of view the biological P fixation in biomass via constructed wetlands or buffer strips will offer better opportunities to recover the P in the food chain.

4 Perspectives for P recovery

The main drivers for P recovery are cost effectiveness and regulations, and these drivers interact. Within the waste sector, often boundaries are set by regulations and within these boundaries cost effective options are sought. Regulations on waste water treatment and sludge disposal, for example, determine possible destinations of the sludge. Costs are covered by sewer taxes, and Waterboards aim at cost effective methods for waste water treatment and sludge disposal. P recovery as such is not part of the regulations, but it can be a cost effective option.

Perspectives for P recovery can be assessed for specific/individual flows, or need to be studied in coherence for several flows when interventions upstream affect P recovery options downstream. The latter is especially valid for the communal waste water flow, where P can be recovered from source separated toilet waste, during processes at the WWTP (e.g. struvite) and/or from ash from mono-incinerated sludge. Perspectives for P recovery may also be increased by combining different flows.

This chapter has a focus on the perspectives for P recovery, while taking into account impacts on other sustainability issues such as energy use, greenhouse gas emissions and economic aspects.
Chapter 4.1 describes P recovery perspectives from waste water, chapter 4.2 from solid waste and in chapter 4.3 perspectives from combinations of flows from waste water and solid waste are discussed.

4.1 Waste water

In the waste sector, the largest amounts of P are in waste water. Largest opportunity for P recovery is therefore in communal waste water treatment, where P can be recovered as struvite at the WWTP and/or from ash after mono-incineration. STOWA (2013-32) quantified annual P recovery for different scenarios, based on the amount of sludge in 2010:

- All sludge to mono-incinerators, and P recovery from ash — 11.6 Mkg P
- Current fraction (60%) of sludge to mono-incinerators, and P recovery from ash — 7.0 Mkg P

- Maximum P recovery as struvite at WWTP (40% efficiency), requiring anaerobic digestion of <u>all bio-P</u> — 2.5 Mkg P
  P recovery from ash after mono-incineration of:
  – All remaining sludge — 9.1 Mkg P
  – Current fraction (60%) of sludge going to mono-incineration — 5.5 Mkg P

The scenarios as used in STOWA (2013-32) indicate the borders of the playing field, and current practice will be a mixture. Anaerobic digestion of sludge is advantageous from an energy point of view (STOWA, 2010), and recovery of P as struvite in WWTP with anaerobic digestion will therefore continue and increase, as it saves on maintenance costs by prevention of scaling and blocking of pipes. Moreover, struvite precipitation reduces the amount of sludge and thereby disposal costs. Application of thermal hydrolysis increases biogas yield, degradation of sludge and the fraction P that is recoverable as struvite. It is a challenge to find users for the struvite, either directly as fertilizer in agriculture, or as input for the fertilizer industry (see chapter 4.4).

Increased recovery of P as struvite at the WWTP will decrease P concentrations in sludge and ash, and thereby reduce the profitability of P recovery from ash. According to Ecophos (pers. comm. De Ruiter) the exact concentration of P in ash is no problem, and a constant concentration of P over time is more important. However, SNB has agreed to deliver sludge with at least 20 percent phosphate (pers. comm. Sijstermans), which means that no or little P can be extracted as struvite. To prevent scaling of pipes, struvite precipitation may be needed, but the amount of struvite precipitation can be limited to a level that is sufficient for reducing maintenance costs, or struvite may remain in the sludge that is mono-incinerated to maintain the P content in the ash at sufficiently high levels to make the ash profitable as input for P recovery industry. Another way to keep the P content at a high level is to extract more P from waste water and have a lower P content in the effluent. This would increase P recovery as a whole (see chapter 3.1.3), and at the same time reduce P emission to surface waters.

Source separation of urine and separate treatment potentially can recover 6 Mkg P as urine contributes for about half of the P in domestic wastewater. Source separation of urine then will reduce the P load to WWTPs and the P content of sludge. However, source separation of urine is expected to remain restricted to festivals and a limited number of buildings, and therefore will have little impact on the P flow to WWTPs and P content in sludge.

4.2 Solid waste flows

Major perspective to reduce losses of P from solid waste flows from industry is to recover it from meat and bone meal that is currently incinerated by the cement industry or power plant. This refers to category 1 and category 2 meat and bone meal, from which about 3.6 Mkg P is lost for further use (Smit *et al.*, 2015). This material needs to be incinerated under the current European regulations. Mono-incineration is therefore required to make recovery of P possible. For use as fertilizer, the ashes may need additional treatment to increase plant availability of P (Postma *et al.*, 2011), and ICL already uses ashes from the UK as input for fertilizer production (Langeveld, 2015). Possibly, incineration of meat and bone meal can be combined with incineration of communal sewage sludge that also produces ashes suitable for P recovery. The ashes of communal sewage sludge, however, contain too high amounts of heavy metals for direct use as fertilizer, and P needs to be extracted.

Perspectives to reduce P losses through solid waste flows from households/retail include reducing food waste. The contribution of reducing food waste is difficult to estimate and also depends on whether P in wasted food is recovered, e.g. through VGF composting, or is lost through the sewer system or by incineration of solid waste. The majority of food waste is in solid waste, divided over VGF (17%) and solid waste (83%) (Van Westerhoven, 2013). Over half of this organic waste is avoidable and regarded as food waste (Van Westerhoven, 2013). Reducing food waste may therefore lead to halving of the current P losses from kitchen waste by incineration of solid waste, saving 0.65 Mkg P (see chapter 2.1.2).
Increased source separation of organic waste can in theory be doubled (Milieucentraal, 2015), resulting in an additional amount of P recovered through VGF composting of 1.1 Mkg P. Whether this increased source separation can be achieved depends on the effort of municipalities to implement and stimulate source separation. This is supported by the decreasing costs for treatment of VGF compared to incineration of solid waste, enabled by biogas production through anaerobic digestion of the VGF (Agentschap NL, 2010). There is some overlap between the effects of reducing food waste and increasing source separation, therefore the estimated effects cannot be just added.

The use of food grinders to collect kitchen waste through the sewer system and recover P at the WWTP is an alternative to increased source separation, and a similar flow may be assumed as increased source separation: 1.1 Mkg P. The amount of P recovered from this flow varies between 0.5 and 1.0 Mkg P as it depends on the method: as struvite at the WWTP at most 40-50% of the P is recovered (most of the remaining P is in sludge), from ash after mono-incineration of sludge about 95% is recovered. In a LCA study on different methods for treatment of kitchen waste, VGF composting scored better with a lower environmental impact than use of food grinders (STOWA, 2015).

4.3 Use of recovered P in agriculture

Use of recovered P in agriculture is expected to be high when this P comes from regular P industry that uses products such as sludge ash and struvite as input for their processes. The derived products are similar to existing products and need no new introduction. For the Netherlands, increased P recovery will increase the amount of P to be exported as there is already more P available than can be responsibly used. Recovered products therefore either will be used abroad, or will displace other products containing P that need to be exported.

Direct use of products from WWTPs is limited. Sludge from WWTPs cannot be used in Dutch agriculture since implementation in the nineties of the Decree on the Quality and Use of Other Organic Fertilisers, as the heavy metal contents are above allowed limits (Ehlert *et al.*, 2013). Only a limited amount of clean sludge from industrial WWTPs is used as fertilizer and wind erosion prevention, and no major changes are to be expected.

Struvite can be used as input in fertilizer industry or directly in agriculture as fertilizer. Legal aspects around transport and use of struvite as raw material or as fertilizer have changed recently; an overview is given in a factsheet by the Dutch Nutrient Platform and EF/GF (NP & EF/GF, 2015).

Effectiveness of struvite as a fertilizer was found similar to commonly used fertilizers (Le Corre *et al.*, 2009; Talboys *et al.*, 2015). However, applicability remains an important issue. When struvite is extracted during waste water treatment it is a wet sludge. For agricultural application it needs to be dried, and the granular composition needs to be relatively homogeneous for spreading. Waternet supplies its struvite to ICL where it is dried and granulated before it is mixed into fertilizer blends (pers. comm. K. Langeveld, ICL).

4.4 Interactions between processes on sustainability criteria

Perspectives for P recovery are also determined by interactions between recovery technologies at different places within the chain. In addition, there are trade-offs between different treatment options that are chosen. This chapter describes a few of these interactions and trade-offs.

4.4.1 Sludge and meat & bone meal: mono or co-incineration?

Sludge is incinerated by the cement industry, in mono-incinerators and as co-fuel in coal-fired power plants. Major drivers are energy efficiency, P recovery options, cleaning of flue gases and overall economic performance. The energy content of sludge is better used when it is co-incinerated at a coal-fired power plant compared to mono-incineration. This is caused by a different design of the plants, where the advantage of a coal-fired plant comes from a larger scale and use of inputs with a lower corrosive effect. Ashes from a coal-fired plant, however, are not suitable for P recovery because of their low P content. Requirements for flue gas cleaning are stricter for mono-incinerators compared to coal-fired power plants.
The oven of a mono-incinerator is aimed at a specific type of input. Current mono-incinerators of HVC and SNB are aimed at dewatered sludge, and including another type of input would require another oven. This means that current co-incinerated inputs cannot be simply diverted to existing mono-incinerators.

Next to incineration, technologies such as oxidation or gasification of sludge may be used. Currently, these technologies are not recommended because of a relatively low environmental benefit and high costs (Frischknecht *et al.*, 2013).

4.4.2 Energy recovery

Energy can be recovered from sludge by anaerobic digestion and/or incineration, and by less frequently applied techniques such as gasification and pyrolysis. Iv-Groep (2014) compared two systems, both yielding electricity and heat:
1. Incineration of sludge
2. Anaerobic digestion, followed by incineration of sludge

Both systems reused energy from the process itself, and supplied heat to an external party under the assumption of 50% efficiency. The system with anaerobic digestion also supplied electricity to the grid. The digester is located at a WWTP and 75% of the input is transported from other WWTPs. Under the assumptions as described in detail in Iv-Groep (2014), incineration of sludge caused 236 kg CO_2 emission per ton sludge dry matter, as the emissions that occur with drying and incineration are not compensated by supply of heat. The combination of anaerobic digestion and incineration avoided 156 kg CO_2 emission per ton sludge dry matter. This mainly results from electricity production from biogas, and a higher heat supply compared to the incineration system. The amount of sludge and associated CO2 emissions for drying and incineration is lower in the system with anaerobic digestion.

Drying of sludge before incineration can be done using heat from the incineration process, but it can also be done by biological drying (STOWA 2013-W03). Biodrying is based on heat produced by composting microorganisms. This method has a negative CO_2 emission balance and the final dried product has sufficient heating value that allows use for energy generation in other facilities (Winkler *et al.*, 2013). Use of dried sludge in mono-incineration may improve the carbon balance of this system.

4.4.3 Struvite *versus* P recovery from ash

A major interaction in P recovery in the wastewater flow is that of extraction as struvite at the WWTP or recovery from ash after mono incineration of sludge. Reduced P concentrations in ash make recovery less profitable, but some struvite precipitation is needed at the WWTP with anaerobic digestion to prevent scaling and blocking of equipment. As discussed in chapter 4.1, the amount of struvite precipitation can be limited to a level that is sufficient for reducing maintenance costs, and/or struvite may remain in the sludge that is mono-incinerated to maintain the P content in the ash at sufficiently high levels to make the ash profitable as input for P recovery industry. Incineration of sludge together with struvite would give a higher P content of the ash. Treatment of struvite into a marketable product and marketing of this product is then not needed. A thorough analysis of different alternatives and quantification of their pros and cons requires a separate study. This analysis can include the option to increase P in sludge by extracting more P from waste water and have a lower P content in the effluent.

4.4.4 Energy requirements for P products

The energy requirements for production of different phosphorus products can be expressed as Gross Energy Requirement (GER value): the total energy expended in manufacturing, including transport. Croezen & Bijleveld (2012) calculated GER values and compared struvite with an equivalent MgNP chemical fertilizer, and elemental phosphorus produced from sludge ash with that from rock phosphate. Assumptions, uncertainties and data ranges are given by Croezen & Bijleveld (2012). When only the inputs needed for struvite production were taken into account, GER value of struvite was 1.8 MJ/kg, compared to 14.5 MJ/kg for chemical fertilizer. Struvite precipitation also gives savings at the WWTP such as reduced energy use, lower need for metals (Fe) and lower amount of sludge. When these effect are included in the calculation, struvite precipitation has an energy gain and a GER value of -19.2 MJ/kg.
Energy requirements for the production of elemental phosphorus were calculated based on the processes of former Thermphos International BV. GER value for phosphorus from rock phosphate was 272 MJ/kg, and from sludge ash 232 MJ/kg. The difference was mainly caused by mining of rock phosphate; no impact was attributed to the production of sewage sludge ash.

4.4.5 Meat and bone meal for fuel or feed

The co-firing of slaughter waste in energy plants replaces fossil fuel and thereby contributes to renewable energy production. The energy content of meat and bone meal is about two thirds of that of a fossil fuel such as coal. However, use of meat and bone meal as feed instead of fuel may have a better energy balance. Wittgren *et al.* (2003) compared incineration of meat and bone meal with the use as feed in two systems with equal production of feed and energy and equal use of arable land. When the meat and bone meal is acceptable as feed, the energy balance and environmental impact (e.g. greenhouse gas emissions) is lower compared to incineration of slaughter waste. However, category 1 and 2 material is not accepted as feed. Current regulations allow processed animal proteins (PAP) from category 3 as fish feed. The European Commission studies the option to allow PAP from pig in poultry feed, and PAP from poultry in pig feed. Currently, all category 3 material from the Netherlands is used in pet food and/or exported for use as bone china, fertilizer, gelatine and/or glue.

4.5 Concluding remarks

Depleting reserves of phosphate rock require efficient use of P and P recycling from waste flows. Members of the Dutch Nutrient Platform and other stakeholders are active in use and development of techniques to recover P from solid and liquid waste flows.

Within the waste sector, the largest flow of P that is lost for further use is within communal waste water treatment. Other major flows of P that is lost for further use are within meat and bone meal used in cement industry and for power generation, and within kitchen waste that is mixed with other solid waste and incinerated.
Perspectives for P recovery are highest from wastewater treatment, both because of the size of the flow and recoverability of P. Meat and bone meal also have good perspectives for P recovery because of the high P content, but it requires mono-incineration instead of use as co-fuel with concurrent impact on businesses. Perspective for additional P recovery from kitchen waste is relatively small because of the limited flow size and of the required effort to implement increased source separation within society.

Within the wastewater sector, P will partly be recovered at WWTPs as struvite but more importantly by P industry that uses sludge ash from mono-incineration as input to replace rock phosphate. Use of sludge ash as replacement of rock phosphate has been tried at small scale in recent years, and a large scale application is in preparation through the agreement of SNB and HVC with Ecophos. This would mean that more than half of the P in sewage sludge is being recovered. A further increase of P recovery from sewage sludge ash is possible when more sludge is mono-incinerated. This could limit recovery as struvite as a high P content of the ash is preferred. Mono-incineration of biologically dried sludge would also increase the amount of ash suitable of P recovery. This cannot directly be implemented within the current infrastructure as it requires other ovens than those currently used by HVC and SNB.

The trend to increase P recovery can be supported by government. In Switzerland, a new waste regulation enters into force 1 January 2016 that includes an obligation for P recovery from sewage sludge and meat and bone meal. It has a transition phase of ten years (Schweizerische Eidgenossenschaft, 2015). Such a transition phase is necessary as optimal recovery of P requires weighing of several aspects. Mono-incineration will play an important role, and the used oven needs to be adapted to the products that will be burnt (e.g. dewatered sludge, biologically dried sludge, meat and bone meal). The method of sludge dewatering determines properties of the sludge such as water content and organic matter content, but also options to recover other products in the process such as N fertilizer. Weighing this together with economic aspects is needed for optimal P recovery and for business to make long-term investments.

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Plant researchers of Wageningen UR aim to utilise plant properties to help solve issues concerning food, raw materials and energy. They are devoting their knowledge of plants and their up-to-date facilities to increasing the innovative capacity of our clients. In doing so, they work on improving the quality of life.

The mission of Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine specialised research institutes of the DLO Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 10,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.

To explore the potential of nature to improve the quality of life

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Bij Wageningen UR proberen plantonderzoekers de eigenschappen van planten te benutten om problemen op het gebied van voedsel, grondstoffen en energie op te lossen. Zo worden onze kennis van planten en onze moderne voorzieningen ingezet om de kwaliteit van leven in het algemeen en de innovatiekracht van onze opdrachtgevers in het bijzonder te vergroten.

De missie van Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Binnen Wageningen UR bundelen 9 gespecialiseerde onderzoeksinstituten van stichting DLO en Wageningen University hun krachten om bij te dragen aan de oplossing van belangrijke vragen in het domein van gezonde voeding en leefomgeving. Met ongeveer 30 vestigingen, 6.500 medewerkers en 10.000 studenten behoort Wageningen UR wereldwijd tot de aansprekende kennisinstellingen binnen haar domein. De integrale benadering van de vraagstukken en de samenwerking tussen verschillende disciplines vormen het hart van de unieke Wageningen aanpak.